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Faculty of Graduate Studies

Towards More Resilient Transportation Network against Natural Hazards in Nablus City, Palestine

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Dedication

"To my first inspiration .. My mother .. Ekhlass"

"To my first teacher .. My father .. Fawaz"

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I hope you will enjoy reading my thesis as much as I have enjoyed writing it.

الاقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

Towards More Resilient Transportation Network against Natural Hazards in Nablus City, Palestine

نحو شبكة مواصلات أكثر قدرة على الصمود في مواجهة الأخطار الطبيعية في مدينة نابلس، فلسطين

أقر بأن ماشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص ،باستثناء ماتمت الإشارة إليه حيث ماورد، وإن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة عملية أو لقب علمياً وبحثي لدى أية مؤسسة تعليمية أو بحثيةأخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name: **اسم الطالبة:**

Signature: **التوقيع:**

Date: **التاريخ:**

List of Abbreviations

CDEM	Civil Defense Emergency Management
CI	Critical Infrastructure
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
HI	Hazard Identification
MASL	Meters Above Sea Level
MPWH	Ministry of Public Works and Housing
NIAC	National Infrastructure Advisory Council
NIU	National Infrastructure Unit
PMS	Palestinian Meteorological Station
RS	Richter Scale
UNISDR	United Nations International Strategy for Disaster Reduction
USDHS	United States Department of Homeland Security
VTPI	Victoria Transport Policy Institute

Table of Contents

List of Tables

List of Figures

List of Appendices

Towards More Resilient Transportation Network against Natural Hazards in Nablus City, Palestine

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Abstract

The resilience of transportation networks as part of any community's critical infrastructure has been a topic of interest and an important field representing a new way of understanding and managing the safety of these networks when exposing to any disruption event in the past few decades.

The major objective of this thesis is to qualitatively assess the resilience of Nablus City transportation network at a macro-scale level against the potential natural hazards that the city would be exposed to, through developing an assessment framework. This ranges from the most severe hazard, which is the earthquake, the least probable hazard, which is the snowing hazard, and reaching to the most probable hazard, which is the intensive rainfalls that could lead to flooding events, in addition to the probable land sliding triggered events as natural hazards have a cascading nature.

Surface transportation networks in Palestine are considered as substantial and crucial part of Palestinian integrated critical infrastructures system as these networks are the only way for traveling between and within Palestinian cities for providing emergency and relief services.

The geographical location of Nablus City made certain peculiarity for the city in terms of location. This peculiarity reflected on the transportation network of Nablus City, as in most cases have narrow roads running a long side the mountains. Because of the steep grades on the mountainous areas, most of the roads in these areas have no access to other parallel roads, which means that the closure of one link during disruption events may cause other links to be inaccessible in the same area. Therefore, the process of evacuation and emergency response through these events will encounter serious difficulties.

The process of assessing the resilience for Nablus City transport networks was divided into three main phases: conceptualization, risk assessment, which forms a major part of the resilience assessment, and resilience assessment. Through these phases, the desired level of resilience for each identified hazard was measured, then spreadsheets including a range of specific measures related to each resilience dimension were developed to assess the current level of resilience for the transportation network.

Based on the results, Nablus City transportation infrastructure has a moderate level of resilience against natural hazards. While the desired level of resilience against seismic hazard for it must be very high resilience, and a high to moderate level of resilience must exist against flooding and snowing hazards. This means interventions and improvements are needed to increase the level of resilience against these hazards to reach the desired level.

The weaknesses that resulted in decreasing the existing level of resilience were explored through the assessment spreadsheets. This helps the decision makers to start mobilizing the efforts to set priorities on which aspects they would start working on to improve the current situation of the network.

Finally, methods on how to increase the level of resilience against each hazard were also proposed through prevention, mitigation, and adaptation measures. This includes establishing disaster preparedness, coping, and management plans, building a national platform database for every natural hazard, and increasing and promoting knowledge, risk wise behavior, and awareness towards such events.

Chapter One

Introduction

Chapter One
Introduction

1.1 Background

Over the past decades, there have been many changes that have created great challenges around the world. The change in earth's climate is one of the major challenging changes of our time, which was significantly witnessed on the global level and the world is on a race to limit the climate change impact and consequences that could affect all aspects of our lives.

The implications of the climate change rise the concentration towards on how the governments and communities should respond to this phenomena in order to minimize the potential adverse impacts resulted from the potential natural hazards associated with it, and to build and increase the resilience of every community to be able to cope with the resulted impacts of these natural hazards, which should be on several levels. The utmost important level in building resilience is to increase the resilience of community's Critical Infrastructures (CIs), because these infrastructure systems of all kinds are essential for day-to-day life as they constitute the backbone of any nation's economy, security, and health. They must be secure and able to withstand the adverse effect of any potential natural hazards and rapidly recover from them because natural hazards have the potential to strike any geographical location with or without warning.

The resilience of transportation networks as part of any community's CI have been a topic of interest and an important field representing a new way of understanding and managing the safety of these networks in the past few decades. The performance of any transportation networks under a specific disruption event summit the need to study the concept of resilience, which highly overlaps with risk assessment and risk management studies.

The State of Palestine as part of the Middle East, has particularly high levels of climate vulnerability (UNDP, 2011). As a result, the Palestinian territory is subjected to many serious changes such as changes in annual rainfall, increase in mean temperature and sea level rise, reduction on the cold periods and more warmer periods, and increasing the probability of hydrological events like floods, meteorological events like snowing and heat waves, and climatological events like droughts (IPCC, 2014).

The surface transportation infrastructure in the West Bank – Palestine, which forms approximately a total length of 3783.6 km of highways (PCBS, 2018), is subject to significant vulnerabilities including the escalating threats of natural hazards resulted from climate change and its consequences.

The integrity and safety of the Palestinian transportation networks ensure providing the essential services that support the society to maintain functioning properly and also affect the entire population if disturbed. They are considered as substantial and crucial part of Palestinian integrated CIs system as these networks are the only way for traveling between and within

Palestinian cities. They form the basic emergency networks to support evacuation, emergency response, relief, and recovery operations during any disruptive event; thus, disruption in these networks may have severe consequences in cases of disasters. Achieving this in Palestine will require efforts to strengthen and maintain secure, functioning, and resilient transport infrastructures through integration with national and local readiness system across prevention, protection, mitigation, response, and recovery.

There are several attempts around the world to suggest and develop methods for evaluating the resilience of transportation networks, which demonstrate the ability of these networks to maintain functionality with an acceptable level of service during a disturbing event and the ability to return quickly to normal operating conditions after the event. These studies emphasized the global trend of assessing the resilience of such networks. On the other hand, there are very limited studies, if any, that have been conducted regarding the resilience of the transportation networks when exposed to disturbed events in Palestine. Therefore, this research focuses on evaluating the resilience of a transportation network/infrastructure at a macro-scale level under natural hazards scenarios in Palestine with a case study from Nablus City.

1.2 Research Question

The main research question is: how to qualitatively assess the resilience of Nablus City transportation network at a macro-scale level under natural hazards scenarios. This will be done through answering four sub main questions related to the infrastructure resilience concept (resilience of what, resilience to what, what problem does it seek to solve, and how to increase it?) as will be discussed in the following chapters.

1.3 Research Significance

According to the United Nations Office for Disaster Risk Reduction (UNISDR, 2013): "Palestine is a highly vulnerable to natural hazard, mainly earthquakes, floods, landslides, droughts, and desertification. The whole region frequently faces small to mid-scale disasters and is vulnerable to large-scale urban disasters, triggered by seismic activity and climate change."

The region of Palestine in the past decades suffered from natural hazards of different kinds. There are many factors that help in the region's vulnerability to such disasters:-

1. The State of Palestine as part of the Middle East, has particularly high levels of climate vulnerability (UNDP, 2011). As a result Palestinian territories are subjected to many potential serious changes on all levels and increasing on the probability of natural hazards occurrence. Because of that, Palestinian territories must have sufficient capacities and readiness to cope with these changes and their consequences.

2. Palestine is considered as a natural disaster prone-area particularly earthquakes and local site effect such as landslides, as it is located in an

active seismic zone, specifically at the junction of two platelets of the earth's crust, along the dead sea rift, which is known as the Syrian-African rift. This could expose Palestine with high probability to a devastating earthquake (Dabbeek, 2010).

3. Palestine suffers from weakness in planning adoption and implementation that resulted in rapid population growth, which causes random urban expansion. This gives a vision about the way the cities are developing in Palestine, as more than 50% of the Palestinian population lives in what is defined as hazard-prone area (Hawajri, 2016).

4. The weakness of land use planning and policy and the inadequate management of water resource and drainage system increased the vulnerability of flooding and landslides in the last years.

5. The weakness in the Palestinian CIs (transport infrastructure, water and wastewater infrastructures, etc.) because of the delay in procedures relating to the planning process and poor control of these existing infrastructures especially in the light of the current political situation, the limited sources, and the lack of maintenance for decades made them inferior to quality.

6. There is an urgent need to build the resilience of Palestinian communities to increase the communities' capacities to cope with disasters at all levels. This could be done through identifying and emphasizing on the preparedness and mitigation measures, and through

increasing the knowledge and the awareness towards such events (Dabbeek, 2010).

7. The geographical location of Nablus City made certain peculiarity for the city in terms of location. This peculiarity reflected on the transportation network of Nablus City, as in most cases has narrow roads running a long side the mountains. Because of the steep grades on the mountainous areas, most of the roads in these areas have no access to other parallel roads, which means that the closure of one link during disruption events may cause other links to be inaccessible in the same area. Therefore, the process of evacuation and emergency response through these events will encounter serious difficulties.

All these factors increase the vulnerability of Palestinian cities to natural hazards. The effect of these natural hazards can reach all types of essential infrastructures, which if damaged or disturbed during or after the hazard will cause a large amount of losses to all aspects of life. One of these CIs in Palestine that must guarantee the normal flow during a hazard is the transportation infrastructure because it is considered as the basic emergency network that forms the most important way to reach safe places and will help the process of rescuing people during any disruptive event. Thus, the safety and the ability of this critical network to withstand the adverse effects of any natural hazards reflect the resiliency of the network. Therefore, it is important to study and understand the resiliency behavior of transportation networks existing in Palestine.

Another important factor that emphasizes the significance of this study is the absence of this kind of studies in Palestine. If such studies are available, they could help in limiting and decreasing the adverse effect of any disruptive event that is likely to occur in Palestinian areas. They also will help in providing a comprehensive picture for the decision makers to choose appropriate emergency actions, feasible solutions, and improvement strategies for the current situation of the existing transportation network in Nablus City.

1.4 Research Objectives

The concept of resilience includes a wide range of dimensions that can be studied to reach desired results; this research concentrates on the following major objectives:

1. Identify the main natural hazards that Nablus City in Palestine would be exposed to, and assessing the risk associated with every type and their direct effects and expected consequences on the transportation network of Nablus City.

2. Identify characteristics that determine the resilience of Nablus City transportation network.

3. Develop a framework to measure the resilience of transport infrastructure at a macro-scale level under natural hazards scenarios, which is practical and feasible to implement, with a case study from Nablus City. This will help in discovering the weaknesses in the

transport infrastructure in Nablus City through understanding of the current situation.

4. By understanding the current situation and related consequences of the potential natural hazards, appropriate mitigation and adaptation measures will be proposed. This will provide decision makers with the required tools to make pre-event decision that can improve the resilience of the network against natural hazards.

5. Increase awareness and understanding of resilience challenges.

1.5 Study Area

Nablus City is selected as the study area; Nablus is a major city in the middle of the West Bank, Palestine. It is considered as the largest commercial and cultural center in Palestine. It is located 60 Km to the north of Jerusalem with an altitude between 600-800 meters above mean sea level. It has a population of 156,906 inhabitants (PCBS, 2018).

Nablus City, like other parts of Palestine, is suffering from the Israeli occupation. It has four main exits and surrounded by 13 Israeli settlements, which prevent the urban and the population expansion of the city and separate it from the rest of the surroundings governorates and villages.

In 2013, Nablus City became the first Palestinian city to join UNISDR's Making Cities Resilient Campaign. In this project, cities are supported to carry out a resilience stock take using the Disaster Resilience Scorecard for Cities and work with local government and non-government partners to develop local disaster risk reduction strategies. The Scorecard also assists countries and local governments in monitoring and reviewing progress in implementing the Sendai Framework for Disaster Risk Reduction 2015-2030; the globally agreed roadmap for reducing the impact of disasters on lives and livelihoods. For Nablus, this takes place in an extremely challenging environment including extreme political instability and an effectively constant emergency state (Preventionweb, 2019).

The transportation network of Nablus City will be studied under the scenarios of the following natural hazards that could occur and highly affecting it: seismic hazard, snowing hazard, intensive rainfalls, which could lead to flooding hazard, in addition to the probable land sliding triggered events as natural hazards have a cascading nature.

1.6 Geopolitical Conditions of Nablus City

The geographical location of Nablus made certain peculiarity for the city in terms of location, because it is considered as a linear city that is located in a valley between two mountains: Mount Ebal to the north and Mount Gerizim to the south.

The total area of Nablus City is 29 km^2, the total built area is about 8.7 km^2, which represents 30% of total area of the city (Nablus Municipality, 2019). The total area of Nablus transportation network is 6.4 Km^2, which constitutes approximately 22.1% from the total area of the city (Nablus Municipality, 2019).

According to the Oslo II Interim Agreement signed in 1995 by the Palestinian Liberation Organization (PLO) and Israel, Nablus was divided into Area A, B and C. Approximately 62% of the city's total area was assigned as Area A, 21% as Area B, and 17% as Area C. In Area C, Israel retains full control over the security and administration of the territory Palestinian. Also building and land management is prohibited unless through the consent or authorization of the Israeli Civil Administration. The majority of Nablus' population resides in Areas A and B, while most of the land lying within Area C is open space and agricultural land located on the southern side of the city (ARIJ, 2014).

Settlements, camps, and Israeli military checkpoints surround the city from all sides. An Israeli military base overlooks the city from above Mount Gerizim and Mount Eibal. These military bases also have been a source of attacks and abuses against Palestinian citizens.

Israeli authorities established a number of military checkpoints located on and around Nablus City territory. These included permanent and temporary flying checkpoints, iron gates, concrete block barriers, earth mound barriers, and observation towers. Among the most important permanent checkpoints that have been set up are Huwwara and Za'tara checkpoints, located on the south side of the city.

Checkpoints continue to hinder freedom of movement and sever the links between Nablus City and the surrounding villages, as well as the connection between the villages and their agricultural lands. This has resulted in heavy economic losses for residents of Nablus as they are forced to travel further distances, which takes more time, in order to reach their agricultural land, especially when checkpoints are closed.

Israeli occupation authorities have established many bypass roads that stretch thousands of kilometers from the north to the south, confiscating hundreds of agricultural and non-agricultural lands in order to link Israeli settlements with each other. It should be noted that the real danger of the bypass roads lies in the confiscated land that was taken for the benefit of what is known as the buffer zone. The buffer zone is imposed by the Israeli army and usually occupies 75 meters on both sides of the road (ARIJ, 2014).

