L'utilisation de l'information géospatiale comme outil d'aide à la réduction des risques de catastrophe ; Etudes de cas du gouvernorat de Baalbek-Hermel/Liban

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The use of Geospatial Information as support for Disaster Risk Reduction; Case studies from Baalbek-Hermel Governorate/Lebanon.

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Résumé:

Étant donné que les catastrophes sont un phénomène spatial, l'application de systèmes d'information géographique (SIG) est un outil pratique et fiable pour le processus de réduction des risques de catastrophe (RRC). Les SIG peuvent servir le processus de RRC en tant que base de données pour la collecte et l'intégration de données, ainsi que pour l'incorporation de données multi-sources, en tant que systèmes d'observation, en tant qu'outil pour la production de cartes de risques, en tant que calculateur d'exposition, constructeur de modèles déterminant les vulnérabilités des éléments, en temps quasi réel, traqueur de crise, etc… Mais ces applications SIG ont été intégrées de manière inégale à travers les différentes phases du cycle de RRC. De plus, l'utilisation efficace de ces technologies nécessite des recherches et des développements plus poussés, en particulier dans les pays en développement où de nombreux obstacles entravent l'utilisation des SIG pour la protection civile. Cette tache devient encore plus compliquée au niveau local en région rurale comme dans notre zone d'étude Baalbek-Hermel, Gouvernorat du Liban. Le manque de ressources humaines et financières et des données spatiales critiques lacunaires limitent l'utilisation des SIG pour améliorer la décision en matière de RRC? Dans quelle mesure le SIG pourrait-il être efficace dans les actions de RRC dans un pays en développement comme le Liban, où le nombre d'enjeux exposés augmentent sans cesse et où le gouvernement a d'autres priorités urgentes que de s'engager dans un plan de RRC? Plusieurs études de cas menées à Baalbek-Hermel servent à tester les hypothèses retenues et à discuter de l'adoption et de l'adaptation de techniques SIG afin de les rendre efficaces et capables de servir tout le cycle de RRC ; évaluation des dangers, de la vulnérabilité et des dommages, planification d'urgence et d'évacuation, systèmes d'alerte précoce, zonage des terres, données en temps quasi réel pour l'intervention, rétablissement et renforcement de la résilience. Les défis posés par le déploiement de ces technologies SIG dans chacune des phases susmentionnées du cycle de la RRC et la manière dont ils peuvent être surmontés sont discutés, en considérant les approches autochtones pour l'application de technologies et d'innovations en matière de RRC. Les résultats de cette thèse offrent le potentiel de surmonter certains des obstacles qui entravent l'utilisation des SIG pour une RRC efficace dans les pays en développement. Ainsi, les praticiens de RRC au

Liban et dans d'autres pays en développement pourraient exploiter ce potentiel pour tenter de réduire la vulnérabilité aux dangers et améliorer la capacité de prévention des catastrophes.

Mots clés:

Catastrophe, Risques naturels, Système d'information géographique (SIG), protection civile, télédétection, pays en développement, réduction des risques de catastrophe (RRC), gestion des risques de catastrophe, géographie du risque.

The use of Geospatial Information as support for Disaster Risk Reduction; Case studies from Baalbek-Hermel Governorate/Lebanon.

Abstract:

Given that natural disasters are spatial phenomenon, the application of geographical information systems (GIS) has proven to be a convenient and reliable tool for the Disaster Risk Reduction (DRR) process. GIS can serve DRR as a database for data gathering, integration and incorporation, an output viewer, a tool for hazard maps production, a calculator for exposure, a model builder for determining assets' vulnerabilities, a near real time crisis tracker, etc… Nevertheless, GIS applications have been integrated unevenly across the different phases of the DRR cycle. Moreover, the effective use of these technologies requires further research and development, especially in developing countries where numerous barriers hamper the use of GIS for civil protection. The task is further complicated at the local level in rural areas such as our study area Baalbek-Hermel, Governorate of Lebanon. Restrictions include limited human and financial resources and a lack of critical spatial data required to support GIS application to DRR. To what extent could GIS be efficient in DRR actions in a developing country like Lebanon where the majority of assets at risk is ever-growing and the government has other urgent priorities than to commit to DRR plans? Several case-studies in Baalbek-Hermel were taken to test these assumptions and discuss the adaptation of GIS techniques to make them effective and to be able to serve the whole DRR cycle; hazard, vulnerability, risk and damage assessment, emergency and evacuation planning, land-use zoning, recovery and resilience building. Challenges in the deployment of GIS technologies in each aforementioned phase of the DRR cycle and how they may be overcome were discussed, considering indigenous approaches for the application of technologies and innovations in DRR. The results of this dissertation suggested ways to control some of the barriers hampering the effective use of GIS for DRR in developing countries. Thus, DRR practitioners in Lebanon and other developing countries could harness this potential in an attempt to reduce hazard vulnerability and improve disaster reduction capacity.

Key words:
Disaster, Natural hazards, Geographic Information System (GIS), civil protection, Remote Sensing, developing countries, Disaster Risk Reduction (DRR), Disaster Risk Management (DRM), Geography of Risk.

Contents

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I dedicate this thesis to my beloved Father no longer "physically" with us. Dad, I hope this work brings peace to your soul and makes you proud of me wherever you are.

Rita Georges Der Sarkissian

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Glossary

Unifying the language is the first step towards an efficient global disaster risk reduction. The terminology in disaster risk management is comprehensive and broad. This section explains the terms that are important to understand the content of this thesis. All definitions have been retrieved from 2009 Terminology on Disaster Risk Reduction/ UNISDR Terminologie pour la prévention des risques de catastrophe. It is important to note that the French translation of the 2009 terminology of UNISDR and its validation process were carried out by the French Ministry of Sustainable Development (le Ministère Français de Développement Durable MEEDDAT) (UNISDR 2009a, 2009b). This glossary gives simple definitions of the terms but does not present any discussion. These terms will be discussed in detail in the first chapter of this thesis.

- **Building code/Codes de construction: "***A set of ordinances or regulations and associated standards intended to control aspects of the design, construction, materials, alteration and occupancy of structures that are necessary to ensure human safety and welfare, including resistance to collapse and damage*" (UNISDR 2009a, 2009b).

- **Capacity/Capacité:** "*The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals*" (UNISDR 2009a, 2009b).

- **Capacity development/Développement de capacité: "***The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions*" (UNISDR 2009a, 2009b).

- **Coping capacity/Capacité à réagir:** "*The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters*" (UNISDR 2009a, 2009b).

- **Critical Facilities/Installations critiques:** "*The primary physical structures, technical facilities and systems which are socially, economically or operationally essential to the functioning of a society or a community, both in routine circumstances and in extreme circumstances of an emergency*" (UNISDR 2009a, 2009b).

- **Direct economic loss/Pertes financières directes**: "*The monetary value of total or partial destruction of physical assets existing in the affected area. Examples of physical assets include… production such as standing crops, agricultural infrastructure and livestock*." (UNISDR 2015b).

- **Disaster/Catastrophe:** "*A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources*" (UNISDR 2009a, 2009b).

- **Disaster risk/Risque de catastrophe:** "*The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period*" (UNISDR 2009a, 2009b).

- **Disaster risk management (DRM)/Gestion des risques de catastrophe: "***The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster*" (UNISDR 2009a, 2009b). DRM is geared towards operational crisis management when natural disasters occur.

- **Disaster risk reduction (DRR)/Réduction des risques de catastrophes:** "*The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events*" (UNISDR 2009a, 2009b). DRR is mainly focused on preventive actions.

- **Disaster risk reduction plan/Plan de reduction des risques de catastrophe:** "*A document prepared by an authority, sector, organization or enterprise that sets out goals and specific objectives for reducing disaster risks together with related actions to accomplish these objectives*" (UNISDR 2009a, 2009b).

- **Early warning system/Alerte rapide**: "*The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss*" (UNISDR 2009a, 2009b).

- **Earth observation/Télédétection**: is the gathering of information about planet Earth's physical, chemical, and biological systems, using remote sensing. It is used to monitor and assess the status of, and changes in, the natural environment and the built environment.

- **Evacuated/Evacués:** People who, for different reasons or circumstances because of risk conditions or disaster, move temporarily to safer places before, during or after the occurrence of a hazardous event. *Evacuation can occur from places of residence, workplace, schools, and hospitals to other places. Evacuation is usually a planned and organized mobilization of persons, animals and goods, for eventual return.*

- **Exposure/Exposition des enjeux:** "*People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses*" (UNISDR 2009a, 2009b).

- **Hazard/Aléa:** "*A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage*" (UNISDR 2009a, 2009b). Uncertainty is an integral part of hazards because the time and place of occurrence are often uncertain.

- **Land-use planning/Aménagement du territoire: "***The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses*" (UNISDR 2009a, 2009b).

- **Mitigation/Mesures d'atténuation:** "*The lessening or limitation of the adverse impacts of hazards and related disasters*" (UNISDR 2009a, 2009b).

- **Natural hazard/Aléa naturel:** "*A natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage*" (UNISDR 2009a, 2009b).

- **Preparedness/Préparation:** "*The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions*" (UNISDR 2009a, 2009b).

- **Prevention/Prévention: "***The outright avoidance of adverse impacts of hazards and related disasters***"** (UNISDR 2009a, 2009b)**.**

- **Recovery/Récupération-reconstruction:** "*The restoration and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors*" (UNISDR 2009a, 2009b).

- **Resilience/Résilience:** "*The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions*" (UNISDR 2009a, 2009b). This complex concept is often misused as synonymous with "Recovery".

- **Response/Réaction:** "*The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected*" (UNISDR 2009a, 2009b). In French, it is known as "forces d'interventions" but the term "civil protection" is used instead to distinguish these intervention forces from military operations.

- **Risk/Risque:** "*The combination of the probability of an event and its negative consequences*" (UNISDR 2009a, 2009b).

- **Risk assessment/Evaluations des risques:** "*an approach to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process*" (UNISDR 2015b).

- **Risk management/Gestion des risques:** "*The systematic approach and practice of managing uncertainty to minimize potential harm and loss*" (UNISDR 2009a, 2009b).
- **Spatial data infrastructures (SDIs)/ Infrastructure de données géospatiales**: "*The fundamental spatial datasets, the standards that enable integration, the distribution networks that provide access, the policies and administrative principles that ensure compatibility, the people including users, providers, and value adders, at each level; local through to state, national, regional and global*".

- **Vulnerability/Vulnérabilité:** "*The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard*" (UNISDR 2009a, 2009b).

Acronyms

AFPCN	L'association française pour la prévention des catastrophes naturelles
AGU	American Geophysical Union
ASDRR	Arab Strategy for Disaster Risk Reduction
CAMRE	Council of Arab Ministers Responsible for the Environment
CASPER	Capacity Aware Shortest Path Evacuation Routing
CatNat.net	CATastrophes NATurelles.net
CGIS	Canada Geographic Information System
CI	Critical Infrastructure
CNRS	Conseil National de la Recherche Scientifique
CRED	The Centre for Research on the Epidemiology of Disasters
CRS	Coordinate Reference Systems
DRC	The Disaster Research Center
DRF	Disaster Risk Financing
DRM	Disaster Risk Management
DRMU	Disaster Risk Management Unit
DRR	Disaster Risk Reduction
DSN	Digital Social Networks
EUG	European Union of Geosciences
EGS	European Geophysical Society
EO	Earth Observation
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FVE	Flood Vertical Elevation
GCC	Gulf Cooperation Council
GDIN	Global Disaster Information Network
GeoRisk	Geophysical Risk and Sustainability
GIERS	*GIS-based intelligent emergency response system*
GIS	Geographical Information System
GEO-IT	Geospatial Information Technology
GNSS	Global Navigation Satellite System
GP	Global Platform for Disaster Risk Reduction
GPS	Global Positioning System
GRF	Global Risk Forum
HFA	The Hyogo framework for Action
HRC	Higher Relief Commission
IATF	Inter-Agency Task Force
ICT	Information and Communication Technologies
IDNDR	The International Decade for Natural Disaster Reduction
IDRiM	Integrated Disaster Risk Management
IJDRR	International Journal of Disaster Risk Reduction
IJDRS	International Journal of Disaster Risk Science
IMdR	Institut pour la Maîtrise des Risques
LCD	Least-Cost Distance

MENA	Middle-East and North Africa
MODIS	MODerate Resolution Imaging Spectroradiometer
NCSR	National Council for Scientific Research
NFIP	National Flood Insurance Program
NRT	Near Real-Time
ODCE	Organisation de Développement et de Coopération Economiques
OSM	OpenStreetMap
PAPI	Programmes d'Actions de Prévention des Inondations
PAR	Pressure-and Release Model
PPR	Plan de Prévention des Risques
PPRI	Plans de prévention des risques inondations
PSSIZ	Plans de Secours Spécialisés Inondation Zonaux
RS	Remote Sensing
SDI	Spatial Data Infrastructure
SRS	Spatial Reference Systems
STAG	Science & Technology Advisory Group
UNDP	United Nations Development Program
UNISDR	United Nations International Strategy for Disaster Reduction
UN-SPIDER	United Nations Platform for Space-based Information for Disaster management and Emergency Response.
VGI	Volunteered Geographical Information
WFP	World Food Program

General Introduction

General Introduction

Looking backward at the history of natural disasters on Earth, it is apparent that the latter is suffering more and more. 80% of natural disasters reported in the 20th century, happened between 1970 and 2000 (Guha-Sapir, Hargitt, and Hoyois 2004). And, based on the "*2015 Global Assessment Report on Disaster Risk Reduction*", natural disasters like earthquakes, floods, hurricanes and tsunamis are now causing on yearly basis around US$300 billion of economic losses. Expected annual losses are predicted to reach US$314 billion in built-up areas alone (UNISDR 2015a). Casualties and damages are obviously on the rise; UNISDR (United Nations International Strategy for Disaster Reduction) Task Force member and The International Federation of Red Cross and Red Crescent Societies confirm the intensifying pattern of human affliction and financial loss due to natural disasters.

Feeling the ascending weight of disasters, human beings as innovative creatures have realized the significant importance to figure out ways to manage risk and cope with disasters. Furthermore, humans are at a point where they refuse the natural and religious determinism concepts; societies totally reject being determined by their surrounding environment, a manifest and insupportable sign of man's failure to control his environment. As Professor Niklas Luhmann, from the University of Bielefeld, says in his paper titled "*Modern society is shocked by its risks*": "*The term risks is a neologism that came into use with the transition from traditional to modern society*" (Luhmann 1996, p.2). People's perception of risk has changed and they do not accept fatality and short longevity; the idea of letting risks to cause damage to humanity is henceforth completely rejected. On the other hand, risk is not denied, recognized to be ineluctable and people are somehow reconciled with the idea of risk. A greater acceptability of risk sees the day insofar as an opportunity to recover by improving the existent assets and tightening social bonding. This concept is called resilience (Reghezza-Zitt 2010). Thereby, the Disaster Risk Management (DRM) science started around 60 years ago. The DRM science could be resumed as crisis response, relief and recovery. But managing a disaster and coping with it, described as reactive actions, revealed not to be enough. In order to minimize the losses, preventive actions are crucial and are the key to manage hazards to impede them from becoming disasters. Thus, DRM science has evolved and stakeholders start adopting Disaster Risk Reduction (DRR) actions, defined as the practice of analyzing the causal components of disasters and managing them by reducing exposure to hazards, decreasing people and properties' vulnerability, wisely managing land uses and occupations, emergency planning (including raising risk awareness in the local population) and improved preparedness for adverse effects (Van Niekerk 2011), which helped societies reduce disasters' induced losses. The first global conference on DRR was the Yokohama conference in 1994, held in the framework of the IDNDR (International Decade for Natural Disasters Reduction). Then, in 1999, the United established a secretariat office dedicated to enforce the implementation of the International Strategy for Disaster Reduction (ISDR). This office (UNISDR) is considered to be the focal point responsible for coordinating DRR actions and ensuring cooperation among the United Nations system and multi-disciplinary organizations from all over the world. UNISDR led, between 2000 and 2005, an Inter-Agency Task Force (IATF) on Disaster Reduction which had as main purpose to discuss the issues of DRR and define strategies for international cooperation. In January 2005, a world conference on DRR took place in Kobe, Japan and resulted in the Hyogo Framework for Action. The subsequent Global Platforms for Disaster Risk Reduction were biennial forums (2007, 2009, 2011 and 2013) for knowledge exchange, discussion of latest innovations and advancements, and creation of inter-sectoral partnership, with the aim of following the implementation of Hyogo Framework. Its primary function is to empower governments, scientists, NGOs, practitioners, and United Nations organizations to share experiences and formulate strategic directions for the implementation of global disaster risk reduction agreements. These platforms prepared the way for Sendai Framework that has been agreed upon and launched at the Third UN World Conference on Disaster Risk Reduction in March 2015.

DRR actions start from desk reviews to developed modelling and improved monitoring. Actually, geo-information technologies and computerized models are of huge interest in the field of DRR (Cova 1999; Van Westen 2013). Geographic Information System (GIS), Remote Sensing (RS), alongside other geospatial database, have proven to be convenient and reliable tools for DRR; in the past years, important natural disasters have been monitored through satellites, such as, for instance, the 2004 tsunami of the Indian Ocean, 2005 flooding in Germany, Austria, Switzerland, and Romania, USA hurricanes also in 2005, Europe wild fires in Portugal and France in 2005, earthquakes in Pakistan (2005) and Indonesia (2006) (Nayak and Zlatanova 2008). These geo-information technologies' efficiency has been revealed in DRR as a database for data gathering and integration and incorporation of multi-source data, as observation systems, as a tool for hazard maps production, a calculator for exposure, a model-builder for determining assets' vulnerabilities, a near real time crisis tracker, etc… Effectively, satellites and their imagery have showed their capacities in weather forecasting, tracking of any asset, early warning systems (National Academy of Sciences and National Geospatial-Intelligence Agency 2016), oil spills, forest fires, drought and floods monitoring, deforestation detection and crops damage assessment. In other words, RS & GIS are extremely valuable tools for civil protection and may have a role in disaster mitigation and emergency preparedness. GIS has an integrative capacity for cross-sectoral analysis; it can be used for multi-hazard study (domino-effects and cascading events, i.e. flood and landslide after wildfires, earthquakes triggering landslides, etc…), for network analysis of roads, for network analysis of energy and water networks, for evacuation routing and planning, for integrated land use-settlement patterns. Also, the production of colorful risk maps could be very efficient for spreading awareness and for land use regulation and planning. Governments and stakeholders should benefit from these geospatial technologies to allocate assets, establish relationships and generate models that are simple representations of real-world systems giving plausible what-if scenarios, in order to reduce financial losses and fatalities.

International seminars, related to geo-information technologies helping disaster reduction, have been held by several national and international organizations and agencies and intended to unify the work of data providers, researchers, developers and users worldwide. The "*Remote sensing and GIS techniques for Monitoring and Prediction of Disasters*" seminar focusing on natural disasters as main theme, was held in September 2006 in Goa, India (Kulawardhana 2012). The most important outcomes of this seminar were auspicious techniques for providing quality data, efficient engagement of geo-specialist in foreseeing and reducing disasters and valuable use of technical expertise in aftermath.

Despite that several geospatial models and satellites technologies have been proven to be important in serving DRR actions, the effective use of these technologies requires further research and development. Considerable challenges remain omnipresent when using satellite positioning and geospatial information technology for recovery in the aftermath; these challenges encompass real-time data gathering, surveying, processing, management, integration, interpolation and dissemination of information. Many other obstacles also do exist for pre-disaster phases, especially in developing countries. Remote Sensing has become a popular source of maps because RS maps are cheap to produce and up-to-date. But, when it comes to land use, remote sensing informs only on visible surface landform, not on land use and land rights. GIS is much larger than remote sensing, it requires integrating population, property, transportation network, information on facilities (building use), data that may be lacking in developing countries. Therefore, the lack of accurate and up-to-date land-use data is a factor of vulnerability to natural hazards.

Establishing a spatial data platform at local, national, regional and even international level would make this data available, standardized and updated in business as usual and in time of crisis. This platform, also called spatial data infrastructure (SDI), would be useless without its link to first responders and cooperation between rescue units. The establishment of a spatial data platform isn't possible without legislation of agreements and laws that oblige the secure sharing of harmonized data. Here comes the crucial role of governments as major driving factor in DRR actions, especially in developing countries. Augmenting the nations' geospatial intelligence capabilities is an extremely crucial step in the process of building back safer and more resilient communities.

In the course of the most recent three decades, in excess of 70 million individuals have been influenced by calamities in the Arab region, with 330 catastrophic events bringing about more than 160,000 fatalities. Along with political instability and conflicts, fast and haphazard urbanization, land and nature degradation, water shortage and migration patterns have been perceived as risk drives in the region (UNISDR-ROAS 2012). Effectively Lebanon, as part of the Middle-East and North Africa (MENA) region which seems to undergo the upward trend of natural disasters more than the rest of the world (The World Bank, UNISDR, UNDP, & GFDRR, 2014). Actually, due to its geographic location and many other factors, Lebanon is exposed to devastating earthquakes, Tsunamis, floods, storms, landslides, forest fires that have hit it in the past and have caused severe damages to its population and economy. Moreover, the Lebanese population is rapidly increasing, especially with the continuous refugees' exodus and ultimately, the concentration of elements and assets that could be exposed to natural hazards in this developing country is on the rise. All this is accompanied with a government considered weak and fragile, unable to prioritize the DRR issue, or even to insert it in its agenda as an important issue. When the DRR issue is taken into consideration by the Lebanese government, it's often on the planning level; the regulation level, implementation level and control level are usually overlooked. Here comes the need for international funding to commit to DRR actions. Risk education is extremely crucial for every part of the Lebanese society to be aware of the threatening hazards and how to react, respond to it and cope with it. To what extent could the GIS be efficient in DRR actions in a developing country like Lebanon where the assets at risk are ever-increasing and the government has other urgent priorities than to commit to any DRR plan?

The chapters of this thesis develop and discuss the ideas aforementioned, focusing on the application of geospatial information technologies to help during each phase of disaster risk mitigation cycle in Baalbek-Hermel, one of the eight governorates of Lebanon. Baalbek-Hermel Governorate was chosen due to its particular rural characteristics and socio economic factors with high poverty levels. Moreover, previous risk assessments were conducted on several Lebanese governorates but not for Baalbek-Hermel due to the presence of ISIS at that time. Several case-studies are taken to test what assumptions have been made and illustrate different applications of geo-information technologies in DRR. This dissertation, at the core of applied sciences, has a main challenge to answer the following question: "how to put GIS and RS to better use for DRR in Lebanon?". Overcoming the limits of a theoretical study, this work offers many elaborated methodologies for effective use of GIS before, during and after crisis.

The work of researchers in the field of geo-information technology serving prevention from hazards, emergency services, disaster management and reduction and civil protection was the starting point for the preparation of this thesis. The thesis consists of three parts and eight chapters highlighting the utility of spatial data and geo-information technologies in each stage of the DRR cycle, recommending different approaches for data gathering, harmonizing and integrating in order to reach end users in the most efficient way possible. DRR cycle consists of pre-disaster phases, including prevention, mitigation, preparedness and planning, and post-disaster phases summarized to response and recovery. Part I entitled "Theoretical Concepts and Literature Review", contains two chapters. In Chapter 1 "Disaster Risk Reduction concepts", a set of brief contextual explanations of natural hazards and disasters are laid while emphasizing their spatial components, and their relation with societies from a natural disaster vulnerability standpoint. Included in this chapter is a more detailed examination of disaster risk reduction and management concepts, followed by a brief review of the phases that comprise the disaster reduction cycle. In chapter 2, geospatial information technologies are highlighted with a review of their contribution to the DRR cycle. Part II tackling the study area is also formed of two chapters (chapter 3 and chapter 4). Baalbek-Hermel is studied in chapter 3 accordingly to its administrative, geographical and socio-economic settings, pinpointing its history with natural disasters and the undertaken DRR measures so far. Chapter 4 reveals the natural hazards threatening Baalbek-Hermel and their maps. In part III "Geospatial Applications to DRR", which form the bulk of the thesis, four chapters are developed exploring the many uses of GIS in each step of the natural disaster reduction cycle with an examination of its applicability to the case of Baalbek-Hermel, highlighting its potential as well as limitations in terms of its ability to fulfill disaster reduction related requirements. Chapter 5 tackles Geospatial information preparation phase, examining a method to overcome the lack of population census. Chapter 6 emphasizes on the involvement of GIS in preventive actions through three case studies related to the resilience analysis of critical infrastructure (road network), vulnerability analysis with operational dimension (identification of the most vulnerable schools, prioritization of actions) and retrospective study of risk on sector of economic activity (here agriculture). Chapter 7 calls attention to preparedness and response planning phase through two case studies focusing on evacuation (pedestrian microscopic evacuation and macroscopic evacuation routing). The last chapter, chapter 8 accentuates the use of GIS during recovery time through implementation of land-use planning. Finally, a discussion is made on the outcomes of this dissertation.

The reason behind choosing many case studies in Baalbek-Hermel comes from the extreme diversity of hazards and problems specific to each type of risk leading to many different methods of evaluation in a geomatic environment, and this involves a selection of specific examples to show that these methods are operational, and for this to develop examples of first-hand treatment. Moreover, the extent of the risks and issues does not allow, in the narrow confines of a doctoral dissertation, carried out for an isolated researcher, to present a comprehensive survey of all the risks that afflict the Baalbek-Hermel governorate and cover all the DRR cycle phases. To present a reasoned sample of some case studies illustrating the diversity of methods and the diversity of the issues covered, was agreed as best representation of this dissertation.

In an applied research perspective, this dissertation comes to respond to the theoretical Framework of Sendai in an attempt to advance on its operational implementation in Baalbek-Hermel and in Lebanon, in general. The goal of this thesis is to adopt geospatial techniques that would be effective and serve the whole process of DRR and complete its cycle in Baalbek-Hermel and Lebanon. One of the criticisms of the DRR approach is that the frontier between the different stages is not always clear. Risk reduction actions may belong to one or more of the DRR steps. Thus, the systems presented below can be broadly grouped into one or more categories of the DRR model. Challenges in the deployment of GIS technologies in each phase of the DRR cycle in information-scarce environments and how they may be overcome will be discussed, considering indigenous approaches for the application of technologies and innovations in disaster reduction. This thesis emphasizes the impact of geospatial data on the overall resilience of Baalbek-Hermel society.

French Summary:

Cette partie sert d'une introduction générale pour la thèse. Dans une perspective de recherche appliquée, cette thèse vient répondre au cadre théorique de Sendai dans le but de faire avancer sa mise en œuvre opérationnelle à Baalbek-Hermel et au Liban en général. Le but de cette thèse est d'adopter des techniques géospatiales qui seraient efficaces et serviraient à l'ensemble du processus de RRC et compléteraient son cycle à Baalbek-Hermel et au Liban. L'une des critiques de l'approche de la réduction des risques de catastrophe est que la frontière entre les différentes étapes n'est pas toujours claire. Les actions de réduction des risques peuvent appartenir à une ou plusieurs des étapes de la RRC. Ainsi, les systèmes présentés ci-dessous peuvent être regroupés dans une ou plusieurs catégories du modèle de réduction des risques de catastrophe. Les défis posés au déploiement des technologies SIG à chaque phase du cycle de la RRC dans des environnements où l'information est rare et à la manière dont ils peuvent être surmontés seront abordés, en considérant les approches autochtones pour l'application de technologies et d'innovations dans la prévention des catastrophes. Cette thèse met l'accent sur l'impact des données géospatiales sur la résilience globale de la société Baalbek-Hermel.

Part I. Theoretical Concepts and Literature Review

Part I. Theoretical Concepts and Literature Review

Configuring the importance of geo-information techniques and their use as help for DRR actions, we need to begin first of all with natural disasters and their history on Earth. This chapter will therefore develop a synthetic look at the history of natural disasters on Earth, the complex relationship between natural disasters and mankind, and the involvement of socio-economic conditions and developments in the shaping of nature disasters; the relationship between humans/societies and disasters and their mutual impacts will take an important place in our discussion. Moreover, the effects of humanity's and technology's evolutions on natural disasters will be addressed. A special attention will be given to the evolution of disaster risk mitigation actions taken by humans, since the antiquity, in order to cope with disasters and minimize their impacts. Ultimately, the genesis of DRR science and its general concepts will be discussed in details. Risk governance and the monetary values of DRR and DRM actions will be argued. This chapter will also bring up the current status of DRR in The Arab Region and Lebanon, and future plans to limit the impacts of predominant natural hazards. The relationship between the socio-economic issues, developing countries, expanding populations and assets, fragile states and natural disasters will be pointed out clearly. The subject would not be adequately addressed without the discussion of geospatial technologies and geographical information systems, their evolution over time and what they bring to the geography of risk that is continuously changing, especially in the middle of an ever-expanding world, vulnerabilities on the rise and fragile states.

Chapter 1 . Disaster Risk Reduction

1. Natural Disasters

First of all, natural disasters should be clearly defined and the difference between hazards and disasters should be set clear. Based on UNISDR 2009 terminology, a natural hazard is: "*Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage*" (UNISDR 2009a). Natural hazards could arise from a variety of meteorological, hydrological, geological, biological factors, and sometimes from the combination of two or more of these factors. A hazard is characterized by its intensity, its frequency of occurrence, its duration and its expansion area. While, based on the same source, a disaster is defined as the following: "*A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources*" (UNISDR 2009a).

For the United Nations Disaster Relief Office, a natural disaster is "*an event, concentrated in time and space, in which a community undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfilment of all or some of the essential functions of the society is prevented*" (Alexander 1993, p.4). Disasters are evaluated by the exposure to hazards, the vulnerability and the capacity of coping. In the face of natural disasters, the main concern is the preservation of life and networks, infrastructure, functionality of systems (transport, drinking water, sanitation, energy, agriculture and food, public health, education, etc…), natural resources (ecosystem services), the environment, cultural and industrial heritage. Disasters impacts on people can be physical (fatalities, injuries, diseases, permanent handicap, etc…), mental (post-disaster trauma, depression, etc…) and may affect the social well-being. While the material damage can be property loss, demolition of assets, services disruption, environmental degradation, etc…It is important to mention that damages and losses due to natural disasters vary enormously and are categorized; there can be: (1) Direct tangible damage to assets such as buildings, facilities, etc., (2) Direct intangible damage to people, historic sites and ecological assets, (3) Indirect tangible damage like malfunction or disruption of services and productions, and (4) Indirect intangible damage such as psychological damage, displacement, development impediments, etc. (Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark 2017).

Thus, unlike natural hazards, natural disasters have important social dimensions; "*A disaster is the result of a hazard's impact on society*" (Twigg 2001). In other words, a hazard becomes or turns into a disaster if it does affect a population and its appurtenances. For instance, an earthquake is considered a hazard if it occurs in a desert. But this same earthquake is perceived as a disaster if it hits an urban zone and causes damages.

Here already appear the ambiguities around the terms used in DRR sciences and arise the great paradigms of the notions of this science. Eventually, some terms like disasters have been debated for over 55 years now. Disaster has always been a confusing term. In short, hazards belong to nature, disasters to the human world; but the main question is: when to define an event as a disaster, what should be the predefined threshold?

What index should be elaborated and used to determine a disaster? Several views have been expressed on what precisely determines a disaster. For some, the determination of a disaster should be based on the amount of losses, life losses and monetary value of losses. For some others, the spatial expansion of an event plays a major role in its determination as a disaster. But what is unanimous about the term "disaster" is the fact that it is an event that attacks a society whose capacities are not enough for facing the consequences of this event (Van Niekerk 2011).

In this upcoming section, only disasters resulting from natural hazards will be discussed, given that their impacts on societies were the turning point and the momentum for the birth of DRR sciences.

1.1. History of Natural Disasters on Earth

Natural disasters have existed since ever, either as slow killers such as droughts and sea level rising or sudden unexpected calamities like floods, eruptions, earthquakes, etc... According to Georges-Louis Leclerc, Comte de Buffon's, author of the artwork "L'Histoire Naturelle" and influential naturalist of the eighteenth century, nature was even divided into different epochs determined by disastrous events (Buffon 1780). Catastrophists like Georges Cuvier described the process of history as a sequence of destructive disasters, in each case turning the world upside down (Cuvier 1830). The oldest reported instance, regardless of whether fanciful or not, of humans facing disasters and coping with natural events even goes back to the legend of Noah's flood in the Old Testament Book of Genesis and its predecessors, including the Epic of Gilgamesh, a 5,000+ year old text. Later on, The Antiquity has witnessed countless episodes of devastating natural disasters, but only few were recorded. Around 1645 BC, Santorini Island (Greece) witnessed the eruption of a volcano that provoked considerable damage on both Santorini and Crete, a neighboring island. In 373 BC, an earthquake and triggered tsunami were recorded in Helike (Greece). The eruption of Mount Vesuvius in Italy in 79 AD, causing the complete destruction of Pompeii and Herculaneum and the death of thousands of their inhabitants; this disaster of ancient history (Antiquity) is well known because it gives rise to an outstanding pre-scientific observation for such an old period. An earthquake took place under the Mediterranean Sea on July 21, 365 AD, in Crete (Greece) and caused a tsunami in Alexandria (Egypt). Syria and Antioch were hit by an earthquake in late May 526 AD, when they were parts of the Byzantine Empire and the number of fatalities reached 250,000. A 7.9 magnitude earthquake, known as The Damghan Earthquake, struck a 320 km stretch of Iran on 22 December, 856 A.D and left behind 200,000 casualties. In 1202 AD, it is said that an intense earthquake hit the entire area from Egypt to Syria and have caused 1.1 million deaths.

Various other cataclysmic events happened all throughout ancient times. It is certain that much more natural disasters happened in the past, other than the ones that have been reported. Populations were not more subject to them than current populations are today. Then how many civilizations were possibly eradicated by natural disasters that we have no knowledge of, as of yet. Evident questions are to be asked here; why only some of the past natural disasters were recorded and other were not? Was it due to their outrageous intensities and impacts? Or was it simply due to lack of reporters or historians in the location they have struck? Or even may it be hiding a deeper reason, related to people's perception of natural disasters and the fact that they, unconsciously, like to forget about natural disasters and erase all their traces?

A German Historian, Arno Borst, asserted around thirty years ago that natural disasters were extensively neglected in modern historiography. Arno Borst was the pioneer in discussing the historicity of disasters, developing their perception, their interpretation, coping with them and the collective memories (Borst 1981). According to Jacques Berlioz, despite the fact that research on natural disasters that history has experienced have been largely developed over the last thirty years, historians still do not seem to show the same enthusiasm for the investigation of cataclysmic events. In the introduction to his book "*Catastrophes naturelles et calamités au Moyen-Âge*", he encouraged the advancement of research that places natural disasters at the same level of importance as the geographical, monetary, social and social sciences (Berlioz 1998).

Nowadays, unlike past catastrophes, natural disasters around the world are being recorded thoroughly into global archives for disasters. Several global data set recording natural disasters exist. EM-DAT database, maintained by the Centre for Research on the Epidemiology of Disasters (CRED), CatNat.net and DesInventar system are global data set recording natural disasters that are publicly available. Other natural disaster global data sets exist but no public access is granted (Guha-Sapir et al. 2004). The NatCatSERVICE database on natural catastrophes operated by the private reinsurer company MunichRe, and the sigma-data presenting historical data on catastrophes is also operated by a reinsurer called "Swiss Re". A multi-agency "PREVIEW" global risk data platform consists of a multiple agencies effort to share geospatial data information on global risk from natural hazards. Although well-documented records of natural disasters began to appear in the late Antiquity, effective disaster mitigation measures did not emerge until the late middle Ages. This idea will be deeply developed and discussed later on.

Looking at the evolution of natural disasters over the time they appear, at first look, to be increasing in their frequency of occurrence, intensity (magnitude) and impacts. But are disasters' intensity and occurrence effectively increasing or is it simply related to the probable undercount of events in ancient times? A part of this obvious "*augmentation in the frequency of occurrence*" can be simply related to the fact that natural disasters are more frequently reported nowadays and the records are well-documented and archived. And is this evolution actually caused by climate change and anthropogenic activities like some scientists say (Van Aalst 2006; López, Thomas, and Troncoso 2015; San Jose University 2012), or isn't this upward pattern foreseen to go on as a combined result of economic growth and the growing number of individuals settling down in areas more exposed to natural hazards? On closer inspection, we realize that the hazards are not necessarily more numerous than in the past, but that their consequences are uncommon (Reghezza-Zitt 2006). No direct relation is yet proven between the increase in natural hazards' occurrence/intensity and climate change. Yet, climate change is modifying the patterns of hydro-meteorological hazards with the potential rise of sea levels, only. While the impact of climate change on the occurrence of natural hazards is still under study, the link between the evolution of impacts and vulnerabilities induced by the evolution and exposure of societies has been proven, researched and well documented (E. A. Gencer 2013). In fact the Anthroposphere, including the entire human presence on Earth along with our way of life, development, built environment, and related activities, is continuously expanding. Socio-economic conditions and settlements patterns have contributed to expand the physical exposure of individuals and economic assets and therefore to increase risk; the climatic conditions and favorable soils that have stimulated economic activities are often related to landscapes exposed to hazards. Furthermore, nowadays' societies have a high rate of urbanization and are profoundly dependent to their infrastructure; and are even called societies of risk (Clarke and Beck 1994; Luhmann 1996). In many developing countries, unchecked urban expansion and haphazard housing characterize these countries' urbanization and conduct more important losses. "*Disasters are deadly and destructive events, particularly in developing countries where economic, social, political and cultural factors increase natural hazard vulnerability"* (Herold and Sawada 2012, p.3). More than 90 per cent of fatalities caused by natural disasters are found in developing countries (Zorn 2018). As well, societies' reliance on infrastructure and interdependency of its complex networks increase disasters' impacts and caused damages (Laugé, Hernantes, and Sarriegi 2013). Some infrastructure are considered critical and are highlighted during natural disasters either because they host the most vulnerable part of a population (patients, elderly, children, person with disabilities, etc…) or because their failure leads to deployment of civilian security and perturbation of first responders services (Lhomme 2012). These facts, related to the cities and urban spaces, induce the idea of double-vulnerability: physical/structural vulnerability and functional vulnerability. As Beucher and Reghezza (2008) declare in their article, the functional vulnerability should be taken into consideration because not only the assets located in the hazard zone are damaged and affected, the impact is spread way beyond the disaster location. Knowing that natural hazards are not isolated events and admitting that they are complex features intimately interrelated with the social system they hit, is crucial. In similar fashion, exposed assets and their vulnerability are not static over time, an aspect that is claimed not to be sufficiently developed in literature (Hufschmidt 2005). This misleads our perception of natural disasters, letting us think that the latter are exacerbating over time.

In other words, according to (Bankoff 1999), this evolution of natural disasters is due to a complex amalgamation of social, economic, political and environmental factors; People and infrastructure concentrating in urban areas, environmental negligence and degradation (deforestation, excessive pasture, etc.), and new weather trends related with Climate Change, altogether are inducing the appearance of unusual natural disasters patterns.

As discussed above, natural disasters are complex features intimately connected with the social system they hit. Their magnitude is multi-factorial, depending both on the natural process itself, on the geological and anthropogenic properties of the environment in which it occurs, and on the populations and infrastructures undergoing it. This necessarily implies a relationship between humanity and nature, and this relationship seems to evolve over time.

1.2. Relationship between Natural Disasters and Mankind

Many authors were interested in this undeniable bonding between Natural disasters and Human. Stevens et al. (2008) search back in the etymology of the word "Man" to find out that it means "born from Earth". This implies that "Man" and "Earth" are intimately linked. And, ultimately, as with word "Earth" comes "Natural Disasters", "Man" and "Natural Disasters" will have to co-exist forever (Stevens et al. 2008).
Grégory Quenet's contribution to seismic events in France between the 17th and 18th centuries shows that natural disasters are both natural hazards and social events (Quenet 2005). Disasters are considered as social phenomena, despite the fact that they may be started by nature. As emphasized by Blaikie et al. (1996), the 'natural' and the 'human' are so inseparably linked together in practically all disaster circumstances,

particularly when seen in an enlarged time and space framework, that disasters cannot be comprehended to be ‘natural’ in any direct way.
Even more, in their article “*The archeology of disasters: past and future trends*”, Robin Torrence and John Grattan (2003) defend, based on archeological analyses, the idea that several environmental events had significant effects on cultural histories and therefore, disasters are considered as major agents of cultural change, determining its pace and character (Torrence and Grattan 2003). Natural forces even have an importance in accounting for the evolution of humanity and societies. As Bankoff.G (1999) attest that a substantial relationship exist between catalytic events and the history of humankind, their evolution and their vulnerabilities to these events (Bankoff 1999).

The interactions between natural disasters and mankind are mutual. As natural disasters impacted humanity, anthropogenic activities also have an influence on Mother Nature, and therefore on natural hazards and disasters, too. Natural hazards have even been qualified as “hybrid” (Reghezza-Zitt 2009, 2015a) or even “anthropized hazards”, due to the massive impact of human on nature and the changing shapes of natural disasters caused by anthropogenic activities (Pigeon 2015). Demographic pressure implies forest loss and more land degradation. It would be important here to address the issue of the ecological footprint. The ecological footprint is the physical space (land and/or shallow sea) required for a human being to provide for a certain activity like eating, drinking, living... (Voet 1999). More newborns each day, means more ecological footprint and more pressure on Earth. Systemic ecological and localized environmental degradation is affecting the trends of disasters more and more, lowering the natural resilience and absorptive capacity to disaster impacts, therefore exacerbating the impacts of disasters, increasing recovery time and deteriorating the resources based on which all human activity is eventually reliant.

Some authors even argue that nature and natural disasters are claimed to be defined by man. These definitions and interpretations are determined spatially and temporally, based on populations and time. Some researchers found no notable tendency in disaster loss and damage, to be explained by climate change or population evolution (Neumayer and Barthel 2011; Okuyama and Sahin 2009). Pielke et al. (2008) has supported this idea by analyzing the losses and damages caused by hurricanes in the United States from 1900 to 2005.

As discussed above, while some researchers suggest no trends in disaster losses damage, some others see a clear tendency in the evolution of natural disasters losses and anthropogenic activities. I fact, there is a growing literature trying to prove that there is an alarming connection between the global increase of hydro-meteorological and climatological events on the one side and anthropogenic climate change on the other (Van Aalst 2006; Benfield 2015; Brown 2012; López et al. 2015; Merkouris 2014; Roberts et al. 2015; San Jose University 2012). Cook et al. (2013) claim that 97% of the more than 10,000 published research studies on climate from 1991 to 2011, agree that anthropogenic global warming is the cause.

On the other hand, it appears that the growing economic damage caused by natural disasters in recent years can account for the development in wealth in the exposed areas, rather than by the rising frequency or intensity of these natural disasters. According to Nedjai et al. (2016), the impact of land use on ecosystems is a reality that continues to interest scientists and managers alike. This is a direct consequence of a social, economic, and biological mutation, with a proven climate change. Some suggest that, even in the absence of human-induced global warming, losses and damage from natural disasters could double simply because of rising incomes. These facts have been proven in studies about tropical cyclones (Mendelsohn et al. 2012; Weinkle, Maue, and Pielke 2012). Even more, Mohleji and Pielke (2014) analyzed data from the reinsurance industry and came with a conclusion that societal change, which implies population and wealth, hides behind the increasing disaster losses and damage. Bouwer (2011) even goes farer, finding out, after an analysis of 22 disaster-loss studies, that if augmentation in population and capital were included in the damage equations, no loss trends can be given to anthropologically induced climate change. This idea is supported by many, considering the expanding urban agglomerations with their growing populations and constructions and the infrastructure buildup to be behind this pattern.

Regardless of the presence of an evident trend in natural disasters losses and damage and anthropogenic activities and climate change, humans are defenseless now to the effect of catastrophic events more than ever before. The main reason behind this, as mentioned previously, is the concentration of individuals living in denser fixations with more exorbitant and sophisticated critical infrastructure. Thomas, Albert, and Perez (2013), consider the three major components behind the global increase in frequency of intense natural hazards; beside the increasing climate-related hazards, the rising population exposure and the greater population vulnerability are the two other factors. Clearly, population is an important component in disasters. Solid monetary considerations drive this human component. Effectively, the above discussed relationship between man and nature has, in most of the times, a socio-economic dimension.

Natural disasters are social phenomena; "*natural disasters can more accurately be seen as social phenomenon, where the overall damage due to natural hazards is the result of both natural events that act as 'triggers', and a series of societal factors,*" (Weichselgartner 2001). Risks have a social dimension; risks exist or are produced within social systems (Van Niekerk 2011). Natural disasters and the risk in general, have a socio-economic dimension and they are in the main, social happenings which are both created and expressed by human behaviors. The socio-economic dimension of disasters was defended by many authors. In his book "*Disasters. The Anatomy of Environmental Hazards*", Whittow (1979, p.397) says: "*the human response to a hazard is not only a function of the hazard itself, but is also related to the prosperity of the particular nation or group*". Quarantelli (1998) declares that natural disasters are best seen for research purposes as established in "*the macro level processes of social changes or societal development*", yet in addition remain as opposed to progressively spread and permanent social pathologies such as unemployment, crime, poverty and other similar negatively viewed phenomena that sociologists usually treat as part of the social problems of a community. Often, the hazards are not the real threat but the attitudes to risk, rooted in societies are the inevitable triggers leading to disasters. This is what Cardona (2003) calls "*the constructivist thinking*". These attitudes and reactions to risk are deeply dependent on the economic conditions and development status of the country. For instance, living in miserable conditions and poverty necessarily force vulnerable people to accept the risks which they face, having no other choice, whereas rich societies can choose and decide to avoid any kind of risk. In affluent but unequal societies, exposure to hazard is often related to social positions, e.g. Pre-Katrina New Orleans social geography (Zaninetti 2007). As for Stallings (1995), yet a sociological theory of risk challenges such a direct bond between physical forces and social reality, because it is not nature that creates beliefs about risk, but human. Stallings thinks that what stands behind defining disasters as social problems are either policy and decision makers or citizens (Stallings 1995).

The processes by which people and goods become more exposed to natural hazards also turned-out to be socioeconomically conditioned. The ongoing and non-stop changing trends in augmenting people's exposure to hazards is determined by relatively recent forces, such as population growth and extensive rural/urban migration, which are considered dynamic pressures. The impact of natural disasters depends on the vulnerability of those affected, which can and often systematically contrasts from one economic class to another (Herold and Sawada 2012). In their study, Montoya and Masser (2004) highlight that the "*1988 Spitak earthquake in Armenia (former USSR) and the 1989 Loma Prieta earthquake in California were of similar magnitude and affected populations of comparable size; however, the Armenian event killed 25,000 people whereas the California earthquake killed 63*,". Moreover, according to Bui et al. (2000), 1970 cyclones that hit Bangladesh caused more than half a million of casualties and another 140,000 in 1991 while hurricanes "*Hugo in 1989 and Andrew in 1992 caused less than 50 deaths each in the U.S.*". Social vulnerability describes the extent to which a socioeconomic class can be affected by the impact of natural hazards and environmental changes. Numerous research studies have proved that education and income affect or even determine vulnerabilities and, eventually, natural disaster impacts (Brooks, Adger, and Kelly 2005; Kahn 2005; Kellenberg and Mobarak 2008; López et al. 2015; Noy 2009; Rentschler 2013).

As a matter of fact, natural disasters do not influence populations similarly; "*Natural disasters do not affect people equally as if by an arbitrary stroke of nature*" (Neumayer and Plümper 2007). Cataclysmic events have constantly postured a greater risk to some human social orders than to others. As a rule, this is just an issue of spatial location and geography. However, this fact could also be exacerbated by financial variables and socio-economic factors. Researchers have accorded importance to how nations' low economic development, poor quality of public institutions, and high level of disparity increment lives losses resulting from natural disasters (Kahn 2005). Losses resulting from disasters are closely linked to population density and to the status of social and economic development. Merkouris (2014), proves by an econometric analysis that, although the impact of Climate change is global, Asian developing countries would suffer much more from natural disasters. In fact, in 20 years of permanent rising of CO_2 concentrations at current rate, Asian countries would yearly increase their disasters numbers by one, higher than the average country where the disasters number would yearly increase by 0.74 in 17 years (Merkouris 2014).

There is a clear difference between the experiences of developing countries and developed ones in the face of natural disasters of the same type and intensity. Developing countries are suffering the most, where more than 90% of fatalities caused by natural disasters are found and the highest economic losses by percentage of GDP are recorded. This number is affected by the lack of coping capacity in these countries. Richer and more developed societies, therefore, are better placed to manage natural disasters. Yet additionally, being poor, the expense of damage to property is, obviously, much lower. When societies are poor, they are not well prepared and equipped to face natural hazards and consequently pay a much higher cost in terms of fatalities. As societies become richer, economic losses tend to rise while the death toll to decrease considerably. In other words, natural disasters result in more material damage in developed countries, but a higher number of fatalities in less developed ones. In his paper "*A history of poverty: The politics of natural disasters in the Philippines, 1985-1995*", Bankoff (1999) explores the relationship between environment and poverty in Philippines, a country inherently vulnerable to natural disasters. Bankoff strongly defends the idea that there is actually more than a causative bond linking the resulting condition of poverty of a significant part of the Third World as a result of trade inequalities and the vulnerability of some countries to cataclysmic events. According to Smith (1996), Asian people suffered historically from natural hazards much more than people in North America and in Europe, with a percentage of 37% of all global disasters recorded during the last forty years of the twentieth century. One should mention that North America and Europe have recorded only 2.8 and 3.9% of global hazards, respectively. Smith also attests that natural hazards threaten to kill the inhabitant of developing countries three to four times more than those living in developed ones. It is important to mention here a dynamic social factor, which is the rural exodus. In less developed countries, the majority of the populations were known to be rural. But extensive migration to cities is modifying the demographic landscapes. Cities in developing countries are often overcrowded, not following any urban planning and with an important propagation of inadequate slums. Every 12 to 15 years, many cities are doubling in size; with yearly around 30 million of the world's poorest moving from rural to urban zones, cities' growth rate is reaching 7 per cent each year (Alexander 2013). Although developing countries are witnessing extensive urban immigration, but an important part of their inhabitants still live in rural zones, especially for agricultural activities. These rural populations are also vulnerable to natural hazards, since they are, for the majority, poor farmers dependent on agriculture. The bottom line in all this contrast between developed and developing countries is economic development, for it allows populations to take a broad range of actions to protect themselves and stop or avoid natural hazards from turning into human disasters. Economic development elevates the value of life and properties and thus makes affordable any financial or technological action to limit the damage. Certainly, economic development even allows private charities to mobilize far more resources far more efficiently and expeditiously to stop the suffering of victims and help them rebuild their lives and recover quickly (Mitra 2000). Another demographic factor in developing countries is that societies are considered young, with a high percentage of citizens under 15 years old. These are considered among the most vulnerable to natural hazards. The age groups factor relation with natural disasters impacts will be discussed below.

Poverty is one of the main socio-economic factors determining the trends of natural disasters. Poverty has a tendency to exasperate the challenges brought on by catastrophic events and highlight the predicament of the poorest, the most marginalized and the most disadvantaged. Actually, poverty clarifies why famine, in the majority of cases, is the side effect of lack of means to buy a subsistence instead of the absence of food, and why droughts affect poor farmers and not wealthy people. Poverty is also the reason that pushes people to leave their villages searching for job opportunities and settling in the cities. Poverty even pushes people to make choices based on economic judgment to build lives and businesses in hazard-prone zones in spite of the existing dangers (López et al. 2015). We go back to what Cardona (2003) calls "*the constructivist thinking*"; living in miserable conditions and poverty necessarily force vulnerable people to accept the risks which they face and accept to live in unsafe environments, having no other choice, whereas rich societies can choose and decide to avoid living in the most risk-prone areas of any given territory. In fact, entire cities are constructed in hazard prone areas because of the great livelihoods conditions these areas may offer, like harbors and ports, fertile soils, transportation, etc., provided in flood plains. A considerable number of studies suggest that even when they are recognized, long-term risks are neglected in favor of short-term economic benefits (Sheets and Grayson 1979). It is crucial here to stress that though poverty may cause vulnerability and understanding urban poverty enclosing both economic and noneconomic factors helps to better comprehend disaster vulnerability (Ebru A. Gencer 2013), and there is a tight bond between these two, but poverty is not the same as vulnerability (Cannon 1994). ''Not all poor people are vulnerable to disasters, and some people who are not poor are also vulnerable'' (Bankoff 2003, p.19). In some situations, rich people may be more vulnerable to natural disasters than poor people. For instance, poor people living in flimsy dwellings in an area prone to earthquakes, don't risk much of their collapse, while more fortunate people of middle-income occupying unsafe housing in same zones may be killed or injured and may, hence, higher levels of vulnerability.

Evidence also shows that social factors other than poverty play a major role in the exposure and vulnerability of people to natural disasters, and therefore shape the impacts of the latter. Education and literacy rates are important social factors influencing the potential impacts of natural disasters. According to several studies, higher educational attainment and literacy have been proven to be directly connected with better disaster management and coping capacity and reduced vulnerabilities (Brooks et al. 2005; Izadkhah and Hosseini 2005; Toya and Skidmore 2007). Muttarak and Lutz (2014) justify this idea by the fact that education and literacy can influence risk perception, skills and knowledge. Thus, when confronted with natural hazards, educated communities are expected to be more self-reliant and self-sufficient, and more adaptable in their response to, and recovery from disasters. In fact, higher education indirectly means reduced poverty, improved health and better access to information and resources; this ultimately induces reduction of vulnerability, empowering of adaptive and coping capacities, building resilience to the challenges of a changing world.

When we talk about social factors, gender is also relevant in shaping natural disasters impacts on societies. It has been revealed that unfortunately and for multiple reasons, natural disasters hit women more strongly than they hit men (Enarson 2000). This was obvious during the Asian tsunami of 2004; female were more affected by this disasters especially that there were more female deaths than males (Birkmann et al. 2007). As pointed out in Neumayer and Plümper (2007) study, the natural disaster impact depends on the vulnerability of those affected, which can and often does systematically represent contrast according to sex. In their article "*The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life Expectancy, 1981-2002*" Neumayer and Plümper prove by a quantitative study that natural disasters impact women differently than men. They noticed a systematic impact of natural disaster intensity on the gender gap in life expectancy if the disaster strikes in societies with low socioeconomic status of women; natural disasters decrease the life expectancy of women more than that of men (Kumar and Quisumbing 2013). Here also, the everyday socio-economic patterns play a major role in the impacts of natural disasters and lead to determine the vulnerability towards natural disasters.

Another social factor is the age groups and the age pyramid of the population. As rapidly mentioned above, the societies in some developing countries are considered young, with a high percentage of citizens under 15 years old. According to Birkmann et al. (2007), age groups below 10 years and those above 40 years are observed to be most vulnerable in the face of natural disasters.

As discussed above, while the livelihood and self-protection elements may strongly relate to level of wealth and income as determined by class, a group's ethnicity may significantly alter their self-protection capacity despite their having reasonable livelihoods. Even the race and religion are factors that seem to be determining in natural disasters impacts. As elaborated by Elliott and Pais (2006), a social infrastructure is affected by Hurricane Katrina and black people were more probably reported to tend to rely on "the Lord", while whites were more probably reported to be relying on beloved ones like friends and family. These ethnic factor involve in the perception of risks and the response to it.

As we have seen, socio-economic factors change the patterns of natural disasters and this manner is well researched, but at the same time, natural disasters also deeply influence the socio-economic conditions of societies. Very few researchers were interested in studying the short and long-term effects of natural disasters on socio-economic factors. One of the most important consequences of catastrophes was that it created opportunities to modernize the layout of towns and their infrastructures. But these states of emergency also had many consequences for the city's inhabitants, upsetting their social, economic, and political structures. Cannon (1994) argues that the impacts of natural disasters may play a significant role in causing the impoverished of new people by the loss of assets, resources, employments or livelihoods (Cannon 1994). Disasters could cause major shifts in individual fortunes and settlement patterns, especially through radical changes in land values and the price of building materials. The occurrence of natural disasters may even cause social segregation; poorer classes of the population with limited resources often end up in highly prone peripheral zones with a poorer quality of houses. Once hit by a disaster, the poor are often left with even less resources which affects their livelihoods, intensify their losses and leave them even more vulnerable. This was clearly revealed by Typhoon Haiyan in 2013; 18 months after striking the eastern Visayas, one of the poorest regions of the Philippines (four out of every 10 families are poor), many Haiyan victims, with limited coping capacities, were still living in informal settlements and tents.

Some of the socio-economic manners and political dynamics developed above, like poverty, are behind the haphazard rapid urbanization, poor land use planning and the development of unplanned over-crowded settlements in dangerous locations, which considerably increases the vulnerability of communities. The infrastructure and market access of the dangerous locations, where often cities are being built, provide comparative benefits which become more compelling as economies and societies become more globalized, which is directly associated to the development of societies and humanity.

Unequivocally, the higher the level of economic development, and ultimately the level of development in general, the lower the threat from natural hazards. So what is the relationship between natural disasters and development?

As pointed out above, the significance of human development in natural disasters is confirmed by the fact that today developing and poorer societies are much more likely to suffer the wrath of nature than the richest ones. Why does human development play such an important role in determining natural disasters effects on societies? And what is, therefore, the relationship between natural disasters and human development?

According to Levy (2005), defining the geography of risk is of a serious concern especially in developing countries, "*where disasters jeopardize important social development goals such as addressing poverty, ensuring adequate food, water, and sanitation, and protecting the environment*," (Levy 2005, p.375).

Human development implies urban development, social development, economic development, systems development and infrastructure development. The interrelation between natural disasters and human development is extremely ramified, complicated, mutual, reciprocal and most importantly paradoxical (Albala-Bertrand 1993). The processes of Human development intimately and profoundly connected to natural disasters has been well researched and documented during the last years (Ahlerup 2013; Albala-Bertrand 1993; Ferreira, Hamilton, and Vincent 2013; Hallegatte and Dumas 2009; Mochizuki et al. 2014; Rodriguez-Oreggia et al. 2013). Hence what makes this relationship so paradoxical?

First of all, both natural disasters and human development can have a reciprocal negative relationship. Natural disasters and their losses can set back the development of a country. In fact, disasters are able only in few minutes to erase years of investment and human development efforts. Also, as reported by Elbers, Gunning, and Kinsey (2007), natural disasters indeed can hamper development measures by representing a considerable deterrent to productive investment, thereby hampering economic growth and development efforts even during periods of time when no disasters occur. More than that, it is important to note that human development, as rapidly discussed in previous sections, is contributing to the exacerbation of natural disasters as well as aggravating their impacts on societies. The coupling of economic and demographic growth, urbanization and social vulnerabilities is a potential source of disasters that needs to be prevented. Urban development relates to the expansion of existing cities and an increasing number of cities turning into national and regional growth centers, agglomeration economies set in, and further expanding investments, increased immigration, and population density. Increasing human and economic exposure in high-risk megacities cannot be limited. Effectively, after a worldwide growing concern and erroneous thinking that the disasters are expanding and their occurrence is increasing, this pattern has been uncovered as an immediate outcome of human development, of growth, of population, of wealth and urbanization (UNISDR 2011). A study of 2010 Xynthia storm in France, revealed that development and urbanization, especially in coastal lines aggravated the impacts of storms. In their study, Chauveau et al. (2012) even talk about "urbanization of risk" and highlight the importance of taking into consideration the natural risks and the climate change impacts in urban planning and development. Moreover, a crucial aspect of human development is the development of technologies, networks and infrastructures. The more a society is developed, the more it is technologically sophisticated, the more it contains costly networks and infrastructure and the greater material damages natural disasters could inflict. Extreme weather events can cause destruction of infrastructure such energy and water systems, telecommunication, transportation, etc. Critical Infrastructure (CI) and Critical Infrastructure Protection (CIP) are very buzzy topics nowadays. Lately, the subjects related to natural disasters and critical infrastructure have deeply interested an important number of researchers (Adams, David; Hoayek 2016; Beckers et al. 2013; Birkmann 2007; Dudenhoeffer, Hartley, and Permann 2006; Fardoun et al. 2012; Francis and Bekera 2014; Giannopoulos, Filippini, and Schimmer 2012; Guikema 2009; Hämmerli and Renda 2010; OECD 2008; Ouyang 2014; Queste 2004; Zhong, Langseth, and Nielsen 2014). Lhomme (2013) declares clearly that, in France, the economic consequences of future disasters, due to interconnected networks and infrastructure development, should exceed those of past disasters. Critical infrastructure are assets and systems that support essential services in a society. The CI can be resumed to transportation networks, airports, sea ports, electricity networks, water networks, communication networks, hospitals and health clinics, governmental buildings and public administration services, first responders' centers, schools, nurseries, elderly housing, refugees' camps and disabled rehabilitation centers. An important question should be pointed out here; why are these facilities considered critical and are highlighted in DRR strategies? Basically, critical facilities can be divided into two categories. The first category is given such criticality because it is directly linked to the civil security and it plays a major role in emergency management. This category encompasses the transportation networks, airports, sea ports, electricity networks, water networks, communication networks, hospitals and health clinics, governmental buildings and public administration services, and first responders' centers. The failure leads to deployment of civilian security and perturbation of first responders' services. Whilst, the second category of infrastructure has a certain degree of specific vulnerability which rendered it as critical. Effectively, schools, nurseries, elderly housing, refugees' camps and disabled rehabilitation centers, these critical facilities are home to highly vulnerable populations. Moreover, the dysfunction of infrastructure networks severely disrupts the functioning of our contemporary societies. This implies that these networks play an essential role in the mechanisms of risk diffusion and in the mechanisms of return to service of the urban system. Understanding the economic and societal influence of infrastructure failures or disruption helps identify vulnerabilities. According to experts in crisis management and critical infrastructure from the University of Žilina, Slovakia, determining vulnerabilities in the road network infrastructure can raise awareness, and help authorities with several aspects of response planning from budget allocation to evacuation plans (Dvorak, Luskova, and Cekerevac 2014). This important aspect of human development not only had effects on natural disasters but it even changed their shapes. Reghezza-Zitt (2009, 2015b) stresses that disasters can be the result of a natural hazard combined with a technological hazard, as was the case of Fukushima disaster. Some researchers even talk about "Natech" (Natural- hazard-triggered technological) as natural hazards having the potential for to trigger technological 'secondary effects' such as explosions, fires and toxic or radioactive leakage at hazardous installations and other infrastructures that manipulate, stock or transport dangerous substances (Krausmann, Cruz, and Salzano 2017). "Natech" accidents can have significant results, including cascading events. These cascading events, know also by "domino" effect, are direct consequences of interdependencies and dependencies between critical infrastructure networks (Kotzanikolaou, Theoharidou, and Gritzalis 2013). Revealing system interdependencies allows cascading failures to be evaluated, with failure of one system can have multiple downstream effects on one or more additional systems. For instance, a natural disaster's impact could be catastrophic in cities because of intra-dependencies, interdependencies and dependencies existing between energy and water infrastructures, road, telecommunications, emergency services, banking and finance, and government services. As Rinaldi, Peerenboom, and Kelly (2001) extensively developed, interdependencies can be physical, geographic, cyber and logical. Building or creating redundancy in networks is a milestone in facing these cascading events (O'Rourke 2007). Beside all the precedents, development processes contribute to the exacerbation of natural disasters prevention or mitigation which is a positive aspect of the argued relationship; but similarly, inadequate development processes and inappropriate choices are able to worsen or even generate disaster risk.

Second, it is important to notice that, although human development sometimes aggravates natural disasters and their impacts on societies, at the same time that same development has been the absolute most essential component in protecting mankind from natural events and their damage throughout history (Mitra 2000). Tackling previously the increase of exposure in cities caused by urban development, it is crucial not to confuse exposure with vulnerability when it comes to development and increase in populations; as Astrade et al. (2007) defend that urbanization and clear increase in elements in prone zones, does not mean that these elements are necessarily vulnerable nor that an ultimate amplification of risk. Moreover, in the same study cited previously to show the exacerbating effects of natural disasters due to urban development, Lhomme (2013) declares that, the French regulatory risk management tools are more comprehensive than ever before and budgets for forecasting, prevention and protection have never been that important. With advancement of the DRR ideas and concepts, disasters were progressively no longer simply seen as unavoidable deviations but have been interpreted as causes and results of inappropriate development or even developments failings. As discussed above, natural disasters cause a higher number of fatalities in less developed countries, but more material damage in developed ones; which means that development efforts are able to protect people and provide them with safer living conditions. Furthermore, beside that natural disasters can have bad effects on development when natural disasters hit, they often provide post-crisis development opportunities (UNDP 2004). Natural disasters can come as a chance to get help and reconstruct and as a momentum to rebuild a country more resilient but also more developed than before the disaster's occurrence. Compassion, better social cohesion and bonding are proved to appear in struck communities. Besides, Ahlerup (2013) point out that democratic developing countries receiving humanitarian aid appears to be driving the overall positive association between natural disaster events and economic performance. Apart from humanitarian aid, mostly in developed countries, natural disasters aids financed by public schemes or insurance schemes are made available for a long period of time to enable businesses and households to develop and implement rebuilding strategies that take into account the latest technologies. This supports the idea that economic development improves risk sharing and risk transfer (an insurance scheme). In addition, Albala-Bertrand (1993) empirically supports this idea by examining 26 countries and the consequences left by 28 natural disasters between 1960 and 1979. The findings show that, in most cases, after a disaster GDP growth increases and this observation was attributed to the substitution of the ruined capital with more efficient one. The economic and technological rebound is not the only development benefits from natural disasters. In his opinion, Okuyama (2003) finds other potentially significant channels between disasters and developments, including through human capital, migration, funding of research and development, or massive inflows of capital from abroad in the recovery. Risk management in emerging countries is also understood as an opportunity to set up *ab initio* a more sustainable development and as part of sustainable development goals.

All these negative and positive aspects discussed above are due to the human development of societies based on technologies, which would make them increasingly become more complex and more vulnerable yet more prepared (Lhomme 2013). In other words, human development increases and/or decreases the risk of natural disasters by increasing and/or reducing vulnerability. As we can see, natural disasters, as risks, have multiple aspects and differ based on an infinity of circumstances. Dealing with natural disasters starts by understanding risk in its multiple contexts.

2. Understanding Risk in its Context

As well known in the Disaster risk management and reduction science, hazards are different than risks. In general, "risk" is explained as the statistical probability that a hazard will occur combined with the expected losses (deaths, injuries, displaced, assets, etc.) that this hazard would cause. Leone (1996) argues that in the analytical sense, the risk (often the risk of losing something) arises from the conjunction of a hazard (natural or man-made) and various assets (goods, people, activities and functions) with a certain value (economic, patrimonial, esthetic, affective, strategic, environmental, etc.) and a certain vulnerability (structural, physical or functional). Disaster risk can be defined as a function of the hazard, exposure and vulnerability as follows;

Disaster Risk = function (Hazard, Exposure, Vulnerability)

These three factors should be studied and assessed in order to establish a policy for natural disasters mitigation. Risk level of an exposed area is the interaction between these three components. The hazard includes the probability of occurrence and the intensity of an event. The exposure implies the people, properties, etc., location in prone areas. The vulnerability involves the potential losses of hazard prone areas and the local coping capacity. The concept of risk obviously involves human value, economic or environmental elements exposed to the hazard. Metzger and D'Ercole (2011) call the exposed element as "what may be lost". Extreme events must be distinguished from disasters and catastrophes, but also major disasters must be understood depending on their locations. Indeed, while a disaster can clearly result from an extreme event, it can also result from a moderate event or a combination of such events having the ability to strongly affect the exposed system. The great catastrophe is therefore not only dependent on the hazard but also on the vulnerability of the elements exposed. Alexander (1993) even reduced the formal definition relating risk to hazard and vulnerability, to:

Risk = elements at risk

Effectively, there is no risk without these exposed assets: it is thus a central element of the vulnerability of territories to be considered in risk prevention and management and not applying a hazard-focused analysis (Berre et al. 2014). The multiple combinations between these three components make each risk a unique one and offer an infinity of risk contexts.

The contextualization of risks is often revealed in their effects. Basically, risks differ from a territory to another, from a society to another, etc… Risk and its urban contexts has been an extremely debated topic recently. Interactions between risk and the specificity of urban space and the urban spatial characteristics of cities are of big scientific interest (Burke 1996; Maantay and Maroko 2009; May, Gault, and Mcinnis 2005; Voet 1999). Due to the complexity of socio-technical systems in cities (Prizzia 2016) , in particular the role of critical networks previously well developed, risks and their impacts in cities come in different shapes and dimensions than in rural regions. The multiplicity of domino effects, the risk chains, the hybridization of hazards, make the disturbances triggered by the hazards become systemic, ubiquitous and trans-scalar. The different impacts produce multiple feedbacks, positive or negative, with time and space shifts. In his 2002 study about natural hazards threatening the Martinique Island (French West Indies), Leone evokes the socio-economic and territorial implications which draw new contexts for the risk. He declares that these exceptional socio-economic and territorial implications change the facets of risks and complicate the dealings of the natural hazards by authorities (Leone 2002).

The contextualization of risk implies institutional and political aspects. Reghezza-Zitt (2015b) evokes in her article entitled "Territorialiser ou ne pas territorialiser le risque et l'incertitude", the political-administrative contextualization dimension of risk. According to the author, risks are the products of a unique relationship, located and dated, between a society and its territory. In other words, Reghezza-Zit argues that risk related to natural hazard cannot be understood, and therefore dealt with out of its local context, not only in the physiographic dimension of "territories", but also (and foremost) in the human dimension of the territory (land use, governance, etc.). The author even claims that "risk arises from territory" and advocates a place-based approach to risk : "*Territorializing risk does not mean creating local conditions for governance of the latter, but simply identifying, cutting off 'official territories' of risk to make it possible to manage them*" (Beucher, Meschinet de Richemond, and Reghezza-zit 2008; Reghezza-Zitt 2015b). Certainly, the bonding between risks and territories is so tight to the point that some territories are even called after the natural risk that is threatening; "*when territories are qualified as prone zones, this can be heard in their given names*". The contextualization of risks, as the cartographic and regulatory translation of risks, are not as simple as it seems to be. Though the metrics of risks are important and three types of risks are to be distinguished: "territorial risk" as natural localized hazard, "diffuse risk" as epidemics and "network risk" as technological risks; regarding the important development witnessed by nowadays societies, discussed above, it is not enough and not accurate to assign a limited territory to a natural hazard. A "territorial risk" can be easily transformed into a "diffuse" or "network risk". In fact, cascade effects and domino effects addressed earlier, are well discussed in research due to critical infrastructure interdependency. Therefore, it's not accurate to limit the space of a natural hazard based on its striking location, but the spreading effects triggered by the potential for rapid spatial, temporal and multi-sectoral diffusion and dissemination should be taken into consideration. Risk uncertainty is revealed here; uncertainty in knowing exactly the location, time, consequences and the limits of diffusion of a certain hazard.

Talking about uncertainty, DRR deal with highly uncertain conditions. These uncertainties in data, in models, etc., can be best accounted for through probabilistic approaches. Decision-makers need to know about and understand these underlying uncertainties and the made assumptions (Apel et al. 2004; Berkes 2007). More than uncertainties, we even talk about the "virtuality" of risks.

Moreover, the perception of risk is so different form a person to another. For instance, the land developer regards the natural risk differently from the businessman, and the perspective of risk for a community leader differs from that of a villager. These diverse perceptions create more contexts for risk. Understanding people's perception of risks is a significant component for efficient and successful risk communication.

With this perception of risk, it is clear that the future era of DRR will not focus on "risk management" but rather on "risk territory management", or place-based DRR policy as advocated by Reghezza-Zit (2015).

3. Disaster Risk Reduction Concepts

As it was previously developed, natural disasters have existed since the dawn of time and have been stalking humanity, which ultimately has had to deal with it since its inception. Natural disasters, mankind and relationship between both that were discussed in previous parts keep on evolving continuously. Today's perception and ways of thinking about this relationship between both could be explained by looking at the environmental history. How had the human perception of natural disasters evolved over time? Human beings share a land they inhabit and inherit in an impersonal way, with all its calamities. Human history includes continuous suffering to escape the various dangers of nature. Natural disasters call for a response from human beings in order to live in common and subsist (Stevens et al. 2008). People have always attempted to anticipate, get ready for, survive, and recuperate from catastrophic events. But what were the shapes of "disaster risk management and disaster risk reduction measures", if it can be called so, long time ago? An attention on the development of disaster risk reduction and disaster risk management would subsequently be deficient without a discussion of the roots and underlying foundations of disaster studies and research both within the social as well as the natural sciences. A special attention will be accorded to the nuance between disaster risk reduction (DRR) and disaster risk management (DRM). The DRR cycle on which the current dissertation is based will also be discussed. The institutional factors are determining in DRR policies and actions. This section will also treat the governance of risk and the role of government in DRR actions. Finally, the manner which interests the most the stakeholders and decision makers, the monetary values of DRR actions will be addressed.

3.1 History and Evolution of Risk Perception and Mitigation Actions

Longtime ago, Human beings were totally submissive to the idea of natural disasters and they had long thought and even believed that they deserve these disasters considered as punishments from a wrathful God (Drabek 1991). In other words, natural disasters were perceived as supernatural forces and were interpreted as signs of divine anger against human sins, transgressions and moral depravity. Thus, dealing with such phenomena and trying to avoid or weaken them implies necessarily actions of a religious nature or rituals of all kinds such as symbolic offerings, prayers and sacrifices. Or even, regarding the transcendent origin of natural disasters, human believed that they couldn't do anything or weren't allowed to take any measure to avoid their occurrence, this fatalistic view of disasters led to inaction. According to Platt and Schott (2002), for some population, to protect themselves against an Act Of God was even considered as a sacrilege. The persistence of beliefs that natural disasters were God's will have acted as a powerful restraint in the effort to achieve the goals of prevention and mitigation measures. This fatalistic view of natural disasters that prevailed in prehistory and early historical times, did not prevent some coping with disasters stories like those of Noah to spread in Ancient times. Also, for some ancient populations, natural events were even interpreted as products of witchcraft. Effectively, catalytic events are perceived as an integral part of human's reality or even a part of the cultural history of humanity.

Perception of natural disasters as impetuses for accelerating the world's decline was common in Renaissance way of thinking, especially in the tradition of pessimistic cosmologies that viewed the earth as a senescent world. This Renaissance pessimism, was hidden by the early Enlightenment optimistic beliefs influenced by Lisbon earthquake. In the aftermath of the Lisbon earthquake in 1755, a controversy between these two great philosophers of the Enlightenment, Voltaire and Rousseau, was born and called into question the perception of natural disasters. While Voltaire accused the destiny and the unfortunate concurrence of circumstances, Rousseau insisted, ironically, that the decision to chaotically build a coastal town in a seismic zone was the exclusive responsibility of Man and that the huge fatalities and losses shouldn't be perceived anymore as Acts of God (Rousseau 1756; Voltaire 1756). It was on the basis of this debate between two great philosophers, recognized and esteemed, that a debate was born on strategies to be taken in the face of the risk of natural cataclysm. The searching in sciences in order to find answers started with Emmanuel Kant who was fascinated by Lisbon catastrophe and devoted enormous efforts to construct a theory on the cause of earthquakes that can deny the act of God. He speculates that any earthquake is caused by the movement of gigantic underground caverns filled with hot gases. Of course this theory was denied later on and modern seismology was born. The theories of German astronomer Tobias Mayer, German mathematician Johan Friedrich Jacobi, German philosopher Johann Gottlob Kruger and British astronomer John Michell, fed the modern seismology theory. Effectively, Ritchie, Jeggle, Wisner, Westgate, Davis, O'Keefe, Cardona, Kent, Cannon, and many other authors, showed with their early work that the development of sciences was a trigger to rethink the effective humans' perception and the truth of natural disasters (Blaikie et al. 1996). With the development of sciences, accompanying the appearance of secularism, natural disasters were increasingly seen as Acts of Nature. Since, investigations concerning the nature of disasters, their causal factors and the human beings' reactions to disasters started to come under the spotlight. The enlightenment optimistic beliefs are even considered as a starting point for our current understanding of natural disasters. People started to feel the need and intention to neutralize the fear of dangerous and perilous events and objects in nature and this couldn't be possible without the rationalization of natural disasters as subjects of scientific research. Catastrophes were now looked at as a useful part of the order of nature; a new scientific-technological approach and socio-political view of nature and disasters started to spread.

Moreover, recently the relationship between man and nature underwent fundamental changes; after being victim of nature for thousands of years, men are henceforth taking the lead. Man's role has slipped more and more from that of victim into that of perpetrator. As discussed in the first part of the chapter, over the past century, human activities have contributed greatly to global environmental change: global warming, massive deforestation and urbanization, changes in agricultural practices, dissemination of pathogens, proliferation of toxic microorganisms, etc… Man has modeled the environment for his benefit without always being able to anticipate the consequences of his developments. The result is an increase in anthropogenic vulnerability that results in rising damage costs in all countries, even if the likelihood of a disaster declines. Environment and climate seem to be influenced and deeply affected by humankind, even some natural catalytic events are partially, not to say totally, caused by humans. Progressively, we have come to consider disasters not as Acts of God, nor Acts of Nature, but these events are perceived as nature's acts of revenge from men, or even as resulting from the Acts of Humans/Societies. The transition from the metaphorical perception of natural disasters as acts of vengeance of God for humans' sins, to act a punishment from a rancorous nature, has been remarkable and this was the trigger behind understanding that social actions are able to prevent and mitigate natural disasters. People, even with the knowledge of natural disasters' origin, they couldn't stop their occurrence, but they started searching for ways to weaken their impacts, without the feeling of culpability. Collective response to natural disasters has considerably evolved overtime. Men then understood that humanity had entered a new era, when it could now take control of its destiny, since chance or God or destiny was not systematically responsible for all the evils on earth, even in the case of natural disasters. The ultimate goal was, henceforth, to bring natural disasters directly under human control.

The idea of risk has evolved over time, in parallel with the evolution of people's perception of the source and origin of natural hazards. As anthropologists have long highlighted, societies have evolved distinctly by adopting collective positions and attitudes towards the risks they face and cope with. According to Quarantelli (1998), societies have developed three types of attitudes towards risk. He claims that societies may (1) accept or even acquiesce fatalistically any threat that occurs, (2) have a more optimistic perception, believing that threats are inescapable but they are able to cope with them, and (3) believe that risk can be stopped or at least largely mitigated. How people perceive natural disasters and their associated risk, is directly linked to their culture, ethnical beliefs, social bonding, economic status, connection with nature and environment, life style, etc… For instance, as developed when discussing socio-economic aspects of natural disasters, some people due to their economic status, accept the risk of living in flood plain because they find this economically beneficial or they do not have other choices. In addition, some groups emigrate and others decide to stay making considerable efforts to withstand to changes or expose themselves to risk because they were strongly emotionally and culturally attached to this particular place or simply having no other place to go.

Despite experiencing major catastrophes and whatever was their perception of the latter, societies have many times lifted themselves up, cleaned themselves off, and proceeded on their determined social developmental way to complexity. This is the humans' adaptation capacity, the power of the continuation of life, which Zaninetti (2013a) describes as a remarkable faculty that human species stems from its capacity for learning and the accumulation of knowledge beyond the limits of personal experience. With the evolution of time, people started to react to disasters and did not remain passive in the face of catastrophic danger. Human now understand that what defines disastrous events is their sense of urgency, and that they therefore need a rapid reaction and quick action to avoid further prompt, if not instantaneous, decline in the situation.

From the above discussion, understanding the historical knowledge and social science on the large topic of disasters, leads to the approach that humans' reaction to disasters is deeply related to the matter of how they perceive and visualize the sources and dynamics of these disasters.

Historical documentation about the evolution and development of civil protection, and specifically risk mitigation actions, is very limited. More precisely, historical records on natural hazard mitigation, at least in Western Civilization, is vague and imprecise until the Renaissance. But it's known that although well-documented records of natural disasters began to appear in the late Antiquity, effective disaster mitigation measures did not emerge until the late middle Ages. For instance, DYE (1995) developed the historical evolution of civil protection in France in his book "La sécurité civile en France". In the case of developing countries is even worse, whereas historical reports on evolution of civil protection is often inexistent. Only few mitigation actions were noticed before the Renaissance. For instance, the civilizations of the ancient Nile and Tigris-Euphrates Valleys clearly recognized how to derive agricultural benefits from floodplains while placing their settlements on higher ground if available. Alike the colonial enclaves established by Greece and Rome who chose sites, where possible, that were both militarily defensible and relatively safe from flood. Also in an Indian text Kautilya's Arthashastra, written around two thousand years ago, when Alexander reached the gates of India, suggestions were made for state storage facilities to be opened to the destitute in times of emergency and that private possessions be seized to nourish the hungry. According to Quarantelli (1998), the earliest hazards, against which preventions measures and mitigations actions were taken against floods. Archeological proofs show that irrigation canals and dams with sluice gates were constructed by Pharaohs in the 20^{th} century B.C.E and in the Chinese empire, during the 2th century B.C.E. Less practical methods like religious practices and customary superstitions were even drew upon as preventive actions in medieval and early modem times. As stated by Bennassar (1996), city occupants used to offer a group of blossoms to avert hailstorms, or raising crosses on slope tops to dispose of merciless spirits and secure oneself against Lightings. In his book "Catastrophes naturelles et calamités au Moyen-Âge", Jacques Berlioz with all the examples that he had given, finds evidence that medieval people had a greater motivation than just fear when confronted by catastrophes. They had a genuine will to survive, proved by a wide range of measures, numerous fruitful, for managing catastrophic events (Berlioz 1998). Noting that Lisbon earthquake, considered as a turning point, happened late after the middle-ages, leads to many interrogations. Why were medieval people fighters more than others? What was the motivation behind medieval people fight for survival? As the experiences to be related from the Great Fire of London in 1666, the Lisbon earthquake of 1755, 1906 San Francisco earthquake, and the 1989 Loma Prieta earthquake illustrate, the recognition of choices in the wake of disaster is fundamental to greater security. It is important to mention that the Great Fire of London of 1666 can be considered as the first disaster to stimulate deliberate and well-documented changes in public policy concerning disaster mitigation actions in modern history (Burby 1998). Missing from ancient disasters as compared with modern disasters, was any significant assistance from the national government. Most help was rendered by states, cities, churches, and other voluntary donors. The role of governments in DRR and DRM actions is to be tackled in following parts.

Advances in literacy, technology, scientific knowledge, and the diminishing influence of unquestioning belief in an omnipotent and punishing God all contributed to the awakening recognition that human settlements may be designed or redesigned to be safer from natural and other perils. In fact, the idea that ordinary people are worth protecting from disaster was a precondition to examining why and where disasters occur and what may be done to reduce their effects. Disasters wisdom starts with the recognition that choices and decisions must be made, from the initial configuration of settlements in prone areas till post-disaster recovery. Indeed, the aftermath of disaster provides important opportunities to examine the available options and possibly to choose a modification of the *status quo ante* to improve protection from future disasters (Sadowski and Sutter 2008). Here comes the concept of learning from disasters. Communities need not suffer destruction over and over again from the same natural hazard. Since the seventeenth century, Europe and the United States have gained considerable experience in preparing for and mitigating the effects of major natural disasters. Elements of this preparation have included: (1) recognizing a disaster as an opportunity to alter laws, policies, and practices relating to the reconstruction process; (2) considering a range of approaches to reduce vulnerability, including both structural and nonstructural measures; and (3) recognizing the limitations of technology, especially with respect to lifelines.

As stressed out above, Mankind’s interpretation and perception for disasters have changed and evolved; thus a disaster is defined by man and not by nature. Today’s fear of disasters is greater than ever. Despite the huge efforts done to cope with cataclysmic events, the perception of risk and danger continues to dominate discussions on natural hazards. This could be explained by the fact that the majority of people are safe from the threats of nature and its havoc, and the fewer who do not flee stand up in sharp contrast as interesting examples to discuss (Mitra 2000). Arbitrary mitigation actions were not sufficient anymore, an urgent need for a science treating the prevention, preparedness, response and recovery (phases of the DRR cycle) from natural disasters was felt.

3.2 Genesis of Disaster Risk Reduction Sciences

First of all, one ought to be careful that we as human don't have supreme control over natural hazards and we have endured noteworthy misfortunes because of cataclysmic events in the past and we will have to endure the same in the future. No risk can be totally eliminated; this is what is known as “residual risk”. We however need to understand that we additionally have ability to settle on the correct choices, execute the correct measures, and take part in savvy advancement arranging which will lessen the danger of calamities happening. The decrease of a hazard showing in a debacle hence requires an extremely wide multi-sectoral and multidisciplinary center where the basic specialist, legislator, social laborer, horticultural augmentation laborer and even kindergarten instructor all have similarly imperative parts in guaranteeing common dangers don't move toward becoming calamities.

Disaster risk management and disaster risk reduction sciences are multi-sectoral and multidisciplinary (Lindell 2013) certainty, but the social and natural/physical perspectives are the most remarkable, from which disaster risk reduction and management take their scientific roots. For human and socio-economic processes, the relevant social scientists involved in studying disaster risk management and reduction are psychologists, sociologists, anthropologists, economists. Scientist who tackle cultural studies, organizational behavior, communication, ethics, political science and law, are invoking human and socio-economic questions related to disaster risk management and reduction.

Sociologists Carr (1932) and Sorokin (1942) pioneered in discussing the effects of disasters on the social patterns. The real concern about disasters and risk saw the light through initiatives, events, studies and research after the Second World War. A few sociological studies started to appear in the 1950s; In 1952 Endelman wrote “An approach to the study of disaster” (Endelman 1952); Powel, Rayner, and Finesinger (1952) wrote “Response to disaster in American cultural groups” in 1952 during a symposium on Stress in Washington D.C; Quarantelli addressed the subject, always in a social perspective, in his articles “The nature and conditions of panic” and “The behavior of panic participants” in 1954 and 1957 respectively (Quarantelli 1954, 1957); Moore (1956) highlighted the topic with his book “Towards a Theory of disaster”; and finally Fritz and Williams (1957) discussed the disaster and risk manners in “The human being in disasters: a research perspective”. In the 1960s, Drabek and Quarantelli (1967) continued to point out the question of disasters, writing “Scapegoats, villains and disasters”. Dynes and Quarantelli (1968) developed emergencies questions in “Redefining of property norms in community emergencies”. Since the 1970s the research in this field has gained an enormous interest, focusing on the risk as a social phenomenon, especially between European researchers and scholars, from Doughty (1971) writing “From disaster to development” to the study of Torry (1978) entitled “Natural disasters, social structures and changes in traditional societies”. In the 1980s and 1990s, researchers like Lavell (1999) and Lechat 1990) started to realize that risk doesn’t reside in the physical event itself but in the vulnerability of communities unable to absorb its impact and cope with it with their resources and capacities. In his study “Studying disasters: a review of the main conceptual tools”, conducted in 1995, Gilbert (1995) highlights the market demand for research in the field of disasters. All these studies dealing with disasters in a social perspective, show the evolution of the humankind perception to disasters and risks and their reaction to it during and after crisis. None of these social studies addressed the prevention and reduction of risks. This approach of risk is described by Cardona (2003) as the constructivist thinking in which the risk is looked at as a social construction and discussed as behavioral paradigm. In opposition, the natural approach, which will be discussed below, is related to school of “objectivism” that focuses on the physical, structural and realist aspects of risks.

The natural approach to disaster quantifies the risk and studies the hazard itself, its causal factors, its intensity, its probability of occurrence, its impacts, its mapping, etc… Many researchers all around the world, geologists, seismologist, geographers, hydrologists, physicians, meteorologists, engineers, etc… studied and assessed earthquake hazard (Ambraseys and Barazangi 1989; Beroza 1991; Kijko and Sellevoll 1989), flood hazard (Hdeib et al. 2016; Pinter, Thomas, and Wlosinski 2001; Rango and Anderson 1974), landslide/mass movement hazard (Abdallah 2013; Bou Kheir, Abdallah, and Khawlie 2008; Corominas et al. 2003; Guzzetti et al. 1999; Metternicht, Hurni, and Gogu 2005; Raetzo et al. 2002; Wang et al. 2005; van Westen, C.J.; Rengers, N.; Soeters 2003; Xu et al. 2012), forest fires hazard (Cruz and Alexander 2010; Peterson et al. 2005; Scott and Reinhardt 2001; Setiawan et al. 2004; Vidal and Devaux-Ros 1995), storm and hurricane hazard (Dales and Reed 1989; Simiu 1997; Webb, Elsom, and Meaden 2009) , volcano hazard (Felpeto, Martí, and Ortiz 2007; Orsi, Di Vito, and Isaia 2004; Waythomas and Waitt 1998), etc...