Nablus City was a refuge for thousands of Palestinians who were displaced from several areas of Palestine in 1948. These refugees were absorbed into three camps; Balata Refugee Camp, ‘Askar Refugee Camp, and 'Ein Beit El Ma Refugee Camp. These three camps currently occupy an area of about 2% of the total area of Nablus City with a population of more than 50,000 (about 30% of the city's population). As well as the difficult humanitarian situation, high poverty rates, unemployment, overpopulation, and deteriorating environmental situation, the refugees have been subjected to invasions, arrests, and closures of checkpoints since the Second Intifada (ARIJ, 2014).

1.7 Research Outline

This thesis is composed of six chapters, which are as follows:

Chapter one includes the background for this research, the significance of the research, the objectives, and finally description of the study area.

Chapter two presents a review from the literature about definitions and the main dimensions and principles for the main concept of this research, which is the infrastructure resilience and on how to measure the resilience of transportation infrastructure. This is presented through explanation for the main steps of this process, which highly overlaps with risk assessment and management.

Chapter three clarifies the adopted methodology used to reach the desired objectives through presenting data collection methods and data analysis techniques.

Chapter four illustrates the collection and integration of data about past events for each type of natural hazard happened in Palestine in general, and particularly in Nablus City through observing the trend for each type.

Chapter five presents data analysis and discusses the results and the outputs. This chapter basically is divided into three main sections, in the first section the basic concepts of resilience is determined. In the second section a risk assessment process for the three main natural hazards is carried out in order to determine the desired level of resilience, which results from the risk level. While in the third section, the transportation infrastructure resilience is measured through determining the suitable dimensions of resilience to be measured, then developing spreadsheets containing a number of measurement categories to reach for the overall resilience level. Then methods on how to build and increase the resilience will be illustrated. This chapter ends by summarizing the developed framework for assessing the resilience in this research.

Finally, chapter six provides the conclusions and recommendations for this study, and suggestions for future studies.

Chapter Two

Literature Review

Chapter Two
Literature Review

The resilience of the transportation infrastructure against natural hazards is the main topic of this research, which if applied in the field of engineering; the general terms that could be found in the literature are ‘transportation resilience’, ‘disaster resilience’, and ‘risk assessment’.

In this chapter, definitions of the essential concepts are presented, combined with a selected literature review of the pertinent researches related to the main concept of this thesis.

2.1 What is Resilience?

2.1.1 Defining Resilience

The term and the concept of resilience is routinely used in many fields, research, and disciplines ranging from environmental research to materials science and engineering, psychology, sociology, ecology, business, and economics. Despite this, the basic concept remains the same and no singular definition has been universally accepted.

The word ‘resilience’ originated from Latin ‘resilio’, composed by ‘re’ (again) and ‘salire’ (to spring, jump) and literally means ‘to bounce back’ (Gay and Sinha, 2013).

Holling (1973) was the first to define resilience in ecology as a measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.

Timmerman (1981) was one of the first authors who discussed resilience of society in the context of climate change and linked the concept to vulnerability. The author defined resilience as ‘elasticity’, or as the measure of a system’s or part of a system’s capacity to absorb and recover from the occurrence of a hazardous event.

Pimm (1984) and Haimes et al. (2008) introduced resilience concept differently; the authors highlighted the time and the cost as important factors for recovery for the system to return to its stability after a disturbance.

Since the beginning of the twenty first century, there has been a greater trend to address the definition of resilience by considerable international organizations. One of these organizations is the United States Department of Homeland Security (USDHS), which defined resilience more than once in several years. The last definition was in 2013, which stated that resilience is “the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents” (USDHS, 2013).

The National Infrastructure Unit (NIU) provided a definition within the national infrastructure plan, the proposed definition stated that “the concept of resilience is wider than natural disasters and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time” (NIU, 2012).

Another international organization that is highly concerned about the concept of resilience and how to increase the awareness about learning from past disasters for better future protection, and to improve risk reduction measures among all countries in the world is The United Nations International Strategy for Disaster Reduction (UNISDR). The definition proposed by this organization is “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, 2009).

Finally, the concept of resilience entered Disaster Risk Management (DRM), Disaster Risk Reduction (DRR), and climate change debate after the adoption of Hyogo Framework in 2005 (UNISDR, 2005). According to the international survey conducted by several contributors about resilience concept of CI; the adoption of the Hyogo Framework protocol, allows the resilience concept to gain new leverage and became a core concept when talking about man-made and natural disasters (Alheib et al., 2016).

2.1.2 Transportation Resilience

In recent years, hazards and disasters have an increasing impact on modern societies in terms of both economic and human losses. Following disasters, transportation networks act as key lifelines enabling access to the affected communities.

Transportation networks are identified as critical lifelines in cases of disasters for a number of reasons: first, the transportation system will support evacuation, emergency response, relief, and recovery operations. Second, the transportation network will remain the sole means for ensuring physical access to the affected communities. Third, transportation infrastructures are highly prone to disasters and therefore their capacity and serviceability will be reduced following a catastrophic event (Konstantinidou et al., 2014).

Prior to 1995, the term resilience was unknown in the transportation community. This language was first used when researchers and policymakers studying earthquakes and earthquake policy began applying the term resilience to communities and their CIs (water, communication, electric power, transportation, etc.) as they looked for ways to mitigate the impact from earthquakes (Fletcher and Ekern, 2016).

The concept of CI was defined according to USDHS (2013) as the nation's CI, which provides the essential services that underpin society and serve as the backbone of the nation's economy, security, and health. The CI is known as the power we use in our homes, the water we drink, the transportation that moves us, and the communication systems we rely on to stay in touch with friends and family. Transportation infrastructure is considered as one of those CI systems, which has been identified by the

USHDS as one of the sixteen CI systems essential to the well-being of modern societies (Zhang and Wang, 2016).

The previous definition of the transportation infrastructure has led to the definition of transportation infrastructure resilience. Research has been conducted concerning transportation resilience and definitions have been proposed. Transportation resilience is introduced by Heaslip et al. (2010) as the ability for the system to maintain its demonstrated level of service or to restore itself to that level of service in a specified timeframe, while Turnquist and Vurgin (2013) defined the resilience of transportation networks as the ability of the system to withstand, adapt, and rapidly recover from the effect of any potentially disruptive events.

Finally, Alsubaie et al. (2015) summarized the link between CI resilience definitions and other disciplines as well as the commonalities between them as shown in Figure 2.1.

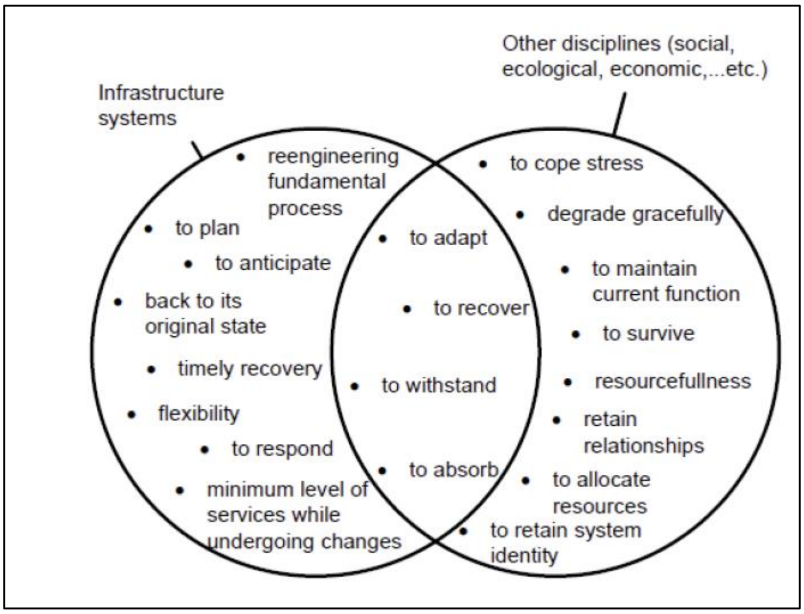

Figure (2.1): Resilience Concepts of CI and Relationship with Other Disciplines. Source: (Alsubaie et al., 2015)

2.1.3 Disaster Resilience

Resilience is not a new idea in the context of hazards and disasters. It is considered as the ultimate objective of hazard mitigation, that is, action taken to reduce or eliminate long-term risk to people and property from hazards and their effects (Godschalk, 2003).

The differences between the term 'disaster' and the term 'hazard' must be pointed out before explaining the concept of resilience in the disaster approach.

<u>Hazards & Disasters Identifications</u>

Hazard is "the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources" (IPCC, 2012).

While disaster is "a severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery" (IPCC, 2012).

The disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability, and insufficient capacity or measures to reduce the potential negative consequences of risk.

While the hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro-meteorological, and biological) or induced by human processes (environmental degradation and technological hazards) (UNISDR, 2004).

From the previous definitions, it’s concluded that hazards like earthquakes, landslides, or floods are not disasters themselves. Disaster occurs when a potential hazard strikes the elements at risk to that hazard. For example, landslide is a hazard and it turns into a disaster when there are presence of people and other elements like animals and properties in fragile condition, which are vulnerable to landslide (Sharma, 2014).

Disaster Resilience Identifications

In the past years, building resilience to disasters becomes priority for governments and local communities worldwide, because states around the world come to accept that they cannot prevent every risk from being realized, but rather must learn to adapt and manage risks in a way that minimizes impact on human and other systems. This emphasizes that the concept of disaster resilience has received considerable attention in recent years and it is increasingly used as an approach for understanding the dynamics of natural disaster systems (Cimellaro et al., 2011).

The topic of disaster resilience acquired an exponential increase across many different fields following a string of disasters such as the Loma Prieta earthquake in 1989, hurricane Katrina in 2005, the financial crisis in 2008, and the Tohoku earthquake in 2011 (Park et al., 2013).

In 2011, a workshop conducted by the National Research Council labeled Community Resilience Framework as one of five grand challenges in earthquake engineering, stating that such a framework also could advance our understanding of both the direct and indirect impacts of earthquakes so that community level interactions and impacts can be better characterized (Furtado, 2015).

Lastly, when talking about disasters, there are traditional approaches used in disaster management that help in understanding disaster resilience of any CI. These approaches are based on the 'disaster cycle', which is a conceptual model that is still used by many emergency management and civil protection organizations (see Figure 2.2: the disaster cycle). The cycle is divided into phases (before, during, and after disaster), each of which requires different forms of intervention (mitigation, preparedness, response, and recovery) (Alexander, 2002).

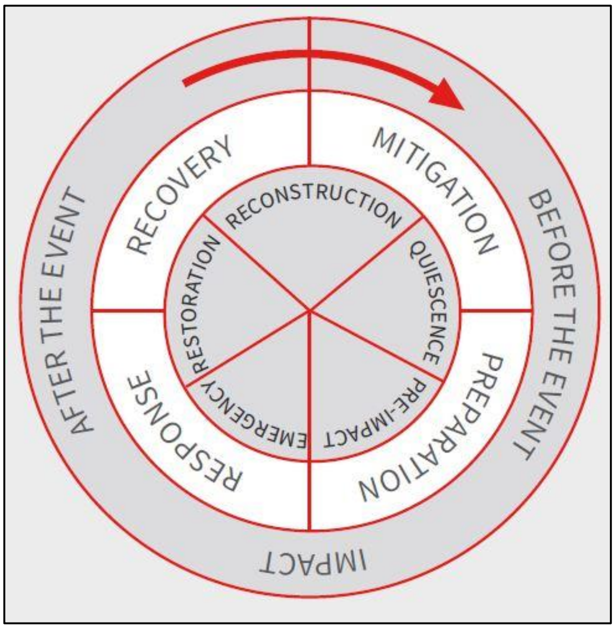

Figure (2.2): The Disaster Cycle

Source: (Alexander, 2002)

To conclude, hazards and disasters have always been a major concern for societies due to their impact on human life and activities. Hurricanes, floods, landslides, earthquakes, and other disruptive events may cause extended damages to infrastructures, loss of lives, and disruption of human activities. Thus, it affects the resiliency of the transportation infrastructures.

2.1.4 Risk, Resilience, and Vulnerability

The risk and resilience approaches are considered complementary and applicable in different circumstances. They are not considered mutually exclusive, and their use will depend on the context of the analysis being undertaken and the understanding of the relevant hazard (Hughes and Healy, 2014). The three terms (resilience, risk, and vulnerability) are fairly overlapping terms, which are widely used in the disasters and hazards assessment, management, and reduction approaches. The term resilience is clearly defined in the previous sections; risk and vulnerability are defined as follows:

- Risk is the possibility of damage or loss, which consists of 3 main elements: vulnerability, hazard, and exposure. Coppala (2007) stated that risk is the likelihood of an event multiplied by the consequence of that event. The term likelihood can be given as a probability or a frequency.

- Vulnerability is the degree of loss of certain elements at risk, which is caused by the natural phenomena of a given certain size (Thywissen, 2006). Based on Berdica (2002), the vulnerability of the road transport system relates to the incident, which may reduce the functionality of the road network.

Although the three terms are overlapping, there is still some key differences between them, which are introduced in the following two subsections.

2.1.4.1 Risk and Resilience

Resilience is founded upon good risk management; resilience is built up based on assessment, treatment, and monitoring and communication of risk (Zubieta, 2013).

Risk analysis is performed to give answer to three main questions, which are (Munier, 2014):

1. What can happen?
2. What is the probability of its occurrence?
3. If the event indeed, does happen, what are the consequences?

While in measuring resilience, among the literature reviewed, most of them raised a number of questions when talking about measuring the resilience of infrastructure systems, which are:

1. Resilience of what?
2. Resilience to what?

3. What problem does it seek to solve?

4. How to increase it?

Risk analysis is useful for estimating how much damage is expected to occur while resilience can help define, which aspects of a system are most critical to recovery (Furtado, 2015).

In short, there are some key differences in a risk-based approach versus a resilience approach, which are as follows:

- A risk-based approach looks to mitigate failure through probability and scenario-based analysis of known hazards. A resilience approach looks to minimize the consequences of failure through investigating scenarios with unidentified causes (Hughes and Healy, 2014).

- A risk-based approach would involve incrementally modifying existing designs in response to emerging hazards that means a risk-based approach would typically generate a 'fail-proof' design (able to withstand a range of known hazards), whereas a resilience approach would involve adapting to changing conditions, and potentially allowing controlled failure ('safe-to-fail' design) at a sub-system level to reduce the possibility of broader loss of function within the larger system (Park et al., 2013 and Snowden, 2011).

- The traditional risk-based design would result in a design that is resistant to hazards, a resilient design would embrace uncertainty and failure via anticipation and adaptation (Snowden, 2011).

2.1.4.2 Vulnerability and Resilience

The resilience of a system is sometimes viewed as an outcome of vulnerability; and it is considered as the flip side of the vulnerability. A system has a certain amount of vulnerability and resilience is the reaction to the events the system is vulnerable to. Other times, resilience is viewed as a process, which at least partially bears the responsibility of damage mitigation (Cutter et al., 2008).

According to Haimes (2008), the vulnerability assessment mainly contributes to a system's protection, whereas the resilience assessment goes beyond the system's protection and additionally includes system's recovery following extreme events. For example; the pre-event investment of hardening a system against region-specific hazards may reduce the vulnerability of the system, but if the recovery needs are not properly addressed, the resilience of the system in terms of recovery time and cost will not always be improved.