Nowadays, disaster risk management and reduction is now considered as science relating natural/physical perspectives to social perspectives (Pica 2018). This science is at an embryonic stage and is highly dependent on other long established fields of sciences. Nevertheless, disaster risk reduction and management has witnessed an explosion of interest over the past few decades. So quickly, related published articles and books reached a high number, and considerable number of research centers, science academies, commissions and bodies are dedicated solely to the subject (e.g. The Disaster Research Center at the University of Delaware, The Disaster Research Center (DRC), The Centre for Research on the Epidemiology of Disasters (CRED), Geophysical Risk and Sustainability (GeoRisk), Disaster Information Management Research center, The Disaster Research Center, Centre for Natural Disaster Science, L'association française pour la prévention des catastrophes naturelles (AFPCN), Institut pour la Maîtrise des Risques (IMdR), etc…). Also, there are numerous scientific journals treating specifically these issues, for instance "International Journal of Disaster Risk Reduction" (IJDRR), "International Journal of Disaster Risk Science" (IJDRS), "Integrated Disaster Risk Management" (IDRiM), and "Disaster Prevention and Management", "Journal of Geography & Natural Disasters", "International Journal of Disaster Resilience in the Built Environment", "Journal of Natural Disaster Science", to cite only a few. The PreventionWeb, sponsored by UNISDR, offers an accessible portal to a considerable database related to disaster risk reduction and management. Furthermore, important international venues, seminars, and symposia gather scientists tackling disaster risk reduction and management issues. A workshop entitled "*Natural Hazards Research and Applications Workshop*" takes place once per year at the University of Colorado. The Global Risk Forum (GRF) Davos promotes the global exchange of know-how and expertise related to integrated risk management and reduction actions, with as major goal to enhance the management of disasters and risks impacting mankind safety and properties. The Global Platform for Disaster Risk Reduction (Global Platform), as set by the UN General Assembly, is the principle global gathering for improving cooperation, knowledge sharing, partnership development and the examination of progress in the execution of DRR frameworks. It holds biennial sessions, gathering stakeholders and decision-makers determined to reducing disaster risk and building the resilience of societies and countries (Joerin and Luo 2015). However, Basher (2013) claims that disaster risk management and reduction is not yet a coherent and strong field of science and is still struggling to create its own systematic realm of knowledge, because it still has a lot to develop in terms of systematic research and teaching programs, senior academic staff working on the topic, a body of knowledge structured in expert journals, reviews and books, and more constant workshops and conferences; "*Disaster risk and its reduction… does not have a single disciplinary home or a well-established place in the scientific world but instead draws on a rich pool of diverse natural, engineering and social sciences*" (Basher 2013, p.31).

In 1989, the International Decade for Natural Disaster Reduction (IDNDR 1990-1999) was launched, promoting Disaster Reduction with main focus on technical and scientific aspects. The Yokohama strategy and action plan came in 1994 as a revision of the IDNDR, and developed a first blueprint for disaster reduction policy guidance (social and community orientation). UNISDR was then created in 2000 having a main goal which is to enhance public commitment associated with sustainable development and enlarge networking and partnerships. In 2002, an implementation plan was launched from Johannesburg, known as Johannesburg World Summit on Sustainable Development (WSSD) (Lindell 2013), and included new section concerning "*an integrated, multi-hazard, inclusive approach to address vulnerability, risk assessment and disaster management…"*. With a main aim to build the resilience of cities, communities and nations towards disasters, the Hyogo framework for Action (HFA) (Uy and Shaw 2012), a cornerstone of DRR, was declared in 2005 in Kobe, Japan, till 2015. Sendai framework for DRR, 2015, reviewed the HFA and incite some improvements like update on monitoring system and periodic review process, voluntary commitments of stakeholders and political declaration.

In this context, the European Commission has a central role in developing and promoting the INFORM index, which is a global, open-source risk assessment tool for humanitarian crises and disasters, supporting the international efforts to empower risk assessments and DRR instruments and strategies (Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark 2017). INFORM can support, in an objective and transparent way, decisions covering the entire DRR cycle from prevention, preparedness, response to recovery. When all DRR actors use a common risk assessment, this facilitates their cooperation and coordination and leads to more efficient results. INFORM has been created in light of proposals by various institutions to enhance the shared evidence basis about the three dimensions of risk, the hazard, exposure, and vulnerability along with coping capacities dimensions and to circulate this knowledge. It is an approach to make easier the use of risk information, based on risk concepts published in scientific literature, by decision-makers.

An important issue to tackle here is that the label designating these social arrangements for protection against, response and coping with natural disasters and collective threats was not agreed on till late 1990's. Quarantelli (1998) starts his paper entitled "*disaster planning emergency management and civil protection: the historical development and current characteristics of organized efforts to prevent and respond to disasters*" claiming that these arrangements are known in Europe as "civil protection", while in many other countries around the world, they are called "emergency management" or "disaster planning". Going back to references, these terms present a considerable but incomplete overlap. In fact, DRR terms have been debated over 55 years now. The most debated terms in disaster risk management and reduction remain the definition of **vulnerability, risk and resilience**.

3.2.1 Vulnerability

Making the subject of several studies and among the most targeted in DRR research (Birkmann et al. 2015; Cardona 2003; Ciurean, Schröter, and Glade 2013; E. A. Gencer 2013; Walters and Gaillard 2014; Wood, Burton, and Cutter 2010; Zebardast 2013), "vulnerability" has been an extremely intriguing term, having an enormous number of connotations. Human vulnerability to any disaster is a complicated phenomenon including health, social, cultural and economic dimensions (Keim 2008). In his paper "Corporate social responsibility and disaster reduction: a global overview", John Twigg says that the vulnerability is the trigger to turn hazards into disasters and give them their social dimension. According to Twigg (2001), vulnerability is the aftereffect of a whole scope of continually evolving physical, social, financial, political and even mental variables that determine and shape individuals' lives and make the conditions in which they live. Therefore, many factors determine vulnerability and its levels. Physical factors affect vulnerability of households, individuals and communities in many ways. Physical vulnerability can appear not only in the design of a building, construction materials, proximity of buildings, but also in access to emergency services and infrastructure, population density, poor planning, etc… Vulnerability levels are determined also, as developed in the first part, by social well-being levels, like education, literacy, social equity, access to basic human rights, information and awareness, fundamental cultural beliefs and ritual values, ethnicity, morality, good governance and a well-organized cohesive civil society (Van Niekerk 2011). We talk about Social vulnerability which designates how much a socioeconomic system is either prone or resilient to the effects of natural hazards and environmental changes. Some parts of the society are even considered more vulnerable than others. This is the case of elderly people, children, orphans, minority groups, refugees, displaced and people with disabilities. Women are also pointed out in disasters. Many authors have highlighted the gender issue in DRR because women are sometimes physically more vulnerable than men, and they play a fundamental role in disaster risk reduction and management (Enarson and Chakrabarti 2009). In their article "The Gendered Nature of Natural Disasters: The Impact of Catastrophic Events on the Gender Gap in Life Expectancy, 1981–2002", Neumayer and Plümper (2007) addressed how disaster mortality affects women differentially from men. They noticed that this is also related to the socio-economic status of women; the gender gap is more profound in societies where women have lower socio-economic status. In these societies natural disasters cause more fatalities among women than among men or cause the death of women at a younger age than men. Political factors play a major role in determining the vulnerability level of a community. In a country where there is no political will and nor commitment to developmental concerns, a total denial of human rights, no access to quality education, lack of access to resources and infrastructure, a high level of corruption, together have the ability to develop, maintain and permanently inflate extreme degrees of vulnerability. Political will is so crucial for disaster risk reduction and its implementation, and is the momentum for addressing abstract long-term threats, driving the disaster risk reduction agenda of the country and start reform processes. Here comes the impact of weak and fragile governments, like the Lebanese government, as increasing the vulnerability of the country and being a barrier for a correct reduction and management for the disasters threatening it. Financial or economic factors directly contribute to levels of vulnerability. This contribution resides not only in the number of lives lost and structural damages, but mainly in the weak coping capacities and the inability to recover quickly and easily or to recover at all. The weak coping capacities and inability of recovering is mostly due to the absence of insurance, lack of savings, etc... Moreover, lack of means often force poor people to live in informal settlements and dangerous locations. One well known concept in the field of Disaster Risk Reduction is the" Pressure-and Release Model" (PAR) developed by Blaikie et al., (1996) in their publication "At risk". This model emphasizes the ability of societies' vulnerabilities to turn hazards into disasters. The principle of the PAR model is that disasters are the junction of two opposing forces: those creating vulnerability on one side, and natural hazard events on the other. The reduction of disaster is embedded in the 'release' idea which implies reducing vulnerability in order to relieve the pressure. One should note that climatic change may not affect the intensity and frequency of occurrence of hazards but certainly affects the vulnerability of communities. Climatic change brings additional stress to societies for coping with natural hazards and therefore increases their vulnerability to natural hazards by reducing the availability of natural resources and degradation of environment and ecosystems. Adaptation to climatic change should be taken into account as part of precautionary actions to face natural disasters (Hallegatte 2014).

3.2.4 Risk

Risk involves components of the scientific and the subjective. The ambiguity over the term “risk” seems to take its origin also from the multidisciplinary dimension of this word. Effectively, “risk” is used in different disciplines and in a variety of contexts to connote the probability of an event and its potential negative consequences. Unlike the disaster, the risk has not occurred yet but could take place in the future. What makes this term more controversial are the different qualifications that have been given to it. For instance, “acceptable risk” is determined by a community as the level of potential damages they can handle, tolerate and overcome with their pre-existing economic, political, social and environmental resources. “Residual risk” is the risk we cannot eliminate. “Extensive risks” and “intensive risk” are also being wildly discussed in the field of DRR. Extensive risks are repeated or persistent hazard, with low or moderate intensity, striking on dispersed populations. These risks often threaten urban and poor areas and have debilitating cumulative impacts. Whilst Intensive risks are intense hazards leading to potentially disastrous events including significant impacts and damage like high death toll and property loss. This kind of risks is typical of large and densely populated areas (Pelling 2011) with high levels of vulnerability. Reghezza-Zitt defends the hybrid nature of risk, claiming that the risk is a result of nature and human interacting together. A disaster can be the result of a natural hazard combined with a technological hazard, as was the case of Fukushima disaster (Reghezza-Zitt 2009, 2015b). The remarkable disaster of Fukushima, which had natural and anthropogenic sources, demonstrates that it is necessary and urgent not only to study each individual hazard and its impacts on human systems, but also to prepare for the "unthinkable" by developing models simulating the possible interactions between different natural hazards and between natural hazards and anthropic hazards. We talk now about “Natech” (Natural- hazard-triggered technological) as natural hazards having the potential for to trigger technological ‘secondary effects’ such as explosions, fires and toxic or radioactive leakage at dangerous installations and other infrastructures that deals with, stock or transport hazardous materials (Krausmann et al. 2017). “Natech” accidents can have significant results like cascading events. While their number and, ultimately, risk is increasing, they are claimed not to be correctly tackled in DRR actions. Another newly French buzzy word is « dike risk » which accuses the risk to be not only hybrid but even “anthropized”. Explaining “dike risk”, Pigeon adds an element to the well know equation of risk which involves the hazard, the exposure and the vulnerability. This element is none other than the remedial works itself. Thus, the concept of “dike risk” is the legal recognition of the limits of protection and correction works, such as dams, and even their involuntary contribution to the production of disasters. This concept defends the protections works co-importance and co-evolution with the hazards and vulnerabilities of systems in the production of risks (Pigeon 2015). It basically calls into question the work of protection, since they now appear, and officially, as preparers of disasters.

3.2.5 Resilience

Another most debated term in DRR over the last decades is “resilience”. The lack of a conventional definition of “resilience” has been admitted internationally during the “2016 World Humanitarian Summit (WHS)”. In response to a call by the UN Secretary General during the WHS process, senior UN officials have committed

themselves to setting one definition and getting it agreed across the various development frameworks. The ambiguity of this term lies in the fact that it has come a long way before being used and adopted by DRR sciences. The concept of "resilience" appeared precociously in the field of risk science (Torry 1979). The resilience term may bear several different meanings, depending on who uses it, and we intend to return to its original definition, as proposed by Holling (1973), distinguishing between local static resilience and dynamic resilience of the system. The systemic resilience in ecology, as defined by Holling (1973) , has influenced (and complicated) the debate about resilience. Resilience is generally defined as the ability to cope with shock and return to normal functioning thereafter, referring to the static aspect of resilience which implies the restoration of the initial conditions of a material after a shock. Most users tend to restrict its meaning to that of static resiliency derived from the physical sciences (Holling 1996) and engineering sciences (Gordon 1978).There is a second aspect of resilience that relates to the ability to renew, reorganize and redevelop itself (Folke, C., Colding, J, and Berkes 2003; Folke 2006; Guenderson and Holling 2002).The study of the historical etymology of “resilience” reveals that the origin of this word is not ecological sciences but mechanical sciences. Alexander (2013) explains in his journal article “Resilience and disaster risk reduction: an etymological journey”, how mechanical sciences passed the term “resilience” to ecological sciences, then to psychology with Garmezy, then to social researches and how it finally attended the sustainability sciences. Urban resilience emerged in the 2000s (Pelling 2003; T.J Campanella and Vale 2005). The term has become so popular today that it is taken up by public actors themselves (www.floodresiliencity.eu) and is popularized by international scientific organizations such as the IPCC (Lavell et al. 2012). Although embedded within the CCA discourse during the COP16 in 2010, also no unique definition of “resilience” is being used. From CC point of view, resilience was viewed as improving the abilities of both socio-economic and ecological systems. It is important to mention that the resilience concept also differ between countries. In English-speaking countries, a large body of recent research has come under the unifying banner of urban, social, or regional resilience (Adger 2000, 2006; Berkes, Colding, and Folke 2003; Berkes and Folke 1998; Folke 2006; Lance, Gunderson, and Holling 2002; Lavell et al. 2012). French-language works on natural hazards (Dauphiné and Provitolo 2007), particularly on North America and New Orleans in particular (Maret and Cadoul 2008), refer directly to this literature while adopting a critical approach to resilience (Djament-Tran et al. 2012).
The major controversy around the term “resilience” lies in what does this word really defines. Stability or dynamic equilibrium? In the latter case, does the dynamic equilibrium (homeostasis), implies the preservation of the initial state or an ultimate evolution? Effectively, some human systems will be definitely modified by natural disasters and will never go back to their state before its occurrence, but maybe to a better state. So can we claim that in this case these human systems are not resilient? And returning to initial state, going back to highly exposed locations, rebuilding with same vulnerabilities without any improvements or progress, can we call this resilience? And a crucial question in the connotation of “resilience” is the time manner. The time frame also increases the ambiguity of the term: why recovering after a week is called resilience and recovering after a year is not? Some relate and associate resilience to hazard and not disaster, when a disaster occurs we talk about coping capacity. This last concept and that of resilience have also been confused; The United States Armed Forces have always believed that the concept of resilience focuses on the capacity of a combat unit or system to sustain damage without compromising operational integrity.

Talking resilience and building resilience should be an integral part of the disaster risk reduction activities (Van Niekerk 2011). Post-disaster territorial adjustments are increasingly discussed in terms of resilience (Adger 2000; Folke 2006; Gallopín 2006). Given this conceptual fog, it seems necessary to go back to the origins of Holling's (1973) concept to show that, beyond the diversity of the sources of the concept, there is also an intrinsic difference between what is termed "static resilience" in the sense of engineering sciences and "dynamic resilience" in the sense of systems. According to Holling (1973), for whom it is not precisely synonymous with a return to the previous stable state, resilience is the reciprocal function of the stability of an ecosystem that can have different points of equilibrium. The systemic concept of multistable dynamic ecological resilience is rapidly weighted in French geography, which focuses on the study of risks (Aschan-Leygonie 1999; Dauphiné 1995, 2001, Dauphiné and Provitolo 2003, 2007). However, the omnipresence of the non-scientific uses of the term imposes the restrictive use of the term in the sense of a return to the stability of pre-disaster conditions, which unfortunately replaces the more explicit term of recovery. Society has the ability to rebuild and adapt in ways that ecosystems do not have. The remarkable adaptability of the human species stems from its ability to learn and accumulate knowledge beyond the limits of personal experience. Social resilience can be defined as an ability for renewal, reorganization and redevelopment (Folke 2006). However, while innovation is a critical component of social adaptability (Smit and Wandel 2006), research also focuses on the systemic features of the process, territorial trajectories, dependence on pre-existing conditions, and self-organizing process. In addition, systems theory has also led to the study of city systems (Pumain 1990; Sanders 1992). The development and construction of an urban network can be modeled as a process of critical self-organization (Krugman 1996).The notion of resilience is used by archaeologists to explain the long-term evolution of city systems (ARCHAEOMEDES 1998). It is at the scale of the city system that it becomes possible to link the study of urban resilience to the concept of dynamic resilience initially advocated by Holling in ecology. Resilience of infrastructure is a function of component based attributes such as reliability and strength, and system based attributes for the network as a whole including redundancy and ability to fulfill their role in response and recovery efforts, including the avoidance of hampering these efforts. Both of these aspects should be addressed when assessing the resilience of various infrastructure sectors. Moreover, Cutter et al. (2008) declare that the way of assessing the resilience of a community, measuring it and determining its level, is still ambiguous and intriguing. While Klein et al. conducted an analysis which showed that resilience has no broadly accepted single definition today, but is a complicated multi-interpretable concept with debated definitions and pertinence. This variety of definitions of resilience originates from the fact that this term is used in multiple interdisciplinary fields, all related to the interactions between Man and Nature. Therefore, for Klein et al., (2003), the resilience of humans relates to their interaction with the ecological systems and not to their stability or capacity to remain intact and return to initial state. According to Lhomme (2013), although resilience appears to bear different meanings, making this multidisciplinary concept difficult to grasp, on the basis of an epistemological analysis of this word, certainty emerges: resilience studies systems (ecosystems, economic systems, social systems, etc.), and who says systems implies dynamics and certainly not static situations. Reghezza-Zitt (2010) tackled the resilience ambiguity in her article entitled: “La Résilience dans les politiques françaises de gestion des inondations urbaines: Quelques pistes d'analyse”. The author claims that, although the term is shrouded in confusion, resilience goes with long-term effects and sustainable development and this may be the solution for promoting the rethinking of flood risk management in France. In another article, Reghezza-zitt (2013) defends the polysemy of word “Resilience” and articulates the different meaning of the word by justifying that this polysemy does not invalidate its relevance; “Resilience” may even be the tool to rethink the numerous paradigms that govern the management and understanding of risks and disasters. Djament-Tran et al. (2012) stated that obvious incompatibilities between certain meanings of the term bring promising response to the recurring difficulties encountered in risk management, which resilience cannot offer. According to the authors, resilience offers heuristic, operational and political opportunities. Moreover, resilience even has a paradoxical aspect; when it comes to recovery, resilience involves a part of forgetting, which allows reconstruction, and a part of adaptation, which requires a change in the structures and in the urban functioning (Djament-Tran et al. 2012).

This discussion pinpoints the fact that resilience has no operational dimension; it is supposed to result from self-organization, and that can be the pretext for passive governments. Therefore of the idea of "systemic resilience" can be misleading and the concept of adaptation is much more focused. Adaptation can be achieved through DRR actions without any ambiguity.

In everyday language, often people confuse disaster risk management and disaster risk reduction. But these two sort of activities are far from being close synonyms. Disaster risk management (DRM) is the concept and practice of emergency planning and management, which supposes that a certain event had happened effectively and curative actions will be taken to manage the situation and avoid its worsening. DRM is simply the "preparedness for response" actions. According to the UNISDR terminology, disaster risk management actions involves: "*The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps. An emergency is a threatening condition which requires urgent action. Effective emergency action can avoid the escalation of an event into a disaster. It involves plans and institutional arrangements to engage and guide the efforts of government, non-government, voluntary and private agencies in comprehensive and coordinated ways to respond to the entire spectrum of emergency need*" (UNISDR 2009a). This definition implies that disaster risk management is tactical and operational actions. According to Basher (2013), disaster risk management encompasses the practices needed to determine, evaluate and deal with or prevent and stop disaster risk, and disaster risk reduction expresses a desirable social and political policy objective that can be accomplished by the creation, development, application and implementation of disaster risk management techniques.

Effectively, while disaster risk management is focused on the strategic level, disaster risk reduction is more about the systematic process which has as main purpose to mitigate the risk, and this before its occurrence. DRR relies on planning tools and requires preventive action, even is no hazardous event has happened, otherwise, there would be no reduction of vulnerability. For instance, drawing an evacuation plan is a DRR action, implementing it is a DRM action.

The DRR cycle or spiral covering prevention, preparedness, response and recovery phases, is shown in Figure 1-1. The "adaptation cycle" concept proposed by Gunderson and Holling (2002) was extensively discussed by Zaninetti (2013b) through the example of the Mississippi Gulf Coast. Zaninetti suggested that the cyclic representation of risk (DRR/Event/DRM/Resilience and so on) is of heuristic value, but adaptation is key to avoid repeated losses and escape the cycle. In this perspective, Figure 1-1 suggests that the ultimate goal of DRR is to escape repeated disasters in the situation of recurrent natural hazard.

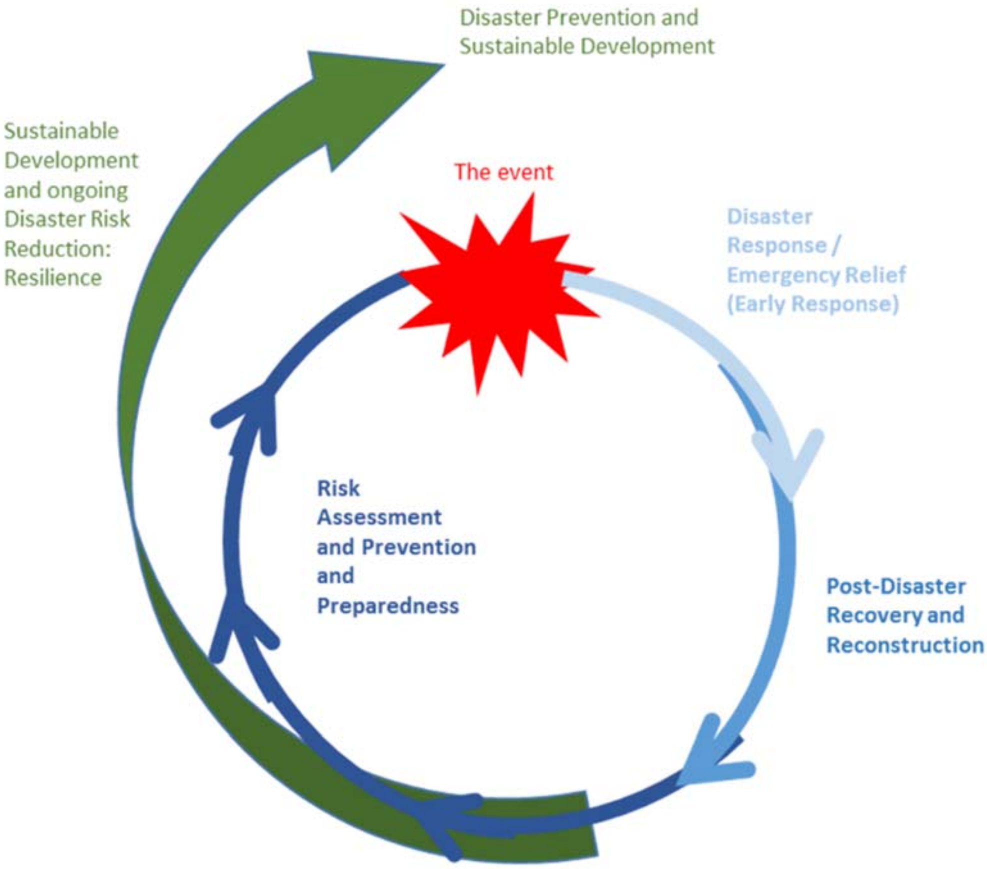


Figure 1-1. DRR cycle

The strategy of disaster risk reduction is to anticipate the events and work, on daily basis, on finding its causal factors and trying to prepare for it and manage it. These actions vary from lessening the exposure to hazards, reducing the vulnerabilities of assets, systems and communities, and following a proper land use planning and management actions. Vulnerability and risk assessment for the communities, their assets, critical infrastructure and critical facilities, are integral parts of disaster risk reduction strategies, along with early warning systems. DRR comprises structural measures like the construction of dykes, implementation of anti-seismic regulations, etc… to enforce physical resistance and non-structural measures to increase resilience, for instance land use planning, zoning, building codes, policies, laws, raising awareness, training and education, capacity building, business continuity planning, etc…. The vast majority of the prevention policies that have been undertaken so far are structural, i.e. retaining walls and dikes (Zaninetti 2007b, 2010, 2013a).

In fact, some of the non-structural measures, like land use planning and zoning, are often rejected by the public due to their effect on land monetary values and on insurance fees. This happened in France by after Xynthia storm when the French government implemented laws determining storms black zones in where no construction are allowed. No one would like to see the price of his land dropping down suddenly because of a new zoning, pointing out his land as a black zone, highly prone to landslides or floods. Or even no one would like to be paying high insurance fees for a hazard that may even not happen in their lifetime. In the opposite way, this issue is very important in DRR strategies and should be addressed in further studies to highlight the regulation effect that has the increase of insurance fees on the urban repartition and real estate investments, and ultimately on the variation of exposure trends. It is important here to mention that these disaster risk reduction plans differ from a country to another (Raheem et al. 2013). For instance, in France regulatory documents exist and they are called « les Plans de prévention des risques » (PPR). These documents can be specific for each hazard: les Plans de prévention des risques inondations (PPRi), les Programmes d'actions de prévention des inondations (PAPI) ou les Plans de secours spécialisés inondation zonaux (PSSIZ). It is important here to mention that PSSIZ are the only texts to consider the urban risk and the functional vulnerability. It tackles also a detailed plan aiming to preserve the continuity of activities in time of crises and in the aftermath.

Despite the nuances that differentiate them, there is a strong interaction and interrelatedness between and disaster risk reduction and disaster risk management. These two process even complement each other, "*Disaster risk reduction concerns activities more focused on a strategic level of management, whereas disaster risk management is the tactical and operational implementation of disaster risk reduction*" (van Niekerk 2011, p.14).

One should point out that these sciences are extremely multidisciplinary; for best DRR practices natural hazards experts (geologists, physicians, epidemiologists, etc…), engineers, social scientists, modelers, economists, emergency planners, geographic information system (GIS) analysts, and software developers are needed, to mention only a few. And most importantly, with the collaboration of all these experts but the absence of governments and legislations, DRM and DRR actions would not see the light. It is important to emphasize that DRR and DRM are meant for action. This is not theory, and that implies DRR sciences have to be comprehensive, accurate and efficient. DRR science does not belong to any academic disciplinary field of research, and any meaningful disciplinary contribution to DRR research is welcome, because efficiency is the only relevant criterion.

3.3 "Monetary Values" of Disaster Risk Management and Reduction Actions

Beside the question of saving lives, the DRR strategies and measures often involves economic interests. "Is it profitable to achieve costly preventive actions?", "Aren't we losing money?", "What if the disaster never happens?" "Why adopt DRR actions?" … These questions always query DRR actions and hamper, especially, preventive actions that are claimed to be costly. The issue of the cost of prevention is highlighted with cost-benefit analyses. Losses, or damage, avoided are considered benefits associated with prevention actions (Berre et al. 2014). The ultimate aims of implementing DRR measures are to reduce losses of lives and economic losses. These two insights have the most powerful convincing effect on governments, stakeholders and public to implement DRR actions. Effectively, the economic benefits of DRR actions are the best way to persuade stakeholders to invest in DRR and prevention. So political leaders need to know that competitive pressures, related with Disaster Risk Reduction actions will unleash new technological changes and create jobs. They also must realize that pressures to go resilient and safe may soon become among the benchmarks of economic, social, and political strength. Therefore, translating impacts of hazards into economic cost could be extremely useful.

The economic benefits and costs of disaster risk reduction actions have been well debated (Cochrane, 2004; Mechler, 2016; Noy & Vu, 2010; The World Bank, 2010; Toya & Skidmore, 2007; VOICE, 2013). The economic issue is highlighted for advocating investment in prevention and as an essential motivation for stakeholders and communities to adopt disaster risk reduction measures and actions. Thus, in 2007 the UNISDR launched plans for major cooperative studies to assess the economic benefits and costs of disaster risk reduction processes. Subsequently, the World Bank has undertaken the task and published in 2010 "*Natural Hazards, UnNatural Disasters; The Economics of Effective Prevention"* as the landmark report (Hallegatte 2014). The World Bank report goes beyond only considering the cost-effectiveness of risk reduction actions and points out the important role of broader policy settings. This report puts forward relatively cheap measures that could lead to considerable decrease in risk and impacts, noting that "*Prevention pays, but you do not always have to pay more for prevention.*" Emphasis was placed on the significance of data availability, the functioning of markets, the role of public infrastructure and the efficiency of public institutions. (The World Bank, 2010).

The cost-benefit analysis is subject to uncertainties. The assessment of the costs of structural measures could be the most accurate due to precisions in the cost of retrofitting and maintenance. Even the cost of awareness campaigns could be accurately determined. But the uncertainties are revealed in the estimation of benefits; it's always hard to value exactly the damages caused by different levels of hazard. It's even more complicated to monetarize damages that do not have a direct monetary translation, as for intangible impacts. "*What is the monetary equivalent of the loss of profits or value resulting from the total or partial, temporary or permanent destruction of services derived from the ecological functions of wetlands, or the loss of a piece of cultural heritage?"* (Berre et al. 2014). Or even how is it possible to give a monetary value for saving someone's life? Taking into consideration that this person may be the only working member in a family and financially responsible of the whole family?

Disaster preparedness is still an under resourced investment. A global changing in mindsets is urgent. Disaster losses shouldn't be regarded anymore as costs to be borne after hazards strike, disaster management agencies must stop relying only on emergency funding; preventive actions should be treated as a priority. Some examples prove the effectiveness of preventive actions. For instance, hospitals in Sendai, Japan, were retrofitted against seism. The importance of this retrofitting was revealed during the 2011 Tohoku earthquake; these facilities continued to function normally in post-disaster without any disruption or dysfunction. It is important to mention that these retrofitting measures added less than a tenth to the cost of new hospitals, eliminating the need to rebuild that virtually doubles the initial cost. A shopping mall in Cabanatuan City, Philippines, was designed to allow the lower basement parking area to act as a flood catchment area. In 2015, during a typhoon that inundated 90% of the city, the mall design reduced flooding and served as a basin during the typhoon. Such a disaster-resilient mall costs 10% more to build, but this additional cost will be recovered in avoided losses from just one typhoon (UNISDR 2016).On the other hand, kitchenware, gas stoves, grocery items, and weighing scales were part of livelihood starter kits distributed in the aftermath of Typhoon Haiyan in the Philippines to help households start small businesses and promote early recovery; beneficiaries reported profits two months after the disaster. These examples demonstrate viable business cases as well as the replicability of DRR interventions.

Moreover, disaster prevention can simply go along with traditional development and growth efforts. Disaster risk reduction actions can involve businesses and the research community to foster innovations and to make the disaster insurance market viable and profitable. Effectively, the growth implications of working with disaster insurance companies and risk markets are gaining noticeable traction. Overseeing endemic catastrophe dangers prompts the improvement of disaster insurance markets, which could have a solid potential to promote other industry-wide investments or spur new economic activities.

Besides the benefits of DRR measures, some see a remarkable loss in applying the latters, especially non-structural measures. Marking territories as threatened implies a regulation both in terms of human occupation and the security standards to be applied to existing or new property, with all that this entails as economic, social, legal, institutional, organizational, social, political and especially land-based changes. Effectively, conflicts could be generated; no one would easily accept his land to be marked as unsafe and to notice its price dropping very low. Even in the absence of regulatory zoning, communities will be exposed to economic sanctions with the application of a coefficient multiplier to the amount of legal deductibles related to insurance contracts covering natural disasters or even a refusal of insurance or disaster compensation (Leone 2002). Politics also plays a major role in the arrangement of land use management and planning.

In the middle of these pragmatics of risks, what is the status of Disaster Risk Reduction measures and risk governance in Arab region in Lebanon?

4. Risk Governance and Role of Governments in Disaster Risk Reduction Actions

It is the duty of governments to protect its economic and social assets, its infrastructure, and especially its citizens, their rights, their liberty, and their properties in the face of natural disasters and ensure their safety, their welfare and access to natural resources and critical infrastructure even in emergency times. Risk governance, as the large number of actors (institutional structure) and processes (policies) that lead to collectively mandatory decisions concerning threatening risks and their policy making, has been the subject of several research studies (Ahrens and Rudolph 2006; Van Asselt and Renn 2011; Ewald and Kessler 2000; ISDR 2010; Jones et al. 2014; Malalgoda, Amaratunga, and Pathirage 2010; Renn, Klinke, and Van Asselt 2011). According to Reghezza-Zitt (2012) it is impossible to negotiate over the protection and security of people, which is a collective responsibility, but first of all it is the Government's responsibility. Protecting human and physical capital from disasters should be regarded as public service. Darwanto (2012) states that this public service should be worthy of spending up to the recommended 1% to 2% of national budgets. Some argue that adaptive capacities to natural disasters are directly related to degrees of governance and civil and political rights (Brooks et al. 2005). Several studies stress out that countries with stronger and more powerful governments, and ultimately with higher governmental expenditures, were seen to be able to better resist and cope with initial disaster shocks (Kahn 2005; Noy 2009; Toya and Skidmore 2007).

In the midst of significant emergencies, it is normal to look to the largest or the most powerful or the most dominant association. What makes sense is that the organs of the states or governments, as first responders and responsible for community development (ISDR 2010), have logically fit that bill from the earliest occasions. Pigeon (2015) declares that the fundamentally geopolitical nature of managing natural hazards is not new. But the involvement of governments in disaster risk management has evolved over time; missing from ancient disasters as compared with modern disasters, was any significant assistance from the national government. Looking back at History, the role that state played in disaster management hasn't been that central. Most help was rendered by states, cities, churches, and other voluntary donors. The lack of help from governments in ancient times was due to the fact that many leaders had the foresight to seek legitimacy from their subjects, and that disaster relief was a visible means for kings to legitimize their administrations. Nowadays, democracy has its word and this role of the state and politicians in times of crisis has become almost a reference point for determining the legitimacy of the state. Moreover, for Williams (2011), any failure or shortcoming in DRR are henceforth pointed out as consequences of weak governance and lack of political will and involvement. Evolved, nowadays treatment of important risks is not following anymore conventional centralized state-driven methodologies, but multi-level governance systems are appearing, involving different public bodies and non-governmental organizations. This multilayered and diversified socio-political landscape (Renn et al. 2011) is proved to be very beneficial to processes of risk analysis, risk management and decision-making (Hacket et al. 2008). It effectively involves a large number of actors with their perceptions (Renn, Klinke, and Schweizer 2018) which presents a multitude of knowledge, skills and evidence claims, value commitments and political interests.

The Hyogo Framework for Action dedicated special attention to issues associated with the political context, including governance and the need for institution building. As for execution, it accentuated the considerable role of governments and the significance of associations and collaboration, and it focused on the DRR-SDG interface. HFA clearly explained the roles of international and regional organizations and the ISDR to bolster national endeavors and help with observing advancement. Addressing special attention to the significant role of local governments in reducing disaster risk, the UNISDR has specifically initiated the 2010-2011 campaign under the theme of "*Building resilient cities*" for local governments. Political commitment to DRR processes plays a fundamental role on the international, regional, national and local levels. Institutional frameworks, risk governance, policy development, legislations and codes, organizational development and community actions have proven to major triggers towards the complete implementation of an efficient DRR strategy. It could be said that government devotion to implementing disaster risk reduction policies and programs and execute security regulations and controls, such as building codes imposed by the government and efficiently enforced, particularly in developed countries, have played a considerable role in mitigating the effects of natural hazards such as earthquakes, floods or wildfires.

The "invisible hand" of the market, after all, is in some cases rarely considered able to deal with such visible crises, especially alone. Inadequate and insufficient financials, manpower, lack of authority hinder the efficiency of government in implementing disaster risk reduction measures and make timely decisions. This points out the urgent necessity for empowering local governments with enhanced governance structure (Malalgoda et al. 2010). Despite the crucial role of Governments and politicians in risk Governance, public discourse increasingly emphasizes the role of local communities, citizen participation and mobilization, empowerment and involvement of individuals, private investment and co-construction of public policies in risk reduction and management. In fact, risk governance pertains to the totality of actors, individuals and institutions, public and private sectors concerned with how pertinent risk information is gathered, analyzed, processed and communicated, and how regulatory decisions are agreed upon. For instance, in the Île-de-

France region of France, skills transfer from government to private actors and citizens is recommended and even encouraged by the OECD (organization of economic cooperation and development) in the face of the centennial flood. This is believed to generate a better articulation of national and local levels, underlining the difficult coordination and lack of involvement of the public sector (Reghezza-Zitt 2015b). In addition, governments sometimes neglect or underinvest in disaster risk reduction and management measures (Gallopin 2006). A massive disengagement from governments is even being noticed; the disastrous management of the Haiti earthquake 2010 reconstruction is the posterchild of weak government lack of capacity to cope with disaster. An important question is to be asked here. Why do politicians continue to put off DRR measures in the face of increasing and intensifying natural disasters? First of all, DRR measures are not a priority due to the limited budgets of Governments, especially in poor countries, like Lebanon. Moreover, disaster risk reduction and management measures can be neglected or underinvested, when governments do not think disasters are imminent. The complexity, uncertainty and ambiguity surrounding risks also hampers the involvement of politicians and governments in DRR measures (Klinke and Renn 2002). The paradoxes of DRR are diverse. First comes the time issue, elected governments need immediate political return from action, long-term benefits weights little in comparison to short-term advantages, whatever the disastrous outcomes that can happen on the long run. Second, some DRR measures that protect property rights and economic assets are immediately popular, but other adaptation measures that reduce economic assets and restrain land-use rights are highly unpopular, creating a bias in government's DRR actions. It is important to mention that corruption, especially in developing countries, hinders the implementation of Disaster Risk Reduction actions. And from the politicians' point of view, DRR and prevention is not as newsworthy and politically eye-catching as disaster response, the provision of relief goods, and reconstruction. These actions are often look at as heroic ones. And the benefits of DRR and prevention are neither as tangible nor as easy to quantify as these. Also, the benefits of DRR and prevention may accrue long after the expiry of the terms of current politicians, gaining them zero political mileage. These assumptions of politicians' ego may be the reasons behind their disinterest in DRR measures and prioritizing other issues. Politicians must be convinced that action on natural disasters is a call to protect natural capital as an investment and not as a cost, and doing so will not jeopardize economic growth. Basically, Politicians are expected to protect their citizen's economic interests, whatever the expected "benefit" on the long run, DRR measures that harm property rights and reduce economic prospect are highly unpopular (Zaninetti 2013a; Zaninetti and Colten 2012).

Cost-benefits measures are very crucial to be done in order to convince local governments and stakeholders to invest in DRR. The question of cost-benefits is even more difficult to tackle in the case of probabilistic phenomena when no event occurs; not to forget that preventive measures are often so costly.

Given the fact that Lebanon is an Arabic speaking country and a State member of the Arab League, it is of high relevance to shed the light on the Status of DRR in the Arab Region and Lebanon. The foundation of addressing the issue of Risk Governance in the Arab Region and then in Lebanon is beyond the fact of sharing a common language, culture and historical heritage, it is actually because Lebanon shares with the other Arab countries a number of regional and trans-boundary risks. In fact, Lebanon is committed to the Arab Strategy for Disaster Risk Reduction 2030 that emphasizes on coordinating the region's efforts with the 15-year plan of Sendai Framework for Disaster Risk Reduction adopted by the international community in 2015. In addition, it is believed that there is an urgency for cooperation between Arab member states in support of the implementation of the Arab Strategy for Disaster Risk Reduction 2030 and the Sendai Framework, in order to make all Arab countries, including Lebanon, more resilient in the face of natural disasters.

4.1 The Arab Region

The Arab region has witnessed an important number of natural disasters in the past, including wildfires, floods, severe storms, landslides, droughts and earthquakes. Seismic activity is a major risk in the Arab countries due to the Jordan rift valley system which expands from the Red Sea, through Palestine and shifts north across the Dead Sea and Lebanon's Bekaa Valley and thus places several countries (Lebanon, Jordan, Syria and Palestine) at high risk of earthquakes. Droughts, also an important risk to the Region, with summers getting hotter and dryer, threaten the Region's food security. Within the past three decades, the Arab countries have faced 276 disaster events affecting more than 70 million people, and more than 160,000 fatalities caused by 330 separate events (EM-DAT 2013). Thus, these events have resulted in loss of life and caused important financial hardship for individuals, communities and governments. Serious challenges to the sustainability of development investments and the stability of economic growth of the region are even being imposed by these natural threats. Furthermore, the situation is worsening overtime and has aggravated over the last few decades, regarding the immense pressures the Arab Region has to face on many levels. These pressures can be resumed by an unstable political situation, an expanding poverty rate, a rapid growth in population (UN-Habitat et al. 2012), unprecedented urbanization (more than 80% of the total population of some Arab countries, example: Lebanon), inadequate urban planning (urbanization extension occurring without commitment to legal frameworks, building codes, land use plans or zoning ordinance) and standards of living. These developments were not without consequences on populations and the environments they live in. Actually, these changes have intensified pressures on the environment, and accentuated the vulnerabilities of the region's inhabitant to natural disasters. Stresses on the environment are extremely dangerous because they participate in modifying the ecology of natural resources on which people rely for survival, which make them more vulnerable and unable to cope with natural disasters and recover easily.

The region's major urban centers contains important cities considered as source of socio-economic development due to the fact that they concentrate opportunities for livelihoods including employment, health, education, transportation, communications facilities, trade and tourism. Thus, disasters' impacts can be considerable on the local and national economy. Moreover, several cities and towns contain major world cultural heritage sites and represent a source of cultural identity and history.

It is of key importance to mention that the majority of Arab countries have, among the other disaster risk drivers, weak and centralized governance systems (UNISDR-ROAS 2012). This ultimately implies a limited and poor access to funds and authority at the local level which hinders local DRR measures. In addition, private sectors and local communities are not involved in decision making on DRR and DRM issues. Knowing that community participation is essential to foster resilience, the situation in Arab countries overloads more pressure on the fragile governments and make communities even more vulnerable to natural hazards.

Feeling the alarming threat of natural hazards, the Arab leaders, with the help of UNISDR, got involved and interested in DRR actions. A number of objectives have been achieved in the region, aiming to reduce impacts of hazards and to get societies ready, better prepared and more resilient.

Arab countries committed to the Hyogo Framework for Action 2005-2015: "*Building the Resilience of Nations and Communities to Disasters at the World Conference on Disaster Reduction held in Kobe, Japan 2005*" (UNISDR 2005, p.2). In 2007, the Region adopted the "*Arab coordination mechanism on disasters*" and the implementation of DRR concepts into environmental management and climate change adaptation policies was openly tackled. In 2008, the Council of Arab Ministers Responsible for the Environment (CAMRE) endorsed decision No. 295, inviting for improved coordination and cooperation with the ISDR thus putting the follow-up of the integration of the HFA as a permanent agenda for CAMRE and its auxiliary body the "*Joint Committee for Environment and Development in the Arab Region*". CAMRE also encouraged Arab states to consistently report on progress in implementation of the HFA at a biannual basis. In 2009, the need to establish an Arab Strategy for Disaster Risk Reduction (ASDRR) was agreed upon member states who requested the development of an Arab regional platform for DRR (at the ministerial and multi-stakeholder level) to support and enhance the integration of the HFA at the regional, national and local level. But the political commitment wasn't felt till 2012, when Heads of Arab States effectively adopted the Arab Strategy for Disaster Risk Reduction 2020, sponsored the League of Arab States through CAMRE and the Socio-Economic Council of the League of Arab States. This master plan was express through a framework of actions to facilitate local, national and regional integration of the strategy and make it efficient and successful. It should be mentioned that in early 2013, a risk reduction road map was developed by the Gulf Cooperation Council (GCC), and the Secretary-General of the Cooperation Council for the Arab States of the Gulf has strongly recommended regional dedication towards the establishment of a disaster risk reduction strategy to improve the resilience of governments and societies to natural hazards (UNISDR 2012a).

Awareness is also being raised mostly by UNISDR which has continued to promote the "*Making Cities Resilient*" campaign (UNISDR 2012b) to help Arab countries' urban areas to better withstand and cope with disasters, with more than 300 cities and municipalities in the region have joined the campaign (20% of all cities worldwide). A translation to Arabic of the Mayors Handbook on "How to Make Cities More Resilient" was done for a better dissemination in the region. UNISDR offered a self-audit tool to all participating cities; the Local Government Self-Assessment Tool (LGSAT) helps local governments to examine their DRR progress, and assists them with facing encountered challenges and gaps.

Disasters losses datasets have been developed in several Arab countries starting to record their disaster damages. These databases will offer a practical basis to conduct risk assessments and set disaster risk reduction strategies and policies. By supporting and leading historical disaster data inventories (www.desinventar.net), the UNISDR enable countries to study disaster patterns and their impacts in a systematic approach. Nine out of the 22 Arab countries have either completed or initiated the development of national disaster loss databases. These include Lebanon, Egypt, Morocco, Syria, Palestine, Jordan, Djibouti, Tunisia and Yemen.

Furthermore, several national partners like Lebanon, Bahrain, Egypt, Comoros, Algeria, Djibouti, Mauritania, Morocco, Jordan, Palestine, Syria, Tunisia and Yemen have drafted national progress reports on the implementation of the Hyogo Framework for Action (HFA). Also, some cities started in 2012 to communicate their progress in reducing disaster risk, challenges and gaps encountered locally through the Local Government Self-Assessment Tool.

UNISDR initiated a DRR Arab States coordination network as a community of practice to advocate data sharing and aligned actions for DRR at local, national and regional scale in the Arab States. This regional mechanism facilitated the discussion of DRR issues among international partners working in/on Arab States to collectively plan application and examination of DRR actions and efforts.

Admitting the necessity of knowledge sharing**,** UNISDR constantly encourages the sharing of knowledge and good practices and challenges in the region concerning the integration of the "*Hyogo Framework of Action (2005- 2015) – Building the Resilience of Nations and Communities to Disasters*". During the 2012 "*Regional Meeting to Advance Disaster Risk Reduction*" experts from Lebanon, Algeria, Bahrain, Comoros, Djibouti, Egypt, Jordan, Mauritania, Morocco, Palestine, Sudan, Syria, Tunisia, Yemen and the United Arab Emirates, were brought together along with important regional partners such as the Regional Centre for DRR Training and Research, the Gulf Cooperation Council, and the Arabian Gulf University. Lebanon and Algeria also held national consultations of the Hyogo Framework for Action and set recommendations for the HFA2 (post-2015 DRR Framework).

During the Second Arab Conference on DRR held in Egypt, in 2014, it was recognized, based on indicators, that disaster losses were doubling in the Arab region and that the latter presented many factors that make it more vulnerable; weak or not available early warning systems, weak institutional structures, increased urban growth rates, environmental degradation, water shortage, structural demographic changes and migratory trends, conflict and unrest in the Arab region (UNISDR-ROAS 2012), that multifaceted challenges negatively affect the ability of Arab States to reduce and manage disaster risks and to decrease the scale of losses caused by disasters in lives, livelihoods, assets, the economy, and the environment. Moreover, the region lacks a comprehensive and updated database of information on hazards, exposures, vulnerabilities and coping capacities.

These challenges facing the Arab region require a number of measures that can be drawn from the Sendai Framework to strengthen national platforms for the advancement of data collection, analysis, management and use; disaster risk assessment, including complex disasters; the use of geospatial information; expand education for disasters and how to prevent them and respond effectively, and increase public awareness of disasters. The high vulnerabilities (social and physical) of Arab region's disaster risks emphasize the need for purposeful commitment of Arab scientific, technical and academic communities at all scales, as well as indigenous and traditional communities.

On September 2018 a consultation meeting held in Beirut, the Arab STAG (Science & Technology Advisory Group) was established with members of scientists, academics and experts from Algeria, Bahrain, Egypt, Iraq, Lebanon, Palestine, Sudan, and Tunisia. The main goal of the Arab STAG is to strengthen Arab cooperation at the national and regional levels to implement Sendai framework in the Arab region and establish links with the international community in the field of Science and Technology to contribute to disaster risk reduction and support scientific decision-making. Also, Arab STAG will promote field action-oriented multidisciplinary research and increase the promotion of good practices and success stories of science and technology for evidence based DRR/DRM decision making, reinforce Arab Disaster Risk Management networking among science, research, academia and policy-makers, raise disaster risk education at all school levels and foster university professionalization and training to ensuring human capital development in the disaster risk reduction field.

Though the region is making noticeable endeavors concerning DRM and DRR actions, important future challenges remain to be addressed. The region witnesses a relatively limited progress on education and public awareness. A better national level coordination is required because it is necessary to better define roles and responsibilities amongst national bodies to make sure that DRR is tackled comprehensively and efficiently. Besides, a huge work remain to be done to develop reliable and standardized databases in order to efficiently inform policy and decision makers. A crucial manner is still missing in DRR actions in Arab countries and it is the tight bonding between the national level and the local levels. This coordination is so important for the correct implementation of laws and regulations and for accounting for the needs and abilities of local societies in applying DRM and DRR measures. The region also notices a lack of focus on scientific research and the advocacy of technical instruments for risk assessment, hazard maps establishment, and vulnerability analysis using GIS and remote sensing tools, and national risk assessment abilities enhancement. This gap would be hopefully addressed by the efforts of the recently established Arab-STAG. One should note that funding remains the main challenge hampering the implementation of disaster risk reduction measures in the Arab region. In line with emerging global commitments, the League of Arab States recommends its member states to dedicate at least 1% of national development budget to disaster risk reduction measures. This percentage is too low compared with the other percentages contributing to DRM and DRR manners in others developed countries. For instance, in Japan, more than 5% of the general national budget goes for mitigation, preparedness, response and recovery measures (Phaup and Kirschner 2010).

4.2 Lebanon

Due to its geographic location and many other factors, Lebanon is exposed to devastating earthquakes, Tsunamis, floods, storms, landslides, forest fires that have hit it in the past and have caused severe damages to its population and economy. Pre-disaster actions like disaster preparedness should take a considerable part in the national agenda of Lebanon, given the frequency and intensity of natural hazards along with their impact on lives and economic development. As Currion, Silva, and Van de Walle (2007) claim "*disaster management becomes a more pressing concern only after the disaster has struck*," (Herold and Sawada 2012) and this is the general trend in developing countries in general and in Lebanon in particular.

In Lebanon, the storms have been registered as the most menacing of all disasters and have caused the most damages to society in terms of deaths and destroyed houses (UNISDR 2014). Moreover, an everlasting unstable political situation reins the Middle East region and Lebanon and makes it subject to wars. Furthermore, it has been identified that disaster risk drivers in Lebanon are as follows:

- Haphazard urbanization. Actually, the urbanization rate in Lebanon is approximately 87%, with 2 in 3 individuals actually live in the 5 important cities of Beirut, Saida, Tripoli, Tyre, Zahle and its suburbs. Lebanon has a high proportion of slums and displaced persons camps in cities reaching 50% of the total population as shown in the report of the United Nations about Human Settlements Program. The percentage of old buildings is increasing in the main cities and in rented houses; owners cannot afford renovating or maintaining the construction because of low rents. In addition people build their constructions on hazardous terrains.

- Environmental degradation. Lebanon suffers from the loss of forests as the percentage of forest area from the total area of Lebanese territory is shrinking 65% in the sixties to 13% in 2006 to up to 12% in 2012. This is causing more damages from floods and landslides.

- Poverty. It affects the ability of the government and municipalities to invest in disaster risk management and prevention measures. The limited ownership of homes affects the ability of initiatives and investment in disaster risk management.

- Lebanon ranks high on the list of potentially failed states, especially when it comes to risk management. Effectively Lebanon doesn't have a unified body responsible for urban planning policies and land zoning and building codes are not being applied.

A study entitled "*Primary Needs Assessment for Disaster Risk Management*" ordered by UNDP showed that in Lebanon, most resources and efforts are often focused at post-disaster actions involving relief, rehabilitation and replacement efforts and not enough at pre-disaster measures such as prevention and that is the case for all sectors. This study also pinpointed the absence of an operational disaster management plan and authority or committee actively working towards developing disaster risk reduction initiatives. The lack of efficient coordination and cooperation between key institutions committed in disaster response and management was also identified as a key factor in strengthening the ability of the Lebanese Government in the field of DRR.

A "*Disaster Risk Response Framework Plan*" has been recently put forward by UNDP in Lebanon and created a Disaster Risk Reduction Unit under the Prime Minister's Office responsible of coordinating measures covering pre- and post-disaster phases. Specifically, this unit would help the Lebanese government, municipalities, service sectors, private sectors and stakeholders better understand risk profile of the country and develop a disaster risk reduction strategy and proper action plans. In fact, when a disaster strikes the nation, the government, municipalities and stakeholders will be in the front row in terms of response and action. The society and its economy should stay operational by the resistance and resilience of the supply and distribution chains, the critical facilities and the businesses.

In this context, hazard and risk assessment projects for several governorates and ministries, achieved by CNRS-Remote Sensing Center, came as part of the Phase II program "*Enhancing disaster preparedness and mainstreaming risk management in national development framework strategies in Lebanon*". This program was meant to develop the DRM capacity building at the sectoral and local levels, institutional mechanisms for DRM enhancement, DRR integration for development planning, and raising community capacity to reduce life and property losses. These projects have focused on risk assessment concerning governorates and ministries capacities to maintain activities and services in time of crisis and a disaster management and response plan when a disaster strikes the area.

There are a number of national agencies playing a role in efforts to develop Lebanon's infrastructure but none of which currently has a clear mandate on disaster risk management. These ministries and acting agencies at national and local levels contexts are:

- Council for Development and Reconstruction (CDR), responsible for national planning and project coordination.

- Ministry of Energy and Water (MoEW), responsible for development of electricity and energy networks, wastewater and irrigation
- Ministry of Public Works and Transport (MPWT), responsible for public works, roads and transport.
- Ministry of Environment (MoE), responsible for environmental protection.
- Ministry of Economy (MoEconomy), responsible for recovery cost and basic infrastructures for trade.
- Ministry of Social Affairs (MoSA)
- Ministry of Defense (MoD)
- United Nations High Commissioner for Refugees (UNHCR)

The high relief committee is entrusted to act in time of crisis in Lebanon. This body strategy is to provide assistance to affected person after a disaster hitting the various Lebanese regions not taking into consideration any political or zonal division. It also provides all cooperation with the military to survey the damage and estimate the necessary compensation to affected people. It is important to note that the only body in Lebanon which is responsible of acting in time of crisis suffers from scarcity of resources. It has a clear mandate on carrying out all tasks related to disaster risk management, but has not yet been empowered through extra staff and capacity building to carry out its task. As such, its work to date has been limited to relief work in the form of distribution of aid to affected citizens. However, this is expected to change significantly as the structure of the HRC is being revised to enable it to fulfill all of its duties in a comprehensive manner.

So the main weaknesses in risk governance and the major problems hampering the adequate implementation of disaster risk reduction and management actions in Lebanon can be resumed as follow:

a) The Lebanese army and the HRC have plans for response and intervention during crisis. But these plans haven't been implemented yet in a proper way. Moreover, these plans are limited to response and curative actions, preventive actions are being ignored. In other words, the Lebanese army works only on DRM and not on DRR.
b) Lack of public awareness and lack of risk reduction governance.
c) Lack of information sharing mechanisms, absence of a national database.
d) Absence of legal framework explicating the mandate for disaster risk management (from prevention through to response).
e) No strategy to build capacities and allocate personnel to work on disaster management issues.
f) The delay in adopting the decentralization law as agreed upon in the Taif[1] conference, the responsibilities of local municipalities are still too limited.
g) Lack of risk assessment studies to inform government, decision makers and stakeholders in their quest to reach a rational methodology for the allocation of resources.
h) No building code implementation enforcement

One of the main goals of this thesis is to help Lebanon resolve some of these challenges, with the use of geo-information technologies. So what are these geo-information technologies and how can they be used as tools

[1] The Taif Agreement, also known as the National Reconciliation Accord, was an agreement concluded on "*the basis for the ending of the civil war and the return to political normalcy in Lebanon*" (Krayem 2005)

for civil protection and disaster risk reduction measures, especially in developing countries with fragile governments like Lebanon?

Chapter 2 . Geospatial Information Technologies

First of all, what does “Geo-information/geospatial information technologies” imply? Geo-information technologies refer to the combination of knowledge and technologies including Geographic Information System (GIS), Remote Sensing (RS) and Global Navigation Satellite System (GNSS) to a wide range of applications. Big data, wearable, mobile devices, augmented reality, crowdsourcing, earth observations, and social media, all these terms go under the umbrella of Geo-information technologies. Remote sensing serves as a valuable technology for analyzing elements on the surface of Earth and in the atmosphere. The aim is to analyze and observe changes of natural environment by selecting data from a wide variety of high-resolution satellites, and using them for several individual purposes. Moreover, Remote Sensing data can be easily and rapidly collected, immediately responding to specific needs, while the GIS can collect, manage, process and analyze spatial data for efficient management of natural resources. In addition, the GNSS can be utilized for rapid and accurate area-based positioning and observing of people and object trajectories. The Geospatial information technology is therefore utilized by several agencies for a wide range of uses, such as natural disasters, agriculture, urban planning, traffic and transportation, military operations, natural resources and environment, and business trade. Outcomes of GIS analysis can be applied to any decision making plan rapidly and efficiently.

Remote Sensing has transformed the geographical sciences in its way to study large and remote earth surfaces rapidly and integrate complicated measurements. Recent Remote Sensing took its origins in 1840s with photos taken from balloons for topographic surveys, by the Paris Observatory. During the Second World War, this technology was developed for military purposes and it started using airplanes. After the War, space-borne Remote Sensing saw the light when American and Soviet military used rockets for photograph the Earth from thermosphere. But this technology was kept exclusive for the military until the late 1950s, after that Remote Sensing started diffusing and became an important academic research topic. The first international roundtable on Remote Sensing took place in 1962 at the University of Michigan’s Willow Run Laboratories at the and then became a biennial event held more than 35 times in different countries around the world. In 1972, Earth observing satellite ERTS (Earth Resources Technology Satellite)-1/Landsat-1 was launched by NASA and it was the first data collection passive remote sensing platform (satellite) concerning earth surfaces conditions and natural resources. Nowadays, many remote sensing satellites, governmental and private, from a multitude of countries are watching the Earth planet. RS technologies provide up-to-date and cheap mapping of the earth surface but no information of people, economics and detailed land (moreover, building) use. For this reason, RS images are just input for GIS, the real core of the Geo-IT.

A geographic information system (GIS) is a system that collects, stocks, processes, analyzes, manages, and displays geolocalized spatial with map-based visualization. In spite of the fact that cartography and the study of maps has dependably formed the core of geographical sciences, the advancement of automated and computerized GIS didn’t just alter grouping, mapping, and visual display of geolocalized information both quickly and proficiently, but also took into account the itemized quantitative spatial examination of individual factors and the investigational integration of numerous factors all at the same time. GIS combines mapping capacity and database analysis. The inception of GIS was with Roger Tomlinson who was convinced that computers could be used to automate maps analysis and then devised the first computerized GIS, and elaborated it further with the help of IBM, while being an employee of the Government of Canada. Tomlinson's vision became later the Canada Geographic Information System (CGIS). This computer software for mapping has been later on developed and evolved progressively. The commercial company Environmental Systems Research Institute (Esri) now is the far most progressing institute in the market for business, administrative and governmental, and scholastic GIS with its ArcGIS applications and interfaces. Innovations in GIS go on today at an undeniably fast pace, helped with many technical inventions like the Global Positioning System (GPS) to help the air transportation industry. One should note that high-performance computers play a considerable role in the progress of GIS. The diffusion of GIS was determined by a series of international symposia. The first symposium was held in 1963 at Washington as the GIS-Pro conference has been ever since running for the last part of the past century. Furthermore, GIS has been pointed out as a key tool for scholar-use applications under the different disciplines of sciences.

Various socioeconomic, and environmental mechanisms function at different geographic scales, and temporal scales. Thus confining Geo-localized Information a direct relevance to many human activities and decisions. The scientific world started having a new perception of RS and GIS in the early nineties and began questioning and debating whether these were only tools or sets of principles, knowledge and theories. In other terms debates, over if RS and GIS could be considered as sciences, began 15 years ago. These high-profile debates contributed to the broad diffusion and dissemination of RS and GIS and classed them as substantial intellectual domains with their own journals, books and symposia. Transformative research is defined as "*research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research also is characterized by its challenge to current understanding or its pathway to new frontiers"* (National Science Board 2007). Noting the latter, RS and GIS are considered as transformative sciences/innovations in the field of geographical sciences within the 65 past years (Committee in Identifying transformative research in the geographical sciences 2016). Effectively, before the mid-20th century one would not have encountered RS and GIS in geographical sciences but nowadays these two subjects are highly published. Recent *n*-gram analysis reveal a sharp increase of usage of the terms of RS and GIS in published books within Google's Library project (database) and related to geographical sciences (Lin et al. 2012). The science of Geographic Information began in concept during the early 90's in response to lacks in GIS technologies, and has grown to be known as Geo-Informatics. This auxiliary science is the fundamental field which aims to interpret geographic data and integrate them within GISs. It also assesses the reciprocal effect of GIS at the social scale and the reciprocal influences of society on GIS, re-assesses some of the most fundamental themes in traditional spatially oriented fields such as geography, cartography, and geodesy, while incorporating further developments in cognitive and information science. It also converges with and extracts from more specialized fields such as computer science, statistics, mathematics, and psychology, and contributes to progress in those fields. It is essential to note that increasing interest in studying climate change played a contributive role towards the formulation and testing of RS and GIS. However, GIS is more a mere tool, because science proceeds not from methods, but from theories and knowledge. GIS-analysts borrow theories and knowledge from various academic fields, foremost of which are geology and geography, but their tools do not generate new theoretical science, but apply science to practical uses instead. Of course there is a sub-field of research in GIS, but it is more related to informatics than to its fields of application.

As rapidly mentioned previously, the Geospatial information technology is an important science used to treat natural disasters manners. So what are the specifications of geo-information technologies that make them important tools to serve disaster risk management and reduction action plans?

1. Linking Geospatial Information Technologies to Disaster Risk Reduction

Hazards always occur in specific locations, DRR is place-based. This spatial component of risk is at the core of the relation between geospatial information and DRR. As in all battles, knowing your enemy is key to win the war. Mr. Ban Ki-moon, Secretary General of the United Nations (2007–2016) once declared that understanding hazard and vulnerabilities is key to save more lives. The success of risk reduction depends on adequate scientific knowledge of hazards, related processes and social assets, the establishment of networks of dense long-lasting observation and monitoring, and the establishment of detection systems and Early Warning Systems. RS and monitoring systems, hazard warning and communication systems, GIS, computer databases and modelling tools, resource management strategies, civil engineering design measures, and risk studies are the technology capabilities on which disaster risk reduction and management practices heavily rely. One should note that these technologies and techniques are not unique to disaster risk reduction and management, but also have many different applications, as mentioned in the previous part. Scientific knowledge, evidence-based techniques and geospatial technologies have shown their fundamental role as a pillar for DRR processes and their effectiveness in reducing property losses and lives losses.

Numerous international frameworks and treaties have stressed the importance of space technologies in upholding UN Member States to put in action the Sendai Framework for DRR. The latters addresses specially the use of spatially-located based data and technologies in Priority for its first Action 1 pillar: Understanding Risk.

At both wide and narrow scales (national and local) the Sendai Framework calls for:

a) Continuous updates and diffusion of location-based risk information (e.g: risk maps, under the form of geospatial information)
b) Allowing access to accurate data, making use of spatial and on-field information, including GIS, and use of appropriate communications technology innovations to improve both measurement and data collection tools, leading to the proper analysis and diffusion of data
c) Enhancing technical and scientific capacities to strengthen and extend the current understanding for developing and applying methodologies to evaluate disaster risks, vulnerabilities and exposure to all hazards.
d) Targeting the development, enhancement and strengthening of the availability and access to Early Warning Systems (EWS), especially multi-hazard and multi-risk EWS, along with promoting for easy to use and low-cost EWS materials

In a parallel fashion, the Sendai Frameworks encourages regional and international institutions to integrate themselves as part of the implementation process through a variety of steps including (United Nations 2015):

a) Enhancing advances and diffusion of scientifically-based methods and tools to build inventories that record and share disaster losses and disaggregated data and statistics, as well as to promote and enhance disaster risk modelling, assessment, mapping, monitoring and multi-hazard early warning systems;
b) To solidify and strengthen, through international trans-boundary cooperation, sharing and use of non-sensitive data and information through geospatial and space-based technologies in an effort to maintain and strengthen both in-situ and remotely-sensed Earth and climate observations
c) Raising awareness regarding the importance intensification of research focusing on disaster risk patterns, causes and effects in order to diffuse risk information via the use of geospatial information technology.

The UN Secretary-General's Special Representative for DRR, Mr. Robert Glasser, commented: *"Thanks to technological progress made in the past few years, geospatial information at the right scale and definition can be made available and provides critical elements to better understand exposure to disaster risk due to natural and human made hazards. It can also assist in ensuring a risk-sensitive approach to development planning to avoid the creation of new risk."* Geospatial Information Technologies (GIS, remote sensing, etc...) have made a particular contribution to the evolution of studies on natural hazards and DRM/R.

GIS started to be integrated in DRM/R procedures as a tool, from the beginning of nineties. It's direct role in natural disasters reduction and management was pointed out in several papers (Coppock 1995; Cova 1996; Dymon 1993; Fekete et al. 2015). The potential of GEO-IT to provide proficient earth observation information for disaster management (e.g., hazard assessment, disaster mitigation, preparedness, response and recovery) is noted and stressed upon in more than 400 scientific articles between 1972 and 1998 (Showalter 2001). In general, geospatial technologies have aided significantly in understanding the mechanism and in the estimation of natural hazards of atmospheric, geological, hydrological, and biological origins. Geo-information techniques also enables researchers to detect social vulnerabilities and work on the modelling or alternative scenario building which in turn can aid in the mitigation of the impacts of disasters (Martins, Silva, and Cabral 2012). Through combination of innovative methods and tools offered by GIS and RS a more detailed insight to the identification of complex disasters is obtained which in turn aids in providing early warnings to settlements potentially at risk (Sian Lewis 2009).

Remote sensing and satellite imagery play an integral role in DRR procedures. According to the Global Disaster Information Network (GDIN), multispectral scanners (optical sensors) and radars are probably the two most widely acknowledged RS capabilities used in the scope of disaster management (J. Rego 2001). By enabling high-speed simulations, real-time data assimilation, geospatial analysis, visualization, machine learning and infrastructure resiliency, Geospatial technologies have an outsized, real-world impact when natural hazards occur. Among the utilities that satellites can offer for DRM and emergency response are weather forecasting, RS, geo-localization, navigation, television and telecommunication (Rimba, Yastika, and Miura 2016). Space applications related to Earth observation, telecommunications and global navigation can play a fundamental role in supporting DRR, response, and recovery efforts, through reliable and real-time information for policy-makers. For example, Earth observation can be used to produce hazard, exposure and risk maps, as well as to identify and store areas that have damaged by natural hazards. In a complementary

fashion, satellite telecommunication allows the transmission of warnings very rapidly from one continent to another thus playing a role of a warning/preventive tool. Global navigation satellite systems are also aiding in developing understandings of the motion of tectonic plates, and to the delivery of humanitarian assistance during crisis-times through the coordination and listing of corresponding shelter coordinates. In recent years the space community has set up several regional and global emergency mechanisms to support disaster response operations through the use of maps issued from satellite imagery. These emergency mechanisms are: the International Charter Space and Major Disasters, the Copernicus Emergency Management Service (EMS) - Mapping, Sentinel Asia and SERVIR. The United Nations Institute for Training and Research (UNITAR) also facilitates access to relevant mapping products through its Operational Satellite Applications Programme (UNOSAT). Recognizing this importance and the fact that no single operator or satellite can match the data-related challenges of DRR, the International Charter on Space and Major Disasters was signed in 2000 by many major space agencies and satellite operators (Bally, Viel, and (ESA) 2012). Numerous organizations and programs are involved in post-disaster mapping activities including UNOSAT (2010), DLR-ZKI (2010), SERTIT (2010), GDACS (2010), and the Dartmouth Flood Observatory (2010). In Europe, the Global Monitoring for Environment and Security (GMES) initiative of the European Commission and the European Space Agency (ESA) actively supports the use of satellite technology in disaster management, with projects such as PREVIEW (Prevention, Information and Early Warning pre-operational services to support the management of risks), LIMES (Land and Sea Integrated Monitoring for Environment and Security), GMOSS (Global Monitoring for Security and Stability), SAFER (Services and Applications For Emergency Response), and G-MOSAIC (GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises) (Van Westen 2013). DigitalGlobe provides 60-centimeter QuickBird images, one of the highest resolution commercial satellite images available. Other operators are Japan’s ALOS, CNES’s Spot-5, the US WorldView and QuickBird platforms, Canada’s RADARSAT-2 and the ESA’s ERS-2 and Envisat sensors (Herold 2012). NASA and various other space agencies currently provide flood-monitoring and response services, images, and computer simulation products. The satellites shown in
Figure 2-1 include only those currently providing images used to assist flood response.

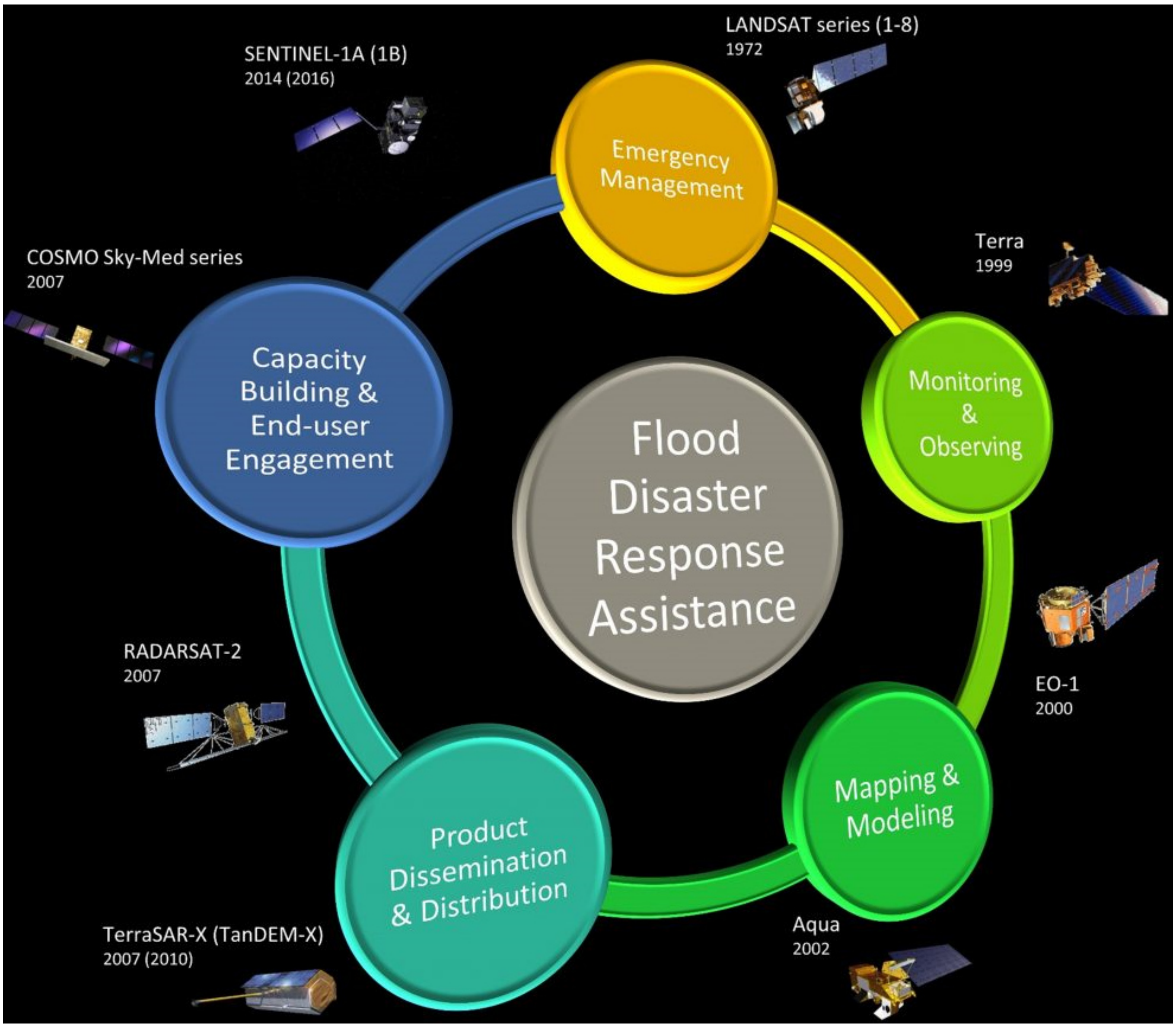


Figure 2-1. Satellites involved in flood disaster response assistance. Source: Schumann (2016)

The delivery of data from these platforms is mediated by Google and GeoEye to leverage Google's web-presence and bandwidth to provide 100s of GBs of high resolution GeoEye 1 and IKONOS images (Herold 2012). In addition, several Google pages like the Google Earth Library offer critical infrastructure data for direct real-time viewing in Google Earth formatted KML. The wide availability of readily accessible post-disaster KML datasets allows for rapid assessments by non-GIS experts thus increasing the effectiveness of managed efforts and overcoming the challenge of user expertise. This International Charter main purpose is to provide a unified system of space data acquisition and delivery to those affected by natural or man-made disasters. The charter has been successfully used on several occasions by countries throughout the world since it provides key high resolution imagery free of charge. For instance, Lebanon has benefited from high resolution imagery during 2006 oil spill incident. This charter help developing countries that cannot send satellites into orbit by providing remote sensing data, is nevertheless criticized. First because this International Charter does not provide free imagery for pre-disaster GEO-IT operations. Second, few mechanisms to help countries in need of support for use of satellite data are offered. Developing countries often lack of knowledge and capacities related to geospatial data management and manipulation.

In 2016 the United Nations General Assembly established the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) (Ndiritu and O'Sullivan 2015). The latter allows access metadata and links to disaster mapping, thus conveying all countries access to develop their abilities and skills to use space-based information to support the disaster management cycle. UNSPIDER is currently developing a space application matrix aiming to offer satellite-based approaches and techniques for each type of hazard and each phase of the disaster management cycle. Numerous other private organizations like ESRI Inc. provide maps and mapping support for the preparation and relief phases.

RS and the use of space-based infrastructure in support of disasters provides several benefits: a) The infrastructure is not vulnerable to the disaster itself; surface-based infrastructure like on-field sensors and communication systems are vulnerable to damage and failure as a result of disasters, while satellites offer a robust source of near-real time and unique information to assist disaster management; b) Consistent and comparable information is collected systematically on multiple scales, from local to trans-boundary to global; and c) Inaccessible and hazardous areas can be sensed without risk, including at all stages of disaster management (Jayaraman, Chandrasekhar, and Rao 1997).

GIS-based risk and disaster management is becoming a feature of local government's natural hazard risk reduction and management procedures (Zerger and Smith 2003). What are the features of geo-information technologies that allowed them to get this important role DRM/R strategies and actions?

First of all, it is of common sense to question the linkage between DRR and Geospatial technologies. The spatial dimension is at the heart of this bonding, risk reduction activities are centered on geospatial information and therefore make use of so-called geographic information. In fact, Natural hazards are themselves spatial phenomena with a geographical extension. "*Even though the natural processes (e.g., floods, earthquakes, landslides, etc.) that generate disasters might be fundamentally different, the techniques to assess and mitigate risk, evaluate preparedness, and assist response have much in common and can share and benefit from advances in geographic information science (GIScience) (e.g., data acquisition and integration; issues of data ownership, access, and liability; and interoperability)*." (Radke et al. 2000, p.15). Coppock (1995) has shown that GEO-IT and especially GIS have a considerable role to play, because natural hazards are multidimensional phenomena, presenting a spatial component, and whose management comes under several disciplines (urban planning, geology, etc.). Assessing exposure and vulnerability requires a good information system on human settlement, land use and the precise location of economic assets, all information gathered through administrative sources, surveys, censuses and invisible to RS images.

Moreover, the location of people, activities and infrastructure imply a spatial dimension necessary for their integration and management in information systems. Since hazards and vulnerability vary spatially, taking this spatial component into account is therefore necessary in any system dealing with the reduction of natural hazards. GIS functions mainly as a support tool to help answer essential questions and make informative, timely and adequate decisions that can help save lives. For instance, RS imagery can answer questions such as: "what did/does the area look like pre-/post-disaster?" RS data can reveal the land cover and topographic features in an area and can reveal infrastructure and population density (Herold 2012). The processing of the spatial component is at the level of acquiring, interpreting, analyzing, mapping, disseminating information, modeling and representation, indexing, geometric calculations. Cova (1996), reports GIS to be an indispensable tool for spatial decision when effectively employed in a field like disaster management dealing with critical spatial decisions.

2. Spatial Data

DRR process is data-intensive. To proceed into the DRR cycle, the starting point is geospatial data, also known as spatial, geographic or location information. Geospatial data is described by C. Bailey and Gatrell 1995, (p.xi) as: "… *data where, in addition to values relating to the primary phenomenon, or phenomena, of interest, the relative spatial locations of observations area also recorded, because these may be of possible importance in interpreting the data*". The contribution of geospatial data in all angles of natural disaster reduction cannot be undermined. It has been declared that "*Accurate and comprehensive spatial data play a critical role in all phases of disaster management*" (Brodnig and Mayer-Schonberger 2000, p.6). DRR is grounded on evidence-based understandings regarding disasters and thus requires detailed information about people and their environment. Increased knowledge regarding the key role of geospatial data needs for DRR has gained wide reputation. Many symposia tackled this subject; for instance, in 2003 the Joint Assembly of the European Geophysical Society (EGS), the American Geophysical Union (AGU), and the European Geosciences Union (EGU) discussed this issue in a symposium entitled "*Geo-databases for disaster risk reduction and management, especially for Natural Hazards and Risk Assessment"*. This state of increased recognition and acknowledgment subsequently led to higher degrees of interest regarding this topic and facilitation of cooperation in terms of data availability, shorten time-frames and easier modes of delivery for different practitioner communities and users.

One of the greatest geo-information technologies specifications is the ability of gathering and stocking data in organized and standardized databases avoiding, when feasible, the old ground-surveys that were extremely costly and time-consuming. For instance, for households' occupation, settlements and activities, field surveys are required. The relationship between GIS and data is mutual. GIS promote for elaboration of spatial databases and permit them to become more widely available. While spatial databases widespread, allow the expansion of the utility of GIS, especially in Disaster Risk Management and Reduction planning. Data collection is a crucial element in efficient disaster risk management and reduction measures. The analysis of the majority of the risks of natural origin uses common information whether scientific (physical, chemical, mechanical ...) or territorial data (exposed elements, civil engineering, and systemic functionality).The achievement of continuous measures for parameters of natural hazards, which will ultimately precede, accompany or follow a given event, requires the existence and permanent operation of dedicated observatories, monitoring networks and warning transmission system whose resources cannot only depend on research funds that can fluctuate according to national priorities and economic contingencies. In recent years, the densification of such observatories and their associated instrumental networks has enabled the acquisition of a large quantity of high-quality data documenting the natural phenomena likely to generate catastrophes. However, the integration of these data into a global and concerted system is still in an embryonic state except for the monitoring of the state of the atmosphere and, to a lesser extent, for the ocean, which are already based on systems forecasting assimilating the available observations. The various observations thus remain fragmented and sectoral. Moreover, with the exception of meteorology, little effort has been devoted to a coordinated, integrated and multi-stakeholder implementation of the means of observation for the various phases from estimation to risk management (anticipatory estimation, prevention, warning systems, crisis management, etc…). An important issue to tackle here, is the quality of data. Disaster risk reduction and management relies on good data. Certainly, the quality of technologies application, e.g. model performance, depends on the quality of data used, as well as who collected the data and for what purpose. "*GARBAGE IN GARBAGE OUT" (GIGO)*: This is one of the most famous acronyms in the history of computing. This means that it doesn't matter if a researcher is using the most brilliant software and hardware: if his data is rubbish then his outputs or analysis will be rubbish as well (Cowan 2011). Montoya (2003) stresses out the necessity of periodic and continuous update of data for efficient disaster risk management, considering that the assets at risk are dynamic and ever-changing systems, especially in urban areas (Montoya 2003). According to the European commission, issues concerning data quality should not be used as an excuse to hinder inputs to risk analysis models, and postpone actions until more accurate data are gathered. But it is much better to set the starting steps for risk assessment and analysis from and invoke resources to develop better knowledge of the risks as far as possible now than be bound by waiting for availability of better data (Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark 2017). Spatial data sets needed for DRR/M models can be summarized into data on population, land use, Digital Elevation Model (DEM), terrain data, geological data, weather related data, administrative setting data, transportation data, energy and water networks data, etc… Natural disasters (ND) data archiving is not an easy task, and this is related to the fact that collecting this data needs great attention to data accuracy and reliability, and especially to methodological issues like data standardization. Actually, data sources can be extremely diversified and thus, data sets would vary enormously. Several global ND databases exist. EM-DAT database, maintained by the Centre for Research on the Epidemiology of Disasters (CRED), the French CatNat.net and DesInventar system are global ND databases that are readily available. Other databases exist but are proprietary. The NatCatSERVICE Database on Natural Catastrophes operated by the private reinsurer company MunichRe, and the sigma-data presenting historical data on catastrophes is also operated by a reinsurer called "Swiss Re". A multi-agency PREVIEW global risk data platform, a result of the effort of multiple agencies to share spatial data information on imposed global risks from natural hazards (Guha-Sapir et al. 2004). These archived data may extend back a century or more, and is therefore of paramount importance as they are the basis for estimating and predicting the probability of occurrence of extreme events and to analyze their trends. International agreements for sharing former/past and timely hazard data among nations and scientific agencies are under the "wings" of the United Nations for a wide range of hazards including earthquakes, tsunamis, climatic extremes, volcanic eruption and wildfires.

First of all, it is of common sense to question the linkage between DRR and Geospatial data. Location and the geospatial dimension is at the heart of this bonding. Every element entangled in a disaster is tied to a specific location. This makes risk reduction activities centered on geospatial information and location a "key field" for all disaster-related databases and a basis for organizing, integrating, visualizing, and analyzing data. Therefore risk reduction activities make use of so-called geographic information. In fact, natural hazards are themselves spatial and temporal phenomena with a geographical extension, as well as the elements-at-risk. It is impossible to consider the physical processes of hazards, or how they affect people and their assets, infrastructure and the environment, if their location on earth is missing. Therefore, geospatial data are necessary to better understand risk and better plan for hazards.

A successful implementation of GIS for DRR actions is greatly governed by the availability of geo-localized or georeferenced information. One of the strong points of GIS is their capacity to incorporate a wide array of data types (Herold 2012). Data types can vary between geographic, socio-economic, political and security data. GIS is able to integrate all these types into a single framework (Dash 1997) and link it to a specific geographical location, thus creating geo-databases and efficiently disperse it. GIS capacity to link attribute tables to a feature represents one of its most utile tools especially in DRR actions where buildings' owners, owner number, year built, condition, pictures and many other data are necessary. All this information is not only stored but spatial data and attribute tables can be updated at any time. Moreover, GIS provide a graphic-friendly user interface enabling users to interactively navigate and browse data, including complex four-dimensional databases (including time dimension).

The capacity to generate geo-databases can solve many issues of current natural disaster reduction practices. As geo-databases, information will always be well organized, comprehensible, supposedly up-to-date, and effortlessly reachable and processed with proficient methods of spreading this data. Geo-databases represent important sources of information for validating physically-based, statistical or conceptual models aiming at assessing risks from natural phenomena. Furthermore, early warning systems, aimed at protecting people and their properties from the vagaries of nature, rely on geo-databases to provide accurate, reliable and timely forecasts. Geo-databases are used to estimate the extent of the potential damage caused by a ND (Couture and Guzzetti 2004). The range of geo-database applicability extends under various applications such as civil protection and use by risk managers working for insurance companies to estimate the frequency and assess damages induced by NDs. At a more local scale, technical end-users and private consultants refer to geodatabase in order to localize hazard-induced problems. Concerned citizens can readily refer to an access available geo-databases to obtain on-site specific physical information regarding a variety of natural hazards and their consequential effects.

This large amount of data imposes a necessity to organize and has led to the development of the spatial data infrastructure (SDI) concept. The latter is an effective mean to organize data collection efforts and/or for sharing spatial data among inter-related departments and ministries, taking into consideration a comprehensive documentation and accurate metadata. Moreover, SDIs are very important for DRR actors and managers whose work are based on spatial data accessing and sharing across multiple departments, ministries and organizations. National SDIs are being established in developed countries, given the abundance of proficient technology, economic power, trained personnel and governmental support and stability contribute to their success (Musinguzi, Bax, and Tickodri-Togboa 2004) . In contrast, in most developing countries, absence of one or more of the factors mentioned earlier, along with the more or less deteriorated quality to quantity ratio of spatial data, hinder the development of SDIs. The absence of a national SDI often results in pointless data redundancy, waste of human/financial resources ultimately hampering DRR actions.

In all phases of a humanitarian crisis, decisions underpinned by accurate data are keystone to reduction of human and economic losses. Data have a crucial role in informing understandings of risk. Risk assessments setting decisions, are built upon data; a weak foundation in data would ultimately lead to faulty assumptions and ineffective DRR approach. In turn, the information produced by risk assessment must be communicated and shared to ensure proper implementation. Data should be collected and shared during each phase of DRR cycle in order to serve each one of these phases. The strength of GIS resides in its ability to pair the spatial data to attribute data. Spatial attributable data captures a very important information about assets. This pairing of data, defined by establishing geospatial databases, is crucial for DRR actions.

Data stored in geo-databases is gathered at different geo-temporal scales, by means of different processes and technologies. The capability of creating geo-databases makes GIS utile for the DRR procedures. Geo-databases are data storage systems representing several advantages as efficient and fast storage, storing all the data in one, central location rather than being spread throughout different files, more than one editor and multiple users, quick search of data, clear organized and standardized structure, and a faster and more accurate data entry and update. These advantages expand to the field ensuring a level of quality control in surveys conducted by volunteers unfamiliar with the region.

Intensive archives studies and historical data are crucial in building geo-databases. Data regarding the spatial occurrence of disasters, their spatial extent, their impact on populations, and their economic cost are key factors of DRR (Van Westen 2013); *"We can gain insight on what to expect if we assume that the future will look like the past"* (Stein, Geller, and Liu 2012, p.2). Although past losses are not a complete indicator of future losses, in light of climate change, growing societal exposure and changes in patterns of vulnerabilities, it is nonetheless essential data for generating vulnerability indices necessary for assessing future risks and for validating and calibrating risk assessments. What is important about historical data is to be collected at the local level for more precision and accuracy. Actually, a variety of undocumented indigenous knowledge regarding disaster occurrences in the field exists (Van Westen 2013). This local historical data usually remains unknown as a result of low commitment and funding capita. A significant challenge arises when using disaster databases for natural hazard and risk assessment given the absence of proper geo-referencing and accurate spatial representation of the reported events within (Verelst 1999). Often, records solely mention the name of the village or even only district's name especially in archives and newspapers. Moreover, historical data should include high-magnitude/small-frequency events know as intensive risks as well as small-magnitude/high-frequency events, called extensive risks. This, along with extended periods of time, are so necessary especially for hazard assessments and for tracking loss patterns and trends.