2.1.5 Dimensions and Principles of Resilience

To further understand transportation infrastructure resilience, researchers have developed a range of dimensions and principles of resilience. It is important to understand them in order to develop an appropriate approach for measuring and improving resilience.

The term dimensions in the resilience concept means the main characteristics and components that identified resilience in the field in which it will be analyzed.

Imran et. al (2014) proposed a holistic approach for measuring the transport resilience through exploring six key dimensions for transport infrastructure resilience, which are: engineering, services, ecological, social, economic, and institutional. It is suggested to achieve this framework to adopt multi-disciplinary approach based on expertise, techniques, and perspective from related professions such as engineering and economics.

A slightly different approach is adopted by Victoria Transport Policy Institute (VTPI, 2014); the dimensions of transport infrastructure resilience are broke down into five levels: individual, community, design, economic, and strategic planning.

Another example is that developed by Bruneau et al. (2003). They developed four dimensions of resilience: Technical, Organizational, Social, and Economic (TOSE). They noted that these four TOSE dimensions cannot be measured by any single performance measure; instead they require different measures for each system under analysis. Each of these dimensions is defined as follows (Bruneau et al., 2003 and Hughes and Healy, 2014):

- **Technical**: The technical dimension is the ability of the physical system to perform to an acceptable/desired level when subject to a hazard event.

- **Organizational**: This dimension refers to the capacity of institutions or organizations to manage the physical components of a system, plan and respond to a hazard event, and improve disaster related organizational performance and problem solving.

- **Social**: This dimension refers to the ability of a society to lessen the negative consequences due to loss of critical services following a disaster, by helping first responders or acting as a volunteer.

- **Economic**: This dimension is related to the capacity to reduce both direct and indirect costs that arise from disaster induced economic losses.

A review of Bruneau et al. study (2003) conducted by Hughes and Healy (2014) proposed that from the four TOSE dimensions, only the technical and organizational elements to be utilized in transportation infrastructure context. Because of the narrow focus on the transport system, the social and economic dimensions are implicitly considered as the network itself provides a vital social and economic service, and its technical or organizational resilience will inherently provide flow-on social and economic resilience.

While for identifying the main principals of resilience, a number of researchers have developed comprehensive lists of principles for achieving resilience, in which they are integrated into a conceptual framework to provide the resilience dimensions explained in the previous paragraphs, which means that each dimension is associated with one or more principle.

The Civil Defense Emergency Management (CDEM, 2005) established 4 main principles for achieving resilience, the recovery principle was added to the main principles of the comprehensive risk management which are reduction, readiness, and response in order to develop a holistic approach for achieving resilience. These principles are considered to be more applicable to the field of emergency management and the cycle before, during, and after an event than to a specific resilience assessment (Hughes and Healy, 2014).

Park et al. (2013) and Snowden (2011) proposed in their infrastructure resilience approaches the principle of ‘safe to fail’. This principle means when one component of the integral infrastructure system fails, it does this gradually with minimum disruption for other parts of the infrastructure or the network in order to minimize more probable catastrophic failures.

Safe to fail principle is an important mean to achieve technical resilience, because transportation system is characterized as a complex system or ‘system of systems’, because of the interdependencies between their several components, which could result in a wide range of possible failure modes when subjected to a disruption event (Hughes and Healy, 2014).

Bruneau et al. (2003) determined four principles for achieving resilience. Their research named these principles in term of 4 R’s: Robustness, Redundancy, Resourcefulness, and Rapidity. These are listed and defined as follows (Bruneau et al., 2003 and Zubieta, 2013).

- **Robustness**: The inherent strength or the capacity of any system to withstand and resist the impact of a triggering event that produces a given level of stress or demand without degradation or loss of functionality.

- **Redundancy**: Ability of a system to satisfy the functional requirements using alternate options, choices, and substitutions in the event of disruption or degradation which results in functionality losses or reduction.

- **Resourcefulness**: The ability to identify problems, establishes priorities, responds efficiently, and mobilizes required resources and services in emergencies circumstances to restore the system performance.

- **Rapidity**: The speed at which a system is able to bounce back, and safety, serviceability, and stability are re-achieved in order to reduce the magnitude of losses and avoid future disruptions.

The previous principles are highly concerned to the technical resilience, while regarding the organizational resilience, several researches were conducted to identify the main principles to define the resilient organization that are responsible to manage CI systems. Three core principles were identified, each of them has a range of indicator subsets, which are as following (REAG, 2011):

- **Leadership and culture**: this principle is related to the leadership capacity of an organization to manage and make decisions in time of any disruption event, and to the level of their staff awareness and engagement to improve resilience.

- **Networks**: this principle is related to the ability to establish external relationships and mutual aid arrangements in order to share knowledge, experiences, and resources with other stakeholders involved in crisis management.

- **Change readiness**: this principle is related to the ability to sense and anticipate hazards, identify problems and failures, develop a forewarning of disruption threats and their effects, the ability to adapt through redesign or planning and learn from the success or failure of previous adaptive strategies. It also relates to how the organization communicates to its members and train them to be ready to effectively respond at the time of the event and their detection to early warning signals.

2.1.6 Summary

Building resilience of CI is important to reduce vulnerabilities to natural hazards. Resilient transport infrastructure has adaptive properties that derive not only from the system's ability to absorb damages and disruptions, but its abilities for constructive change and learning. Resilience does not mean automatically bouncing back, fully resuming life as it was before adverse impacts of any disruption event. Instead, a resilient system is one that learns and adapts, can correct past errors, self-organizes, and shapes new solutions that minimize disruption events impacts.

The previous explanations help the researcher to develop an appropriate approach for selecting and identifying the most suitable dimensions and principles of resilience related to the case to be studied in this research.

To conclude, as mentioned in section 2.1.5, only the technical and organizational elements are to be utilized in measuring the resilience of transportation infrastructure. For the technical resilience, Bruneau et al. (2003) principles of robustness and redundancy are considered suitable for this research as the two other principles (resourcefulness and rapidity) proposed by them are implied within the organizational resilience. While the principle of safe to fail, which was proposed by Park et al. (2013) and Snowden (2011) is included as a third technical resilience principle.

For the organizational resilience, the three principles proposed by REAG (2011) are considered suitable for this research.

Summary of the chosen dimensions and principles are shown in Table (2.1).

Table (2.1): Adopted Dimensions and Principles for Transportation Infrastructure Resilience

Dimension	Principle	Definitions
Technical Bruneau et al. (2003), Park et al. (2013), and Snowden (2011)	Robustness	Section 2.1.5
	Redundancy	
	Safe to fail	
Organizational REAG (2011)	Leadership and culture	Section 2.1.5
	Networks	
	Change readiness	

2.2 Resilience Assessment

As shown in the previous sections, measuring resilience basically depends on the dimensions and principles identified for the case to be studied. Past studies and researches about transportation infrastructures resilience are generally divided to those, which developed a qualitative framework for measuring resilience, and to those which attempted to quantitatively measure the resilience.

Quantitative approaches are appropriate for narrow assessments of networks and systems, so they may lean to be less flexible, time consuming, and data intensive, which could be difficult to implement. While qualitative approaches can provide wider process, although they are more subject to interpretation but are flexible in terms of scale and context (Hughes & Healy, 2014).

As this research is concerned about assessing the resilience qualitatively at the macro-scale level, the following paragraphs will summarize the main topics that will help in qualitatively assessing the resilience of transportation infrastructures through answering the four main questions related to infrastructure resilience (resilience of what?, resilience to what?, what problem does it seek to solve?, and how to increase it?), and how the process of risk analysis forms a major part in this assessment.

It is known that there is a wide range of hazards types that could affect the transportation infrastructure system; therefore, a resilience assessment requires awareness that the hazard itself maybe unpredictable and this summits the need to think beyond typical disaster scenarios (Park et al., 2013)

In the transport context, there are some consequence scenarios that have been adapted, and considered applicable. These scenarios are specifically relate to the loss of service as well as other impacts. Which are as follows (Hughes & Healy, 2014).

- **Regional event**: which is related to the significant physical damage to transport infrastructure, coupled with severe disruptions to other lifeline services such as electricity, water, and telecommunications. An example of this type of event may be a major earthquake or flood.

- **Localized event**: a transport-specific incident resulting in loss of life, severe disruption to normal operations, and reputation impacts. Examples may be a collapse of a transport structure or a hazardous spill affecting the immediate locality.

- **Societal event**: a societal event, which may cause unexpected impacts or demand on the transport system. In this case, all physical infrastructure is intact; however, the transport system is unable to cope with demand. Such as; a surge in traffic demand due to a specific event, or a major gathering of people, growth in demand over time, growth in public transport demand due to, say, fuel price rises, and an illness pandemic (influenza or SARS), meaning operational staff are unavailable.

- **Distal event**: impacts transport operations through key suppliers or interdependencies. This consequence scenario can identify the ways the transport system and related organizations may be affected through its networks of inter-organizational relationships. Examples of this scenario could be the failure of a key dependent utility (power, telecommunications, or water), failure of a key supplier, or an international shortage of key resources.

Depending on these scenarios and the context of the evaluation, there are two approaches that can be used for resilience assessment and analyses, which are 'all hazards approach' vs. 'specific hazard approach', which are summarized in Figure (2.3) (Hughes & Healy, 2014).

- An all-hazards approach would involve a high-level assessment looking at resilience measures in response to all hazards in general, and would consider a relevant event scenario as detailed above (regional, local, societal, and distal).

- A specific-hazard approach would be more detailed and therefore might be appropriate for certain critical assets, which would involve identifying the complete range and type of potential scenarios, and assessing the risk of them occurring. The resilience assessment and response could then be tailored accordingly.

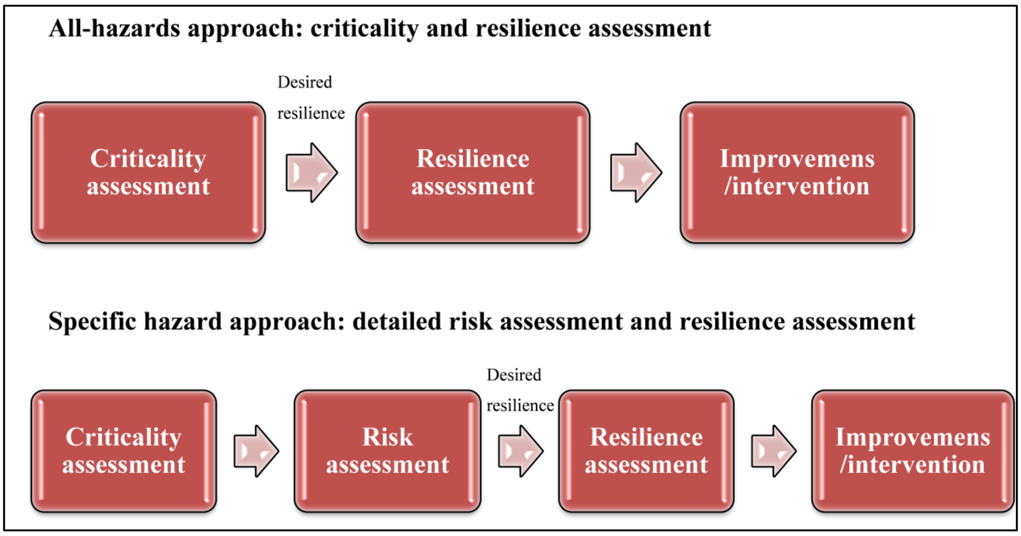

Figure (2.3): Two Alternative Approaches for Resilience Assessment

Source: (Hughes and Healy, 2014)

Figure (2.3) shows the steps to achieve the resilience assessment for CIs, in which the criticality assessment defines, which infrastructure should be assessed for resilience, and based on it the scale of assessment will be determined (regional, network, or asset). The following next steps determine the appropriate level of resilience for a given asset. It also shows that resilience assessment highly overlaps with risk management studies in the specific hazard approach. Because of that the risk assessment process is considered as the first step in assessing and building resilience, and the output of the risk assessment would determine the desired level of resilience. In specific words, the resultant risk level derived from a risk assessment could be translated to a desired level of resilience as shown in Table (2.2).

Table (2.2): Translation of Risk Score to Desired Level of Resilience

Risk level	Desired level of resilience	Definition of desired level of resilience
Extreme	Very high	Meet all requirements
High	High	Acceptable performance, some improvements could be made
Moderate	Moderate	Less than desirable performance, specific improvements should prioritized
Low	Low	Poor performance, improvements required

Source: (**Hughes and Healy, 2014**)

It should be clarified that risk management is performed out through 3 main steps; the first step is the risk analysis process, which consists of Hazard Identification (HI) process that identified the hazards and threats related to a system with the potential hazardous events, and the determination of causes and consequences which could be done through the Bow-tie model (Figure 2.4). The second step is the risk evaluation, which is the process of comparing the results of risk analysis with risk criteria to determine if the risk is acceptable or tolerable that could be done through the "Risk Matrices". These two steps when they are carried out in a joint process, the overall process is called the risk assessment. While the third and the last step is the risk control, which involves risk planning, risk mitigation, and risk monitoring (Rausand, 2011). Figure (2.5) summarizes all the steps of risk management.

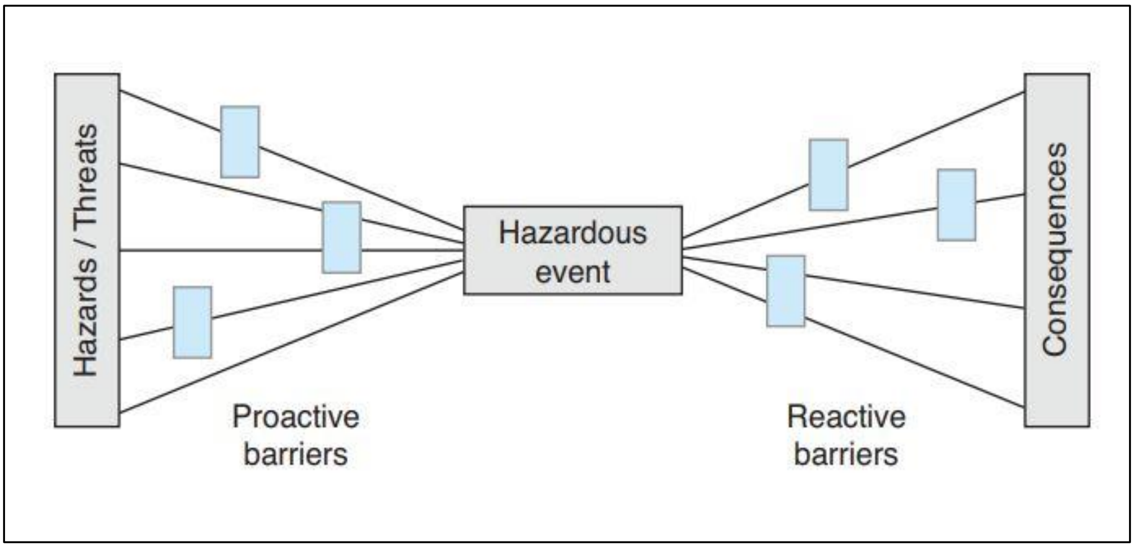

Figure (2.4): Bow-Tie Model

Source: (Rausand, 2011)

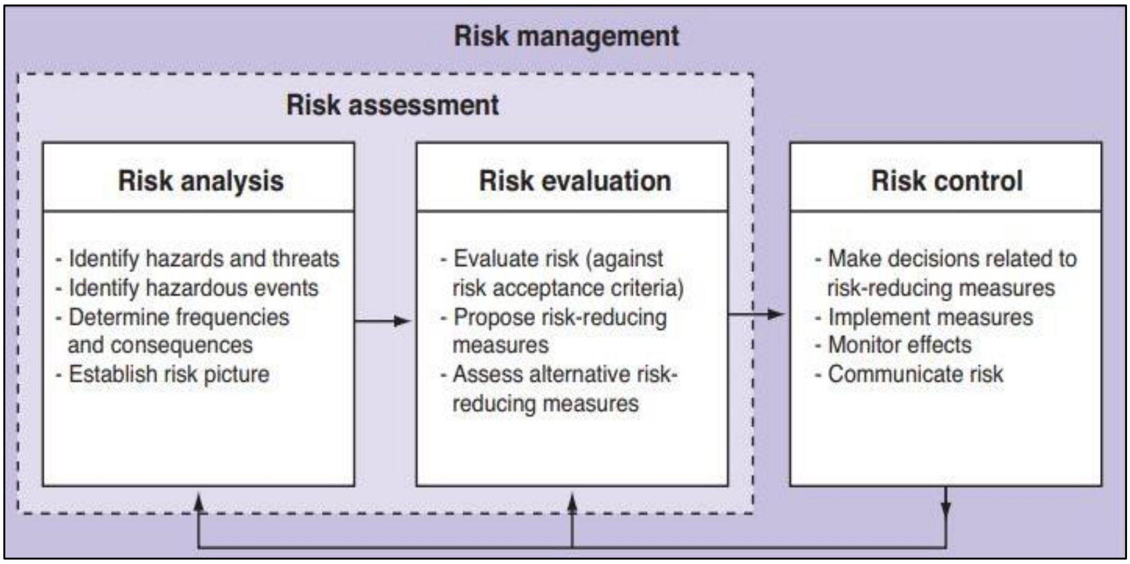

Figure (2.5): Risk Analysis, Evaluation, Assessment, and Management

Source: (Rausand, 2011)

Beside the previous research, many researches were conducted to develop frameworks for assessing resilience, examples are summarized in Table (2.3).

Table (2.3): Summary of Previously Proposed Frameworks for Assessing Resilience

Author	Proposed methodology
Murray-Tuite (2006)	Proposed metrics for evaluating the ten components of the transport infrastructure resiliency which are: redundancy, diversity, efficiency, autonomous components, strength, adaptability, collaboration, mobility, safety, and the ability to recover quickly and compares the system optimum and user equilibrium traffic assignments.
Brabhaharan (2006)	Developed a method to establish performance criteria by which elements of the transport system could be measured after an event. These were based on specific levels of service requirements following hazard events.
Heaslip et al. (2010)	Proposed a framework for assessing the resilience of the transportation networks, which called the 'resiliency cycle' that depends on four basic network performance indexes (network availability, network accessibility, traveller perception, and transportation cost). There are four stages in the resilience cycle: normality, breakdown, self-annealing, and recovery.
Mostashari et al. (2013)	Adopted a resilience measurement process that is called the Networked Infrastructure Resilience Assessment. The proposed framework allows decision-makers to assess the resiliency of networked infrastructure systems such as transportation networks from a multi-metric perspective. It consists of three stages of analysis, which are: boundary definition, resiliency assessment process, and resiliency scheme identification.
UNISDR (2017)	Developed a framework as a preliminary level assessment tool that called "Disaster Resilience Scorecard" to help any city to assess, understand, mitigate and respond to any disaster risk it may face, so that immediate and longer term loss of life or damages to property, infrastructures, and the environment is minimized. This Scorecard is structured around the ten essentials for making cities resilient, which offer a broad coverage for all the issues any cities need to undertake to build and maintain resilience which include the assessment of transport infrastructure which fall under infrastructure resilience assessment.

2.2.1 Summary

The previous section illustrated that there is a wide range of great attempts to assess the resilience of transportation infrastructure. Each is based on specific measures. This enables the researcher to understand the main points related to resilience of transportation network and the way it could be introduced and measured.

Literature reveals that there is an interrelated relationship between all the research specialized in the concept of assessing the resilience of CI systems, the outlines of the measurement and the terminology of estimating resilience are similar but the process of determining the specific measures differ according to the case to be studied.

Consequently, based on all that stated in the literature, the researcher set up the measures needed and the methods that will be adopted to perform this research, which are summarized in Table (2.4).

Table (2.4): Steps for Measuring Resilience of Transportation Infrastructure

Resilience assessment context			
Consequence scenario	**Approach**	**Scale of assessment**	**Shock/stress event**
Based on natural hazard type	The specific-hazard approach	Asset scale (transportation network)	Based on natural hazard type

Source: adopted from (Hughes & Healy, 2014)

Chapter Three

Methodology

Chapter Three

Methodology

3.1 Introduction

This chapter presents the methodology carried out in order to develop this research. The methodology is composed of three main phases: conceptualization, risk assessment, and resilience assessment. Within each phase, different research methods were applied to reach for the desired objectives of this research. Figure 3.1 describes the overall methodology.

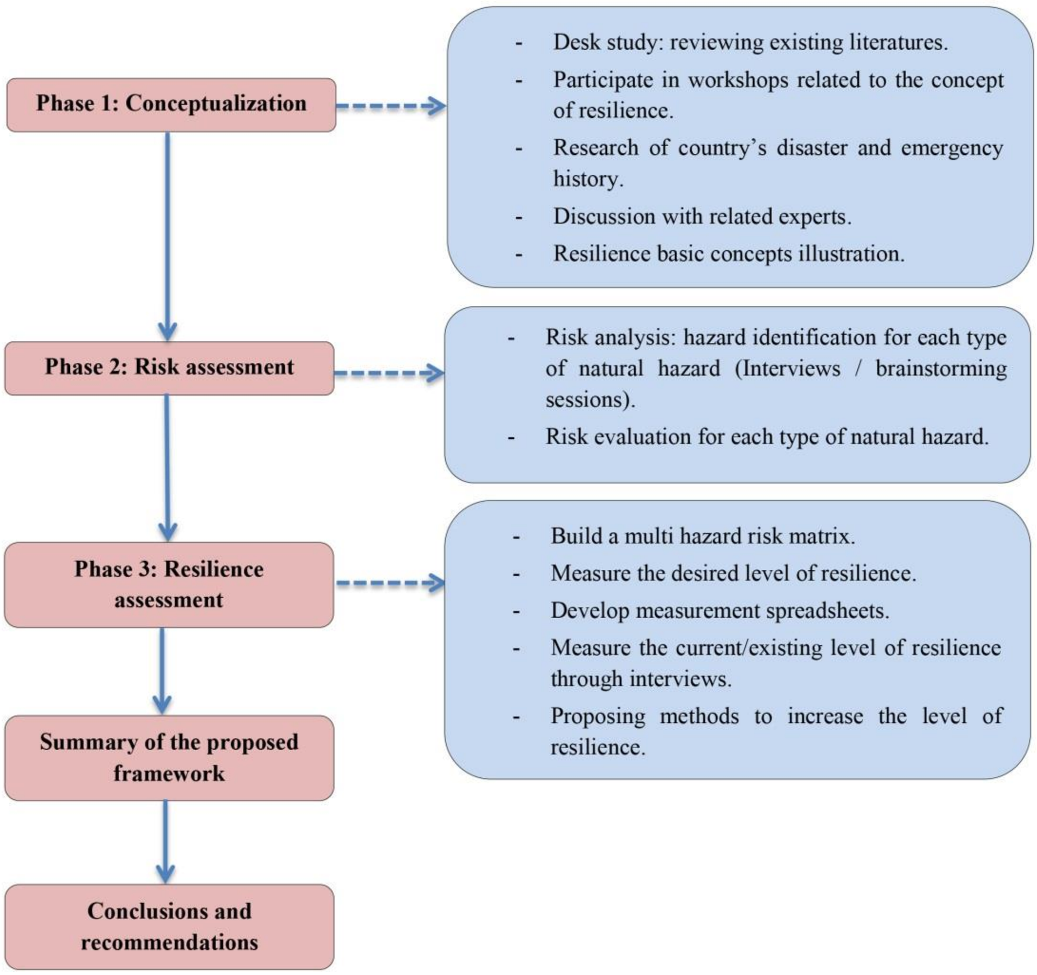

Figure (3.1): Methodology Flow Chart

3.2 Conceptualization

The first step in conducting any research is to perform a conceptual review about the main concept of the research. Through this phase three main steps were conducted as follows.

1. A review for the existing literature about the concept of resilience was conducted; this helps in understanding the global definitions of the word resilience in general and in the transportation context in specific, illustrating the main dimensions and principles related to it, and help in building a framework to measure the resilience.

2. Participating in local and international workshops related to the concept of resilience, as it is a new context that is enhanced to be built locally and globally.

3. The collection and integration of data about natural hazards past events happened in Palestine in general and Nablus City in specific, which were needed as a basis for the whole analysis process. This was done through the research of the country's disaster and emergency history and the in-depth discussion with the related experts. Specific data about rainfall and snow were collected from the Palestinian Meteorological Station (PMS).

4. Illustrating the basic concept related to the proposed resilience measurement framework through the determination of the scale of assessment, the appropriate approach for assessment, the consequence scenario, and the classification for each type of natural hazard.

3.3 Risk Assessment

Resilience assessment highly overlaps with risk management studies. Because of that the risk assessment phase is considered as the first step in assessing and building resilience for transportation infrastructure as it elaborated the overall risk picture for the three identified natural hazards. The output of this assessment would determine the desired level of resilience for each natural hazard. Risk assessment was performed through the following steps.

1. The qualitative risk analysis process for the three main natural hazards (seismic, intensive rainfalls that could lead to flooding events, and snowing), which consists of HIs for each hazard. Through this step the data that were collected about natural hazards were integrated to propose a number of scenarios for each hazard then illustrating the potential resulted hazardous events from each scenario and identifying the possible triggering events related to each hazard. The process of proposing the scenarios was firstly conducted through research of the country's disaster and emergency history. Secondly; through investigation of similar HI efforts in neighboring countries. Finally; interviews with key stakeholders who are responsible of the management and safety of Nablus City CIs were conducted. Through the interviews, brainstorming sessions were conducted, which are of the most effective methods for HI studies. HI tables are illustrated in Chapter 5.

2. Risk evaluation through evaluating each scenario proposed in the HI process for each hazard through a multi risk rating matrix proposed by European Commission (2010) as in Figure (3.2), including the four categories (people, assets, environment, and reputation). The assets reflect the transportation network situation related to the mentioned hazard scenarios. Multi risk rating matrices are illustrated in Chapter 5.

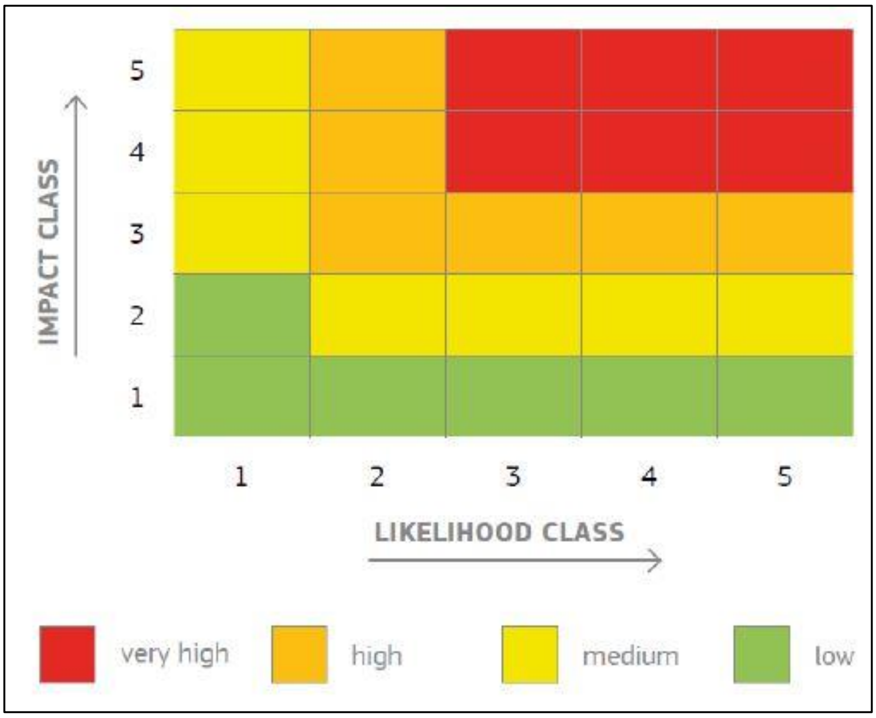

Figure (3.2): Risk Matrix Proposed by the European Commission (2010)
Source: (**European Commission, 2010**)

3.4 Resilience Assessment

The last phase in the methodology is proposing a method to measure the resilience of Nablus City transportation network at the macro-scale level. This is done as follows.

1. The first step in initiating this phase was developing a multi hazard risk matrix, which combined the three identified hazards, by introducing the

risk level for each hazard as will be illustrated later. This matrix is the purport of the risk assessment in which it enabled to measure the desired level of resilience.

2. Measuring the desired level of resilience for each hazard based on the concept that the risk level resulted from the multi hazard risk matrix could be translated to a desired level of resilience (the risk level is the opposite of the resilience level) as will be illustrated in Chapter 5. This helps in comparing the level of resilience that must exist for the transportation network and the current existing level.

3. Identify the dimensions of resilience to be used in evaluating the resilience of the transportation network and thoroughly identify the principles related to each dimensions, and finally the measures that is suitable to evaluate each principle.

4. Develop a spreadsheets to measure the resilience for each dimension. The spreadsheets contain a number of measurement categories related to the selected dimensions and principles. Each category contains a number of measurement items with a scale (0=low resilience, 1=moderate resilience, 2=high resilience, 3=very high resilience). This will give the overall resilience score for each dimension, which will lead to the overall current resilience score. The proposed scale in this research for assessing the resilience is consistent to the global scale proposed by the UNISDR (2017) in its framework for the preliminary resilience assessment tool for cities (Disaster Resilience Scorecard for Cities). Spreadsheets are included in **Appendix D**. Spreadsheets were

arbitrated by two Academics from an-Najah National university specialized in risk management and statistics.

5. The spreadsheets were completed through in-depth interviews with the related stakeholders in Nablus City. Nine stakeholders were interviewed (Nablus Municipality, Civil Defense, Emergency Committee, Public Works Directorate, Police Department, Fire Department, Red Crescent, Electricity Company, Telecommunications Company). In total, 18 expert persons completed the spreadsheets as included in **Appendix D**. Then the final scores that were assembled through the interviews were measured to reach for the overall current resilience score for Nablus City transportation network.