Measuring, observing and collecting data in the aftermath of recent disaster, or so known as damage data, is also considerably important. This importance of damage data resides in the fact that it can support a variety of actions in several steps of the DRR cycle. For instance, this information can help to identify priorities for intervention, resources mobilization and guide relief in the response phase. As for the recovery and reconstruction phase, physical damage and its monetary counterparts can be used to prioritize compensation schemes and determine the victims, their losses, and thus financing requirements. This information can also contribute to prevention and preparedness actions by creating complete event scenario and damage models, and prepare for a timely and effective response. These damage models directly feed cost-benefit/cost-effectiveness analysis for loss reduction investments, serve for insurance schemes and plan for structural and non-structural actions.

2.1. *Population data*

An essential part of the data needed for focused, targeted and accurate DRR actions and that must be highlighted is population data. The number and distribution of people is pre-requisite in each and every phase of the DRR cycle. Accurately estimating population distribution and exposure is recognized as a key component of effective DRR & DRM especially for disaster loss modeling (Chen, Liew, and Kwoh 2005; NRC 2011). Efficient DRR actions require careful consideration of the people's exposure, their vulnerability and coping capacity. Population's diversity should be taken into consideration; Population groups don't have same living conditions and responding capacities as some are more vulnerable than others. Children, elderly and people with disabilities cannot easily escape and protect themselves during disasters. Furthermore, people's livelihoods should be accounted for. Disadvantaged people, under poverty line, and refugees don't usually recover easily and rapidly from disasters and need special help. Populations have a dynamic component. Estimating and mapping populations is claimed to be a complicated task due to the nature of human activities patterns which change over space and time (Lwin and Murayama 2009). Usually, population data is derived from population and housing censuses, and household surveys along with large-scale sampling surveys. These surveys are also supposed to collect data about critical infrastructure including education and health facilities, roads, energy network, public places, etc… Projections of future scenario are possible at a regional scale, accounting that this data provide population dynamics, such as births, deaths and migration. At the local scale compatible with most DRR actions, forecasters have to deal with a great lot of uncertainty. In fact, data collected from these sources are grouped by administrative area, not disaggregated to the local level, and need to be integrated in geographical system. GIS has the capacity to turn population censuses into territorial data, building layers for each group of information, disaggregating it into a finer resolution (top-down). Once integrated, censuses mapping is possible, highlighting the location and characteristics of important demographic features and social infrastructure. It is of key importance to point out that spatial databases offer substantial savings in terms of time and resources in the long run as they are easier, and cheaper to maintain, update and access than the basic printed maps. For more focused and targeted DRR actions, this administrative distribution should be replaced by a larger scale and a finer resolution. In fact, the bottleneck of census information compiled at an administrative unit level and not having data at the micro level geographical distribution of population is now solved by resorting to GIS and RS techniques to generate desired data. The methods used can be grouped by areal interpolation methods and statistical modeling methods (Wu, Qiu, and Wang 2008). All aerial estimation methods have been criticized as they present many uncertainties; these methods give information about where people live but some buildings may be simply empty of residents. UN recommend that each country should conduct at least one population census once in every ten years (Valente 2015). Nevertheless, Herold and Sawada (2012) claim that fine resolution census data essential for various GIS-based natural disaster reduction is often unavailable, outdated, or unreliable in developing countries for various reasons. In developing countries figures do not always reflect the real demographic situation (Herold and Sawada 2012).The case of Lebanon and Baalbek-Hermel is not different, yet even more complicated. Because of the precarious and delicate sectarian repartition in the body politic, the Lebanese government has deliberately avoided conducting a comprehensive update of the 1932 census. The main reason of this is political. The balance of powers is based on religious communities. An update of detailed population figures could entail some communities to claim a larger share of seats in the parliament or in the government if a census would demonstrate this particular community represents a larger share of the total population. This absence of official statistics renders a demographic analysis of the Lebanese population a difficult task.

2.2. Temporal data

In the past, GIS was thought to provide only spatial data. Nowadays geo-information systems provide with real-time data and the temporal resolution issue is solved especially for response times. Recent advances in the technological domain convey protection agencies with tools and functionalities that allow obtaining timely information pre, during and post the disaster situation. Data from monitoring systems like satellite platforms, historical information and weather forecasts are integrated in combination with data provided by recent technologies and interfaces such as mobile apps, augmented reality glasses and social media analysis tools or Digital Social Networks (DSN), which monitor social media platforms to build real-time information inventory on the disaster situation. Posts and tweets, if monitored closely, may allow real time mapping of disasters thus assisting the emergency response process. This technique is borrowed from a methodological approach often employed by scientists aiming to recreate historic events that occurred in times of precision instrumentation absence. Under absence of precise data, scientists turned to written historical references. Similarly, scrolling through uncountable tweets by inputting relevant keywords into a text-mining query, then filtering those of good quality, information documented in posts and tweets are gathered and integrated in GIS to serve as input for mapping disasters. GIS can serve as decision support tools for Disaster Risk Management actions and emergency management by allowing a real-time disaster planning (Cova 1996). A real-time emergency management disaster scenarios are possible using geo-information techniques. For instance, real time data/Imagery based flood monitoring scenario strongly depends on continuous user process monitoring. Even GIS-based evacuation modelling is possible (Alaeddine et al. 2015; Cova and Church 1997; Kwan and Lee 2005; Newsom and Mitrani 1993). Kwan and Lee (2005) talk about a "*GIS-based intelligent emergency response system (GIERS)*" which is a spatial decision support system that simplifies both the organization and implementation of rapid emergency response operations such as evacuation and rescue (Kwan and Lee 2005). Crowdsourcing from social networks has enormously helped for real-time data collection (Middleton, Middleton, and Modafferi 2014; Douvinet, Kouadio, et al. 2017). Social networks are working on developing options to contribute in building safe communities. "Facebook", the biggest social network of the century, in collaboration with the U.N. children's agency UNICEF, the International Federation of the Red Cross and Red Crescent Societies, the World Food Programme, launched on the 7th of June 2017 "Disaster maps" as an initiative aiming to help first responders and humanitarian organizations save lives in emergencies (Mis 2017). This initiative came along knowing the response organizations urgent need of accurate and quick information about the location and the movements of people in order to save lives. The critical infrastructure systems issue, especially telecommunication, is being tackled here. The traditional communication channels and networks are supposed to be disrupted during crisis, which would hamper the response measures, ignoring where people need help and first responders not being able to communicate between each other. Assuming that victims have enough power and a working network access, "Facebook" declared it would provide three different map categories: (1) Location density maps to reveal people's location pre, during and post disaster. (2) Movement maps to simulate flight times between neighborhoods or cities over several hours. (3) Safety check to allow users to inform family and friends that they survived the event(s). These maps will also highlight the location of people in post-disasters times to help rescue personnel and organizations decide where they should deliver food, water and necessary medical kits.

Recent studies have proved that spatial data alone is not sufficient (Weichselgartner and Pigeon 2015). To properly reduce risks, there is a need for not only spatially (grid square averages) high resolution data, but also temporally (collection intervals). Near-real time data and temporal resolution are a must for accurate DRM actions, especially for early warning, crisis management, damage mapping, etc...

For risk assessments and real-time decision making, population density is not enough; scenarios based only on spatial distribution of people can be very misleading. Alexander (1997) states that casualties vary significantly between night and day and therefore recommends to study exposure and vulnerability in this temporal cycle. If a tsunami hits the same location at night or at a day peak hour, human losses won't be equivalent. Population is not static, so the calculation of the exposure is problematic. The spatial distribution of population shifts dramatically between night and day as people migrate from residences to places of work and commerce. To know how many people present at a certain location at a precise time, data about work places, traffic jams, weekends, vacations, seasonal internal migration, touristic activities, etc. is required. Talking about population distribution, census population figures and the majority of available population datasets are most of the time a de jure population, in contrast to a de facto population (Wu et al. 2008). A de jure population is the number of residents of an area (i.e., nighttime) and therefore have no temporal component; while a de facto population reports all people in place at a certain time is considered daytime population (Wu et al. 2008). Bhaduri et al. (2007) established conceptual Equation 2-1 & Equation 2-2 for the repartition of a de facto and a de jure population:

Day-time population= Workers + School children + tourists + business travelers + residual night-time residential population + (static population)

Equation 2-1. Day-time population of an area. Source: Bhaduri et al. (2007)

Night-time population= Night-time residential population + night-time workers + tourists + business travelers + (static population)

Equation 2-2. Night-time population of an area. Source: Bhaduri et al. (2007)

2.3. Big data and Crowdsourcing data

An important issue to tackle here is the "Big data" referring to the explosion of information. Big data showed efficiency in facilitating DRR actions (Yu, Yang, and Li 2018). Nowadays, data are constantly increasing in volume, variety, and velocity (the speed at which data accumulate) especially with the development of software able to manage, retrieve, visualize and interpret large data sets in a tiny period of time. But the size of this mounting trove of information in itself poses a problem. Big data require super computers and resources. It is essential to know how to make the data useful and enhance collaboration with communities and among experts in order to avoid the redundancy.

Crowdsourcing and crisis-mapping are defined by Douvinet, Kouadio, et al. (2017) as "*concepts supported by the involvement of a large number of persons that enable, in a voluntary way, consolidation of information collected in situ during the course and progress of a phenomenon (such as a flood for example)*". A dilemma around trusting posts and tweets (crowdsourcing) and integrating them in scientific studies, is their reliability. Studies tackling this subject have compared maps elaborated with crowdsourcing information and those elaborated with satellite or aircraft imageries. Results revealed a strong positive agreement between Twitter-sourced and actual disaster extent data, thus confining social media significant reliability in disaster projection applications.

Geo-information systems have even allowed the creation of Smartphones applications that can serve in predicting and alerting of the upcoming hazard (Douvinet, Gisclard, et al. 2017; Douvinet and Kouadio 2015). Earthquakes Early Warning (EEW) provides warning prior to seconds and minutes, thus allowing alerted individuals to relocate. The handful of EEW systems operating around the world rely on traditional seismological and geodetic data networks that are rarely existing other than in some developed nations. Smartphones are far more prevalent than traditional networks and contain accelerometers which in turn can be used in earthquake detection. The development of a new type of seismic system, MyShake, encourages personal/private smartphone owners to collect data and analyze earthquakes via their sensors. Smartphones have the ability of recording magnitude 5 earthquakes at distances of 10 km or less and develop an on-phone recognition system to differentiate between earthquakes and other normal vibrations. In Lebanon, In order to reduce the obstacles to communication between the population and public and private institutions, CNRS-Lebanon through its National Center for Geophysical Research has developed in 2018 the new Lebquake mobile application. The latter allows anyone with a smartphone to access reliable information concerning the location, magnitude and time of earthquakes in and around Lebanon. According to Douvinet (2018), these applications, allowing the population to be alerted and guided by the ongoing crisis situation, are barely used and invested in. In addition, Douvinet claims that the lack of awareness has made a significant portion of the population unaware of the existence of these warning applications, or even more, neglecting them.

Talking about big data and collaboration and cooperation with communities, the proliferation of "smart devices" and "social media" has helped and enhanced this collaboration for better data collection serving all phases of disaster risk reduction cycle, prevention (Houston et al. 2015; Maresh-Fuehrer and Smith 2016; Spence, Lachlan, and Rainear 2016; Teodorescu 2015), preparedness (Anson et al. 2017) response (Becker and Bendett 2015; Carley et al. 2016; Chae et al. 2014; Ma and Yates 2017; Murthy and Gross 2017; Panagiotopoulos et al. 2016), and recovery (Albuquerque et al. 2016; Basu, Bandyopadhyay, and Ghosh 2016; Cheng et al. 2016; Maresh-Fuehrer and Smith 2016). These technologies have allowed to spread "*eyes on the ground*" in time of a crisis, generating a huge amount of data. Any person can now witness, record and report an event as it occurs and hence help disaster response and damage assessment. The challenge is the accurate filter of these non-conventional data, their interpretation and validation in order to assess the extent of a disaster over space and time as well as correctly estimate damage. The integration of this data should be done very carefully; several motives lead people to post false information on social media as to get attention, pushing a money-making scam... However, if well filtered, this new source of data is able to complement model simulations; it's possible to generate real-time maps by combining these volunteered data sets and applying geo-locations to images gleaned from social.

Moreover, new technologies have even generated “Volunteered Geographical Information” (VGI) and “Participatory GIS” (PGIS). PGIS invokes communities in both generation of spatial data and subsequent decision-making process (Van Westen 2013) for more efficient disaster risk reduction actions. The interesting point about VGI & PGIS is the capture of local know-how and its combination with more conventional spatial information which facilitates GIS production and application through GPS surveys. Thus, PGIS complement data (Zaninetti, Ngo, and Grivel 2014), contribute to more accuracy where input data is not precise enough and to verify GIS output for more accurate hazard mapping and even for more proficient recommendations for mitigation measures. This participatory approach is encouraged being transparent and reusable, scalable and maintainable, collaborative, foster more use of the data, builds local ownership and trust in the data, raises community awareness of risk and resources are only focused towards building capacities (Mccall and Dunn 2012; Rambaldi et al. 2006). Testing PGIS, Kienberger & Steinbruch claim that : *“participatory approach is suitable for the collection of spatial information and to capture the perception of the local people regarding disasters”* (Kienberger and Steinbruch 2005, p.3), and thus may be useful to raise public awareness. In turn, traditional data collection is claimed to present many constraints such as being consultant driven, an opaque collection process, expensive up front, static, out of date and costly to be updated. OpenStreetMap (OSM) can be considered as the largest and most popular VGI for different mapping purposes. The accuracy of OSM, has been tested by several studies (Girres and Touya 2010; Zielstra and Zipf 2010) through a comparison with other reference data sets, and has revealed to be fairly accurate.

Communities can be involved in more than VGI and PGIS; “indigenous knowledge” is also recognized as important data for disaster risk reduction actions (Ngo 2014). Especially in rural areas where local communities livelihoods heavily rely on surrounding environment and natural resources, indigenous knowledge and traditional environmental knowledge are declared to be fundamental for accurate DRR actions (Brodnig and Mayer-Schonberger 2000). This knowledge is considered as a geographical information system itself and a data repository originating from the deep relationship bonding between local communities and nature. Integrating this traditional knowledge with new technologies, like VGI and PGIS, would be extremely valuable notably as data input for efficient hazard assessment, authentic mitigation measures and coping capabilities and as calibration and verification tools for the models’ outputs, disaster risk scenarios and risk mapping. Furthermore, these community-based methods are key to sustain and maintain systems /operations on the long term since conventional ways to update datasets are costly and time-consuming.

2.4. Spatial Data Requirements and limitations

This part addresses the basic requirements of spatial data for GIS integration, disaster related risk analysis, mapping and modelling. From a theoretical aspect, when building an inventory for guiding risk decisions, it is important to bind to the basis of model consistency, where the resolution of parameters is measured to be consistent with the accuracy, validity and integrity of the risk model as a whole.

At first, Table 2-1 describes the data needs for disaster risk reduction cycle, along with their spatial data type in GIS and relevance and use in the DRR cycle. The administrative area is considered as the base layer to which all other attribute data are linked.

Table 2-1 Crucial spatial data for Disaster Reduction (adapted from Gunes and Kovel (2000)*)*

Data needs	Description	Spatial data	Type	Relevance to DRR
Administrative area	Including the national, governorate, district and cadastral boundaries with locations of main towns and villages	Governorate borders	Polygon	This information are basic requirements; it's the base layer to which all other attribute data are linked
		District borders		
		Villages borders		
Infrastructure and public facilities/Amenities	Including all the assets and utilities	Road network	Polyline	This data contribute enormously to an accurate vulnerability assessment and to efficient preparedness and response actions (through optimal routing, allocation, flow models, evacuation plans, etc…)
		Tunnels	Polyline/Points	
		Bridges	Polyline/Points	
		Schools	Points	
		Hospitals	Points	
		Other health facilities	Points	
		Industries	Points	
		First responders centers	Points	
		Place of worship	Points	
		Touristic places	Points	
		Airports	Points	
		Seaports	Points	
		Energy network	Polyline/Points	
		Shelters	Points	
		Resources (supplies, equipment, vehicles, or other material resources)	Points	
Population & land-use	Including the characteristics of the population	Urban settlements	Polygon	This socio-demographic data provide detailed attributes of the population, necessary for accurate vulnerability modelling and risk assessment
		Population density	Points	
		Land use/Land cover	Polygon	
		Watersheds	Polygon	

Data needs	Description	Spatial data	Type	Relevance to DRR
Hydrology, Meteorology, and Climatology	Including the environmental characteristics	Rivers	Polygon	Inputs for assessment of variety of hazards, as for preparedness planning and input for mitigation for critical facilities.
		Lakes	Polygon	
		Rainfall	Polygon	
		Climatic zones	Polygon	
Topography, soil and Geology	Including the geological characteristics	Contour lines	Polylines	Hazard assessment. The utility of elevation data depends on its resolution/scale at which it is derived. For mitigation purposes, high resolution DEM is usually required.
		Geology	Polygon	
		Soil types	Polygon	
Satellite Imagery, Radar, and Aerial Photos	Including the necessary images	DEM	RASTER	Excellent source for preparing thematic maps related to terrain parameters and natural resources. These images are of key importance for damage assessment of the actual impact of a hazard
		High-resolution satellite imagery (<1m)	RASTER	

A special attention should be given to RS digital elevation/topographic data, known as DEM (digital elevation model) or DTM (digital terrain model). Elevation data can be extracted by various means, namely on-screen digitizing of contour lines from ancillary existing topographic maps, topographic levelling, EDM (electronic distance measurement), differential Global Positioning System (GPS) measurements, digital photogrammetry, Interferometric Synthetic-Aperture Radar (InSAR), and LiDAR (Van Westen 2013) . Data source selection is a process governed by numerous factors namely: data availability, cost, and application purposes (Van Westen 2013). From DEMs, several topographic parameters such as slope, aspect, contour lines, flow direction, flow accumulation, watersheds, solar insolation, hillshade visualizations, etc… (Herold and Sawada 2012) can be generated through GIS operations. Overall, surface features and topography are of key importance for Disaster Risk Reduction actions. They are frequently used as critical data input for the assessment of natural hazards especially coastal hazards like tsunami, landslides (Abdallah 2013; Guinau, Pallàs, and Vilaplana 2005), and floods (Dewan et al. 2007). The spatial resolution and vertical accuracy of a DEMs play a major role in their applicability to DRR actions. For instance, combined to precise land-use attributes (i.e. artificialized surfaces) and geologic attribute (impervious surface or not), high-resolution elevation data are essential to create accurate flood exposure models.

Further, it is necessary to collect information on 'actors', or whoever performs specific occupations. Such information can be obtained by local administrators coupled to the willing integration of communities. Participating factors can consist of NGOs, social groups, community groups and individuals prepared to be readily participate in a disaster situations. Such data can also include key information regarding parties and service agents that can act and interfere during crisis times. However, this data requires to be specifically geo-localized to be efficiently integrated with other forms of spatial data.

Lately, 3D geospatial information significance in DRR cycle especially during emergency response has been a buzzy debate (Amirebrahimi et al. 2016; Gaillard and Cadag 2013; Kwan and Lee 2005; Lee 2007; Lee and Zlatanova 2008; Ozbek et al. 2016; Tiwari and Jain 2015; S. Zlatanova et al. 2004; S Zlatanova, Oosterom, and Verbree 2004). Since the 9/11 incident of New York, a rising interest and significance for 3D building and sub-ground systems and models has emerged. Three-dimension data has always been a challenge, and until recently no commercial system promoting the ease of manipulation or analysis of 3D data exists. As for Disaster Risk Reduction, there is a lack of 3D geo-information models (Ozbek et al. 2016). What is challenging about 3D geospatial significance is the wide array of existing data models, their resolution, and graphical representation methods (boundary representations, voxel, constructive solid geometry, CSG). Moreover, obtaining 3D models of indoors through laser scanning or images and reconstructed by 3D modelling software is a complicate task, especially when they have to be created in real time.

Although efficient for helping supporting Disaster Risk Management and Reduction measures, geo-information techniques present challenges and some impediments hamper their application. According to Zerger and Smith (2003), the scale of spatial data is one of the heaviest limitations and its adequacy for decision-making at the regional scale. The multi-scales problem arises for the aggregation or non-aggregation of data within the database. Moreover, implementation failures, user access difficulties, knowledge obstacles, and lack or inaccuracy of spatial data and models are reasons behind the limiting of the use of GIS in Disaster Risk Management, especially in urban zones (Zerger and Smith 2003). Besides all, computational overheads cause problems; these geo-information techniques often gather a huge amount of data that requires super computers to be treated completely and accurately. Unfortunately these super computers aren't always at reach of all governments and stakeholders due to their extremely high cost and reduced economical sources. The lack of expertise were slowing down the evolution of GIS in the field of DRR in past years, but these problems seems to be solved.

Unfortunately, concerning the application of geo-information technologies in DRR/M actions is hampered due the varying developmental status of countries. Developing countries, like Lebanon, are in particular need of help and assistance to fill gaps they face in their scientific capacities, institutions, expertise levels and data. The main data gap lies on the exposure/vulnerability side, as RS provides cheap and plentiful information about surface conditions. Henderson (2004), through investigation of the risk of NDs in the face of developing countries, stresses that "*lack of information about disaster risk, poor telecommunications,… frequently exacerbate natural disasters,*". Basher reported, after a personal communication with Professor Laban Ogallo, a senior scientist, that the reasons lagging behind this fact are mainly: (1) the constraint of vulnerable groups and nations to utilize accessible science and innovation items attributable to absence of training, questionable quality or even absence of education, and failure to communicate in the language of technical communication (e.g. English or French), (2) limited assets for financing exploration, research and innovation for establishments at all levels, (3) Often inflated cost of science/technological tools, which hinders openness and powerful and efficient application, (4) absence of applicable strategies and qualified institutional structures for science and technologies, (5) the lack of data and observations that may serve as baseline sources for hazard statistical data, exposure and vulnerability and the lack of projections of future situations and scenarios, particularly at local scales, (6) and lack of pluri-disciplinary approaches that may serve as linkers between DRR climate change responses and sustainable development (Basher 2013).

While developing countries are fertile grounds for geospatial information causality mitigation measures, it is recognized that in these countries disaster-risk management and emergency response communities do is not take full advantage of geo-information techniques.

The latter process is due to the fact that effective use of geo-IT under all aspects of the disaster reduction cycle demands access to data, tools and know-how's . When data and data products become accessible and the ability to build or explore resources becomes present, countries, as well as national or international organizations will be able to create space-based products adapted and modified to their individual needs and conditions. But weak governance structure when it comes to DRR, emergency response and management is found most importantly to the management of geographical information in general. More precisely, in terms of information, the core datasets are either completely missing, incomplete, inaccurate, poorly organized, not accessible or not shared at all. Those responsible of both DRM and emergency response efforts may at the moment not acknowledge the reliability of space-based information, as translated by the absence of policies or regulations enforcing use of such information. Further, practitioners might not be aware of the location or the know-how to access spacely-derived data. In addition, even if disaster managers acknowledge the importance of satellite-technologies and know the methods to access such data, they might not necessarily possess the required capacities and skills, to extract the useful case specific data. The massive capability of the programs involved in GIS make it difficult to learn without a formalized class. Finally, they also might not possess the necessary techniques, hardware(s) and/or software(s) to access and process acquired data due to the high cost. It is here noteworthy that absence of the capacity to effectively make use of relevant technology is a societal factor that aggravates disaster vulnerability.

However there are some limiting factors and potential barriers that hinder the potential of data to assist disaster reduction. These limitations usually include data condition, quality and reliable metadata, multi-user databases, not-updated data and low image resolution. The reuse of data in new applications is very often a difficult task. We often ignore the quality of archived or input information, its structure and representation, when does it refer, what scale is used. These doubts are due to unclear semantics of data, diversity of datasets, the wide array of existing systems in terms of concepts used in modeling of data, data encoding techniques, storage structures, access functions, etc. Some data requirements are then necessary:

- Data quality and accuracy: The importance of fine resolution of spatial data as inputs for GIS applied in DRM cannot be underestimated. The successful use of GIS strongly depends on data quality namely spatial precision, the characteristics of the attribute data, and by the formalities of data transfer (Coppock 1995; Herold and Sawada 2012).
- Data standardization: Data is extremely heterogenic and diverse which ultimately requires a huge work to standardize these schemes. Data sources must have standardized formats, consistent structures and schemas, stable and reliable release procedures to be easily interoperable and integrated for Emergency Management in an automated fashion. Goodchild, 2003 p.100, interprets interoperability of geospatial data in this context as *"the ability of systems to exchange information, based on the shared understanding of meaning (semantic interoperability) and mutually agreed formats (syntactic interoperability)."* Standardization must happen at all levels, from coordinate systems and map projections, to scale and resolution. Spatial Data Infrastructure (SDI) is crucial to adopt standards, along with improving easy data access, gathering, integration and sharing.

- Data update: The majority of data needs shown previously in **Erreur ! Source du renvoi introuvable.** is dynamic and not static. This data, not remaining valid for a long time, needs to be periodically updated. The time scale required for updating dynamic varies from the hourly to daily (e.g., meteorological data and its effect on hydrology), to monthly even yearly for mapping or integrating land-cover and land-use data. Land-use information should be cautiously interpreted, since it is this is at the interface of environmental factors and elements at risk. At the environmental scale land use is able to determine the occurrence of new events (such as forest fires, landslides, and soil erosion), while presenting itself assets at risks of hazards.
- Scale requirements: Scale also is a limiting factor governing spatial data. Most often data is available at large scales (national) and derived from smaller-scale sources. Such "coarse" data is often non appropriate for use at finer scales such as regional or local use for a variety of reasons, including locational inaccuracy and a lack of attribute information (Herold 2012). For accurate risk assessment, the establishment of spatial databases should be "built bottom up from the lowest administrative unit in country; top-down methods are less accurate". Concerning hazard assessments, these can be performed at different scales, via an array of spatial resolutions. The study area, the aim of the assessment, the type of studied hazard, and the operational scale at which these hazard processes start and manifest themselves (Van Westen 2013), available data and resources, and the needed accuracy determine the geographic scale which in turn effectively governs the cartographic scale at which data will be mapped. Details about this range of scales are represented in Table 2-2.
- Images resolution: High resolution is required to create digital datasets of elementary, yet fundamental information for disaster management. Most often, Google Earth and ESRI base-maps (with resolution of 1m or less sometimes in big cities) and Landsat or ASTER imagery (at 15-30 m resolution) are public and readily available, especially for developing countries. High image resolution is essential for the tracing linear features such as roads, railways and waterways… and generally all ground spatial features.
- Metadata: Metadata's importance arises especially when used in prompt situations, like for response, and shared among ministries, organizations, etc. Metadata records document and clarify the who, what, when, where, how, and why of a data resource; thus enhancing any processing.
- Geospatial data licensing and legalization: Laws are a must in order to set responsibilities, liabilities and the respective tasks of intergovernmental organizations and commercial and private firms (Von Der Dunk 2005) surrounding the use and share of spatial data.

Table 2-2 Scales related to hazards types with indication of basic mapping units. Indicated is the applicability (+++=highly applicable, ++=moderately applicable, and +=Less applicable). Adapted from : Van Westen (2013)

Scale	Level	Cartographic scale (million)	Spatial resolution	Area covered (Km²)	Hazard type					
					Earthquake	Drought	Storm	Flood	Landslides	Wildfire
Small	National	0.1-1	0.1-1Km	30-600 (thousand)	+++	+++	+++	+++	+	++
Regional	Provincial	0.05-0.1	100m	1000-10000	+++	++	+++	+++	++	+++
Medium	Municipal	0.025-0.05	10m	100	++	++	++	+++	+++	++

Scale	Level	Cartographic scale (million)	Spatial resolution	Area covered (Km²)	Hazard type					
					Earthquake	Drought	Storm	Flood	Landslides	Wildfire
Large	Community	<0.025	1-5m	10	++	+	+	+++	+++	+

3. Mapping

One of the first uses of geo-information techniques is the cartographic presentation of results and elaboration of maps; mapping hazards, mapping exposures, mapping vulnerabilities, mapping risks, mapping evacuation plans, etc. is not possible without geo-information technologies. Manche (1997) declares that through GIS, we are henceforth able to develop a risk mapping that truly takes vulnerability into account. The elaboration of expressive and accurate maps have tremendously helped in reducing losses from natural disasters. Monmonier (1997), in his book entitled "Cartographies of danger: Mapping hazards in America", suggests that while a picture reflects a thousand words about risks, a map can say a million. Maps are achieved aiming to assess and communicate natural hazards, their potential location, their intensity, their occurrence and their potential damages. Maps are used as a heuristic tool to engage stakeholders invest in DRR and to elicit local knowledge by raising awareness and to support the identification of integrated prevention measures (Douvinet, Delahaye, and Langlois 2010) and to develop adaptation strategies. Beck and Kropp (2011) highlight the significance of mapping strategies and their results for risk governance. DRR and GIS mapping tools are also being used for investment purposes. Deutsche Bank AG's asset-management unit consists of utilizing a detailed map to determine where natural disasters triggered by climate change may impose the heaviest risks to its investment portfolios**.** Maps can reveal how heat waves, wildfires may affect the operational course of action; Deutsche Asset Management utilizes data from Four Twenty Seven, a California climate advisory firm that performed the mapping task of more than 1 million corporate, manufacturing and retail sites globally to gauge companies' exposure to hazards such as hurricanes, heat waves, floods, droughts and wildfires (Janssen 2017). The maps can show the way heat, wildfires and rising sea levels may affect operations, quantify demands on natural resources from corporate supply chains and predict how weather events could influence consumer behavior in particular countries. Heat waves, for example, can increase energy costs, cause power outages and hurt productivity because workers are more stressed in high temperatures, according to the report.

Maps have a rich history in DRR, long before the development of digital data and computerized GIS, and a long-standing role, considered as one of the main geospatial tools (Hodgson and Cutter 2001; Monmonier 1997). For instance, in 1968, in order to determine the National Flood Insurance primes for the properties located in high-risk flood areas, the Federal Emergency Management Agency's (FEMA) began Flood Hazard Mapping. The primary service confined by maps is offering the understanding the geographical context of a disaster (Tomaszewski 2014), as they report the basic *"who, what, where, why, and how aspects of a disaster situation"* (Tomaszewski and MacEachren 2012, p.2). The term risk mapping is even sometimes confused with risk assessment and analysis. This is related to the fact that maps are often the main deliverables of risk assessments; without maps risk assessment would be "spatially blind". Seeing spatial relations and location of assets is important for understanding risk. Despite the fact that risk maps are viewed as the definite result of all risk investigations, and ought to be the primary resource looked for under any risk decision-making/assessment, based on Peggion, Bernardini, and Masera (2008) the whole cycle of DRR can benefit from cartography and geographical representations. Maps can serve before, during and after crisis.

Maps made before crisis, resulting from risk assessment, are crucial for the rest of DRR cycle, serving mitigation, preparedness, response and recovery measures. These maps are considered to have two key important roles. The first role is to serve as visualization/display tool and the second one as communication/dissemination tool (Monmonier 1997). Maps are the basis to assist visual thought processes and analysis by displaying the geographic areas that may be possibly affected or threatened by crisis, shelter location, the nearest rescue services, population at risk, damaged roads, etc..., all without having to read large volumes of information. Moreover, information about hazards and disasters is commonly disseminated through maps. In fact, maps help for communication and wide dissemination of findings for raising awareness, preparing, training and engaging all interested actors, decision makers, emergency managers, NGOs, and the public in a society and root a risk prevention culture. To serve visualization and communication, maps often share the same symbology with a given set of colors to describe different danger levels.

GIS are best positioned to serve the visualization and dissemination roles of maps. GIS allows the mapping of all risk-related data thus transposing it into visual information (Thomas, Ertugay, and Kemec 2007). GIS capabilities of visualization and creation of tactile experience, through data synthesis and mapping, have showed key importance for policymakers, disaster managers. Performing a quick graphical sensitivity analysis of the factors affecting the risk potential is feasible from the outputs of a GIS analysis of risk often taking the form of zonation maps where areas are sub-divided into different zones of roughly homogeneous risk. Beside visualization, GIS serve dissemination by enabling policy makers make information public with its ability to show as much details required for public understanding. This offers people even outside the scientific community the opportunity not only to understand what is going on but to interact by offering informative feedback, given its importance to policy-decision related processes and analysis. After years of establishing hazard and risk maps in isolation without input from the intended audience, the public can now even participate to mapping supported by GIS that allows collaborative and participatory approaches to planning (Mccall and Dunn 2012). This is called “Participatory GIS” (PGIS). PGIS, involving communities, has been proved to contribute to more accurate hazard and risk.

Whether totally conducted by experts or following a participatory approach, risk assessment mapping has considerable impacts on communities and societies. It can in the process become an instrument of solidarity for building societal resilience or a source of conflict. The example of Xynthia storm, discussed previously in Chapter I, demonstrates how zonation mapping can be a source of inconvenience and disagreement among citizens. Although maps show the results of risk research, they inherently contain complex information that includes uncertainties. In the case of the Great East Japan Earthquake (GEJE), hazard maps wrongly created before the event, possibly have given people a false sense of security through underestimation of the disaster’s potential impact (Stein et al. 2012). These uncertainties scare stakeholders and the public in general, especially when material interests are involved. Furthermore, sometimes maps do not communicate their message effectively. In his book entitled “cartographies of danger”, Mark Monmonier shows that maps, besides giving important information about hazards and risk, can also be dangerously misleading. The Northridge earthquake in January 1994 was a good example showing that even reliable seismic-hazard maps can be deceiving if misinterpreted; The public focused only on represented fault-lines as vulnerable areas (Monmonier 1997). In addition, map design and target audience are both often ignored, which may hinder correct access to the displayed data. When creating hazard and risk maps, not just scientific findings and understanding should be considered but also people's perceptions of risk, their map reading skills and how risk can be reduced. This effective understanding, perception and usage of maps calls for multidisciplinary engagement. Appropriate choice of colors is an important factor in the cartography risk requiring to be expressive to effectively express the spatial variation of risk and accordingly transmit the danger (Seipel and Lim 2017; Silva, Madeira, and Santos 2007). As shown in Figure 2-2, effective hazard and risk maps should bring together elements of science, technology, and design to improve the functionality of the end product.

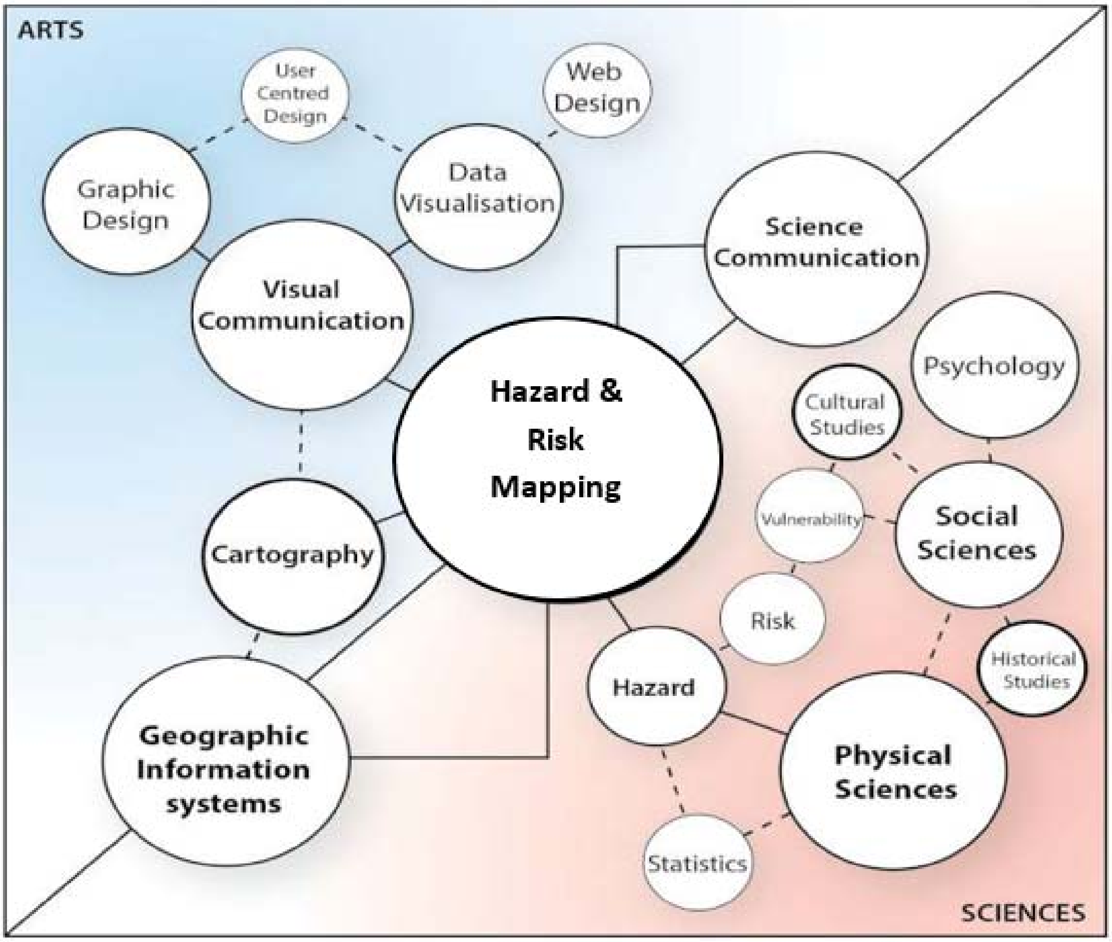


Figure 2-2 Interdisciplinary approach for creating hazard & risk maps. Adapted from Charlton (2018).

4. Role of Geospatial Technologies in the DRR cycle

Beyond maps, GIS have spatial analytical capacities like spatial modelling and simulations. Natural phenomena are foreseeable but not always predictable. In contrast to prevision which is simply an expert view, prediction involves a deterministic mathematical tool. These tools are often based on geo-information technologies for inputs, and complemented with science for process modelling. Moreover, the methodology of risk assessment highlights the importance of research on epistemic and random modeling issues and uncertainties. For many natural phenomena, an approach combining observation and modeling (deterministic and probabilistic), through the assimilation of data, makes it possible to considerably enrich the understanding of the processes that govern their dynamics. In few words, based on geo-information technologies sophisticated computer models can now replicate what knowledge we have the Earth physics, its weather systems and the behavior of all its elements. GIS is particularly useful for integrating modelling results in time and space, for assessing exposure and risk and for assisting remedial decision-making (Abdallah 2007). GIS allow decision makers and users in general, to interactively integrate with the geographical dimension of a disaster. They are claimed to be multi-scaled, and this specificity avoids an overly large census of data (Manche 1997). Thus, GIS serve as exploratory tools in the search for spatial combinations to approximate the overall risk (hazard, exposure and vulnerability) of each territory. Multi-hazard and multi-risk approaches are even easy to tackle and elaborate with geospatial techniques and modelling processes. Moreover, the speed and ease of setting up representations make GIS tools indispensable in Disaster Risk assessments.

Since each phase of the DRR cycle is geographically related to the spatial-location of people, places, and assets (Gunes and Kovel 2000), the entire disaster reduction process can be significantly optimized through effective implementation of GEO-IT. Hussain et al. (2005) , in
Figure 2-3 incorporate GEO-IT into the disaster management cycle to stress the central role it plays during all phases. GEO-IT provides the essential mean for estimating and mapping risk, planning evacuation routes, determining suitable zones for shelter installation, identifying/attending disaster victims, and assigning or distributing resources during recovery, among many other essential tasks (Goodchild 2006).

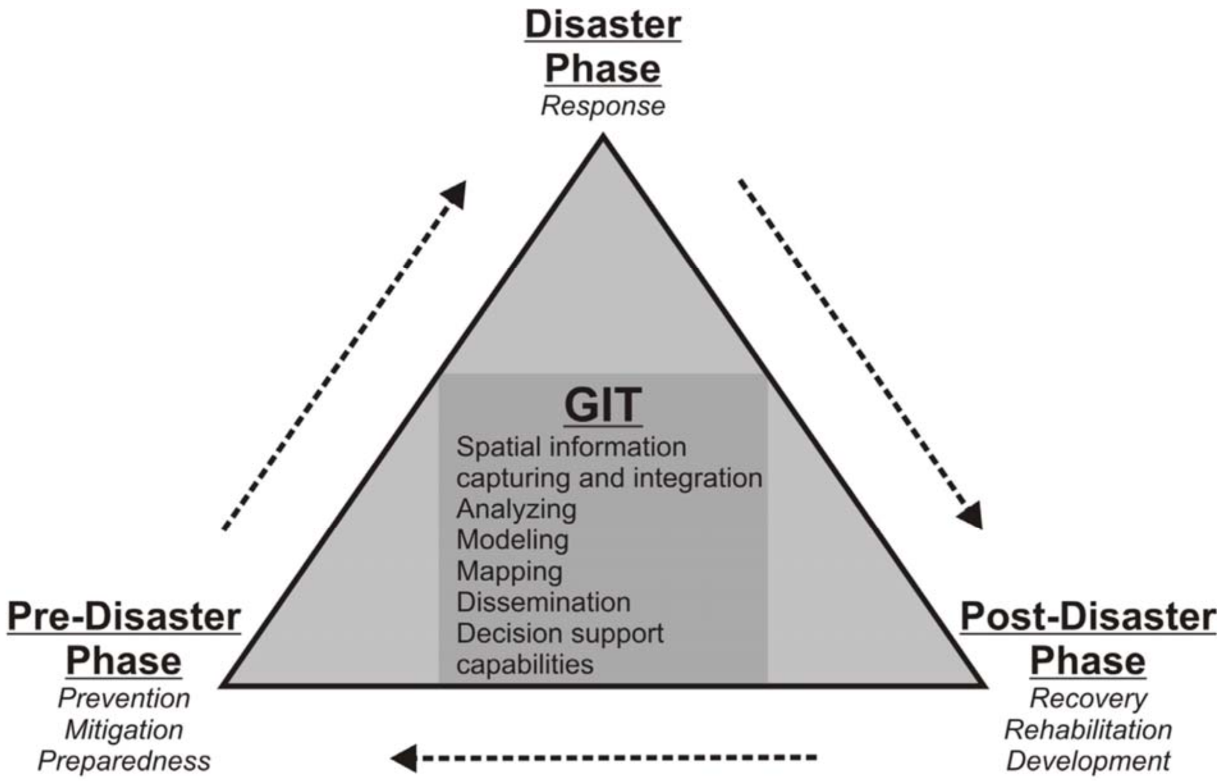


Figure 2-3. Disaster Risk Reduction cycle integrating GIT (adapted from (Hussain et al. 2005)*)*

4.1. Prevention Phase

Disaster prevention and mitigation consist of intensive planning to reduce risks and long-term activities to reduce the degree of risks on human lives and properties. This stage is a stage for removal, control, or preventing disaster triggering factors. The complete removal or avoidance of hazard being not feasible, all efforts are turned into that of lessening exposures and/or vulnerabilities through mitigation actions. The main aim of the latters is to minimize either the impact and/or likelihood of the risks to life and property and prepare for it in advance (Godschalk et al. 2000). These pre-disaster set of measures, also known as “corrective risk management” or “prospective risk management”, fall into two broad categories; structural and non-structural mitigation. Structural measures include physical constructions, engineering standards, evacuation shelters, building code enforcement, design/construction of damage resistant infrastructure. An excess of these measures is not encouraged; they are claimed to require maintenance works and not to keep pace with the ever-changing environmental and socio-economic conditions. Non-structural measures, known as “soft” measures, can be summarized to research and risk assessments, policies, land-use zoning/regulation/planning/management, building codes and their enforcement, insurance measures, public awareness raising, training, communication and education to risks, business continuity planning. The most efficient disaster risk reduction plan should organizationally combine structural and non-structural measures.

4.1.1.Risk assessment

Risk assessment is the overall process that allows to identify, analyze and evaluate the risk by taking into account the extent and the impacts of several potential natural hazards considering the communities' exposures, vulnerabilities and coping capacities (Hill, Sparks, and Rougier 2011). The basis of a concise risk assessment is that risk is location dependent and can only be assessed when geo-location specific data is available. Most of the data required for risk assessment and DRR measures has a spatial component, and is also changing over time. Therefore the use of GIS and Remote Sensing has become essential in risk assessment and DRR measures. Moreover, risk assessment process generally relies on numerical models and scenarios supported by GIS analysis tools to estimate occurrence probability of an event with its degree of intensity in a given site and to project several scenarios. GIS also offers graphical representations, of the risk assessment outputs, useful for the whole DRR cycle.

a) Hazard assessment

Risk assessment starts with hazard determination; Hazard assessment and analysis can be used to analyze and map hazards delineating prone areas and their corresponding susceptibility levels. Natural hazard research aims to understand the processes behind hazardous events, estimate their probability of occurrence and their precursory signs, as this understanding is the first necessary step in anticipating the occurrence of such events and lessening their impact as much as possible. Natural hazards vary greatly in terms of frequency, duration, scale, impact, etc., and these partly dictate the spatial data and technology needed to effectively reduce, prepare for, respond and recover from potential disasters which may be induced from their occurrence (Herold 2012).

Hazards can be classified in several ways; depending on their source, these can be subdivided into natural, human-induced and human-made/technological (Montz and Tobin 2012); a second more detailed subdivision is according to the main origin of the hazards separating them into geophysical, meteorological, hydrological, climatological, biological, extraterrestrial and technological hazards (Guha-sapir et al. 2016) or in a more simplified way into biological, geological, hydro-meteorological and technological hazards (UNISDR 2009a). These classifications are sometimes unclear as some hazards could be grouped in more than one category. Moreover, these are not the only possible classifications of hazards. Assessing hazards is based on knowledge of natural phenomena and on predicting geospatially how much intense the hazard is expected to occur with a probability within a period of time. "*The fundamental determinants of natural hazards are location, timing, magnitude and frequency,"* (D. Alexander, 2000, p.7). The spatial scale and duration of natural hazards can vary greatly, which is important from a GIS perspective, and in particular from the perspective of data requirements. The study of hazards has important spatial components, therefore an additional classification of hazards could possibly be adopted, especially in a GIS and spatial analysis manner. Some types of hazards can be called "deterministic location hazards" as they are restricted to specified geographical regions and both their initiation and their run-out or spreading vary spatially in a predictable manner. This type of hazards have their prone areas known in advance. GISs and RS permit the integration and manipulation of spatial layers to analyze spatial patterns of hazard occurrence and to derive risk at different levels with a margin of uncertainties. For instance; Landslides occur in specific hilly and mountainous regions and have a local well defined and determined zone of impact (Abdallah 2007); Major floods can affect a large region limited to the flood plain; whereas storms, forest fires, heat waves, cold waves, and drought have indeterminate location and spreading over space and it is difficult to predict in advance which site will be affected. Hazards with uncertain place of initiation and diffusion are called "stochastic location hazards". These hazards can occur anywhere; Therefore, early warning systems and DRR measures still lack of means to predict the exact place of occurrence of these hazards and accurately prepare for. This has consequences in terms of DRR. For example "deterministic location hazards" lend themselves well to structural measures (e.g. embankments, construction of landslides barriers, retainer walls). While for "stochastic location hazards" structural measures cannot really help. "Semi-stochastic location hazards" are those hazards with specified general location but uncertain place of occurrence. Earthquakes occur along active tectonic-plate margins but one cannot predict where will a specific seismic event happen; Storms can also occur in several zones at unpredictable times; It is noteworthy that the role which GIS plays in hazard assessment is specific to the type of the hazard and thus differs from a hazard to another. Probabilities (return period) can be established for all these types of hazards, but this is not enough to define an indisputable "hazard zone". For instance, the US Public Insurance policy subsidized the "100-years floodplain" in the National Flood Insurance Program (NFIP). But, probability estimates become obsolete for the calculation of insurance premiums when they are modified by external changes such as climate change. For example, sea-level rise aggravates the probability of marine submersion in the event of a storm.

Moreover, hazard assessment is based on mathematical and numerical models. Two ways exist for hazard assessment; analyzing and mapping physical conditions that make an area more susceptible to hazards and mapping the history of hazards (retrospective assessment). The best would be a combination of both methods, since a hazard could happen where it has never happened before (UNISDR 2015a) especially with climate change. GIS enable geospatial thematic information extraction of the morphological, topographical, geological, soil and water features concerning the phenomenon. RS contribute to information extraction; a visual interpretation of hazard phenomena is possible through GIS by analyzing and mapping (converting raster to vector data layers) of very-high resolution imagery like QuickBird, IKONOS, WorldView, GeoEye, SPOT-5, Resourcesat, Cartosat, Formosat, ALOS-PRISM, etc. (Ren and Zhou 2012). Using relatively simple hazard modelling steps that consist of weight assignment to each data type extracted (to represent varying significance) and the use of functional overlay, or even more complicated procedures like multivariate statistical raster analysis or two-dimensional numerical model, GIS create maps depicting hazard prone zones with probability of occurrence. Hazards susceptibility is usually calculated and visualized through GIS as a continuous (raster) data which is then classified into several classes for ease of interpretation. GIS and RS can also provide a historical insight through time series that contribute to assess the likelihood of future events, such as the extent of historical events over a given area. Once hazards have been identified, an established representation can subsequently and adequately stored in GIS databases. The result and deliverable of a hazard assessment are often hazard zonation, revealing hazard footprints and which subdivides the land into more or less homogenous hazardous zones with the same level of hazard. Such maps, also called susceptibility maps, indicate the hazard's spatial probability with a certain intensity and provide a way of comparing different administrative areas (for instance villages, districts or governorates). More efforts and historical data are needed in order to provide information on the temporal probability of the hazard (frequency, return period and relation with intensity/magnitude).

b) Exposure

Natural disasters are social phenomena and hazards without elements at risk do not turn into risk or disasters. If an area is prone to a hazard but there exist no people or infrastructure, then risk of disaster is non-existent. Unfortunately, often hazard prone zones present many benefits like a fertile soil, easy water supply, beautiful scenery, etc. For this reason, people tend to build their houses, touristic facilities, industries, commercial areas, infrastructure, farms and croplands in these zones. It is important to evaluate and map the exposure to hazards implying the people, properties, essential facilities, infrastructure, activities, economies, environment, etc., location in hazard-prone areas. Some of the assets, having a specified location and being static, remain fixed in space like buildings; others are dynamic and vary in time and in space like people. Elements at risk are the basic spatial units for risk assessment and exposure is a key factor of any risk assessment employing GIS for supporting mitigation, preparedness, early warning & response.

Exposure is directly linked and even determined by geographic location of the asset. In general terms, top-down and bottom-up GIS approaches (combining RS and statistical modelling) are used to define and map exposure. These methods have proven to be particularly useful in developing countries which lack accurate data collection resources. Data of different natures related to exposure can be obtained via GIS and RS as important inputs, such as the land occupation pattern and the distribution of socio-economic units in prone areas (Masek, Lindsay, & Goward, 2000; Islam & Sado, 2002; Jain, Saraf, Goswami, & Ahmad, 2006). The spatial interplay between the assets at risk and hazard footprints are detected in a GIS by simply by using the latter's capacity to overlay hazard and elements at risk maps. The overlay operations are easily effected by GIS, which makes it possible to quantify elements-at-risk and associate graphic data and attribute data, in a simple, dynamic manner. For instance, exposure maps can reveal the geographical position of buildings, their specific attributes, size, type of use and number daytime and nighttime, even seasonal population distribution, in hazard prone areas. Exposures can also be measured and visualized with different indicators varying with spatial aggregation schemes; For instance, the density of exposed assets measured as the density of exposed assets per surface unit (km^2) and the ratios of exposed assets which represent the share of exposed assets compared to total amount of assets in a specific spatial unit (i.e. administrative unit, grid cells, etc.) (Röthlisberger, Zischg, and Keiler 2017).

On contrary of tangible elements mentioned above, intangible elements are difficult to quantify or map, as they do not have a particular spatial dimension (Van Westen 2013). The cultural and historical values, the livelihoods of communities, psychological conditions, sociological behavior, etc. are all elements that cannot be analyzed utilizing geospatial tools, despite the fact that they may be severely impacted when a disaster strikes.

c) *Vulnerability*

Since by definition hazards cannot be controlled, it is by strengthening the assets and people that it becomes possible to control the risks. Strengthening assets and people means decreasing their vulnerability and enforcing their coping capacity. The assessment of exposure alone is not enough; an element may be exposed but not necessarily vulnerable and thus, not at risk of damage. Moreover, two elements may have similar exposure level but one may endure more damage because of its higher degree of vulnerability. Some people are more vulnerable to natural disasters than others; these include young, elderly, dysfunctional people, and generally "poor" people. Even access to information, science and technology are vulnerability parameters. Vulnerability is multi-faceted (Ebert, Kerle, and Stein 2009) and its concept is complex. Assessing and understanding vulnerability is a necessity for any risk assessment, often enhanced with demographic, social, structural and economic criteria. But yet, according to Simpson and Human (2008) no unique conventional method to assess vulnerability to natural hazard.

Geo-IT is used for vulnerability assessment, since spatial location sometimes directly affects vulnerability (S.L. Cutter, Mitchell, and Scott 2000; Weichselgartner 2001). GIS-based studies that assessed vulnerability exist though it has been claimed that there is a "*void in the literature on spatial analytical approaches to vulnerability assessment*," (Cutter 1996, p. 530); Clark et al. (2012) analyzed the link between vulnerability and land use, along with transportation infrastructure; Rashed and Weeks (2003) considered the physical conditions as indicative of the social conditions which themselves influence and even determine the spatial distribution (social segregation/marginalization); Westen and Hofstee (2001) used GIS and RS to build a spatial database consisting of buildings, land parcels, roads and other infrastructure through on-screen digitizing aerial photographs; Cutter, Mitchell, and Scott (2000) reported how GIS can be used to integrate, in spatial terms, both biophysical and social factors which combine to exacerbate hazard vulnerability.

Many factors that determine physical, social, economic, and environmental vulnerability are spatially variable making vulnerability adequate for assessment via GIS. According to Tobler's First Law of Geography *''everything is related to everything else, but near things are more related than distant things''* (Tobler 1979); this law directly applies to physical and social vulnerabilities and can be statistically investigated through spatial data analysis. Thus homogeneous units exist; these are mapping units that have more or less the same characteristics in terms of elements at risk. For instance the same land use type or the same building types. Criteria such as age categories (schools, elderly housing), gender (sex), ethnicity and socioeconomic status are generally sought to be influential components for social vulnerability (Cutter, Boruff, and Shirley 2003), and these characteristics have a high degree of spatial variability, particularly within large urban areas. These social criteria influence physical and economic vulnerability too. Such information are typically collected by performing a census, and then can be processed, manipulated and studied by assigning weights and combining them using spatial multi-criteria evaluation and mapped at varying scales.

Critical infrastructure protection and assessing their vulnerabilities can be facilitated by GIS since the latter provides an insight to the spatial interdependency of these factors (Espada, Apan, and McDougall 2015; Kulawiak and Stepnowski 2010; Wolthusen 2005). Road network, energy network and water network can be studied and analyzed revealing the critical nodes through network analysis. Critical nodes are those with highest levels of vulnerability, because their cut off the network would cause much larger effect on the whole network and even a cascading event.

d) Damage and loss

Geospatial systems can even help to determine the damage of natural disasters. Leone et al (2007) elaborated a method for spatial analysis of 2004 Tsunami damages on buildings in Banda Aceh, Indonesia, using GIS and photographic interpretations. This method was supported by fieldwork and surveys; some interpolations were necessary and were therefore done carefully by kriging method using Vertical Mapper. A "macro-tsunamic" intensity scale of 6 degrees was elaborated based on buildings damage, and correlated with the height of submersion, which led to the establishment of potential tsunami losses scenarios. Relevant results have been revealed and most importantly, inspired other applications to be treated in Tsunami potential damage modelling (Leone et al. 2007).

Targeted damage and loss assessments are with reference to potential future events (ex-ante), knowing that damage may also be carried out in the aftermath of an event (ex post) (Meyer et al. 2013).

Risk assessment essentially aims at evaluating several aspects of disaster damages and resultant human and material losses. Loss estimation potentially increases the effectiveness of risk assessment, and is even considered indispensable part of proper risk assessment. The success of risk assessment depends upon the correct evaluation of the cost of elements at risk. Translating the impacts of hazards into human loss and economic costs could be extremely useful in telling people about the extent of the disaster and persuading them later on, with cost-benefit studies, of the importance of DRR and preventive measures in particular (Meyer et al. 2013). In other words, Quantitative estimation of potential damage and loss from natural hazards has shown to bring natural disasters into the public eye and to inform the appropriate actions and measures to be taken (Kron et al. 2012). Although estimating losses was originally designed for reinsurance business purposes, it has been proven efficient for studying catastrophic events, hazards, their intensities and potential damage. Moreover, according to Bendimerad (2001) ,assessing the potential damage and losses from a hazard serves a lot in allocating resources and planning for emergency response. The various consequences of a natural event are generated by the complex interaction of several factors, all needed to be thoroughly studied for reliable loss estimation.

Damage and loss assessment require high resolution spatial data. Most data and information in damage estimation are closely related to geographic coordinates describing the location on the ground; for instance land use/land cover, buildings, crops, etc… (Tapia-Silva et al. 2011). Furthermore, asset values are often related to their geographical location, for example average economic value of residential spaces or crop price in a given village. Given that damage is local and hazard and exposure data are associated with spatio-temporal variations, catastrophe loss estimation models are often built under geospatial analysis environment (Chen et al. 2004). The following estimation of losses can be done through a specialized computer based modelling approach, using GIS and RS techniques (Chen, G.-P. Li, et al. 1998). This modelling, via statistical functions available in GIS systems, is capable of simulating physical and economic damage/loss estimations under different hazard impact scenarios. Past events loss data are needed to calibrate and validate the potential loss estimation models.

Different GIS-based methodologies exist for damage assessment (Chen et al. 2005; Rivereau 1995). Comprehensive Approach for Probabilistic Risk Assessment (CAPRA) is a GIS platform in which probabilistic assessments of hazards are made and then combined with exposure and vulnerability data, allowing the evaluation of probabilistic losses on exposed elements (Quijano et al. 2015). The WorldRisk is a GIS-based application program which aims to analyze and determine the global seismic loss (Chen, G. P. Li, et al. 1998). FEMA’s HAZUS software, based on mathematical modelling through GIS, estimates multi-hazard losses of life and property with visualization on map.

4.1.2.Assessing critical infrastructure

GIS also facilitates CI and network analysis and thus makes easy to study and understand the complexities of the infrastructure networks and their interdependencies. Cova and Church (1997) modelled the transportation network in order to help evacuation operations, all in a GIS context. Of course, the ease of these technologies should not be misleading. Models have to be confronted to facts, and if a model fails to simulate the reality, it has to be revised or even entirely discarded. The difficulty with predictive models is to assess their accuracy with retrospective observation.

Generally speaking, Critical Infrastructure (CI) refers to physical and information technology facilities, networks, services assets that are necessary for proper functioning of a society and its economy and if disturbed or damaged, would have considerable effects on the health, safety, security or economic well-being of citizens or the effective functioning of governments (Gordon and Dion 2008). No concise definition of CI exists and what Infrastructures are counted as "critical" differs from country to country, depending on their concerns on safety, security, and wellbeing (Fekete 2011; Fulmer 2009; McBain, Wilkes, and Retter 2010; Moteff and Parfomak 2004). CI are categorized into: 1) Utility services (Energy and water, telecommunications and transportation), 2) Welfare and social systems (schools and hospitals, monuments, banks, financial institutes, etc.) and 3) Administrative and emergency service buildings (first-responders centers, police stations, EWS research centers, etc.). What elements are mostly considered for CIs is relative to the scale of the CI analysis, the type of hazard considered and the purpose of the CI analysis. Another approach might be to consider any infrastructure required to disaster response as critical.

Natural hazards, disasters and CI are closely linked to each other. Natural hazards turn out into humanitarian disasters when they aggravate human vulnerabilities that mainly range from very concrete weaknesses in infrastructure (Blaikie et al. 1996). Failure of critical infrastructure systems are often the reason a hazard becomes a disaster. CI, as mentioned before, is a general term that refers to an array of engineered systems, assets and facilities that are key for everyday social and continued economic functionalities during and in the resulting consequences of a disastrous event (Bach et al. 2013). During times of crisis, the resilience of CI networks is a crucial element for first responders. It is also the right of the population to be provided by electricity, water, fuel and transportation in time of crisis, which may play a huge role in survival. CI plays a fundamental role in the recovery of societies from disasters and even the recovery process starts by fixing damaged CI. Thus, CIs are considered "critical" because their damage, destruction, outage or disruption, may have adverse effects for disaster response, national defense, economic security, well-being, public morale or public health and safety of part or all of citizens over a long period.

CIs "criticality", especially during natural hazards' occurrence, is linked to their intra-dependencies and interdependencies. Infrastructure systems do not operate in isolation; dependency is defined as the reliance by one piece of infrastructure on a service provided by another and exists on the scale of one network when components interact inside each single infrastructure (intra-dependency) and an the larger scale of how different CI networks interact and rely on each other (interdependency) (Pederson et al. 2006). Many different types or classes of intra-dependencies and interdependencies were defined by authors; input (system requires input from another system) and mutual (at least one infrastructure operation relies on others) by Wallace et al. (2003), logical (states depends via control mechanism), geographical (elements are in close spatial proximity), cyber (states depends on information transmission) by Rinalidi, Peerenboom, and Kelly (2001), physical (operation on one depends on output of other) by Dudenhoeffer et al. (2007) and Rinalidi et al. (2001) and Zhang and Peeta (2011), functional (operation of one infrastructure system is necessary for the operation of another infrastructure system (Ouyang 2014)) by Zhang and Peeta (2011) and Zimmerman (2001) and spatial (referring to proximity between infrastructures systems) by Zimmerman (2001). For instance, damage in a number of roads can contribute to loss of connectivity for the entire road network, energy and water infrastructure have a high level of interdependency; electricity needs water for cooling and production whilst water needs electricity to pump into networks; gas stations need power to pump fuel, the lack of fuel access creates challenges with evacuation and search-and-rescue efforts. Transportation (roads, bridges, tunnels in particular) and energy networks have proven to be the most important elements of CI during major disasters, i.e. Hurricane Maria in Puerto Rico, Harvey in Houston (2017), Sandy in NYC and New Jersey (2012), Katrina in Louisiana and Mississippi (2005) (National Research Council (U.S) 2011).

Mutual dependence, intra-dependency and interconnectedness are considered to increase the vulnerability and criticality of an asset, a network or a society and reduce the resilience. CI resilience is defined as the joint ability of a system to resist (withstand in this case) hazards, absorb the initial damage, and recover to its normal state (Ouyang and Dueñas-Osorio 2012; Ouyang, Dueñas-Osorio, and Min 2012; Rao, Krueger, and Klinkhamer 2017). In other terms, resilient CI must be robust, redundant, resourceful, and capable of rapid response (Bruneau et al. 2003). Besides reducing CI resiliency, dependencies are considered to constitute a risk multiplier: they can turn CI themselves be a threat or hazard, affect their resilience and performance, and lead to cascading and escalating failures. According to Reghezza (2006) 21st century disasters can become more and more complex, involving multiple risk chains, characterized by processes of damage spread and intensification of initial disturbances that transform impacts into time and space. Unknown dependencies and interdependencies often lead to emergencies escalating in unexpected directions through cascading failures, thereby delaying and hampering rescue and recovery efforts and in some instances leading to additional fatalities and economic losses (Kull 2014). The need for understanding of infrastructure relationships and interdependencies is therefore a must for minimizing and reducing cascading failures among complex interdependent infrastructure systems. Evaluation of CI networks vulnerability differs from conventional vulnerability assessments that are conventionally performed by recurrence to empirical methods focusing only on direct economic deterioration (Kappos, Stylianidis, and Pitilakis 1998). Evaluation of indirect and collateral effects of infrastructure damage and outage is the utmost purpose of CI vulnerability/criticality assessments whereas direct infrastructure damages are of reduced significance when compared to the indirect effects of their outage. An example of these indirect effects would be blackouts due to an electricity cut, loss of lives in hospitals due inaccessibility caused by disrupted or destroyed road networks or electricity service interruptions are more relevant than damage to lines, power plants and roads themselves . Thus, more complexities are embedded in CI networks vulnerability assessment than in conventional vulnerability assessments.

All these systemic and geographical complexities and interdependencies of CI, call for spatial data and GIS. GIS is capable to deal with CI complexity and to model systems-of-systems by mapping various CI networks to a core model based on geometric networks, consisting of spatially-embedded labelled graphs (Becker, Nagel, and Kolbe 2011). These GIS methods and techniques are best used in detailing the spatial coexistence and spatial interdependencies of infrastructure sectors. GIS provides a common semantic basis for presentation, analysis, modelling, simulation, visualization, data sharing and several important tools to support CI resilience strategies (Petit et al. 2015). GIS role starts by helping for spatial inventory of CI complex networks, and continues to facilitating their protection and assessing their vulnerabilities (Espada et al. 2015; Kulawiak and Stepnowski 2010; Wolthusen 2005). CI spatial interrelationships, interdependencies and vulnerabilities can be determined through modeling /simulation and can be thus used to perform, GIS based risk assessment modelling approaches. Furthermore, GIS can be used as a planning tool to provide “what if” simulation and situational awareness related to the response of CI to natural hazards. The use of GIS to assess risk on CI can help in the preparation, mitigation and to the response and recovery from emergencies.

4.2. Preparedness and response planning Phase

Preparedness phase involves developing knowledge, capacities and a set of operational plans to proactively foresee, cope with, react, and recoup from the impacts of hazard events (UNISDR 2009a, 2009b). These pre-disaster set of emergency response planning measures, also known as “prospective risk management” fall into emergency planning, EWS, training exercises, simulation and drills, evacuation planning, shelter planning and resources mobilization and delivery planning actions. These measures should be able to deal with a set of different scenarios. During the response phase, for more effectiveness, emergency services and public assistance understand the emergency situation promptly and proceed in connection with outputs of risk mitigation and preparedness phases (Lee 2002), in order to rescue as much as possible, reduce the possibilities of more losses, assure public safety and satisfy the basic subsistence needs of affected populations (UNISDR 2009a, 2009b). Therefore, preparedness and response phases are deeply interconnected especially when it comes to GIS applications.

The majority of preparedness and response planning measures, especially emergency planning, shelters allocation and evacuation routing and planning, involve use of geospatial information and GIS analysis as an important instrument that reveals several areas of effectiveness and an important support for decision-making (Greene 2002). Preparedness is complex and challenging task requiring an integrated approach to heterogeneous spatial datasets like population, land use/land cover, landscape, road network and facilities. Moreover, preparedness options vary spatially, as evacuation zones or shelters assignment can reflect the spatially variable nature of hazard. The performance of an evacuation plan depends on knowing the spatial distribution and allocation of shelters (Sherali, Carter, and Hobeika 1991). Computer-based simulations through GIS can make evacuation process more understandable and serve to complement real-life experiments with a variety of scenarios that may take massive effort to set up. Simulation can also be used as an experimental technique to test hypotheses and conduct scenario-based analyses (Helbing 2012). Indeed, without the contributions made by GIS tools and techniques, this new way of thinking about natural hazard would be virtually impossible (Radke et al. 2000).

4.3. Recovery and building resilience Phase

Recovery phase is the least investigated and most poorly understood of the phases of the DRR cycle (Rubin, Saperstein, and Barbee 1985; Stryker 2011), from the viewpoint of both the research community and practitioners (Rodriguez, Quarantelli & Dynes 2008).

The final stage of the DRR cycle, and the most time and resources consuming (Kates and Pijawka 1977), is the recovery from disasters. This phase compiles activities directly from post-crisis that has occurred till the affected area, its facilities, livelihoods and living conditions are restored and improved to a better and more resilient state. Recovery activities involve local redevelopment planning including local efforts to enhance the pace, location, type, density, design, and cost of redevelopment (Berke, Kartez, and Wenger 1993). While typical past response and recovery programs have been to rush in with disaster relief funds and long term finance programs to rebuild the same structures, build protective infrastructure and restore the same hazard prone areas (Blondel 2010), new concept about recovery emphasizes on its importance in building resilience. Sendai framework points out the recovery is a critical opportunity to "Build Back Better", in its priority number four *"Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction"*. Moreover, one of its guiding principles discusses risk reduction during recovery: "*In the post-disaster recovery, rehabilitation and reconstruction phase, it is critical to prevent the creation of and to reduce disaster risk by "Building Back Better" and increasing public education and awareness of disaster risk"* (UNISDR 2015c).

To build resilience, recovery should include efforts to learn from disasters and reduce disaster risk factors. Some of the challenges during the recovery phase include public education and preventing the recurrence of disaster incidents. An after-action report can be generated to highlight the shortcomings and effectiveness of the mitigation, preparation, and response phases of a disaster event. Emergency management officials use this information to update emergency plans and improve the effectiveness of each phase of DRR. In fact, mitigation activities are often entwined into disaster recovery activities such as in the recovery phase presenting an adequate time for implementation of disaster mitigation measures thus offering insights to reconsider DRR legislation and plans. Hazard mitigation measures are even much more accepted immediately following a disaster (Rubin et al. 1985).

GIS plays an important role in the recovery phase; when wisely implemented, GIS can speed up disaster recovery and rehabilitation processes in an effective and efficient manner. GIS helps with detailed assessment of damage impacts to determine the spatial coverage of damage and what resources concerned areas may require for reconstruction and rehabilitation. Joining this information with census data and land ownership maps, analysts can determine individual losses, in order to determine eligibility for grants and government financial assistance. (Zaninetti 2013a) used GIS to track New Orleans' post-Katrina disaster recovery, revealing that a "second-order" adaptation has taken place through a more inland urban resettlement. After the 2004 Indian Ocean tsunami, GIS was used for of post-disaster assessments and planning and the provision of humanitarian assistance in future natural disasters (Doocy et al. 2007). Moreover, GIS was an invaluable tool helping Indonesian agencies rebuild and repair infrastructure along with more than 100 educational facilities, allowing children to return to school. GIS modeling can also produce better data for analysis and decision making and serves to spatially coordinate activities during the recovery phase. Almost all of the challenges to the recovery phase involve the limitation of financial resources. Emergency management officials must make the most of limited budgets. GIS can be a cost-effective tool for emergency management during the recovery phase (Gunes and Kovel 2000).

Land use planning is a crucial process in DRR strategies (Burby et al. 2000). GIS are used as decision support tools for land use and urban planning. Efficient land use planning cannot be achieved without the use of geo-information techniques which allowed collaborative and participatory approaches to planning (Mccall and Dunn 2012). Moreover, Geo-information techniques allowed the establishment of detailed land use/land cover (LU/LC), which key to highlight the elements at risk. Following LU/LC changes and their spatio-temporal patterns is possible in a GIS context. This following-up allows a better prediction for the changing patterns of natural hazards (Astrade et al. 2007; Nedjai et al. 2016). LU/LC can be observed directly via RS and, ideally, verified and enhanced by field surveys, since not every aspect of land use is visible by RS, e.g. property rights, protection status, etc. Today, earth resource satellites data are very applicable and useful for land use/cover detection. With the invent of RS and GIS techniques, LU/LC mapping has provided a detailed means to improve the selection of areas designed to agricultural, urban and/or industrial areas of a region (Reis et al. 2003). Application of remotely sensed data made possible the study of LU/LC at timely intervals, at low cost and at a higher accuracy (Kachhwala 1985) in association with GIS that provides a suitable platform for data analysis, update and retrieval (Chilar 2000). With advances and fine tuning of high spatial resolution satellite imagery and more advanced image processing and GIS technologies, a switch to more routine and consistent monitoring and modeling of LU/LC patterns was obtained (J.S. Rawat and Kumar 2015). RS has been widely used in updating LU/LC maps and LU/LC mapping has become one of the most important applications of remote sensing (Lo and Choi 2004). Recently LU/LC has become a focal point for sectors such as agriculture, forestry, rural and urban communities since these evolve in response to changing economic, social, and biophysical conditions. LU/LC is one of the principal components for territorial management. Its identification and monitoring are essential in informing agricultural pollution risks, occurrence of soil-water erosion, triggering of mass movements and propagation of forest fires (Abdallah and Kobaissi 2007), and evidentially in informing exposure and natural risks. Deep knowledge of the present land use/land cover is necessary for DRR actions. LU/LC geospatial information serves the DRR process in almost all phases of the cycle, starting by the exposure assessment. Land use is the main parameter to estimate the tangible loss occurring if a disaster hits, based on damages estimated for a typical unit of area for a particular land use category. Therefore, understanding the nature, extent and vulnerability of several land use types in risk zones is a must in this thesis.

As discussed in this last part of the chapter, geospatial technologies have served DRR actions in several ways, starting by prevention, to crisis management, to damage estimation. To what extent and in what ways can geospatial/geo-informatics-based technologies adapted to help DRR actions in developing countries like Lebanon and scaled down at a local level of Baalbek-Hermel Governorate, considered a rural area, where implementation is threatened by population growth, poverty and weak government and many other impediments. All these issues and Baalbek-Hermel's characteristics are to be discussed in the upcoming chapter.

French Summary Part I:

Cette première partie travaille la revue bibliographique. En configurant l'importance des techniques de géo-information et leur utilisation en tant qu'aide pour les actions de RRC, l'histoire des catastrophes naturelles sur Terre a été reprise. Ce chapitre a développé un regard synthétique sur l'histoire des catastrophes naturelles sur Terre, la relation complexe entre les catastrophes naturelles et l'humanité, ainsi que sur l'implication des conditions socio-économiques et l'évolution de la formation des catastrophes naturelles; la relation entre les humains/sociétés et les catastrophes et leurs impacts mutuels ont occupés une place importante dans notre discussion. De plus, les effets des évolutions de l'humanité et de la technologie sur les catastrophes naturelles ont été abordés. Une attention particulière a été accordée à l'évolution des mesures d'atténuation des risques de catastrophe prises par les humains, depuis l'Antiquité, afin de faire face aux catastrophes et de minimiser leurs impacts. En fin de compte, la genèse de la science de la RRC et ses concepts généraux ont été discutés en détail. La gouvernance des risques et les valeurs monétaires des actions de RRC et de DRM ont ensuite été abordés. Ce chapitre a également discuté le statut actuel de la RRC dans la région arabe et au Liban, ainsi que les projets futurs visant à limiter les impacts des risques naturels prédominants. La relation entre les problèmes socio-économiques, les pays en développement, les populations et les atouts en expansion, les États fragiles et les catastrophes naturelles a clairement été mise en évidence. Le sujet n'aurait pas été abordé de manière adéquate sans la discussion des technologies géospatiales et des systèmes d'information géographique, de leur évolution dans le temps et de ce qu'ils apportent à la géographie du risque en constante évolution, en particulier au milieu d'un monde en expansion constante, de vulnérabilités qui ne cessent d'augmenter et des États fragiles.

Part II. Study Area

Part II. Study Area

The gathering and integration of data through GIS is used at the first place in the study area description. The study area for this thesis is Baalbek-Hermel, one of the eight governorates of Lebanon. Baalbek-Hermel governorate is subject to many hazards because of its geographical location, its topography or, more recently, unprecedented historical environmental processes producing disasters that the region has rarely experienced in the past.

Baalbek-Hermel is a relatively poor Governorate, whose economy is mainly based on agricultural sectors. This economic issues, coupled with significant population growth and refugees exodus, pose some technical challenges to its community. Thus, public services and infrastructures are severely strained, in business-as-usual, for instance the road network is saturated, the electricity network witnesses many blackouts per day, etc… Baalbek-Hermel, as the rest of Lebanon, can even be regarded as a "poster child" in relation to issues concerning the management and reduction of natural risks in developing countries. Actually this territory concentrates a fairly diverse set of natural hazards and must face continuous population growth exerting continuous pressure and increasing exposure to risks. Moreover, the Lebanese Government is considered as fragile state, which amplifies the vulnerability of Baalbek-Hermel and hamper the course of efficient DRR and DRM actions.

The use of GIS, for civil protection, starts to appear early in this study. In order to know the characteristics of our study area, all the collected data were integrated in a geographic system. Maps and geospatial data were also gathered from CNRS-Lebanon, National Remote Sensing Center.

Chapter 3 . Study Area Description

This chapter explains, in relation to natural disasters, the characteristics of Baalbek-Hermel Governorate as case study. As stated previously, natural disasters involve "nature" and "human". As a result, the developed features of the current study area include aspects of its geographical framework, relating to the "nature" component of risk and administrative, governmental, social and economic parameters relating to the "human" component.

1. Administrative Settings

In Lebanon, below the national level, the governorate is the largest administrative division. Lebanon has eight governorates: Baalbek-Hermel, El Nabatiyeh, Beirut, Bekaa, South, Mount-Lebanon, Akkar and North.

The Governorate has no legal identity nor independent authority. It is an administrative subdivision set by the government and directed by a grade one civil servant (the Governor) designated upon a decision of the Ministry of the Interior. The responsibilities of the Governor are mainly administrative and include local execution of governmental policies and the coordination between the government offices and officials within the Governorate. The Governor represents all the ministries except for the Ministry of Justice and Ministry of Defense. The functions of the Governor, according to articles 4 to 26 of Decree 116/1959, involve executing laws and regulations, applying political directives given by the government and reporting the government on the general political situation in the Governorate, administering all issues in relation to personnel status, and monitoring and supervising all governmental offices and civil servants within the Governorate, ensuring public safety, personal freedom, and private property, and coordinating events, when required, in collaboration with internal security forces placed under his command. The cadastral divisions follow; each caza is headed by a Caimacam. The caza is divided into municipalities, which could be joined in a union of municipalities.

Baalbek-Hermel Governorate, one of the eight governorates in Lebanon, was established by the enactment of Law 522 on 16 July 2003, in which the districts of Baalbek and Hermel were separated from Bekaa Governorate. Official implementation of the new governorate only started in 2014 with the designation of the first and current governor, Bashir Khodr. Its administrative center is located in the city of Baalbek. This governorate extends over a length of 60 km and a width of 13 km with a total area of 3444 km^2 equal to 33% of the Lebanese territory and 64% of the total area of the Bekaa Valley. The administrative subdivision of Baalbek-Hermel Governorate is clearly developed in Figure 3-1 below. Baalbek-Hermel Governorate, is bordered by Akkar Governorate to the northwest, to the west by the Northern Governorate, Mount Lebanon Governorate to the southwest, Bekaa Governorate to the south, and the Syrian governorates of Homs and Rif Dimashq to the northeast and southeast. Around 416,000 people are living in Baalbek-Hermel Governorate (Inter-Agency Coordination-Lebanon 2015) and scattered over its two districts:

1. Baalbek, is divided into 99 cadastral limits, 74 municipalities and 4 federations of municipalities: 1) Federation of Baalbek Municipalities, 2) Federation of Charqeh Baalbek Municipalities, 3) Federation of Ech Chalal Municipalities and 4) Federation of Gharbeh Baalbek Municipalities. It is by far the largest district in the country comprising a total of 2,278 km^2 corresponding to one fourth of the total area of Lebanon. It is bounded by the Syrian border to the north and east, by Hermel District and Minieh-Danniyeh District, Bcharreh District, Batroun District, Jbeil (Byblos) District and Keserwan District to the west, and by the Syrian border and Zahleh District to the south. The number of its inhabitants is estimated at approximately 333 000 (a density of 146 inhabitants per square kilometer) (Inter-Agency Coordination-Lebanon 2015), equal to 9% of the Lebanese population. Major towns of the district are Baalbek, Aarsal, Hallanieh, Temnine, Chmistar, Douris, Jdeide, and Kasarnaba. The administrative center of the district is situated at the city of Baalbek that hosts a population of approximately 32,608. This city is known for its cultural heritage, the Arab ruins and especially Roman ruins, built from year 14 AD, (2,000 years-old) and was expanded during the 2 following centuries. Enjoying an important touristic status in Lebanon, it is home to the annual Baalbek International Festival.

2. Hermel, with an area of 731 Km^2 (6.9 % of the total area of Lebanon), is divided into 12 cadastral limits and 9 municipalities. Hermel District is situated at the extreme northern part of Baalbek-Hermel Governorate. It descends from the Lebanese mountains at an altitude of 3 000 meters, to reach the Syrian borders and the mountains of Baalbek in the northern and the eastern parts. It is the farthest Lebanese district from the Capital Beirut and from urban areas, being linked to other regions only by two major roads, the first crossing Baalbek District, and the second passing through the mountains of Akkar and creating the connection with the Northern Governorate. This district has the least number of inhabitants in Lebanon with a population estimated at 48,000 inhabitants, corresponding to only 1.3 % of the total population of Lebanon, and a density of no more than 66 inhabitants/Km^2 (Inter-Agency Coordination-Lebanon 2015). Its semi-arid land mainly contributes to its low population density. Hermel district is surrounded by Akkar District and Minieh-Danniyeh District on its west, the Baalbek District in the south and east, and Syria on its north. The city of Hermel hosts its administrative center.

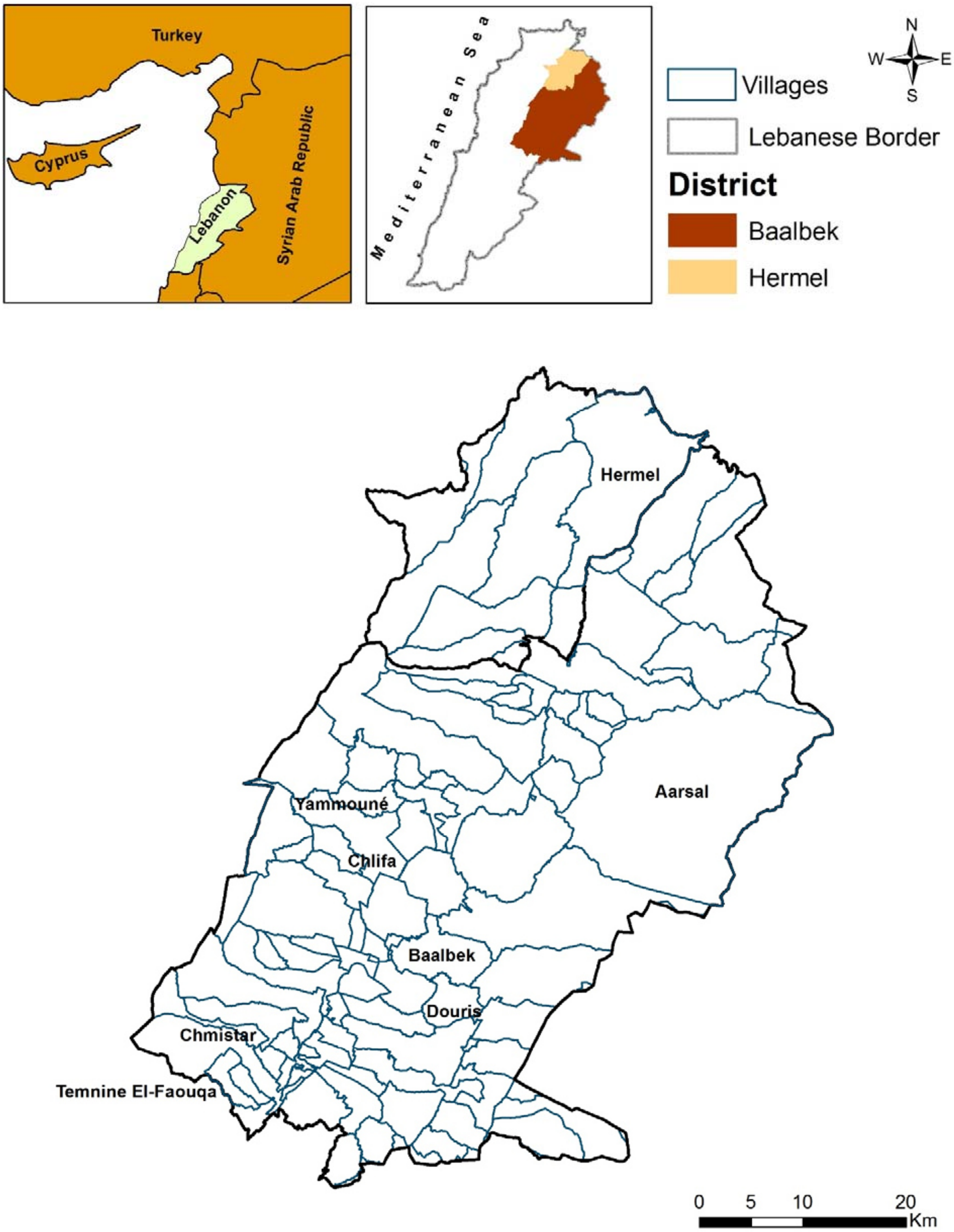


Figure 3-1 Baalbek-Hermel location and administrative setting. Source: CNRS, 2017

2. Geographical settings

Located 86 Km from the coastal line, Baalbek-Hermel governorate has an average altitude of 1,000 m above sea level with altitudes ranging between 800 and 3,060 m (Figure 3-2).These altitudes and many other factors contributed to give the governorate more than one type of climate.

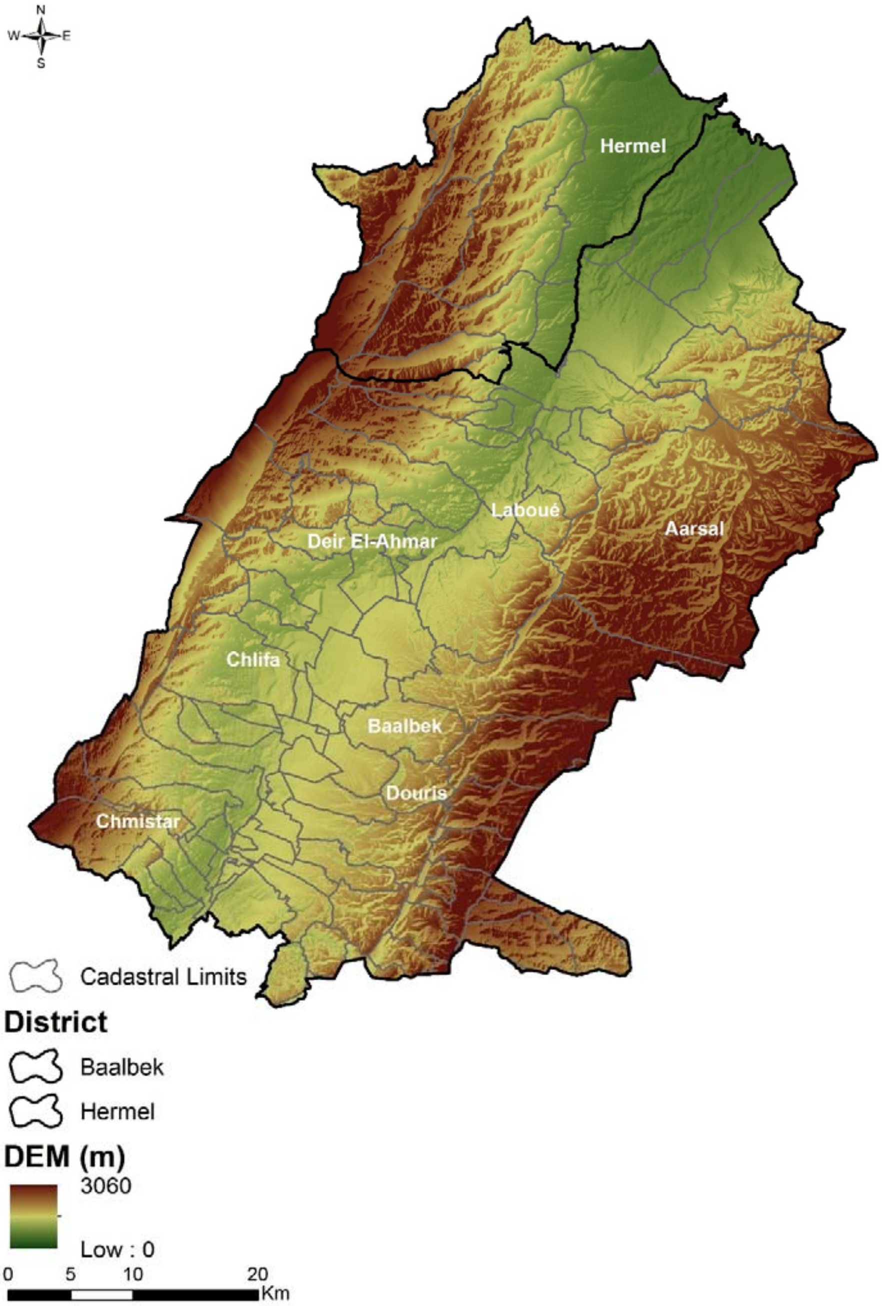


Figure 3-2. Digital elevation map for Baalbek EL Hermel. Resolution: 10m. Source: CNRS, 2015

Baalbek-Hermel is crossed by the Orontes (AL Assi), the largest and most regular freshwater of Lebanon (whose flow at the source is 7-16 m^3/s), flowing northwards in direction of Syria. This governorate is also crossed by Litani River, which divides it into 2 main watersheds. The governorate is also divided into two micro-climatic zones; the interior Assi and interior Litani. In fact, the natural landscape is marked by the absence of large green areas. Baalbek-Hermel is considered to be the most prone area to desertification in Lebanon (Darwish et al. 2012), characterized by cold winters and hot dry summers with a considerable heat gradient. Temperatures range between 40°C in hot and dry season, and fall below 0° in winter. The average annual precipitation is around 400 mm (MoA and FAO 2010), concentrated mainly from November to February. All these specifications are shown in the hydrographic map in Figure 3-3.These topographic and climatic specifications differ between the two districts:

- Baalbek District, located between the peaks of the western chain of Mount Lebanon and the eastern chain of the Anti-Lebanon, has a continental climate and receives a rainfall of 600 to 800 mm per year. It contains mainly lands in arid semi-desert climate, except for banks of the Litany and Orontes Rivers (El Assi), around which are located the majority of residential settlements. Other areas remain unpopulated and constitute the majority of desert zones known as "Jouroud Baalbek."
- Hermel descends from Lebanon high mountains to reach the Syrian borders and the mountains of Baalbek in the north and the east. This district has a harsh climate, receiving no more than 200 mm of rainfall/year. Its semi-arid land, explains its low population density compared to other regions of Lebanon (Inter-Agency Coordination-Lebanon 2015); this is a relatively high density for a semi-arid rural area and constitutes an economic vulnerability.