6. Propose methods on how to build and increase the resilience of the transportation network. This was done through building Bow-tie model for each hazard by using Bow-tie XP Software. Each Bow-tie includes a wide range of control and adaptation (prevention and mitigation) measures in addition to the explanation for the causes and the potential consequences for each hazard. This step is a crucial part of the risk analysis and this proves that risk assessment and resilience assessment are overlapping at all levels.

After finalizing all the previous phases, the proposed framework that was followed in this research to assess the resilience will be summarized.

Finally, based on the results and the data analyzed, conclusions, recommendations, and suggestions for future work studies will be explained.

Chapter Four

Main Types of Natural Hazards in Palestine

Chapter Four
Main Types of Natural Hazards in Palestine

This chapter highlights the observed trends for the main types of natural hazards that happened in Palestine in general, in addition to the allocation of these natural hazards in the selected case study for this research, which is Nablus City. This is done through illustrating the collection and integration of data about past events to produce a scientifically defensible conclusion, starting by the main contributor that increases the potential of natural hazards occurrence, which is the climate change.

4.1 Climate Change Globally & in the Case of Palestine

Climate change, as defined by the IPCC (2014), refers to “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties”. These changes extend over long periods, typically decades or longer.

Climate varies naturally over time, but the pace of climate change has accelerated in recent decades corresponding to intense human activity, such as burning of fossil fuels, urbanization, industrial activities, and deforestation (ARIJ, 2012).

Over the last century, the temperature of our planet has gradually increased, but in the last 1400 years, the 30-year period between 1983 and 2013 had the highest average temperature (IPCC, 2014). There are many indicators that proved that the climate is changing and the earth’s climate is warming; these indicators have been witnessed and measured globally over the past decades (NOAA, 2014). Figure (4.1) summarizes the main ten key indicators.

Figure (4.1) illustrates that the indicators with the white arrows represent an increasing trend and the indicators with the black arrows represent a decreasing trend.

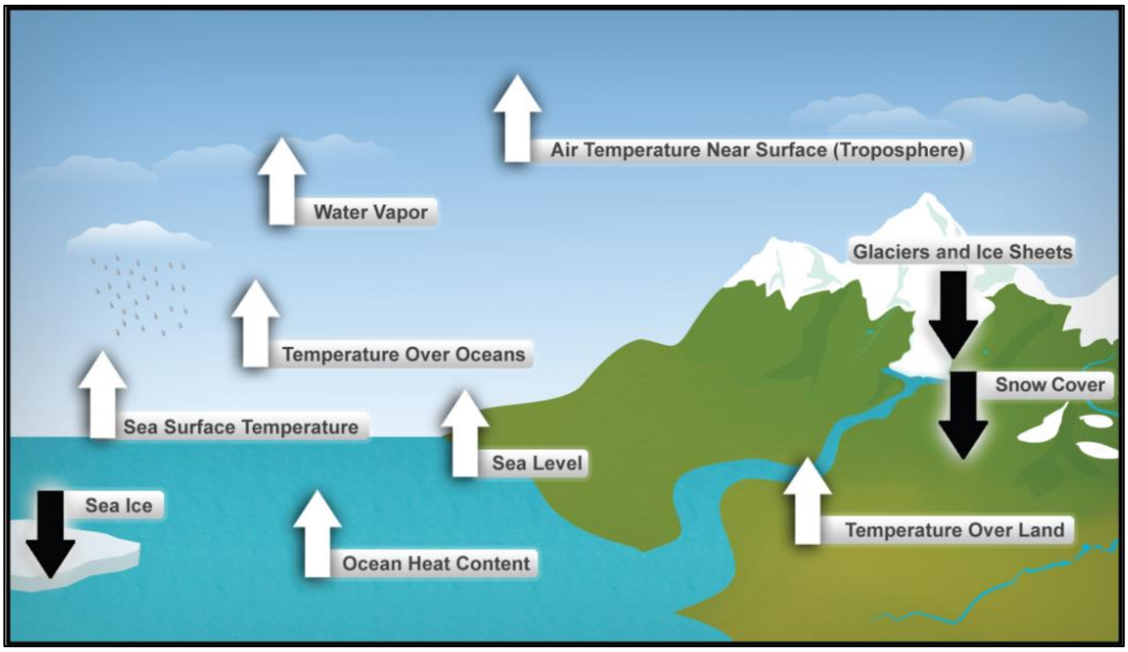

Figure (4.1): Ten Indicators of Warming World
Source: (NOAA, 2014)

Outcomes related to climate change are indisputable; climate change presents serious and long term challenges, which have the potential to affect every part of the globe. A changing climate leads to changes in extreme weather and climatic events, which were witnessed globally over the past decades. Since 1950, extreme hot days and heavy precipitations have become more common around the world. Accordingly, climate models project more frequent hot days, more heavy rain events, and increasing in the frequency of natural hazards (e.g. floods, droughts) throughout the 21st century (IPCC, 2014).

The consequences resulting from these changes affect humans and all parts of communities they live in. The effects will reach people, animals, constructions, infrastructures, and environment alike. Because of these forced changes, communities must adapt according to the types of changes they will face, because changes in climate extremes and their consequences vary across regions, as each region has unique vulnerabilities and exposures to the resulted hazards (IPCC, 2014).

As a result of climate change, the Middle East region is expected to have higher future temperatures and a reduction in the rainfall in the region. On the other hand, an increase in extreme daily rainfall and a decrease of annual rainfall is a widely accepted prediction for the Eastern Mediterranean region and as a result increased droughts (Salem, 2011).

Palestine, as part of the Middle East, had been and will be exposed to many serious climate changes that include increase in the mean temperature and sea level rise, reduction in the annual rainfall amounts, changes in snow fall amounts and frequencies, and increase in the potential of the meteorological, hydrological, and climatological events such as heat waves, storms, floods, and droughts (Salem, 2011).

A study in climate change for historical Palestine inferred that by the year 2020, the mean temperature will increase of 0.3-0.4^{o}C and precipitation will decrease by 2% to 1%. Whereas by 2050, mean temperature will increase of 0.7-0.8^{o}C and precipitation will decrease by 4 % to 2% (Pe'er & Safriel, 2000).

Table (4.1), which is upgraded from Samaro (2016), shows some extreme weather events that happened in Palestine during the period from 1997 to 2016, as a proof that Palestine witnessed several climatic fluctuations.

Table (4.1): Extreme Weather Events Happened in Palestine (1997-2016)

Date	Event
18-19 March 1997 (Salem, 2011)	A heavy storm hit the central and southern parts of the West Bank, which was the second heaviest storm in March during the past 60 years.
July-August 1998 (Salem, 2011)	The hottest summer in 35 years where the temperature rose up to 46.8°C in Jericho.
September-November 1998 (Salem, 2011)	The driest and warmest autumn during the past 58 years.
24 January 1999 (Salem, 2011)	A hail storm hit Jerusalem with hail stones as big as marbles (1.3 cm in diameter).
28 November 1999 (Salem, 2011)	Unusually cold and dry weather. The temperature in Jerusalem dropped to 6°C below zero.
July 2000 (Salem, 2011)	The hottest month of July in the last 50 years, with a mean temperature of 4°C higher than average. The highest recorded temperature (41°C) in Jerusalem since 1888.
February 2003 (Salem, 2011)	The wettest month since December 1991, and the wettest February ever recorded.
29-30 May 2003 (Salem, 2011)	Lowest pressure (995 mb) ever recorded in May, accompanied by an incredible sand storm that covered the entire Palestinian territories and the region with thick red sand and dust.
9-10 May 2004 (Salem, 2011)	Very intense heat affected the Palestinian territories, especially during the night of 9 May, when 32°C was recorded in Jerusalem. In the following nights, the temperature in Jerusalem was 20°C lower than the temperature at noon.
2013 (IMS.gov.il., 2015)	2013 was among the warmest in the last 60 years.
4-10 January 2013 (IMS.gov.il., 2015)	Uncommon event of rainfall with regard to the number of successive rainy days (6-7). Over the last 60 years there were only 3 other events alike.
12-14 December 2013 (PMS, 2019 & IMS.gov.il., 2015)	Significant extreme snow fall up to 65 cm in depth in Ramallah, (50-70) cm in depth in Hebron mountains and surroundings, and (70-90) cm in depth in the northern peaks of West Bank. Besides frequent snow fall three times at the same year.
2014 (PCBS, 2016)	Extreme humidity ratio in Nablus which reached up to 83% and the least was in Jericho which reached up to 43%.
2015 (PMS, 2019)	Repeated snow fall in Ramallah, Hebron, and Nablus.
2016 (PMS, 2019)	Very intense heat affected the Palestinian territories; ex. the maximum daily temperature reached around 40.5 °C in Nablus City.

Moreover; in 2018, many countries in the Middle East suffered from serious consequences as a result of the effects of climate change. Jordan suffered from torrential floods, the last of which caused the loss of dozens of lives. In Kuwait, the lack of infrastructure to deal with floods emerged clearly. Saudi Arabia suffered from severe thunderstorms, while Palestine suffered from drought and severe heat waves in the summer (24FM, 2018). And in 2019, Lebanon suffered from Norma storm, which was described as one of the rare storms that could happen in Lebanon; this storm with its very heavy rain caused a flood that resulted in terrible damage for infrastructure and caused citizens to be stuck in their cars, resulting in heavy traffic congestion (Annahar, 2019).

From the above, it is concluded that climate change is a main contributor that help in increasing the potential of natural hazards specifically heavy storms, floods, and droughts. And there is an accelerated need to perform adaptation strategies to cope with these potential natural hazards and this could be done through building and increasing resilience in every community. Thus, resilience has become the new goal of disaster risk reduction and climate change adaptation of international and national policies (Karen, 2011).

Finally, as the transportation infrastructures are the main concern of this research, the followings are examples about some expected impacts and consequences resulted from different climate change indicators that could affect the transportation systems (DoD, 2014):

- Rising temperatures indicator means more days with high temperatures, and more wormer soil; this will degrade the transport infrastructure and will increase the maintenance costs.

- Changes in precipitation patterns indicator, either by decreasing, which will lead to more severe droughts, or by increasing, which will lead to more extreme precipitation events. This means higher maintenance cost and higher costs for flood control and erosion prevention.

- Increasing storm frequencies and severity means changes in flood event patterns, which will lead to increase inundation, erosion, and inland flooding damage, increase wind damage, increase damage in infrastructure, and increase in the cost of flood control and erosion prevention.

4.2 Observed Trends of Natural Hazards in Palestine, Specifically Nablus City

According to data obtained from different statistical reports and scientific research studies, the Palestinian territories are highly vulnerable to natural hazards, which are mainly earthquakes, floods, landslides, droughts, and desertification, and the whole region frequently faces small to mid-scale disasters and bears a high potential for large-scale urban disasters (Dabbeek, 2010).

Based on hazard mapping, the probability of natural hazards occurrence is increasing in Palestine. One main reason that contributes to increase the probability is the geographical area of Palestine (Hawajri, 2016).

Natural hazards in general are classified according to the type and the resulted impacts, the classifications range from the most severe hazard, the most probable hazard, to the least severe, and least probable. Besides that, every hazard has its own classification based on specific characteristics.

In this study, the main types that will focus on are: seismic hazard, intensive rainfalls that could lead to flooding hazard, snow hazard, and land sliding hazard that could happen in Nablus City. In which, the seismic hazard is the most severe one and the intensive rainfalls is the most probable. The following subsections provide explanation of these four hazards.

4.2.1 Seismic Hazard

Severe earthquake hazard and its terrible after effects is one of the most frightening and destructive phenomena of nature. Earthquakes strike without warning and can happen any time of the day or night, and if an earthquake occurs in populated area, it can cause deaths, injuries, and extensive property damages, and a large earthquake might have huge effects on road infrastructure. While sometimes, consequent triggered events can be even worse than the earthquake itself, such as fires, aftershocks, and the induced landslides, which is considered as the most abundant types in form of rock falls and slides of rock fragments that form on steep slopes, which often resulted in life and economic losses.

Palestine is natural disasters prone-area particularly earthquakes and local site effects such as landslides, liquefaction, and amplification. As a result of the geographical area of Palestinian land and the highly seismic activity of the Dead Sea, the earthquakes in the region are considered a major severe hazard, with low probability but high adverse impacts (Hawajri, 2016).

Seismological studies show that there is a high probability of damaging earthquakes occurring in the region. At the same time, engineering studies show that seismic vulnerability of common buildings and infrastructures in Palestine is very high (Dabbeek, 2010).

Through the last two centuries, Palestine suffered from a series of earthquakes, the most important occurred in the following years: 1834, 1837, 1854, 1859, 1872, 1873, 1896, 1900, 1903, 1923, 1927, 1954, 1995, and 2004 (Dabbeek, 2007).

The two most major earthquakes that Palestine suffered from are summarized in Table 4.2, which shows the data related to these two earthquakes.

Table (4.2): Major Earthquakes Happened in Palestine

Year	Description	Magnitude (on Richter Scale)	Location	Results	Triggered Events
1837	Tremendous event	6.25-6.8	Epicenter in the Jordan Rift Valley, east of Safed (Dead Sea Transform fault system).	-Safed city was destroyed completely. -Other villages in its vicinity were severely damaged. -Human losses exceeded 5000 persons.	Occurrence of landslide.
1927	Devastating event	6.25	Epicenter near the Damiye Bridge on the Jordan Valley.	-Caused severe damages in Nablus City: 800 houses were destroyed and the human losses reached about 350 persons in the city. -Had less damage to other cities.	-

Source: (Wachs and Levitte, 1997 & Dabbeek, 2007)

The 1837 earthquake had a greater damage when compared to that in 1927 because the former took place during a winter season with heavy rainfall; the ground was wet and the water table was high, which besides the earthquake, helped in landslide occurring causing more damages. Whereas the 1927 earthquake took place in summer where the soil is dry and the water table is generally lower (Wachs & Levitte, 1997). This demonstrated that the damage resulted from earthquakes does not only depend on the magnitude and the distance to epicenter, it also closely depends on the local geology and topography, and on the weather condition in the event time.

Another recorded earthquake, which is not comparable to the two previously mentioned, had struck the Palestinian Territories in 2004 with magnitude of 5.2 points on Richter scale and an epicenter in the north eastern part of the Dead Sea basin. This earthquake was mainly felt in Nablus City because of the effect of local geological conditions of the city such as the geological formations. This event caused slight damages to some regions in Palestine, but no life losses were reported. In Nablus City nine old masonry buildings suffered from slight damages, four old masonry buildings suffered from substantial to heavy damages, and two buildings (masonry and old masonry buildings) suffered very heavy damage (El-Kelani & Dabbeek, 2005).

Based on the seismic return period analysis, if the epicenter of the earthquake is to the north of the Dead Sea, it will happen every 80 to 100 years. But if the epicenter is to the north of Palestine, the earthquake will happen every 200 to 250 years (Dabbeek, 2007).

Furthermore, based on the seismic peak ground acceleration map for the region, Palestinian cities are categorized into four parts according to the seismic zone factor on the rock (Z) (see Figure 4.2). As the factor increases, the exposure of the city to the earthquake increases. For example, Nablus City has a factor of Z=0.20; that means when an earthquake strikes the city, its buildings will be affected by 20% of their weight.