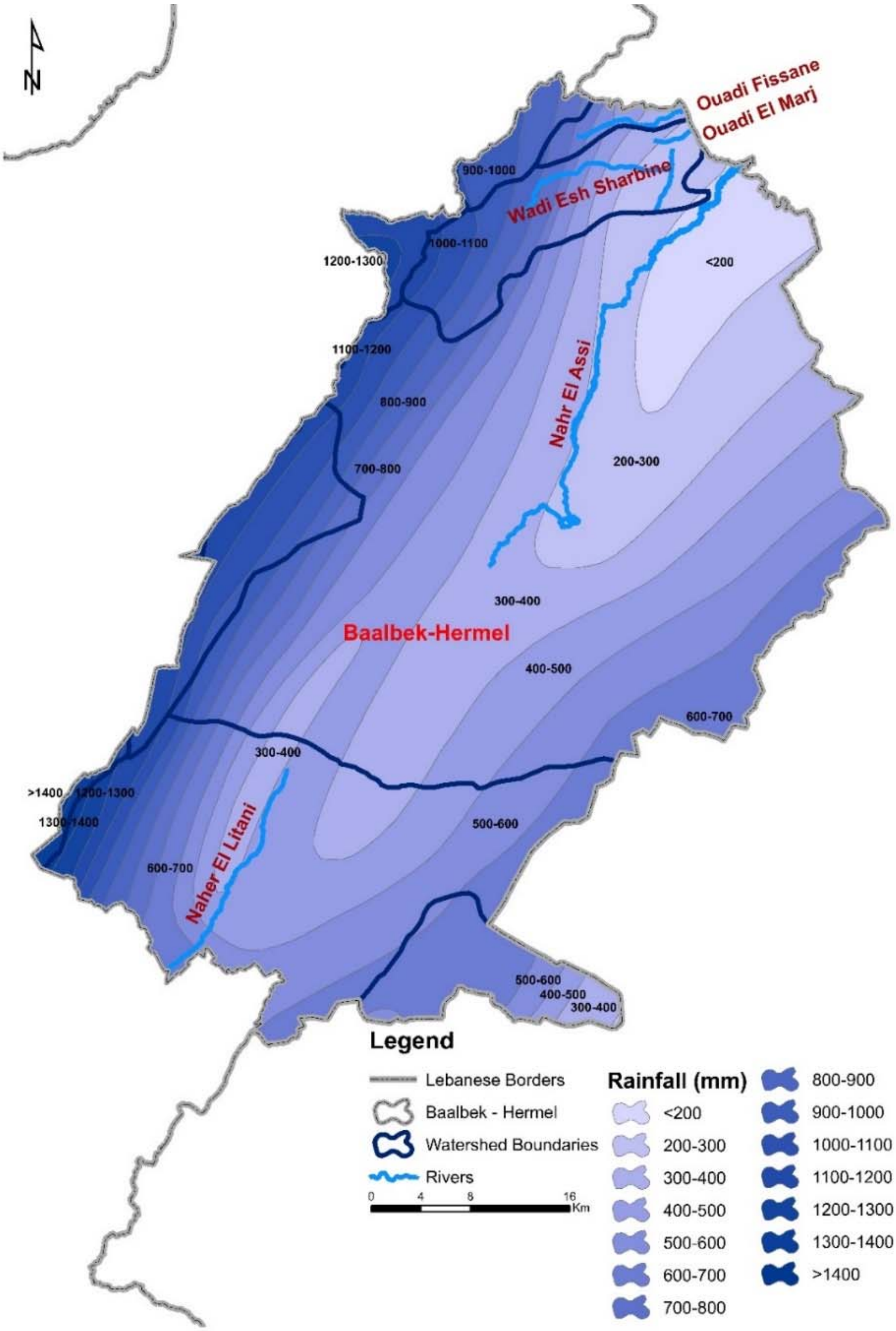


Figure 3-3. Hydrographic map for Baalbek-Hermel. Source: Plassard, 1970-CNRS, 2018

3. Socio-economic settings

Socio-economic data about Baalbek-Hermel Governorate is a pillar for DRR actions. Actually, it is of significant importance to know the number of persons in prone areas, the density of population, the population pyramids, the poverty status, etc. in order to have a good knowledge about the vulnerable groups, their distributions, estimate the human damage for future events, evaluate the coping capacity and predict recovery time. Demographic information was mainly obtained from the Central Administration of Statistics (CAS).

Baalbek-Hermel governorate is generally characterized by the low population density in comparison to other parts of the country, the large size of families, the low income, the poverty of a large part of the population, and the importance of agricultural activities. These elements rank the governorate in the forefront of deep rural areas; 80% of the total resident population is considered rural, much higher than the national average of 13%. Moreover, this governorate suffers many permanent problems under normal conditions (Nahas 2011):

- Electricity system is not underground, with regular disruptions;
- Poor water network with irregular fresh water supplies (15 minutes per week in some areas);
- Deterioration of some cultural heritage sites;
- Haphazard restoration of individual structures;
- Lack of economically and ecologically sustainable industries;
- Agricultural sector suffering from inadequate mechanization of production and exportation;
- Haphazard and unplanned urbanization;
- High unemployment and poverty;
- Underdeveloped tourism infrastructure.

Baalbek-Hermel is one of the least populated Governorates in Lebanon. The UNHCR estimated the governorate population at 416,427 in 2015 representing 7% of the total Lebanese population with approximately 107,642 households (Inter-Agency Coordination-Lebanon 2015). Its population density does not exceed 180 people/Km². Baalbek district is the more populated than Hermel. The total population includes 137,788 registered refugees of the Syrian Civil War and 8,117 Palestinian refugees. Non-Lebanese residents registered in Baalbek-Hermel governorate represent more than 44 % of those in Lebanon (UNHCR 2015), noting that there are more refuges that are unregistered. The majority of refugees live in informal settlements. Statistics describe at least more than 26% of Baalbek-Hermel population as deprived (UNHCR 2015). All these demographic specifications are detailed in Figure 3-4 below.

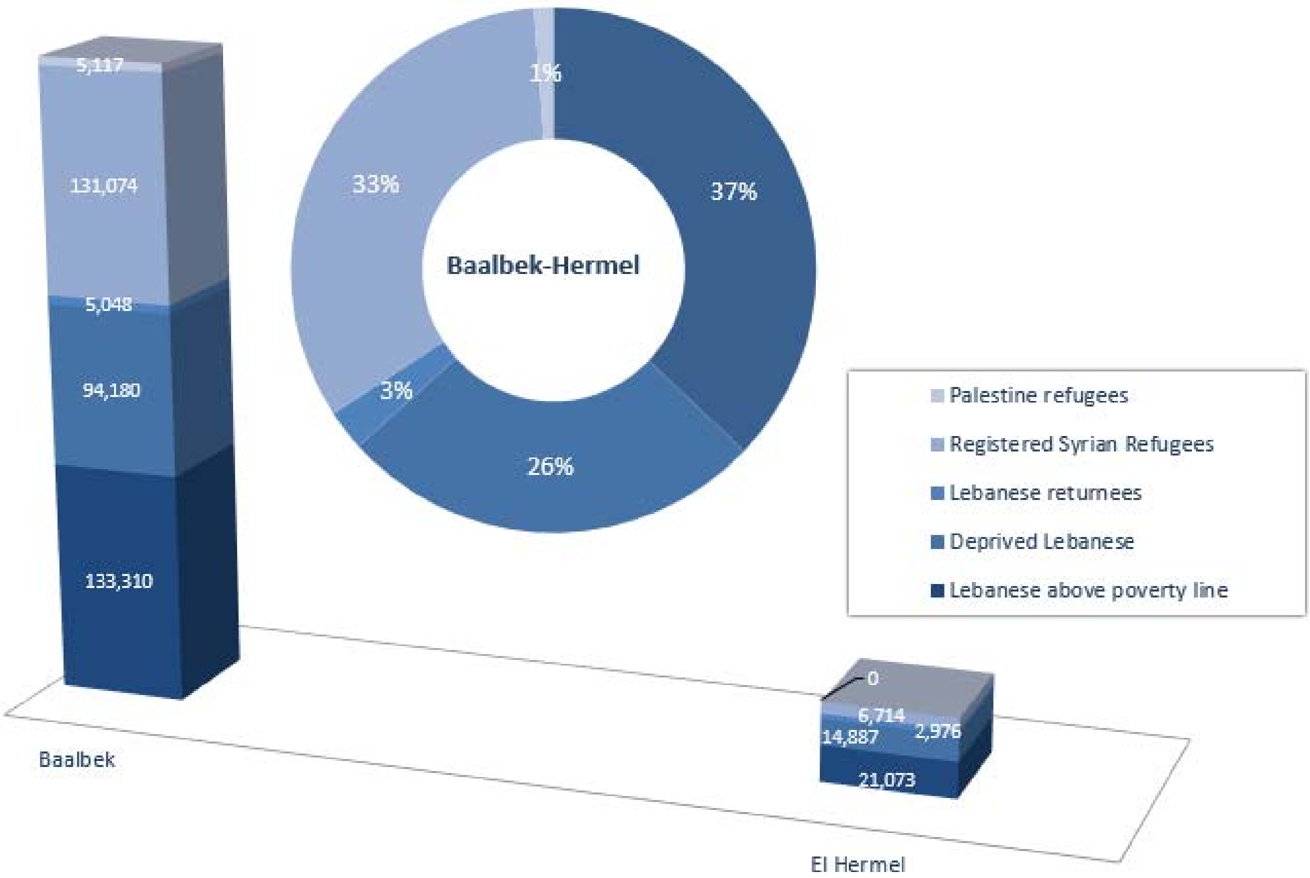


Figure 3-4 Baalbek-Hermel Governorate demographic Profile (as of 5 June 2015) Data Source: Lebanese Population - Central Administration of Statistics (CAS) and OCHA

The population of Baalbek-Hermel is composed of 50.5% males and 49.5% female. The overall age-sex pyramid (Figure 3-5) indicates an overall decline in the "youth" population. This decline can be the result of low birth rate or can be related to the conflated figure of refugees and permanent residents. At the same time, this pyramid indicates a more uniform trend of growth of women than for men in the same age group. This is probably related to differentiated migration patterns. Those in the 0 to 4 age group, which make up 8% of the total population, are less than 11.6% in the 5-9 age group and well below 13.7% of the total population formed by the cohort of 15-19 year olds. In addition, there is also a significant decrease in the number of young adults (aged 22 to 44), who make up the majority of the labor force.

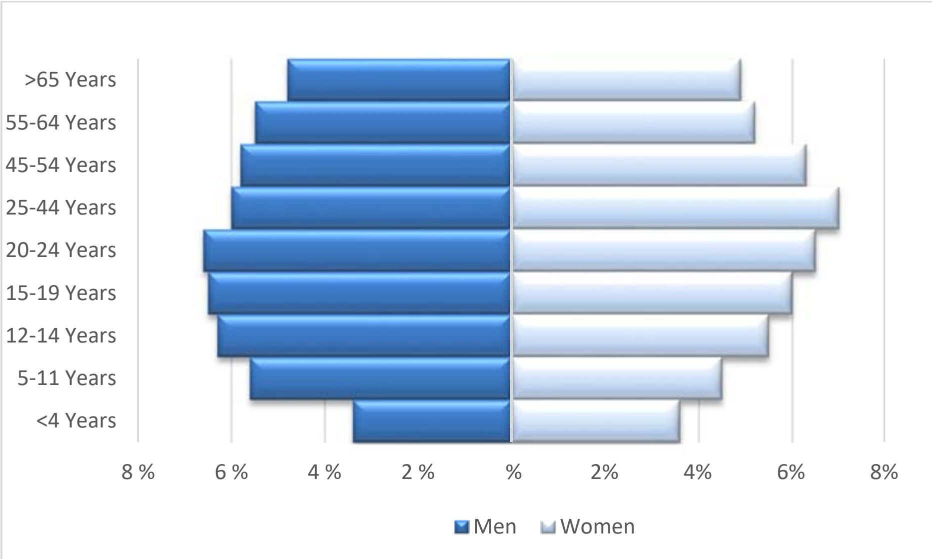


Figure 3-5 Age-sex distribution pyramid of Baalbek-Hermel. Source: CAS, 2010

The specific characteristics of this population can be associated to various probable reasons. At the first place, a new trend to move towards smaller families may be behind the decline in birth rate. Secondly, school-age children (5-19) immigrating into Baalbek for better educational institutions may be the cause of the reversed age distribution. The relatively important portion of extended families in the city (14.7%) support this assumption. Moreover, Baalbek presents better employment opportunities and thus attract young adults (15-19); this could have also reversed the overall percentages of respective age groups. The exodus of labor force segments (25-44) to Beirut and abroad in search of employment would also have a negative effect on gender distribution in the governorate. According to UNDP (2015), the region's local leaders have expressed great concern over the increasing tendency of young people to migrate out of the region or even the country, causing dramatic disruption in communal networks and reduction in local talent. Finally, the truncated appearance of the age groups 25 to 44 could be associated to losses during the war.

In general, the governorate also suffers from high levels of illiteracy; about 13.6% of people over the age of 10 are considered totally illiterate (Nahas 2011). The education level of the total population also differs considerably by age group and gender. As shown in Figure 3-6 , the percentage of individuals with only the elementary level is notably high especially for women. Simultaneously, the percentages of illiteracy increases with age, also with higher numbers of illiterates among women. Nevertheless, these components did not represent an important number of graduates of vocational training programs, due to the shortage of such programs or the lack of interest and job prospects in what is currently being proposed. Finally, no differences were found across genders concerning the percentage of university graduates in the 20-24 and 25-44 age groups.

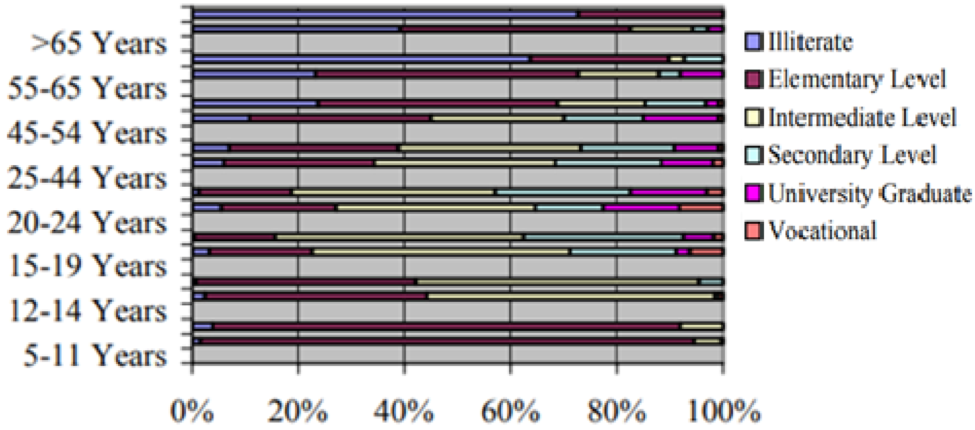


Figure 3-6 Age, sex and education level distribution in Baalbek-Hermel governorate (the bottom and the top line represent men and women respectively in each age group). Source: CAS, 2010.

As extensively discussed previously in Chapter I, natural disasters are as much the consequence of poverty and fragile states as tectonic faults and weather conditions. Thus, natural disasters strike the world's poorest the hardest. The same happens in a smaller scale, in the Governorate level, poorest settlements would be the most affected by a disaster. Firstly because they are not prepared at all and then because they cannot afford the replacement costs. Moreover, natural disasters turn into human catastrophes when they root the underlying poverty and drag more and more people into poverty as their properties disappear, as well as their means of generating income.

This area is one of the least developed regions of the country, and people often suffer from relative isolation. According to "Poverty, Growth & Inequality in Lebanon", 2007, a study made by UNDP, 33 % of the population of Baalbek-Hermel lives below poverty line. Baalbek- Hermel is home to two thirds of the extremely poor and half of the entire poor population in Lebanon (UNDP 2007). The poverty lines were set on the basis of the cost of a minimum expenditure, based on the food required for a recommended calorie intake, and supplemented by nonfood allowance consistent with the consumption habits of the poor themselves. The lower poverty line for the governorate is equivalent to LBP 500.000 per month (approximately US $332) for an average household with 5.26 members; this is less than 2.1$/day/person, as the absolute poverty line according to the World Bank, since October 2015. The regional upper poverty line is equal to LBP 1.000.000 per month (around US $652) for an average household with 5.26 members. 58% of households (and 65% of the population) are considered to belong to the upper poverty line. The headcount index for the governorate is around 25.5% of households in the lower poverty line. Poorer families, with a higher number children (amounting to 3.7 children per family), are considered to be larger in family members than richer families (an average of 3.1 children per family). The average number of family members of poor families in the area of study is of 5.9 members, considered to be relatively high. This average is higher than the average number for the entire region reaching a maximum of 5.2 members and much higher than that for Lebanon that do not exceed 4.7 members. Already one of Lebanon's poorest regions, with an unemployment rate reaching 4%, the recent influx of Syrian refugees has put additional pressure on the already fragile infrastructure and services of the governorate.

Based on this analysis, a study has conducted a social vulnerability assessment (UNICEF, OCHA, and REACH 2015). The study has shown that there are 26 vulnerable localities in Baalbek/Hermel, five of which are considered as most vulnerable. Sixteen of the 26 localities are also classified as high pressure where the number of refugees compared to the poor Lebanese is at least three to one or even more (Figure 3-7).

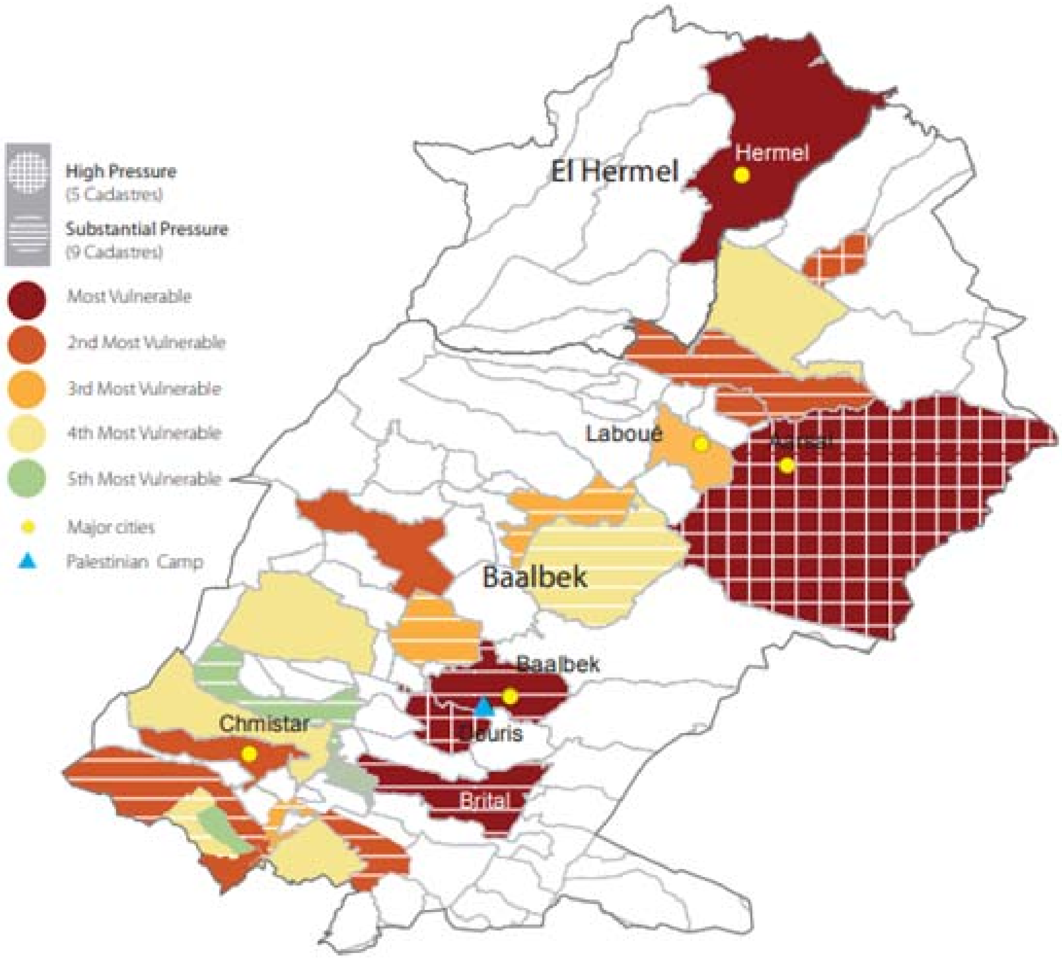


Figure 3-7 UNICEF classification of worst to lowest vulnerable cadasters and sub-classification of Baalbek-Hermel. Source: UNICEF, OCHA, REACH, 2015

The governorate contributes enormously to the agricultural production of the country. The large majority of its population, dispersed in groups with strong tribal mores and traditions, is employed in the agricultural sector. Agriculture, livestock and fish farming dominate the economics of the study area. The governorate is part of the Bekaa Valley (northern part), Lebanon's most productive agricultural area. Moreover, essentially rural, the region's economy heavily relies on agricultural production, with commensurate concentration of employment. Around 41 UN agencies and NGOs have offices across the valley part of the governorate and periodic inter-agency and sector coordination meetings are held. Localized coordination structures are also established for Aarsal and the Hermel district.

4. Land Use/Land Cover & Critical Assets

The land use/cover pattern of an area is the result of natural and socio-economic elements, their interaction and their utilization by man in space and time. According to FAO definition, land cover is "*the observed (bio) physical cover on the earth's surface*", and land use is characterized by "*the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it*" (FAO 2005, p.2). Although land cover is simply a description of the current surface conditions and land use is more complex, and can include key information that cannot be seen by remote sensing, land use/cover are distinct terminologies that are so often used interchangeably (Dimyati et al. 1996, Rawat and Kumar 2015). Land use affects land cover and changes in land cover influence land use.

The utilization of remote sensing (satellite imagery), field validations and integration of satellite digital data into a geographical information system (GIS) are approaches that the NCRS adopted in the past 20 years and lead to three releases of land use and land cover 2002, 2010 and 2013 and most recently 2017 where remote sensing was used as the basis and on field verification using tablets and collectors followed. The used land use/land cover map (Figure 3-8) in this thesis were established from latest Geo-Eye satellite images-2013. The classification was based on the European CORINE classification (Coordination des information sur l'environnement) adopted for Lebanon, level 4 of discrepancies.

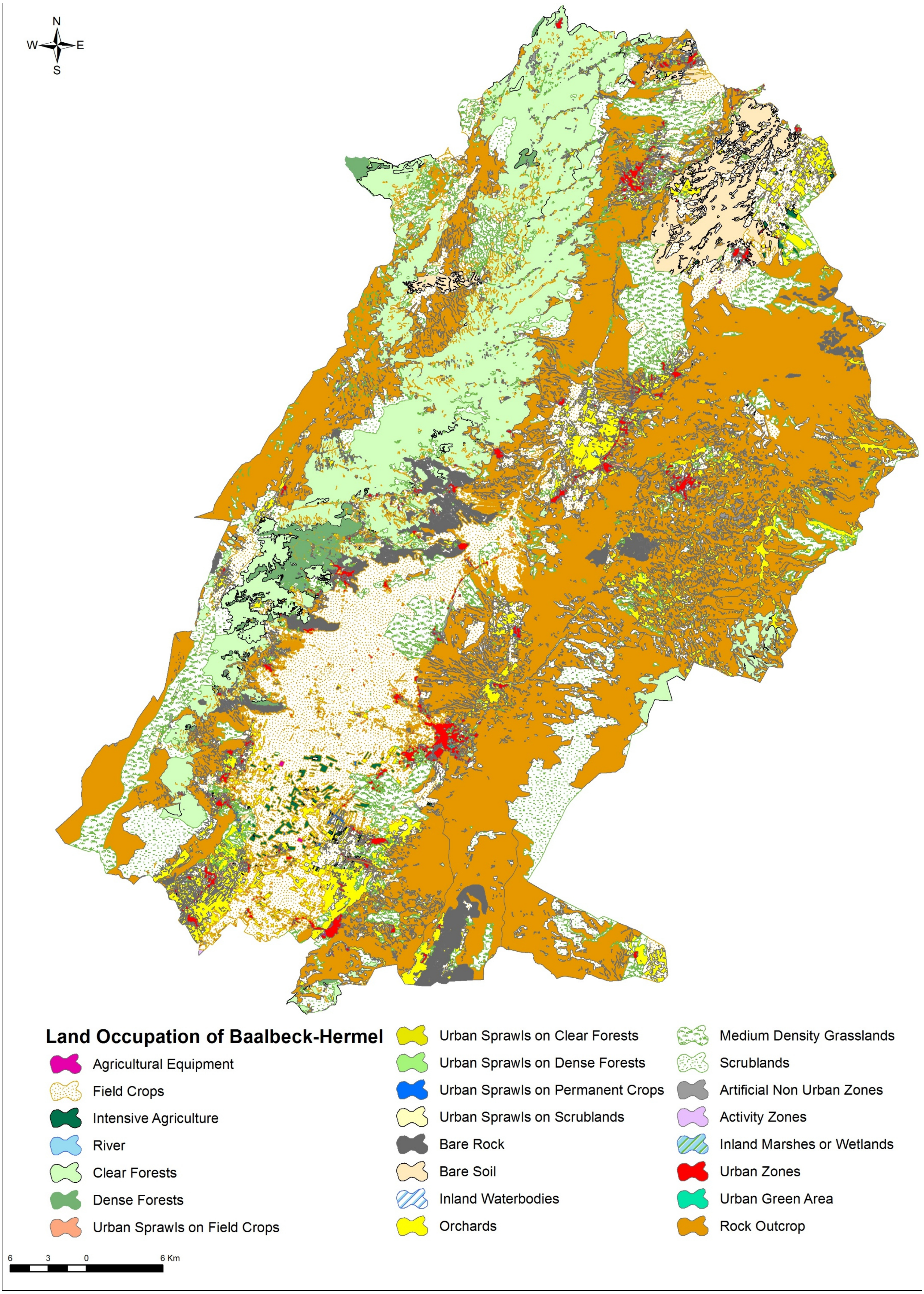


Figure 3-8 Land occupation of Baalbek-Hermel. Scale: 1/20,000. Source: CNRS, 2017

The statistics of this LU/LC revealed some of Baalbek-Hermel's characteristics.

The Governorate's land cover is classified into six categories and 52 sub-categories (Figure 3-9). The largest cover type is "unproductive area" (rocky and bare lands) which covers 46% of the total area followed by "agricultural area" covering 23% of the total area and "wooded land" covering 20%. The rest of the areas are classified as "grassland", "artificial area" and "water bodies" covering respectively 8%, 2% and 1% of the total area. These statistics point out the rural character of Baalbek-Hermel.

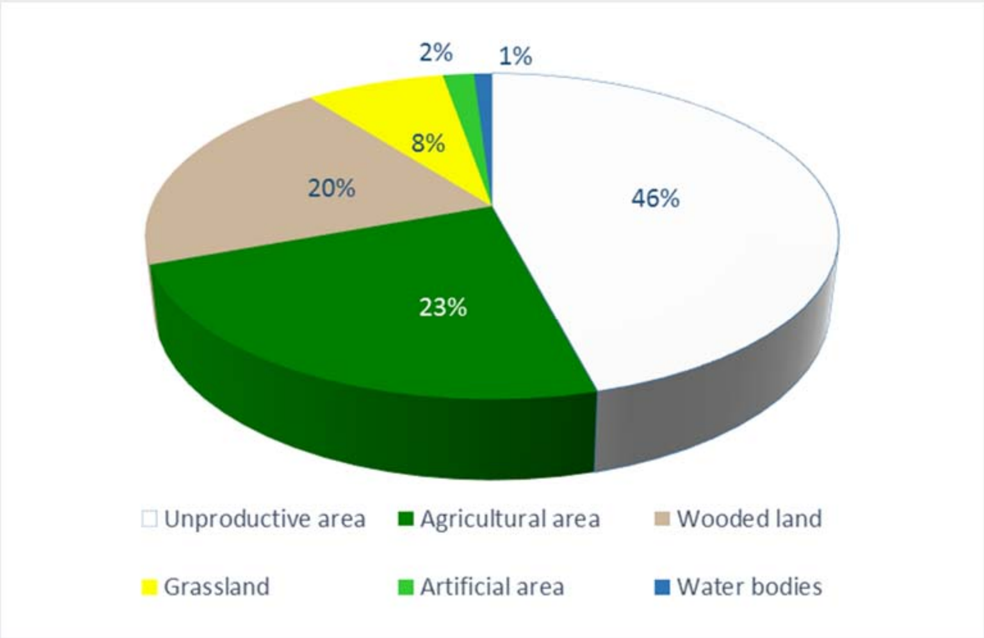


Figure 3-9. Major Land use distribution in Baalbek-Hermel.

The detailed percentages of different land use distribution in Baalbek-Hermel Governorate is shown in Table 3-1.

Table 3-1 Types of land use/land cover of Baalbek-Hermel

Land use/Land cover types (Level 1)	Land use/Land cover types (level 4)	Area (Km²)	Percentage of Area From Total	Percentage of area from level 1
Unproductive area	Outcrop	1472.18	42.74%	91.54%
	Bare soil	71.16	2.07%	4.42%
	Bare Rocks	64.96	1.89%	4.04%
Agricultural area	Field crops in small fields/terraces	411.02	11.93%	50.80%
	Deciduous fruit trees	164.16	4.77%	20.29%
	Field crops in large areas	137.43	3.99%	16.98%
	Vineyards	35.09	1.02%	4.34%
	Abundant farmland	27.94	0.81%	3.45%
	Open horticulture	10.92	0.32%	1.35%
	Urban sprawl on field crops	8.49	0.25%	1.05%
	Olives	6.08	0.18%	0.75%
	Urban sprawl on permanent crops	4.66	0.14%	0.58%
	Agricultural Units	2.51	0.07%	0.31%
	Protected agriculture	0.82	0.02%	0.10%

Land use/Land cover types (Level 1)	Land use/Land cover types (level 4)	Area (Km^2)	Percentage of Area From Total	Percentage of area from level 1
	Citrus fruit trees	0.01	0.01%	0.00%
Wooded land	Low density juniper forest (Junipers)	255.98	7.43%	36.78%
	Shrub lands (with scattered trees)	162.97	4.73%	23.41%
	Mixed low density forests	152.96	4.44%	21.98%
	Low density oak forest	56.19	1.63%	8.07%
	Mixed dense forest	33.15	0.96%	4.76%
	Dense forest of Oaks	11.65	0.34%	1.67%
	Shrub lands	10.12	0.29%	1.45%
	Dense fir forest	4.85	0.14%	0.70%
	Low density pine forest	2.35	0.07%	0.34%
	Urban sprawl on low density forests	1.48	0.04%	0.21%
	Low density cypress forest	1.48	0.04%	0.21%
	Another type of leafy low density forests	0.85	0.02%	0.12%
	Another type of dense forests	0.70	0.02%	0.10%
	Dense pine forest	0.58	0.02%	0.08%
	Dense cypress forest	0.15	0.01%	0.02%
	Urban sprawl on dense forest	0.04	0.01%	0.01%
	Urban sprawl on shrub lands	0.25	0.01%	0.04%
Grassland	Grasslands of medium density	267.35	7.76%	100.00%
Artificial area	Low-density urban fabric	25.95	0.75%	43.25%
	Medium density urban fabric	18.17	0.53%	30.29%
	Material Extraction Sites	9.92	0.29%	16.54%
	Airport	2.69	0.08%	4.48%
	Industrial or commercial area	0.92	0.03%	1.54%
	Low-density informal urban fabric	0.70	0.02%	1.16%
	Diverse Equipment	0.63	0.02%	1.06%
	Archeological Site	0.13	0.01%	0.22%
	Complex Resort	0.09	0.01%	0.15%
	Dense informal urban fabric	0.05	0.01%	0.09%
	Urban Extension and/or site	0.43	0.01%	0.72%
	Dumpsites	0.01	0.01%	0.02%
	Green urban area	0.10	0.01%	0.17%
	Urban vacant land	0.14	0.01%	0.24%
	Sport and leisure facilities	0.04	0.01%	0.07%
Water bodies	River	2.98	0.09%	0.03%

Land use/Land cover types (Level 1)	Land use/Land cover types (level 4)	Area (Km^2)	Percentage of Area From Total	Percentage of area from level 1
	Hill lake	0.42	0.01%	0.01%
	Wetlands or continental swamp	0.01	0.01%	0.01%

These LU/LC categories are not enough for DRR actions. Critical assets according to each category must be studied as they may be elements at risk.

Agricultural area: Agricultural lands occupy the highest percentage of land in this governorate. The Governorate hosts 25% of the total agricultural cultivated area in Lebanon, 29% of annual crops, 19% of permanent crops and 28% of the irrigated area. The main figures relating to the Governorate's contribution to the main totals of the national agricultural production are 30% of cereals, 36% of industrial crops, 33% of vegetables, 36% of pulses, 55% of stone fruits and 39% of grapes. The two districts include nearly 21,825 farms (MoA and FAO 2011).

In Hermel district, the limited rainfall and soil low fertility make the wheat and barley the main cultivated crops in addition to livestock farming of sheep and goat. Moreover, the presence of the Assi River makes the region suitable for fish farming mainly for Trout and Tilapia. 80% of aquaculture fish farms in Lebanon are located in El Hermel region along the Assi River with an estimated average yield of 10-12 tons/year. As for Baalbek, the soil texture provides a great potential for crop production.

The region of Baalbek-Hermel consists of 9 homogeneous agricultural areas (Figure 3-10). Some characteristics of the later are shown in Table 3-2 below. This table mainly shows that it is the Baalbek area which marks the highest threshold with 27% of the total UAS of this region followed by far by the plain north of Orontes with 15%. The lowest rate was recorded in the southern plain of Orontes with 7%. Irrigation is concentrated at the Baalbek level with 33% of the total irrigated UAS (Utilized Agricultural Surface) in this region, followed by the Northern plain of Orontes with 24%. This rate reaches its lowest level on the eastern slope of the Orontes with 1%. The areas of the northern plains of Orontes and Baalbek have the highest levels, with respectively 24% and 20% of the total livestock in this region. The minimum threshold was raised to the southern plain of Orontes with 3%.

Figure 3-10. Agro-climatic zones & homogeneous agricultural areas in Baalbek-Hermel. Source: MoA, 2010

Table 3-2Characteristics of homogeneous agricultural areas of Baalbek-Hermel. Source: MoA, 2010

Characteristics of homogeneous agricultural areas								
Homogenous agricultural area	Number of holders	%	Utilized agricultural area	%	Irrigated area	%	Livestock	%
Bassin Versant Ouest de l'Oronte	2353	11	49433	8	5658	2	4896	9
Plaine Nord de l'Oronte	2784	13	94590	15	64442	24	13831	24
Plaine Sud de l'Oronte	1392	6	41709	7	24568	9	1500	3
Zone de Deir el Ahmar	1686	8	50605	8	24378	9	3436	6
Bassin Versant Est de l'Oronte	1483	7	43582	7	1520	1	8034	14
Zone de Baalbek	4013	18	172012	27	88632	33	11127	20
Zone de Chaat – Younine	1769	8	54662	9	20968	8	3560	6

Characteristics of homogeneous agricultural areas								
Homogenous agricultural area	Number of holders	%	Utilized agricultural area	%	Irrigated area	%	Livestock	%
Zone de Britel	1828	8	47673	8	12374	5	5125	9
Zone de Bednayel	4517	21	84496	13	25598	10	5457	10
Baalbek-Hermel	21825	100	638762	100	268138	100	56966	100

As for other Lebanese governorates, Baalbek-Hermel Governorate is covered by the Lebanese Agriculture Research Institute (LARI) Early Warning System (EWS) through SMS specialized for Agro-Meteorology for farmers and fishermen with regard to most risks related to natural hazards including information on how to mitigate the impact of hazards.

Artificial area: Artificial areas usually comprise the most of people and their goods. As for DRR, the ultimate goal is to reduce human losses and economic losses. The components of artificial areas tackled in this thesis are residential buildings, educational facilities, health facilities, electric network, road network, all these assets are shown in Figure 3-11 .

It is important for people to know the risk they face while being in their houses if a natural disaster occurs. Consequently, data about residential buildings in Lebanon is essential in order to evaluate these buildings and their potential vulnerability and resistance to disasters. Lebanon contains around 495252 residential buildings, 11.5% of these residential buildings are situated in Baalbek-Hermel with more than 56722 buildings and 65511 housing units. The urban settlements in Baalbek-Hermel occupy an area of 46 Km² which represents only 1% of its total area. One of the biggest urban settlements in the governorate is the city of Baalbek (16% of the governorate's buildings), consisting of a dense urban fabric that extends east and north along the two main roads north (Hermel-Homs axis) and southwest (Zahle). This residential fabric is dotted with critical assets, infrastructures and facilities like educational facilities, health facilities, religious facilities, commerce, etc. Also, on the outskirts of the urban centers dispersed villas have been constructed on privately lands. In fact, as Table 3-3 shows, 63% of these buildings have only one upper floor, 28% have two upper floors and about 3% have three upper floors. Information about lower floors is often not available (58%). The general distribution of these residential buildings on the village level is shown in Figure 3-12 below.

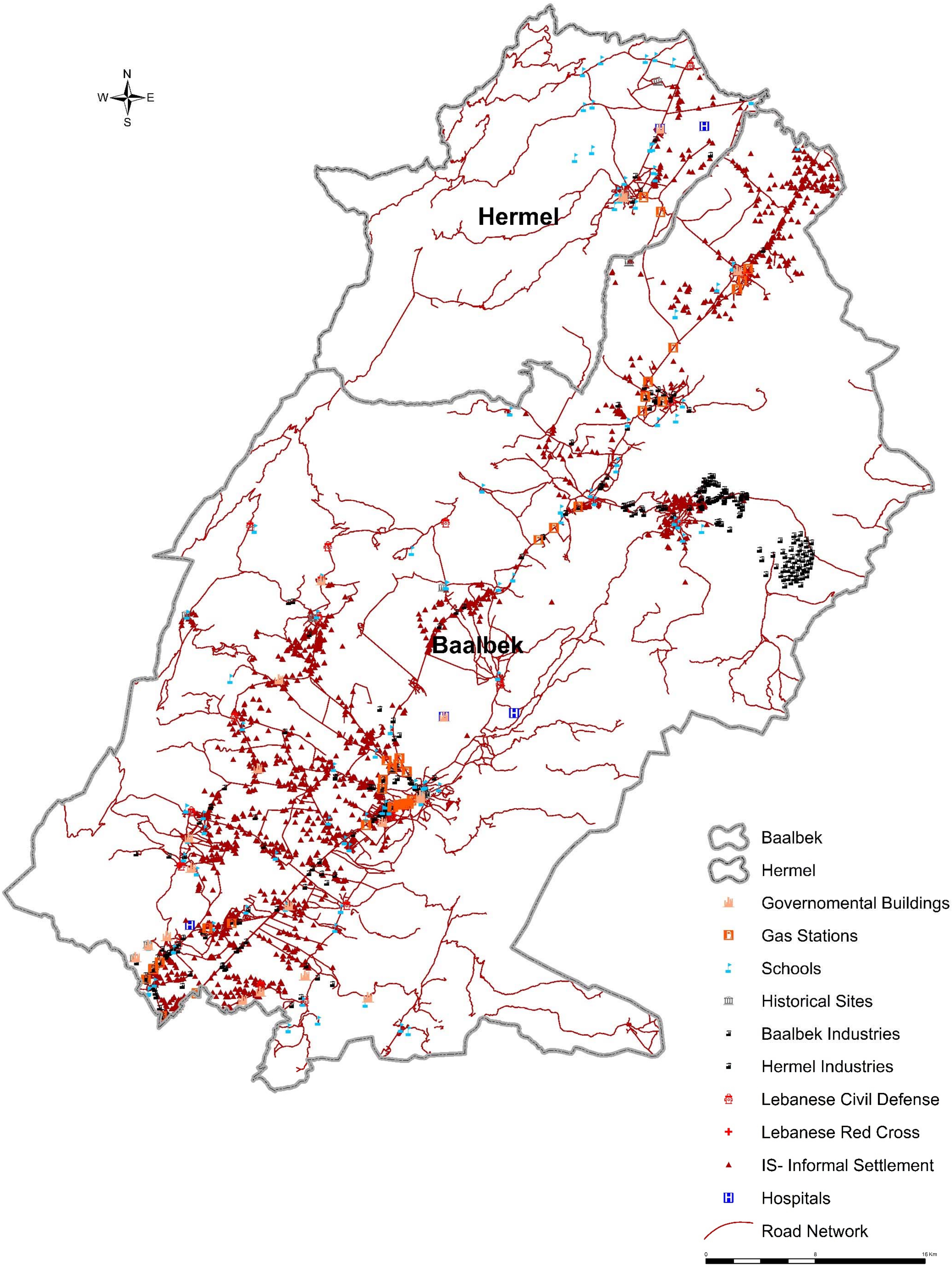


Figure 3-11 Critical assets in Baalbek-Hermel

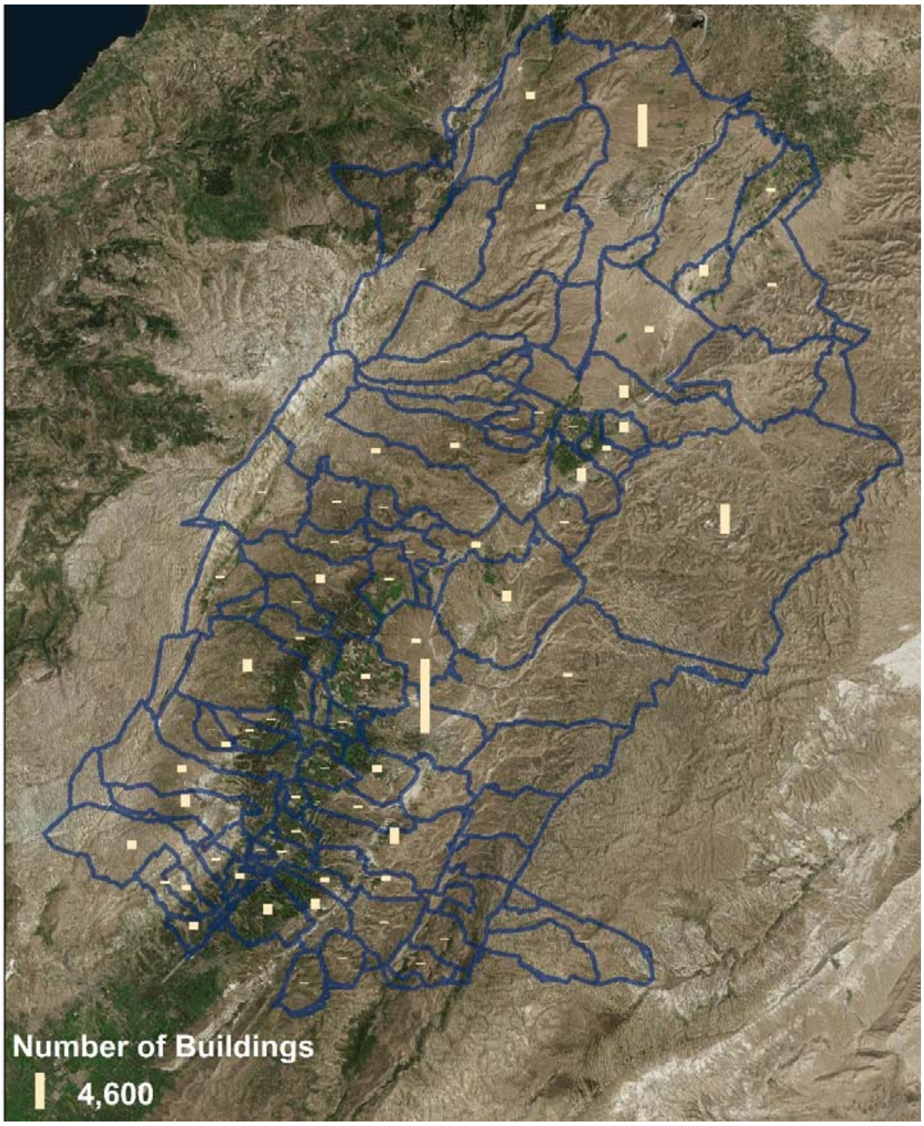


Figure 3-12. Buildings distribution per villages in Baalbek-Hermel. Source: CNRS, 2010

Table 3-3 Buildings in Baalbek-Hermel and their floors number information. Source: CNRS, 2015.

	Upper floors information							Lower floors information			
	One upper floor	Two upper floors	Three upper floors	Four upper floors	5 to 9 upper floors	More than 10 upper floors	Not available upper floor data	Only Ground floor	One Lower floor	More than 2 Lower floors	Not available Lower floor data
Number of buildings	35697	15686	1910	292	43	2	3092	19877	1139	11	26451
Percentage from total	62.93%	27.65%	3.37%	0.51%	0.08%	0.00%	5.45%	35.04%	2.01%	0.02%	46.63%

Among the 65511 housing units, 82% are considered as main residence housing units, 8% are secondary housing units and 10% are unoccupied housing units. High Lebanese emigration rates, seasonal migration and foreigners buying houses and investing in real estate in Lebanon could have caused the increase in the number of unoccupied houses.

The architecture of the buildings is very important. Effectively, the main elements that characterize the building envelopes in Lebanon include:

• Walls: Predominantly consist of hollow concrete blocks with a thickness of 15-20cm with 1 cm of plaster on each side. Exterior cladding when installed is typically stone cladding (limestone, sandstone, granite, etc.).
• Roofs: Are either flat or tilted. They are usually not insulated. Pitched roofs tend to be covered with tiles.
• Windows: Are typically made of single or double glazing (single is still the most popular) with aluminum frames. Glass panes are usually six millimeters thick and in some cases are tinted or with a reflective coating. Some high end buildings use double glazing but it is not the dominant trend. Low-e windows have been reported in some projects, but it is a relatively new trend.
• Other architectural features: Balconies are widely used in residential buildings.

Another main component of the vulnerability of a building is its age/construction date. Therefore, data about the buildings' age in Baalbek-Hermel was collected and showed that the percentage of the buildings built between 1971 and 1975 was the highest reaching 15%. 8% of the buildings were built before 1960 and 1970 and only 8% were built after 1994. Information about the year of construction for 11% of the buildings were lacking (Table 3-4).

Table 3-4 Buildings' year of construction in Baalbek-Hermel

	Not available building age data	Built before 1950	Built between 1951 & 1960	Built between 1961 & 1970	Built between 1971 & 1975	Built between 1976 & 1980	Built between 1981 & 1985	Built between 1986 & 1990	Built between 1991 & 1993	Built after 1994
Number of buildings	6177	2738	2358	6803	8560	7234	6047	6125	6046	4634
Percentage from total	11%	5%	4%	12%	15%	13%	11%	11%	11%	8%

Along with residential buildings, informal settlements exist in Baalbek-Hermel. According to UNHCR-2017, Baalbek-Hermel is among the regions that host the highest number of Syrian displaced in Lebanon. With more than 1,515 camps, 7,396 tents hosting over than 62,159 displaced, the situation has put more pressure on the Governorate and its communities; by competing over employment, accommodation, access to public services and infrastructure, along with refugees are making the host communities more vulnerable. Governmental buildings are also considered as critical facilities and need to be assessed. Baalbek-Hermel comprises around 21 governmental buildings.

Children are among the most vulnerable age groups. Assessing the places where children could be present at a time of crisis, like educational facilities is a must. During sudden-onset events like landslides and earthquakes, the presence of children in schools that are not built to withstand hazards, make them even more vulnerable. Moreover, education facilities are considered critical and therefore, they should certainly be highlighted. The total number of schools in Baalbek-Hermel is 243 comprising of 124 public and 119 private. In terms of students, Baalbek-Hermel counts a total of around 56,600 students, 23,000 in public schools and 33,600 in private schools. 2 universities and higher education institutions are available in Baalbek-Hermel (Lebanese University faculty of Sciences and American University of Culture & Education).

Health facilities and first responders' centers are considered as one of the most important critical facilities in a region, especially during crisis. Data about health facilities were gathered through interviews with the Ministry of Health (MoH). According to the Ministry of Health, there are 30 health facilities in Baalbek-Hermel. These include 11 hospitals, medical centers, dispensaries and private clinics. The total number of beds in these health facilities is 640. The health facilities in Baalbek-Hermel represent 5% of the health facilities in the whole country. Concerning first responders' centers, there are 2 Red Cross centers and 21 Lebanese civil defense centers (Lebanese public authority mandated with responding to emergencies) staffed by approximately 250 personnel distributed between administrative and operations in this governorate. The Lebanese Red Cross is a National society that strives to take immediate action to help and assure the survival of the most vulnerable and needy during any kind of emergencies along with well planning and preparing to reduce the risks. What LRC has had to confront recently constrained it to demonstrate incredible enthusiasm for the subject of coping with emergencies through planning and preparedness in pre- and post-disasters programs. LRC is also working on preparing for disaster response in highly urbanized areas, in an attempt to limit the risks through direct intervention. This corresponds to the goals of the international Federation of Red Cross and Red Crescent Societies particularly in the field of natural disasters since 2002. In view of the repercussions of the 2011 Syrian crisis, and after the exodus of 1.5 million Syrian displaced to Lebanon and pressing need to help them overcome the tragedy, the Disaster Management Unit has been initiated and a working group of the administration central has been established; 13 working groups have been formed to monitor the management of coordinating donor cooperation through programs and projects, as well as with the branches of society and its operational departments.

The industrial sector is very significant to the society and evaluating the industries and their resilience to disasters constitutes a serious part of the DRR process. Around 324 industrial firms are located in the governorate (8% of the industries in Lebanon), 34% of which are engaged in agro-food related activities.

Cultural heritage is the primary link to a nation's past, and must be protected for the future generations in order to ensure coherence and continuity between past, present and future. More than their economic value, historical sites represent a spiritual and cultural and sometimes ethnic value for the society and should be protected from natural and man-made disasters. The inventory showed that Lebanon contains around 282 historical sites of which 10 at least are situated in Baalbek-Hermel. This governorate is additionally rich in archaeology and history has left some of its most famous monuments dispersed everywhere this region.

The road network contributes to the survival of people especially in time of crisis. Moreover, if the roads were not well managed they may increase the losses caused by a disaster. Based on OSM (open street map) the roads in Baalbek-Hermel, divided into 12 categories, have a length of about 1738 Km. These categories are shown in Table 3-5 below.

Table 3-5 Roads' categories total length (Km) in Baalbek-Hermel Governorate (OSM, 2016)

Classification	Length (Km)	Percentage from total
Primary	228.96	13.17%
Tertiary	352.95	20.30%
Residential	253.42	14.58%
Secondary	93.82	5.40%
Trunk	21.95	1.26%
Living Street	4.78	0.27%
Services	23.69	1.36%
Unclassified	705.46	40.58%
Track	454.22	26.13%
Road	0.65	0.04%
Footway	17.76	1.02%
Path	18.58	1.07%
Total	1738.56	100%

These 1738 kilometers are divided into track roads of 26.13%, tertiary roads with 20.3%, and unclassified roads with highest percentage of 40.58%. Baalbek-Hermel comprises 22 bridges, 17 in Baalbek and 4 in Hermel. No tunnels exist in Baalbek-Hermel. It is important to mention that conducted surveys showed that a high percentage of the classified network can be categorized as in poor to critical condition.

The electric network represents a major part of the vital facilities. There is 1 power plant in Baalbek-Hermel (5% of the power plants in Lebanon). There are 5 electric substations in Baalbek-Hermel (7% of the electric substations in Lebanon); 4 substation has a capacity of 66 KV and 1 has a capacity of 220KV. Baalbek-Hermel counts more than 164,000 meters of electric lines (8% of the electric lines in Lebanon); 96000 meters have a capacity of 66 KV, 39,000 meters have a capacity of 220 KV and 30,000 meters have a capacity of 400 KV. Baalbek-Hermel's electric network is represented in Figure 3-13 below, in a simplified way.

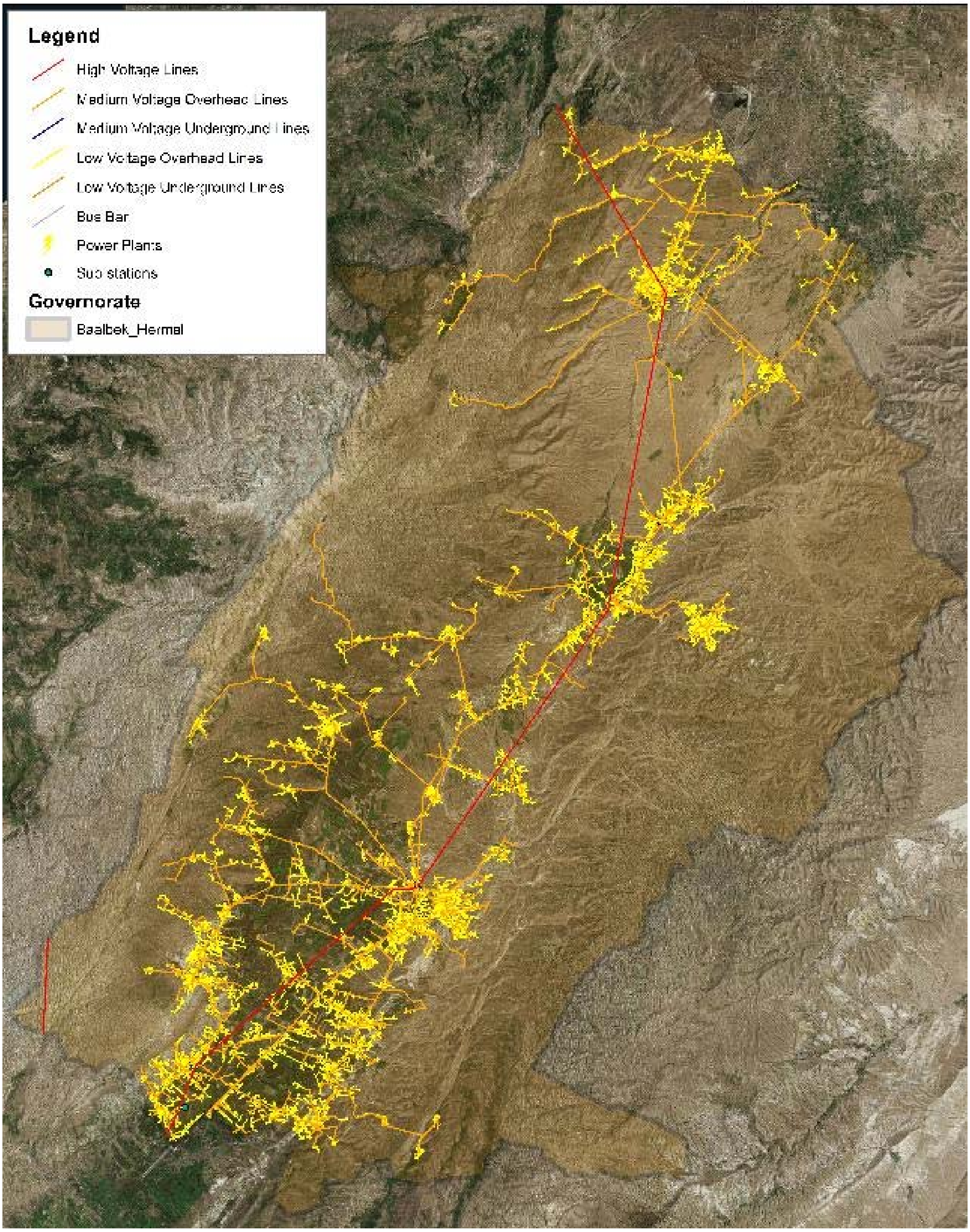


Figure 3-13 Simplified representation of Baalbek-Hermel's electric network. Source: EDL, CNRS, 2016

Chapter 4 .Natural hazards and Disasters

In this chapter, natural hazards threatening Baalbek-Hermel will be discussed along with historical disasters events and past records. A quick review will follow about DRR and adaptation measures taken by Baalbek-Hermel governorate community, government and NGO stakeholders to respond to these disasters.

1. Natural Hazards

Several natural hazards, like earthquakes, floods, landslides, wildfires and storms, threaten Baalbek-Hermel. It is important for any DRR action to be based on information about the natural hazards and for DRR managers to be aware of their frequency and their spatio-temporal footprints. Hazards susceptibility mapping has been conducted in Lebanon and Baalbek-Hermel for several hazards.

1.1 Earthquakes

Lebanon is part of the African Rift Valley System that is crossed by the Dead Sea transform Fault System (DSF); DSF runs from the Red Sea (Sinai Peninsula) south to the Marias triple junction SE Turkey and forms the continental boundary between the Arabian plate to the East and the African plate to the south. The DSF splits in Lebanon into several faults; the off shore Beirut-Tripoli Fault (in 551. M7+), Yammouneh fault (last major event 1202 of M7.5), and Serghaya-Rachaya fault (2 events in 1759 of M6.5). Seismological trench studies along these faults showed that the return periods varies between 1100 and 1500 years (Daëron et al. 2007; Elias et al. 2007; Gomez et al. 2003). The most recent large earthquake took place on the 16th of March 1956 that killed around 136 people, destroyed 6000 houses and damaged 17,000 (Khair, Karakaissis, and Papadimitriou 2000). Geologist estimate that some of the faults in Lebanon are now sufficiently mature to provoke, at any time, earthquakes with magnitude higher than 7. This is due to the accumulation of sufficient deformation combined to a rich collection of previous paleoseismic and historical events (Salameh et al. 2016).

The Probabilistic Seismic Hazard is presented (Figure 4-1) in terms of peak ground acceleration and response spectral values for different specified annual exceedance frequencies, or return periods (Huijer, Harajli, and Sadek 2011). Baalbek-Hermel Governorate is crossed by two faults which are Yammouneh fault and Serghaya fault.

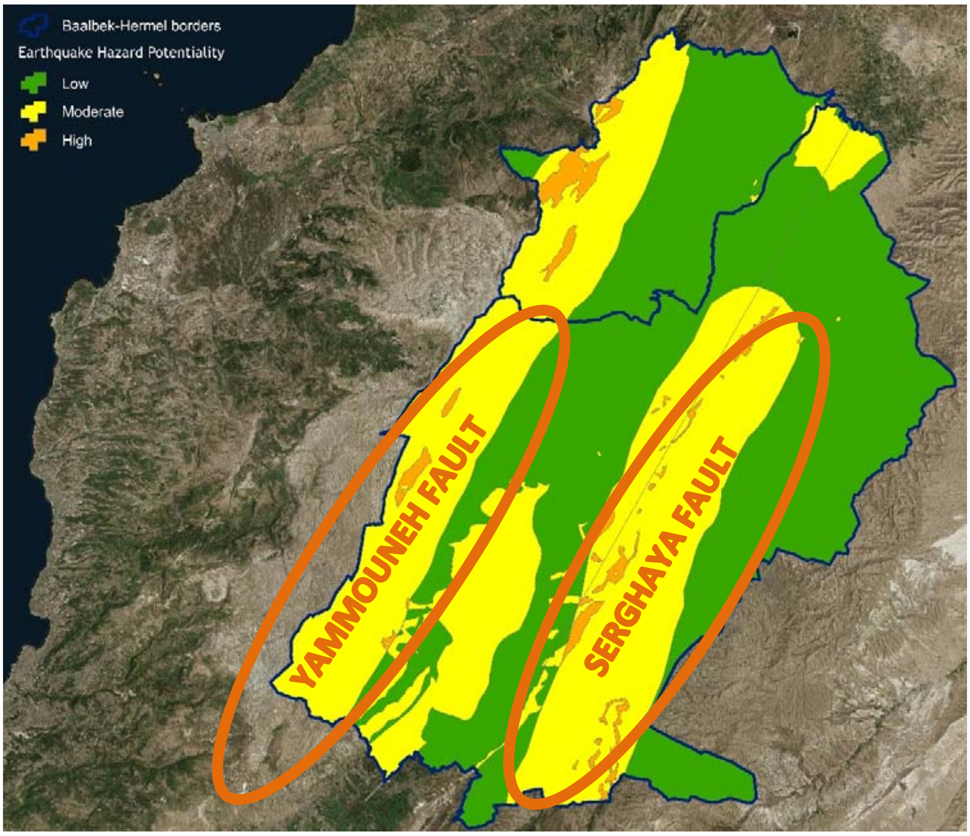


Figure 4-1 Earthquake hazard map Baalbek-Hermel.

This makes the Governorate very prone to earthquakes; over the years, it has suffered from numerous earthquakes that left their marks on the Temple of Jupiter and other ruins:

- In year 565 an earthquake of 6.7 Richter magnitude caused important destruction in Baalbek-Hermel.
- On the 5th of April 991, also an earthquake of 6.7 Richter magnitude caused enormous damages to Baalbek-Hermel Governorate
- The 12th Century witnessed several intense earthquakes; the most destructive earthquakes occurred in 1139, 1157 and 1170.
- On the 20th of May 1202, an earthquake of 7.5 Richter magnitude caused important destruction at Baalbek-Hermel and temples collapsed.
- On the 30th of October 1759, of 6.6 Richter magnitude earthquake hit Baalbek-Hermel followed by another earthquake on the 25th of November 1759, of 7.5 Richter magnitude causing destructions and more than 2000 dead. An important part of Baalbek temples collapsed, three of the nine still standing columns of the Jupiter Temple.

1.2 Floods

Floods in Baalbek-Hermel normally take place during the wet season, generally after a strong storm or at the beginning of the spring with the melting of the snow. During floods, rivers burst their bank causing damages to buildings and agricultural lands. The impacts of these events are dramatic involving annual financial losses, fatalities, loss of livestock, destruction to houses and agricultural lands, damage to structures, utilities and public services, in addition to triggering landslides. Baalbek-Hermel is crossed by the Orontes River (AL Assi) and the Litani River. The Litani River witnessed several floods in the past.

Flood Hazard Assessment and Mapping for Lebanon study was conducted in 2013 by the National Center for Remote Sensing (NCRS). The flood scenarios were prepared 0.1 exceedance probability (or return period T=10 years) as a high probability scenario based on the local history of flood events. A 0.02 exceedance probability (or return periods T= 50years) as a medium probability scenario. And a 0.01 exceedance probability (or return period T=100 years) as a low probability scenario to indicate the worst case scenario (Figure 4-2).

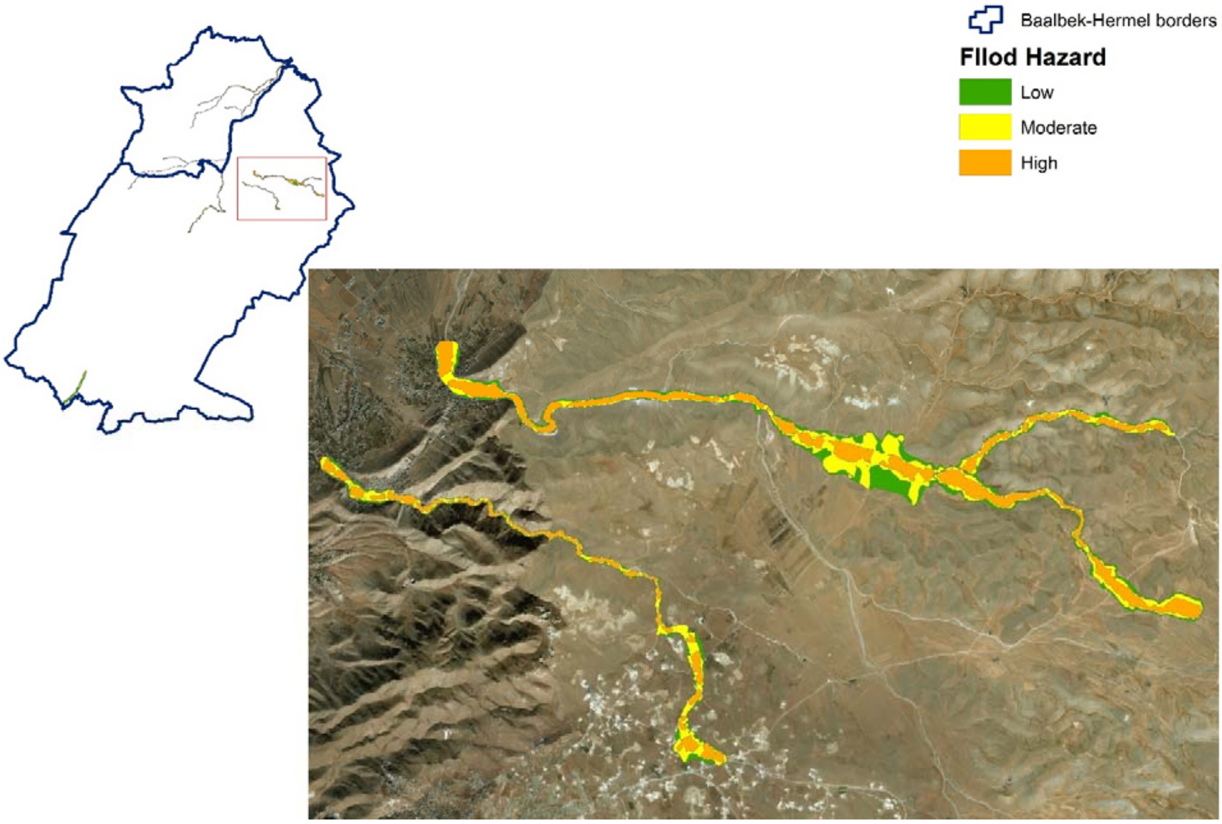


Figure 4-2 Flood hazard map for Baalbek-Hermel. Source: CNRS, 2013.

1.3 Landslides

Landslides constitute one of the major hazards in Lebanon; 10-15 millions of US dollars are the estimations of annual mass movements cost based on the last 40 years. These numbers are relatively high for a small country like Lebanon; alongside with numerous fatalities and injuries (Abdallah 2007; Khawlie 2000).The climatic, human and engineering geological parameters are contributing altogether to enhance landslides susceptibilities in Lebanon and especially in Baalbek-Hermel Governorate.

Cracks in buildings and roads, destruction of agricultural terraces, and escarpments of various sizes are notably common. Major movements occurred in 1860, 1914, 1924, 1948, 1954, 1956, 1960, 1983, and 2015. While minor movements occurs on a yearly basis. Some large movements are triggered by intense earthquakes, especially those of 1924 and 1956 (Khawlie and Hassanain 1984), and by periods of heavy rainfall in the middle or at the end of winter season, as well as man-induced activities involving the modification and degradation of landforms.

In spite of the negative impacts of landslides in Baalbek-Hermel, appropriate management plans are non-existing. Neither a risk map exists, nor have strategies as yet been formulated in the country for this purpose. Furthermore, lack of awareness among local population clearly indicates a misapprehension of the potential risks, and the carelessness and negligence of the contractors in implementing geotechnical site analysis may increase the damage costs; in addition there is a lack of legislative prevention measures on engineering firms that tend to apply minor and local mitigation measures at specific sites (Abdallah 2012). The CNRS mapped around 10, 000 different type of landslide in the country through visual interpretation of satellite imageries and published in 2010 the Landslide Susceptibility/Hazard maps at the scale of 1/ 50, 000. These maps (Figure 4-3) were based on the Binary-Univariate statistical approaches that explored objectively the dual relationship between 17 terrain parameter in relation to their contribution in provoking landslides (Abdallah and Faour 2017).

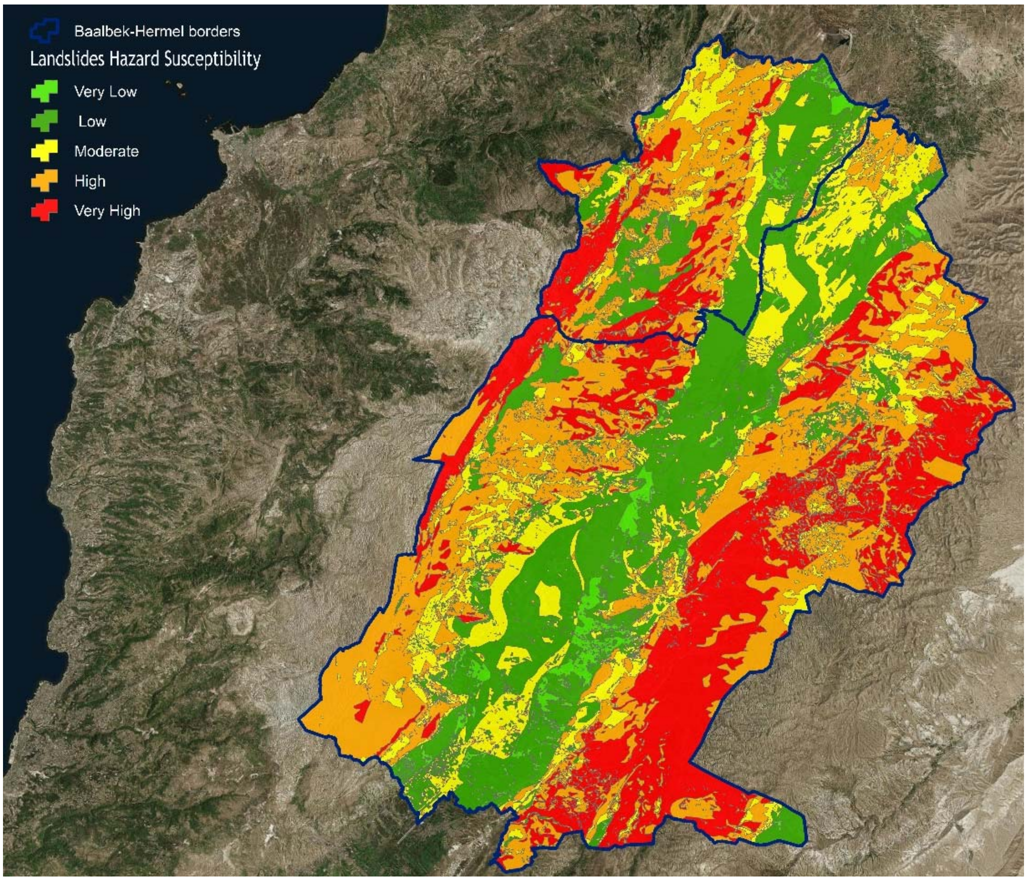


Figure 4-3 Landslide hazard map Baalbek-Hermel. Source: CNRS, 2015

1.4 Wildfires

Wildfires are of the threats to Lebanon's already vulnerable forests. One of the potential negative impacts of anthropogenic climate change is the increase in the frequency of forest fires. High temperatures and recurrence of droughts are significantly interconnected with an increase in the number of fires and areas burned in various types of forests (Chmura et al. 2011). In many cases, areas once burned and recovering their pre-fire conditions will be burned again. These circumstances are clearly conductive to progressive degradation of these ecosystems, altering their structural and hydrological soil conditions, reducing the total biomass, modifying the dominant vegetal species and affecting the land stability (Tessler et al. 2015). Accordingly, More than 35% of the initial forest cover has deteriorated during the last few decades leading to a forest cover reduction from 35% in 1960 to 13% in 2010 meaning a 22% in 50 years only (Abdallah et al 2015). In Lebanon, most forest fires occur between June and October (Mhawej et al. 2016) with a maximum frequency in August and September with 25 and 27 percent of fires, respectively (Faour, Bou Kheir, and Verdeil 2006).

A forest fire potentiality hazard map was established by the National Center for Remote Sensing of the CNRS (Figure 4-4). The approach was based on GIS modeling of related affecting factors such as topographic base parameters, Land cover use, road network, fire intensity of different vegetation types, and the intensities of these fires collected from the archive s of the newspapers and from the database of the civil defense (1983-2013).

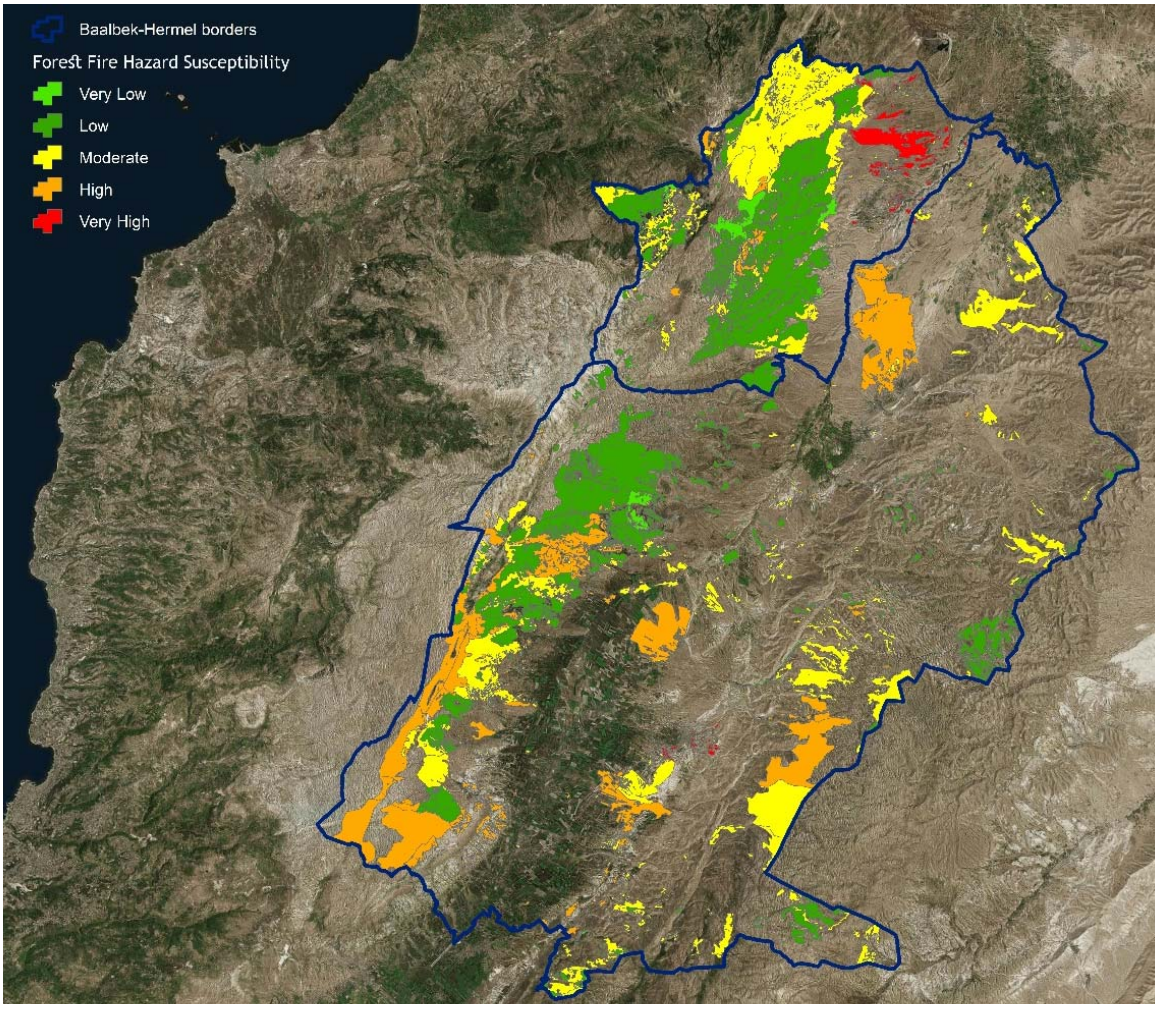


Figure 4-4 Fire potentiality map for Baalbek-Hermel. Source: CNRS, 2014

1.5 Storms

Baalbek-Hermel enjoys a harsh climate characterized by cold winters with temperatures falling below 0°, erratic rainfalls, heavy winds, frost and snow. The average annual rainfall is around 400 mm (MoA and FAO 2010), concentrated mainly from November to March. This period is responsible for 75-80% of precipitations with a maximum reached in January in which rainfall records can show 160-180 mm/month. Dryness takes over again from April to October. The 20-25% of the remaining precipitation constitute the fall thunderstorms and spring rain showers. The number of rainy days varies between 60 and 80 per year. The number of snow days is equivalent to 10 at 1000 m altitude and can exceed 30 days at altitudes higher than 1200 m. At least 10 snowy days are recorded in January. At 2000 m, snow becomes more frequent and represents 3/4 the quantity of precipitation. Snowmelt occurs gradually from April-May, but some plaques persist until fall season (Abdallah 2007). Severe storms are of frequent occurrence and a source of major concern throughout Baalbek-Hermel. On a yearly basis storms, with different intensities, hit Baalbek-Hermel and their combined perils of heavy rainfalls, snow, ice, freezing temperatures, and high winds cause damages mainly to the infrastructure and agriculture sectors. All sectors are threatened by risk of storms and have been affected during past events. Moreover, low-income populations and refugees constitute a considerable part of Baalbek-Hermel population, this increases exposure risk to severe storms and weather conditions because these people are more likely to live in low-quality, poorly insulated housing, informal settlements and even tents, without domestic heating or they are obliged to make tradeoffs between food and heating expenditures.

According to the historical records, storms belong to the most costly natural hazards in Lebanon. Based on the Higher Relief Committee (HRC), the losses from storms attended, between 2010 & 2013 alone, 45 M$ in Baalbek-Hermel Governorate. It is important to mention that 44% of this sum is the agricultural losses. Nevertheless, it is felt that there are still deficits with respect to research on storms hazards at a global and a national scale. Storm phenomena have complex and irregular spatial and temporal distributions that make it complicated to model and predict their behavior (Economou, Stephenson, and Ferro 2014). Moreover, storms constitute extensive risks with high frequency but low intensity, which makes them underestimated by DRR experts compared to earthquakes and other intensive risks, although their cumulated losses are considerable.

Storms archived records in Baalbek-Hermel from 1980 to 2018 were collected and geo-referenced by single storm event. Cluster analysis, by means of the space-time scan statistics permutation model (STSSP) in Spatial Scan Statistic (SaTScan) version 9.6 (Kulldorff et al. 2005), permits the detection of the space/time pattern distribution of storms. SaTScan is a common tool used to determine if points (in this case, recorded storm events) are randomly distributed in space and time or if they are clustered (Kulldorff 1997; Kulldorff et al. 2005). Knox's defines spatial clusters as "*geographically … bounded group[s] of occurrences … of sufficient size and concentration to be unlikely to have occurred by chance*"(Knox 1989). Scan statistics, are a family of methods introduced during the 1960s and first developed in the field of health sciences by (Naus 1965); their use has expanded into hazards and adapted for several risks applications like wildfires (Vadrevu 2008; Vega Orozco et al. 2012), casualties due to volcano's eruption (Witham and Oppenheimer 2004) and recovery process (Stevenson et al. 2010). However, SaTScan technology has not been yet utilized to quantify spatial patterns in storms occurrences and to assess storms susceptibility. This is likely due to the historical lack of data with the level of spatial or temporal resolution needed to evaluate "clusters" of storms.

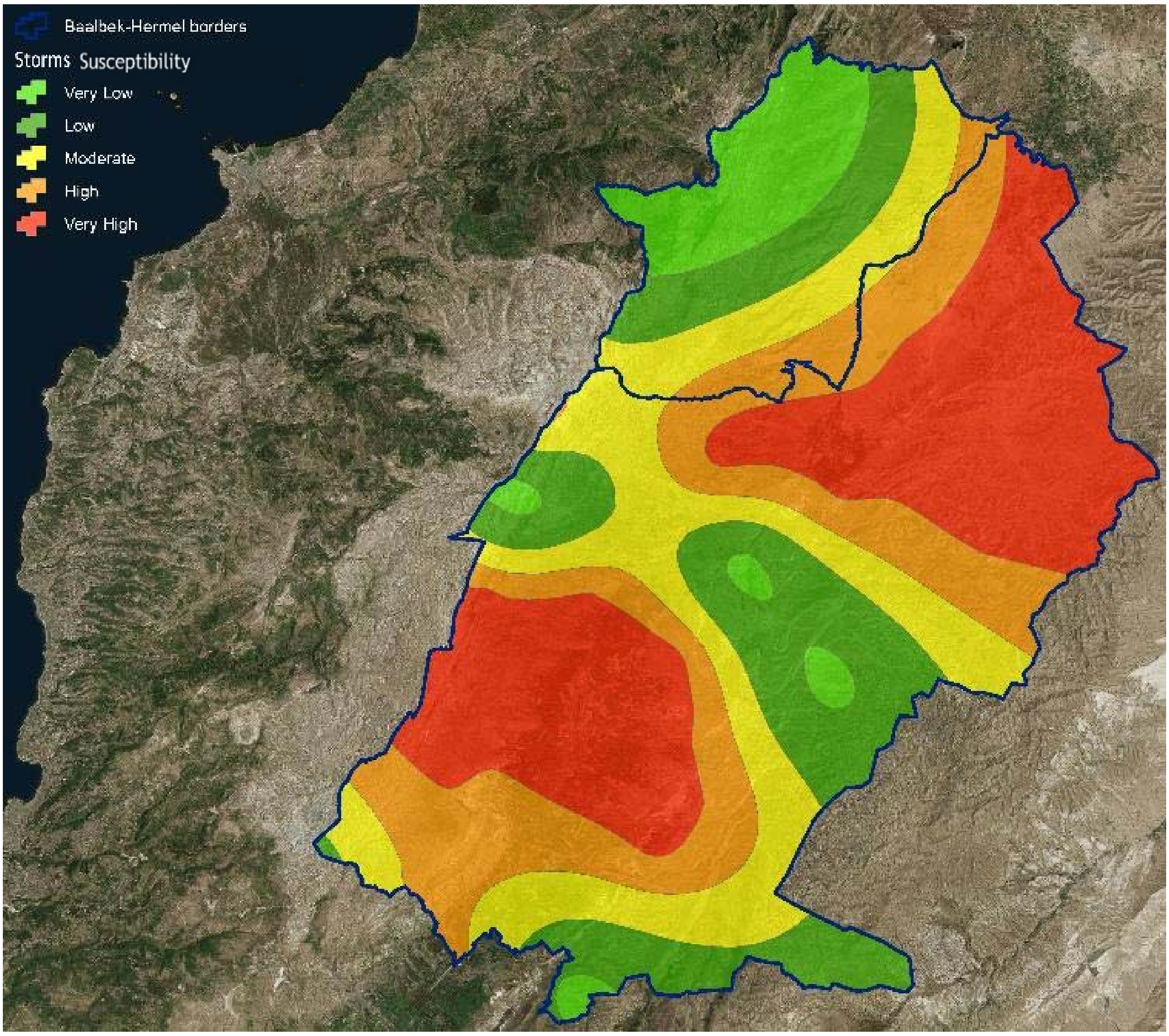


Figure 4-5 Storms susceptibility map for Baalbek-Hermel.

2. Historical disasters

An extensive effort has been conducted to summarize all major and minor events in Baalbek-Hermel governorate together with their impacts and damages. The methodology will be discussed in chapter III. The collected events are summarized in Table 4-1 below. It is important to mention that Data do not cover all incidents, only registered events are mentioned. Data collected in Baalbek-Hermel covers the period 1980 to 2017 (except for earthquakes) and presents 140 disaster events. It appears that storms cause most frequent disasters in the governorate, followed by floods with respectively 66 and 26 events. Baalbek-Hermel's disaster loss database records 1513 deaths, of which earthquakes caused the highest number of casualties. These events caused significant damage on buildings. The destroyed and damaged houses totaled respectively 46 and 499, ruined mainly by heavy rain, storms and flood.

Table 4-1 Summary of past events in Baalbek-Hermel (NA: Non-Available). Source: DesInventar, 2018

Event	Data cards	Deaths	Houses Destroyed	Houses Damaged	Indirectly Affected	Relocated	Losses $USD	Hospitals	Damages in crops Ha.	Lost Cattle
Cold Wave	1	2	NA	NA	NA	NA	NA	NA	NA	NA
Erosion	4	NA	NA	NA	NA	NA	NA	NA	NA	NA
Earthquake	5	1500	NA	NA	NA	NA	NA	NA	NA	NA
Flood	26	NA	10	30	27	NA	666666.7	0	0	0
Forest Fire	19	NA	NA	NA	160	NA	10866.67	0	48.85	0
Heavy Rain	18	1	25	270	NA	NA	302105.3	1	168.5	140
Sand storm	1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Storm	66	10	11	199	7022	30000	668833.3	1	385.7	115
Total	140	1513	46	499	7209	30000	1648472	2	603.05	255

It is necessary to point out the discrepancies and incoherence in the data, particularly as no financial losses are attributed to earthquakes (despite the 1,500 fatalities). Earthquake is considered to be the most threatening intensive hazard in Baalbek-Hermel Governorate, having caused enormous losses during historical events.

All these records, transformed to a GIS database, show that the consequences of earthquakes, storms, forest fires, floods and landslides are tragic including financial losses, casualties, injuries, loss of livestock, destruction to houses, roads bridges, vehicles, infrastructure and agricultural lands, damages to structures, utilities and public services, displacement of people and isolation of villages. The storms, considered as extensive risks, are the most recurrent in Baalbek-Hermel (around 50% of total records). They cause the highest losses, the relocation of around 30,000 people and damage to crops. Floods are the second most recurrent in this governorate. Heavy rains also cause the destruction of a considerable number of houses. The shared basin of Aarsal and Ras Baalbek is prone to exceptional and erratic rainy events caused by high humidity combined with hot temperatures. The resulting flash floods result in considerable losses due to damage to properties (houses, orchards, shops, livestock, etc.) and the injury, displacement or even death of people. Each flood event can lead to 5 million dollars of direct damages. The strongest reported flood in recent times lasted for 15 hours covering only one watershed. Concerning human losses, they are recorded during earthquakes, considered intensive risks.

The summary of geographic distribution of disaster damages and losses in governorate during the period is displayed in Figure 4-6 . Most events occurred in Baalbek city (47), followed by Aaynata Baalbek (10), and Hermel (9).

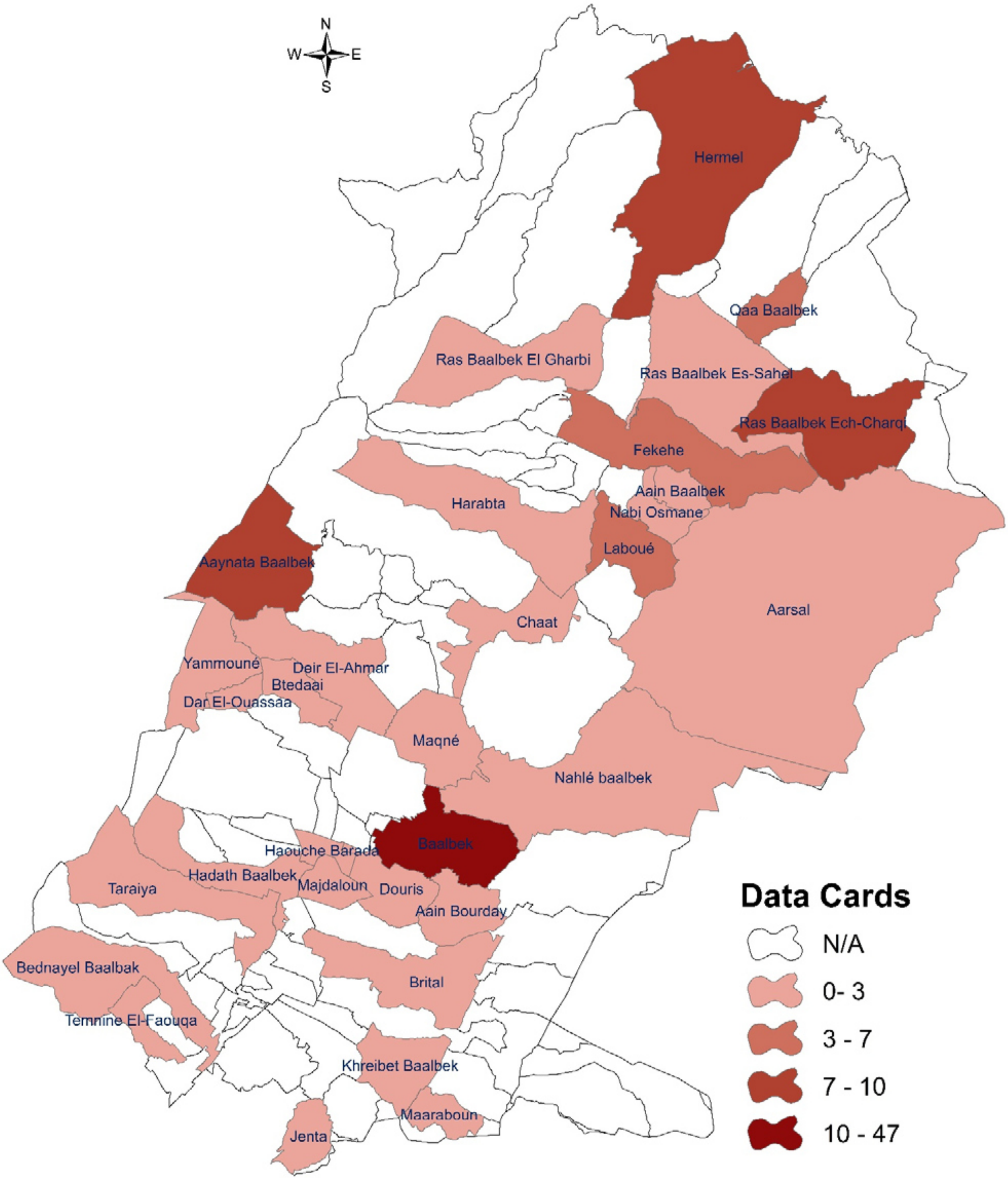


Figure 4-6 Past disasters distribution in Baalbek-Hermel per village. Source: DesInventar, 2018

The records have revealed that the Governorate of Baalbek-Hermel registered considerable percentages of damages among those registered in Lebanon (Table 4-2). 10% of registered national deaths were recorded in Baalbek-Hermel. Noting that this governorate is among the least populated ones in Lebanon, this percentage is considered relatively high. Moreover, around 37% of damaged and destroyed houses and 90% of relocated people from natural disasters are recorded in Baalbek-Hermel. These numbers related to damage on houses, hospitals and relocated inhabitants pinpoint the underlying lack of land-use planning and absence of building codes implementation.

Table 4-2 Disasters and their impacts in Baalbek-Hermel and Lebanon 1980-2012. Source: DesInventar, 2018

	Baalbek-Hermel		Lebanon Total
	Number	Percentage	
Data Cards	137	5.90%	2339
Deaths	14	9.60%	146
Injured	13	1.60%	810
Houses Destroyed	46	31.70%	145
Houses Damaged	499	36.80%	1356
Losses	1648472	18%	9117635
Affected	7209	1.30%	562917
Relocated	30000	90.30%	33222
Evacuated	125	2.50%	4983
Affected hospitals	2	66.70%	3
Damages in crops Ha.	603	3.50%	17438.45
Lost Cattle	255	5%	5067

The big number of fatalities and large amount of damages made Baalbek-Hermel governorate, already facing economic problems and debts, unable to cover the damages expenses. Moreover, most people are not able to cover the expenses of recovery from damages alone while insurance policies don not cover any natural disaster.

3. Disaster Risk Reduction Actions in Study area

Strategies in Baalbek-Hermel used to tend toward those that promote adaptation and fast recovery instead of investment in mechanisms which harden assets against loss. In the last three years, several DRR actions happen in Baalbek-Hermel governorate with the support of the Swiss Agency for Development and Cooperation, the Embassy of the Netherlands in Lebanon, the European Union in Lebanon, the German Embassy in Beirut, and the Government of Kuwait. Baalbek-Hermel has a DRR committee since 2015. This DRR committee undergo many trainings in order to improve its capabilities (Figure 4-7). In 2016, the Regional Operation Room (ROR) for crisis management in the

Governorate of Baalbek-Hermel was launched by the UNDP Disaster Risk Management project at the Presidency of the Council of Ministers.

Figure 4-7. Training for enhancing Baalbek-Hermel DRR committee capacities in the presences of the governor and representatives of ministries (governorate operational room- Baalbek June 2015)

In 2014, the UNDP project "*Flood risk management and soil conservation for livelihood recovery in Baalbek-El Hermel*" funded by the Lebanese Recovery Fund and implemented in partnership with the Ministry of Agriculture, took some structural flood protection measures in an attempt to reduce the losses. These measures (Figure 4-8) consisted of reservoirs and walls to obstruct flood waters and consequently decrease the damage in the concerned villages. Although these flood risk management structures were claimed to save lives of the locals and the Syrian refugees after May 2014 extreme intensity flashfloods, due to poor maintenance and other reasons, flash floods in recent years have caused significant losses and even some fatalities.

Figure 4-8. Flood Risk Management Structures in Aarsal. Source: DRM unit, 2014

Efforts to preserve Baalbek-Hermel's cultural heritage sites and safeguard them from natural and manmade disasters are being taken. On April 2016, a study titled "*Towards Developing a National Strategy for the*

Protection of Cultural Heritage Sites in Lebanon” was launched at the archeological site of Baalbek, and opened up discussions on the necessity to establish a common national roadmap to protect the historical heritage from natural disasters. This study was launched under the auspices of the UNDP Disaster Risk Management project at the Presidency of the Council of Ministers in cooperation with the Ministry of Culture and UNESCO, Governor of Baalbek-Hermel, UNDP Country Director, the Secretary General of the Supreme Council of Defense of Lebanon, UNESCO Programme Officer for Culture, the Counsellor of the Embassy of Italy, the Director of General of the Antiquities Directorate, Head of Baalbek Union of Municipalities. This project recognizes that the protection of cultural heritage against disasters is an important intersectoral issue for all international frameworks.

On May 2017, a tabletop exercise was organized for the first time in this region, simulating a flood scenario on borders of Assi River (Figure 4-9) in order to build resilience in response to disaster risk. The exercise was attended by several officials and the region's dignitaries was organized under the patronage of the President of the Council of Ministers Mr. Saad Hariri who followed the simulation from the National Operations Room (NOR) with several ministers in the Grand Serail in Beirut using a special communication system, tested for the first time, connecting the NOR with a Mobile Operations Room (MOR) present close to the flood area. During the call, Baalbek Hermel Governor Mr. Bashir Khodor briefed the Prime Minister on the situation on the field and the measures taken for rescue and evacuation. In fact a public school and a Syrian refugees camp located near the flood area were evacuated to safe sites, and several injured and casualties were rescued from the river and transferred to the nearest hospitals. The simulation offered the opportunity to put into action the disaster risk response plan, exclusively designed for the governorate of Baalbek-Hermel by Governor and the Governorate’s DRM Committee, representing all the administrations, ministries, key local stakeholders, Civil Defense, Lebanese Army, Internal Security Forces, and the Lebanese Red Cross in the region and making use of the latest floods risk assessment that was conducted by the CNRS and UNDP in 2015.

Figure 4-9 Flood simulation in Assi River, May 2017

French summary Part II:

Cette partie travaille la zone d'étude. La collecte et l'intégration de données via un SIG est utilisée en premier lieu dans la description de la zone d'étude. Baalbek-Hermel, l'un des huit gouvernorats du Liban, constitue le domaine d'étude de cette thèse. Le gouvernorat de Baalbek-Hermel est soumis à de nombreux aléas en raison de son emplacement géographique, de sa topographie ou, plus récemment, de processus environnementaux historiques sans précédent, qui ont provoqué des catastrophes que la région a rarement connues.

Baalbek-Hermel est un gouvernorat relativement pauvre, dont l'économie repose principalement sur les secteurs agricoles. Ces problèmes économiques, associés à une croissance démographique importante et à l'exode des réfugiés, posent certains problèmes techniques à sa communauté. Ainsi, les services publics et les infrastructures sont sévèrement mis à l'épreuve, par exemple, le réseau routier est saturé, le réseau électrique est témoin de nombreuses coupures de courant par jour, etc… Baalbek-Hermel, comme le reste du Liban, peut même servir de modèle en ce qui concerne les questions relatives à la gestion et à la réduction des risques naturels dans les pays en développement. En réalité, ce territoire concentre un ensemble assez divers de risques naturels et doit faire face à une croissance démographique continue, exerçant une pression continue et une exposition croissante aux risques. De plus, le gouvernement libanais est considéré comme un État fragile, ce qui amplifie la vulnérabilité de Baalbek-Hermel et entrave le déroulement d'actions efficaces de RRC.

L'utilisation du SIG, pour la protection civile, commence à apparaître au début de cette étude. Afin de connaître les caractéristiques de notre zone d'étude, toutes les données collectées ont été intégrées dans un système géographique. Des cartes et des données géospatiales ont également été rassemblées auprès du Centre national de télédétection du CNRS-Liban.

Part III. Geospatial Application to DRR

Part III. Geospatial Application to DRR

With the increasing trend of natural disaster losses, disaster risk reduction, as an applied science, is becoming more important. How to better use GIS to mitigate natural disaster risk in Baalbek-Hermel, and Lebanon in general?

This part constitutes the bulk of this dissertation. It addresses several case studies of GIS implication in every phase of the DRR cycle; this part covers the geospatial information preparation phase that could serve the entire cycle, the prevention phase, the phase of preparedness and response planning and the recovery phase.

Chapter 5 . Preparation of Geospatial information, a focus on Population Data.

This chapter discusses the role of GIS in creating geo-databases, treating it and thus serving the DRR cycle. The spatial data have many requirements to be adequately integrated in GIS and give accurate results to be implemented in the DRR cycle. These requirements are evoked and detailed in this chapter. The methodological approach adopted in this dissertation is developed, covering all the various stages necessary for the construction of geo-database to serve all phases of DRR cycle risks in following chapters. These stages start from data acquisition, storage, system management and access to the final treatment of these data which is known as geo-processing.

1. Methodological Approach

The spatial information requirements of disaster reduction and management often overlap those of government departments or organizations, and relevant data may already exist and be stored. Good quality spatial data, essential in all areas of disaster reduction, is hard to come by, especially at the local level in developing countries (Herold 2012). Data sharing intrinsically linked to underlying politics, institutions and social conditions (Clark and Guiffault 2018). For example, the transportation network is present in the Ministry of Public Works and Transportation in the form of obsolete paper maps (dating back to the 1970s). The Ministry of Energy and Water does not have maps locating gas stations and, although they have the maps of electrical and hydraulic networks, they are not ready to share them with another institution even if it is governmental one for reasons of national security.

Within the midst of data scarcity, data gathering was rendered an exhaustive task and adopting conventional methodologies was not enough.

Accordingly, an extensive work was conducted to summarize all major and minor disaster events in Baalbek-Hermel along with their consequences and damages. A database for events affecting Baalbek-Hermel was prepared by the researchers through screening old documents and archived microfilms of Lebanese newspapers like "An-Nahar" and "As-Safir" from year 1971 to date (Figure 5-1). This database is now available at CNRS and is updated daily by gathering events records from newspapers like “AL-Akhbar”, “Aliwaa”, “As-Safir”, “AlMustaqbal” and many other websites like “Tayyar”. Recorded events are transformed to a GIS database and allocated to equivalent Municipality levels.


المتن وعاليه: العاصفة مرت من هنا.. أضرار الزراعة المحمية بملايين الدولارات

١٥٠ ألف دولار من اليابان لمتضرري العاصفة
كوارث زراعية في حاصبيا ومرجعيون وازدحام في ضهر البيدر
العاصفة حطمت ٩٥٪ من زيتون المنطقة

الخسائر الأكبر في بر الياس والأضرار شملت المواشي والمواسم الزراعية
إحصاء أولي بأضرار البقاع الأوسط استناداً الى مصادر البلديات

١٥٠ ألف دولار من اليابان لمتضرري العاصفة
كوارث زراعية في حاصبيا ومرجعيون وازدحام في ضهر البيدر
العاصفة حطمت ٩٥٪ من زيتون المنطقة

Figure 5-1 Collected archived microfilms of Lebanese newspapers recording natural disasters

Moreover, historical events for Baalbek-Hermel data were collected from DesInventar (Sistema de Inventario de Desastres) database, a conceptual and methodological tool for creation of National Disaster Inventories and the construction of databases of damage and losses all what disasters can induce. This conceptualization was developed by UNDP and UNISDR and compiles information about the type of natural event recorded, date of occurrence, location of incidence (administrative levels), number of deaths, number of affected, injured, displaced people, economic losses (some recorded in local currency and some in USD $), damage to agriculture and livestock, damage to infrastructure like roads, education centers, etc., for the period extending from 1981 till 2018. Some of natural events and damages records were also collected through meetings conducted with the Lebanese Supreme Commission for Relief (الهيئة العليا للإغاثة) during previous studies. Data requested include the elements at risk, nature of damages in the Governorate, cost of damages and method of estimation of damages.

There are base data within various ministries and centers related to exposed elements; however, this data needs collation and validation. Therefore, even for the validation of the base maps, some data collation and validation is first necessary. Some missing data were retrieved from OpenStreetMap (OSM). OSM is an open, web-based crowd-sourced map, through which data sets and information may be freely accessed and used, subject only to certain basic license conditions relating to sharing and attribution (Clark and Guiffault 2018).

As discussed earlier, indigenous knowledge and bottom-up approach are extremely important, thus interviews were achieved in two timeframes. First interviews were gap-filling interviews aiming at collecting background data about Baalbek-Hermel assets in order to complete the database. The main findings were integrated in the study and served completing the governorate background database. Second interviews were consultation meetings with selected stakeholders presenting different sectors and representatives of the governorate operation room. The community consultation meetings started with an open discussion on various types of hazards that affect Baalbek-Hermel. In a second step, the identified hazards were ranked into matrix according their probability to occur and their impact on the governorate. After risk profiling, locals were invited to provide recommendations on how to overcome challenges and better cope with the identified risk. Indigenous knowledge of people living and working in hazard-prone areas should be considered as complementary to scientific knowledge in the establishment of community-based disaster risk reduction plans.

In all meetings, interviewed people were asked to fill in risk matrix, shown in Figure 5-2 below, by placing the risks and threats according to their perceptions and past experiences.

	Impact					
Probability	Very small	Small	Moderate	Severe	Critical	Disastrous
Major probability						
Probable						
Less probability						
Minor probability						
Very little probability						

Figure 5-2 Risk matrix to be filled accordingly to locals' perception

The probability levels could be explained as follow:

- Major probability: More than once per year
- Probable: Once per year
- Less probability: Once every 3 to 5 years
- Minor probability: Once every decade
- Very little probability: Once every 50 years and above

In the impact levels, many factors are involved:

- Death & injuries
- Affected sectors
- Affecting livelihoods
- Geographical extent of impact (local, national, regional)
- Economic losses
- Recovery time
- External help and compensation

The main aim of these interviews was to introduce participants with desk research findings, downscale vulnerability assessment findings and exposure maps produced for their governorate and then derive their comments, updates, recommendations through:

- Discussion on various types of hazards that affect activities and sectors of the participants

- Ranking of presented and identified hazards according to their probability of occurrence, probability of occurrence and to participants perceptions. This ranking helped completing hazard matrix and seasonal risk calendar.
- Discussion and approval of the business as usual and worst-case scenarios accorded to their governorate specific sectors.

A careful assessment of available data including field surveys and statistical analysis were conducted, resulting in the creation of a data product called most likely status. All these collected data are of very varied nature, they gather spatial and non-spatial data, historical documents, multimedia documents, and real-time data necessary for the monitoring of phenomena. The diversity of formats and data structures remains an important problem that must be considered during the integration phase. To standardize the collected data, collation and validation have been carried out. Spatial data was linked to non-spatial data (attributes) and field based data so that they can be visualized in the form of maps, which can then be used in cartography-based modeling to provide inputs for risk mapping. In most cases, this data has been digitized and georeferenced in a format that allows the integration of base layers such as new location components (new raster and vectors) and metadata such as accurate descriptive information. All these collected data and records are organized in a dataset and converted into GIS formats, allocated to equivalent location, and assembled in GIS geo-database through an established model (Figure 5-3).

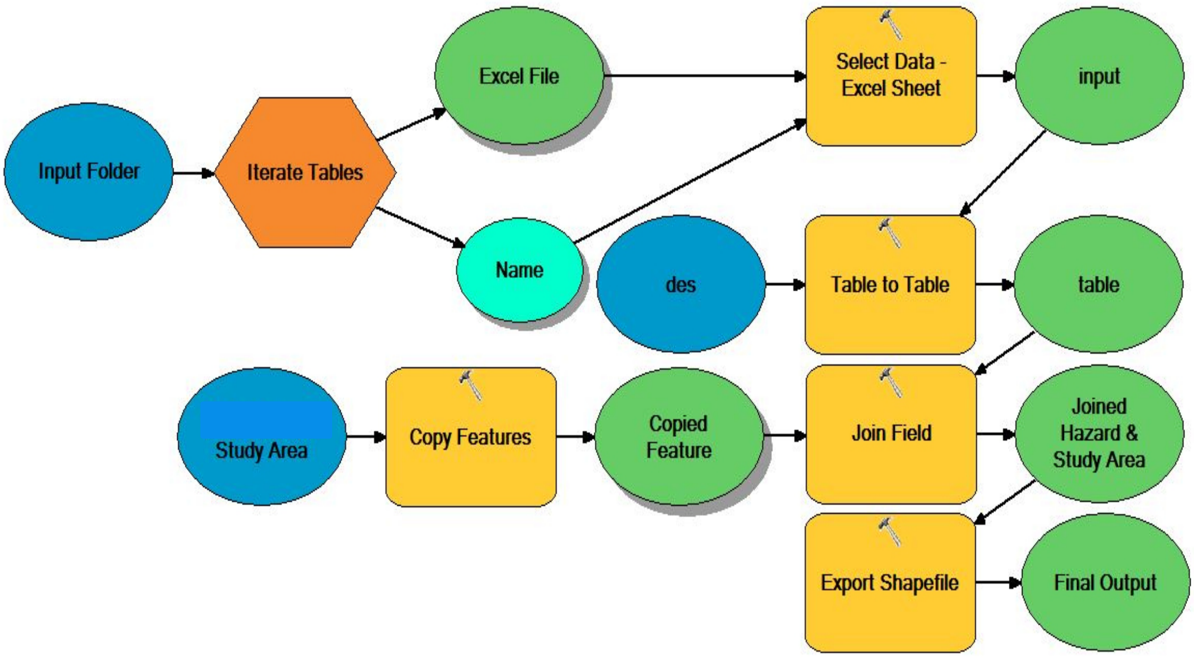


Figure 5-3 Established model for transforming the collected data into geospatial databases

The created geo-database can be directly accessed, visualized and updated by entering existing survey information or even information collected in the field using a GPS device with GIS integration capabilities.

Geo-processing the collected data allows to gain new information from existing data through a series of GIS functions and operations. The utilized functions fall into three categories: data extraction, overlay, and proximity. The data extraction was used to create a new subset of features based upon the extent of another feature class. In an overlay function, combination of layers, extraction of needed attribute information from all layers were possible. To find features that are new or within a certain distance of other items, the proximity methods were adopted. To make the geo-processing goes faster models, containing a selection of geo-processing tools automatically executed in order, were run. Models provide many benefits: 1) graphical representation of all the processes used to find the end information (simplify a complex workflow), 2) can be reused indefinitely or have its parameters altered to perform new functions and 3) can be shared so that every team member working in GIS can quickly perform the exact same process. Furthermore, models and geo-processing enable the spatiotemporally analysis of data and thus serve for hazard, exposure, vulnerability, risk assessments, land use planning, etc…ultimately covering the different phases of the DRR cycle.

The collected information about the inhabitants of Baalbek-Hermel wasn't enough especially for preparedness, response and accurate risk assessment; the geo-processing of this data was necessary to accurately estimate population distribution at a finer resolution. Figure 5-4 resumes the workflow of the dasymetric method (Balk et al. 2006) adopted to estimate population in this dissertation.

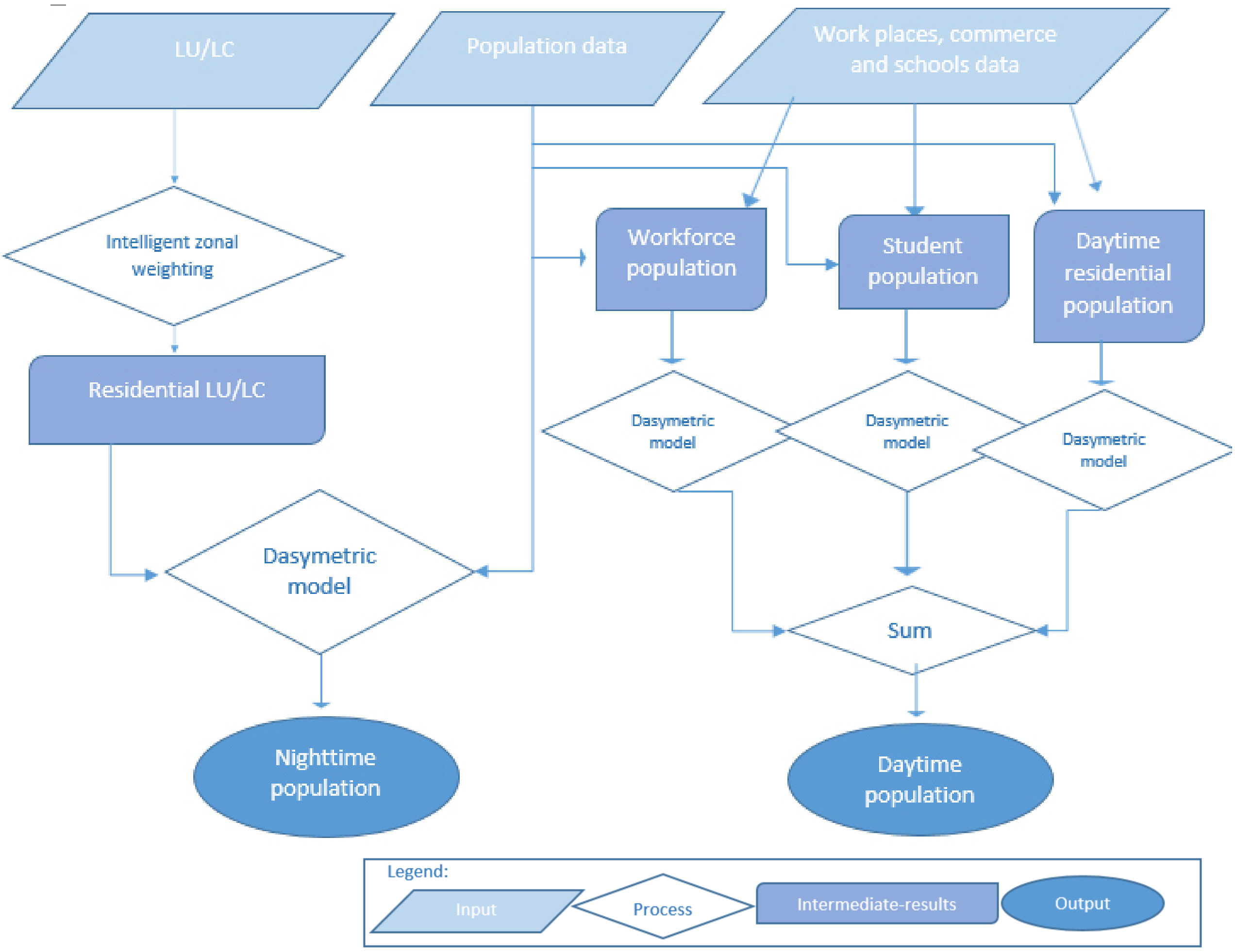


Figure 5-4 Flowchart of main tasks involved in modeling the spatial and temporal distribution of Baalbek-Hermel population.

Population data was collected, at the village level, from Population Explorer (2019) worldwide source that interpolates information of the last population census and based on demographic parameters (growth rate, deaths, etc…). These numbers are evenly distributed on all the area of the village (Figure 5-5-a), even though some areas are totally uninhabited. Moreover, people are often in other locations during the day. This distribution at the village level was not efficient for precise risk assessment and effective disaster response. What was needed is finer-grained averaging; that is, to disaggregate area-based population data at a finer spatial resolution. To estimate the population, micro-spatial distribution, among the methods mentioned earlier, an aerial interpolation and disaggregation method was used, the dasymetric method. This method is a thematic "top-down" mapping that refines the spatial accuracy of aggregated data using ancillary information to divide the areas into zones that better reflect the statistical variation of the population distribution. The dasymetric method was chosen because it is assumed to be one of the most accurate in previous testing (Eicher and Brewer 2001) and the most feasible with the available data, linking the Land use data depicting urban settlements and buildings with the administrative population census (Fisher and Langford 1996). The disaggregation of population counts (Figure 5-5-b) in urban spaces followed the assumption that areas with similar land cover will have similar population densities in one village (Anderson et al. 2014). The basic assumption for distributing population based on land use/land cover classes was that people would be concentrated only within residential classes, with higher densities in dense urban areas and decreasing densities as we move towards suburbs. Thus, based on the fourth level land use/land cover produced by NCRS-Lebanon based on CORINE classification and adopted for Lebanon at a scale of 1/ 20,000, categories implying urban specifications were given simple weights (Table 5-1) and resulted in the establishment of three urban-residential classes and one exclusion class representing all unpopulated zones (Holloway, S., Schumacher, J., Redmond, R. 1997; Mennis 2003).

Table 5-1 Assigned weights for urban classes based on population densities

Land use/Land cover fourth level categories	Assigned weights	Reclassified	Urbanization classes
Medium density urban fabric	6	1	High density
Dense informal urban fabric	5	1	
Low-density urban fabric	4	2	Medium density
Urban sprawl on low density forests	3	2	
Urban sprawl on dense forest	3	2	
Urban sprawl on shrub lands	3	2	
Low-density informal urban fabric	2	3	Low density
Industrial or commercial area	1	3	
Others	0	4	Uninhabited

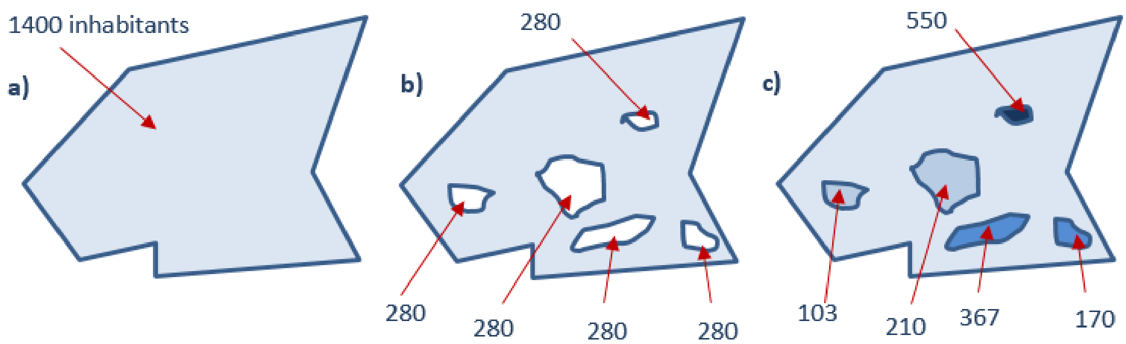


Figure 5-5 A simplified representation of the applied steps in dasymetric method with a) total number of people aggregated by the village which is the census delineated unit, b) populated (white) versus unpopulated (blue) zones with populations uniformly dispersed within the inhabited land use, and c) an "urban 3-class method," where populations are distributed in high, moderate and low (from darker to lighter blue respectively) population classes based on land-use class code and areal weighting.

The total population of each village, extracted from Population Explorer (2019), was used as primary base input along with the village areas and the assigned weights of each land use/land cover category falling within the village. The newly generated land-use/land-cover layer is rasterized at a 50-m resolution corresponding to the target zones in the population data interpolation per village. The population data layer was overlaid

and intersected with land use/land cover layer considered as ancillary data layer. To estimate population of respective land use/land cover polygon within each village, a statistical model was run to automate the disaggregation following areal weighting and empirical sampling of corresponding densities which gives a three-level population density distribution at a resolution of 50-m pixel.
The method adopted in this algorithm, called intelligent dasymetric mapping, introduces sampling of the population into the area of origin to quantify the population density in the ancillary data classes, in a way to prepare the dasymetric mapping more realistically (Neves, Strauch, and Ajara 2017). This intelligent dasymetric mapping technique downscales from source populations to target populations P for each land cover cell (pixel). The algorithm accounts for an origin area "o", an auxiliary area "d" attributed to the auxiliary class "c" and a target area "t" representing the intersection areas between o and d. Consequently, the calculation of population counts in the target area follows Equation 5-1:

$$\mathrm{Pd} = Po\left(\frac{At.Dc}{\sum(At.Dc)}\right)$$

Equation 5-1 Algorithm used for population disaggregation model

In which: P_d is the estimated total population; P_o is the population of the origin area; A_t is the overlapping area among the origin and ancillary areas; and D_c is the population density of the origin area.
Regression analysis of the population and ancillary layers are behind these estimated population (Nagle et al. 2014).

One of the practical advantages of this algorithm is its pycnophylactic, or volume-preserving aspect. The target populations are coherent with the origin populations; as if summing up the obtained estimates from dasymetric method, the numbers of origin populations are found (Tobler 1979).

The implementation of a micro-scale day-time population density map offers a realistic snapshot of who is on the ground when a hazard occurs, thus reflecting the actual risk. The methodology for detecting the diurnal temporal shift in population during work hours and calculating daytime population density is more complex than the previously calculated nighttime population. This difficulty is due to the lack of uniform information related to people's location during a given working day. A combination of work places, schools, commerce and age variables were collected from various databases to estimate population distribution per land parcel during workdays. The x,y location of every business and every school was spatially joined to land use/land cover polygons. The number of students in each school was gathered, but no data indicated the number of employees. To solve this issue, having the number of each age group in each village, assumptions were made; 0-4 years and 65^{+} years normally stay at their residence, 5-18 years are schools students, 20-64 are employees taking into consideration the unemployment rate (residing at home) in Baalbek-Hermel. The applied equation revealing the transfer of population to the daytime inhabited areas is a simple subtraction equation. With the adjusted daytime population, the dasymetric model used previously for nighttime population can be run.

As for every model, evaluation and validation are necessary. Generally speaking, this validation is conducted through a comparison of the dasymetric modelling results with collected actual numbers through linear regression analysis to determine the correlation coefficient, R^2 between estimated and actual population counts. Usually for rigorous quantitative assessment of results derived from this type of models, two methods are adopted for collection of actual numbers; 1) "ground truth" through field campaigns to give estimation for population, 2) higher-resolution of population census reference datasets.

However, the driver behind this methodology, as for many studies of this type, is precisely the absence of a suitable reference database for residential and worker count data, a fact that limits the scope of validation (Dobson et al. 2003; McPherson and Brown 2004). As a result, field surveys were conducted with the support of the Lebanese Red Cross DRM unit in an attempt to obtain reliable data for the validation process (Appendix I). People usually are comfortable cooperating and sharing information with Lebanese Red Cross members. Field surveys were an attempt to collect the following useful information for validation of nighttime and daytime population distribution:

1. Population numbers per settlements.
2. Verification of workplaces', schools' and commerce's addresses through cross-checking with used locations.

2. Results & Discussion

All the collected information above have allowed the execution of a detailed dasymetric method (described earlier in the methodology) and revealed Baalbek-Hermel population distribution at 50 meters pixel size/grid resolution, for daytime and nighttime.

Figure 5-6 displays the night and day population distribution for the whole Governorate of Baalbek-Hermel aggregated at 1 km² resolution (as mentioned previously, raw databases are at 50 m resolution). This figure reveals that major shifts between the day and night population are in the cities of Baalbek, Hermel and Aarsal respectively.

Zonal statistics were conducted, through GIS, to calculate the difference between the two raster of nighttime and daytime populations. Results are shown in Figure 5-7 and reveal the percentage of difference between the day and night population derived databases of Baalbek, Hermel and Aarsal cities in the downtown regions. In these regions, the daytime population is 36 to 42 percent greater than the nighttime population highlighting that considerable variations do exist in the spatial distribution of populations throughout the day periods. In fact, these city centers, contain the largest number of work places and commerce in Baalbek-Hermel governorate. This spatial-temporal population variation should be taken into consideration in every hazardous scenario.

A zoom into these city centers, in Figure 5-8, 9 and 10 show comparisons of the nighttime and daytime population models for Baalbek, Hermel and Aarsal, respectively. In every city, a daily migration from the surrounding residential/suburban areas to the city centers from night to day is clearly observed.

Field verification surveys conducted for workplaces', schools' and commerce's addresses cross-checking with used locations showed an accuracy of around 93%. However, on-field validation of population numbers per settlements was extremely difficult due to lack of official numbers; some mayors refused to cooperate, some other gave numbers they think right; downscaling to the neighborhood level, each met person gave a totally different number.

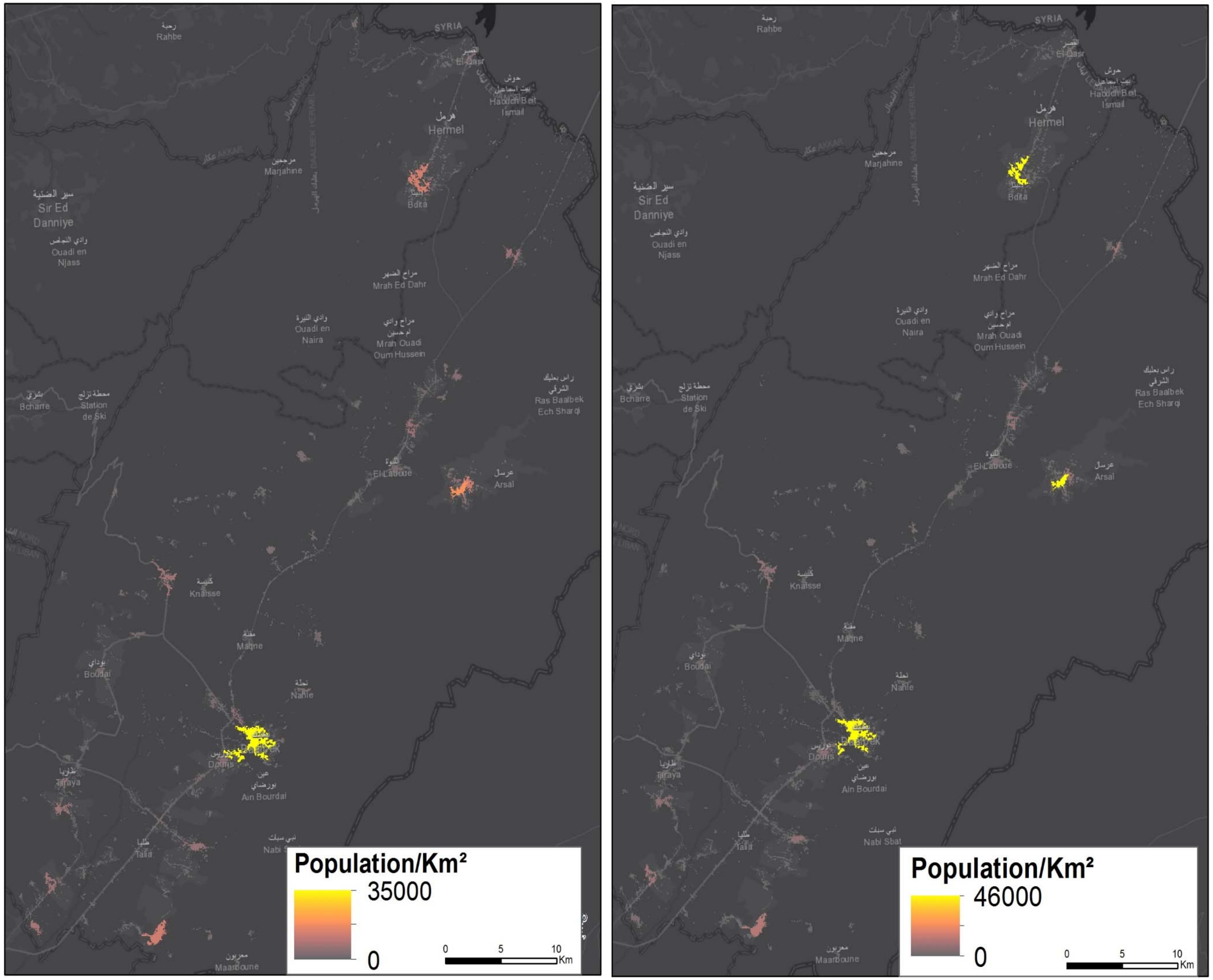


Figure 5-6 Derived nighttime (left) and daytime (right) population aggregated to 1 km² resolution (Raw databases are at 2500 m² resolution) for Baalbek-Hermel Governorate.

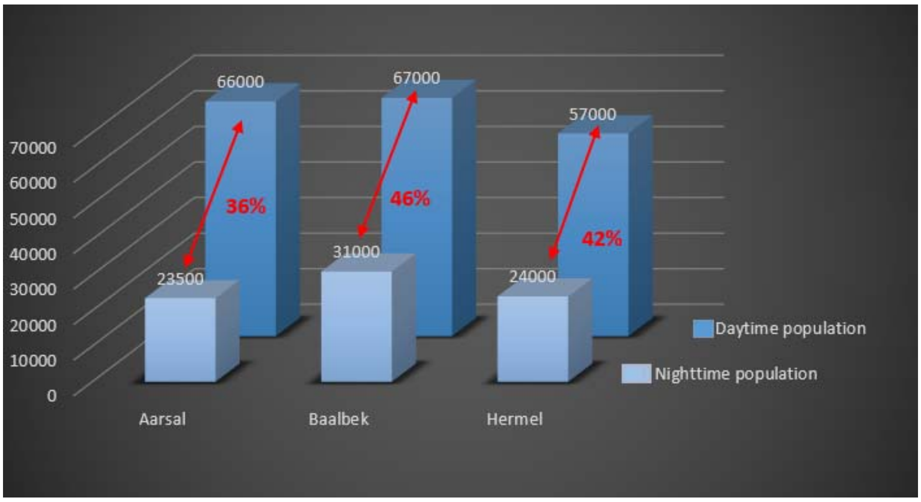


Figure 5-7 Daytime versus nighttime Population counts in the city centers.

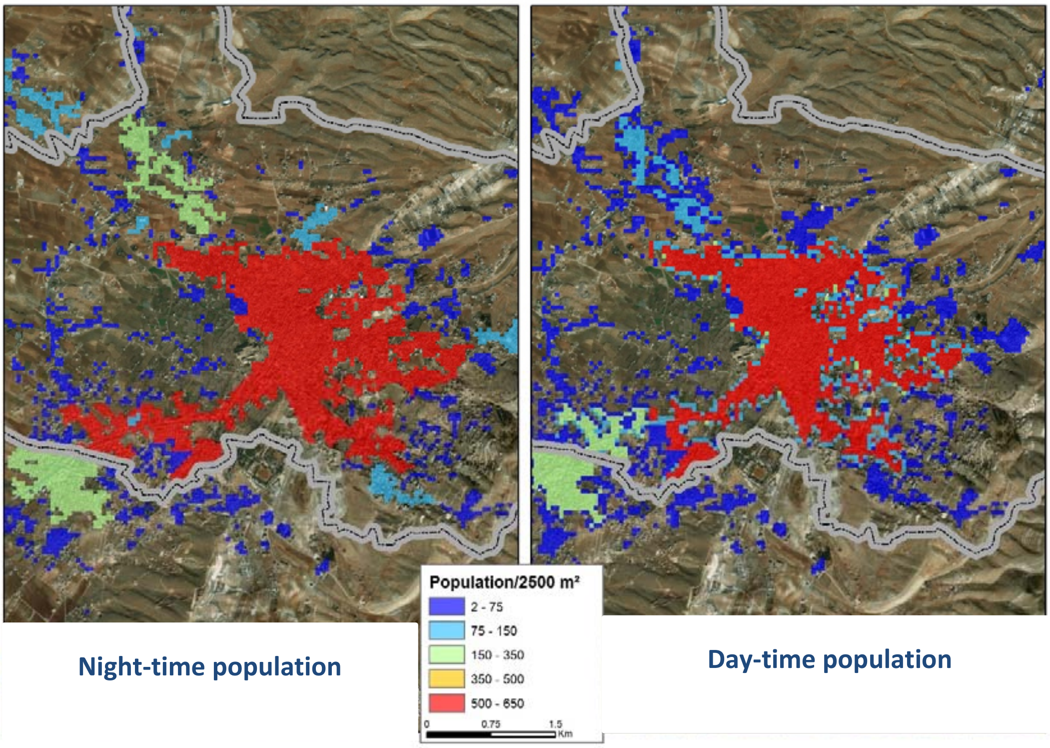


Figure 5-8 Nighttime population versus daytime population distributions in Baalbek city

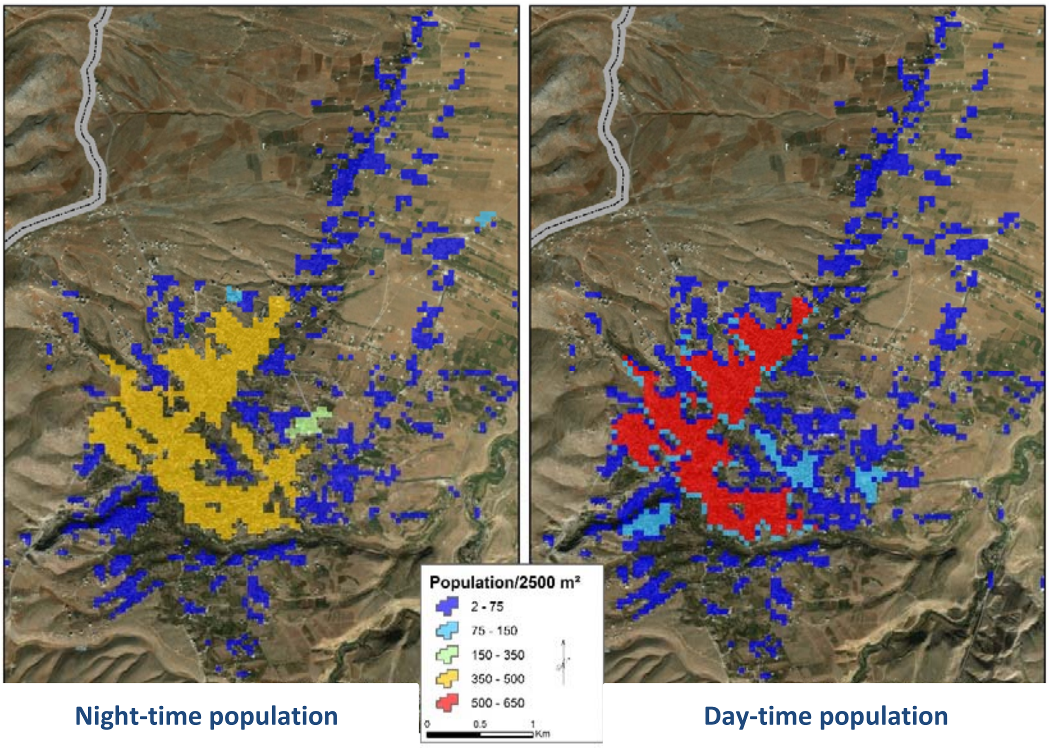


Figure 5-9 Nighttime population versus daytime population distributions in Hermel city

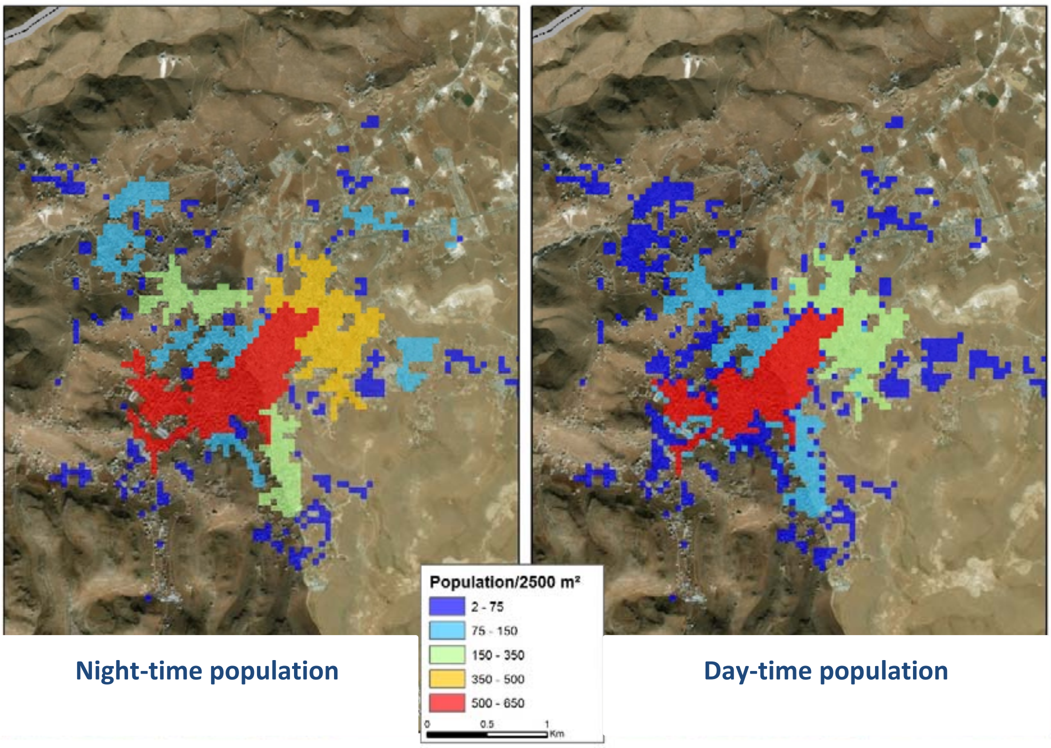


Figure 5-10 Nighttime population versus daytime population distributions in Aarsal city

3. Gaps, Challenges & Uncertainties

In Baalbek-Hermel, and in general Lebanon as a developing country where there is a conservative approach in terms of data and information sharing, it is a challenge to find geospatial data and meet the requirements of DRR. Data availability constitutes a main constraint for this dissertation as for all DRR actions in Baalbek-Hermel and Lebanon. Gathering related information and data was an exhaustive task, and the precision of the results depends of the precision and accuracy of the provided data. The finer were the input information the more robust were the results. Accordingly, the following challenges encountered during data gathering have been identified and highlighted for possible corrective interventions in future efforts:

- Fragmented data: Data is fragmented across ministries, agencies and organizations; to consolidate all the necessary data and complete the DRR cycle was an exhaustive task and required a lot of time (weeks to months). Moreover, all these parties have undertaken individual data collection, never been forget into a full picture, and often with an inconsistency between datasets. The replacement of staff over time causes knowledge transfer issues, an ongoing challenge for the maintenance and use of GIS (lack of continuity).
- Duplicated and redundant information: The non-cooperation and lack of coordination between agencies, ministries and parties, have led to waste of time and resources maintaining redundant datasets.
- Incomplete/unclear data: Digital data are almost absent. Found data has unclear semantics and metadata, unstandardized (heterogeneity) and is at a level of resolution not helpful for DRR actions and not updated often enough (old, outdated). Historical data showing local incidents and natural disasters impact are scarce and cover relatively small period of time, not enough to study intensive risks. Data of risks factors like buildings and structures standards are very limited and rare.
- Centralization of data/ Hierarchy and Bureaucracy: Independent approaches for data desegregation have been faltered by ministries perceiving information as their property and loss of control and revenue when data is shared. Lack of networking mechanism and data centralization within the Governorate and between different departments.

Besides data-related uncertainties, model-based uncertainties also needed to be taken into consideration. Population micro-spatial analysis errors may reside in modeling spatial variation, by supposing spatial homogeneity among land use/land cover categories. Moreover, census boundaries, the villages here, do not overlap the boundaries of land use/land cover; this is the “spatial incongruity” (Thapa et al. 2011). The subjectivity and accuracy of the land-use/land cover classes’ weight assignment can be argued. The daily displacement of people from and to Baalbek-Hermel couldn’t be calculated due lack of data. Although nighttime and daytime population datasets have been generated for Baalbek-Hermel Governorate, these results are preliminary. Results obtained by applying the method described in this section are representative of maximum counts for daytime and nighttime residential population. Despite the fact that these peaks reflect an enhanced estimation of the populations’ temporal distribution compared to traditional nighttime population datasets, several potential recommendations are required to further improve the accuracy of the databases. For instance, more detailed data about the temporal and spatial distribution of population will greatly improve exposures and risk assessments. Potential enhancements to the databases involve, but are not limited to, the following:

1. More precise temporal distribution of populations commuting between work, schools, retails and home, i.e., hourly distribution with the traffic component of the population.
2. More precise temporal distribution of populations in weekends and holidays, i.e. hotels, etc.

Chapter 6 . Prevention/Mitigation phase

This chapter emphasizes on the contribution of GIS in integrating innovative and complex analysis tools and producing hazard, exposure, vulnerability and risk maps that facilitate the communication of the result of very complex analyses in simple terms both to the general public and to policymakers (risk maps). Thus three specific case studies dealing with the phases of prevention and mitigation in Baalbek-Hermel are represented in this chapter. The three cases selected showcase the diversity of methods available in GIS environment and represent a good mean of rising risk-awareness that is part of DRR preventive goals. The first case study deals with assessing Critical Infrastructure networks resilience to natural hazards through modelling of intra-dependencies in a predictive approach, a focus on road network. GIS, through network analysis contributed for the accurate achievement of the assessment and produce new knowledge and expert insight about hotspots of vulnerability in spite of the vast amount and heterogeneity of data. The second case study deals with developing a School Vulnerability Index (ScVI) using Principal Component Analysis (PCA) in conjunction with GIS. Floods, landslides and earthquakes, hazards that regularly affect the area leaving considerable damage on schools. The third case consisted on a geospatial approach for assessing agricultural risk combining retrospective and community-based methods with temporal dimensions implementation. In order to assist the local farmers in emergency management and building resilience, a database was built at parcel level, involving cadastral information as well as hazard, exposure and vulnerability information. Data was collected and verified by means of interviews and surveys.

1. Assessing Critical Infrastructure networks resilience to natural hazards through modelling of intra-dependencies in a predictive approach, a focus on road network

Infrastructure in Lebanon and Baalbek-Hermel gains criticality due to many factors. The sixteen-year civil war that ended in 1991, had a devastating effect on the Lebanese infrastructure. Besides the near total destruction of infrastructure, the war led to rapid and hazardous urbanization. Long-standing political impasses over the prioritization of investments in national infrastructure have further prevented the government from making the necessary investments. The large public debt places excessive burdens on the budget and possibility to invest in development initiatives, in case of future significant destruction to existing infrastructure. And on the other hand, in the middle of the political unstable crisis, capitalists from the private sector are scared to invest in the infrastructure. Moreover, it is important to understand that the services provided by CI are not an end in themselves. Rather, they are a means to a series of wider ends which may be any combination of political, economic, industrial, military, social, or related to civil protection and response and relief measures. The consequences of the construction, maintenance and use of CI are intermediate economic "goods" that contribute to wider benefits or disadvantages. The Lebanese economy is mainly based on the services sector contributing to around 60% of the national GDP (compared with around 70% in the 1970s). The main subsectors are trade, tourism and financial services. This makes the Lebanese economy closely related and interdependent to the infrastructure. Actually, any damage to the infrastructure i.e. cut in roads may cause severe losses to the Lebanese economy.

Despite the significance of infrastructure, very few studies have been conducted in Lebanon, and none in Baalbek-Hermel, to assess the vulnerability/robustness and impact of natural hazards on CI and explore their resilience and redundancy. Road networks are among the most important CI during crisis times and the less redundant in Lebanon, compared to the energy and water CI. A basic step towards achieving DRR and resilience goals in Baalbek-Hermel is to conduct a comprehensive vulnerability assessment of the road network considered among the key critical infrastructure sectors in the governorate and evaluate the risk of natural hazards and its resilience. It is essential for the societal functioning of Baalbek-Hermel to know where the weak points in their urban infrastructure networks are and how do they influence the networks' entire connectivity and study the networks performance and operability following a disaster. Therefore, this section of the dissertation explores the use of GIS-based numerical models and R-NetSwan function (Network Strengths and Weaknesses Analysis, (Lhomme 2015)) to evaluate the governorate's road network internal dependencies (known as components interdependency) and thus reveal its vulnerability/criticality and test its resilience in the face of natural hazards. The work suggests a network-based approach, for CI modelling and simulation, through a well-organized pattern of analysis in three steps: network analysis, analysis of the vulnerability of the network elements, and analysis of resilience to natural hazards (the effects of elements failure on the entire network). The scope of this analysis includes earthquakes, storms, landslides, floods and wildfires. The results reveal the most aggressive hazard on the network, causing the highest connectivity loss percentages. The analysis of the road network is useful to assist first responders in identifying critical roads and bypasses, implementing protection and strengthening measures for the identified critical nodes and conducting strategies for an efficient distribution of the first responders' centers and hospitals.

1.1. Methodological approach

To assess vulnerability and resilience of road network in Baalbek-Hermel to natural hazards, there is first a need to make a rough inventory of this CI network; the methodology conducted started by interviews with the Ministry of Public Works and Transport (MPWT) for data collection in order to achieve a detailed inventory for the entire transportation network. Data was also gathered from CNRS report "*Hazard and risk assessment for the ministry of public works & transport for developing a national critical infrastructure protecting program for Lebanon*" conducted in 2016 (Abdallah et al. 2016).

There are several approaches to model CI networks and their intra-dependencies, clearly identified in the industry and used in civil engineering, and classified into two groups: internal methods and external methods. External method and statistical analysis are used herein because the modelling of physical or functional mechanisms is technically unfeasible due to lack of data and the complexity of the system (Lhomme et al. 2011). The methodology employs GIS-based numerical models and NetSwan function (Network Strengths and Weaknesses Analysis, (Lhomme 2015)) to achieve the following steps: 1)Network building and analysis, 2)Assessing vulnerability by studying the governorate's road network internal dependencies (known as components interdependency) and 3)Assessing the risk of natural hazards and the network's performance response by modeling the component failures from hazards 4)Testing resilience by simulating the cascading failures within the CI network and examining the effects of element failure on the network and their ability to provide continuity in operation. This network-based methodology is about modeling the topology of the network. The following steps showed in the diagram (Figure 6-1), resuming the methodology, were executed:

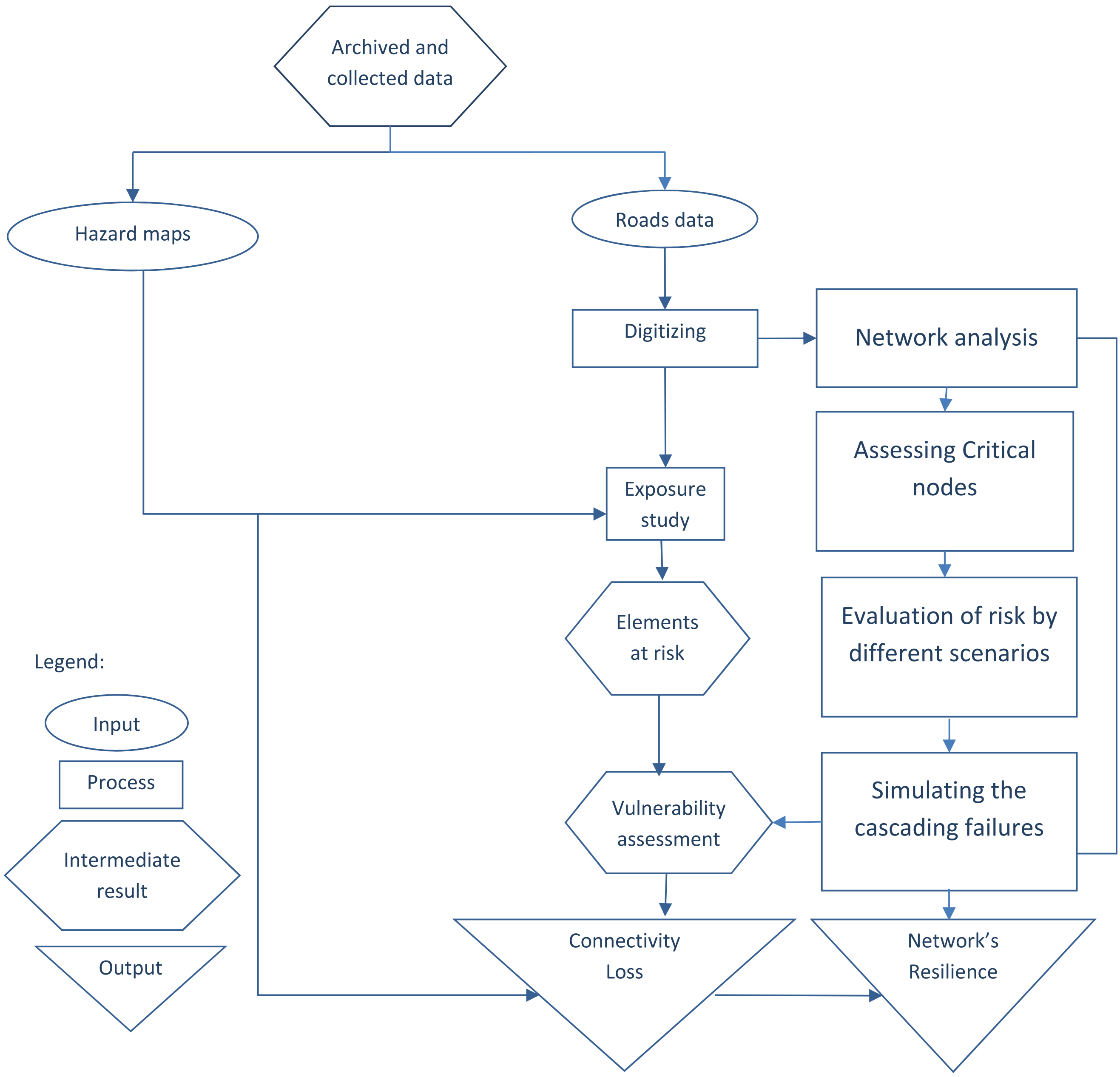


Figure 6-1 Flow diagram showing the methodology conducted for CI vulnerability & resilience assessment.

The vulnerability assessment of the road network starts by network analysis based on concepts from *modern graph theory*, consisting on the identification of its critical nodes/junctions and edges along with the effect of their removal on the network flow. A network, assimilated to a graph simple structure, is composed of nodes and edges, the latter being the roads while the former are the roads' extremities. In the case of road network, the study of the graph is topological and geometric (distance). In graph theoretic terms, the nodes with high centrality are considered to be critical and the most important in the network (Lhomme 2015; Lhomme et al. 2013), meaning that they play a vital role in maintaining the network's connectivity (Albert, Jeong, and Barabasi 2000). The centrality of a node, also known as "*betweenness",* is explained in a simplified way in Figure 6-2.

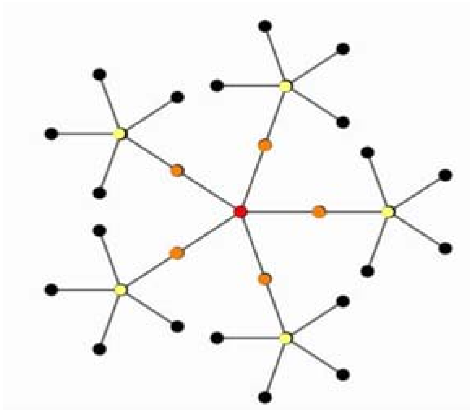


Figure 6-2 Characterizing critical nodes in an illustrative example for a simple road network; red node affects the most the flow over the entire network, followed by orange nodes and yellow nodes respectively.

The applied method for the identification of the critical nodes follows the hereinafter algorithm:

Calculation of each node's centrality defined to be the number of its ties and the number of shortest paths from all nodes to all others passing through it (

1- Equation 6-1):

$$C(x) = \frac{1}{\sum d(i,j)}$$

Equation 6-1. Nodes centrality by Ganguly, Bhatia, and Flynn (2018)*.*

Where d(i, j) is the shortest path between nodes I and j.

If the destruction of a road leads to the disconnection of many locations then the node is central. Centrality is then a measure of the importance of a road in the transportation network.

2- Computation of percentage of nodes that if damaged would lead to total connectivity loss in order to test the network vulnerability, using four metrics: 1) random centrality, 2)betweenness centrality, 3) degree centrality, and 4)cascading centrality

It is noteworthy that the destruction of these points in a network will lead to a complete loss of connectivity. The herein tested vulnerability represents the internal dependencies or components interdependency of the road network.

To test the resilience of road network, the flow robustness is considered after network's components damage. In fact, the connectivity of the network is measured by computing the flow robustness defined as the ratio of number of flows to the total number of possible flows in a network. A new value of the flow robustness is calculated every time a node is removed from the network. The obtained value is normalized with the total number of flows of the network, which is $n(n-1)$, where n is the number of nodes in a network (Pinnaka, Yarlagadda, and Cetinkaya 2015). More precisely, the blockage or destruction of critical points will cause a disruption of transportation and the cessation of the vehicles' flow. For this purpose a simulation of worst-case disaster scenario is conducted, for each hazard, where nodes highly exposed are impacted following a cascading order and are removed. To test the network's resilience to node removal from natural hazards, the applied method follows the hereinafter algorithm:

1- Natural hazard occurrence is simulated by removal of the highly exposed nodes, supposed to get damaged.
2- Iteration of the process over the resulting network; the measurement of robustness is adaptive meaning that the flow robustness of the network is reevaluated after every damage, accounting for the centrality values at each iteration (Pinnaka et al. 2015).
3- Computation of percentage of nodes damaged.
4- Measurement of the effective loss of connection from each hazard.

This analysis reveals the effects of the failure of critical parts of roads (identified earlier) on the functioning of the entire network (resilience of network, redundancy) in response to each natural hazard.

As for every modeling and simulation approach, validation and applications are crucial. In the present study, the outputs of the model were validated by comparison with historical data about the 2006 Lebanese war when the road network was targeted.

1.2. Results & discussion

The conducted methodology results in, at a first place, the fraction of nodes at which there is a complete loss of connectivity in Baalbek-Hermel road network. This network has a total of 3324 critical nodes and it reaches a complete loss of connectivity when around 60% of these critical nodes (1995 nodes) are damaged as shown in Figure 6-3 in the four used metrics (random centrality, betweenness centrality, degree centrality, and cascading centrality). Random errors produce smaller disturbances; a complete loss of connectivity is reached when around 80% of the critical nodes are damaged. The identified critical nodes with their corresponding vulnerability levels are mapped in Figure 6-4 which highlights the concentration of low vulnerability critical nodes in the city centers where most of hospitals and Red Cross centers are located. The most vulnerable critical nodes appear away from city centers, as well as the vulnerability rate of these critical points becomes more and more high while moving away from the centers of cities. In these regions, there is often no bypasses to the disruption of a single component of the road, eventually resulting in the isolation of some parts of the governorate. These results reveal that Baalbek-Hermel's well meshed road network is moderately vulnerable and relatively redundant, especially in urban areas.

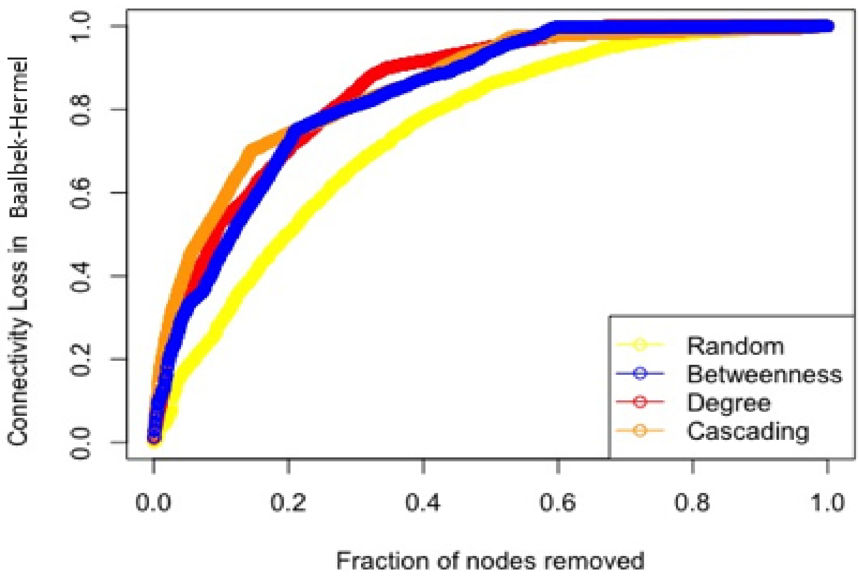


Figure 6-3. The change in connectivity as a function of the fraction of targeted nodes in Baalbek-Hermel

The results of the critical nodes removal due to natural hazards damage are shown in Figure 6-5. These results uncover the most aggressive hazard on Baalbek-Hermel's road network.

The connectivity loss due to earthquake hazard starts with the first nodes removal, which indicates that vulnerable critical nodes are highly exposed to this hazard. The maximum connectivity loss subsequent to the occurrence of an earthquake, damaging around 1750 critical nodes, can reach 70%. Concerning wildfires hazard, the connectivity loss starts after the removal of 500 critical nodes. The maximum connectivity loss subsequent to the occurrence of wildfires damaging more than 1750 critical nodes, can only reach 35%. In the case of floods hazard, the connectivity loss starts with the first nodes removal, which indicates that vulnerable critical nodes are highly exposed to this hazard. The maximum connectivity loss subsequent to the occurrence of floods, damaging around 275 critical nodes, can only reach 6%. As for the storm hazard scenario, the connectivity loss starts after the removal of 2200 critical nodes. A total connectivity loss (99%) subsequent to the occurrence of storms can be reached after damaging more than 2325 critical nodes. The connectivity loss due to landslides hazard starts after the removal of 2000 critical nodes. The maximum connectivity loss subsequent to the occurrence of landslides damaging more than 2750 critical nodes, can reach 75%.

Earthquakes are the most aggressive hazards on Baalbek-Hermel's road network threatening its connectivity disruption. Whereas this road network is resilient to floods and wildfires. The resiliency of roads in Baalbek-Hermel governorate is relatively reassuring due to its obvious capacity to operate in a degraded mode after natural hazards occurrence.

The models outputs were validated by comparison with historical data about the 2006 Lebanese war when the road network was targeted. In fact, it has been found that the Israeli strategy was to target the uncovered nodes in this current study and that the impacts were important connectivity loss in the networks.

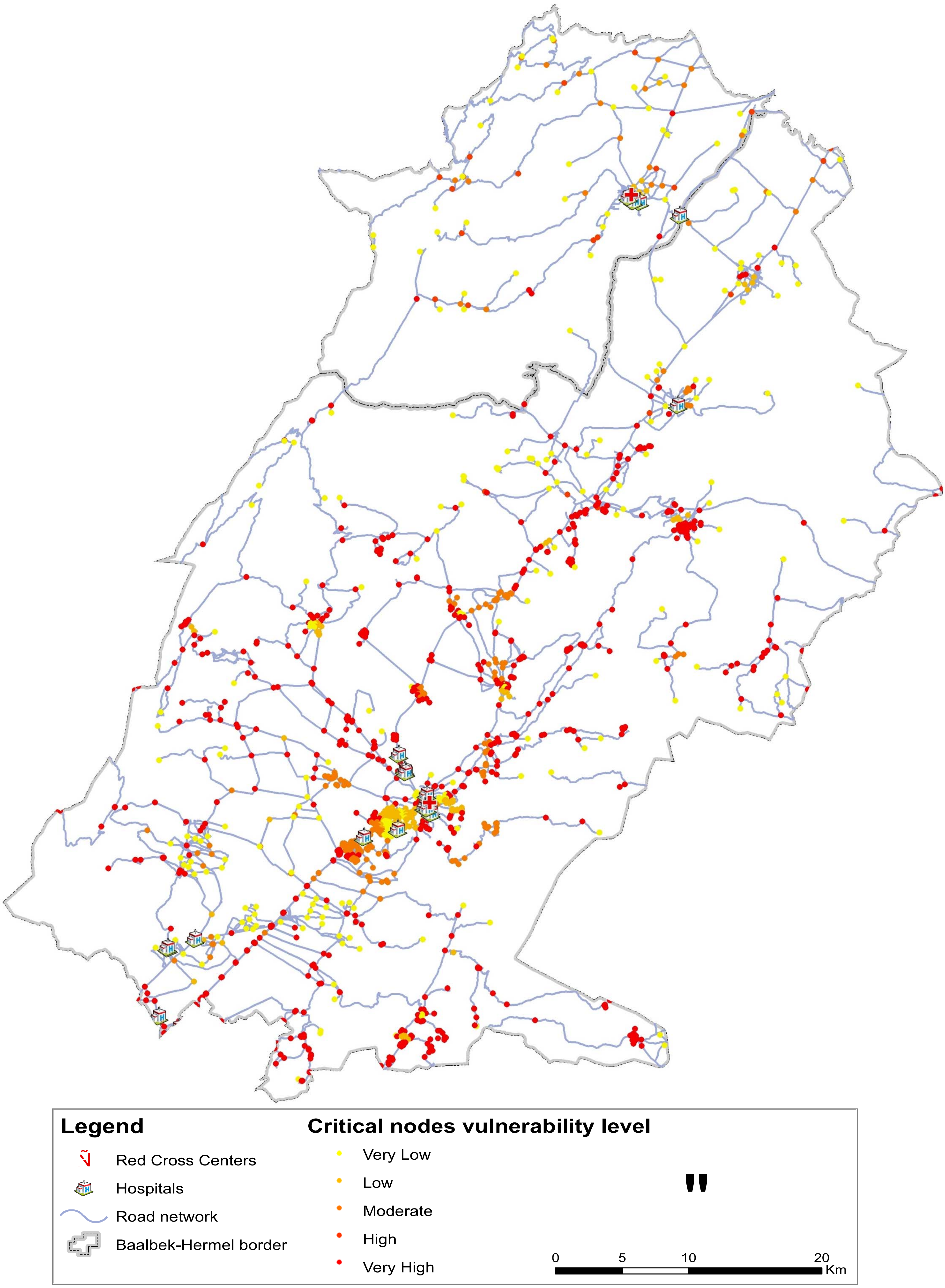


Figure 6-4. Vulnerability of Baalbek-Hermel's road network and the identified critical nodes

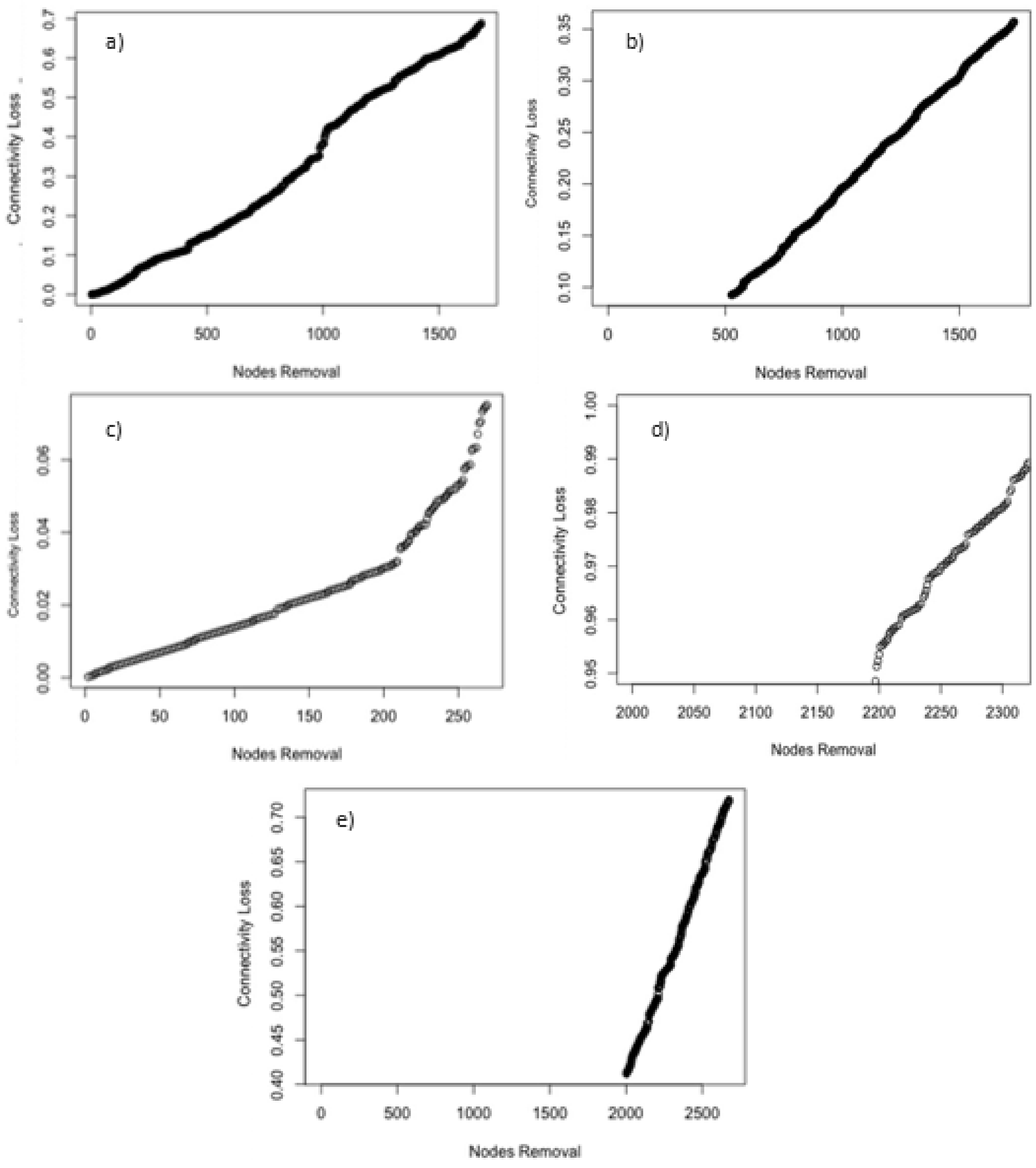


Figure 6-5. Road network potential connectivity loss following: a)Earthquakes, b)Wildfires, c)Floods, d)Storms and e)Landslides.

1.3. Conclusion

This section tests the criticality and vulnerability of CI network, a focus on Baalbek-Hermel’s road network, and proposes a novel predictive method to evaluate its resilience in order to be able to predict its future behavior in response to natural hazards. This methodology is of significant importance since it provides considerable information about the road network essential for the general understanding of its internal dependencies or network components interdependency and thus facilitates the implementation of a proactive approach to risk reduction management and critical infrastructure protection in Baalbek-Hermel. In fact, the blockage or destruction of critical points of road network will cause its disruption and the cessation of the vehicles' flow which can have fatal effects in time of crisis. In natural disaster scenario, the identification of those critical roads, bridges, and tunnels becomes essential in planning routes for first responders, locating the vulnerable population including seniors and disabled in addition to securing routes to schools at risk, which are usually used as refuge in the times of crisis. Also, it is essential in assessing the continuity of access to hospitals, pharmacies, food suppliers which are pivotal for the quick recovery and resilience of the community. Protecting and strengthening the uncovered critical nodes in this study with high vulnerability levels should be prioritized and taken into consideration in prevention and mitigation measures.

As a result of the conducted work, Baalbek-Hermel’s road network proves to be well meshed and moderately vulnerable with a good level of redundancy, especially in urban areas. This work also contributes to the implementation of the resilience concept in an operational way, revealing how resilient Baalbek-Hermel’s road network is to every studied natural hazard. Although all the prevailing natural hazards in Baalbek-Hermel, and especially intensive hazards, present a threat to the road network, the latter presents a good level of resiliency. Earthquakes are the most aggressive hazards on Baalbek-Hermel’s road network threatening its connectivity disruption from the first nodes damaged. Whereas this road network is resilient to floods and wildfires. The resiliency of roads in Baalbek-Hermel governorate is relatively reassuring due to its obvious capacity to operate in a degraded mode after natural hazards occurrence.

The methodology developed from this analysis can be adopted for vulnerability and resilience assessment of other CI networks in Baalbek-Hermel and Lebanon, and comes to fill the information gap regarding physical detailed causal mechanisms of CI.

Further research is recommended to test the degree of detour as consequence of node suppression in redundant graphs in case of crisis and its impacts on road network. Even with redundancy, the loss of connectivity can result from extensive detour leading to major loss of time for emergency services that could prove critical to disaster response.

2. Developing a multi-hazard School Vulnerability Index (ScVI) using Principal Component Analysis (PCA) in conjunction with GIS

Education sector is a pillar of the society and education facilities are considered among the most critical facilities, since they host mostly children who are considered vulnerable especially in time of crisis. During the UN world conference on Disaster Risk Reduction, in Sendai 2015, it was recognized that disasters have a major impact on children, youth and education systems (Chatterjee et al. 2015). Collapsing educational centers in large scale, natural disasters have killed thousands of children over the past twenty years and cleared billions of development investments in educational institutions worldwide (ISDR 2012). Moreover, according to many studies, schools are expected to function as post-disaster shelters or safe havens center which may play a huge role in the survival of society. In this case, schools should serve as models of disaster-resilient construction (United Nations et al. 2015). Thereby, the education sector is profoundly affected not only during but also in the aftermath of a disaster due to the educational interruption and recovery. To assure a continuous access to education, a fundamental right of children, is the ultimate goal of Disaster Risk Reduction for education sector. Moreover, during times of crisis, the resilience of these education facilities is a crucial element. It is important to understand that the services provided by educational facilities are not an end in themselves. The education sector provides jobs opportunities for a huge number of people (6% of the Lebanese GDP), it contributes to the development of the country, and it reduces the crime ratio, etc...

In response to the need to protect schools and make them more resilient, several studies assessed the impact of natural disasters on educational facilities (Bendimerad 2004; Ochola, Eitel, and Olago 2010; Rodgers 2012; Tewari 2014). Studies on disaster risk in the education sector in Lebanon are also beginning to emerge. A recent study showed that the repair and replacement of Lebanese schools affected by a devastating earthquake would require a budget of 1.1 billion (US) dollars, while a seismic retrofitting initiative can be expected to range from 2 to 2.5 billion (US) dollars (Naja and Baytiyeh 2014). Baytiyeh and Öcal, 2016 compared Lebanese High school students' perceptions of earthquake disaster to those of Turkey, to find out that although both groups highly adhere to fatalistic beliefs and schools fail to provide efficient disaster risk education, Lebanese students have less awareness and knowledge about earthquake risks.

Few are the studies that used a GIS-based approach model to assess the schools' vulnerability to natural disasters (Chen and Lee 2012; Esnard et al. 2018). Moreover, while physical and structural vulnerability has been widely and extensively studied and in many cases well assimilated, the knowledge of social vulnerability is still lacking especially when it comes to schools. A school vulnerability index haven't yet been developed.

In Baalbek-Hermel, some educational centers were built in the eighteenth century and are still hosting students, without any periodic maintenance or renovation works. Furthermore, as a rural region, the education plays a major role in Baalbek-Hermel's development and is a key in its road to end poverty and reach important development goals. Also, Baalbek-Hermel education facilities are facing huge pressure and responsibilities to host the exponential number of refugees. According to UNHCR (2015), there are nearly 400,000 school-aged refugee children in Lebanon, about 25 percent more than the number of Lebanese students enrolled in Lebanese public schools. This situation makes Baalbek-Hermel and its education sector much less resilient to a number of threats.

Schools are among the most vital structures and reducing their vulnerabilities in order to upgrade them against the various natural hazards is important for reducing loss of life as well as property in Baalbek-Hermel. Based on all the above reasons, this section aims to assess the vulnerability of the Baalbek-Hermel's schools. This objective is achieved by highlighting a multi-criteria aggregation method of relative vulnerability indicators using principal component analysis (PCA) and geographical information system (GIS) in order to create a specific composite Index of School Vulnerability (ScVI). The goal of ScVI is to identify, quantify and classify the vulnerability of schools in a comparative way in which the vulnerability scores of schools are given relative to each other. This index, which includes school characteristics that do not depend directly on the hazard parameters, could be thereby applied to all natural hazards. This methodology aims to answer the following questions: What are the relative levels of social-physical vulnerability of Baalbek-Hermel schools? What underlying factors are behind these increased levels of social-physical vulnerability? And what natural hazard entails the highest risk in Baalbek-Hermel schools.

This section goes beyond the physical components of risk to weigh the social conditions that affect the vulnerability and resilience of schools to natural hazards; innovation in methodology is the multi-criteria approach, a new way of measuring and assessing the social-physical vulnerability of schools as a structural, physical and human entity, or even as a small community.

The results indicated that 21% of schools in Baalbek-Hermel are highly vulnerable to natural hazards and therefore their retrofitting should be seriously considered. The findings of this section can be used in a number of various ways to decrease the vulnerability of Baalbek-Hermel schools and protect the children.

2.1. Methodological approach

The herein analysis consists of building the ScVI, that is a weighted composite index of Schools vulnerability. Given that in the construction of the ScVI, as in many decision-making, the indicators are both quantitative and qualitative, it is therefore necessary to resort to specific methods such as multi-criteria decision making (MCDM) techniques. Furthermore, It is noteworthy that there is not a conventional or common methodology shared among the scientific community for assigning weights (Rygel, O'Sullivan, and Yarnal 2006, Frigerio et al. 2016), several authors used different methods to weight indicators and build indexes (Cutter 2003; Fekete 2009; Rygel et al. 2006). The decision of assigning weights to indicators always causes a problem; it is important to achieve and 'objective' and unbiased weighting. Principal Component Analysis (PCA) is a multivariate statistical method used herein as MCDM technique (Malczewski 2006) to objectively assign weights, rank the indicators impacting schools vulnerability and aggregate them indicators into a ScVI.

A combination of PCA and GIS-based method was created and used herein to construct a weighted composite ScVI and rapidly analyze the vulnerability of schools to natural hazards in Baalbek-Hermel. To create ScVI and identify vulnerability of schools facilities, the following steps were executed: 1) Data gathering through field surveys to fulfill prepared questionnaires (Appendix G), preparing and transferring the data to the GIS environment, 2) Assessing exposure of the educational facilities, 3) Selecting a group of individual vulnerability indicators, 4) Normalizing the chosen vulnerability indicators, 5) Applying PCA, classifying and ranking and assigning weights to the factors and indicators 6) Calculation of ScVI for each school by aggregating the normalized indicators, and 7) Determining risk levels for each school.

The evaluation of schools vulnerability requires a huge amount of data concerning many related characteristics. This model requires, at a first place, the collection of data and its treatment, thus the methodology starts by interviews with different departments of the Ministry of Education & Higher Education (MEHE) and field survey for data collection. The inventory of school facilities and vulnerability indicators, in the first step, required the preparation of several questionnaires and checklists (L. Appendix) to be filled by the ministry's departments and during field surveys. This stage of the study is a crucial stage due to the big amount of data to be gathered, categorized and arranged, noting that organized and standardized databases do not exist in Lebanon nor in Baalbek-Hermel. After each interview, collected information was linked to their geographic location and/or transformed to comprise them within the hazards/risks GIS Geodatabase for further analysis and modeling. The related database was utilized to generate the required model layers like background layers, infrastructure elements layers, hazards layers, element at risk layers Figure 6-6.

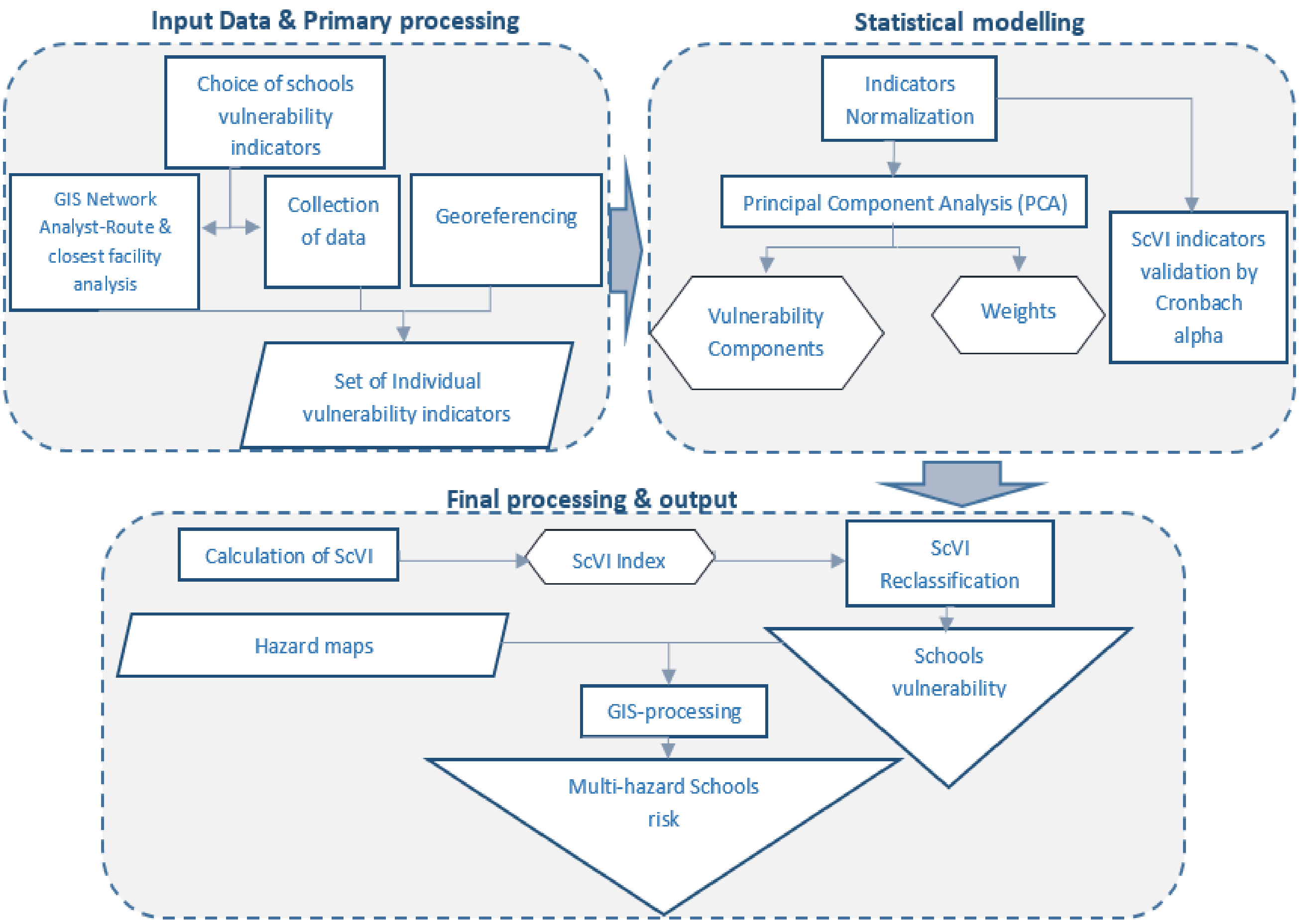


Figure 6-6 Flow flowchart illustrating the methodology used for the preparation of the ScVI, the schools vulnerability map and for the estimation of multi-hazard risk on schools of Baalbek-Hermel.