All predictions regarding the next earthquake that may happen in Palestine show that a major destructive earthquake is expected at any time in the near future with a magnitude of 6-7 points on the Richter Scale

(RS), expected with huge damage to buildings and infrastructures with a possibility that the human losses may exceed thousands (Dabbeek, 2010).

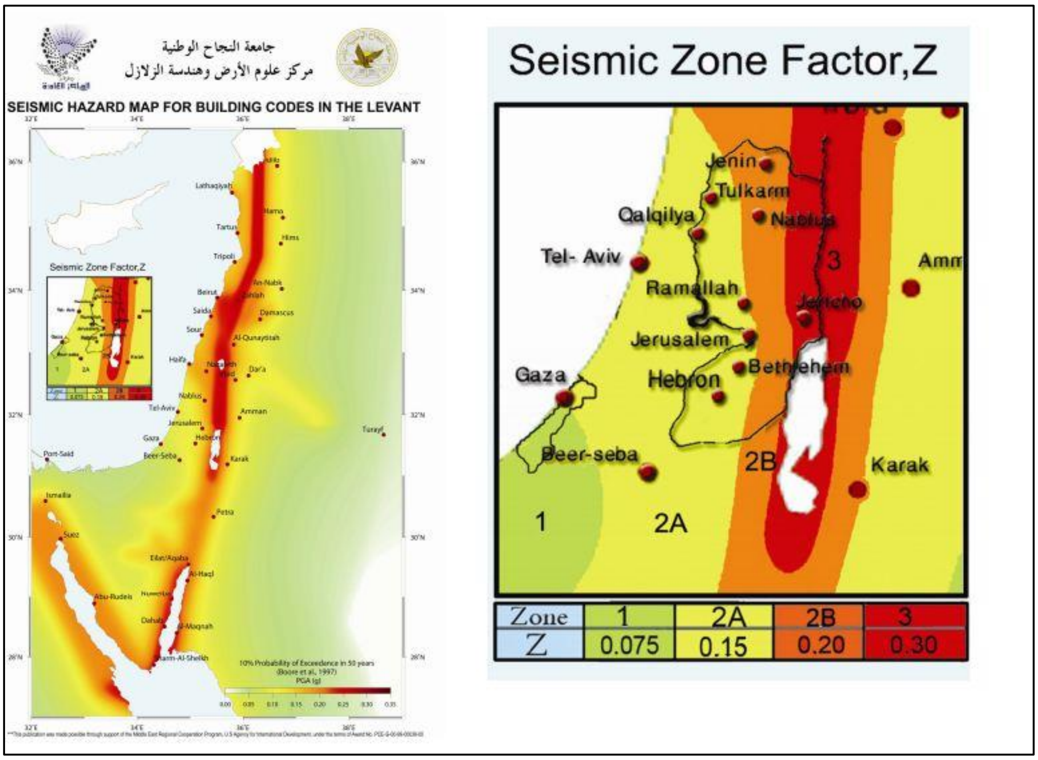

Figure (4.2): Seismic Hazard Map and Seismic Zone Factor for Palestinian Territories

Source: (SASPARM Project, 2012)

Based on the previous Seismic Hazard Map, if an earthquake with magnitude of 7 points on RS strikes the Palestinian territories, 5-10% of the buildings would be totally damaged while 20-30% of the buildings are expected to be partially damaged in some areas of Palestinian cities, and the number of human losses will range from five thousands to eight thousands and more than twenty thousand would be injured with an estimated readiness for the country of 25% (SASPARM Project, 2012).

These predictions in the case of Nablus City show that the collapse of buildings will cause total and partial closures of the roadways, especially in the mountainous regions, which are in most cases have narrow roads running a long side the mountains. In addition, if the earthquake hits during the winter rainy season, the probability of several landslides and accordingly the collapse of many retaining walls will increase (Abaza, 2008).

While regarding the effects of the earthquake on the transportation network in Nablus City, a study conducted by Abaza (2008) proposed three scenarios of earthquake severity that Nablus City could be exposed to. The first scenario shows the impact of an earthquake with magnitude up to 5 points on RS, which will result in no closure of the transportation network of Nablus City.

The second scenario proposed an earthquake with magnitude between 5-6 points on RS. In this case, several roadway links in the southern and northern mountainous areas will be either totally or partially closed for traffic, which form 76.6% of the total links in the city.

The third proposed scenario was about an earthquake with magnitude larger than 6 points on RS, in which most of the mountainous and lower mountainous regions would suffer from devastating destruction, and additional destruction to the roadway links of the already inaccessible routes shown in the second case above.

It should be pointed out that the earthquake could be classified based on the following seismic standards: earthquake magnitude, earthquake intensity, earthquake moment, and earthquake energy.

The previous standards highly depend on many factors that contribute to the destructiveness of an earthquake, which are (Zielinski, 2011):

- The location of the earthquake.
- Magnitude.
- The depth of the earthquake.
- The distance from the epicenter.
- Local geology conditions (local site effects).
- Triggered events: earthquake can trigger landslides, fires, or floods.
- Seismic vulnerability of constructions: weak buildings and infrastructures that do not comply with seismic resistant requirements contribute significantly in increasing the intensity of the resulted damages and destructions.

All of these factors explain the expected high percentages of damages and human losses if an earthquake hits the Palestinian territories especially Nablus City. Because the effects of the previous factors in Nablus City are highly extent if an earthquake hits it, because of the bad construction practices thus the highly vulnerable constructions, the lack of national seismic code for design and construction (Dabbeek, 2010), the privacy of its location as it’s located in a valley between two mountains, and the geology conditions of the city as the downtown is built in the central part of the city on soft clay, marl, and valley deposits, whereas the northern and southern parts of urban areas in Nablus City lying on mountains consist of consolidated carbonates bedrock, which significantly would result in higher amplification for the earthquake (El-Kelani & Dabbeek, 2008).

Finally, the type of classification that this research will adopt in the analysis process is the magnitude of the earthquake.

4.2.2 Intensive Rainfalls that Could Lead to Flooding Hazard

Intensive rainfalls could lead to both flood and flash flood events; therefore, it's important to clarify the differences between the flood and the flash flood events before elaborating the probable situation in Palestine.

According to UN-SPIDER (2017), flood is defined as "the overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch, ponding of water at or near the point where the rain fell. Flooding is a longer term event than flash flooding; it may last days or weeks". Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to manage excess water (NOAA, 2019).

While flash flood is "a rapid inland flood caused by heavy or excessive rainfall in a short period of time, that produce immediate runoff, creating flooding conditions within minutes or a few hours during or after the rainfall, generally less than 6 hours. They are typically associated with thunderstorms and can occur at virtually any time" (UN-SPIDER, 2017).

Flash floods are considered as one of the worst kind of hazards as they have severe effects on humans in the form of life losses, cause severe damages to properties and infrastructures, and cause disruption of communication and transportation systems. They are characterized by their suddenness, rarity, small scale, heavy rain and peak discharge, unpredictable, fast, and violent movement. For example, in sloped terrain, the water flows rapidly with a high destruction potential. In flat terrain, the rainwater cannot infiltrate into the ground or run off due to small slope, as quickly as it falls (Ali et al., 2017).

Through the past years, Palestinian people faced many floods events ranging from flash floods to floods as a result of the extreme weather events. These events caused enormous losses whether on individuals or in properties.

A study conducted by Shadeed (2019) illustrated that most of the Palestinian communities in different districts are located in high and very high flood hazard prone areas, where about 90% of the total population are living. It also indicated that extreme rainfall events accompanied with flash floods are getting more frequent in Palestinian Governorates. The main flooding events that were documented in Palestine were in 1963, 1966, 1987, 1991(Dabbeek, 2007), and in 2013.

The intensive rainfalls that happened in Palestine in January 2013 had generated flash floods in several parts of the Palestinian territories, which resulted in the death of 4 citizens in the West Bank, two of them were swept away and drowned by the flood to the west of Nablus City, the third one was drowned in Tulkarem flood, and the last was skidded and died in Jenin flood. Many roads across the West Bank were totally flooded. This winter storm was characterized by its torrential rains, strong winds, low temperatures, and heavy snowfall (Hawajri, 2016).

The vulnerability of floods has increased in the last years in Palestine. A flood hazard map for the West Bank, Palestine shows that 29% of the West Bank communities have medium vulnerability to floods, while 36% have high vulnerability, and 12% have very high vulnerability to floods (Shadeed, 2019). Figure 4.3 shows the vulnerability level for the main cities in the West Bank.

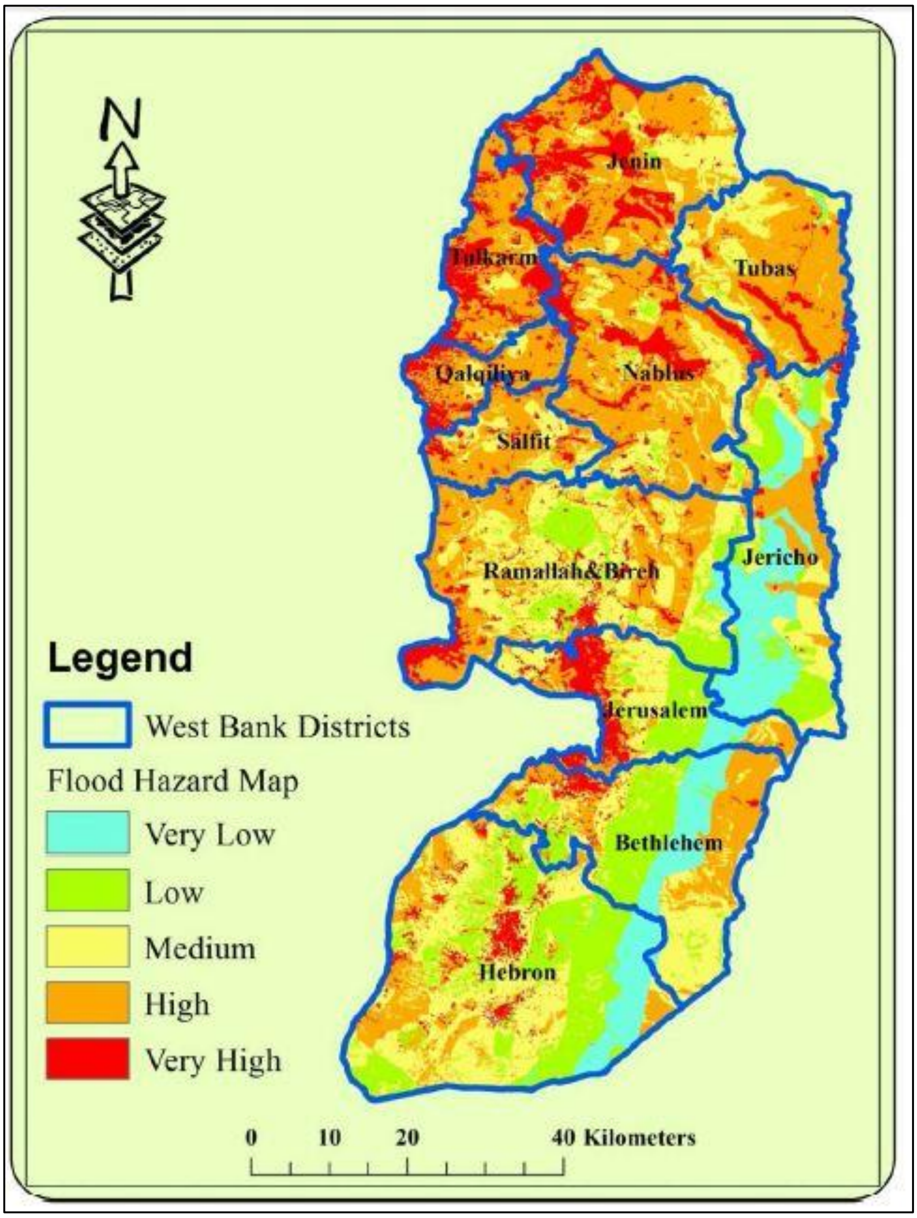

Figure (4.3): Flood Hazard Map of the West Bank, Palestine

Source: (Shadeed, 2019)

From the map, the area in km^2 exposed to flood hazard in every city are calculated by the researcher. In the case of Nablus City, 0.60 km^2 of the city could be exposed to low intensity of floods, 14.3 km^2 could be exposed to low intensity, 143.5 km^2 could be exposed to medium intensity, 361.5 km^2 of the city could be exposed to high intensity, while 106.8 km^2 could be exposed to very high intensity.

The concentration of this thesis will be on intensive rainfalls events that happened and could happen in Nablus City, which could lead to inland inundation, flooding, or flash flooding events, and their impacts on the transportation infrastructure.

During the period of rainfall records from PMS, the following figure (Figure 4.4) shows the recorded data about the maximum daily rainfall events in mm that happened on Nablus City between the period 1955 and 2018. This figure gives indications about the maximum daily events of rainfall that could produce hazardous events.

The maximum amount of daily rainfall events that lead to disruption during the past 63 years in Nablus was 91.5 mm in November 1955, 114.8 mm in November 1979, 98.9 mm in March 1980, 115.5 mm in December 1992, 101.8 mm in February 1996, 95 mm in February 2005, 105 mm in December 2006, and the highest among them all was 123 mm in December 2013, which as stated, before resulted in severe flash floods. It should be noted that there were missing data between 1962 and 1964. It is noticed that all the previous events had a value of daily rainfall above 90 mm/day, in which above this value disruption and damages would start to occur.

More detailed data are attached in **Appendix (A)**.

It should be indicated that the flood could be classified based on the following standards (Schumann, 2011):

- The event parameter: area flooded in square kilometers, the volume in cubic meters, or the speed of water in meters per second.

- The site parameter: depth of flood water in meters, depth of the inundation areas in meters.

Finally, the type of classification that this thesis will adopt in the analysis process is based on the site parameter.