Estimating the vulnerability of a structure is a difficult task because rarely can analysts afford the luxury of a detailed appraisal for a structure. Vulnerability arises from a combination of interdependent physical, socio-cultural, economic, and institutional circumstances. The innovation in this section resides in the integrated multi-criteria approach to assess the vulnerability of schools as physical and social entities. The definition of vulnerability chosen for a study is an integral part of the indicators and factors chosen to quantify vulnerability and make it measurable, and must therefore be clearly explained and their inclusion justified (Rygel et al. 2006). It was proposed to derive a synthetic vulnerability method to estimate the corresponding criteria. The input schools vulnerability indicators of the ScVI are identified, selected and their functional influence on vulnerability determined according to thorough literature review and community-based questionnaire filled from field surveys to reduce subjectivity. Since not all chosen indicators are quantitative or measurable, the selection of appropriate proxy variables is necessary in order to quantify the indicators and achieve computation and comparability. It is important to identify the hypothesized or expected functional influence of each indicator proxy and school vulnerability; and give each proxy variable a sign. If an increase in the proxy of an indicator induces and increase of the school vulnerability then it is a positive correlation, but if vulnerability decreases with an increase in the proxy of an indicator then it is a negative correlation. This is necessary to ensure that higher proxy values mean higher ScVI values and thus higher vulnerability, and vice versa. The ScVI construction focused on measurement of the following 23 descriptive parameters and their proxy variables:

- Type of the structure (Educational, residential or religious center). A building primary designed as an educational facility is considered less vulnerable.
- Presence of warehouses serving for permanent food storage, blankets, etc. The presence of warehouses decreases the school’s vulnerability.
- Age of the structure. No building code was applied before 2005 (Salameh et al. 2016).Furthermore, the longer a building’s lifetime is, the greater is its vulnerability. In other words, the vulnerability of a structure increases with its age.
- Condition of the structure (Very bad, bad, acceptable, good). The condition of the school is evaluated from obvious and easily detected criteria like cracks in the wall.
- Maintenance/Rehabilitation works (Yes or No). Maintenance/Rehabilitation works are considered to lessen the vulnerability of a structure.
- Number of past events that caused damages. A school with a considerable number of past events is ultimately more vulnerable.
- Water sources (well, water tank, others). Schools connected to the public water network and having at the same time private water tanks are less vulnerable.
- Electricity sources (EDL, private generator, mutual generator). Schools equipped with private generators have a more redundant energy system and are therefore less vulnerable.
- Equipped for students with special needs. Disabled students have higher chance to survive during crisis time in an equipped school for their special needs, which decreases the vulnerability level.
- Presence of air conditioning system. Continuous heating can play a fatal role for the survival of students during cold waves, as for air conditioning in heat waves, which lessens the level of vulnerability.
- Ownership (owned, rented). Ownership status plays a role in indicating vulnerability (Cutter et al. 2003). It has been noticed that rented schools are less maintained that owned schools, which make them more vulnerable to natural hazards.
- Distance to the nearest first responder (Lebanese Red Cross, Lebanese Civil defense).

- Distance to the nearest hospital. The neighborhood to first responders and hospitals can play a major role in reducing lives losses and renders a school less vulnerable.
- Location in the road network and relative position to the critical nodes identified in previous section. Schools can be easily isolated when they are located between two critical nodes on the road network and are therefore more vulnerable.
- Number of exists and presence signs for evacuation. A high number of exists and presence of evacuation signs reduces the vulnerability of a school.
- Age of students with as proxy variable the percentage of students under 10 years and that of those above 10 years in one school. Young students are considered more vulnerable to natural hazards (Dwyer, Zoppou, and Nielsen 2004) because they must depend on adults in times of crises and often seek special assistance or care during emergencies.
- Gender issues, dominance girls or boys with as proxy variable the percentage in each school. Girls are considered physically more vulnerable (Enarson and Hearn Morrow 1998).
- Number of students and staff with as proxy variable the total number of employees and teachers. The more a school contains students and staff, the more panic situations are possible, the more evacuation plans are difficult and thus the more it is vulnerable to natural hazards.
- Overcrowded facility with as proxy variable the ratio of the number of occupants and the maximum capacity. Other than the number of a school's occupants, this ratio is important and increases the vulnerability of a school community especially in crisis time when stampede can take place.
- Presence of refugees with as proxy variable the percentage of refugees from total number of students in one school. A higher percentage of refugees indicates higher social vulnerability of the school.
- Presence of students with special needs with as variable their percentage from the total number of students. Disabled students present a unique challenge in times of response and recovery and are thus considered more vulnerable (Morrow 1999).
- Poverty rate of the school's region with as proxy variable the percentage of families living below poverty line from the total number of families in the village where the school is located. There exists a strong correlation between poverty and vulnerability (Bankoff 2003).The quality of schools' construction is often affected by the region's poverty rate (Clark et al. 1998) and municipalities cannot help with preventative measures (structural and non-structural measures), emergency supplies preparedness, and recovery efforts (Petreski, Petreski, and Tumanoska 2017). A school located in a poor region is considered to be more vulnerable to natural hazards.
- Students' level of awareness and preparedness. It is believed that students who have been prepared through trainings, courses implemented in the curriculum and awareness campaigns are less vulnerable.

Some of these aforementioned parameters were collected during field surveys and desk review. But when limited availability of data and lack of resources and time for exhaustive field work were faced, the use of different GIS tools compensated the gaps. Moreover, some vulnerabilities are not obvious and need geospatial analysis. Closest facility in Network-analyst GIS tool, was used and served directly the assessment of schools' vulnerability by revealing the following parameters:

- Distance to the nearest first responder (Lebanese Red Cross, Lebanese Civil defense).

- Distance to the nearest hospital,
- Distance to the nearest food supplier.
- Relative position to critical nodes of the road network.

Each of the above mentioned indicators is measured in different scales and units. Data standardization or normalization into homogenous format is now necessary to make the indicators comparable scale independently. The Range standardization method was applied as shown in Equation 6-2 whereby the normalized observation (x_{ij}) is calculated as a ratio from the maximum and minimum observations for a given proxy variable of an indicator with positive correlation with vulnerability:

$$x_{ij} = \frac{x_i - x_{j\,min}}{x_{j\,max} - x_{j\,min}}$$

Equation 6-2. Normalization of proxy variables of indicators with positive correlation with vulnerability

While for a given proxy variable of an indicator with negative correlation with vulnerability, the Range standardization method is applied following Equation 6-3:

$$x_{ij} = \frac{x_{j\,max} - x_i}{x_{j\,max} - x_{j\,min}}$$

Equation 6-3. Normalization of proxy variables of indicators with negative correlation with vulnerability

where x_{ij} is the normalized value of indicator (j) with respect to school (i), X_i is the actual value of the indicator with respect to school (i), and $x_{j\,min}$ and $x_{j\,max}$ are respectively the minimum and maximum values of indicator (j) among all the schools.
This leads to all observation values being standardized and classified on a scale from 0 to 1, with higher proxy values indicating higher vulnerability (Rygel et al. 2006).

After indicators normalization, an inductive approach is necessary because the relationship between indicators and school vulnerability is unknown and literature shows that all indicators do not contribute equally to vulnerability (Mortsch and Hebb 2008). Within the inductive approach, a principle component analysis (PCA) is the most common factor analysis technique. Indicators are analyzed by a PCA to summarize them into composite indices with orthogonal linear combinations and assign weights by identifying the proxy variables explaining most variation within the collected data. PCA transforms the input data into a set of orthogonal vectors that are the principal components. All the components having an eigenvalues greater than one are retained (Žurovec, Čadro, and Sitaula 2017). A varimax orthogonal rotation with Kaiser Normalization is applied to achieve higher loadings on individual components and reduce the number of indicators having a high loading on the same component, by rotating the axes of the components perpendicular to each other (Kaiser 1958). This procedure, resulting the rotated component matrix, helps to interpret the resulting components and to estimate the influence of the principal components on school vulnerability, based on which original indicators load with a different weight. A second PCA, only with retained components, is run to generate factor loadings for all indicators. The square of factor loadings represent the proportion of the total unit variance of the indicator that is explained by the factor. The generated loading factors are used as weights.

The composite ScVI for each school is then calculated as the sum of the weighted indicators of the rotated principal components for every school. Based on Gbetibouo, Ringler, and Hassan (2010), Equation 6-4 was used to summarize all weighted indicators into the single composite index, the ScVI:

$$ScVI_j = \sum_{i=1}^{n} \left[w_i\left(x_{ij} - \bar{x}_i\right)\right] / s_i \quad i = 1, \dots, n;\ j = 1, \dots, J$$

Equation 6-4. The composite ScVI for each school

Where ScVI is the School vulnerability index, w is the identified weight from PCA, i is the indicator, x is the indicator value, j is a specific school, $\bar{x}$ is the mean indicator value, and s is the standard deviation.

It is noteworthy that the PCA is itself a validation method of the constructed ScVI; it checks on validity the independent variables used as input data for school vulnerability indicators. For more accuracy, according to literature, it is essential validate the composite index derived by factor analysis through either internal statistical reliability analysis such as Cronbach's alpha, or through an independent second dataset (Fekete 2009; Raykov 1998). Due to lack of data, the Cronbach Coefficient Alpha was run to estimate of internal consistency of the integrated indicators in the ScVI. Cronbach Coefficient Alpha assesses how well our chosen indicators reliably measures ScVI.

After calculating ScVI for each school, its risk from natural hazards can now be estimated. Risk is mostly understood as the damage due to the consequences caused by natural hazards of defined probability of occurrence. Risk can be expressed as a function of the hazard, exposure and vulnerability as follows;

Disaster Risk = function (Hazard, Exposure, Vulnerability)

The estimated risk in this step is a result of the GIS overlay of hazard, exposure and vulnerability layers for each school. The resulting risk categories follow risk matrix for every hazard as shown in Figure 6-7.

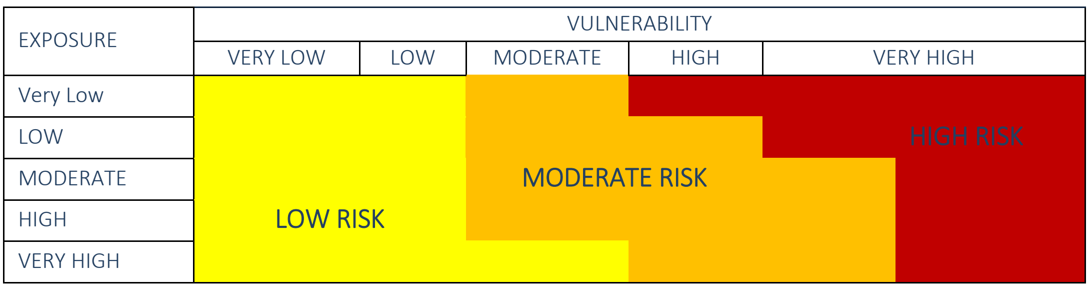


Figure 6-7 Schools' risk matrix according to exposure and vulnerability levels.

2.2. Results & discussion

The network analyst and closest facility methods ran, revealed the following ScVI indicators: distance to the nearest first responder (Lebanese Red Cross, Lebanese Civil defense), distance to the nearest hospital, distance to the nearest food supplier and relative position to critical nodes of the road network. An example of the findings from the applied network analyst to find the distance to the closest hospital is shown in Figure 6-8.

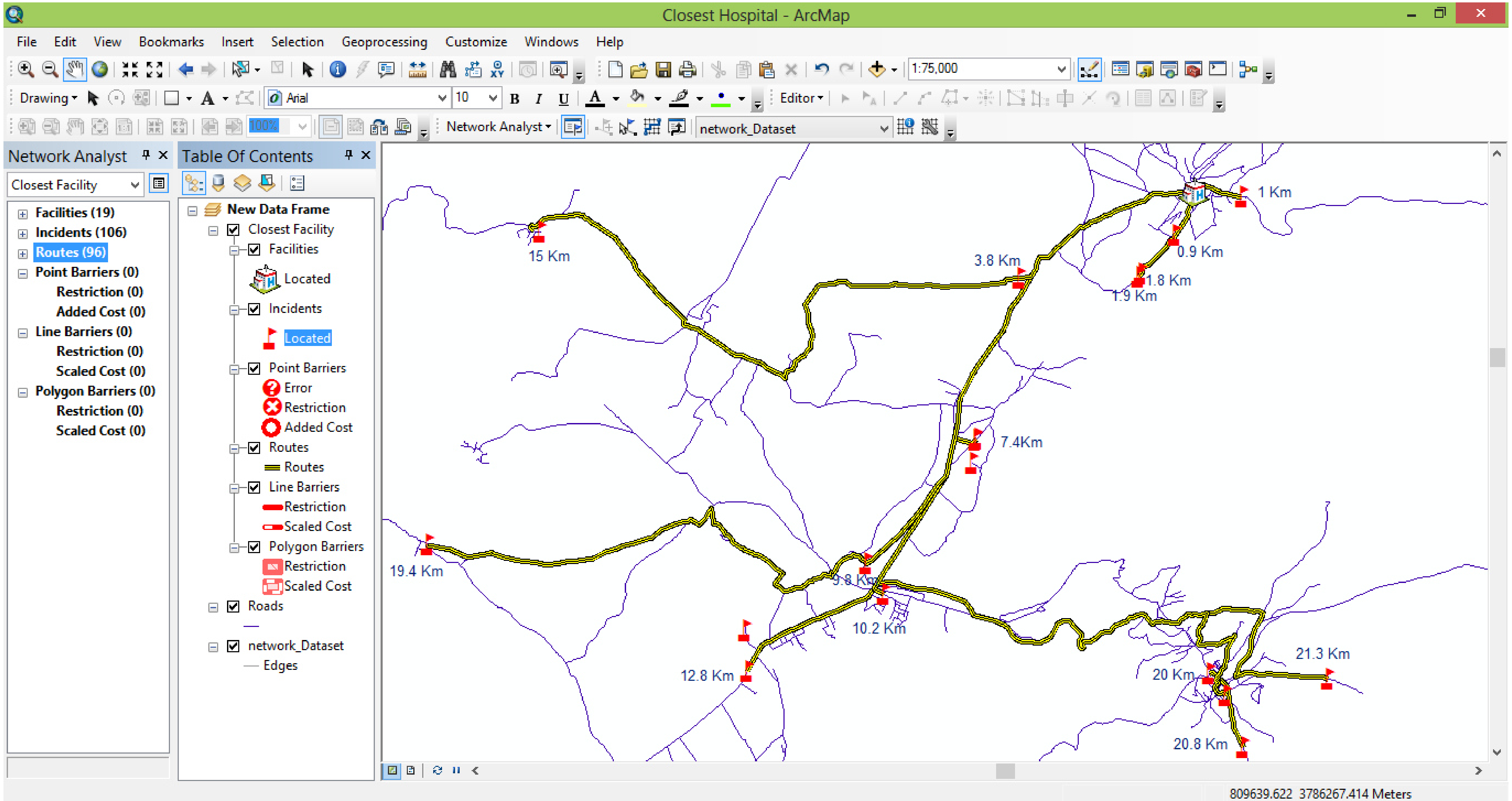


Figure 6-8. Network analyst applied to find each school distance to the nearest hospital in Baalbek-Hermel; example of one hospital and its neighboring schools.

The applied statistical technique of Principal Component Analysis, retained all the 23 input indicators discussed earlier but generated only three factors considered significant having eigenvalues greater than 1. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) of 0.819 points out that the selection of these variables is adequate for factor analysis and that 81.9% of variance in the variables might be caused by underlying factors. The Bartlett sphericity test value of less than 0.02 rejects the fact that the variables are not related and therefore are not suitable for structural detection. The scree plot of the variability explained by each factor (Figure 6-9) shows that the first three factors on the curve are particularly capable of explaining the majority of the data.

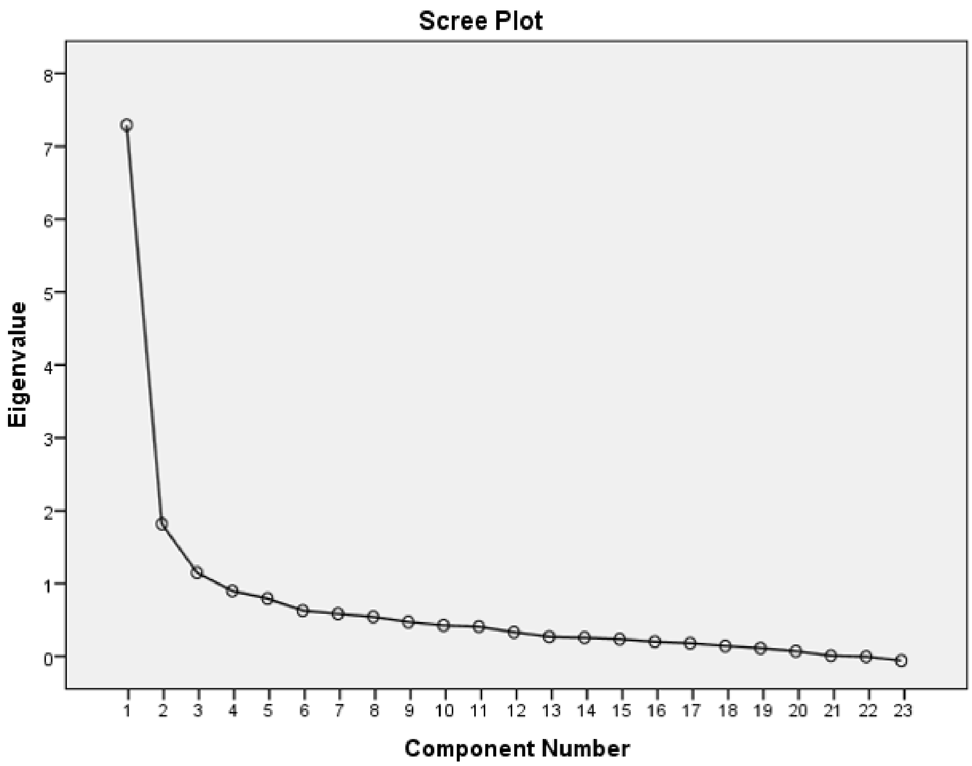


Figure 6-9. Scree plot of the conducted factor analysis showing the eigenvalues (y-axis) explained by the resulting factors (x-axis)

The three retained components describe relationships between all variables and account for a total of 89.9% of the cumulative variance of the dataset. This variance reports that the determined composite indicators are representative for the entire dataset. The first principal component explains most of the variation (53%), the second principal component explained 23%, and the third explained 13.9%. Each of the three components was easily explained in terms of the most heavily loaded raw variables (marked in red in Table 6-1) to reveal major latent groupings. The highest loading highlighted for each variable represents the correlation between a component and this indicator, which reveals the contribution of the indicator to the variation accounted for by this component and is therefore used as a weighting factor in constructing the composite ScVI. Table 6-1 highlights that school vulnerability has been observed in the light of three components or factors representing vulnerability structural dimensions, socio-economic dimensions and dimensions to Critical Infrastructure related. Thus, the three components are named after what aspects of schools vulnerability their variables capture or connote.

Table 6-1 Rotated Component Matrix of the conducted factor analysis revealing the computed value loadings for ScVI indicators.

	Principal Components		
Input indicators	**1**	**2**	**3**
Type of the structure	-0.586	0.175	-0.215
Presence of warehouses	-0.548	-0.303	0.146
Age of the structure	0.629	0.29	-0.213
Condition of the structure	-0.701	0.144	-0.149
Maintenance/Rehabilitation works	-0.556	0.101	-0.074
Number of past events that caused damages.	0.571	0.097	0.562
Water sources	0.252	0.039	-0. 634
Electricity sources	0.401	-0.323	-0.549
Equipped for students with special needs	-0.627	-0.284	-0.008
Presence of air conditioning system	-0.437	0.363	0.035
Ownership	-0.209	0.652	0.245
Distance to the nearest first responder	0.051	-0.048	0.669
Distance to the nearest hospital	0.278	0.076	0.673
Location in road network	0.023	0.198	0.656
Presence of multiple exists and signs for evacuation	-0.593	0.01	0.117
Age of students	0.014	0.679	-0.138
Gender ratio	0.021	0.643	-0.33
Number of students and staff	0.033	0. 685	0.298
Overcrowded facility	0.39	0.427	0.095
Proportion of refugees	-0.205	0.436	-0.404
Proportion of students with special needs	-0.055	0.658	-0.187
Poverty rate of the school's region	-0.302	0.465	-0.116
Students' level of awareness and preparedness	-0.239	-0.589	0.003
Interpretation:			
Percent variance explained	53%	23%	13.9%
Factor name	**Structural dimensions**	**Social-economic dimensions**	**Connection to Critical Infrastructure**

According to Table 6-1 the condition of the structure is the indicator with the highest weight, followed by the number of students and staff, the age of students and the distance to the nearest hospital.

Cronbach's alpha having a value of 0.805 highlights a high level of internal consistency with this specific sample. If an indicator was deleted, that would result in a lower Cronbach's alpha.

After aggregation of components, based on the scoring factors, the ScVI value was obtained for each school in Baalbek-Hermel, and reclassified to attribute low-, moderate- and high-vulnerability levels to schools. The results of the overall ScVI for each school are depicted in Figure 6-10. The results revealed that 3% of public schools in Baalbek-Hermel are considered of low vulnerability, 76% are considered to be moderately vulnerable and 21% are considered to be highly vulnerable. To derive the risk of these schools from different natural hazards, these vulnerability results were integrated in a GIS-model and added to hazard and exposure layers. The output results, shown in the multi-hazard risk matrix (Figure 6-11), pinpoint that Baalbek-Hermel's schools and students are mostly threatened by storms, while floods only threaten 1 school.

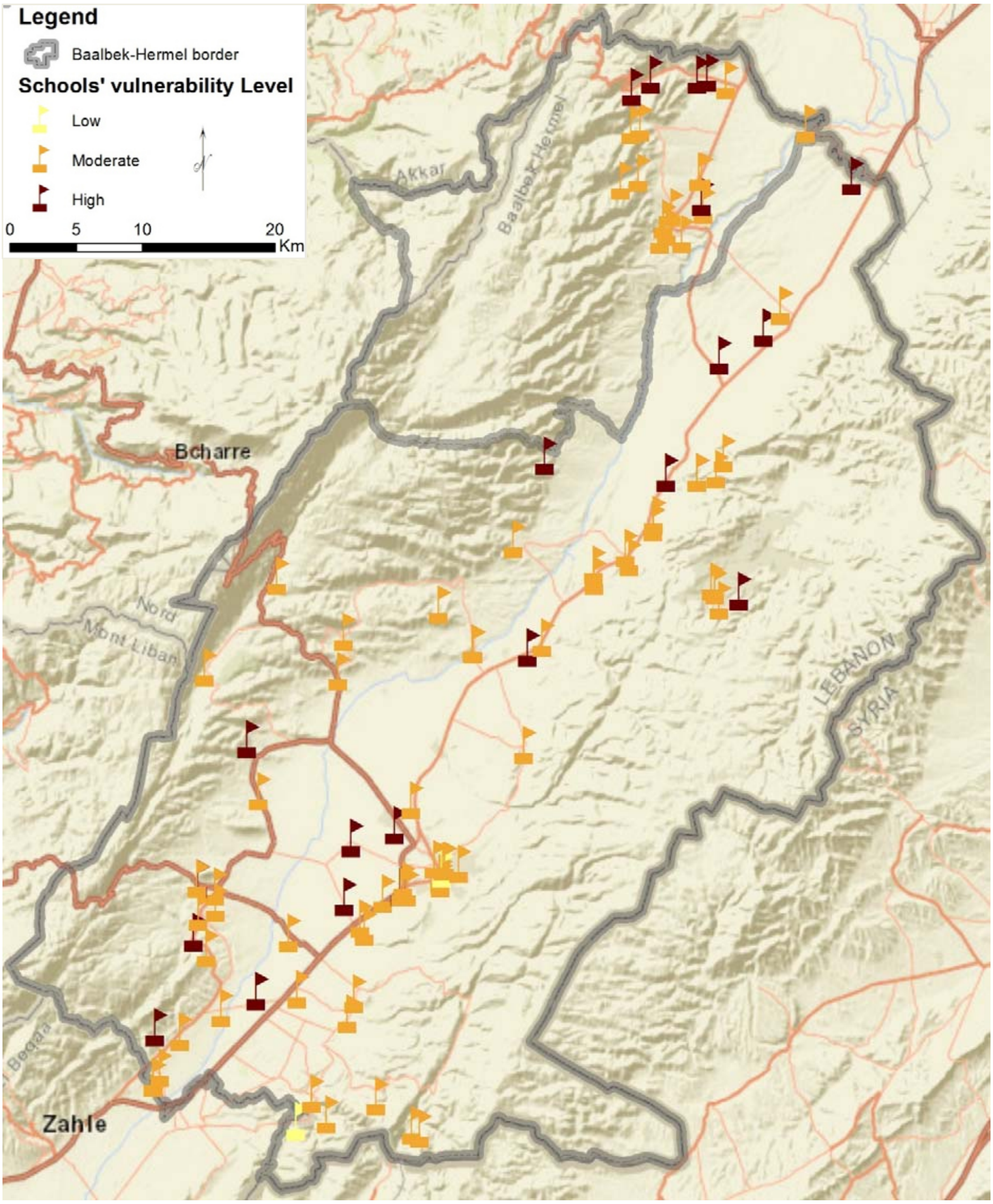


Figure 6-10. Baalbek-Hermel's schools vulnerability levels based on ScVI values.

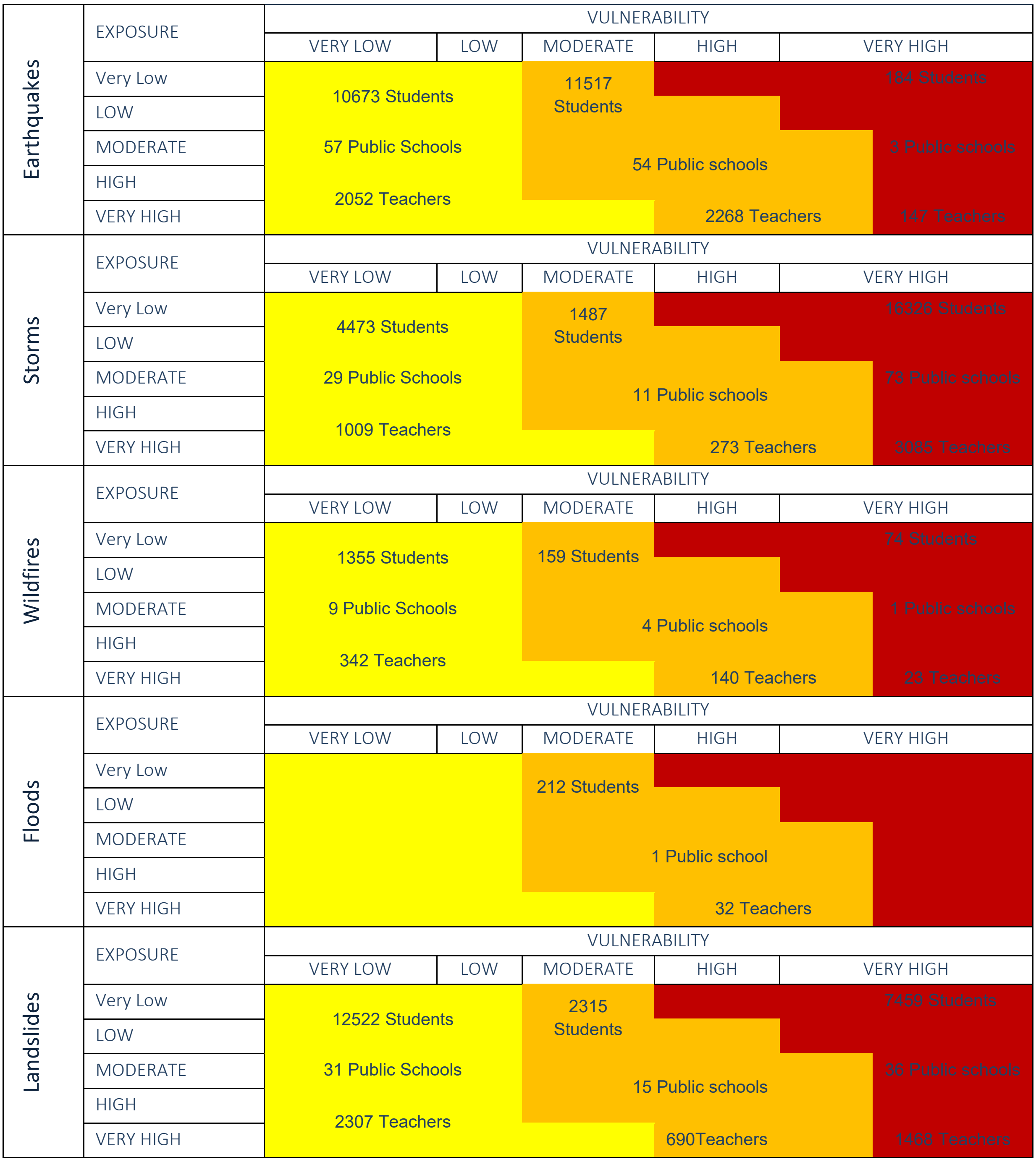


Figure 6-11 Baalbek-Hermel's public schools risk matrix according to natural hazards

2.3. Conclusion

Considering the importance of schools, making them more resilient is necessary to reduce education disruptions and make them able to serve as a refuge or shelter in times of crisis. In order to create truly resilient schools that can adapt, withstand and respond to natural hazards occurrence, their multi-dimensional vulnerability must be understood, planned, and mitigated for. Therefore, being mindful that vulnerability is not a measurable quantity, this section aimed to evaluate the vulnerability of schools in Baalbek-Hermel, through quantitative approaches, by constructing a multi-hazard School Vulnerability Index (ScVI).

The conducted PCA used in conjunction with GIS-based modeling facilitated the construction and calculation of the ScVI and the rapid multi-hazard risk assessment of schools in Baalbek-Hermel. This composite index captures the multi-dimensionality of schools vulnerability in a comprehensible form. Although the PCA results provide insights into correlations among the three dimensions of schools vulnerability (structural, socio-economic, and Critical Infrastructure related), the key objective here is to statistically generate aggregating weights for the composite score of the ScVI, in a relatively objective way. This section of the thesis does not dismiss the subjective approach, showed in the choice of some indicators, and recognizes that every approach will have some level of subjectivity. While the weighting is a quite complicated process, combined with field surveys, extensive literature review and interviews it showed (through Cronbach's alpha validation) that it could ultimately produce a much more accurate Index. The GIS-based indicators, helped with the spatial data management and analysis capabilities of GIS, revealed vulnerabilities unobvious on the field, like the distance of a school the nearest first responder, hospital and its risk of being isolated from the road network.

The condition of the school structure, the number of students and staff, the age of students and the distance to the nearest hospital were revealed to be the indicators with highest weight in the ScVI. Findings revealed that 3% of public schools in Baalbek-Hermel are considered of low vulnerability, 76% are considered to be moderately vulnerable and 21% are considered to be highly vulnerable. This ScVI created from a suite of indicators and evaluating the relative vulnerability of schools, are needed in Baalbek-Hermel for practical and operational decision-making processes, to provide policymakers with appropriate and accurate information about where the most vulnerable schools are located and prioritize funding.

The rapid multi-hazard risk assessment on schools in Baalbek-Hermel reveal that all the prevailing hazards present a threat to schools and to the education sector, and especially hazards with lowest intensity are the ones with the highest impacts on these facilities. For example, storms, though intensive risks, are considered to be the most threatening hazards to schools, causing an important number of losses and the disruption of education several times per year.

3. Geospatial approach for assessing agricultural risk combining retrospective and community-based methods with temporal dimensions implementation

As highlighted by UNISDR & FAO, natural disasters and food insecurity are strongly interrelated (FAO and UNISDR 2016). According to Garschagen et al. (2015) agricultural risks, by creating a poverty trap for millions of households across the developing world, constitute the major cause of transient food insecurity that creates a wicked spiral of shock and recovery. In fact, agriculture is heavily affected by natural hazards but is also critical to help communities recover from crises. Weather-related hazards, in particular, affect agriculture; these hazards are expected, worldwide, to increase their frequency, intensity and uncertainty due to Climate Change (Davies et al. 2009).

Efficient agricultural risk reduction is essential to enhance economic growth, improve food security, and decrease poverty (Wout et al. 2013). Agricultural livelihoods can only be safeguarded from multiple hazards if appropriated disaster risk reduction and management efforts are consolidated within and across various agricultural sectors, fixed in the context-specific needs of local livelihoods systems. FAO consider resilient livelihoods to be critical contributors to help the world's most vulnerable people reach one of the most basic human rights which is food security and the freedom from hunger (FAO 2013). At FAO, disaster risk reduction consists of saving people's livelihoods from shocks, and improving their abilities to withstand the effects of, and recover from, disasters and linking planning and capacity development for DRR, resilience, sustainable development and climate change adaptation (CCA). Therefore, FAO launched a study "*Vulnerability and risk Assessment to Facilitate Planning for Disaster Risk Reduction and Climate Change Adaptation in Agriculture Sectors in Lebanon*" as part of its efforts to assist in making the Lebanese agricultural sectors more resilient to risks and crises in cooperation with the Lebanese Ministry of Agriculture (MoA) (Abdallah et al. 2018).

Baalbek-Hermel Governorate is an important area for agricultural production in Lebanon. It has a considerable livestock production; with a large and expanding forage area, cattle, goat, and sheep rearing is concentrated on the eastern slopes of the valley. Moreover, the presence of the Assi River makes the region suitable for fish farming mainly for Trout and Tilapia; 80% of aquaculture fish farms in Lebanon are located in Baalbek-Hermel region with an estimated average yield of 10-12 tons/year. Also, Baalbek-Hermel's soil texture provides a great potential for plant production; the region grasps the highest share (25%) of total cultivated land in Lebanon. Thus, agriculture accounts for an important percentage of Baalbek-Hermel's Gross Domestic Product (GDP) and plays a major role in its economy as it remains the principal source of livelihood for the majority of the population and an important source of income. Baalbek-Hermel's agricultural sectors have always been threatened by the vagaries of weather, diseases, increasing rainfall and temperature, with possible links to climate change. The key components to resilience are the protection of livelihoods from natural shocks and the strengthening of food production systems capacities to absorb, cope and recover from crises.

In this context, carrying a full risk assessment of Agricultural sectors in Baalbek-Hermel is a must if further actions would be taken to make this governorate resilient in the face of natural hazards. This agricultural risk assessment comes as an evidence and a starting point for better understanding the risk threatening the agricultural sectors, improving risk reduction and management strategies and advising on increasing the resilience of agricultural sectors in face of several natural hazards.

Few are the studies that integrated geospatial data and GIS for assessing agriculture risk from natural hazards (Wang et al. 2016; Wu et al. 2011; Yin et al. 2014; Yue et al. 2016). Assessing risk and estimating losses over agricultural sectors is a difficult task. This complexity is due to the lack of detailed reports and records that allow knowing what type of crops was lost along with the percentage of damage; data on damage and losses in the agriculture sectors are not systematically gathered or reported worldwide (FAO 2016). The case in Lebanon and Baalbek-Hermel does not differ. FAO recognizes the urgent need to better record, in national disaster loss databases, the damage and losses on agriculture due to disasters (FAO 2015). Moreover, the temporal dimension is to be considered; the economic loss is function of the type of element (crop/livestock) and the stage at the productive cycle in which they are at the time of the disaster (Velásquez et al. 2014). Losses are different when crops are just planted than when ready to harvest. Without trying to solve all the elements of the difficult task of assessing the economic loss including those from intangible damage on agriculture caused by a disaster, the main objective of this section is proposing a simple but detailed methodology. This methodology allows estimating the risk and losses to agricultural sectors, in an innovative approach combining community-based and retrospective assessments and considering spatial-temporal dimensions.

This section reveals Baalbek-Hermel's agricultural risk profile and agricultural subsectors risk profiles by the establishment of seasonal agricultural risk calendar and agricultural risk maps. The evidence generated through the study will help in prioritizing risks on the agricultural sectors level in Baalbek-Hermel. These findings should mainstream agricultural risk reduction and management into Baalbek-Hermel agricultural strategy and investment and development plans.

3.1. Methodological approach

The ultimate goal of this section is to obtain agricultural risk profile of Baalbek-Hermel by developing a detailed GIS-based agricultural risk assessment method. The thorough adopted methodology in carrying out this section, resumed in Figure 6-12 and detailed below, combines community-based and retrospective assessments while implementing spatial-temporal dimensions for loss estimation.

1-Data collection, arrangement, and transformation into geospatial database.

2-Identifying gaps and setting list of meetings and preparing questionnaires for surveys

3-Community-based assessment, though field consultations

4-Retrospective Vulnerability Assessment of agricultural sectors.

5-Evaluating agricultural risk on municipal level and upscaling to governorate level for risk mapping.

6-Estimating damage on agricultural sectors.

7-Setting agricultural risk profile and seasonal agricultural risk calendar for Baalbek-Hermel

8-Prioritization

Figure 6-12: Agricultural risk assessment methodology organigram.

a) Data Assembly & Interviews

To accomplish an accurate multi-hazard agricultural risk assessment, the methodology required sector specific information along with data about past damaging events. In a retrospective approach, this study attempted to collect, analyze and quantify crop, livestock, aquaculture, and forests damage associated with disasters over the past decades, as a starting point to set the agricultural risk. To assemble this data, information gathering procedure described in chapter 5 was adopted, along with interviews with local farmers and responsible from the MOA to fulfill prepared questionnaires (Appendix B-C-D-E-F). Recorded events affecting specifically agricultural sectors, were collected from old documents and archived microfilms of newspapers are transformed to a GIS database and allocated to equivalent Municipality levels. In a community-based approach, interviews and field consultations with farmers, smallholders, stakeholders and MoA officers were achieved in order to collect required data and to determine the resilience of the four agriculture sectors in Baalbek-Hermel. These community consultation meetings started with an open discussion on various types of hazards that affect agriculture activities of the participants and then ranking these hazards into matrix (Figure 6-13) according to their perceptions and past experiences regarding probability to occur and impact on agriculture, livestock, aquaculture, and forestry. After the profiling risk, farmers were invited to provide recommendations on how to overcome challenges and better cope with the identified risk by improving resilience. Indigenous knowledge of farmers living and working in hazard-prone areas should be accounted for as an important complementary aspect to the scientific knowledge, especially in the establishment of community-based disaster risk reduction studies and strategies.

	Impact					
Probability	Very small	Small	Moderate	Severe	Critical	Disastrous
Major probability						
Probable						
Less probability						
Minor probability						
Very little probability						

Figure 6-13 Agricultural risk matrix to be filled accordingly to farmers' perception

It is noteworthy that all the collected data is on the municipal level and it was impossible to downscale it. However, this data served the methodology, carried out on the municipal level, well and increased the accuracy of obtained results.

b) Hazard Vulnerability Assessment

After data collection and community consultation, the hazard vulnerability of agricultural sectors needs to be evaluated. To assess the vulnerability of agriculture to a natural phenomenon, it cannot be expected to access complete data required to make a full assessment. The bio-physical vulnerability of crops, fruit trees, forests, and livestock species, requires a detailed and specific assessment of all the characteristic of each asset and climatic requirements (thermal and hydrological), which is beyond the scope of the current study. A hazard vulnerability assessment, that systematically evaluates the severity of impact of a natural hazard and the damage that could be caused, was applied in a retrospective approach. This hazard vulnerability assessment method, related to data availability, is based on historical information, both written reports and oral accounts from interviewed long-term farmers and MoA officers. The possibility of evaluating the effects of previous small natural disasters on the agricultural sector makes it possible to identify and characterize the vulnerabilities to natural hazards as well as their spatial footprint while allowing to account for their cumulative effects (Velásquez et al. 2014). The adopted and adapted methodology could be defined as a retrospective hazard vulnerability assessment, employing large numbers of disasters records in a systematic way (Velásquez et al. 2014). This method is known as the probabilistic approach which provides an estimate of the hazard vulnerability after assessing the probability (timing and sequences of events) and intensity of each hazard affecting an area, based on past recorded events. Vulnerability was calculated using the four main components collected from newspapers archived records, DesInventar cards and collected data i.e.; (1) Number of events, (2) damage on agricultural sectors, (3) Economic losses and (4) Village Vulnerability Index. Thus, the hazard vulnerability of agricultural sectors (Equation 6-5) would be a function of these three indices:

$$\text{Vulnerability}=\int(Data\ cards\ Index * Agricultural\ damage\ Index * Economic\ losses\ Index * Village\ Vulnerability\ Index).$$

Equation 6-5. Hazard vulnerability function adapted and utilized in current section.

It's worth noting that hazard vulnerability can't be expressed simply as a product of terms but must be expressed as a functional relationship (Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark 2017). Agricultural impact dimensions are the impacts on cropping systems including destruction of crops and greenhouses, the impacts on livestock including death or slaughters of animals, and impacts on aquaculture including fish production and ponds destruction, and damage to forest including pine and oak destruction. Economic dimensions are limited in this study to the monetary value of agricultural assets affected. Impacts and damages could be divided into tangible, intangible, direct, indirect, physical and non-physical damages. In the archived records, there is neither a clear information that indicates the past events damages and losses, nor clear damage assessment and detailed estimation. Our study is limited to direct tangible damages and especially to physical damages. Measuring relative loss (relative to what can potentially be damaged) rather than absolute loss, implies accounting for differences across spatial location (Neumayer and Barthel 2011) to make an accurate comparison of relative disaster loss between villages (Peduzzi et al. 2009). Therefore, the agricultural damage index was calculated relative to the agricultural elements in the village. Data about the approximate yearly distribution of agriculture areas was needed. An extrapolation method of previous agriculture census results was necessary, taking into consideration LU/LC analysis and urban sprawl. Concerning the village agricultural vulnerability index, any factor, that may affect the degree to which agricultural sectors are affected or may increase the damage or economic loss when any hazard strikes or hamper the coping and/or recovery processes, was taken into consideration and introduced in the calculation of this index. The vulnerability of the agriculture sectors in a certain village was determined relatively to:

- The percentage of cultivated areas relatively to the area of the village and also to the total cultivated area of Lebanon. Here, two important points are underlined. When the percentage of agricultural lands in a village is high, often the majority of householders are farmers and therefore hazards may threaten more the livelihoods of the village's inhabitants. Moreover, if the percentage of cultivated areas in a village relatively to the total cultivated area of Lebanon is high, the damage of these areas may have a wider impact and affect the national food security.
- The diversity of cropping systems, fruit trees, and livestock are tackled. The higher diversity of crop types decreases the vulnerability; not all crops get affected the same way by natural hazards.

- The percentage of irrigated area relatively to the total cultivated area of the village. In a climate change context where droughts are likely to increase with the potential decrease of precipitations, rain-fed agricultures are considered to increase vulnerability, especially in Lebanon where water scarcity is not an issue yet.
- The percentage of protected area (greenhouses) relatively to the total cultivated area of the village. Greenhouses protect crops from weather vagaries and thus decrease its vulnerability.
- The topography and slope of agricultural lands. The more the slope of an agricultural land is steep the greater is its vulnerability, especially to mass movements and land erosion.
- The percentage of livestock number relatively to the total number of livestock in the related governorate and in Lebanon. The large number of livestock increases the vulnerability due to the fact that livestock are often affected by contagious epidemics and the total eradication is the solution. Furthermore, the more the percentage of livestock in a village is high relatively to the Governorate and/or to Lebanon, the wider the impact would be and would affect the national food security and the GDP.
- The number of affected and damaged sectors deducted from the retroactive assessment conducted previously. These affected agricultural sectors certainly reveal vulnerabilities in the later and should be considered when calculating vulnerability.
- The number of holdings; the more an agricultural area is divided on many holders, the more the risk and losses would be shared between holders and then decreased)
- The age of holders/farmers; studies have proven that older farmers have less power and resources to cope and recover from disasters
- The sex of holders/farmers; it's claimed that the presence of female gender in the agricultural sectors tends to have other perception about risks and disasters and increases the resilience of the sectors
- The socio-economic obstacles that holders and farmers face. These obstacles, studied in FAO/MoA 2010 census, tend to increase the vulnerability of agriculture sectors (Reddy 2015) and hamper the coping and recovery processes.

All these factors were studied scrupulously on the village level and given weights using the PCA method detailed in previous section 2 of this chapter. All these corrected indicators and Indexes were compiled in GIS format. Models were built and ran to convert all database to geospatial data. Python scripts were established in order to estimate hazard vulnerability levels per villages.

c) Risk assessment

Risk assessment procedure is described to be an approach "*to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend*" (UNISDR 2009a). Following the above definitions and ISO 31000 norms, agricultural risk assessment was achieved in a GIS-based model by the combination of hazard, agricultural elements-at-risk and the calculated vulnerability function. Obtained results of risk were categorized as low, moderate and high. The risk levels can be explained as follow:

- Low risk: Low damage, no threat to livelihoods nor to the national food security, fast recovery
- Moderate risk: Medium damage, pressure on livelihoods, no long-term damage, recovery without external help

- High risk: High and often long-term damage (to yields, to livestock, etc…), no possible coping and recovery without external help

d) Loss estimations

Based on the determined risk value in each village, the damage to every agricultural sector was estimated. The temporal scale was also taken into consideration in the current risk assessment; damages were calculated depending on seasons and harvests according to seasonal crop calendar (Appendix A). Disaster damage is defined as the "*total or partial destruction of physical assets existing in the affected area. Damage occurs during and immediately after the disaster and is measured in physical units (i.e. square meters, etc.)*" (Israel and Briones 2013). While there are many methods for estimating damage to structures, there are few, usually simple, approaches to estimating damage to agriculture. The methodology used to assess damage and losses was adopted from the European Commission, World Bank, PDNAs Volume A and B Guidelines and GFDRR, 2010, and United Nations. 2013, and adapted to the Baalbek-Hermel agriculture sectors' context (European Commission 2011; GFDRR 2010). In the case of the study, only direct economic loss of damage will be estimated. Disaster damages result in reduced crop yield and quality and may need supplementary costs for sowing, tillage, and application of fertilizers and crop protection agents. Hence, damage to crops is understood as the loss in crop yield, and the main principle in the generation of crop damage functions becomes the correct evaluation of the values of these crops and their maximum yield production achieved. Direct economic loss is estimated on the basis of the original characteristics of the item and the unit prices prevailing at the time of the disaster or the prevailing market price according to yield production. The damage to destroyed physical assets is estimated by multiplying the damaged area by yield prices (for crops and fruit trees) or number of destroyed units with the replacement cost (e.g., for greenhouses and ponds) or current market price (in the case of dead animals, poultry and fish). To identify the crop yield and its respective market value or price the crop inventory of the Ministry of Agriculture was used, in addition to the established field data to fill the gaps. There are a wide variety of agriculture products in production at any given moment within the hazards zone. Information on the types of farms, methods of farming, average costs of production, average yields, average market values, available machinery, and past damage were also collected whenever available. All established parameters were assembled in the designed GIS database for further modeling procedures**.**

In this study, the crop value is understood to be the maximum yield production achieved at crop maturity. A GIS model was developed to generate the estimated values of crops. The crop essential data involve the crop yield per unit area (ha, m^2) and the price per unit (Kg, Bushel, Piece, etc.) value of the crop. Hence, the market crop value per square meter is obtained by multiplying the yield by the value per square meter. For any type of crop the value of crop can be calculated using Equation 6-6 below, after applying the required unit conversions:

$$\mathrm{CV} = Y \times CP$$

Equation 6-6. Value of crop equation

Where: CV: Market crop value in dollars per square meter, (\$/m2), Y: Average yield of crop, in unit per square meters, (unit/m2), CP: Crop Price per unit value, in dollars per unit, (\$/unit).

In greenhouses two seasons are planted per year. 75% of greenhouses are used for the production of vegetables were as 25% are used for flower and decorative plants production. Tomato and cucumber are the main vegetables grown in greenhouses, with around 50% of tomato, 40% of cucumber and 10% of other vegetables. Farmers benefit economically from the protected agriculture; this type of agriculture allows a continuous production through the year and can double or even triple the average production yield. Several interviews with the local farmers were performed through various field investigations to estimate the value of greenhouses. The price of construction of greenhouses was found to vary between 5 and 15 dollars per square meter depending on the quality of the material used in construction.

The degree of damage being a function of risk levels, direct economic losses are calculated in accordance with the estimated risk level for each level. For instance, the damage on agricultural assets may reach 25%, 50% and 75% respectively in low, moderate and high-risk levels.

In order to measure the expected losses on agricultural lands from each studied hazard, good knowledge of the affected agro-climatic zones is required. Information is required on the type and mixture of crops typically growing in each hazard prone agricultural area. Information on the available crop types was collected through interviewing the local farmers, and through reviewing the available documentations and surveys.

As developed in chapter III, Baalbek-Hermel contains four agro-climatic zones, each characterized with its own cropping pattern. Hence, these- major agro-climatic zones affected by hazards were established for the damage modeling, along with major crop categories. These agro-climatic zones are: 1) Coastal areas, 2) High mountain areas, 3) West and central Bekaa (inland areas) and 4) North Bekaa (inland area). Several major crop categories were established for damage modeling, each category is characterized by its own growth pattern: Potatoes, Wheat, Other crops, Olives, Grapes, Pome fruits (apple and pear), Cherries, Other stone fruits (peaches/nectarines, almonds, apricots, plums), Greenhouses, Cucumber (protected), Tomato (protected), Vegetables and vegetables (protected).

Moreover, crops and fruit trees damage and economic loss are directly related to their growth and productivity according to seasons and to their location based on agro-climatic zones. Therefore, losses in agricultural areas show a strong seasonal trend. Many authors highlight the fact that the time of occurrence of a hazard with respect to crop growth stages and critical field operations plays a central role in the intensity of damage (County, Crow, and Crow 2014). Depending on the time of hazard occurrence and the affected crop types the resultant damages may vary considerably. The adapted methodology is mainly inspired by the Agricultural Flood Damage Analysis (AGDAM) which has been developed by the US Army Corps of Engineers (AGDAM 1985) aiming to evaluating flood management and reduction projects (Brémond and Grelot 2013). Estimations are based on crop loss potential throughout the year, crop distribution patterns, and weighted seasonal frequency hazard events. Damage to agricultural crops represents the economic benefits lost due to the occurrence of a hazard. Potential agricultural damage (D) attributed a given crop is determined by applying the general Equation 6-7 below, with the components of damage explained:

$$D=ICt+NR+OC$$

Equation 6-7 Agricultural damage equation

Where (IC): the Investment Cost associated with bringing the crop to market; (NR) Net Revenue explained as income minus costs after harvesting mature crops; (OC) as damage to the crop, related land, soil or agricultural infrastructures as determined by the cost of correcting the damage.

The potential damage to a specific crop varies throughout the year, from the initial preparation of the soil for sowing to the end of the harvest. AGDAM has designed a crop loss function to define variations in the crop damage potential throughout the year (as percent loss versus time-of-year for each crop). The function describes a continuous relationship between the days of the year and the potential investment and net income (profit) attributed with the crop based on production costs, constant costs, harvest cost, and the value of the crop at maturity. Figure 6-14 describes a generalized crop loss function showing the equation used to define the monetary loss function (AGDAM 1985). The crop maturity period represents the greatest (100%) damage (loss) potential, which is equal to the gross value of the crop less harvest costs. The potential loss subsequently decreases, once harvest begins, through the completion of harvest (zero loss potential). Thereof, upon establishing the previous model, the damage can be estimated depending on the time of year a hazard occurs.

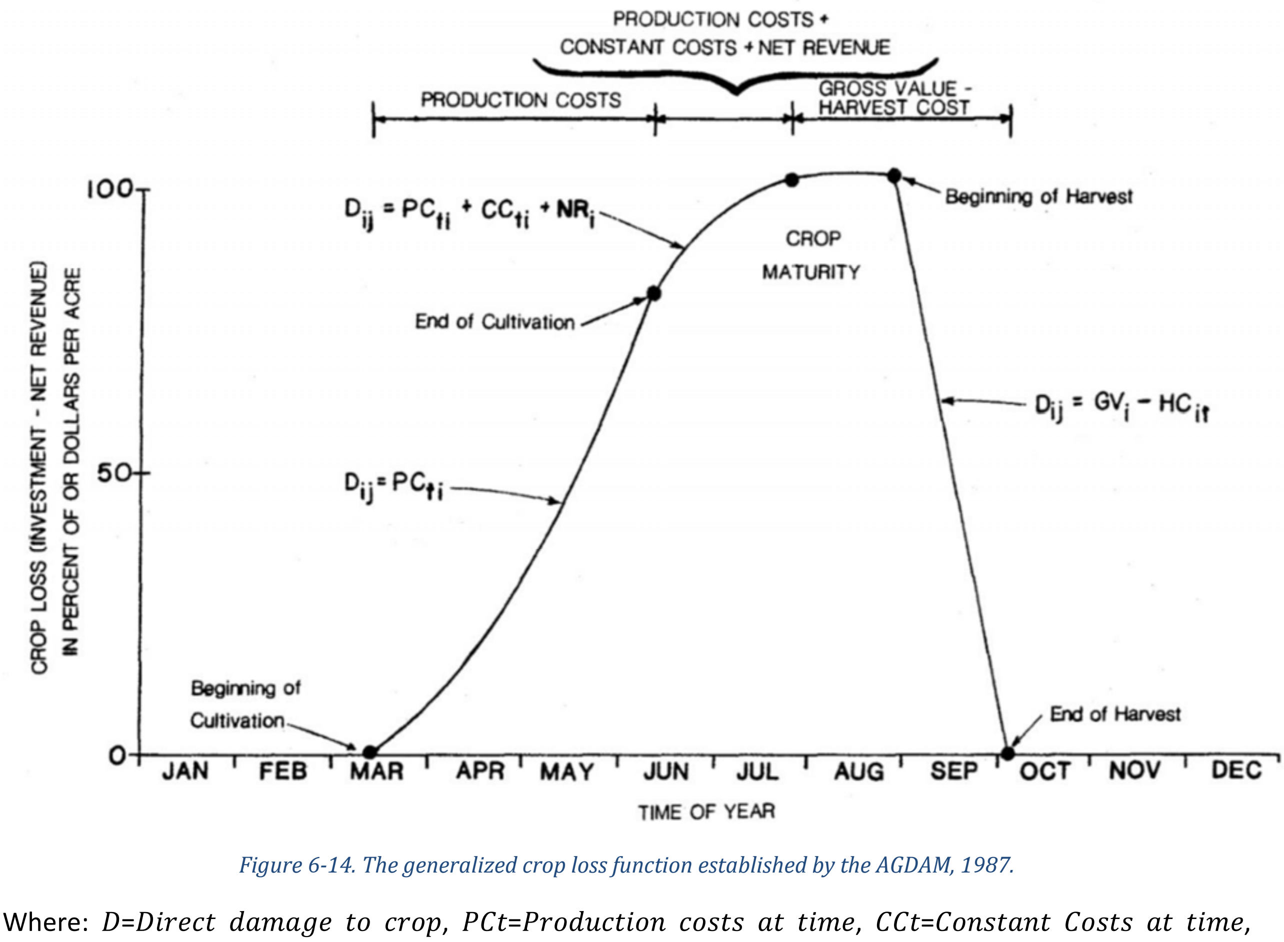


Figure 6-14. The generalized crop loss function established by the AGDAM, 1987.

Where: $D{=}Direct\ damage\ to\ crop$, $PCt{=}Production\ costs\ at\ time$, $CCt{=}Constant\ Costs\ at\ time$, $NR{=}Net\ revenue\ for\ crop$, $GV{=}Gross\ value\ of\ crop\ at\ maturity$, $HCt{=}Harvest\ cost\ of\ crop\ at\ time$.

Crop growth curves (damage functions) consistent with the AGDAM loss function were established for each crop category and for each agro-climatic zone (Appendix H). The main points (stages) describing the crop damage function are the beginning of cultivation, end of cultivation, crop maturity, beginning of harvest, and end of harvest (Rudari et al. 2016). Hence, effort was necessary to establish the main growth stages for each crop in each zone depending on the time of year. Once these growth stages are established the corresponding damage function can be depicted. Based on the date of occurrence of a hazard, the already invested cost of cultivation is also implemented in calculations. The damage to forests, livestock and beehives was calculated independently from seasons, only their market price was taken into consideration.

3.2. Results & discussion

The analysis of damage focused on four broad categories of crop, fishery, forestry and livestock products, which have been selected on the basis of available data and international comparability criteria, as well as their importance for food security, sectoral growth, rural income and the livelihoods of Baalbek-Hermel's farmers. The quantitative assessment of production losses was achieved by analyzing yields and production time series at the agro-climatic zone level. The damage calculation was done relatively to the season and agro-climatic zones, since the planting and sowing date for each crop differs in time and geographical zones. Therefore, crop growth curves (damage functions) were established (Appendix M). Some crops showed similar growth patterns, others required a separate growth curve because of their particularity. For the protected agriculture by greenhouses there is always an expected crop production throughout the year, in all the agro-climatic zones, except for July and August where generally no plantation is assumed to be found in greenhouses. Hence greenhouses in all agro-climatic zones share the same growth pattern.

Findings revealed that agricultural sectors in Baalbek-Hermel are effectively exposed, vulnerable and at risk of natural hazards. Baalbek-Hermel scores a damage of 130.3 million USD for worst case scenario per year considering total destruction of yields during winter and total destruction of yields during summer season. Damage from natural hazard on Baalbek-Hermel's agricultural sectors are shown in Figure 6-15. These results show that in Baalbek-Hermel temporary crops are mainly affected by flood, permanent crops by heat wave, greenhouses by land erosion/landslide, fruit trees by heavy winds, forestry by wildfires, fisheries by floods and livestock by cold and heat waves. The most damaging hazard in Baalbek-Hermel is the flood hazard with damage reaching out 90 million USD in worst-case scenario, followed by cold waves; winter is thus the most threatening season to agriculture. Concerning sectors, temporary crops are the most threatened (Figure 6-15).

The conducted analysis also contributed to the achievement of Baalbek-Hermel seasonal agricultural risk calendar (
Figure 6-16), and the related agricultural risk maps (Figure 6-17). These findings sum up the obtained results and consist of a helpful deliverable to raise awareness among farmers and stakeholders for what hazards to be careful of on what agricultural sector and in which months of the year in order to prevent it become a disaster.

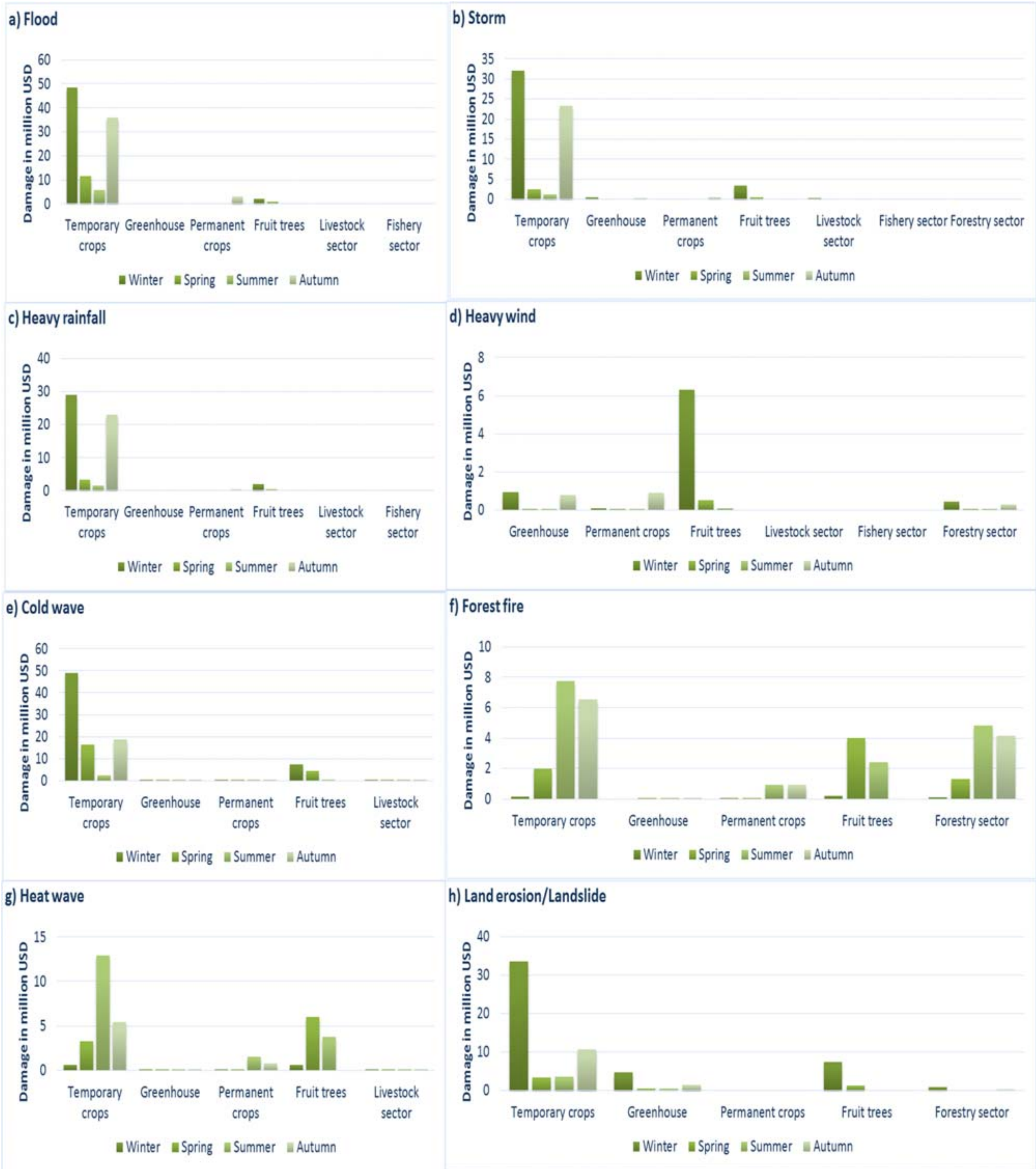


Figure 6-15 Damage (in million USD) on agricultural sectors & sub-sectors in Baalbek-Hermel, from a)Flood, b)Storm, c)Heavy rainfall, d)Heavy wind, e)cold wave, f) wildfire, g)heat wave, and h) Land erosion/Landslide, according to seasons.

Baalbek-Hermel	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Floods												
Storms												
Heavy rainfalls												
Heavy winds												
Cold waves												
Wildfires												
Heat waves												

Baalbek-Hermel	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Landslides												

Legend:

: Crops, : Fisheries, : Fruit trees, : Wheat, : Animal sector, : Greenhouses, : Olives, : Grapes, : Beehives,

: Potato, : Poultry

Figure 6-16 Agricultural risk calendar for Baalbek-Hermel.

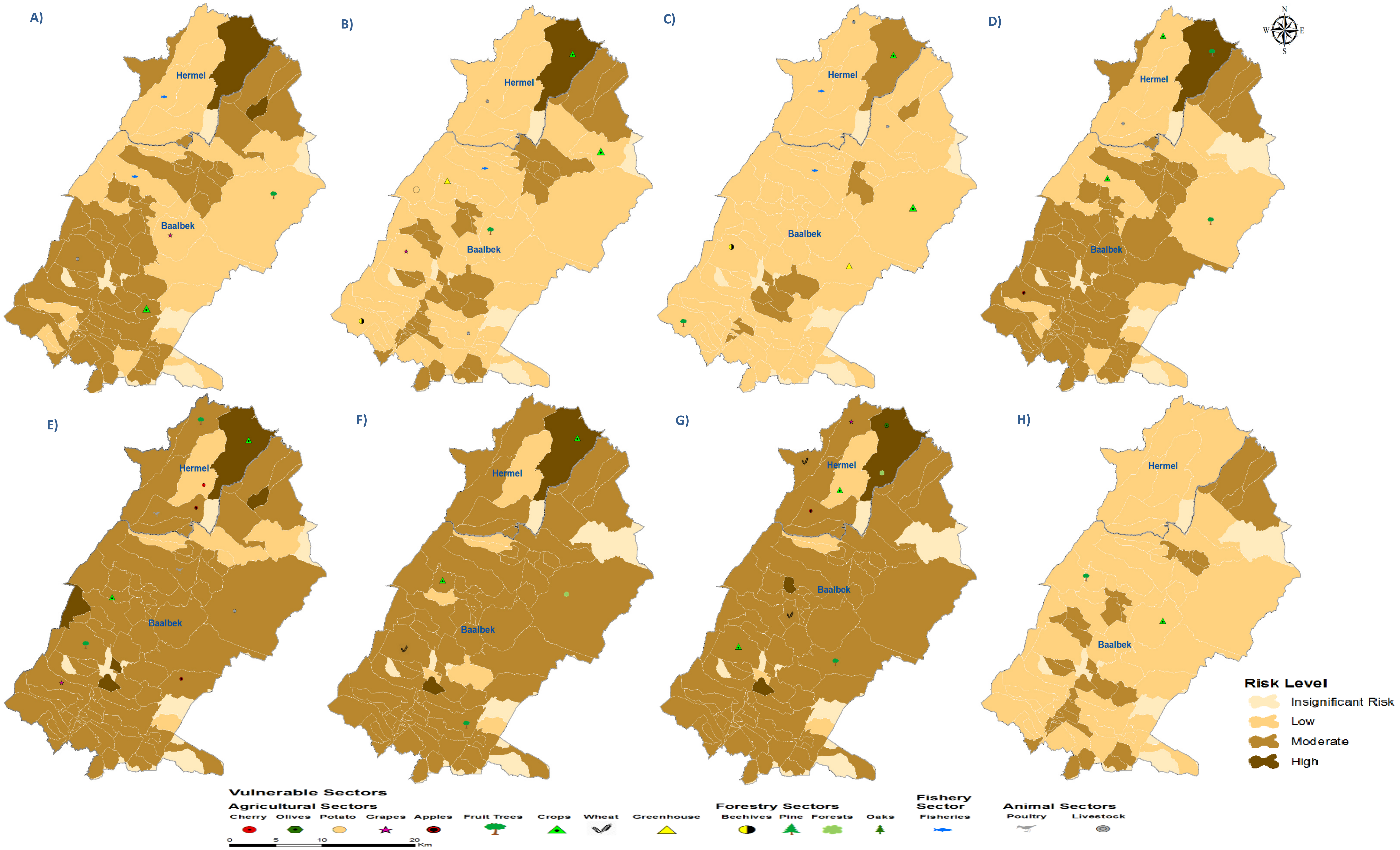


Figure 6-17. A) Flood, B) Storms, C) Heavy rainfall, D) Heavy wind, E)Cold wave, F)Wildfires, G)Heat waves, and H)Land erosion/Landslides risk on agricultural sectors.

Evidence emerging from the conducted risk analysis in this section leads to agricultural risk prioritization in Baalbek-Hermel.

In prioritizing the identified agricultural risks (Table 6-2), the key factors to consider in ranking these risks based on weighted scores were 1)the yearly probability of occurrence of the risks; 2)the intensity of the impacts on sub-sectors due to these risks; and 3)the estimations of average annual losses attributed with the worst case scenarios when they occur. The assessment is weighted 50 percent for the probability and the intensity; the 50 percent remaining is assigned to the impact of the worst-case scenario.

Table 6-2 Scoring of agricultural risks in Baalbek-Hermel.

Risk	Average Annual Frequency	Average Severity	Worst -Case Scenario	Score
Floods	Moderate	High	Very high	8.5
Cold waves	High	Moderate	Very high	8.5
Winter Storms	High	Very high	High	8.5
Heat waves	High	Very high	Moderate	7.5
Heavy rainfalls	Low	Very high	Moderate	6.5
Wildfires	Low	High	Moderate	6
Heavy winds	High	Moderate	Low	5.5
Land erosion/Landslides	Very Low	Moderate	Low	4

Based on the conducted study, all the above-mentioned risks reflect the agricultural risks to be prioritized in Baalbek-Hermel, but with different levels of prioritization:

1- Floods, cold waves, winter storms are ranked at the top of the overall reported score in Table 6-2. However, annual average probability is medium to high, the comparatively high intensity on sub-sectors as well as high to very high intensity of the worst case scenarios are the cause of the high scoring.
2- Heat waves rank as the second highest priority as their average annual probability is high to very high and their impacts on agricultural sub-sectors is severe. Additionally, the intensity of the worst case scenarios of these extreme temperature events in Baalbek-Hermel, which tend to coincide with climate change effects, is high.
3- Heavy rainfalls, Wildfires and Heavy winds are ranked for moderate prioritization. Although these risks might have moderate to high impact in worst-case scenarios, they scored so low annual probability and moderate impact on agricultural sub-sectors.
4- Land erosion/Landslides come as the lowest priority as their average annual probability is very low and their impacts on agricultural sub-sectors and intensity of the worst-case scenarios are moderate.

The impacts of the identified agricultural risks across different sub-sectors are summarized in Table 6-3 below. Temporary crops and fruit trees can be ranked as most vulnerable as they are highly vulnerable to at least two risks. High priority risks like floods and winter storms have high impacts on more than two sub-sectors.

Table 6-3 Sub-sectors vulnerability (yellow: Low, orange: moderate, red: high) to agricultural risks in Baalbek-Hermel.

Sectors / Risk	Temporary crops	Fruit trees	Other permanent crops	Greenhouses	Animals	Fisheries and aquaculture	Forestry
Floods							NA
Cold waves						NA	NA
Storms							
Heat waves						NA	NA
Heavy rainfalls							NA
Wildfires					NA	NA	
Heavy winds					NA		
Land erosion/ Landslides					NA	NA	

Table 6-4 describes geographical vulnerability to identified agricultural risks in Baalbek-Hermel. Most of the identified agricultural risks have spread impacts but their incidence might be different. For instance, heavy rainfalls impacts on agricultural sectors are comparatively higher in the central region of Baalbek-Hermel governorate. On the other hand, agricultural sectors in the North-Eastern region of the governorate are highly exposed to three risks, while the Southern-Eastern Region is the less exposed.

Table 6-4 Geographical exposure (yellow: Low, orange: moderate, red: high) to agricultural risks in Baalbek-Hermel.

Regions / Risk	North-Western	North-Eastern	Central	South-Western	South-Eastern
Floods					
Cold waves					
Storms					
Heat waves					
Heavy rainfalls					
Wildfires					
Heavy winds					
Land erosion/Landslides					

Table 6-4 ranks the North-Eastern region of Baalbek-Hermel as highest priority for action, followed by the North-Western region. The south-Eastern region of Baalbek-Hermel comes in the last place.

3.3. Conclusion

To achieve proper prevention and mitigation strategies or plans in Baalbek-Hermel, rural region, it is first essential to develop a concise understanding of agricultural vulnerabilities and their driving factors. Vulnerability and risk assessments are the first phase in the DRR cycle, as these highlight priorities for action. Therefore, the developed agricultural risk assessment is the starting point for planning for risk reduction and setting adaptation plans. As stated previously, the outcome of the current agricultural risk assessment is ultimately to build Baalbek-Hermel agricultural risk profile and facilitate the adoption and implementation of a comprehensive agricultural risk reduction strategy in the governorate.

The assessment was tackled on two axes, seasons, and agricultural sectors. The studied agricultural sectors are a) cropping systems, b) Livestock, c) fishery sector and d) forestry sector. DesInventar historical events data and Lebanese newspaper archive were gathered, treated and geospatially transformed to serve as inputs for the defined methodology. Special attention was given to historical events with damage on agricultural sectors for the retrospective assessment. Agricultural risk was tackled on cadastral levels for floods, storm, heavy rainfall, heavy wind, cold wave, forest fires, heat waves and land erosion/landslide, following EU commission guidelines and ISO 31010 and UNISDR/FAO methodologies. Damage and losses calculations required sophisticated python models. The innovative aspect of this section is the combination of retrospective and community-based assessment, and the implementation of spatial-temporal dimensions for agricultural loss estimation based on the drawn crop growth function for each crop category relatively to climatic zones.

The study confirms that agricultural sectors in Baalbek-Hermel are not safe from weather vagaries and natural disasters. Natural hazards affecting Baalbek-Hermel's agricultural sectors can be resumed to weather-related hazards such as floods and cold wave (hail, frost). These hazards revealed to be the most damaging to agricultural sectors and Temporary crops are the most vulnerable agricultural sub-sectors. The results helped ranking agricultural risks in Baalbek-Hermel based on the weighted scores of average yearly probability, intensity of the risks as well as impact and damage for a worst case scenario in a year time scale. Floods (90 million USD of economic losses in worst-case scenario) is considered to be the most damaging disaster on agricultural sectors, followed by cold wave (76 million USD). Thus winter is considered as the most damaging season to agricultural sectors in Baalbek-Hermel.

Multi-hazard agricultural risk maps and seasonal agricultural risk calendar were achieved for Baalbek-Hermel. This calendar sums up the obtained results and consists of a helpful deliverable to raise awareness among farmers and stakeholders for what hazards to be careful of, on what agricultural sector and in which months of the year. Automated systems created through Python scripting language to facilitate complex geospatial calculations provides new opportunities for in-depth analyses during damage assessment in the aftermath and enhance compensation procedures.

4. Gaps, Challenges and Uncertainty

This chapter, through its several case studies, discussed the use and benefits of GIS and modelling in each step of prevention phase. These risk assessments, scenarios and models, with as ultimate goal to provide valuable insights allowing Baalbek-Hermel decision-makers to take more effective prevention and mitigation measures, present some known limitations and unknown uncertainties and probabilities that should be pointed out. Pre-disaster actions in Baalbek-Hermel, as for other regions in developing countries, often present a conundrum, where risk assessments are hampered by lack of crucial information. Societal challenges behind mitigating intensive hazards reside in the uncertainty of the latters. The field of risk necessarily entails uncertainty which is an inherent part of risk assessment as probabilistic and because risk, as noticed, by definition is assessment about something that may or may not happen. These uncertainties form a considerable debate, especially about the acceptable level of risk when considering the costs of associated prevention and mitigation measures. Moreover, Baalbek-Hermel as of other regions in developing countries, face some barriers in the implementation of GIS and GIS-based models to fulfill DRR related requirements. These uncertainties present many challenges and lead to an increase of vulnerability to natural disaster in these regions. The faced gaps, challenges and uncertainties in this chapter reside in:

a) Uncertainty In hazard, exposure, vulnerability and risk

Only few findings from natural and social science are claimed to be 100% certain. Uncertainty emerging from natural hazard risk assessment can be grouped into two classes: Aleatory and epistemic uncertainty. Aleatory uncertainty underlies in the intrinsic variability of a hazard. For example, climate change contributes to hazards' uncertainties residing in frequencies and intensities of hazards. Epistemic uncertainty comes from a lack of understanding and validation of the real behavior of a hazard, owing to the natural randomness of hazards and the fact that information and understanding of hazard, exposure and vulnerability is incomplete. Possibly, one of the most significant sources of uncertainty in models is the level of vulnerability and hazards impact is complex and can be variable. The retrospective assessment of vulnerability adopted in this chapter is based on claims data losses that may lead to outdated vulnerability information; past losses are not necessarily always identical to future. It is clear that vulnerability assessments need to keep pace with lifestyle changes, urbanization, building standards, infrastructure and changes in climatic patterns. This uncertainty is cumulated and exacerbated at each subsequent stage of a risk assessment, from hazard till the production of the final risk. The significant impediment is that uncertainties are not accordingly constantly conceivable to make reasonable speculations about conceivable future situations.

b) Data issues

"*Accurate and comprehensive spatial data play a critical role in all phases of disaster management*" (Brodnig and Mayer-Schonberger 2000, p.3) and are needed for efficient GIS use, yet in Baalbek-Hermel as in many regions in developing countries, trustworthy spatial data are a rare resource. The precision of the obtained results depends of the precision and accuracy of the provided data; a significant data checking, processing and cleansing was required for establishment of accurate models. Furthermore, due to sparse historical records, it is necessary to interpolate and extrapolate in order to get a more complete picture that can serve as suitable input for probabilistic modelling; Interpolation and extrapolations are often important sources of uncertainties. The finer were the input information the more robust were the results. The dearth of data consists of major gaps and impediments in the analysis of various risks. If past events damages large database exists, further validation could have been done for the multi-hazard School Vulnerability Index (ScVI) developed this chapter, through logistic regression. Moreover, if more detailed data exists, the inclusion of more indicators in the developed ScVI, excluded herein, would have been possible and would have led to more precision of the model.

c) Choice of the approach

Risk analysis can be done either in a qualitative, semi-quantitative or quantitative approach, depending on data availability. Quantitative methods are claimed to entail uncertainties and not considering all the components associated with the social and economic spheres that are highly interrelated to the problem. These components are covered by qualitative methods as they aim to investigate the interaction of spatial, territorial, social and economic factors in the face of hazards. Qualitative methods are also claimed to entail subjectivity which could lead to uncertainties. To combine qualitative and quantitative methods with statistical models (PCA), as done for developing a multi-hazard School Vulnerability Index (ScVI) section of this chapter and in studying the agricultural hazard vulnerability, is a good approach to lessen uncertainties.

d) Reliability of economic estimations

It is important to be aware that the resolution and the reliability of claims and compensations are not totally accurate, especially in developing countries. Considering that in the majority of these countries as it is in Lebanon, no scientific methodology is adopted for damage estimation and some corruptions do exist, there are exaggerations in some cases in order to get more money out of compensations and underestimation also in others where the poorest have illegal properties and therefore don't get any governmental compensations. Moreover, no insurance data is available since no insurance system covers natural disasters losses. Thus, loss estimations may entail considerable uncertainties.

e) Challenges in mapping and communicating the findings

While the importance of risk assessments and their findings and deliverables to increase resilience was acknowledged worldwide, tackling the exposed and vulnerable societies, groups or regions is to be done carefully. Effectively, different reactions to mapping exposure and vulnerabilities and pointing them out could be observed. For instance, the public schools that were found out highly vulnerable based on the multi-hazard School Vulnerability Index (ScVI) developed in this chapter, if not carefully introduced may cause a panic for the parents of the enrolled students. In other cases, proprietary of some assets pointed out as vulnerable may feel offended. Therefore, the meaning of the risk information provided on this type of maps needs to be clear and adequately explained to the public and effectively communicated in a way to serve constructive discussion and the implementations of measures to increase resilience.

It is of key importance to seek to reduce uncertainty as much as possible but inevitably it must be accepted and taken into account that uncertainty will always exist especially in the field of risk where uncertainty is inherent and knowledge is not complete.

Chapter 7 . Preparedness and Response planning phases

Preparedness and response planning actions in Baalbek-Hermel, as for other regions in developing countries, are often a conundrum, where investments often involve painful trade-offs among competing priorities and immediate necessities. As mentioned in the "Study area" Chapter 4, this Governorate is prone to floods and earthquakes, hazards that require emergency planning and evacuation routing. However, detailed evacuation routing plan does not exist for any hazard, nor did local municipalities designate specific roads and label.

This chapter emphasizes on the contribution of GIS in emergency planning, shelters allocation and evacuation planning in demonstrating the spatial-temporal aspect of complex evacuations and how it can be implemented in Baalbek-Hermel. To explore the usage of spatial analysis techniques (Network Analyst) for emergency planning, two case studies dealing with the phases of preparedness and response plans in Baalbek-Hermel are represented in this chapter. The first case study deals with modelling flash floods pedestrian evacuation potential in the village of Ras-Baalbek using Least-Cost-Distance based approach. Previous flash floods episodes in Ras-Baalbek have caused casualties; preparedness measures for flash floods risk must be planned and implemented as soon as possible by the different authorities. The second example deals with planning a larger-scale, macroscopic evacuation routing model in case of high-intensity earthquake event in Baalbek-Hermel Governorate. Baalbek-Hermel Governorate is located in a seismic-prone zone, crossed by Yammouneh fault and Serghaya fault and has a long history with earthquakes, which renders an evacuation plan a necessity.

1. Pedestrian evacuation planning for Ras-Baalbek flash floods scenario using Least-Cost-Distance based approach

Floods, among other hydro-meteorological hazards, are the most pervasive and prevalent (Arrighi et al. 2019) affecting more people worldwide than any other type of natural hazard (EC 2017; Guerreiro et al. 2018). Hazards such as floods have the potential to cause extreme property damage and great loss of life. During floods, according to Arrighi et al. (2019),the majority of fatalities occur outdoors when people attempt to escape by driving or walking in floodwaters (FitzGerald et al. 2010; Kellar and Schmidlin 2012; Salvati et al. 2018). Despite developments in early flood warning systems, studies have also demonstrated that the impact of floods is intensifying over time (Ferreira, Hamilton, and Vincent 2011; Jha, Bloch, and Lamond 2012). Besides being key components of the Sendai Framework (UNISDR 2015d), preparedness and planning play a pivotal role in reducing the impact of floods on lives, livelihoods and societies (Petrucci et al. 2017). Emergency evacuation is often one of the most effective and feasible preparedness strategy that can be undertaken in response to floods (European Commission 2003; Hector Lim, Lim, and Piantanakulchai 2013; Na, Xueyan, and Mingliang 2012; Zhai and Ikeda 2006). However, confusing and contradicting evacuation information can aggravate flood situations; some field investigations often reported that many people lost the chance to evacuate due to their late decision and limited information. Knowing exactly where to go during an evacuation is crucial to survival for people in a flood hazard prone zone. Moreover, Siebeneck and Cova (2012) found that people are motivated to evacuate when the level of risk to their homes is displayed on maps.

This calls for microscopic flood evacuation models that can provide an effective mechanism to analyze the population's spatial-temporal exposure, flood risk and evacuation response in order to raise awareness and educate people about risk. Although the need for tools and models to assist facilitating evacuation under flooding scenarios is becoming increasingly sought (Johnstone and Lence 2009), evacuation planning and modelling studies that specifically consider flood hazards are still limited in number (Lim, Lim, and Piantanakulchai 2013). In the literature, relatively few studies have modelled flood evacuation through different approaches, e.g., a heuristic and implicit enumeration algorithm (Sherali et al. 1991), a telephone survey and face-to-face interviews (Pfister 2002), timeline modelling (Opper et al. 2010), inundation analyses (Opper et al. 2010), Geographic Information System (GIS) (Masuya, Dewan, and Corner 2015), a logit model (Lim, Lim, and Piantanakulchai 2016), dynamic modelling approaches (Dawson, Peppe, and Wang 2011; Dressler et al. 2016; Lumbroso et al. 2010; Mordvintsev et al. 2014; Southworth and Chin 1987; Wang et al. 2010) and integrated, large-scale, micro-level multi-models for simulating human behavior and routing (Wolshon and Dixit 2010).

It is important to note that these evacuation models serve also for exposure assessment. Basic population exposure numbers do not reveal the full risk story; distances to safety of each evacuee shows variations in population exposure as a function of pedestrian travel times to safety (temporal exposure). Exposure functions based on these evacuation micro-models can be used to estimate life loss and identify the effects of management response (Dawson et al. 2011). Preparing a community for future floods requires not only an understanding of the hazards faced, but how residents are exposed to those hazards.

Flash floods are among the most dangerous hydro-meteorological hazards threatening the Mediterranean Region, resulting in significant losses (Gaume et al. 2017). This is due to the local semi-arid climate with long spell of consecutive dry days, and bare soils on mountain slopes with little infiltration capacities. Short intense bursts of rainfall would lead to runoffs rushing immediately into usually dry channels, called "oueds". Moreover, Mediterranean countries have a considerable population growth rate which, leads to a rapid increase in urbanization, especially in flood prone areas (Gaume et al. 2009). Several papers and projects focused on past flood events in Mediterranean countries (Barnolas and Llasat 2007; Barredo 2007; Barrera, Llasat, and Barriendos 2006; Llasat et al. 2005). Despite the fact that the entire Mediterranean region is exposed to floods, the incidence and impact of these vary considerably throughout the region

(Payrastre et al. 2018). While developed information and preventive measures exist in the north-western part, though with limited success and further research is required (de Jong and Ira Helsloot 2010; Soon, Kamaruddin, and Anuar 2018), some southern and eastern countries lack information on floods and mitigation measures are often forgotten (Llasat et al. 2010).

Flash floods in Baalbek-Hermel Governorate-Lebanon, eastern Mediterranean country, are frequent especially in Ras-Baalbek, a relatively dense village with buildings not exceeding one or two floors. The region's semi-arid land along with the limited vegetation cover hamper the absorption of the excess water and increase the runoff. These flash floods, the most catastrophic of which occurred as recently as 2018, caused considerable damages to the road network, infrastructure, crops and livestock, severe soil erosion in addition to, and most importantly, casualties. Structural flood protection measures were taken in the forms of reservoirs and walls to intercept flood waters. It was notable that relying only on such structural measures is not a proper way for reducing flash floods risk in Ras-Baalbek, as they are not consequently maintained (Abdallah and Hdeib 2018). Raising awareness of, preparing and planning for these catastrophic and sudden hazards that arrive within a short lag of time is of ultimate importance to reduce losses of lives and mitigate the negative impacts of floods. Among these risk preparedness measures, a detailed flood evacuation planning of the population of Ras-Baalbek is required, especially that no studies on flood evacuation have been conducted and no evacuation plan exists in this highly exposed and vulnerable area. Due to the suddenness flash floods, lack of early warning system, and the relatively small floodplain and limited road network in study site, as in other similar region of the world, evacuation is self-initiated by walking/running across the landscape without any routing restrictions (Wood and Schmidtlein 2012). Vehicle use, which may lead to road congestion, represents a potential threat to the physical safety of pedestrians, drivers and passengers alike, which should be highly discouraged (Trindade, Teves, and Catita 2018).

In response to all the above, this work investigates using an ArcGIS extension “The Pedestrian Evacuation Analyst” (PEA) developed by USGS (Wood et al. 2014; Wood and Schmidtlein 2012, 2013), pedestrian emergency flood evacuation potential on the landscape characteristics in Ras-Baalbek village. Employing anisotropic least-cost-distance (LCD) modelling and exploratory geospatial analysis approaches, this section addresses the need for evacuation maps in the region for supporting evacuation outreach, emergency response, relief planning, and disseminating a culture of risk (Wood et al. 2016). Modeling pedestrian evacuations from natural hazards by using LCD approaches is a fairly new yet developing subject in the literature with numerous growing techniques for examining and modeling pedestrian travel costs like travel time (Graehl 2009; Laghi, Cavalletti, and Polo 2006; Post et al. 2009), probability functions based on existing routes (Pingel 2009), energy expenditure (Jobe and White 2009) and agent-based model focusing on individual evacuee behavior (Pluchino et al. 2015). Aiming to understand the spatial distribution of evacuees over the time within Ras-Baalbek community, the LCD-based approach was chosen over the other cited methods. The adopted method and detailed analysis of potential evacuation times necessitates an important amount of high-resolution data and several processing steps since, in opposition to many other pedestrian evacuation analysis (Girres et al. 2018), it takes into account the elevation changes (i.e. how steep the path is) and the different types of land use /land cover (maintained road, sand, grass, forest, buildings, rivers, etc.) that a person would encounter on his way, along with travel speed of the evacuee (walking, running, etc.).

Maps of pedestrian evacuation times to high/safe ground for every location in Ras-Baalbek floodplain area were elaborated after estimating how long it would take for someone to escape the hazardous area on foot with the impediments faced through each traversed parcel represented as a cost surface. Taking into consideration current land covers and population distributions across the floodplain, a baseline of potential pedestrian evacuation times was achieved and counts of people at different travel time intervals were also calculated, revealing that among the 1550 evacuees simulated, more than 12% would not reach safety at the time of flash floods arrival. In order to reduce this percentage, potential vertical evacuation structures, like high flood-resistant “shelter” buildings, were proposed and their effectiveness and tradeoffs were assessed through new potential evacuation-time maps. The use of proposed vertical evacuation buildings can reduce the risk of fatalities from 12 to 3%. Finally, as the main purpose of evacuation is to route evacuees to the nearest road that would allow for a quick departure before the arrival of flash floods, evacuation signs were proposed to be integrated on roads.

These pedestrian evacuation-modelling results have preparedness implications and application to flood-evacuation outreach, educating and training (for the community, emergency managers, community planners and first responders), response procedures, mitigation (reducing the risk or even the loss of life of people living in Ras-Baalbek high flood risk areas), and long-term land use/land cover planning to increase Ras-Baalbek community resilience. One of their most important applications is to initiate Ras-Baalbek population to self-evacuate and prepare and plan for this evacuation. Moreover, the elaborated evacuation model can serve as a decision-making support tool through detailed comparisons of the proposed flood vertical evacuation options.

1.1. Methodological Approach

The main focus of this study is to estimate the potential pedestrian evacuation time to safety in Ras-Baalbek flash floods prone areas, propose vertical-evacuation buildings to reduce this time and organize the evacuation accordingly with the implementation of evacuation signs. This section describes in details the steps of the conducted geospatial analytical methodology resumed in the workflow diagram (Figure 7-1). The main approach consists on the anisotropic Least-cost-distance (LCD) modelling based on the development of a raster in which each pixel holds a value accounting not only for the geometric distance but also for the cost and directionality of movement across open landscape (Wood and Schmidtlein 2012). This cost is calculated through mathematical functions linking the slope, land cover, and movement components based on optimal routes. In this case study, evacuation routing is not constrained to a road network, thus allowing for the use of the entire accessible terrain.

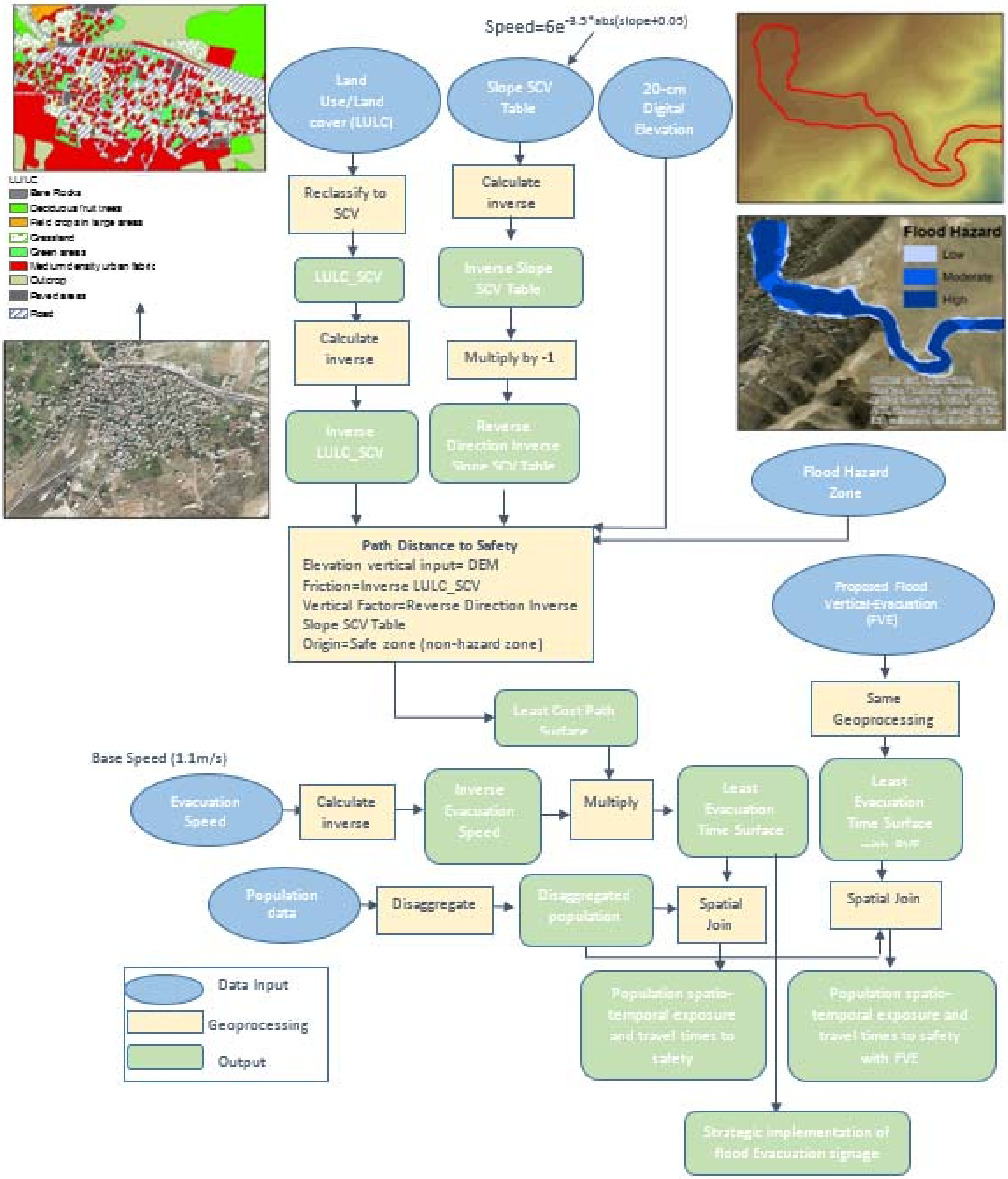


Figure 7-1. Workflow diagram of Pedestrian evacuation modelling for flash floods in Ras-Baalbek. Source: Adapted from Wood and Schmidtlein (2012)

1.1.1. Gathering and data preprocessing

Data required for pedestrian evacuation modeling include: 1) high resolution digital elevation model (DEM), 2) detailed land use/land cover datasets, 3) flood hazard zone, and 4) population data of the concerned floodplain.

a) Floodplain

The flash flood hazard zone used in this study is based on the Flood Hazard Assessment and Mapping for Lebanon study conducted in 2013 by the National Center for Remote Sensing (NCRS). The worst possible flash flood scenario was considered despite its low 0.01 exceedance probability (or return period T=100 years). This decision is related to the fact that the worst-case scenario provides a clear indication of the maximum area that will be affected by the flooding; and therefore by adopting this scenario, the less severe scenarios are inherently safeguarded. Concerning the available time for evacuation, although the flash floods lag time in the concerned watershed is estimated to 2 hours, due to the lack of early warning system, people are warned only 10 minutes before the arrival of the floods.

b) DEM

DEM is used to derive slope; High/safe ground can be reached usually by moving away from the river bed and climbing the hillside. The degree of slope is one of the most important components for determining evacuation speed in an anisotropic LCD approach which is slope dependent (Laghi et al. 2006). Anisotropy incorporates the influence of a given slope on the direction of travel (uphill or downhill). Moreover, the model uses the slope information to detect possible changes in travel speeds. The spatial resolution of the DEM has a large impact on the results of the computed pedestrian travel-time map. Wood and Schmidtlein (2012) have showed, in a model sensitivity analysis, that varying elevation data resolutions from 1- to 10-m grid cells had a significant impact on evacuations times across the entire study area and, eventually, on the number of people to reach safety on time. Therefore, a 20-cm DEM, conducted by CNRS-L via drone imagery was utilized in the current study. More than 5000 raw images were captured from several drone photography surveys covering the whole floodplain. These raw images were acquired in strips with adjoining photographs having an overlap of 80% in the flight direction and 70% between parallel flight tracks (Hdeib et al. 2018; Abdallah and Hdeib 2018). To generate the 20 cm-resolution DEM, the images were integrated and processed in the Pix4DMapper software following criteria provided by the American Society of Photogrammetry and Remote Sensing (Mikhail et al. 2004).

c) LULC

Land use/Land cover map is another important component of anisotropic LCD modelling. The study of Wood and Schmidtlein (2012) has proved that LULC resolution also greatly influences travel times and the use of higher resolution LULC datasets is highly recommended for more accurate results. In this context, drone aerial photos were used to manually map and classify a

1/100 resolution land use/land cover for the concerned zone of Ras-Baalbek. A total of 319 residential structures were delineated in the studied floodplain.

d) Population

Data about population distribution and characteristics is necessary to separate each time step by geographic unit and indicate the population by time and location during every phase of the evacuation. High resolution population datasets are also essential for accuracy of outputs. For this purpose, and having elaborated a 1/100 resolution LULC for Ras-Baalbek floodplain, the population data were obtained by applying an intelligent dasymetric method. Disaggregating population homogenously to residential structures contains uncertainties but determining exact population counts at each household was considered beyond the scope of this study.

After gathering, preparation and treatment, all of these inputs were converted to raster grid formats.

1.1.2. Reclassifying LULC into SCV

This step consists on defining the relationships between LULC types and movement/walking speeds of a human. Each class of the produced LULC was given a new value describing its capability to modify or conserve the speed of a person's movement. These values are ''speed conservation values'' (SCV) based on the inverse of the landscape-energy coefficients discussed in (Soule and Goldman F. 1972) and revealing the proportion of a maximum speed that could be reached across the given LULC type. Table 7-1 shows the land-cover types delineated for Ras-Baalbek community, PEA simplified LULC classes and their associated SCVs. Values range from zero, indicating that travel is not possible, to 1.0 indicating that pedestrian evacuation speed is 100 percent of the base travel rate. Consequently, LULC_SCV layer was generated and converted to a cost-inverse raster implying the friction of the evacuation movement.

Table 7-1 Ras-Baalbek Land-use/Land-cover types, PEA land-cover classes and their corresponding Speed-Conservation Values (SCV). Source: adapted from Soule and Goldman F. 1972.

Ras-Baalbek Land-use/Land-cover types	PEA Land-cover classes	Speed-conservation values (SCV) (fraction of maximum travel speed)
Not available	Water	0 (No through travel possible)
Industrial /Urban	Buildings	0 (No through travel possible)
Bare rocks/outcrops	Unconsolidated Beach (sand)	0.5556
Forests/fruit trees	Heavy Brush	0.6667
Grasslands /crops	Light Brush	0.8333
Urban sprawl/open space	Developed	0.9091
Paved areas/Roads	Roads	1

1.1.3. Slope reclassification into SCV

Slope, derived from 20-cm DEM, is combined with a table based on Tobler's (1993) hiking function converting slope to inverse "speed conservation values" (SCV) following the empirical Equation 7-1. Walking speed as function of slope :

$$\text{Walking speed} = 6e^{-3.5*|slope+0.05|}$$

Equation 7-1. Walking speed as function of slope (Tobler, 1993)

SCVs herein represent the fraction of maximum travel speeds expected on areas with different slopes. Consequently, a SCV surface for slope is obtained and used as vertical factor to retrieve the anisotropic cost. The direction of the inverse slope SCV table is then reversed because the search direction in the LCD path algorithm is opposite the direction of evacuation, beginning from safe zones (set as the origin) and expanding to floodplain (set as destination) for easier means of search for the shortest paths.

1.1.4. Calculating path distance to safety and creating Least Cost path surface

In respect to anisotropy, travel cost distances are calculated using Path Distance geoprocessing tool allowing for both the calculation of three-dimensional distances between cells of changing elevations and different LULC types in the floodplain, as well as the path from a given cell to each of its adjacent cells reaching out the nearest safe zone (Wood and Schmidtlein 2012). All artificial structures like buildings, walls, etc. are automatically removed from the model, considered inaccessible; the model considers detours during evacuation to avoid these structures.

1.1.5. Calculating Evacuation Speeds

Human walking speeds vary with multiple factors. Several authors addressed evacuation speed issues and suggested speed values that widely range from 1.0 m/s (González-Riancho et al. 2013; Yagi and Hasemi 2010) to 2.80 m/s (Post et al. 2009). In this study, 1.1 m/s is adopted as the fixed average value considered for the normal speed of an adult (United States Department of Transportation 2009). This speed, though seen as conservative (Wood et al. 2014), is considered to be appropriate for the floodplain mixed population with ranges in age and physical mobility; demographic data show that 16% and 7% of the population in Ras-Baalbek are children and elderly, respectively (Population Explorer 2019). This value is a simplification of actual travel speed, especially for children, elderly people, and evacuees with special needs, since these groups may also have mobility problems prior to the flashflood occurrence, may encounter more difficulties evacuating flood-prone areas and influence evacuation response (Heller et al. 2005; Schiff 1977). Moreover, fatigue also affect the travel speed; to quantify, in our study area, the

interrelation between traveled distance, land cover conditions and fatigue, additional physiological research is required.
To obtain SCVs, speeds were then divided by the greatest potential walking speed, a universal calculation across the full extent of the slope-based, walking-speed surface (Wood and Schmidtlein 2012).
Overall, the use of a lower travel speed is justified by the probability of individuals moving faster but also likely to be delayed for various reasons (Wood et al. 2014).

1.1.6. Generation of Least Evacuation Time map

To illustrate the time it would take to walk, in minutes, to the closest flood-safe evacuation site, the LCD surfaces were converted to pedestrian least-evacuation-time pixels, multiplying it by the inverse of the previously fixed base travel speeds.

Flood Vertical-evacuation (FVE) structures, such as buildings, replace natural heights in a flood zone, designed to tolerate flash floods and provide safe shelters for neighboring population evacuation. If the least-evacuation time exceeds the flood arrival time, it is important to consider hypothetical FVE structures in the modeling and test their efficiency in decreasing the evacuation-time. Therefore, two potential FVE1 and FVE2 structures were considered in the floodplain, as safe zones, and placed in the revealed "hotspots of evacuation" zones (to enhance evacuation time) and empty areas where construction may be possible. Consequently all the previous step were executed to lead to the generation of Least Evacuation Time map with FVE.

1.1.7. Generation of Population spatio-temporal exposure and travel times to safety

After generation of Least Evacuation Time maps, spatial joins are performed to integrate evacuation results (transformed to vector formats) with various population data. This geospatial function results in portraying the number and distribution of populations as a function of minimum travel time to safe areas.

1.1.8. Model validation

To test the accuracy of the computed evacuation time maps, a field model verification was performed. Ras-Baalbek community was visited and a subset of road-based routes were walked and timed, then compared to the model results.

1.1.9. Strategic implementation of flood Evacuation signage

The obtained results allow for a range of preventative response options. Communicating the produced evacuation maps is essential for Ras-Baalbek residents to know where they are situated in the floodplain and for first responders and emergency services to easily reach people who cannot self-evacuate and could be in danger. Proposing accurate and precise flood evacuation route signs and distributing them in a strategic manner throughout the floodplain, based on the analysis of obtained potential pedestrian evacuation maps, is also an important part of the preparedness and planning in order point the fastest way to safety for Ras-Baalbek community. Additional signs are proposed to indicate when evacuees are in a place of safety from flash floods, encouraging them to carry on to a final destination as opposed to stopping where the routing signage ends, as this could lead to assemblies build-up in the floodplain threatened area. This permanent signage will maintain a culture of risk-awareness in Ras-Baalbek, reinforce public education to flood hazard and help the community to become more prepared and even more resilient. It is noteworthy that no methodologies or international standards have been found related to the flash flood evacuation route signage, inspired by tsunami evacuation route signage (Girres et al. 2018).

1.2. Results & Discussion

To initiate people to self-evacuate and prepare their evacuation, the potential baseline of pedestrian evacuation (under current conditions) was tested and solutions were proposed for better preparedness and evacuation planning. This section discusses the revealed clearance time for each evacuee in Ras-Baalbek as a function of potential pedestrian travel time to safety in current conditions and the percentage of people who may have enough time to successfully evacuate from the floodplain and reach safety before the flash floods arrival. The results also highlight hotspots of evacuation, where people need more than the available time to evacuate. These zones need more planning and alternatives such as vertical evacuation propositions. The change after implementation of potential flood vertical evacuation (FVE) alternatives in the modelling is highlighted to test their efficiency. These results present a decision-support for FVE and allow for a strategic proposition of evacuation signage and their efficient distribution on roads.

1.2.1. Pedestrian evacuation potential under baseline conditions

The LCD approach has led, at a first place, to understand the spatial distributions of required evacuation times within Ras-Baalbek community under current conditions. Figure 7-2-a) demonstrates the baseline evacuation-modeling outputs. These modeled pedestrian-evacuation times simply focus on the land surface, regardless of where people actually are. Assuming an average travel speed for evacuees of 1.1 m/s, the resulting pedestrian-evacuation travel times to safe ground out of the flash floods-hazard zone in Ras-Baalbek range from less than a minute to more than 13 minutes in some locations. Although the flash floods lag time in the concerned watershed is estimated to 2 hours, due to lack of early warning systems, the “available time” to evacuate is estimated at 10 minutes. This available time is the period starting by Ras-Baalbek residents detecting the arrival of floods in indigenous ways, warning each other and until the onset of flooding. Locations with required pedestrian evacuation time exceeding available time of 10 minutes, showed in red on the map, represent “hotspots of evacuation”. This is probably due to the steep slopes in the northern parts of the floodplain and the haphazard and unorganized urbanization with some buildings too close to each other and not directly connected to roads or paved areas.

It is important to know the number and distribution of people along these evacuation time land surfaces to point out the evacuation challenges. Therefore, evacuation travel time maps were merged with the obtained population data. Population distribution as a function of travel time to safety in baseline conditions were plotted in red (Figure 7-3). Accordingly, the model show there are approximately 190 people at locations that would require only 1 minute to reach safety and a considerable number of people may encounter problems evacuating before the flash floods arrival at 10 minutes. These people, representing 12% of the initially exposed community, would be probably located in “hotspots of evacuation” at floods arrival, and thus they won’t be able to reach safety at time. It is noteworthy that this percentage should not be translated as definitive estimates of the number of victims for many components that may delay evacuation and influence travel times. These components include the time needed to take the decision of evacuation, to leave a car or a building, to navigate unfamiliar environments, to have mobility issues, etc. Some individuals in flood-hazard zones may also completely refuse to evacuate. To better account for these factors, assuming that some people in the 8-10 min window of time may delay their evacuations, it may be more appropriate to summarize “hotspots of evacuation” to areas that would require more than 8 min. In our study area, this assumption allowed to increase the percentage of the population potentially unable to evacuate before floods arrival from 12 to 20%.

The field model verification performed in Ras-Baalbek community revealed an accuracy if 91% by comparison of computed values to on-field measured values.

1.2.2. Changes in pedestrian evacuation landscapes with FVE options

Although the maximum pedestrian evacuation time exceeding the flash floods arrival time only with 3 minutes may look insignificant, but difference between life and death may come down to a matter of seconds. Planning for efficient solutions is therefore is to reduce casualties. Installing FVE has as primary objective to maximize the number of lives saved from future flash floods is Ras-Baalbek.

Based on the disclosed “hotspots of evacuation” zones, representing significant challenges, and empty areas, two FVE were proposed. To test the efficiency of each of these proposed FVE options, they were introduced to the modelling of the potential evacuation time to safety in the floodplain. To characterize differences in pedestrian evacuation potential due to the introduction of FVE alternatives, geospatial efforts focused on two major factors. The first factor depicts spatial variance in evacuation potential; the variations in the evacuation landscape with the introduction of FVE1 and FVE2 are shown in Figure 7-2 b) and c) respectively. Again, people in the area are assumed to start evacuating approximately 10 minutes before the arrival of flash floods is predicted. At a glance, the area of “Hotspots of evacuation” zones (where required evacuation time is higher than 10 minutes) represented in red, decreased compared to the baseline (Figure 7-2-a) after introduction of FVE1 (Figure 7-2-b) and even more after the introduction of FVE2 (Figure 7-2-c). A second set of parameters aimed to describe changes in population exposure as a function of travel time to safety based on the FVE alternatives. The spatial distribution of the population as a function of travel time to safety if FVE1 and FVE2 existed are plotted respectively in yellow and green in Figure 7-3 . This figure shows that while there were approximately 190 people at locations that would require only 1 minute to reach safety under baseline conditions, this number increases to 205 and 210 after installation of FVE1 and FVE2 respectively. Moreover, this figure shows that the number of people who may encounter problems evacuating before the flash floods arrival at 10 minutes are decreasing with these FVE options. The main evaluation criterion is the additional number of people who can reach a proposed FVE in less than 10 min. The efficiency of an individual FVE was measured by changes in the exposure of the population relatively to current landscape conditions. While 88% of the residents may have enough time to successfully evacuate from Ras-Baalbek floodplain under current conditions, this percentage increases to 94 % and 97% after introduction of FVE1 and FVE2 respectively (Figure 7-4). In other words, FVE1 and FVE2 reduced the percentage of people potentially not being able to reach safety at time to its half and to its quarter respectively (from 12% to 6% to 3%).

All the above results demonstrate that FVE2 may be a preferred option. Furthermore, red “Hotspots of evacuation” zones, denoting areas where timely evacuations are improbable, decrease but do not completely disappear in scenarios with FVE1 and FVE2. This shows that each FVE option could only serve evacuees near its proposed construction site, but that a single FVE option cannot constitute the unique solution and help the evacuees of the entire floodplain. Decisions based on tradeoffs and compromises would need to be made, especially that Ras-Baalbek population exposed to flash floods was estimated to approximately 1550 individuals. These exposed individuals represent half of the total community of the village. The relatively high percentage suggests that, although the total losses may not be as high as in other larger communities, this small community may be less likely to weather those losses and have greater difficulty recovering. However, as mentioned earlier, this basic population exposure approach doesn’t tell the full risk story since it ignores the ability of at-risk individuals to evacuate before flash floods arrive. This ability needs preparedness and planning; it is important to convince people that not only they have higher chances of survival if they evacuate, but also that they can lose their lives if they refuse to.

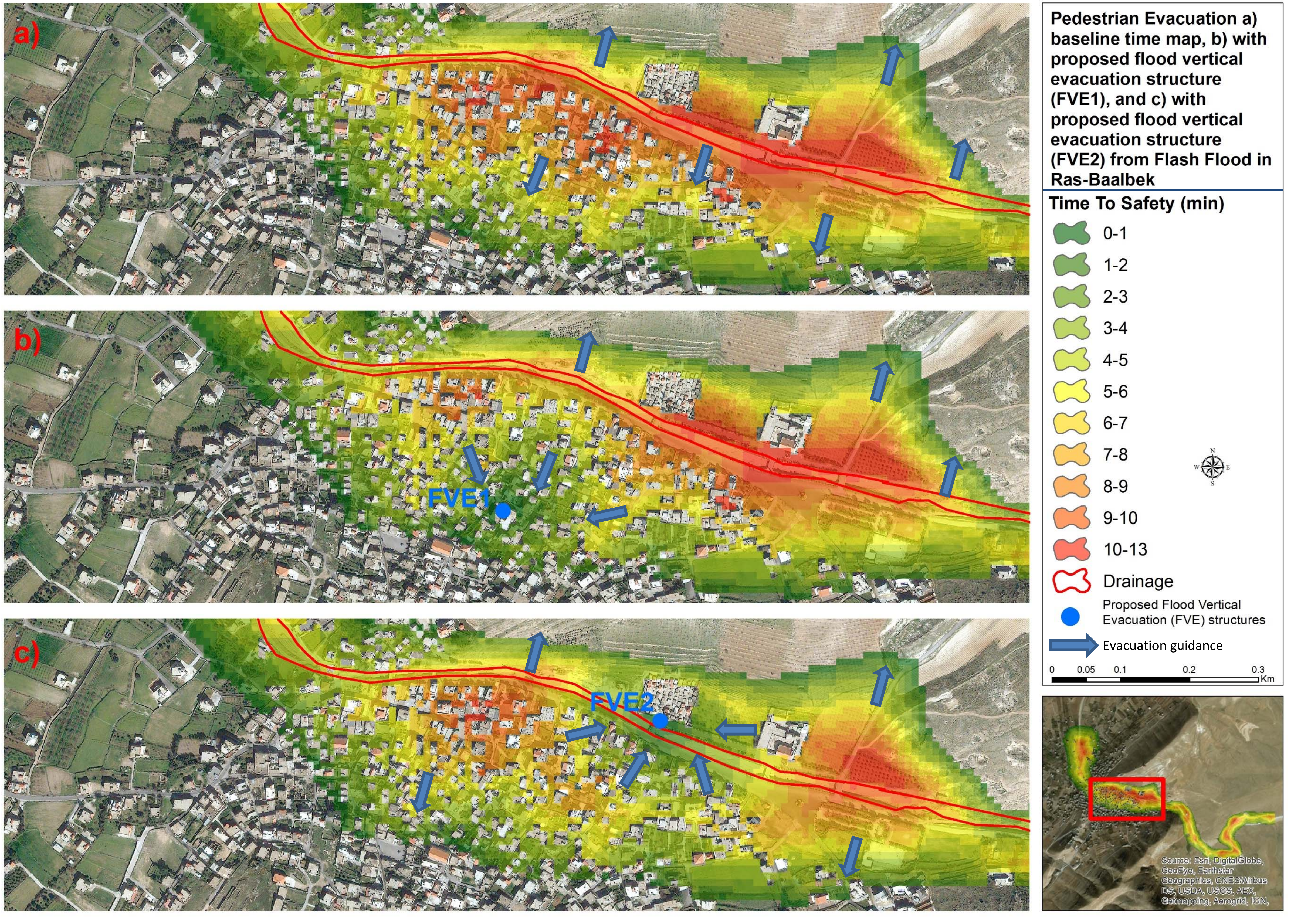


Figure 7-2. a) Pedestrian evacuation times map under current conditions and b) with vertical evacuation solution VE1 and c) with vertical evacuation solution VE2.

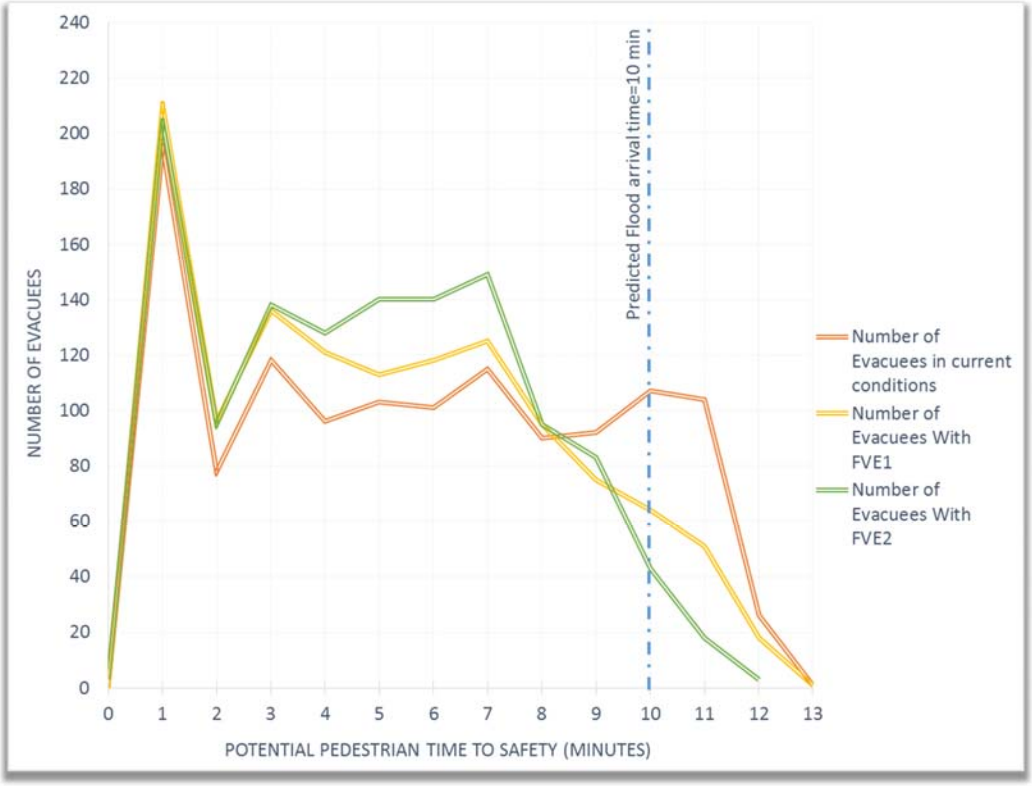


Figure 7-3. Distribution of Ras-Baalbek residents as a function of travel time toreach safety in Baseline conditions (red),after installation of proposed FVE1 (yellow) and after installation of FVE2 (green).

Figure 7-4 Percentage of Ras-Baalbek residents to reach safety with less than 10 minutes travel time in current conditions (baseline), after introduction of FVE1 and FVE2.

Implications and applications of obtained results

The above obtained pedestrian evacuation-modelling results have several implications and applications. First of all, the pedestrian evacuation potential maps produced have a primary purpose, which is to raise awareness among the community of Ras-Baalbek to the danger they face if they do not evacuate before the arrival of the floods, and thus initiate them to pedestrian self-evacuation. From the perspective of risk psychology, model results suggesting successful evacuations could be used as part of flash flood outreach to raise positive outcome expectancy, which is the degree to which people believe there is a way to reduce risk to hazards. For instance, Ras-Baalbek population is more likely to prepare and plan for future flash floods and take action if they believe that successful evacuations are possible and that their actions will have positive outcomes. The models produced also apply to education and training (for the community, emergency managers, community planners and first responders) for effective and successful evacuation. Efforts should focus on educational campaigns to help Ras-Baalbek residents read the produced maps and know the most effective evacuation route from their residence or from any possible location they can be at in the floodplain at the moment the flash floods arrive.

Second, results strongly support preparedness, evacuation planning efforts and response procedures on community based level. Evacuation strategy planning includes a mix of measures to help people evacuate in a flash flood emergency. The obtained pedestrian evacuation maps directly serve the evacuation strategy in Ras-Baalbek by guiding the production of flood evacuation road signage and their distribution along the floodplain to safety. Although residents are familiar with the region, during the sudden flash flood, they may be confused and panicked and will need guidance to evacuate. Signaling evacuation directions is therefore imperative, and must be made with easy to read sings. The pedestrian evacuation times shown in Figure 7-2-a), were used to propose four types of flash flood evacuation signs. These proposed evacuation signs (Figure 7-5), on which information is written in both Arabic (mother tongue) and in English languages (for potential presence of foreigners) will guide Ras-Baalbek residents to the direction they should follow to evacuate successfully, and will indicate the needed time to reach safety at an average pedestrian travel speed. The four types are related to the time required to reach safety; Green signs represent 3 min to safety and should be strategically installed in green color regions (Figure 3a). Yellow signs represent 6 min to safety and should be strategically installed in yellow color regions in map. While, orange signs represent 9 min to reach safety and should be strategically installed in orange color regions. Consequently, Red signs indicate that 13 minutes are needed to reach safety and should be strategically installed in red color, considered as “Hotspot evacuation zones”. Setting these evacuation roads signs should be done carefully and with the consent of residents and landowners to prevent conflicts. Many landowners may oppose the installation of these signs, especially the red ones, seen as an indicator of the flash floods risk threatening their lands and thus lowering its per capita value in the real estate market. Therefore, the education campaigns previously discussed are of key importance for the acceptance of these evacuation signs and make best use of their role in Ras-Baalbek community. Additional blue signs (Figure 7-5) were proposed to indicate when evacuees are in a place of safety from flash floods, encouraging them to carry on to a final destination as opposed to stopping where the routing signage ends, as this could lead to assemblies build-up in the floodplain threatened area.

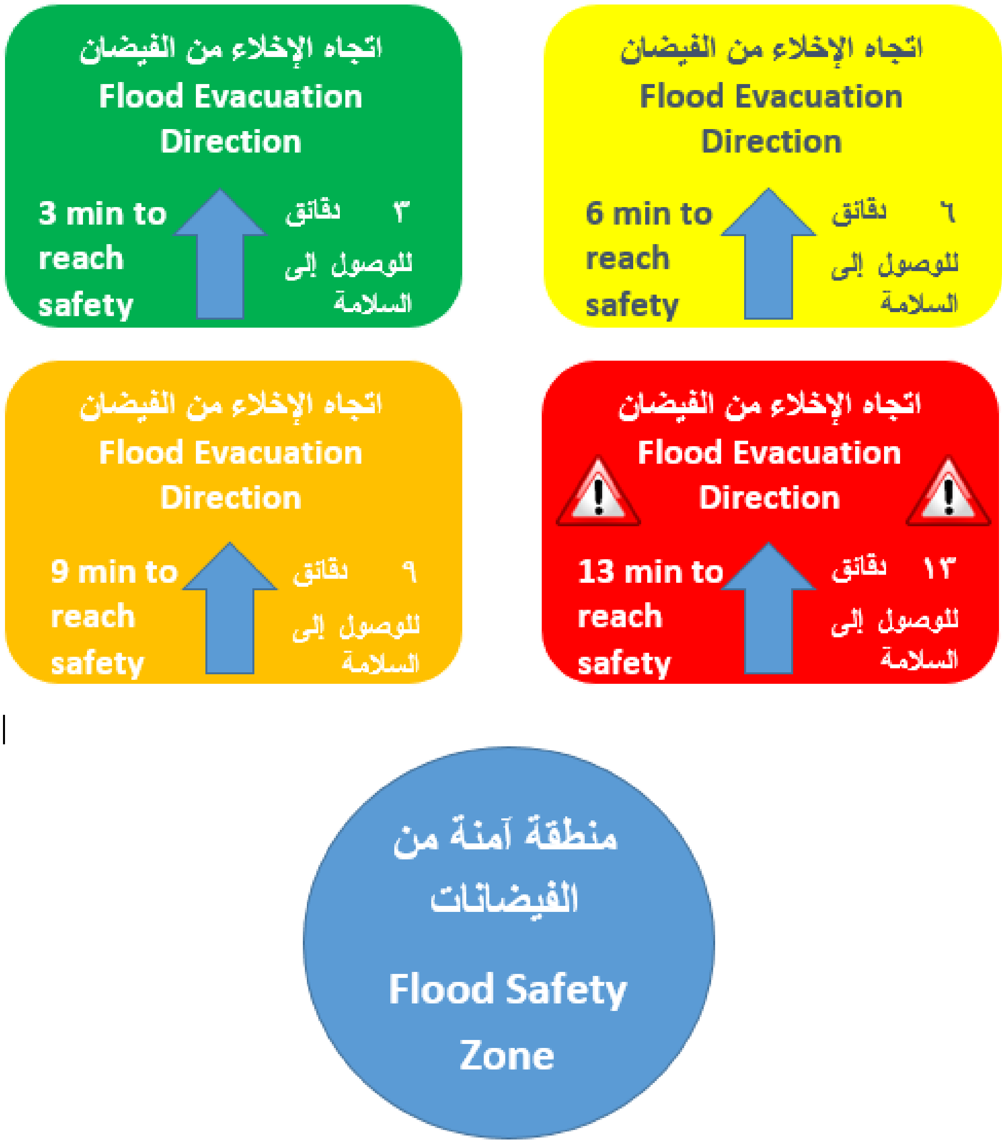


Figure 7-5. Proposed flash flood evacuation road signage for Ras-Baalbek community.

Another measure for efficient evacuation strategy planning, provided by the obtained pedestrian evacuation maps, is the potential of FVE structures (Figure 7-2-b,-c). The elaborated evacuation models can serve as a decision-support tool through comparisons of FVE1 and FVE2 options and their effect on evacuation times. Results showed that FVE2 would save more lives and is therefore more favorable. The construction of FVE should also be carefully studied, well-planned for and designed to meet several requirements. Engineering studies are necessary to design FVE able to resist to the floating debris and heavy objects transported by the floods waters. These structures may remain flooded in waters for a period of time. Therefore, they must also have access to basic livelihoods needs such as food, drinking water, sanitary, emergency kits and means of communication.

1.3. Conclusion

Ras-Baalbek is a village which has a long history of flash floods. The prevailing flash floods, the most catastrophic of which has hit as recently as 2018, lead to several casualties. Some structural measures were taken in order to mitigate the risk but no studies on flood evacuation have been conducted nor does an evacuation plan exist in this highly exposed and vulnerable area. Ras-Baalbek village is in urgent need for evacuation maps and planning for supporting evacuation awareness, emergency and relief planning.

This section comes in an attempt to fill, with spatial analysis and simulation modelling approaches, the existing preparedness and evacuation planning gaps in Ras-Baalbek. The main focus is to organize pedestrian evacuation in the studied floodplain and enhance its effectiveness. Thus this study estimated the potential pedestrian evacuation times to safety in Ras-Baalbek flash floods prone areas, proposed vertical-evacuation buildings to enhance this time and organized the evacuation accordingly with the implementation of evacuation signs.

The methodology presented in this study employed anisotropic least-cost-distance (LCD) modelling and exploratory geospatial analysis approaches, to determine potential pedestrian evacuation times in the floodplain and make more efficient simulations of evacuation. LCD method and analysis of evacuation potential called for a considerable amount of high-resolution data and several processing steps since it took into account the terrain elevation and the varying types of land use/land cover that a person would come across on his way, along with travel speed of the evacuee. The resulting maps of pedestrian-evacuation travel times to safe ground outside of the flash floods-hazard zone in Ras-Baalbek range from less than a minute to more than 13 minutes in some locations, exceeding the flash flood arrival time estimated at 10 minutes. "Hotspots of evacuation" zones were disclosed. After LCD, geospatial functions were used to portray the number and distribution of populations as a function of minimum travel time to safe areas revealing that among the 1550 evacuees simulated (number of exposed population to flash floods), more than 12% would not reach safety at the time of flash floods arrival.

Successful evacuation planning depends on implementing effective measures to decrease the evacuation "required time" to meet the "available time" to evacuate. In order to enhance this percentage, potential FVE structures, like high buildings, were proposed and their effectiveness and tradeoffs were assessed through the elaboration of related time maps for the modeled travel-time landscape. FVE1 and FVE2 reduced the percentage of people potentially not being able to reach safety at time to its half and to its quarter respectively (from 12% to 6% to 3%). These structures should be well designed and their construction carefully discussed with locals and decision makers.

Finally, as the main purpose of evacuation is to plan for evacuation and route evacuees to the nearest road that would allow for a quick departure before the arrival of flash floods, evacuation signs were proposed to be integrated on roads. Five types of signs were proposed; Green signs represent 3 min to safety, yellow signs represent 6 min to safety, orange signs represent 9 min to reach safety, red signs indicate that 13 minutes are needed to reach safety, and blue signs to indicate when evacuees are in a place of safety from flash floods, encouraging them to carry on to a final destination as opposed to stopping where the routing signage ends, as this could lead to assemblies build-up in the floodplain threatened area. Setting these evacuation roads signs should be done carefully and with the consent of residents and landowners to prevent conflicts. This permanent signage will maintain a culture of the risk in Ras-Baalbek, reinforce public education and awareness of flood risk and help the community to become more prepared and even more resilient.

These pedestrian evacuation-modelling results have multiples preparedness implications and application to flood-evacuation outreach, educating and training (for the community, emergency managers, community planners and first responders to understand likely evacuation corridors), response procedures, mitigation (reducing the risk or even the loss of life of people living in Ras-Baalbek high flood risk areas), and long-term land use/land cover zoning and planning to improve Ras-Baalbek community resilience. One of their most important applications is to initiate Ras-Baalbek population to self-evacuate and prepare and plan for this evacuation. Moreover, the elaborated evacuation model can serve as a decision-making support tool through differentiation between the proposed vertical evacuation options.

Some gaps of the proposed modelling like hazards uncertainties and population characteristics and behavioral uncertainties were highlighted for further research development.

2. Planning for a Shelter-Capacity-Based Evacuation Routing after an Earthquake using Capacity Aware Shortest Path Evacuation Routing (CASPER) Algorithm

Earthquakes have the least warning time among all natural hazards (Wilmot 2001), representing typical examples of little- or no-notice disasters (Zimmerman, Brodesky, and Karp 2007) often showing no precursory signals (Bakun et al. 2005) or, in some cases, showing signals like foreshocks (I.e. the 2016 Kumamoto Earthquakes) (Yanagawa et al. 2017). Foreshock activities have been noticed for about 40% of all moderate to large earthquakes, and about 70% for events of magnitude higher than 7.0 (Kayal 2008). Evacuation, as an inevitable part of DRR, plays a significant role in earthquake preparedness and is one of the principal relief activities in the earthquake response phase (Pourrahmani et al. 2015). Earthquakes require immediate post-disaster evacuation to take place (Afshar and Haghani 2008). Post-earthquakes evacuations take place in an attempt to reduce human exposure and avoid life losses related to threats like structural damage or collapsing of vulnerable buildings after foreshock, potential aftershocks that can cause further damage to already weakened buildings and geological (Pourrahmani et al. 2015) or man-made secondary hazards (landslides, floods, fires, etc.) that are common in post-earthquake situations (Amini Hosseini et al. 2009). At least two successful evacuations based on foreshock detections have been reported (Mignan 2014); the 1975 Haicheng, China earthquake evacuation (Jones et al. 1982; Wang et al. 2006) which have saved from 8,000 to 24,000 lives according to a retrospective scenario (Wyss and Wu 2014); the 1995 Kozani-Grevena, Greece earthquake evacuation (Bernard et al. 1997). So called little or no-notice evacuations are complex (Zimmerman et al. 2007) and need special decision making based on early advanced preparation, preparedness and preplanning measures like evacuation route planning, traffic management strategies and shelter planning (Chiu et al. 2006).

Although disaster-evacuation planning is well developed in the literature, only few studies concentrate on earthquake evacuation. Yoji and Tetsuro (2005) selected earthquake events as study cases to analyze the degree of evacuation routes and evacuation centers safety and to build common principles for evacuation. Chang (2010) and Tamima and Chouinard (2012) applied the deterministic user equilibrium and dynamic traffic allocation models to calculate travel cost related to traffic delays and congestions after an earthquake taking into consideration travel demand due to damage to infrastructure. In their research, Shimura and Yamamoto (2014) addressed the identification of routes for evacuation on foot in seismic disasters as a multi-purpose optimization problem, and aimed to propose a quantitative search method for evacuation routes using a multi-objective genetic algorithm (multi-objective GA) and GIS. Pourrahmani et al. (2015) proposed, in a part of Tehran, an earthquake evacuation routing plan to take evacuees, by means of public vehicles, from local shelters to regional ones for a long-term safe settlement. Zhang et al. (2016) developed a vehicle routing problem in order to optimize emergency transportation system for post-earthquake and reduce the total journeys taken for delivery of goods.

Baalbek-Hermel Governorate is located in a seismic-prone zone, crossed by Yammouneh fault and Serghaya fault. Seismological trench studies along these faults showed that the typical return periods varies between 1100 and 1500 years (Daëron et al. 2007; Elias et al. 2007; Gomez et al. 2003). These two faults surround some parts in the center of the governorate and make them highly exposed to earthquakes (an area of over 444 km^2); parts of Ain Bourday, Nahlé Baalbek and Baalbek city are situated in these highly exposed quake-prone zones. Baalbek city hosts the administrative center of Baalbek-Hermel Governorate and a population of more than 31,000 individuals. Baalbek city is highly vulnerable to major thrusts: no building codes have been implemented, building structures are weak and old, and there is no retrofitting programs. These weaknesses are combined with relatively high exposure (high population and assets density). Over the years, the region have suffered from numerous earthquakes that left their marks on the Temple of Jupiter and other ruins (in Baalbek city); in year 565 an earthquake of 6.7 Richter magnitude caused important destructions; on the 5th of April 991, also an earthquake of 6.7 Richter magnitude caused enormous damages; the 12th Century witnessed several intense earthquakes; the most destructive earthquakes occurred in 1139, 1157 and 1170; on the 20th of May 1202, an earthquake of 7.5 Richter magnitude caused important destruction and temples collapsed; On the 25th of November 1759, of 7.5 Richter magnitude causing destructions and more than 2000 fatalities. An important part of Baalbek temples collapsed, three of the nine still standing columns of the Jupiter Temple (Zaineh et al. 2013). This main event was preceded by a 6.6 Richter magnitude foreshock on October 30, 1759, in the southern part of the epicenter of the main shock (Ambraseys and Barazangi 1989).

The vulnerability of these areas, in a combination with the unpredictable nature of earthquakes, has highlighted the need to plan an emergency response process before the occurrence of an earthquake. This study area, with a relatively dense population, is mainly crossed with local roads and few major highways. In other words, the studied road network was not built for nor designed to support the sudden evacuation of thousands of people; evacuating this amount of people to shelters destinations would not be feasible without prior planning. In response to the above, this section discusses a hypothetical evacuation scenario following a foreshock of 5 to 6 Richter magnitude, during which buildings were weakened but did not collapse and no damages to roads were noticed. In such a case populations would be forced to evacuate, using the still intact road network, in an attempt to reduce human exposure and avoid loss of life due to forthcoming threats like structural damage or collapsing of vulnerable buildings after foreshock, potential larger aftershocks that can cause additional damage to already weakened buildings and geological or man-triggered secondary hazards (landslides, fires, etc.) which are probable in post-earthquake situations (Pourrahmani et al. 2015). These threats, along with aftershocks, can occur in the first hours; time is a crucial factor to indicate the effectiveness and success of evacuation operations. In general, the common unplanned evacuation problem is that an excess of traffic in a limited time immediately exceeds the capacity of the roadway, increasing the evacuation time and leaving evacuees in dangerous consequences resulting in unexpected losses (Wolshon 2007). Since the costs of building new roads and increasing their capacity are prohibitive especially to Baalbek-Hermel Governorate, the best feasible ways are to maximize the effectiveness and utility of the existing transportation network (Han, Yuan, and Urbanik 2007).

This section of the dissertation proposes a post-earthquake evacuation routing plan for high-earthquake zones in Baalbek-Hermel Governorate. Its major aim is to minimize network bottlenecks and decrease global and average evacuation times through intelligent shelters allocation and evacuation routing. GIS spatial toolkits like CASPER (Capacity-Aware Shortest Path Evacuation Routing) (Shahabi and Wilson 2014) in GIS network analyst were employed to analyze the shelter assignment and routing strategies based on the optimal path search problem of the “graph theory”. Two routing algorithms were used: 1) a basic shortest path (SP) algorithm, implying an unplanned evacuation and 2) a CASPER algorithm.

Results revealed that an unorganized evacuation, as simulated by the shortest path technique, resulted in an evacuation scenario counting of about 148 minutes, while CASPER algorithm enhanced the evacuation time to 64 minutes. The results confirm that a planned evacuation through CASPER evacuation routing approach is able to reduce both the total clearance time and total travel time of the vehicles and increase the number of evacuated population. The findings in this study demonstrate that the application of the proposed model can offer beneficial information for disaster preparedness in several ways; By studying the capacity and performance of the road network during evacuation, problems of accessibility, network configuration and network design in this region of Baalbek-Hermel governorate, inherent in evacuation planning can to be revealed; The established evacuation map also make it possible to avoid overcrowded shelters and provide vulnerable residents with appropriate information on where and how to escape; the generated products allow, after analysis, to propose sites for the establishment of new shelters; and finally by providing knowledge and implementation of evacuation routes, these results can decrease the vulnerability of Baalbek-Hermel population and make it more resilient to earthquakes.

2.1. Methodological Approach

The methodological approach consists on modelling the post-earthquake evacuation for the constructed scenario in order to plan for a road network evacuation solution and predict some of its possible outcomes, that is the number of evacuated people, the time of access to shelter, optimal evacuation route for each residence, the total evacuation timed, and the traffic jams on the computed routes. The current work depends on a map-oriented evacuation modelling as a problem of network-based graph route finding computed on the ArcCASPER tool (Shahabi and Wilson 2014). Fundamental components required for the computation of the proposed evacuation model are as follows:

1) How many people need to be evacuated (evacuees in evacuation origins)?

2) Where are the shelters or destination points of the evacuation routes?

3) What are the attributes of the existing road network (road type, speed limit and capacity)?

After data assembly and pre-processing, evacuation simulations were run in two times. In the first evacuation simulation, the Shortest-Path (SP) algorithm, which shows an unplanned evacuation, was adopted. At a second time, CASPER algorithm was adopted for evacuation routing optimization. Figure 7-6 provides an overview of the workflow that will be processed in this section.

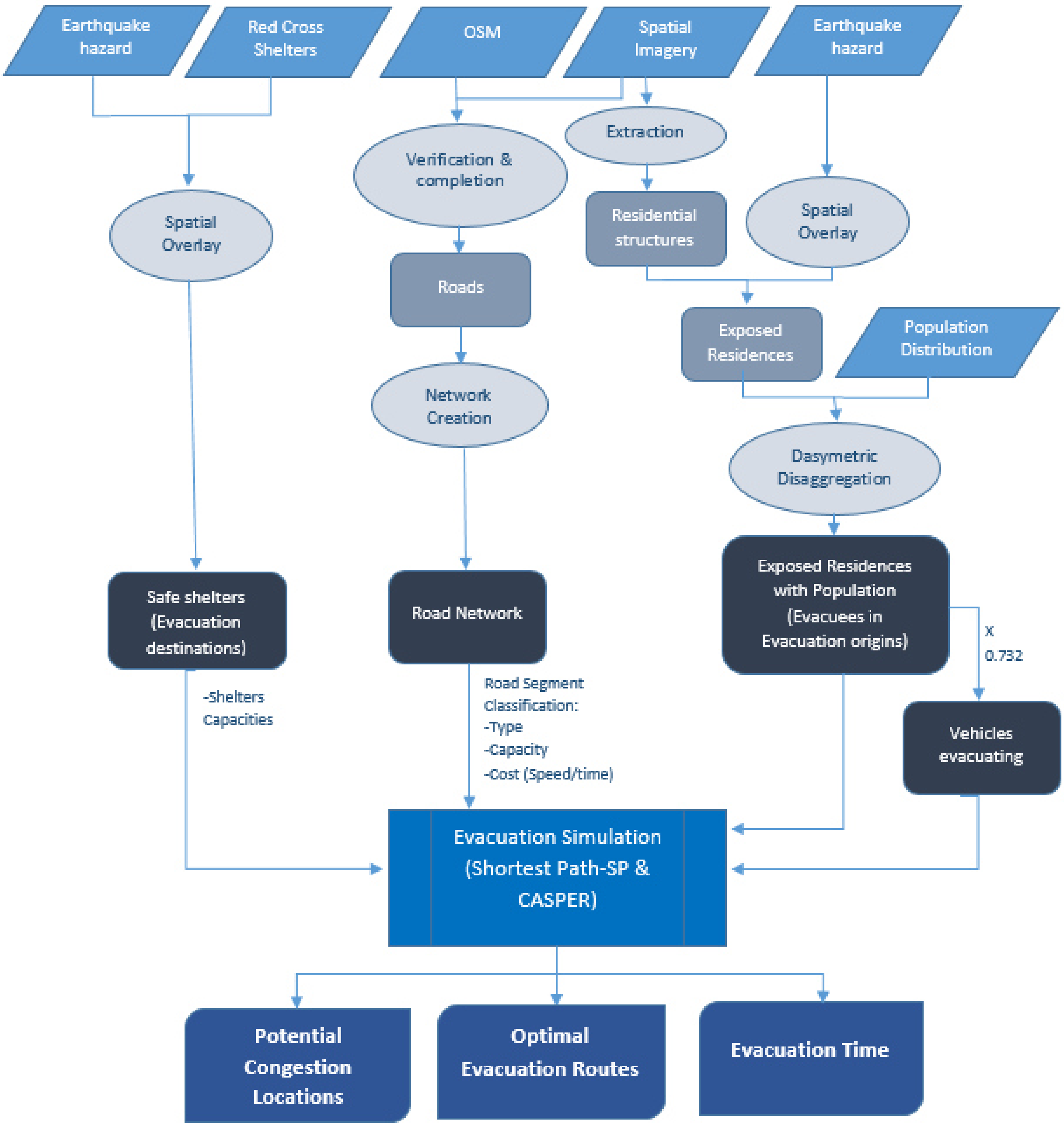


Figure 7-6. Post-Earthquake Evacuation routing model.

a) Population estimation and determination of evacuation starting points

One of the fundamental components in efficient shelter assignment and evacuation preparation is the estimation of the number of displaced people seeking shelter (Tamima and Chouinard 2012). To fulfill the requirements of this spatial analysis, obtained population results from the dasymetric method in chapter III were further disaggregated to residential structures under same approach and only in highly-earthquake prone areas (exposed houses). Residential structures were chosen, because it's believed that people in a post-earthquake scenario, wherever they were, would go back home, pack, assemble with family members and evacuate from their homes (evacuation origins) (Yun and Hamada 2012). Each residential structure was manually identified from the Geoeye-2017 imagery and designated by a point containing as attributes the population values. These points were then set as origin points of the evacuation routes (S). The set S includes all the evacuee points and their estimated populations with every evacuee point (s) having a positive weight w(s) (Shahabi and Wilson 2018). The weight, represented in Equation 7-2, is the number of vehicles at that origin point (residential structure).

$$\forall s \in S,\ S \subset V\ w_{(s)} > 0$$

Equation 7-2. Evacuee point weight (Shahabi and Wilson 2018).

Taking into consideration that no reliable public transportation system exists in Lebanon and in the studied area and that the members of a household would decide to evacuate all of their cars, it was important to estimate the number of private vehicles implied in this evacuation. The approach applied to estimate the number of vehicles used in this evacuation depends on statistics performed in 2001 which shows that the number of vehicles for each 1000 persons in Lebanon is 732 vehicles (Abdallah and Hdeib 2015). Hence, the number of vehicles utilized in this evacuation was estimated by multiplying the evacuees with the coefficient 0.732 (vehicle occupancy of 1.36).

b) Evacuation destination and shelter planning

People must not only evacuate their residential units, but must also be housed in safe shelters. In this case study, shelters are multipurpose constructions taken over for temporary use in a post-earthquake situation to provide relief, such as a school or church, etc. These shelters were already designated by the Lebanese Red Cross after scrupulous assessment related to capacity, electricity and water resources, structural conditions, telecommunication systems, medicine and sanitary facility supplies, etc. The designated shelters and their related information were then integrated into GIS and, after earthquake exposure assessment, only shelters outside of earthquake-prone zones (considered safe) were retained as evacuation destinations for the modelling.

c) Road network creation and classification

The OpenStreetMap (OSM) database was verified via satellite imagery to check alignments for accuracy, completeness, and connectivity. The network dataset representing routes was then built using ArcGIS Network Analyst Tool to represent a graph G(E,V) with |V| vertices and |E| directional edges (Shahabi and Wilson 2018). Vertices are comprised of origin of evacuees, and shelters. Edges reflect the path with the shortest travel time between two vertices on the road network (Pourrahmani et al. 2015).

Defining the cost (or impedance) of a road segment was essential since the conducted evacuation routing aims to maximize the evacuees movements on the road network, optimizing the routes and cutting down costs. In this study, the “Cost” attribute was in the first place assigned to the distance to run the SP algorithm and test an unplanned evacuation in which evacuees take the shortest path thinking it will be the fastest path. For CASPER algorithm, the “Cost” attribute was then assigned to the traversal time (in minutes) considering road type and its relative speed limitations. “Capacity” is also important for considering potential jamming problems in CASPER algorithm. The type of a road conditions the number of its lanes and therefore its capacity. The road capacity reflects to the number of cars that can move simultaneously, side by side, in a unit of a road segment, restricting the network (graph) to its road and intersection capacities. This value was simply equivalent to the number of lanes (1 car per lane). Capacity and impedance values are not constant since the transportation network can be modified in time of the evacuation.

The information and spatial distribution of evacuees, and shelters with the road network were then imported into GIS for execution of spatial analysis.

d) Routes simulation

The computation and spatial analysis of evacuation routes were executed using Evacuation Routing extension of the Network Analyst tool of the ArcGIS software. Two routing options were tested for optimal evacuation routes; first the Shortest-Path (SP) algorithm and second the CASPER (Capacity-Aware Shortest Path Evacuation Routing) algorithm.

i) SP algorithm

SP algorithm is a distance-based route optimization method (Dijkstra's method, (Dijkstra 1959)) using the distance or length as cost network attribute, ignoring all the capacities. This algorithm, technically similar to the Closet Facility tool, connects evacuee points with the identified shelters and calculates the optimal time and travel distance for each evacuee. SP completely ignores traffic models, assuming no traffic congestion, and returns shortest paths for each source point. This evacuation algorithm is claimed to be complete since it finds a path for each source point linking it to destination (Shahabi and Wilson 2014). SP was run to test an unplanned evacuation in which evacuees take the shortest path thinking it will be the fastest path.

ii) CASPER algorithm

CASPER route optimization method developed by Shahabi and Wilson (2014), is a heuristic path-finding algorithm that successfully links each source node (evacuee) to its nearest destination (shelter) while accounting for the capacity constraints of the road network and the flow of a number of evacuees to maximize evacuation flow while minimizing traffic jams and travel times during the routing execution. The emergency evacuation model begins first by filling the nearest shelter sorting evacuees under shortest and least-cost path and then takes the remaining evacuees to another shelter, which is the second nearest shelter. The algorithm chooses the shortest route for every vehicle evacuated taking into account the expected traffic times and car density. Once the route is chosen, the algorithm reserves the route for the correspondent car evacuated and then continues to evacuate the next car. It imposes a delay between each point of departure of the evacuation, which minimizes the overall evacuation time and eliminates the need to schedule evacuation times. Considering this delay set at 20 s, every evacuee point (s) produces a different density on each edge. The density on an edge from and evacuee point (s), represented in Equation 7-3, is calculated as the number of cars that fits on that edge depending on the initial delay between each vehicle. Without any metering (zero interval), the density on edge e would be simply equal to the population (Shahabi and Wilson 2014, 2018).

$$den(s,e) = \min(\frac{imp(e)}{delay}, w(s))$$

Equation 7-3. Density from an evacuee point on an edge (Shahabi and Wilson 2018).

For every source point, only one path (Ps) is attributed. A path (Ps) is an ordered set of edges generated to guide the entire population to evacuate, from source point (s) to shelter (t). Thus, the total density on edge (e) can be measured by summarizing all densities of all paths that pass through (e) (Shahabi and Wilson 2014) (Equation 7-4).

$$den(e) = \sum_{s,e\in Ps}^{\forall s\in S, Ps\in\varphi, Ps\subset E} den(s,e)$$

Equation 7-4. Total density on an edge

The traffic model T(d,c) is a mathematical model that predicts the congestion on an edge as a function of two parameters, its total density (d) and its capacity (c). The traffic model results in a number between 0 (infinite congestion) and 1 (no traffic congestion). The traffic model assures an optimal evacuation flow with a reduced number of congestion points by returning a new speed estimation value for the road edge and consequently affecting the route finding procedure (Shahabi and Wilson 2014). In the current computations, the Power traffic model was chosen, , among several available options, as it is claimed to offer one of the best performance in predicting traffic points and predicting evacuation time (Shahabi and Wilson 2018). Additionally, the Critical Density per Unit Capacity was set at 20 to indicate that the traversal speed would be affected only if more than 20 cars were evacuated at the same time. The Saturation Density per Unit Capacity reflecting the threshold of evacuees that would decrease to half of the initial traversal speed on a road edge, was given a value of 100.

From there, the cost of traversing an edge (Equation 7-5), and thus the cost of traversing a path (Equation 7-6), can be measured. The first component in the path cost formula (Equation 7-6) represents the extra time imposed by the initial vehicle delays, while the second component summarizes the cost of each edge of the path, called the arrival time of evacuee (s) to edge (e) over its path (arrival (s,e,Ps) ∊ GC) (Shahabi and Wilson 2018).

$$cost_T\ (e) = \frac{imp(e)}{T(den(e), cap(e))}$$

Equation 7-5. Cost of traversing an edge

$$cost_T(P_s) = interval(s) * w(s) + \sum_{e \in P_{s, arrival(s,e,Ps)}} cost_T(e)$$

Equation 7-6. Path cost formula

The main objective of this evacuation routing is to reduce the cost of the path with the highest cost, applying Equation 7-7. This equation, once all the paths are reserved, accounts for both the previously reserved paths and the new population density (i.e. den(s,e)) and calculates the costs of all the paths. This phase plays a significant role in determining the most accurate global evacuation time since the registration of the reserved paths is not complete during the path finding process, the costs are therefore only a lower limit (Shahabi 2015).

$$cost_T(e, s) = \frac{imp(e)}{T(den(s, e) + den(e), cap(e))}$$

Equation 7-7. Minimized cost path formula

During the analysis, the algorithm addresses the randomness of the evacuation by constantly rerouting if congestion is high and dynamically updating the edge travel costs (amount of time it takes to travel a segment of road) depending on the number of attributed evacuees and the capacity of the road segment (Shahabi 2012), ensuring global evacuation times are at a minimum (Shahabi and Wilson 2014). This iteration is assured by CARMA (Capacity-Aware Reverse Map Analyzer). CARMA module is utilized to navigate the graph backwards and create data in order to improve CASPER execution time, noting that CASPER slows down as it retains more routes. CARMA sorts the source points based on their predicted evacuation time and minimize the overall evacuation time without any hard constraints. This option is influenced by CCRP (Capacity Constrained Route Planner) and A*(A-star) algorithm (Hart, Nilsson, and Raphael 1972) which is a faster version of Dijkstra's algorithm (Dijkstra

1959). In this current study, the CARMA directive specifying the assortment of evacuees before being processed, was set as “BW Continuous” and U-turns were allowed. CARMA has a mechanism to detect the right moment to reconstruct the heuristics. After rebuilding the heuristics, CASPER resumes to proceed with more evacuees (Shahabi and Wilson 2018). This process of going back and forth between CASPER and CARMA continues iteratively until no more evacuees are left, indicating that the exposed population has been successfully removed from the hazard area.

2.2. Results & Discussion

Approximately 14000 individuals were estimated, based on further development of the dasymetric disaggregation method proposed in Chapter III, in high-earthquake risk zones area in Baalbek-Hermel Governorate and would be enforced to evacuate after a foreshock. These evacuees are distributed in 1941 evacuation origin points (residential structures) from which more than 10300 cars would evacuate.

a) SP algorithm results

After running the SP routing for the conducted post-earthquake scenario, as many routes as the number of evacuees’ origin locations (1941) were generated; all evacuees were evacuated successfully.

The shortest path algorithm resulted in the total evacuation of the exposed zone in about 148 minutes (Figure 7-7). Generated evacuation routes indicate for each residential structure its allocated shelter, the route length and the evacuation travel time. The majority of the evacuation routes were in the high range of 102 to 132 minutes meaning that it “costs” an evacuee 132 minutes of time to evacuate to a shelter and the least cost evacuation route revealed to be of 82 minutes. The map displayed in Figure 7-8 shows optimal evacuation routes generated by SP algorithm for the conducted post-earthquake scenario.

High difference between evacuation cost and original cost (traversal time without congestion considerations) was found for SP algorithm. As road capacity was not taken into account, all evacuees were transported by the shortest routes. In fact, SP method reproduced an unplanned evacuation when evacuees take what they believe to be the fastest route, which most often results in heavy traffic jams and a slower evacuation. However, on normal days, the used evacuation routes necessitates, at most, a 50 minute drive (original cost). Figure 7-9 representing roads edges travel evacuation time, shows congestions on roads edges. Highest travel times (30 min per edge) were found on edges of final roads leading to shelters. In fact SP algorithm found, for the majority of shelters, only one final road.

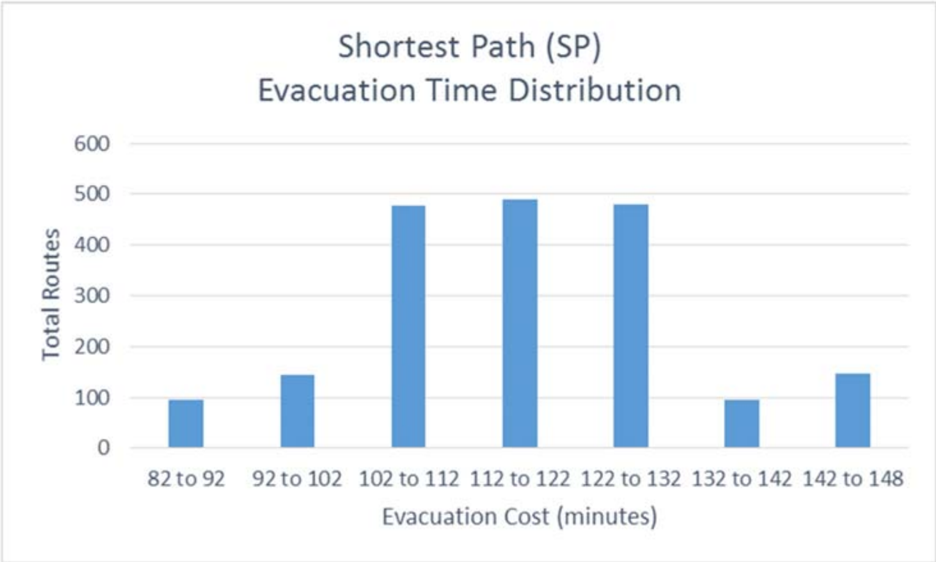


Figure 7-7. Shortest path (SP) algorithm evacuation time distribution

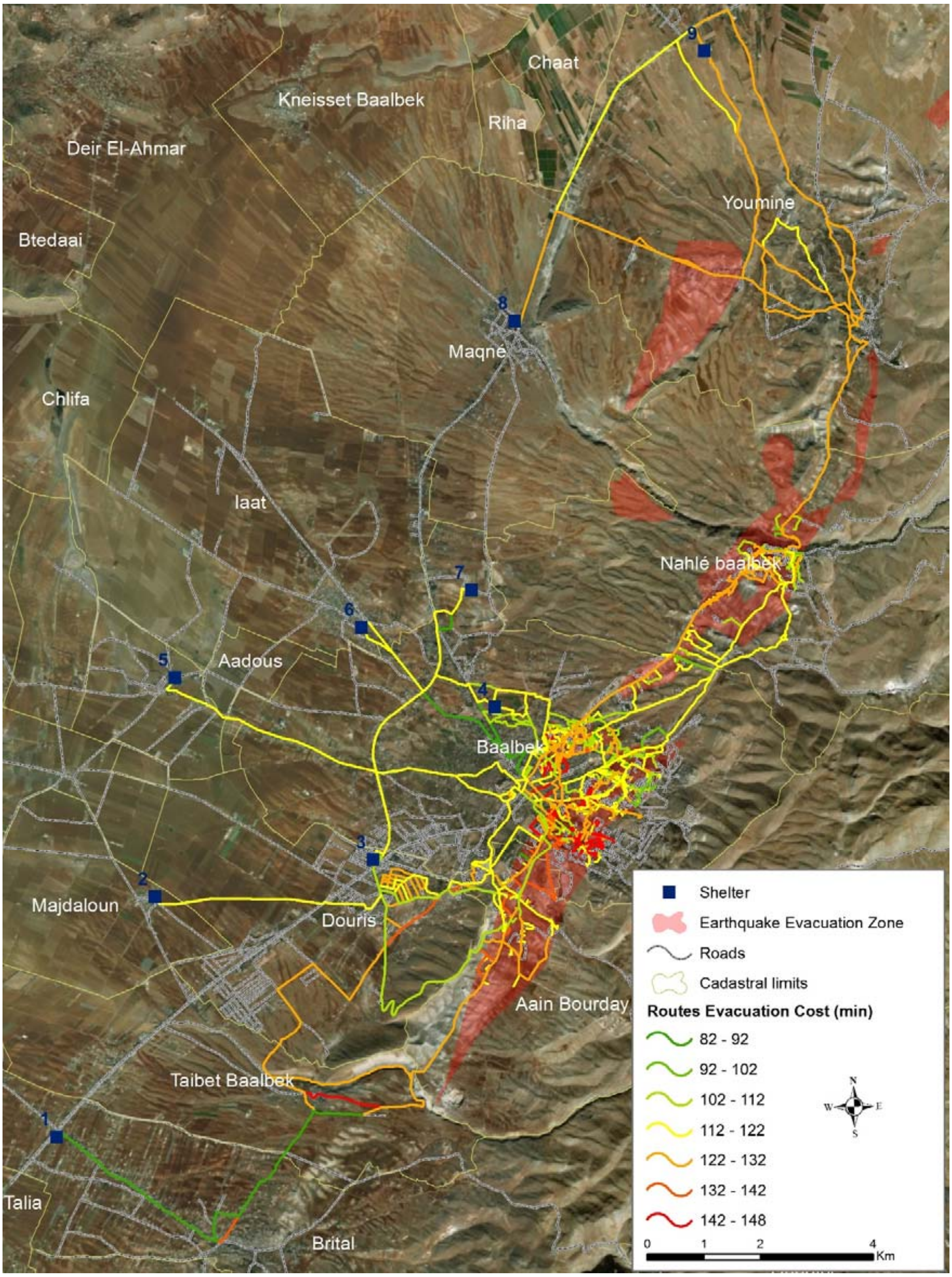


Figure 7-8. SP algorithm generated evacuation routes Baalbek-Hermel post-earthquake scenario

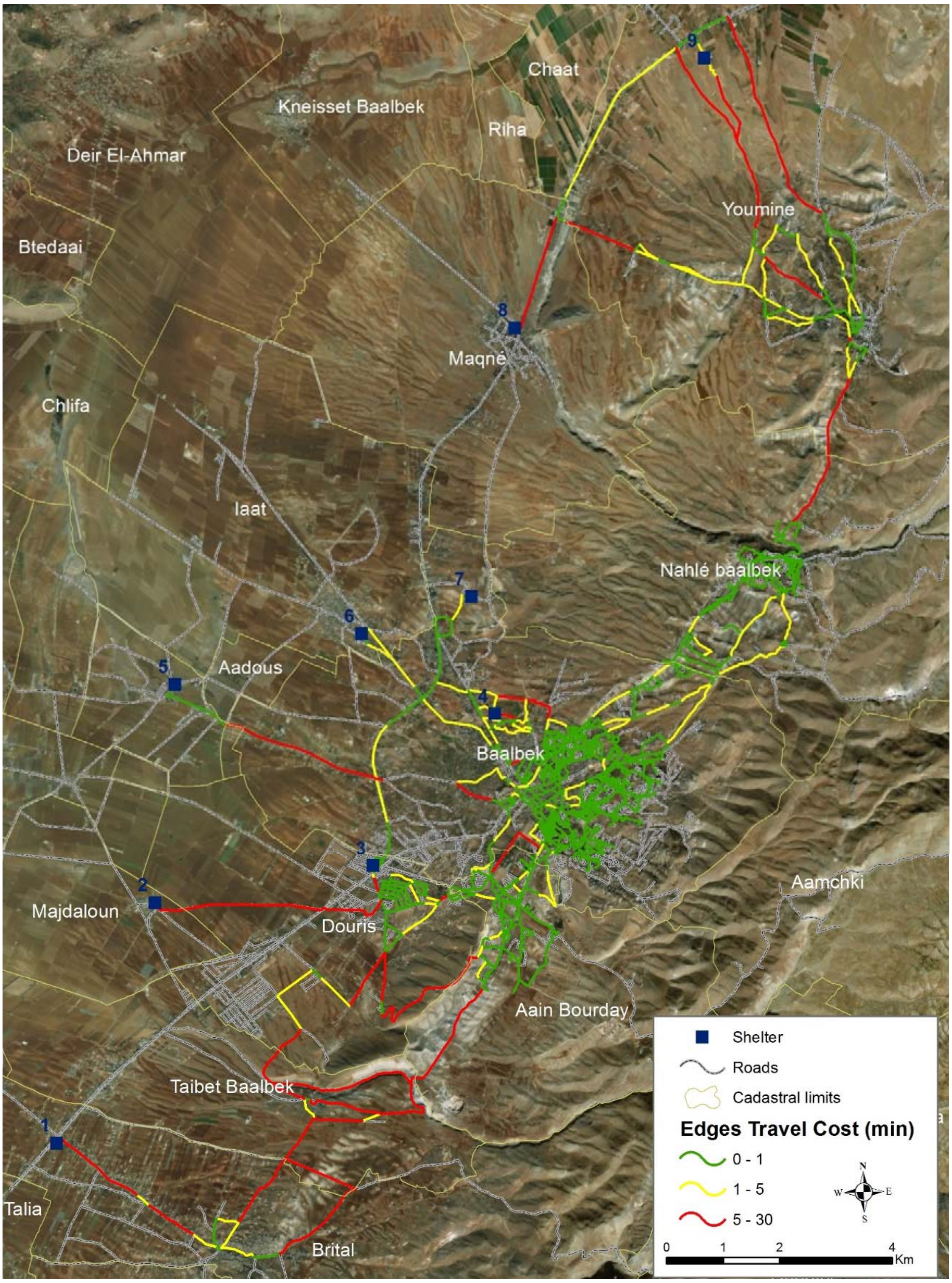


Figure 7-9. Roads edges travel evacuation time generated by SP algorithm.

b) CASPER algorithm results

After running the CASPER routing for the conducted post-earthquake scenario, as many routes as the number of evacuees' origin locations (1941) were generated; all evacuees were evacuated successfully.

The CASPER algorithm resulted in the total evacuation of the exposed zone in about 64 minutes (Figure 7-10), more than half the evacuation time resulted from the SP algorithm. Generated evacuation routes indicate for each residential structure its allocated shelter, the route length and the evacuation travel time. The majority of the evacuation routes ranged between 54 to 64 minutes. The map displayed in Figure 7-11 shows optimal evacuation routes generated by CASPER algorithm for the conducted post-earthquake scenario. This map, compared to SP resulted map, shows that CASPER used more roads segments, even if longer, to reduce the total evacuation time.

Small differences between evacuation cost and original cost (traversal time without congestion considerations) were found for CASPER algorithm. Figure 7-12, representing roads edges travel evacuation time, shows congestions on roads edges. Roads edges with highest congestion values (a maximum of 5 min) reflect hot spots where the evacuee's flow may experience any kind of slowdown and, in some cases, even stagnate. These hotspots are observed especially in route confluences and in final edges before shelters even if CASPER algorithm forces the deviation of evacuees pushing them to opt alternative routes (longer paths) to avoid new traffic jams. Results also allude to accessibility, network configuration, and network design issues in this region of Baalbek-Hermel Governorate, inherent to evacuation planning.

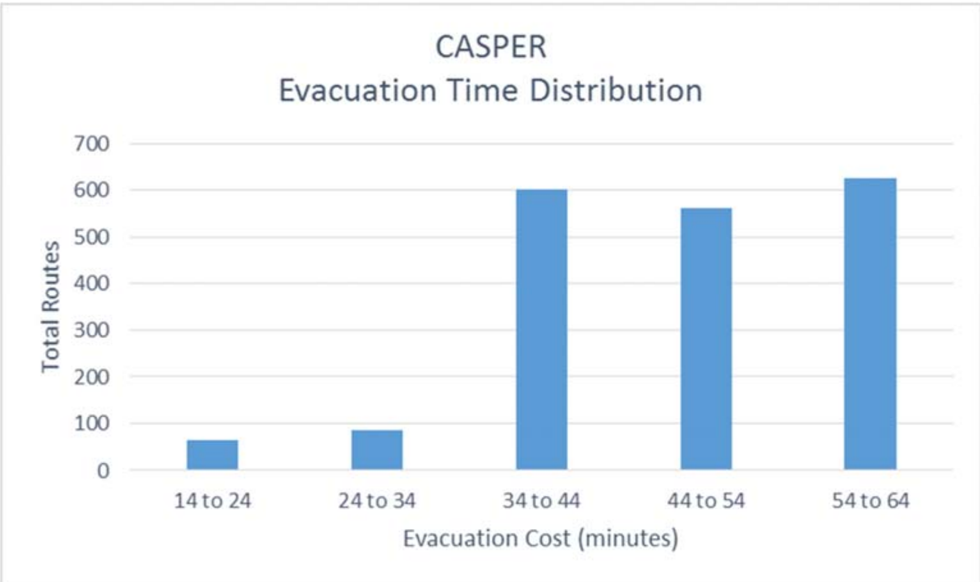


Figure 7-10. CASPER Algorithm Evacuation Time Distribution

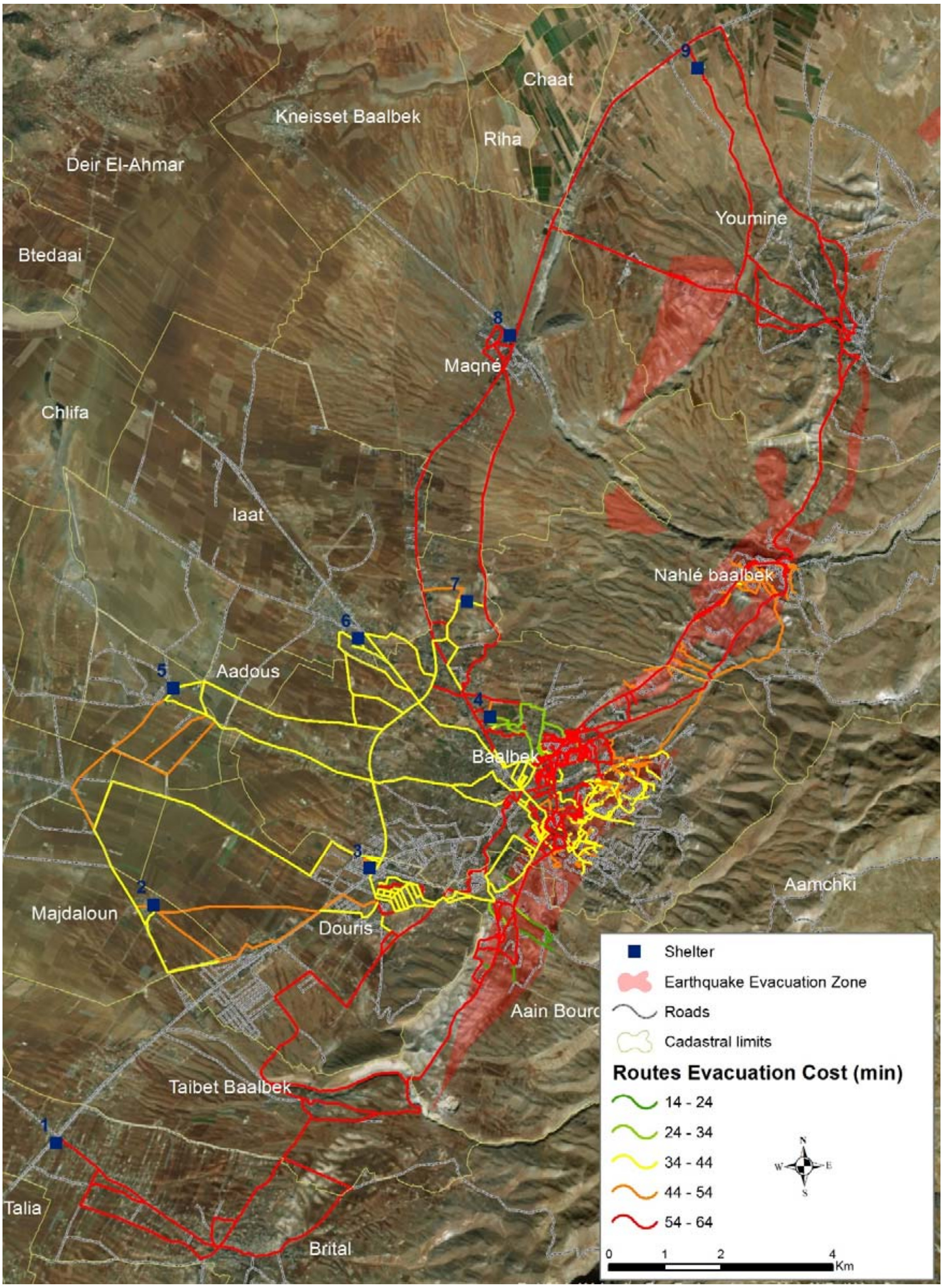


Figure 7-11. CASPER algorithm generated evacuation routes Baalbek-Hermel post-earthquake scenario

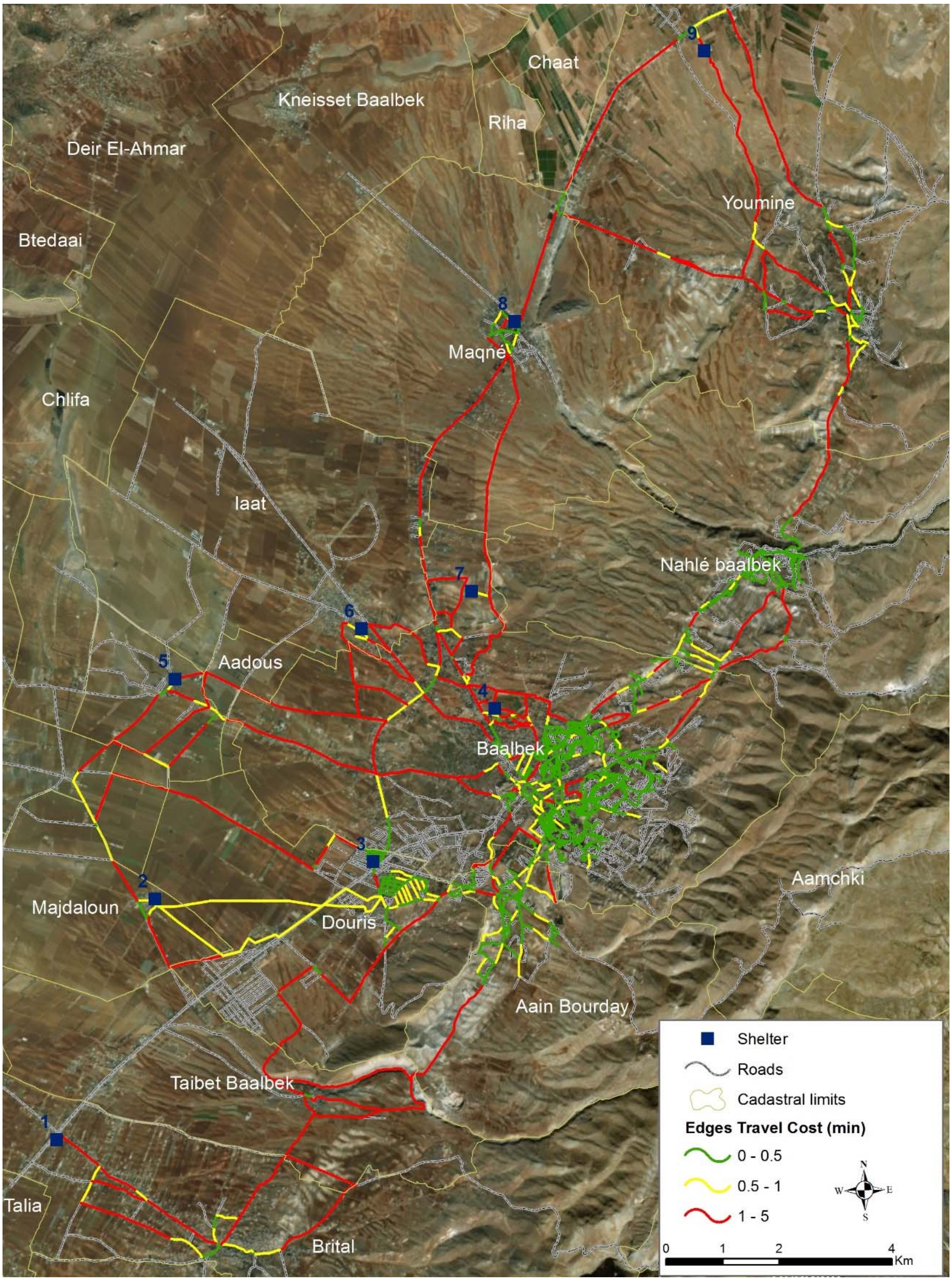


Figure 7-12. Roads edges travel evacuation time generated by CASPER algorithm.

Table 7-2 summarizes characteristics about the number of evacuated cars per road segment obtained from SP and CASPER algorithm. The shortest path method used far fewer road segments (3402), just as it would happen during unplanned evacuation, and has a larger number of cars per segment compared with CASPER method.

Table 7-2. Number of cars evacuated per road segment for both SP and CASPER methods

Method	Total Road Segments	Car Per Road Segment			
		Min	Max	Mean	Standard Deviation
Shortest Path (SP)	3402	1	9572	242	865
CASPER	5262	1	1966	184	288

The ultimate goal of this study is to establish an evacuation plan map for Baalbek-Hermel after a potential foreshock scenario. Therefore, the following outputs of CASPER method can serve as a baseline for post-earthquake evacuation of the studied area: evacuation routes and predicted traversal times for each residential structure, with allocated shelter and the directions to follow.

An important output of the conducted CASPER method is the allocation of shelters with respect to earthquake safe zones and as a function of shelter capacity to accommodate evacuees who are unevenly distributed in space, optimal evacuation routes, and minimum travel time. Shelters in the study area are "dual-use" facilities that have been built for purposes other than emergency shelters. Shelters locations and capacities are generally unknown to the population. Appropriately located post-earthquake shelters were 9 shelters chosen as candidates for meeting points. These shelters have a combined capacity of 14100 individuals, enough to host all the 14000 potential evacuees. If this evacuation planning is to be applied, further shelter planning is needed and should include the food, water, and medicine demand.

2.3. Conclusion

Evacuation is an essential measure to be taken in a post-earthquake situation. The fear of forthcoming aftershocks, the psychological condition of the population and experience transferred from generation to generation, enhance the evacuation behavior especially in regions highly exposed to earthquake like the center of Baalbek-Hermel Governorate. The process takes place on impulse; a large number of evacuees will chose the same paths and will most probably cause significant traffic congestions. Therefore, planning comprehensive interventions for a safer, faster and more effective emergency evacuation is necessary.

This section comes to test, via realistic traffic model, the road capacity in a post-earthquake evacuation scenario in highly exposed region of Baalbek-Hermel Governorate and plan for an optimal organized evacuation. Results concluded that an unplanned evacuation would take more than 148 minutes and high traffic congestions, while a Capacity Aware Shortest Path Evacuation would achieve far better results with an evacuation time of less than 64 minutes, using most of the same road segments and predicting traffic jams and road edges delays more efficiently. The CASPER models' outputs provided an evacuation plan, the time required for evacuation, the areas of highest congestion and shelters allocation, showing the authorities and the people the safest routes to take away from the crisis. The findings of this section emphasize the significant role of a managed evacuation strategy in disaster preparedness measures. The selection and agreement upon evacuation routes and plans are a decision of local authorities. Enhancing the accessibility of the evacuation origin sources or the expansion of certain roads to reduce travel times, are also decisions to be accounted for.

3. Gaps, Challenges and Uncertainty

This chapter, through its two case studies, discussed the use and benefits of GIS and modelling in the preparedness and response planning phase and especially in evacuation planning. Evacuation in response to any particular event is a unique, complex, and uncertain response. Evacuation scenarios and models, with as ultimate goal to provide valuable insights allowing Baalbek-Hermel decision-makers to take more effective preparedness measures and response actions, have been conducted using the most accurate data available; nevertheless, their preparation required many assumptions and therefore they present some known limitations and unknown uncertainties and probabilities that should be pointed out. Preparedness actions in Baalbek-Hermel, as for other regions in developing countries, are often ignored. Societal challenges behind preparing for intensive hazards is to cope with risk uncertainty and its low probability. The field of evacuation planning necessarily entails uncertainties. These uncertainties form a considerable debate, especially when considering the costs of associated preparedness measures. These uncertainties present many challenges and lead to an increase of vulnerability to natural disaster in Baalbek-Hermel governorate. The faced gaps, challenges and uncertainties in this chapter reside in:

a) Hazards uncertainties

Flood hazard, on which the modelling in section 1 (Pedestrian evacuation planning for Ras-Baalbek flash floods scenario using Least-Cost-Distance based approach) was performed on a scale of 1/20000. Further analysis needs to be done to perform a new flood hazard map on a larger scale, which would lead to the implementation of the dynamics of the flood in time of the evacuation.

The utilized earthquake hazard map for the evacuation routing in section 2 of this chapter (Planning for a Shelter-Capacity-Based Evacuation Routing after an Earthquake using Capacity Aware Shortest Path Evacuation Routing (CASPER) Algorithm), lacks a micro-zonation. This gap may lead to uncertainties in the number of exposed population and residential structure. Moreover, besides the foreshock and the following main shake, several secondary hazards triggered by earthquake could threaten people and assets, involving landslides, fires, liquefactions, and flooding. No studies have been conducted in Lebanon, indicating the location and probability of these secondary hazards threatening the passengers of the congested cars and thus significantly impeding the circulation of the emergency vehicles. Also, the time available for evacuation, separating a foreshock and main earthquake is still unpredictable.

b) Population characteristics and Behavioral uncertainties

The elaborated modeling identified where pedestrian evacuations are likely; however, there are aspects of individual behavioral issues and mobility that require consideration before localized evacuation may be realistic. The conducted modeling simplified actual travel resulting from a generalization of speeds for the entire population; individuals will not travel at similar speeds, especially as fatigue sets in for those with longer travel distances and different demographic groups with different mobility (elderly, children or people with special needs) who need assistance. More data is needed to assess different demographic groups and their location in order to increase the accuracy of the model.

Moreover, considering the evacuation routes modeling in section 2, not all evacuees may want to go to shelters. It is likely that evacuees would prefer to evacuate to relatives, friends, hotels, motels, etc.

c) Roads uncertainties

During evacuations, roads and traffic problems may change the expected situations. These road network problems, that may affect the road network and the number of evacuating cars from neighborhoods, can be summarized as potential background traffic not initially envisaged, road accidents that may slow down the evacuation, modifications in the road network such as a damaged bridge, partially blocked or totally disrupted road. All these uncertainties may greatly affect the evacuation routes and the total evacuation time.

It is of key importance to seek to drive down uncertainty as much as possible but inevitably it must be accepted that uncertainty will always exist especially in the field of evacuation preparedness where uncertainty is inherent in the risk planned for and knowledge is not complete.