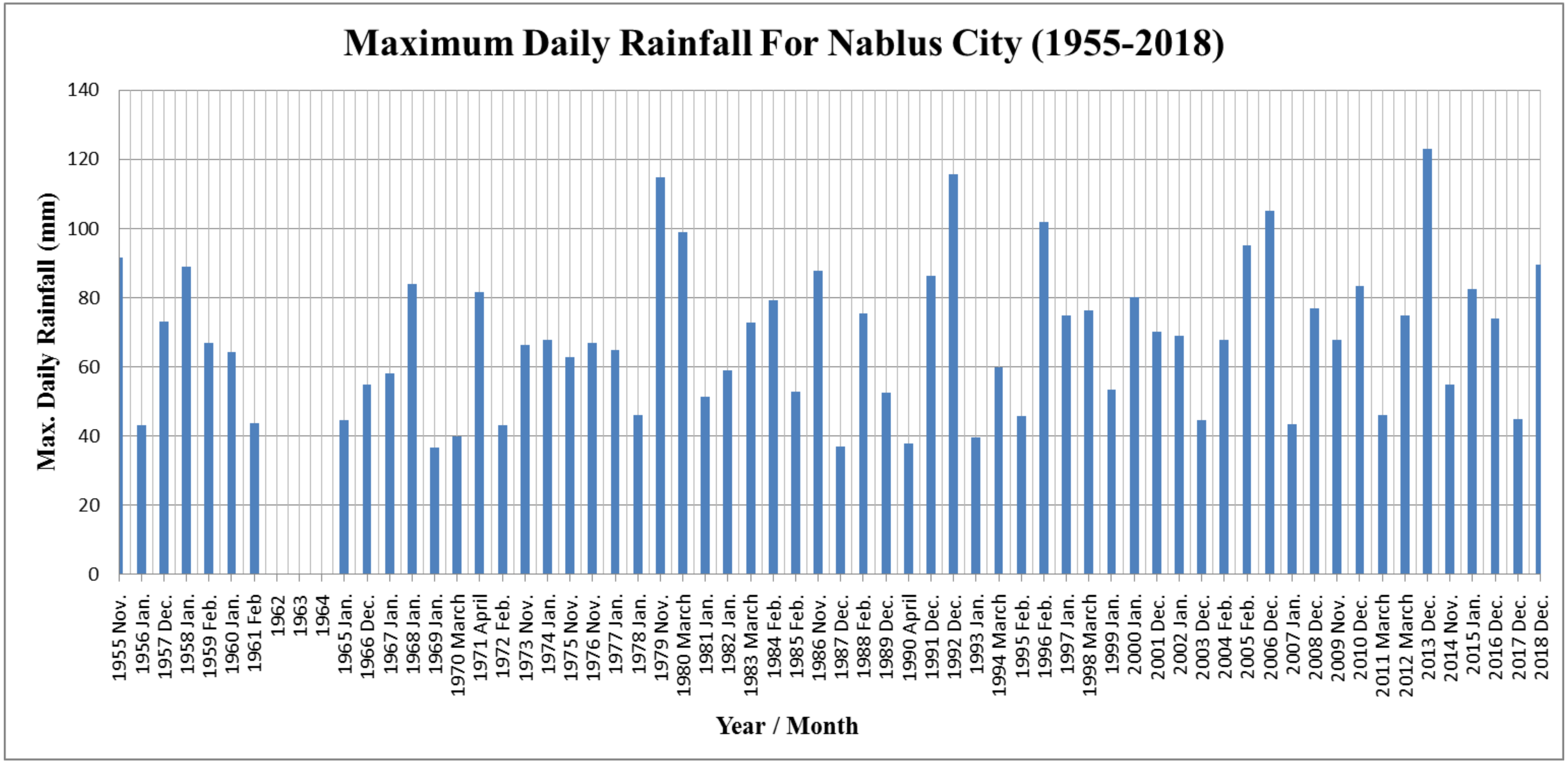

Figure (4.4): Maximum Daily Rainfall Events / Year in Nablus City (1955-2018)

Data Source: (PMS, 2019)

4.2.3 Snowing Hazard

Snow storms are relatively frequent in many parts of the world, their effect on transportation networks are the regularly closure of roads for traffic due to snow accumulation. The periods for roads closure are different from country to country based on the quantity and quality of equipment to clear the street from the accumulated snow in every country. The longer periods the roads are closed and the snow is accumulated, the higher probability of accidents, the higher probability of roads failures and cracked, and the higher the travel time will be because of the congestion due to reduced capacity of the roads.

Historically, Palestine was exposed to many snowing events since more than 100 years ago. The most memorable events that had huge impacts on the Palestinians lives were as follows: in 1911, the snow began to fall profusely, where snow continued to fall for forty days without melting. In 1950, the snow falls for four consecutive days without stopping and reaches a depth of 90 cm in Jerusalem. In 1992, that winter season was called the season of the seven snow events, temperatures reached 10^{o} below zero in some high areas, and snow accumulated for more than one meter for long periods of time in some areas (P-Weather, 2015 & ShashaNews, 2016).

The PMS has started to record snowfall events since 1997. Based on these records, snowfall events occurred frequently in Palestine over areas of 500+ MASL (meters above sea level), while for areas of 500-800

MASL, snow had fallen with an average of 3 times per decade, and an average of 4.5 times per decade for areas of 800+ MASL, both in the 20th century. During the 20th century, most of the snowfalls events occurred as once throughout the certain year that had snowfall. Multiple events as 2-3 times in a year were started in the 21st century, and specifically since 2008 (Samaro et al., 2016).

For Nablus City, the data recorded from the PMS are illustrated in **Appendix (B)**. Based on the data available, the snow fall events between 1997 and 2015 are illustrated in Figure (4.5).

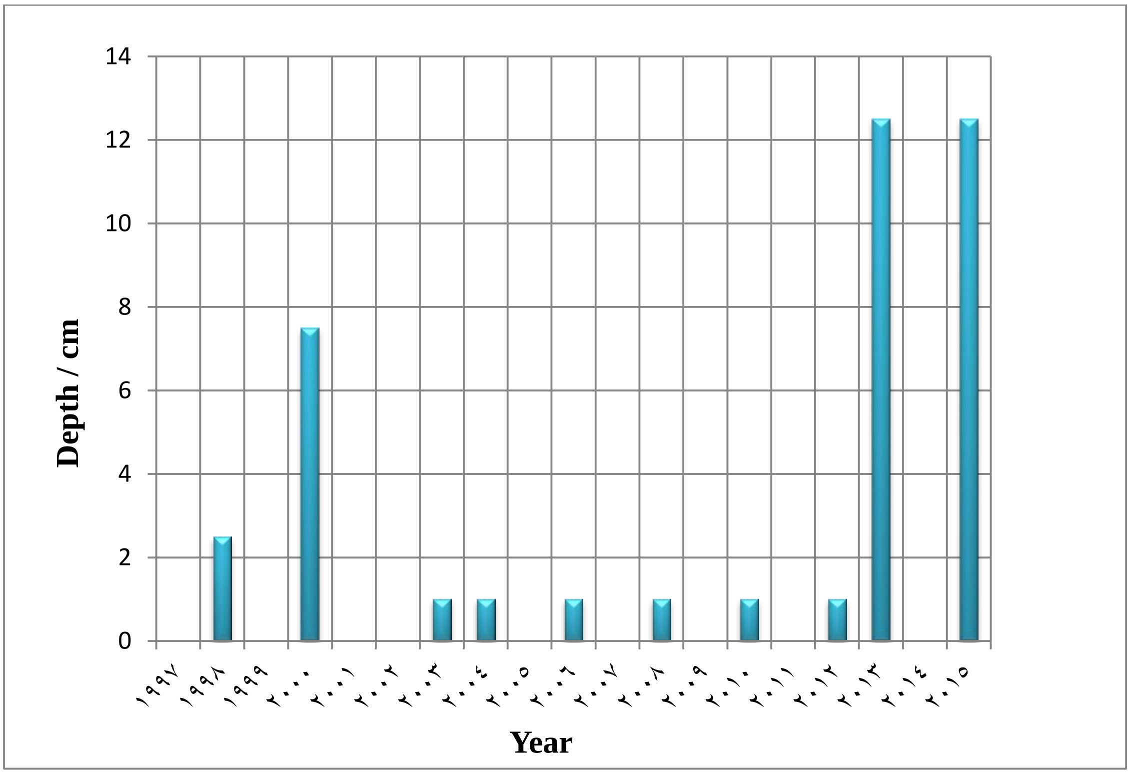

Figure (4.5): Snowfall Events in Nablus City (1997-2015)

Data Source: (PMS, 2019)

From the figure, the highest depth of recorded snowfall in Nablus City was in 2013 and 2015.

One of these snow events that the researcher witnessed in Nablus City was the storm Alexa between 11 and 14 of December in 2013. This winter storm was characterized by its heavy rains, strong winds, low temperatures, and heavy snowfall. The extreme amounts of snowfall left dozens of communities across the West Bank inaccessible, and caused heavy infrastructure damage, including power outages in tens of thousands of homes and road closures with many drivers stranded. The snow in that year covered nearly all parts of Nablus City, which caused the closure of high percent of roads for 2 to 3 days and some areas were difficult to be reached for 4 days like Nablus Aljadeda (Al-Sahili, 2019).

Finally, snow could be classified based on the following standards (Deodatis et al., 2014):

- The event parameter: event occurrence (discrete or continuous), duration, or intensity.
- The site parameter: depth of snow.

The type of classification that this thesis will adopt in the analysis process is based on the site parameter, which is the depth of the snow.

4.2.4 Land Sliding Hazard

Landslides occur in many places around the world, especially in the mountainous areas. The occurrence of land sliding events in any place would cause losses in humans and damages in buildings and infrastructures in the area near them. In addition to that, these events could lead to the closure of roads and mountain paths.

Landslides can be triggered by earthquakes, heavy rainfalls, and in some cases occur through general instability with no significant triggering event. The risk of land sliding events increases if it’s triggered by an earthquake in a winter season, or if it occurred during heavy rainy days or flood events because the soil will be saturated and wet, thus its slide ability increases (Seville & Metcalfe).

Landslides can have very significant consequences if they occur at the wrong places. Two different kinds of consequences can be assumed depending on where the landslide occurs. In the case of landslide at high elevations where the landslide sweeps down over the road surface, the road would be blocked and/or the road surface would be destroyed. In the case of landslides occur in slopes at the side of the road beneath the road surface, the stability of the road will be affected and/or the road surface would be destroyed.

Palestine was exposed to many land sliding events through the last decades, especially in Hebron, Nablus, Jenin, and Ramallah. The four severe ones happened in 1992, 1997, 2003, and 2005. The last three happened in Nablus City (Dabbeek, 2007).

The topography and geology of the West Bank have been the main reasons behind several quite large landslides occurring over the past years (Jardaneh et al., 2004)

Based on different studies and field surveys, there are more than thirty Palestinian residential and industrial areas that are built on lands that have medium to high sliding ability, see Figure 4.6 (Dabbeek, 1999).

There are several factors that are considered key factors for landslides occurrence in some areas of Palestine, which are as follows (Dabbeek, 2013):

- Soil quality, such as rocky silt soil and clay soil.
- The existence of steep slopes, such as the mountainous areas with high steep slopes.
- The presence of soil layers that have high humidity, so it's often get to slide in winter seasons.-

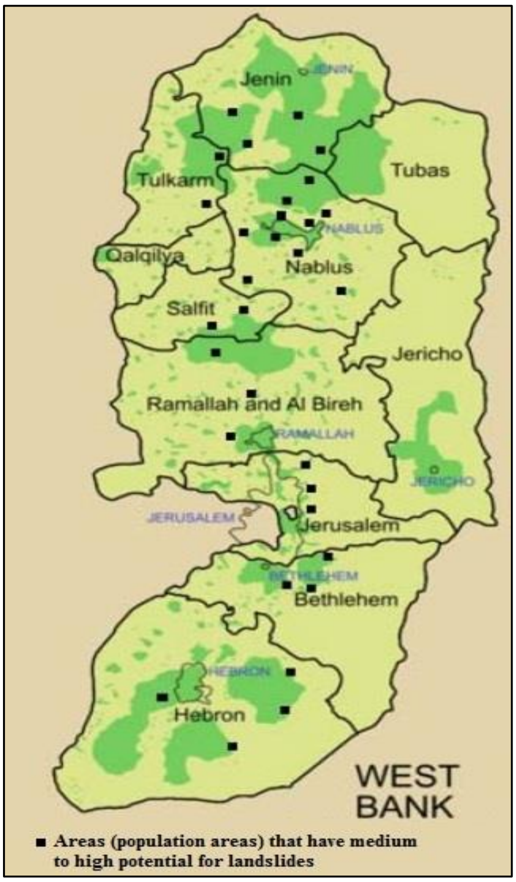

Figure (4.6): Palestinian Areas That May be Exposed to Landslides

Source: (Dabbeek, 1999)

Nablus City is known for its significant geographic location, as it is located in the center of the mountainous highlands in Palestine between Mount Ebal to the north and Mount Gerizim to the south. Its topography is rocky on the mountains of Ebal and Gerzim, topped by a low layer of clay soil mixed with different sizes of gravel, and this soil is suitable for agriculture. While the area lies between the two mountains is a valley with many orchards rich of agricultural clay soil, full of springs and with the existence of groundwater near the earth’s surface (Jardaneh, 2007).

As shown in Figure 4.6, there are 10 locations in Nablus City that have probability of being exposed to land sliding events. An important example is the White Mountain, which is located in Al-Ma’ajeen area west of Nablus City. This mountain suffered from large land sliding events in 1997, 2003, and 2005. These events resulted in many damages and losses, such as a complete failure of a house and a collapsed of a barracks of steel structures in the landslide area besides a damage in a main road that connects Nablus City with Tulkarem City as shown in Figure (4.7) (Jardaneh et al., 2004), and recently there is an urgent need to evacuate a house and a kindergarten in the area near the mountain due to the risk of these renewed landslides (Dooz, 2018).

Figure (4.7): The Bottom of the White Mountain Landslides and Nablus-Tulkarm Damaged Main Street

Source: (Jardaneh et al., 2004)

4.3 Observed Failures of Natural Hazards in Nablus City

This section summarizes the effects, the failures, and damages resulted from natural hazards that happen in Nablus City during the past years mainly on roads. It should be noted that the roads may not be directly affected by the natural hazard itself, but there are indirect damages and failures that could affect the roads and the traffic conditions that result from the collapse of the surrounding retaining walls and buildings or the failure of any construction in general.

Table (4.3) summarizes the damages in construction resulted from different types of natural hazards that occurred in Nablus City between 2006 and 2014, in which these damages have high impacts on the nearby roads.

According to the Ministry of Public Works and Housing (MPWH, 2014), these damages costed nearly 231,000 USD. With the indication that these results do not include the damages that have occurred in transportation infrastructures, as the researcher didn't find a recorded reports or statistical data related to them.

Table (4.3): Damages Resulted from Natural Hazards in Nablus City (2006-2014)

Year	Event	Results (Consequences)
October 2006 (Civil Defense, 2019)	Intensive rainfall	The closure of the sewage networks in Nablus, which led to a large number of traffic accidents.
March 2010 (Civil Defense, 2019)	Heavy rainfall	2 Retaining walls collapsed.
January 2013 (MPWH, 2014)	Intensive rainfall Flash floods in many parts of the city.	5 Retaining walls collapsed. 2 External walls collapsed. 9 Houses were highly affected.
December 2013 (MPWH, 2014)	Snowfalls	3 External walls collapsed. 1 Brick wall collapsed. 2 Retaining walls collapsed. A collapsed in a culvert shoulder. 1 Land sliding event.
January 2014 (MPWH, 2014)	Intensive rainfall Flash floods in many parts of the city.	1 Retaining wall collapsed. 2 Houses become inhabitable.

While through the winter season of 2018-2019, the following are examples of damages observed in Nablus City roads as a result of the intensive rainfall events.

Figure (4.8): Land Sliding With Debris Flow in Al- Najah Old Street Due to the Intensive Rainfalls in March 2019

Source: (Dooz, 2019)

Figure (4.9): Failure in Golden Tree Hotel Street Due to the Intensive Rainfalls in Winter of 2018/2019

Source: By Researcher

Figure (4.10): Inundation of Beit Iba Main Road Due to the Intensive Rainfalls in February 2019

Source: (Qamhia, 2019)

Figure (4.11): Subsidence under the Sidewalk in Ibn Qutaiba Street Due to the Intensive Rainfalls in January 2019

Source: (Nasrallah, 2019)

Figure (4.12): Partial Collapse of Al-Arsad Street Due to the Intensive Rainfalls in December 2018

Source: (Nasrallah, 2019)

Further examples of the effects resulted in Nablus City mainly on roads from the main types of natural hazards through the past years are illustrated in **Appendix (C)**. Finally, it must be confirmed that besides the effects that resulted from natural hazards themselves, the human's bad practices before and through the event time could affect the situation in the worst way.