Chapter 8 . Recovery Phase

The majority of the GIS-based conducted case studies in previous chapters can serve the recovery process in Baalbek-Hermel. Critical Infrastructure (CI) plays a fundamental role in the recovery of societies from disasters (enhancing it if CI in good conditions or hampering it in the opposite case) and even the recovery process starts by fixing damaged CI; assessing Baalbek-Hermel road network resilience to natural hazards established support information to stakeholders to reinforce roads and therefore enhance and accelerate recovery processes in the future. Assessing Baalbek-Hermel schools' vulnerability is important for rehabilitation and a better planning during recovery. Assessing agricultural risk in Baalbek-Hermel has led to the establishment of automated system prepared for disaster loss assessment on agriculture. These automated systems facilitate the rapid assessment of damage and thus, accelerate the compensation process and recovery. Moreover, results of agricultural risk assessment have emphasized on the importance of integrating DRR strategies into post-disaster recovery efforts and to ensure that investments made for agricultural sectors recovery also build resilience to future shocks. Long-term structural solutions were also recommended; coping and recovery solutions that will help the affected population cope with losses (compensation (cash or in-kind), social protection programs, and livelihood recovery programs). Preparedness and evacuation planning would ensure the decrease in life losses, and therefore enhance a rapid come back to normal life.

This chapter focuses on land use planning perspective of a better recovery. Al-Assi floodplain was chosen as case study to design a land use planning. GIS-based analyses were conducted retracing the development of land use/land cover in the floodplain after floods occurrence and proposing, in a geo-spatial manner, a better planning to cope with flood hazard. This method is believed to enhance recovery and build resilience.

1. Land-Use Recovery Planning for Al-Assi (Orontes River) floodplain

An important aspect of recovery is the implementation of risk-based land use planning and regulations to build back safer by reducing the underlying causes of disasters (Donovan 2013). Pre-planning for how land may be 'recovered' or used after an event is important because it turns the reactive recovery often leading to poor decision-making, into a proactive recovery (OECD 2017). Urban planners actively engaging DRR in land-use planning processes and mechanisms, was highlighted as a need during the IDNDR and set as a priority action in the HFA as in SDFR (United Nations 2015). Land use planning is a nonstructural measure that advocates cautious investments and utilization of land and natural resources in a way that ensures sustainable development (UNECE 2008). Land use planning is correlated to the protection of infrastructure and assets offering a particular support to decision-makers and an opportunity to build resilience and limit vulnerabilities and risk during post-disaster rebuilding through control of new developments in hazard prone zones (Burby 2005; Godschalk 2003). Planners have the responsibility to move communities forward in allocating secure lands and encouraging more hazard-resilient structures, thereby decreasing "*underlying risk factors*" (ISDR 2005, p6), mostly asset exposure in the hazard area.

Actual land use, assets exposure, and property rights comprehensive assessments through GIS, are required information for DRR and zoning decision-making. LU/LC mapping is an important use of GIS in land use planning (Al Sayah et al. 2019). Up-to-date land occupations maps have been proven to be a necessity not only to scientists but also to planners, resource managers and decision makers (Mohammady et al. 2015). The LU/LC change impact has long been studied at different scales and sectors, it has aroused ever since humans came to the conclusion that they and their activities are the major modifiers of the biosphere (Riebsame, Meyer, and Turner II 1994). The LU/LC patterns of a region results from environmental and socio-economic factors and their use by mankind over time and space. Changes of these patterns have become a prevailing and accelerating process, driven by natural phenomena and exacerbated by anthropogenic activities impacting the natural ecosystem (Ruiz-Lana and Berlanga-Robles 2003; Turner and Ruscher 2004). Therefore, it is essential to have information on land occupations and on the possibilities of their optimal use for the selection, planning and implementation of new land-use programs in order to respond to the growing demand for basic needs and social protection (Goswami and Khire 2017) since these are principal components for territorial management, along with reducing risks. For tacking these changes, mapping of LU/LC through remote sensing (RS) is used as one of the most important applications of the latter, where it has been shown to be the most effective tool for spatial data acquisition (Cetin 2009) and for revealing changes through historical time series tracking using satellite images with different acquisition dates for the study area. In addition, the use of RS for mapping objectives considerably contributed to reducing the complexity of field work and study time given the amount of quantitative and qualitative information it provides (Abburu and Golla 2015). The advent of RS and GIS allowed the integration, mapping and analysis of large scale landscapes pin pointing the location, time, type and rate of change. Nevertheless, this task is not easy but is limited by several factors, namely the resolution of satellite imagery, classification schemes and the physical characteristics of the study area (Lu and Weng 2007a). Given the strong dependence of information in remotely sensed data to image resolution and the effect that the latter possesses on image classification (Suwanprasit and Srichai 2012), advances in remote sensing sensors have provided imagery at finer resolutions yielding more accurate analysis for mapping (Fisher et al. 2018). The mapping task itself is a process of pixel attribution to the different LU/LC classes or categories (Lu and Weng 2007b). The mapping of these two independent yet entwined terminologies has become a central component of current and future policies for natural resources management and environmental dynamics monitoring (Kaul and Sopan 2012). The objective of mapping land cover is to describe and locate natural or man man-made resources, whereas land use mapping aims to identify the goals, products and benefits from these resources (De Pauw, Oberle, and Zoebisch 2004). Particularly for the scope of this study, the impact of LU/LC is not only considered to reflect current conditions but also to perform simulations since the modelling approach exceeds the known period (Paegelow and Camacho Olmedo 2005) and sought results are futuristic propositions. Moreover, GIS helps to get complete and accurate analysis and results not only to help in decision making, but to legally support those decisions. However, GIS mapping can turn a two edged sword in this perspective. For instance, zoning ordinances restricting building rights or imposing building codes based on GIS can be contested by stakeholders if they're able to prove GIS data are incorrect at higher resolution (i.e. elevation). In fact, zoning ordinance and all what comes with like land-use planning, property rights and mitigation policy decisions have important social consequences for communities and conflict can arise.

Flood hazard is the most widespread and most frequent natural hazard worldwide and in the Mediterranean Region, resulting in significant losses (Gaume et al. 2017). Zoning ordinance has revealed to be efficient for floodplains management during recovery through land-use planning, to delineate flood levels and related land occupations, and building codes, to guarantee the construction of flood-resilient structures (European Commission 2003). Following a flood, when the community's experience and memory are fresh and the political parties are willing to act, it is particularly the right time to benefit from the opportunities to rebuild better through a risk-informed land use planning framework, and therefore reduce future risk (OECD 2014). Land use planning to manage flood risks has been significantly discussed in literature (APFM 2016; Gondwe, Manda, and Kamlomo 2017; Morrison, Westbrook, and Noble 2018; Ran and Nedovic-Budic 2016). In addition to natural exposure such as locations in floodplain or as a result of the physical characteristics of an area, alteration in land use patterns, location and choice of infrastructure, business and housing increases the exposure and vulnerability of assets and populations (Asian Development Bank 2016). That is why Land use zoning is viewed as one of the most fundamental and necessary inputs at the core of flood risk reduction, capable of improving both the security and resilience of affected people (Roy and Ferland 2014). By monitoring and planning LU/LC patterns, in a mere preliminary diagnosis phase to propose change (e.g. buy-out zones) or restrictions to property rights, the zoning ordinance and the associated building code, resilience and sustainability is obtained (Glavovic 2010). Nevertheless this task is not easy, it requires long-term systematic planning and contributions from various disciplines, stakeholders and decision makers (Asian Development Bank 2016). Also, integration of future scenarios by time series analysis of land occupation patterns promotes the understanding of the interaction with existing and future conditions to infer the required socio-economic or political measures to be undertaken. Further, land use planning plays an integral role in the reduction of current risk by assisting in the identification of potential flood zones based on the land occupation classes present within (Stone, Jenkins, and Westerman 2006). It is also used as an efficient tool for reflecting the most compatible uses for the land in hand by prohibiting or regulating development in high flood zones and re-designing land occupation patterns in areas of low risks to mitigate potential natural disaster impacts (Stone et al. 2006). In addition, efficient land use planning enhances DRR, climate change adaptation and sustainable development at local and regional levels (King et al. 2016) especially considering the large numbers of people, lacking local DRR knowledge, moving and expanding anthropogenic activities towards more cities, many of which are situated in the midst of hazard prone zones (King et al. 2016). Moreover, existing hazard maps offer some setbacks, which typically include debatable risk threshold and related spatial extent (e.g. U.S. 1% floodplain footprint is smaller than the Dutch 0.01% reference floodplain that led to the "Plan Delta" design in the 1950s).

In general, a cross-country study showed that the adoption of hazard and risk-informed land-use planning decisions is still problematical, even in countries like France, Austria and Switzerland (OECD 2017). Mayors, official and politicians try to negotiate over the land-use planning regarded as a blockage of their urban power (Douvinet et al. 2011). In developing countries, the implementation of land use plans and other regulatory instruments is further complicated by the complexities of informal settlement, fuzzy land tenure and controversial land ownership, along with the lack of resources and capacities (UFCOP 2017). Lebanon generally lacks specific flood policies, strategies, and plans. Although Al-Assi River (Baalbek-Hermel Governorate) has flooded several times in the past (1987 with 10 dead and 200 displaced, 2003, 2014, 2017 and 2019), no zoning ordinance exists (DAR and IAURIF 2005). So far, knowledge of land use planning is still in its earliest stages in Lebanon; a lack of restraints is observed under a context of random evolution of land occupation patterns in the country. Urbanization expands without any planning nor recognition of the potential risks. This may in turn cause more vulnerability and increase a chance for man-triggered disasters.

This chapter comes in an attempt to fill a part of this gap by studying the development of land occupations in Al-Assi floodplain throughout the years and proposing an optimal LULC for a better recovery. The conducted methodology consisted of establishing four LULC time series (from 1998 to 2018) in order to monitor the development and changes of land occupations in the floodplain and study the element at risk. This analysis showed so unplanned development and land degradation in the floodplain. To improve this alarming situation, an optimal LULC planning matrix was developed to be implemented during recovery.

1.1. Methodological Approach

The main focus of the current section is to propose a land use planning for Al-Assi floodplain to be applied during recovery to better withstand future flooding. This section describes in details the steps of the conducted geospatial analytical methodology. At first, different timeframes LULC were digitized and used for detailed analysis using an LU/LC time series approach to track the development in floodplain. In a second step, statistics were conducted to highlight the number of assets (structures, roads, agricultural lands, etc.) at risk in the floodplain, and their exposure levels. Finally, based on international methodologies, land use regulation was proposed to be applied in the aftermath of a flood event for a better recovery.

The flood hazard zone used in this study is based on the Flood Hazard Assessment and Mapping for Lebanon study conducted in 2013 by the National Center for Remote Sensing (NCRS). The worst possible flood scenario was considered despite its low 0.01 exceedance probability (or return period T=100 years). This decision is related to the fact that the worst-case scenario provides a clear indication of the maximum area that will be affected by the flooding; and therefore by adopting this scenario, the less severe scenarios are inherently safeguarded.

Given the importance of data quality and its subsequent effects on outputs, high resolution multispectral satellite imagery was used for LU/LC mapping. The CORINE classification and nomenclature is the method of choice for categorization in order to harmonize both databases of the study area.

Al-Assi floodplain was observed using five multispectral satellite imageries Landsat, IRS, IKONOS, GEOEYE and SPOT, provided under their pan sharpened and corrected forms (atmospheric and geometric) by the CNRS-RSC (Table 8-1) .

Table 8-1 Utilized multispectral satellite imageries for LULC mapping.

Satellite	Date of acquisition	Pan sharpened spatial resolution (m)
Landsat and IRS	1998	5.8
IKONOS	2005	1
GEOEYE	2013	0.5
SPOT	2018	1.5

LU/LC maps for the years 1998, 2005, 2013 and 2018 were digitized. These are used as reference maps particularly for the artificial areas present in the floodplain since the level 4 discrepancy (2nd most detailed level) of the CORINE LU/LC classification is targeted.

Moreover, field verification was performed using the ESRI collector, an application installed on tablets to which the LU/LC shapefiles are input allowing the collection and update of information on the field by providing offline availability and syncing capacity when connected. This approach permits proper data collection with ensured spatial accuracy through the possibility of correcting polygons under question using a GPS record on field, and by capturing geolocalized coordinated photos for credibility and integrity of results. A total of 1627 polygons corresponding to different LU/LC classes were obtained, and each was verified through a polygon by polygon approach. Polygons in question or falsely interpreted ones were labelled with remarks to be corrected. Presenting a total of 163 corrected points meaning a total of 10% error only at the level 4 of discrepancy. An accuracy of 90% at the level 4 (second most detailed level of the CORINE LU/LC classification) implies a highly accurate description (overcoming the 85% accuracy margin set for land management purposes). The 10% error was corrected and optimized through post-field corrections and modifications on a pixel-based classification and user holistic interpretation to obtain a higher spatial organization, resolution, accuracy levels and representativeness.

Detailed analysis using an LU/LC time series approach was carried out. LU/LC maps for the years 1998, 2005, 2013 and 2018 were analyzed for changes and for tracking historical changes to obtain an insight regarding the evolution of land occupation classes within the floodplain.

Spatial statistics were conducted on the current 2018 LULC map to highlight the number of assets (structures, roads, agricultural lands, etc.) at risk in the floodplain, and their exposure levels.

Accordingly, a land-use planning matrix that represents reference to follow when any parcel is damaged from floods and needs to be recovered, was developed. The matrix approach, adopted from the Hawkesbury Nepean Flood Management Advisory Committee's report "*Land use Planning and Development Control Measures*" (HNFAC 1997), offers the opportunity to recognize that various land uses have different vulnerabilities to flood hazard. The matrix responds to flood hazard levels through spatial allocation of land occupations and also implement controls in buildings structure and local conditions to manage and minimize the effects of floods. The multifunctional land use approach (Mander, Helming, and Wiggering 2007) was respected by combining multiple functions that would offer various benefits in one area.

In respect to the above, the land-use planning matrix is created by demarcating zones by level of flood hazard (low, moderate and high) and associate them with appropriate, secure, and authorized land uses, building codes, controls, enforcement and potential buy-out areas where necessary. In other words, this matrix identifies what land occupations are suitable for specific zones of the floodplain and where different levels of flood-related development or construction controls are required to decrease the risk (UFCOP 2017):

- High exposure areas are assigned for low-occupancy uses such as recreational activities, ecosystem-based livelihoods involving agriculture, or ecotourism riparian activities. In these areas most development is restricted and existing development must be prioritized for protection and retrofitting.
- In moderate exposure areas, a "living with water" approach should be adopted through development controls, flood-resistant building codes and green infrastructure (green-roofs) to decrease impermeable surfaces and ameliorate the connectivity between green spaces.
- In low exposure areas, preventative relocation and urban growth is possible with development controls including strictly enforced building codes, mandatory flood insurance programs, etc.

The matrix is filled following basic requirements:

- To create environmental buffers to reduce runoff.
- To reduce development and settlement in floodplain and prevent unsuitable development.
- To conserve and maintain agricultural productivity and ecosystems.

1.2. Results & Discussion

Obtained LULC maps for years 1998, 2003, 2013 and 2018 are represented in Figure 8-1.

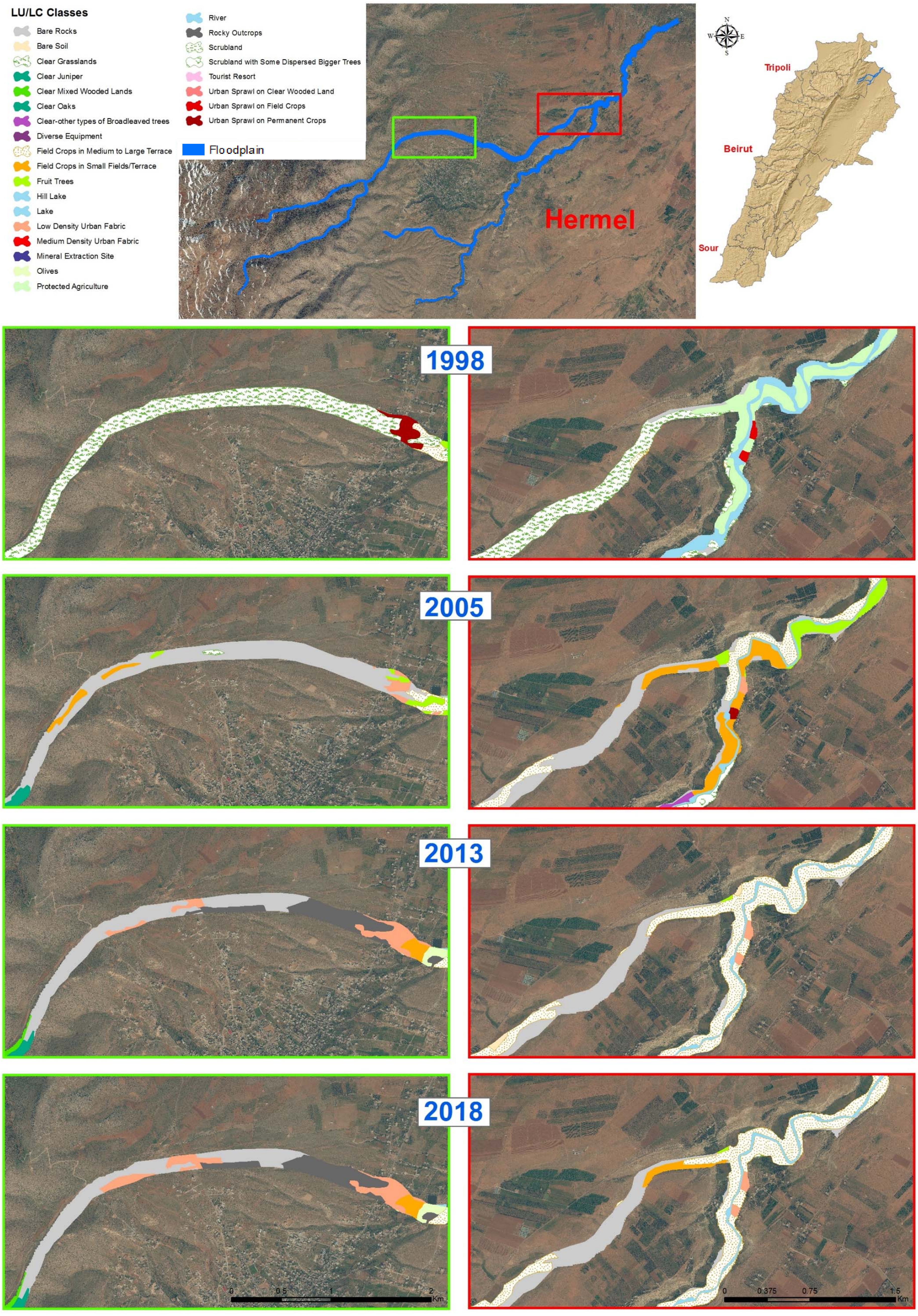


Figure 8-1. Al-Assi floodplain LULC maps for years 1998, 2003, 2013 and 2018.

Analysis of digitized LULC maps revealed important changes of land occupations over the year and a lack of planning during recovery from 2003 (comparison between 1998 and 2005 LU/LC), 2014 and 2017 (comparison between 2013 and 2018 LU/LC) floods.

Natural classes (forests, scrublands and especially grass (Table 8-2 & Figure 8-2)) have also decreased in the study period, these collectively presented 61.19% of the study area in 1998 and have decreased progressively to become 10.41% indicating a considerable regression of natural categories (six times less) that may serve as protective covers during flood times mitigating even to a minimal rate damages from flooding. To the previously cited numbers, increase in percentages (+20%) (Table 8-2) of unproductive lands in the study area combine to aggravate the deteriorating state of land use planning in the floodplain (less water infiltration, more runoff) increasing further the vulnerability and exposure of populations and assets at risk.

Evolution of artificial/urban classes are the focal point of analysis, since their increase (Figure 8-2) in the floodplain strongly solidifies the lack of knowledge in land planning, the absence of restraints and the contribution to flood risk increase. The analysis of LULC dynamics in Al-Assi Floodplain has shown, as seen from Table 8-2, that, although floods have occurred in 2003, 2014, and 2017, urban categories under the form of low and medium density urban tissues have been seen to have increased of 3.4% for the period 1998-2018, with a rate of approximately +0.2 per year. This state presents an alarming situation since evolution of urban fabrics is still increasing despite its location in a floodplain thus increasing the exposure of populations at risk. In addition, a more serious state is further observed, where urban sprawls (urban tissues in early stages of development) have increased through the period 1998-2018 evolving from 0% to 2.3% with rate of +0.1% increase per year. This further shows an intensification of urbanism in an area prone to danger. Moreover, an increase of 0.014% per year is observed for touristic resorts in the floodplain. When considering the year 2018 in contrast to 1998, a rate of 6.15% of total urbanism is observed. In fact, a total of two hotels, two industries, 1 school, 1 villa, 44 resorts, 133 single houses and 4 refugees' tents were detected in the floodplain for the year 2018.

Table 8-2. LULC time series analysis results.

	Area (Km2)				Percentage change				Rate of change (%/year)
LU/LC	1998	2005	2013	2018	1998-2005	2005-2013	2013-2018	1998-2018	1998-2018
Unproductive lands	0.076	1.68	1.42	1.38	+25	-4.5	-1	+20	+1
Diverse Equipment	_	0.06	0.007	0.007	+1.03	-0.92	0	+0.11	+0.0055
Mineral Extraction Site	_	0.02	0.02	0.017	+0.34	-0.06	0	+0.28	+0.014

	Area (Km2)				Percentage change				Rate of change (%/year)
LU/LC	1998	2005	2013	2018	1998-2005	2005-2013	2013-2018	1998-2018	1998-2018
Clear-other types of Broadleaved trees	0.002	0.06	0.005	0.005	+0.99	-0.93	0	+0.06	+0.003
Clear Juniper		0.64	0.35	0.35	+10.21	-4.7	0	+5.51	+0.2755
Clear Mixed Wooded Lands	0.002	0.30	0.24	0.24	+4.78	-1.06	0	+3.72	+0.186
Clear Oaks	_	_	0.03	0.03	0	0	+0.42	+0.42	+0.021
Scrubland	0.69	_	0.004	0.004	-10.1	+0.06	+0.004	-10.036	-0.5018
Scrubland with Some Dispersed Bigger Trees	0.15	0.12	0.008	0.008	-0.46	-1.83	0	-2.29	-0.1145
Medium density grasslands	0.07	_	_	_	-1.18	0	0	-1.18	-0.059
Clear Grasslands	2.18	0.16	0.06	0.06	-32.22	-1.5	-0.14	-33.86	-1.693
Field Crops in Medium to Large Terrace	0.33	0.44	2.06	1.98	+1.75	+25.79	+1.32	+26.22	+1.311
Field Crops in Small Fields/Terrace	0.19	1.46	0.40	0.43	+20.13	-16.84	+0.57	+3.86	+0.193
Fruit Trees	0.07	0.69	0.41	0.49	+9.85	-4.49	+1.31	+6.67	+0.3335
Olives	_	0.0003	0.11	0.11	+0.006	+1.72	-0.03	+1.69	+0.0845
Protected Agriculture	1.26	_	0.009	0.009	-19.97	+0.15	0	-19.82	-0.991
Recreation	_	0.01	0.02	0.05	+0.23	+0.06	+0.4	+0.69	+0.0345
Hill Lake	_	0.006	0.03	0.03	+0.10	+0.37	0	+0.47	+0.0235
Lake	_	_	0.001	0.001	0	+0.02	0	+0.02	+0.001
Low Density Urban Fabric	0.05	0.05	0.19	0.26	+0.02	+2.27	+1.07	+3.32	+0.166
Medium Density Urban Fabric	_	_	_	0.000032	0	0	+0.0005	+0.0005	+0.000025
Urban Sprawl on Clear Wooded Land	_	0.02	0.04	0.035	+0.30	+0.26	0	+0.56	+0.028
Urban Sprawl on Field Crops	_	0.01	0.02	0.04	+0.23	+0.06	+0.33	+0.62	+0.031
Urban Sprawl on Permanent Crops	_	_	0.008	0.06	0	+0.14	+0.83	+0.97	+0.0485
Tourist Resort	_	0.04	0.06	0.02	+0.56	+0.41	-0.69	+0.28	+0.014

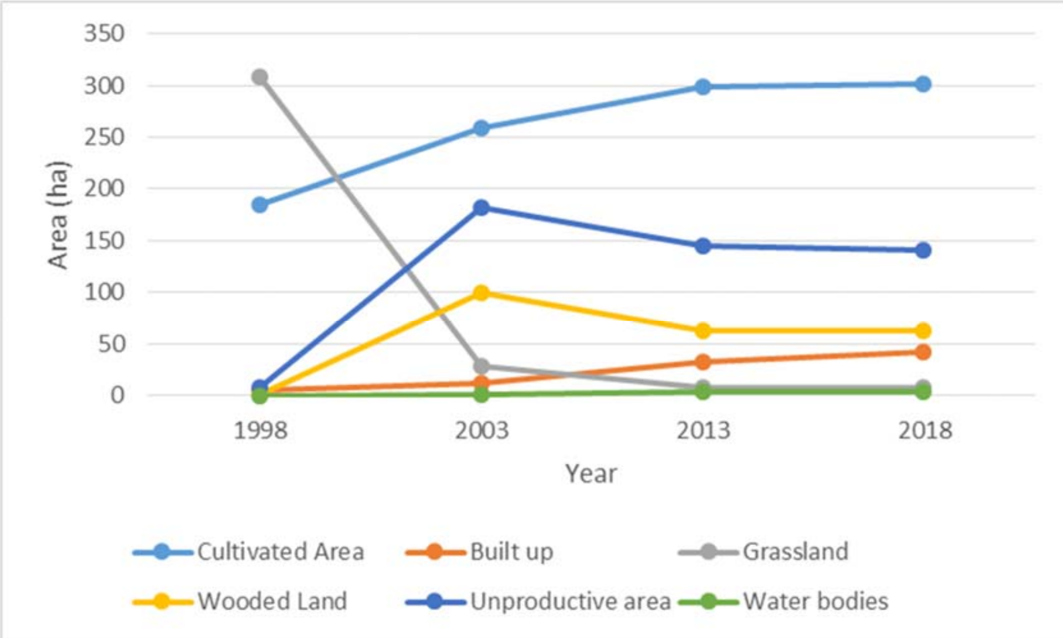


Figure 8-2. Temporal pattern of Land Use/Land Cover change.

In addition, to the statistical evolution of land occupation classes, their location with respect to the hazards level has been determined for current situation (2018). As revealed from Table 8-3, besides their presence in a floodplain, all urban classes are occupying zones of high level hazard highlighting further the unplanned distribution of land occupation categories in the study area.

Table 8-3. Current LULC classes exposure level to flood hazard.

	Flood Hazard Level		
LULC 2018	**Low**	**Moderate**	**High**
Unproductive areas	X	X	X
Diverse Equipment	X	X	
Mineral Extraction Site	X		X
Clear-other types of Broadleaved trees	X	X	X
Clear Juniper	X	X	
Clear Mixed Wooded Lands	X	X	X
Clear Oaks	X	X	X
Scrubland	X	X	
Scrubland with Some Dispersed Bigger Trees	X	X	
Medium density grasslands	X	X	X
Clear Grasslands	X	X	X

LULC 2018	Flood Hazard Level Low	Moderate	High
Field Crops in Medium to Large Terrace	X	X	
Field Crops in Small Fields/Terrace	X	X	X
Fruit Trees	X	X	X
Olives	X	X	X
Protected Agriculture	X	X	X
Recreation		X	X
Hill Lake		X	X
Lake		X	
Low Density Urban Fabric	X	X	X
Medium Density Urban Fabric	X		
Urban Sprawl on Clear Wooded Land	X	X	X
Urban Sprawl on Field Crops	X	X	X
Urban Sprawl on Permanent Crops	X	X	X
Tourist Resort	X	X	X
Industry		X	

X LULC class presence

X Misplaced LULC class

To further understand the gravity of the situation in Al-Assi floodplain, the exposure of different valuable assets was studied. Figure 8-3 & Figure 8-4 show respectively the exposure of artificial structures and agricultural lands. It is noteworthy that all the hotels present in the floodplain are situated in high-flood hazard zones, as for the only school in the floodplain, it is moderately exposed to floods. The majority, not to say none, of these structures do not follow any building codes and are not flood-resistant.

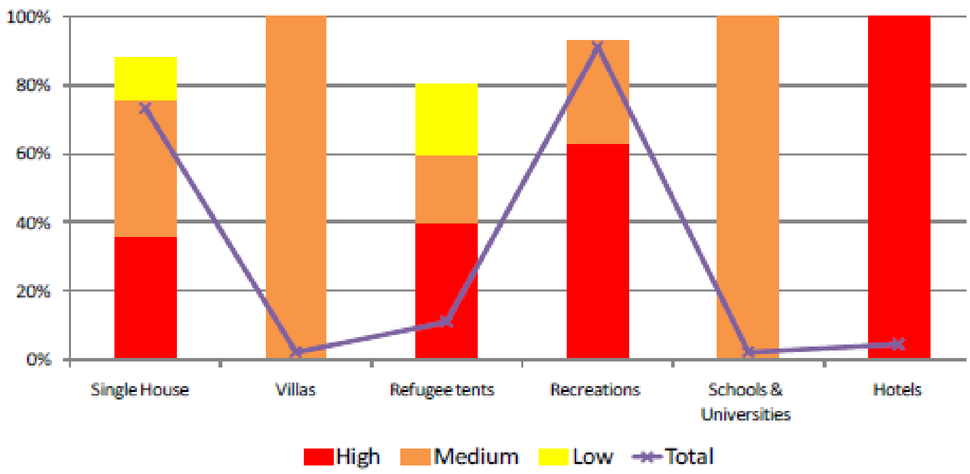


Figure 8-3. Endangered structures in various flood hazard zones.

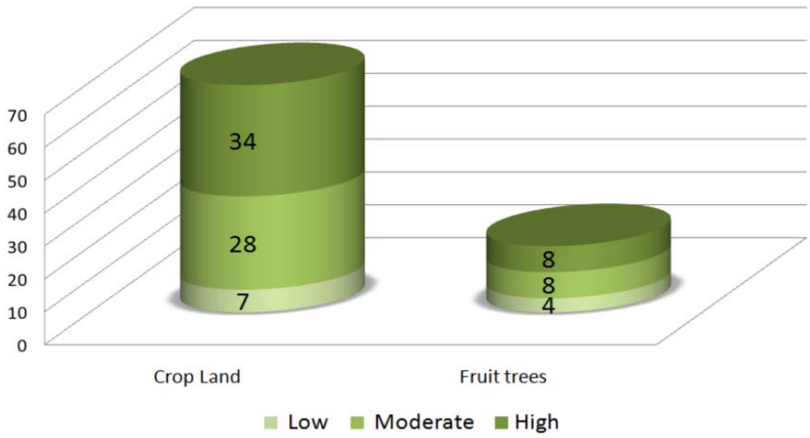


Figure 8-4. Distribution of agricultural lands (Ha) in flood hazard zones.

The above results reflect the lack of oversight and systematic monitoring of the integration of hazard assessments into land-use decisions. This alarming situation indicates that proposing a land-use planning to be implemented as zoning ordinance during recovery is a necessity in Al-Assi floodplain. The proposed recovery zoning ordinance measures focus on translating information from flood hazard assessment into land-use planning by minimizing development in the floodplain, reducing water runoff by development controls of flood risk reduction, mitigating losses caused by inevitable floods and accommodating urban development and growth in flood-safe zones (relocation and rebuilding during recovery). This sustainable hazard-informed land use planning approach was proposed to benefit as much as possible from waterfront touristic, economic and recreational activities along with the services offered by the ecosystem while at the same time protecting people and properties, by following three basic principles: 1) Safe location, 2) Safe construction (building codes, raised and/or multi-storied housing units), and 3) Safe activities (landscaping and design of drainage and natural flood retention zones). A special attention was given to the efforts of combining flood mitigation measures with agro-environmental practices since the studied floodplain is situated in a rural region.

In respect to the above, a land-use planning matrix was created (Figure 8-5), in an attempt to offer specific land-use requirements while avoiding the narrow traditional management approach that prohibited specified developments in highly exposed areas of the floodplain. This matrix specifies if the LULC class is suitable to the flood level and if planning controls are required to be applied to make existing land-uses more resilient, or if it is not suitable and needs to be relocated and replaced by another less vulnerable LULC class. It is also an opportunity to explore options for maximizing the use of the floodplain to meet development expectations, while managing the development and allocation of land use in ways that minimize vulnerability and, ultimately, risks.

LU/LC current classes \ Flood zonation	High flood prone area	Moderate flood prone area	Low flood prone area
Unproductive lands	✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation
Diverse Equipment	✓	✓	✓
Mineral Extraction Site	✗ Retention ponds ✗ Recreation	✗ Retention ponds ✗ Recreation	✗ Retention ponds ✗ Recreation
Clear Juniper	✓	✓	✓
Clear Mixed Wooded Lands	✓	✓	✓
Clear Oaks	✓	✓	✓
Clear-other types of Broadleaved trees	✓	✓	✓
Scrubland	✓	✓	✓
Scrubland with Some Dispersed Bigger Trees	✓	✓	✓
Grasslands	✓	✓	✓
Field Crops in Medium to Large Terrace	✓ Flood resistant species ✓ Levees	✓ Flood resistant species ✓ Levees	✓ Flood resistant species
Field Crops in Small Fields/Terrace	✓ Flood resistant species ✓ Levees	✓ Flood resistant species ✓ Levees	✓ Flood resistant species
Fruit Trees	✓	✓	✓
Olives	✓	✓	✓
Protected Agriculture	✓	✓	✓
Recreation	✓	✓	✓
Hill Lake	✓	✓	✓
Lake	✓	✓	✓
Industry	✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs

Flood zonation / LU/LC current classes	High flood prone area	Moderate flood prone area	Low flood prone area
			✓ high-level storage ✓ Immediate shut-down system ✓ Soil isolation
Urban Sprawl on Clear Wooded Land	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs
Urban Sprawl on Field Crops	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs
Urban Sprawl on Permanent Crops	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs
Low Density Urban Fabric	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs
Medium Density Urban Fabric	✗ Relocation ✗ Retention ponds ✗ Forests	✗ Relocation ✗ Retention ponds ✗ Forests	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs

Flood zonation / LU/LC current classes	High flood prone area	Moderate flood prone area	Low flood prone area
	✗ Grassland ✗ Recreation	✗ Grassland ✗ Recreation	
Tourist Resort	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✗ Relocation ✗ Retention ponds ✗ Forests ✗ Grassland ✗ Recreation	✓ Flood resistant ✓ Elevated floor level ✓ Green roofs

✓ Suitable Land Use; may be subject to development considerations

✗ Unsuitable land use

Figure 8-5. Land-use planning matrix for flood recovery

Planning the built-up area, or "grey" area, and its recovery is complex. Therefore, the proposed approach to artificial zonation responds to the need to maximize the number and complexity of regulations in order to indirectly obstruct residential intensification efforts in highly to moderately exposed areas. Construction rights and permits should be very reduced and strict, and real estate development for residential purposes should be prohibited. Building codes should be imposed to indicate minimum design standards for floor levels, materials and access points, required for implementation in each hazard level zone. Moreover, if damaged, these artificial areas are not recommended to be repaired but to be relocated and to shift the LULC class to forests, or grassland, or recreation. Medium density urban fabrics were revealed to be located on low hazard in the floodplain, however building codes are still needed and planning must take into consideration not to build on moderate or high hazard levels. Urban sprawls must be controlled in planning since they are still in the sprawl state and must not be allowed to be extended into tissues. To examine the issue in detail, it is important to emphasize that urban sprawl is fragmented and dispersed in the floodplain, leading to tremendous damage and potential isolation. The exposure of these already existing buildings cannot be modified, however, their vulnerabilities can be reduced through retrofitting measures. On the other hand, recreation like restaurants, public parks, sport fields and other low-key occupations that are only used only intermittently and without overnight stays, may be the only artificial suitable occupation in highly exposed areas. These opens space/recreational areas may also be utilized to maximize water retention capacities; they should be designed to function in a dual purpose such as retention ponds or retention basins during wet season, taking into consideration a distance away from urban areas to avoid incidents like suddenly overtopping or embankment failure creating flash flooding situations. Al-Assi restaurants, scattered along the river in highly exposed areas and representing a well-known destination in Lebanon, can be preserved. However, evacuation of visitors and workers should be well planned for. Concerning the road network, it should be strategically located and built to appropriate heights to preserve emergency routes to and within flood zones. Establishment of public facilities, such as educational facilities, hospitals, commercial centers, etc. should not be allowed in the floodplain. The development of structural protection (e.g. levees, dams…) should be done carefully to avoid their unwanted side-effects. Usually, structural protection suppresses the hazard area and opens its land to development, increasing associated exposures. According to the Australian Institute for Disaster Resilience (2018), structural protection systems incentives and feedbacks encourage risk accumulation (Gissing et al. 2018). Furthermore, if not properly-maintained due to lack of resources or simply negligence, these protective structures may turn into catastrophe (Burby 2006). Finally, obstruction of river flows should be totally prohibited.

Planning the recovery of agricultural zones has an ultimate purpose to preserve the existing agricultural uses and maximize opportunities for agricultural sectors and sub-sectors. Relocation of agricultural classes is not an option since flooding makes fertile alluvial soils. Agricultural areas are the most severely impacted by floods, flood adaptation measures are recommended. Flood adaptation measures include farming restriction to non-flood periods, cultivation of flood-resistant species and the construction of levees, private dikes and stock refuges. Nevertheless, the advantages should be weighed against the loss of nutrient replenishment from the river and the potentially increasing river erosion.

Planning the recovery of natural zones (forest, grasslands, scrublands, etc.), through ecological protection and restoration (Sudmeier-rieux, Ash, and Murti 2013), is of considerable importance to reduce flood hazard. It is highly required to preserve at least 80% of lands with gardens, orchards, grass, or vegetables (permeable surfaces). The specific goal of this zonation class is to create a buffer zone by increasing natural areas, to enhance water retention and infiltration, reducing soil erosion and landslides while protecting and providing green space, parks, and recreational amenities to Al-Assi floodplain community. Fish-breeding activities are well-spread throughout the river banks. Already in place riparian systems must be protected for river banks integrity, water quality and water quantity modifications neutralization and biodiversity conservation. Unproductive areas must be converted into natural; those suitable for productivity must be optimized, those on low hazards must be planted, while those on moderate and high hazard levels must be overlaid by vegetative protective cover. Natural areas not only store and reduce flooding, but also improve the communities' livelihoods through ecosystem services and offer urban recreation areas (outdoor sports facilities, parks, nature reserves). Buffer zones have been discussed in U.S.A. at least since the 1970s. For instance, Americans are aware that the loss of wetlands increases storm surge hazard along the Gulf Coast, and specifically in the Mississippi Delta. Similar studies have reached similar conclusions for inland floodplains, and that, among other considerations led to the introduction of the compensation principle for wetland losses under section 404 of the Clean Water Act of 1972 (National Research Council (U.S) 2001). Moreover, strategic natural spaces can be used for emergency and relief operations that can also serve as locations for temporary shelters and medical field stations.

The proposed zoning ordinance should be implemented at the local/municipal level, since the municipality grants building permits, and monitored by the governorate and national subdivisions. The success of implementing the proposed land-use planning, lies in the fact that is less costly than structural measures, and is fairly easy during recovery for communities, such as those of Al-Assi floodplain and Baalbek-/Hermel, with few financial or technological resources to implement. During recovery, denial of reparation of services, necessary to sustain livelihoods like electricity and water, in high exposure parts of the floodplain can help to limit development and discourage growth. Moreover, living in a floodplain with risk-informed land-use planning would necessarily raise awareness among inhabitants and create solidarity in terms of facing the risk.

2. Gaps, Challenges and Uncertainty

Establishing a recovery land-use planning and its adoption and implementation hold a number of challenges, especially in the case of Al-Assi floodplain, as for other regions of developing countries. These encountered gaps, challenges and uncertainties reside in uncertainties of Climate Change, unclear tenure and contentious land ownership, dynamic changes leading to rapidly outdated plans, societal unacceptance/locals consent, difficulty of relocation, lack of laws and flood insurance, political and legal implications and jurisdictional and risk borders.

a) Climate change

The conducted land-use planning was based on a flood hazard not accounting for the impact of Climate Change. With Climate Change, flood depth may become higher and the extent of the floodplain may become greater. For a more efficient recovery, land use planning must be able to withstand a changing and uncertain future by incorporating the effect of climate change as well as the surrounding uncertainties to design more resistant and sustainable structures and infrastructure in flood prone zones.

b) Continuous update

In addition to the climatic change, new needs will arise in the upcoming years. Excessive use of natural resources can cause soil subsidence, altering some hydro-geological parameters and thus expanding the flooding area. The established land-use plan is therefore not a static document and, if not updated, may not keep pace with ever-changing situations; this document needs to be periodically updated and more actions remain to be done continuously in order to be consistent to actual risk patterns.

c) Unclear tenure and contentious land ownership

Missing land tenure constitutes an important impediment during the recovery phase. Implementation of land zoning in Al-Assi floodplain, as in other regions of a fragile state like Lebanon, constitutes a challenge due to the controversy over land ownership and land tenure. Digital cadaster and property right assessment is an essential part required for the completion of the methodology leading to the establishment of accurate digital zoning ordinance maps including building codes, and potential buy-out areas as well, with enforcement areas delimitation consistent with reliable flood hazard map. No records exist about land tenure and important surfaces are communal or religious lands. The development of a digital cadastral database, indicating land properties is essential and would help in solving the issue. Moreover, complexities related to informal settlement of land could significantly impede the implementation and application of land use planning.

d) Societal unacceptance/locals consent

Although the efficiency of land use planning in decreasing flood risks is generally recognized by decision-makers, its implementation is locally controversial and even faces reluctance. This is the major Achilles' heel of any non-structural land-use based DRR policies. Adaptation measures that reduce economic assets and restrain land-use rights are highly unpopular, creating a bias in government's DRR actions. Municipalities' hesitance to restrict development is explained by the halt of revenues that would be consequently caused. Moreover, no one would accept to be resettled out of its land or want to see its land marked as unsuitable for construction or investment. Locals prefer to see structural measures that reflect the fact that flood risk is being tackled. In fact, locals would have difficulties to understand the costs versus benefits of spatial planning, specifically when comparing green infrastructure procedures to structural measures. Furthermore, risk predicted by scientists may not be seen as a real risk by the community. Any overall plan would also require trade-offs in implementation because of stakeholder participation.

e) Relocation and resettlements

Preventive resettlement and relocating residents, chosen as a last resort to increase or create flood retention zones, is difficult to put into practice especially in Al-Assi floodplain and in Lebanon. This difficulty results from the scarcity of lands due to excessive consumption of space, lack of consensus or approval among locals and of the high incentive/compensation required. Also, zoning affected areas can become politicized and relocations can be regarded as efforts to reallocate lands to more powerful interests. Lack of resources represent an important impediment in the application of Land-use zoning. The Lebanese government should provide alternative safe lands instead of the ones where construction and investment is banned and put in place an exchange formality. Solidarity is key element in mobilizing resources to finance post-disaster measures (relocation or reconstruction) or any other type of risk mitigation through the contribution of mandatory insurance.

f) Lack of flood insurance

Lebanon lacks of natural disasters insurance, at the same time, the Lebanese Government is not capable of compensating all the losses. Flood insurance imposing high premiums on restricted lands constitutes an important support to land-use planning adoption and also plays a significant role in flood risk communication. Some insurance schemes may be imposed to encourage self-protection by decreasing premium amounts or increasing pay-outs.

g) Political and legal implications

To be efficient, land-use planning needs to be accompanied by legislations and jurisdictional-based approaches; "*The regulatory framework of non-structural measures is the key for ensuring that actors carry out their roles and responsibilities with the full information and the right incentives*" (OECD 2017). Legal procedures must be initiated and serious penalties must be imposed if constructions and land occupation did not stick to land-use zoning ordinance matrix. In Lebanon, lack ok laws related to this issue, the long procedure to issue a law and the numerous political involvements would hamper the implementation of land zoning decisions. Furthermore, effective risk governance requires strong leadership. Politicians may be reluctant to invest in non-structural measures because their consequences are not as visible as response and relief actions.

h) Jurisdictional and risk borders

Hazard and risk do not overlap with the administrative borders and their mitigation constitutes a cross-jurisdictional issue. Flood risk can be shared by more than one administrative level, three villages in the case of Al-Assi floodplain (Hermel, Zighrine, and Deir Mar Maroun Baalbek). The involvement of multiple municipalities may constitute a challenge to the implementation of land-use zoning ordinance and planning due to lack of collaboration, coordination and cooperation. A review of the scale of risk governance structures in adequately applying land-use ordinance is a must. The monitoring of zoning ordinance implementation should be carried out by the Governorate of Baalbek-Hermel.

French Summary Part III:

Avec la tendance croissante des pertes dues aux catastrophes naturelles, la réduction des risques de catastrophe, en tant que science appliquée, devient de plus en plus importante. Comment mieux utiliser les SIG pour atténuer les risques de catastrophes naturelles à Baalbek-Hermel et au Liban en général?

Cette partie a constitué l'essentiel de cette thèse. Elle a abordé plusieurs études de cas sur l'implication des SIG dans chaque phase du cycle de la RRC; Cette partie couvre la phase de préparation des informations géospatiales pouvant couvrir l'ensemble du cycle, la phase de prévention (chapitre 6), la phase de préparation et de planification des interventions (chapitre 7) et la phase de récupération (chapitre 8).

General Conclusion

General Conclusion

This dissertation is the first of its type in Lebanon on the topic of Disaster Risk Reduction using GIS and remote sensing techniques. In an applied research perspective, this dissertation came to respond to the theoretical Framework of Sendai in an attempt to advance on its operational implementation particularly in Baalbek-Hermel and in Lebanon, in general. Specific encountered challenges, such as economic, societal, cultural, governmental, geopolitical, etc., made the integration of some of Sendai Framework general objectives and norms inapplicable without adaptation to the local context. The employed approaches can also serve research requirements and management needs in many other developing countries worldwide, starting to develop their own DRR plans with limited amounts of detailed data and financial resources. Through its multiple case studies, this dissertation answered the challenge of "how to put GIS and RS to better use for DRR in Baalbek-Hermel in particular, and in Lebanon in general?" by covering each and every phase of the DRR cycle and highlighting the application of geospatial data. The need and use of geospatial information and GIS for prevention, mitigation, preparedness, response planning and recovery was clearly pinpointed.

Main Achievements

Geospatial data is often lacking in developing countries, and Baalbek-Hermel, which hampers the DRR efforts. The lack of data required non-conventional methodologies for data acquisition and a down-scaling approach. This study explored an aerial interpolation method, the dasymetric mapping technique, for estimating nighttime and daytime population density. Raster based models of nighttime and daytime population were constructed in a GIS with a 50-meter resolution. Considerable differences were found between the derived daytime and nighttime population datasets. Daytime populations in downtown census tracts Baalbek city were found to be 46% greater than the nighttime populations. These differences could have profound impacts on exposure assessments and emergency management decisions. The value of the models for exposure assessments is significant; especially that population distribution is at the core of risk assessments, mitigation, preparedness, and response and recovery measures.

On the other hand, this dissertation explored the use of GIS-based numerical models and R-NetSwan function (Network Strengths and Weaknesses Analysis) to evaluate Baalbek-Hermel's road network internal dependencies (known as components interdependency) and thus revealed its vulnerability/criticality and tested its resilience in the face of natural hazards. The results revealed that Baalbek-Hermel's road network is well meshed and moderately vulnerable with a good level of redundancy, especially in urban areas and that earthquake is the most aggressive hazard on the network, causing the highest connectivity loss percentages. The analysis of the road network is useful to assist first responders in identifying critical roads and bypasses, implementing protection and for stakeholders to strengthen measures for the identified critical nodes and conducting strategies for an efficient distribution of the first responders' centers and hospitals.

A specific composite Index of School Vulnerability (ScVI) was additionally created by highlighting a multi-criteria aggregation method of relative vulnerability indicators using principal component analysis (PCA) and geographical information system (GIS). The goal of ScVI was to identify, quantify and classify the vulnerability of schools in a comparative way in which the vulnerability scores of schools are given relative to each other. This index, which includes school characteristics that do not depend directly on the hazard parameters, could be thereby applied to all natural hazards. The results indicated that 21 % of schools in Baalbek-Hermel are highly vulnerable to natural hazards and therefore their retrofitting should be seriously considered and prioritized. Findings can be used in different ways to decrease Baalbek-Hermel schools' vulnerability and protect children. The results may also solve the problem of limited resources by prioritizing the actions to be carried out in each school.

Furthermore, a simple but detailed methodology was proposed for estimating the risk and losses to agricultural sectors, in an innovative approach combining community-based and retrospective assessments and considering spatio-temporal dimensions. Baalbek-Hermel's agricultural risk profile and agricultural subsectors risk profiles were revealed by prioritizing agricultural risks and by the establishment of seasonal agricultural risk calendar and multi-hazard agricultural risk maps. Automated systems created through Python scripting language to facilitate complex geospatial calculations provides new opportunities for in-depth rapid analyses during damage assessment in the aftermath and enhance compensation procedures. The evidence generated through the study will help in prioritizing risks on the agricultural sectors level in Baalbek-Hermel. These findings should mainstream agricultural risk reduction and management into Baalbek-Hermel agricultural policy and investment plans.

This dissertation developed, based on GIS, a pedestrian evacuation in Ras-Baalbek floodplain by estimating the potential pedestrian evacuation time to safety, proposing vertical-evacuation buildings to reduce this time and organizing the evacuation accordingly with the implementation of evacuation signs. The methodology employed anisotropic least-cost-distance (LCD) modelling and exploratory geospatial analysis approaches that required a large amount of high-resolution data. The resulting maps of pedestrian-evacuation travel time to safe grounds ranged from less than a minute to more than 13 minutes in some locations, exceeding the flash flood arrival time estimated at 10 minutes. "Hotspots of evacuation" zones were disclosed where more than 12% would not reach safety at the time of flash floods arrival. Flood Vertical Evacuation FVE1 and FVE2 reduced this percentage to its half and to its quarter respectively (from 12% to 6% to 3%). Accordingly, as, the main purpose of evacuation is to plan for evacuation and route evacuees to the nearest road that would allow for a quick departure before the arrival of flash floods, evacuation signs were proposed to be integrated on roads. This permanent signage will maintain a culture of the risk in Ras-Baalbek, reinforce public education and awareness of flood risk and help the community to become more prepared and even more resilient. These pedestrian evacuation-modelling results have multiple preparedness implications and application to flood-evacuation outreach, educating and training (for the community, emergency managers, community planners and first responders to understand likely evacuation corridors), response procedures, mitigation (reducing the risk or even the loss of life of people living in Ras-Baalbek high flood risk areas), and long-term land use/land cover planning to increase Ras-Baalbek community resilience. One of their most important applications is to initiate Ras-Baalbek population to self-evacuate and prepare and plan for this evacuation. Moreover, the elaborated evacuation model can serve as a decision-support tool through comparisons of vertical evacuation options.

Moreover, a macroscopic evacuation routing model in case of foreshock in high-earthquake zones was also planned. The foreshock evacuation process takes place on impulse, many evacuees will pick the same paths and will most probably bring traffic to a standstill. Therefore, planning comprehensive interventions for a safer, faster and more effective emergency evacuation was necessary. Results concluded that an unplanned evacuation would take more than 148 minutes and high traffic congestions, while a Capacity Aware Shortest Path Evacuation (CASPER) would achieve far better with an evacuation time of less than 64 minutes, using most of the same road segments and predicting traffic congestion and road segment delays more accurately. The CASPER models' outputs provided an evacuation plan, the time required for evacuation, the areas of highest congestion and shelters allocation, showing the authorities and the people the safest routes to take away from the crisis. The findings emphasized the significant role of a managed evacuation strategy in disaster preparedness measures. The selection and agreement upon evacuation routes and plans are a decision of local authorities. Enhancing the accessibility of the evacuation origin sources or the expansion of certain roads to reduce travel times, are also decisions to be accounted for.

Last and not least, this dissertation also highlighted the role of GIS in boosting DRR governance by discussing recovery from the perspective of land-use planning and highlighting the importance of spatial planning for better land occupations suitability and development controls to build back better in the aftermath of a disaster. Land-use zoning ordinance is a multi-disciplinary approach. Monitoring and analyzing LU/LC temporal patterns of Al-Assi floodplain revealed that although Al-Assi River has flooded several times in the past and caused tremendous damage and losses, no land use planning exists so far. Recoveries were often unplanned and lead to reconstruction of same structures at same locations. An optimal LULC planning matrix that can be implemented to recover by control flood risks arising from occupation of the floodplain was developed. This matrix demarcates areas by degree of flood hazard (low, moderate and high) and link them to appropriate, safe, and permissible land uses and controls where necessary. The proposed land use planning measures focused on minimizing unplanned development in the floodplain, reducing water runoff through development controls for flood risk mitigation, mitigating damages from unavoidable floods and accommodating urban growth and expansion in flood-safe areas (resettlement and reconstruction during recovery). Through spatial planning, GIS serve as a decision-making and risk communication support tool; scientifically-based land-use zoning ordinance are claimed to convince municipalities and locals of implementation, communicate risk and spread the culture of "*living with risk*", strengthen social cohesion. Living with floods through land use planning is believed to increase public awareness and thus resilience.

Gaps

Although this dissertation, through its several case studies, answers "how to put GIS and RS to better use for DRR in Baalbek-Hermel and in Lebanon in general", knowledge gaps and challenges remain and are omnipresent.

The field of risk (something that may or may not happen) necessarily entails uncertainty which is an inherent part of every phase of the DRR cycle. DRR actions in Baalbek-Hermel, as for other regions in developing countries, often present a conundrum, where risk assessments and their main findings, on which the majority of DRR efforts are based, are hampered by governing bodies, low level of risk culture among the society and lack of crucial information. Societal challenges behind mitigating hazards reside in the uncertainty of the latters. These uncertainties form a considerable debate, especially about the acceptable level of risk when considering the costs of associated mitigation measures. These uncertainties faced during this dissertation, presenting many challenges and leading to an increase of vulnerability to natural disaster in Baalbek-Hermel, resided in:

- Prioritization by governing bodies having multiple consequences (lack of data, hampering implementation of DRR efforts, etc.). In the specific case of Baalbek-Hermel and Lebanon, missing data can basically reflect lack of political will or even conflict-laden political issues technical studies are unable to solve. For instance, religious factionalism and the perilous equilibrium of Lebanese politics are responsible of the lack of accurate census, because population count is a controversial political issue. On the other hand, even when data exists, it is either fragmented, uncompleted, outdated, unclear or duplicated due to the prevailing conservative perception in terms of data and information sharing. Unclear tenure and contentious land ownership is also believed to be a consequence of certain political measures. Furthermore, effective risk governance requires strong leadership and political implication. Lebanese politicians may be reluctant in investing in DRR efforts, imposing laws, encouraging natural disasters insurance and enforcing cooperation and coordination among all DRR actors.
- Lack of means (expertise, money, etc.) generating hazard, exposure, vulnerability and risk uncertainties. The natural randomness of hazards and the fact that information and understanding of hazard, exposure and vulnerability is yet incomplete, along with climate change uncertainties, all contribute cumulative uncertainties. Modelling vulnerabilities and hazards impact in Baalbek-Hermel was found to be the most complex, requiring expertise and high resolution and detailed data. The retrospective assessment of agricultural vulnerability adopted

in this dissertation and based on claims data losses may lead to outdated vulnerability information; past losses are not necessarily always identical to future. It is clear that vulnerability assessments need to keep pace with lifestyle changes, urbanization, building standards, infrastructure and changes in climatic patterns. This uncertainty is cumulated and exacerbated at each subsequent stage of a risk assessment, from hazard till the production of the final risk.

- No scientific methodology nor reliability in losses estimation and recording. It is important to be aware that the resolution and the reliability of claims and compensations are not totally accurate, especially in developing countries. Considering that in the majority of these countries as it is in Lebanon, no scientific methodology is adopted for damage estimation and some corruptions do exist, there are exaggerations in some cases in order to get more money out of compensations and underestimation also in others where the poorest have illegal properties and therefore don't get any governmental compensations. Moreover, no insurance data is available since no insurance system covers natural disasters losses. Thus, loss estimations may entail considerable uncertainties.
- Lack of population awareness to risk leading to challenges in communicating the findings. While the importance of risk assessments and their findings and deliverables to increase resilience was acknowledged worldwide, tackling the exposed and vulnerable societies, groups or regions is to be done carefully, especially in Baalbek-Hermel where there is an obvious lack of risk culture and awareness. Effectively, different reactions to mapping exposure and vulnerabilities and pointing them out could be observed. For instance, the public schools that were found out highly vulnerable based on the multi-hazard School Vulnerability Index (ScVI) developed in this dissertation, if not carefully introduced may cause a panic for the parents of the enrolled students. In other cases, proprietary of some assets pointed out as vulnerable may feel offended. Therefore, the meaning of the risk information provided on this type of maps needs to be clear and adequately explained to the public and effectively communicated in a way to serve constructive discussion and the implementations of measures to increase resilience. Moreover, some people would neglect the proposed evacuation plans, refuse to stick to them, or oppose to the installation of evacuation signs on their lands, thinking it may decrease its real-estate value. This evoked low awareness level would also lead to societal unacceptance and under-estimate of the proposed land-use planning.

Perspectives

Further research prospect from this dissertation perspectives involve, but are not limited to the following:

a) To enhance the obtained population distribution

- More precise temporal distribution of populations work places and day occupations,
- More precise temporal distribution of populations commuting between work, schools, retails and home, i.e., hourly distribution with the traffic component of the population,

- More precise temporal distribution of populations in weekends and holidays, i.e. hotels, etc.
- More precise data about different demographic groups and their distribution (age groups, disables, etc…).

b) To improve the resilience assessment of the road network:

- Connectivity loss is just one part of the problem. In case of crisis, the degree of detour is another consequence of node suppression in redundant graphs. Even with redundancy, the loss of connectivity can result in extensive detour that leading to major loss of time for emergency services that could prove critical to disaster response.

c) To strengthen the agricultural risk assessment and its implementation:

- Need to develop and periodically update digital maps of the cultivated specie in every parcel of land, at every time of the year.

- Baalbek-Hermel's agricultural sectors, on which the Governorate's economy mainly relies, were observed to be perpetually exposed to risk. Therefore, there is a need to put more emphasis on long-term structural solutions and non-structural solutions, rather than rapid and short-term response actions in order to enhance the resilience of the agricultural sectors. The design and implementation of an efficient agricultural risk reduction plan will need: substantial financial investments, support to decentralized decision-making at the community- and farm-level, integrating agricultural risk reduction into existing and new development frameworks, prioritizing agricultural risks in agricultural strategies and focusing on implementation. Accordingly, the proposed recommendations cover solutions for 1) **mitigation** (measures to avoid on decrease the exposure and/or vulnerability, and/or potential losses; for instance, using the deliverables of this dissertation to raise awareness among farmers), 2) **transfer** (transfer of risk to a consenting party for a fee or a premium; encourage insurance that cover agricultural risks), and 3) **coping** (activities designed to help cope with losses; governmental help). It is important to emphasize that most of these potential interventions are of a complementary nature and that most of them are needed to effectively manage agricultural risks in Baalbek-Hermel.

d) To ameliorate the evacuation planning:

- More detailed data about population is required,
- Multi-disciplinary approach, linking social experts (for behavioral analysis) with engineers (to study the response of roads to natural hazards),
- Develop detailed multi-risk assessment of roads to be able to predict their response to hazards,

- Develop larger-scale multi-risk assessment (i.e. earthquake micro-zoning) involving cascading events to reveal secondary hazards or triggered hazards.

e) For a more efficient land-use zoning proposal:

- Flood-informed land-use planning, not only on the scale of a floodplain, but at the watershed level; this level is believed to be more efficient in reducing flood hazard frequency and intensity but may face more implementation challenges,
- Development of digital land properties maps and clear tenure maps. This would require the strengthening and clarifying of land rights by the Lebanese Government.

f) It is also important to work on developing a national database that involves information about all sectors, hazards and regions, in a way that fosters all actors' contribution. This national database should be continuously updated.

g) The development of complete multi-risk, multi-sectoral assessments at the local level of a land parcel and continuous update, implementing cascading effects in multi-risk assessments.

h) To develop the near real-time use of GIS technology during disaster response emergency in Lebanon and developing countries.

i) Linking DRR to climate change is essential to keep pace with ever-changing hazards due to global warming and to reveal the degree climate change impacts and modify the intensity, frequency and footprints of natural hazards. This linkage has been done but on a regional scale (MENA level). Down-scaling is not completely accurate; further studies, on lager scales (national and sub-national levels) must be developed.

French Summary:

Cette thèse est la première du genre au Liban sur le thème de la réduction des risques de catastrophe à l'aide de techniques de SIG et de télédétection. Dans une perspective de recherche appliquée, cette thèse est venue répondre au cadre théorique de Sendai pour tenter de faire avancer sa mise en œuvre opérationnelle, en particulier à Baalbek-Hermel et au Liban en général. Des problèmes spécifiques rencontrés, tels qu'économiques, sociétaux, culturels, gouvernementaux, géopolitiques, etc., ont rendu l'intégration de certains objectifs et normes généraux du Cadre de Sendai inapplicable sans adaptation au contexte local. Les approches utilisées peuvent également répondre aux besoins en matière de recherche et de gestion de nombreux autres pays en développement dans le monde, en commençant à élaborer leurs propres plans de RRC avec des quantités limitées de données détaillées et de ressources financières.

À travers ses multiples études de cas, cette thèse a répondu au défi suivant: «Comment mieux utiliser les SIG pour la réduction des risques de catastrophe à Baalbek-Hermel en particulier, et au Liban en général?» tout en couvrant toutes les phases du cycle de la réduction des risques de catastrophe et en soulignant l'application des données géospatiales. La nécessité et l'utilisation des informations géospatiales et des SIG pour la prévention, l'atténuation, la préparation, la planification des interventions et la récupération ont été clairement identifiées.

Thesis Scientific Contribution

A number of publications have been produced in the context of this work. All prepared and submitted articles are summarized as follows:

a) Der Sarkissian, R., Abdallah, C., Zaninetti, J.M., 2019. Examining the operational aspect of pedestrian evacuation modelling in Mediterranean data-sparse regions, A case study of the Ras-Baalbek flash floods–Lebanon. International journal of Risk Analysis. Wiley Online Library. (Under review)
b) Der Sarkissian, R., Abdallah, C., Zaninetti, J.M., 2019. Developing a multi-hazard School Vulnerability Index (ScVI) using Principal Component Analysis (PCA) in conjunction with GIS. Journal of Risk Research. Routledge Taylor & Francis. (Under review).
c) Der Sarkissian, R., Abdallah, C., Zaninetti, J.M., 2019. Preparing an emergency evacuation plan: examining the operational aspect of Capacity-Aware Shortest Path Evacuation Routing (CASPER) Algorithm. GeoRisk Journal. Routledge Taylor & Francis. (Under review).
d) Der Sarkissian, R., Abdallah, C., Zaninetti, J.M., Najem, S., 2019. Modelling intra-dependencies to assess road network resilience to natural hazards. Earth Science Informatics Journal. Springer. (Under review).
e) Der Sarkissian, R., Abdallah, C., Zaninetti, J.M., 2019. Implementing Land-Use Planning to Post-Flood Recovery. *Disaster Prevention and Management Journal. Emerald Group. (Under review)*

In addition to these articles, oral communications and posters of the thesis work were presented in international conferences. These interventions are summed up as follows:

a) Abdallah, C., Der Sarkissian, R., Najem, S., Faour, G., 2018 Hazard and risk assessment for the Ministry of Education and Higher Education (MEHE) in Lebanon. General Assembly (EGU), 11/4/2018, Vienna, Austria. Geophysical Research Abstracts; Vol. 18, EGU2018-2439, 2018. (Accepted abstract)

b) Abdallah, C., Termos, S Der Sarkissian, R., Sadek, T., 2018. Climate change and disaster risk reduction in the Arab region: linkage of climate extreme events and disaster frequencies using stochastic geospatial models. General Assembly (EGU), 11/4/2018, Vienna, Austria. Geophysical Research Abstracts; Vol. 18, EGU2018-2456, 2018. (Accepted abstract)

c) Der Sarkissian, R., Zaninetti, J.M., Abdallah, C., 2019. Approche prédictive pour l'évaluation de la résilience des réseaux d'infrastructures critiques aux risques naturels, axée sur le réseau routier de Baalbek-Hermel (Liban). Assise National des Risques Naturels (ANRN)-2019. (Oral presentation + poster+ published abstract)

d) Der Sarkissian, R., Zaninetti, J.M., Abdallah, C., 2019. Adaptive contribution to Intelligent Dasymetric mapping for estimation of daytime and nighttime populations at risk from natural disasters, case study Baalbek-Hermel-Lebanon. General Assembly (EGU), 9/4/2019, Vienna, Austria. Geophysical Research Abstracts; Vol. 21, EGU2019-3555-2, 2019. (Oral presentation + published abstract)

e) Abdallah, C., Der Sarkissian, R., Darwich, T., Faour, G., Saade, S., Koshoev, M., 2019. Assessing agricultural risk in Lebanon combining retrospective and community-based approaches with temporal dimensions implementation. General Assembly (EGU), 12/4/2019, Vienna, Austria. Geophysical Research Abstracts; Vol. 21, EGU2019-3533, 2019. (Oral presentation + published abstract)

A. Appendix: Seasonal crop calendar

Crop name	Crop cycle			Number of days for each phase						Kc		
	Plant Date	Harvest Date	Number of days for the complete cycle	Init	Dev	Mid	Late	H (meters)	Sr (meters)	Init	Mid	End
Potato (early)	**early March**	**July**	**140**	30	35	40	35	0.6	0,4-0,6	0.5	1.15	0.75
Potato (late)	**July**	**October**	**120**	25	30	35	30	0.6	0,4-0,6	0.5	1.15	0.75
Wheat (Winter Wheat)	**November - December**	**June - July (next year)**	**240**	30	140	40	30	1	1,5-1,8	0,4-0,7	1.15	0,25-0,4
Peach - Apricot	**March**	**May - June**	**110**	25	35	30	20	3	1-2	0.45	0.9	0.65
Olive	**March**	**November - December**	**270**	30	90	60	90	3-5	1,2-1,7	0.65	0.7	0.7
Apple - Pear	**March**	**May - June**	**110**	20	30	40	20	4	1-2	0.45	0.95	0.7
Tomato	**late April**	**early October**	**145**	30	40	45	30	0,6 -1,5	0,7-1,5	0.6	1,0-1,1	0,70 - 0,90
Green Bean	**late August**	**November**	**75**	15	25	25	10	0.4	0,5-0,70	0.5	1,05-1,15	0.9
Bean (generical)	**March - April**	**June - August**	**95**	15	25	35	20	0.4	0,6-0,9	0.4	1,15-1,20	0.9
Corn (early)	**April**	**August**	**150**	30	40	50	30	2	1,0-1,7	0.3	1.2	0,60 - 0,35
Corn (late)	**July**	**November**	**120**	20	30	45	25	2	1,0-1,7	0,3-0,5	1,05-1,2	0,55-0,6
Watermelon	**May**	**August**	**80**	10	20	20	30	0.4	0,8-1,5	0.4	1	0.75
Sunflower	**late April**	**September**	**130**	25	35	45	25	2	0,8-1,5	0.35	1.0-1,15	0.35
Barley	**November**	**February**	**120**	15	25	50	30	1	1,0-1,5	0.3	1.15	0.25
Lettuce (early)	**late February**	**June**	**100**	25	35	30	10	0.3	0,3-0,5	0.7	1	0.95
Lettuce (late)	**May**	**August**	**60**	15	25	10	10	0.3	0.3-0.5	0.7	1,1	0.95
Cucumber (Summer)	**March**	**June**	**105**	20	30	40	15	0.6 -1.5	0,7-1,2	0.6	1,00 - 1,15	0.75
Cucumber (Winter)	**September**	**January**	**130**	25	35	50	20	0.6 -1.5	0,7-1,2	0.6	1,00 - 1,15	0.75
Gombo	**May - June**	**July - August**	**60-120**	15	30	35	30	1	0.5-0.75	0.4	0.9-1.1	0.75
Sweet Pepper (Summer)	**April - June**	**August - October**	**135**	25 - 30	35	40	25	0.7	0,5-1,0	0.6	1,05 - 1,15	0.9
Sweet Pepper (Winter)	**October**	**April**	**210**	30	40	110	30	0.7	0,5-1,0	0.6	1,05 - 1,15	0.9
Zucchini (Winter)	**April - May**	**June - July**	**100**	25	35	25	15	0.3	0,6-1,0	0.5	0.95	0.75
Zucchini (Summer)	**May - June**		**90**	20	30	25	15	0.3	0,6-1,0	0.5	0.95	0.75
Egg Plant (Winter)	**October**	**February**	**130**	30	40	40	20	0.8	0,7-1,2	0.6	1.05	0.9
Egg Plant (Summer)	**May - June**	**September - October**	**140**	30	45	40	25	0.8	0,7-1,2	0.6	1.05	0.9
Parsley	**March**	**December**	**270**					0.4	0.3-0.5	0.7	1	0.7
Alfalfa	**November**	**April (1st cut)**	**100**	10	15	15	60	0.7	3	0.4	1.2	1.15
Melon	**April - May**	**July**	120	20	40	35	25	0.5	0.6	0.6	1.1	0.8
Sesame	**June**	**October**	**100**	20	30	40	20	1	1,0-1,5	0.35	1.1	0.25
Lupin	**Decermber - January**	**June - July**	210	30	90	60	30	0.5	0.6	0.4	0.9	0.6
Yellow Pea	**March - April**	**July**	**100**	20	30	35	15	0.5	0,6-1	0.5	1.15	1,10 -0,3

B. Appendix: Questionnaires for crops, Heat wave example

Heat waves/موجات الحرّ																					
											Agricultural damage/المزروعات المتضررة										
إقترحات و توصيات؟ & Comments/ recommendations	وصفها ومدى فعاليتها؟ / EWS description and efficiency	هل من أنظمة للإنذار المبكر؟ Any EWS/	التدابير المتخذة/ Procedures	تكلفة التعافي/ Recovery cost	طرق وأساليب التعافي/ Recovery techniques	وقت التعافي/ Recovery time	الأضرار المادية/ Financial cost	تكلفة الإنتاج والمتر المربع والصيانة/ Production cost construction- & Maintenance loss	وصف مفصّل للأضرار/ Damages description	هل تضررت الأرض والتربة؟/ Any soil damage	قدرة على الإنتاج مجددًا أو تلف إنتاج موسم كامل/ Ability to produce again or the production of a full damage season	نسبة تضرر النبتة ذاتها/ Damage ratio of the plants	المساحات المتضررة/ Damaged areas	مرحلة النمو G/ rowth	نوعها t/ ype	المنشآت المتضررة Damag/ ed structures	الشدة Mag/ nitude	وصفها Desc/ ription	المدة/ Duration	المنطقة/ Location	التاريخ DAT/ E

C. Appendix: Questionnaires for Livestock sector, Cold wave example

Cold waves/موجات الصقيع																
										Damage to Livestock/تضرُر الماشية						
إقترحات و توصيات؟ & Comments/ recommendations	وصفها ومدى فعاليتها؟ / EWS description and efficiency	هل من أنظمة للإنذار المبكر؟ Any EWS/	التدابير المتخذة/ Procedures	تكلفة التعافي/ Recovery cost	طرق وأساليب التعافي/ Recovery techniques	وقت التعافي / Recovery time	الأضرار المادية/ Financial cost	تكلفة الإنتاج والمتر المربع والصيانة/ & Production cost construction- loss Maintenance	وصف مفصَّل للأضرار/ Damages description	قدرة على الإنتاج مجددًا أو تلف مطلق و كامل/ Ability to produce again or the production damage	عدد و نوع المواشي المتضررة/ Damage to Livestock	مرحلة النمو Gr/ owth	نوعها t/ype	المنشآت المتضررة Damag/ ed structures	الشدة Ma/ gnitude	وصفها Des/ cription	المدة/ Duration	المنطقة/ Location	التاريخ/ DATE

D. Appendix: Questionnaires for Aquaculture sector, Flood example

Floods/الفيضانات																			
										Damage to Aquaculture farms/تضرُر قطاع تربية الأسماك									
إقترحات و توصيات؟ & Comments/ recommendations	وصفها ومدى فعاليتها؟ / EWS description and efficiency	هل من أنظمة للإنذار المبكر؟ Any EWS/	التدابير المتخذة/ Procedures	تكلفة التعافي/ Recovery cost	طرق وأساليب التعافي/ Recovery techniques	وقت التعافي / Recovery time	الأضرار المادية/ Financial cost	تكلفة الإنتاج والمتر المربع والصيانة/ & Production cost construction-loss Maintenance	وصف مفصّل للأضرار/ Damages description	قدرة على الإنتاج مجددًا أو تلف مطلق و كامل/ Ability to produce again or the production damage	عدد و نوع السمك المتضررة/Damage to Fish	مرحلة النمو Gr/owth	نوعها t/ype	المنشآت المتضررة Damag/ed structures	الشدة Ma/gnitude	وصفها Des/cription	المدة/ Duration	المنطقة/ Loc/ation	التاريخ/D/ATE

E. Appendix: Questionnaires for Fisheries sector, Storms example

Storms/العواصف																					
											تضرُر الثروة السمكية و الزوارق/ Damage to fish resources & fishing boats										
إقترحات و توصيات؟ & Comments/ recommendations	وصفها ومدى فعاليتها؟ / EWS description and efficiency	هل من أنظمة للإنذار المبكر؟ Any EWS/	التدابير المتخذة / Procedures	تكلفة التعافي/ Recovery cost	طرق وأساليب التعافي/ Recovery techniques	وقت التعافي/ Recovery time	الأضرار المادية/ Financial cost	تكلفة الإنتاج والمتر المربع والصيانة/ & Production cost construction-loss Maintenance	وصف مفصّل للأضرار/ Damages description		عدد الزوارق المتضررة/ Damage to Fishing boats				نوعها ty/pe	المنشآت والمعدات المتضررة Damage/d structures	الشدة Mag/nitude	وصفها Desc/ription	المدة / Duration	المنطقة/ Location	التاريخ/ DATE

F. Appendix: Questionnaires for Forestry sector, Forest Fires example

Forest Fires/حرائق الغابات																			
										Damage to Beekeeping, pine nuts production, wood collection and charcoal production / تضرُر قفران النحل، إنتاج خشب الصنوبر، جمع الأخشاب وإنتاج الفحم النباتي									
إقترحات و توصيات؟ & Comments/ recommendations	وصفها ومدى فعاليتها؟ EWS / description and efficiency	هل من أنظمة للإنذار المبكر؟ / Any EWS	التدابير المتخذة/ Procedures	تكلفة التعافي/ Recovery cost	طرق وأساليب التعافي/ Recovery techniques	وقت التعافي/ Recovery time	الأضرار المادية/ Financial cost	تكلفة الإنتاج والمتر المربع والصيانة/ Production cost construction- & Maintenance loss	وصف مفصَّل للأضرار/ Damages description	قدرة على الإنتاج مجددًا أو تلف مطلق و كامل/ Ability to produce again the production or damage	عدد و نوع ألأشجار المتضررة/ Damage to Forest	مرحلة النمو Growt/h	نوعها type/	المنشآت المتضررة Dama/ged structures	الشدة Ma/gnitude	وصفها De/scription	المدة/ Duration	المنطقة/ Location	التاريخ/ DATE

G.Appendix: Questionnaires for Schools' assessment

Schools/المدارس													
حوادث سابقة/ Past events	خطط الإخلاء/ Evacuation plans	مصدرها من المياه/ Water supply	مصدرها من الطاقة/ Power supply	عمليات الصيانة/Maintenance	مواد البناء/ Construction material	عدد المخارج/ Number of exits	عدد الطوابق/ Number of floors	معايير البناء/ Building codes	وضع المبنى/ Present situation	عدد الموظفين/ Number of employees	عدد التلاميذ/ Number of students	المنطقة Location/	المدرسة School/

H. Appendix: Crop growth function for each crop category relatively to climatic zones

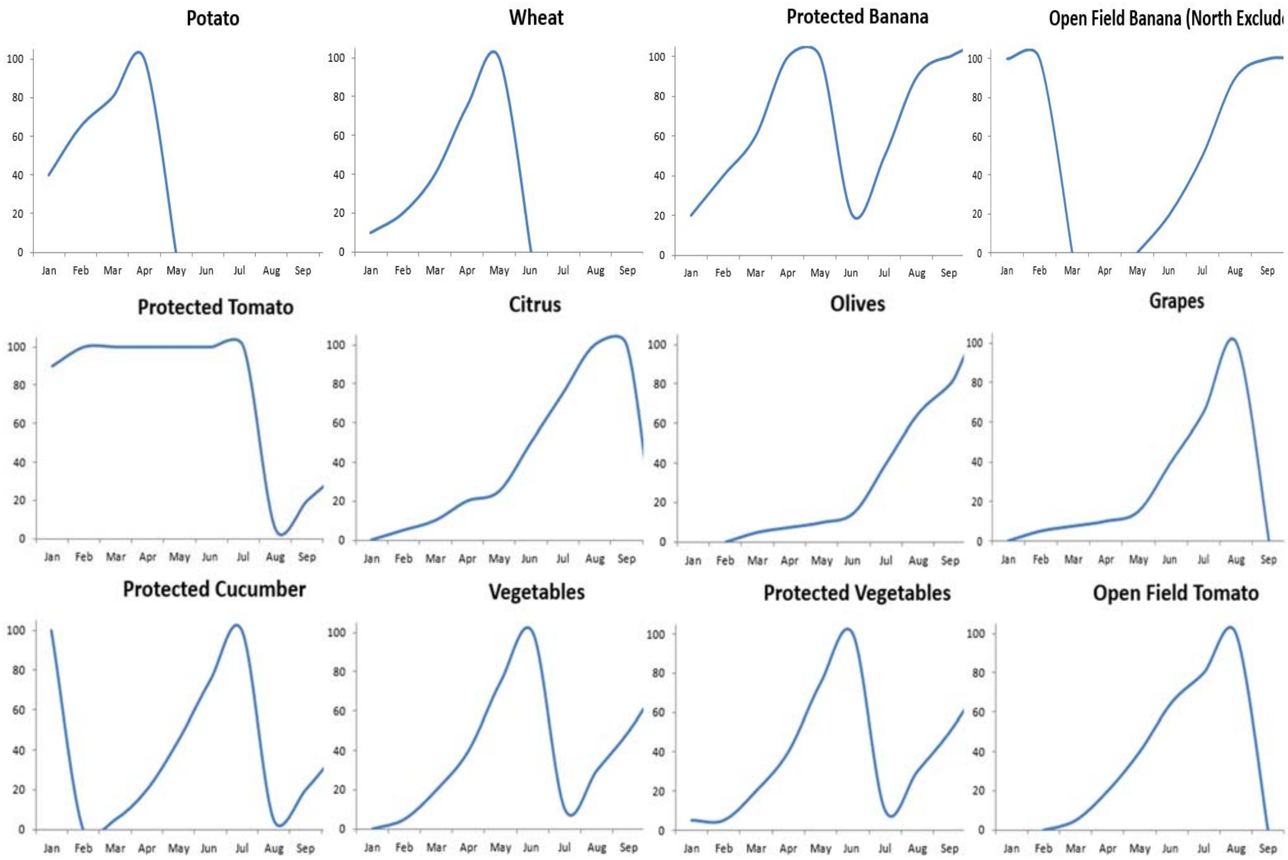
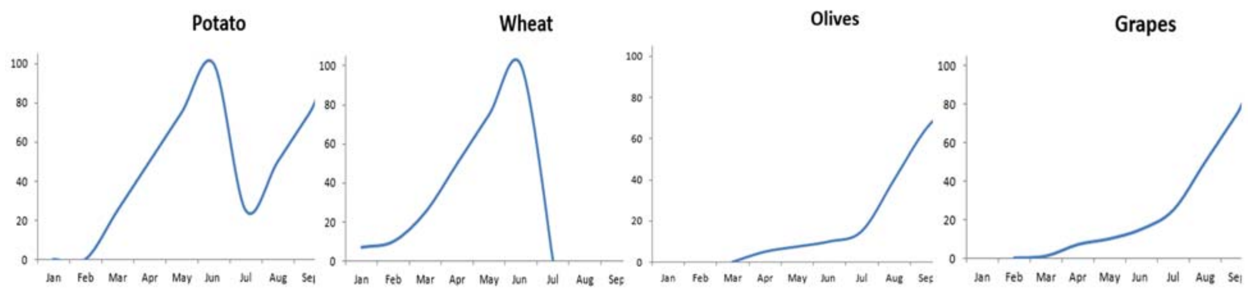


Figure H-1 Crop growth function for each crop category in Coastal area.



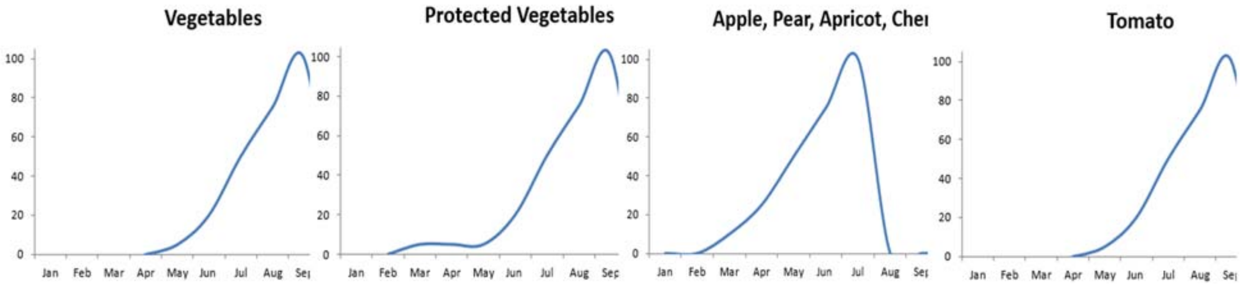


Figure H-2 Crop growth function for each crop category in High mountain area.

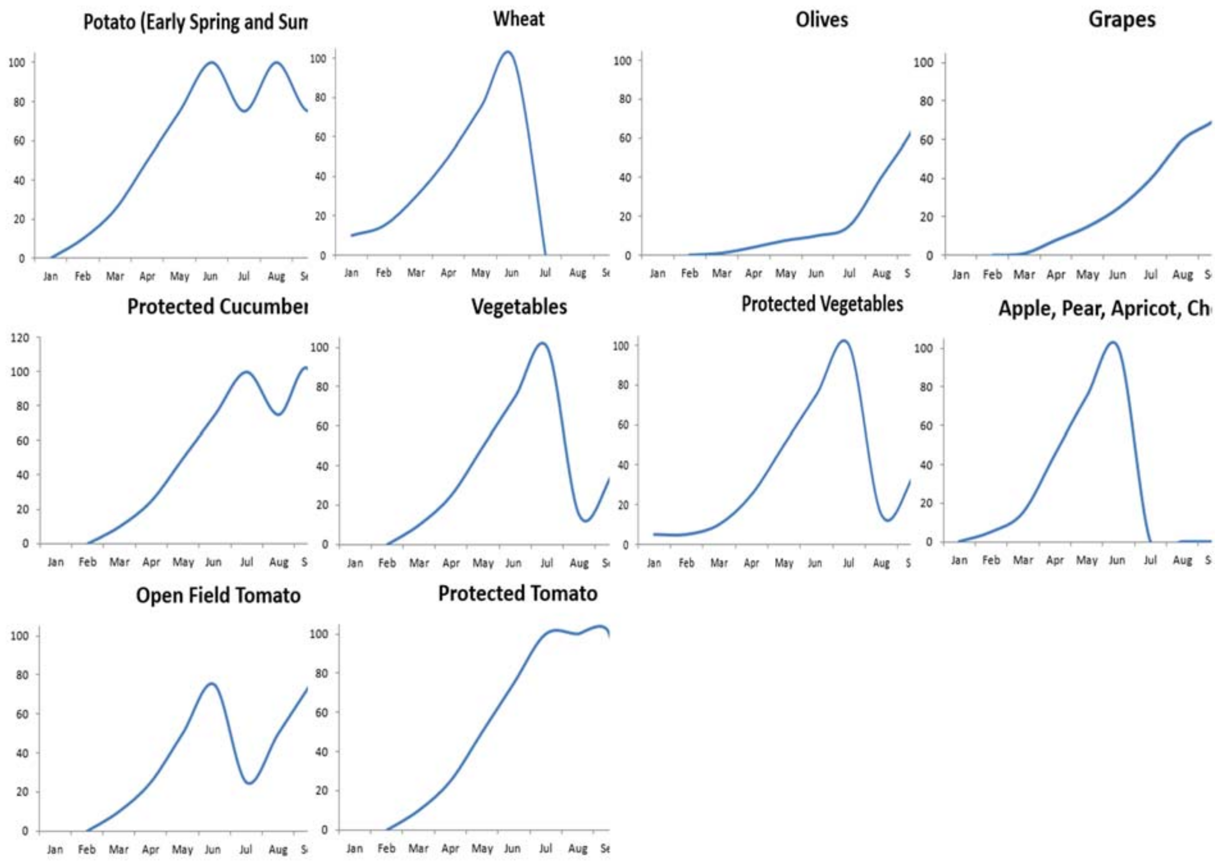


Figure H-3 Crop growth function for each crop category in Central & West Bekaa, inland area.

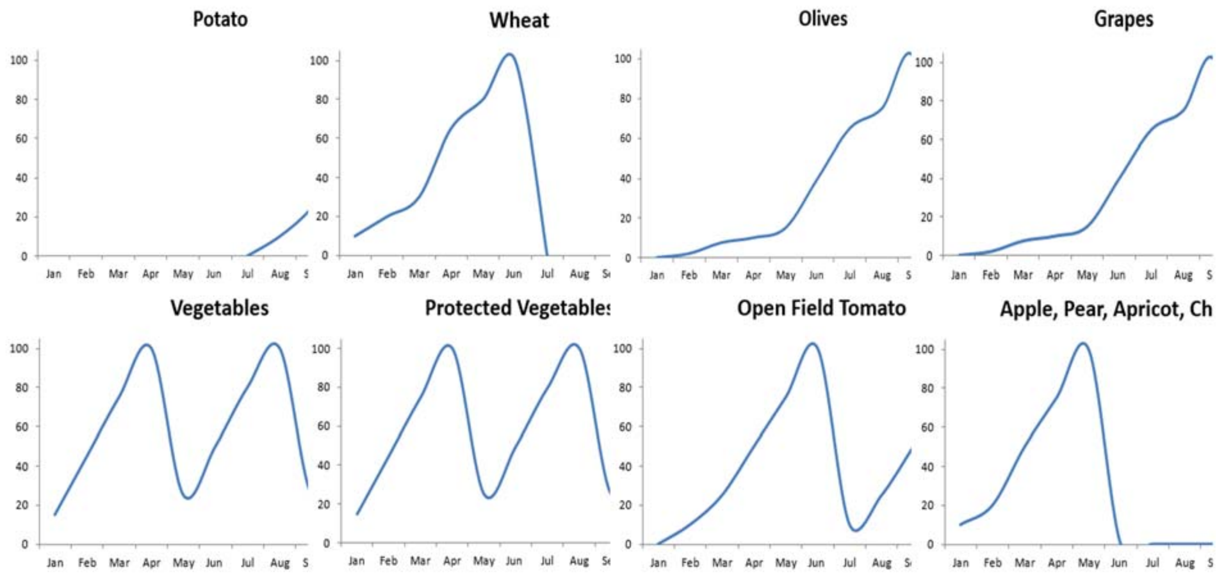


Figure H-4 Crop growth function for each crop category in North Bekaa, inland area.

I. Appendix: Pictures taken during meetings and field work

Figure 0I-1.Urban settlements in Baalbek-Hermel (Fekehe)/Photo taken during population distribution on-field validation. 03/08/2018

Figure 0I-2Field surveys supported by the Lebanese Red Cross DRM unit (Qaa).17/08/2018

Figure 0I-3 Meeting with the farmers during the community-based agricultural risk assessment field surveys (Baalbek).05/01/2018

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