Chapter Five

Data Analysis and Results

Chapter Five
Data Analysis and Results

5.1 Overview

This chapter illustrates in details the concept and the main steps for measuring the resilience of Nablus City transportation network against natural hazards (seismic hazard, flooding events, snow hazard, and landslides). The data that have been collected through the literature and interviews based on the mentioned techniques and processes will be analyzed in this chapter.

The analysis is divided into two main steps, the risk assessment and the resilience assessment. The later step includes developing a macro-scale framework for measuring the resilience including the technical and organizational resilience of surface transport infrastructure. Based on the results from these two steps, methods on how to build the resilience of transportation infrastructure are illustrated. Finally, the overall proposed framework will be summarized.

5.2 Basic Concept Illustration

For initiating the first steps on measuring resilience framework, there are main concepts relating to it that should be first determined as illustrated in Chapter 2, which are:

- The scale of assessment (regional, network, or asset scale) and the relevant approach (all-hazard approach or specific hazard approach) should be first determined. As this research is concerned about the transportation infrastructure, the scale of assessment is chosen to be as the asset scale, which involves assessing the resilience of one asset (the transportation infrastructure). The hazard specific approach is chosen to be the suitable relevant approach, which is considered as appropriate for certain critical assets. It involves assessing the resilience in relation to specific identified hazards through identifying the complete range and type of potential scenarios, and assessing the risk of them occurring through the detailed risk assessment for every type of natural hazard to reach for the desired level of resilience.

- The consequences scenarios (regional, localized, societal, or distal event), which relate to the loss of service and other impacts resulted from each type of natural hazard should also be determined. Based on the natural hazards adopted for this research, the regional events are chosen to be suitable. Similar to the seismic hazard, the intensive rainfalls, which could lead to flooding events and the snow hazard, are considered as regional events that may cause physical damages to the transport infrastructure coupled with disruptions to other lifelines services such as electricity, water, and telecommunications.
- Finally, the adopted natural hazards should be classified as either shock events or stress events. The seismic hazard as it is known is considered as a shock event while the intensive rainfalls, which could lead to flooding events, and the snow hazard are considered as stress events.

Table (5.1) summarizes the previous chosen main concepts that help in initiating the resilience assessment framework for this study.

Table (5.1): Main Concepts of Resilience Assessment Framework

Natural hazard type	Shock event / stress event	Consequence scenario	Scale of assessment	Approach
Seismic hazard	Shock event	Regional event	Asset scale (Transportation infrastructure)	Specific hazard approach
Intensive rainfalls which could lead to flooding events	Stress event	Regional event		
Snowing hazard	Stress event	Regional event		

5.3 Risk Assessment Process

As mentioned in the literature, risk assessment is considered as the first step in transportation infrastructure resilience assessment, and it's a prerequisite step in the specific hazard approach, which is adopted in this research. This leads to help identify the desired level of resilience for the most probable natural hazard scenarios that could occur in Nablus City. For the current analysis, the qualitative risk analysis will be used.

Risk analysis involves developing and understanding of the overall risk that may result from each type of natural hazard and finally it provides an input to risk evaluation. This step is done through the HI of the three hazards and the resulted hazardous events for each, their causes, and consequences that may result on the transportation network of Nablus City. Thus, for the purpose of the risk analysis process, the data that were collected about natural hazards were integrated to propose a number of scenarios for each type of natural hazard based on appropriate classifications related to specific standards appertaining to each hazard.

The process of proposing the scenarios was firstly conducted through research of the country's disaster and emergency history, which helps in generating a list of known hazards. Such resources could provide dates, magnitudes, damages, and further evidence of past disasters in the Palestinian community. Secondly; through investigation of similar HI efforts in neighboring countries, as many disasters will extend beyond country borders, especially in the case of small countries or ones that share regional climatic or geologic characteristics, the neighboring countries are likely to share many of the same hazard risks. Finally; interviews with key stakeholders who are responsible of the management and safety of Nablus City CIs were conducted. Through the interviews, brainstorming sessions were conducted, which are of the most effective methods for HI studies. These sessions were used to reach for a satisfactory end point about each hazard and it's after effects on Nablus City transportation network

Causes and consequences are illustrated by employing Bow-tie models for each hazard by using Bow-tie XP Software in which this step help in proposing measures for increasing the resilience.

Each scenario proposed in the HI process was evaluated through the multi risk rating matrix including the four categories (people, assets, environment, and reputation), in which the assets reflect the transportation network situation related to the mentioned hazard scenarios.

The four categories are analyzed in this research because the effect of each type can’t be separated from the other. For example; when a disruption occurs and result in collapsing a part of the transportation network, the effect will clearly extend to people who are using this network, and the surrounding environment will also be affected through resulting in (environmental pollution as an example, if the sewage infrastructure existed under the transportation network is disturbed). In addition it will also clearly affect the reputation of the institutions responsible about the safety and management of this network.

This section is divided into three subsections, each subsection explains the risk assessment for each type of natural hazard through clarifying the two successive methods that perform the overall risk assessment, which are the risk analysis and the risk evaluation.

5.3.1 Risk Analysis and Evaluation for Seismic Hazard

The seismic hazard, which is the most severe hazard, can be identified based on earthquake magnitude, intensity, moment, or earthquake energy as mentioned in Chapter 4. The magnitude (M) in Richter Scale (RS) is used in the identification process as it is found to be the most suitable. Therefore, the seismic hazard is divided into 5 proposed scenarios as shown in Table 5.2. Each scenario is described based on the strength of destruction.

The next step is conducting the risk evaluation process for the proposed seismic hazard scenarios in Table (5.2), through a multi risk rating matrix that combined (people, assets, environment, and reputation) as described in Figure (5.1), in which the assets reflect the transportation network situation related to the mentioned seismic scenarios.

From Figure (5.1), it is shown that scenario #1 ($3.0<M<4.5$) that is likely to happen, has insignificant impact over the transportation network (green color).

Scenario #2 ($4.5<M<5.0$), has minor impact on the transportation network (yellow color) because slight to minor damages might be occurring in the lower ground layers (natural subgrade) of the road. This scenario could happen only if the epicenter of the earthquake is close to the city.

For scenario #3 ($5.0<M<6.0$), it might cause formation of cracks in the surface layer of the roads, partial settlement could be generated in poorly built roads, traffic interruption might happen, and some roads might be used by limited traffic. This scenario is classified to have moderate impact (orange color).

While for scenario #4 ($6.0<M<7.0$), which is the expected scenario that would happen in Palestine at any time in the near future (Dabbeek, 2010), it might cause failure of subgrade and sub base or fault rupture in roads thus big cracks and settlement will be generated. This will lead to roads closure and limitation for the movement of the emergency vehicles, in addition to the severe land sliding triggered events especially in areas with steep slopes. This scenario is classified to have severe damages (red color).

The last one, scenario #5 (M>7.0), which is unlikely to occur, is classified to result in severe damages (red color) as the roadbed could be washed away or slides (shifted on the horizontal or vertical plane or both). It should be noted that the European Commission matrix 2010 classifies the scenario with the severe damages, but unlikely to happen as a high risk level scenario (orange color). However, in this thesis it’s changed to a very high risk level (red color) as it’s more suitable for the analysis of Nablus City under the potential hazardous event that would result from this scenario.

Table (5.2): Seismic HI & the Probable Hazardous Events on Transportation Network in Nablus City

Proposed scenarios	**Scenario #1 (3<M<4.5)**	**Scenario #2 (4.5<M<5.0)**	**Scenario #3 (5.0<M<6.0)**	**Scenario #4 (6.0<M<7.0)**	**Scenario #5 (M>7)**
Description	Slight / perceptible	Rather strong*	Very strong	Destructive	Very disastrous-Catastrophic
Potential hazardous events on transportation network	- Felt by very few people indoors on upper floors of buildings. - **Negligible damages on transportation network.**	- Felt indoors by many, outdoors by few during the day. At night, some awakened. - **Slight to minor damages in the lower ground layers (natural subgrade) of the road.** - **Standing cars will shake noticeably**.	- Felt nearly by everyone. In some cases people frightened and run outdoors. - Sway of tall objects (trees, electricity poles) - **Formation of cracks in the surface layer of the roads.** - **Partial settlement generation in poorly built roads**. - **Traffic interruption/ some roads will be used by limited traffic**. - Moderate nonstructural damages, slight structural damages in structures. - **Indirect damages to roads from**	- Will be felt by everyone. Everyone will run outdoors/ people will be trapped in specific locations/ significant number of human losses. - **Significant disruption for moving cars/ limited movement of emergency vehicles.** - Substantial structural damages in poorly built or badly design structures/ slight to moderate structural damages in well-built structures. - **Blockage of roads due to debris of collapsed buildings and retaining walls**. - **Road closures due to failure of subgrade and sub base or fault rupture in roads thus cracks and settlement generation**.	-State of panic will be prevailed among people/ people will be trapped in specific locations/ uncountable number of human losses. - **Badly cracked ground; severe restrictions for post disaster emergency response.** - Debris found all around; buildings could be shifted from their foundations/ Severe structural damages in buildings. - **Total roads closure due to severe failure of subgrade and sub base or fault rupture, thus big cracks and settlement generation.** - **Total width of the road will be damaged.** - **Roadbed could be washed away or slides (shifted on horizontal or vertical plane**

			overturning and falling objects (ex. trees, electricity poles), or from collapsing of poorly built or badly designed retaining walls and buildings.	- Severe failure in underground storm and sewage systems in some areas. **- Severe land sliding triggered events especially in areas with steep slopes.**	**or both).** - Complete failure in underground storm and sewage systems. **- Ruinous land sliding triggered events.**

***Special case in some areas, when the epicenter of the earthquake is close to Nablus City.**

					Likelihood				
People	**Assets**	**Environment**	**Reputation**	**Impacts**	Very unlikely 1	Unlikely 2	Possible 3	Likely 4	Very likely 5
Multiple fatality	Extensive damage	Massive effect	International impact	5 Severe		**Scenario #5 (M>7.0)**	**Scenario #4 (6.0<M<7.0)**		
Single fatality	Major damage	Major effect	National impact	4 Major					
Major injury	local damage	Localized effect	Considerable effect	3 Moderate			**Scenario #3 (5.0<M<6.0)**		
Minor injury	Minor damage	Minor effect	Limited impact	2 Minor			**Scenario #2 (4.5<M<5.0)**		
No injury	No-Slight damage	No-Slight effect	Slight impact	1 Insignificant				**Scenario #1 (3<M<4.5)**	

Figure (5.1): Multi Risk Rating Matrix for Seismic Hazard in Nablus City

5.3.2 Risk Analysis and Evaluation for the Intensive Rainfalls Leading to Flooding Events

For the most probable hazard, which is the flooding event that could result from the intensive rainfalls, it can be identified based on various parameters as mentioned in Chapter 4. The standard that is suitable for the analysis process is the site parameter. Therefore, the flooding hazard is divided into 5 proposed scenarios based on the height (h) of the inundation roads in centimeters (cm) as in Table 5.3. Each scenario is described based on the capability of roads inundation. A multi risk rating matrix is described in Figure (5.2).

From Figure (5.2), it is shown that scenario #1 (1cm<h<5cm) is likely to happen, and has insignificant impact over the transportation network as it may cause slight interruption for the traffic flow (green color).

For scenario #2 (5cm<h<25cm), it has minor impact on the transportation network (yellow color) because moving vehicles might slip, and travelling may be prevented due to debris flow, which will act as barriers on roadways.

For scenario #3 (25cm<h<45cm), which is the probable scenario to occur in the city under the current conditions, some roads will be completely impassible due to debris flow; others experience very slow running traffic for hours, and some roads will be closed due to partial collapse of weak retaining walls located on street edges or on the near buildings. This scenario is classified to have moderate impact (orange color).

While for scenario #4 (45cm<h<65cm), this scenario could have moderate to major impact on the transportation infrastructure (orange color-red color). It will cause traffic stagnation and roads closure due to the generated floods with debris flow and due to street edges collapse form the high rise of accumulated rainfalls, which generates high pressure in the pavement itself and the street edges,.

The last one, scenario #5 (65cm<h<85cm), which is unlikely to occur, has severe impact on the transportation infrastructure as it will cause instability of road foundation due to the high rise of the accumulated rainfalls, and severe physical damages in the transport infrastructure, thus longer periods of roads closure. It should be noted that the European Commission matrix 2010 classifies the scenario with the severe damages, but unlikely to happen as a high risk level scenario (orange color). However, in this thesis it’s changed to a very high risk level (red color) as it’s more suitable for the analysis of Nablus City under the potential hazardous event that would result from this scenario.

The inaccessibility of inundated roads in scenarios 3, 4, and 5 could result in serious limitation for emergency management activities if there are no detour routes. This could cause indirect damage to the operability of strategic structures such as hospitals and fire stations.

An important factor that helps in these major impacts for scenarios 3, 4, and 5 in some areas, is that the intensive rainfall is coupled with inadequate, poorly maintained, and insufficient capacity in the drainage system.

Table (5.3): HI of Intensive Rainfalls that Could Lead to Flooding & the Probable Hazardous Events on the Transportation Network in Nablus City

Proposed scenarios	**Scenario #1 (1cm<h<5cm)**	**Scenario #2 (5cm<h<25cm)**	**Scenario #3 (25cm<h<45cm)**	**Scenario #4 (45cm<h<65cm)**	**Scenario #5 (65cm<h<85cm)**
Description	Weak capability	Minor capability	Moderate capability	Strong capability	Very strong capability
Potential hazardous events on transportation network	- No effect on people. **- Slight interruption for traffic flows.**	- Minor effect on people. **- Traffic interruption.** **- Slippage of moving vehicles might occur.** **- Slight possibility of pavement erosion.** **- Debris flow due to accumulated rainfalls will act as barriers on roadways and may prevent travelling until removed.**	- Major effect on people that could lead to injuries. **- Apparent disruption for the traffic flow.** **- Poor visibility due to development of spray behind vehicles (this could lead to traffic accidents especially during rush hours).** **- Some roads will be completely impassible due to debris flow; others experience very slow running traffic for hours.** **- Moderate possibility of pavement erosion.** **- Collapse of weak street edges.** **- Closure of some**	- Major effect on people that will lead to injuries or single fatalities. **- Strong traffic flow disruption / traffic stagnation.** **- Roads closure due to: generation of floods, debris flow, blowing down of different kind of objects and structures (ex. trees, weak retaining walls).** **- High possibility of pavement erosion and street edges collapse (due to the high rise of accumulated rainfalls, which generates high pressure in the pavement itself and the street edges).**	- Similar hazardous events like scenario #4, but in a stronger way. - Major effect on people that will lead to injuries or multiple fatalities. **- Instability of road foundation due to the high rise of the accumulated rainfalls.** **- Severe physical damages in the transport infrastructure.** **- Vehicles in the worst case will aquaplane and swept away by the generated floods and debris flow.** **- Longer periods of roads closure /traffic stoppage (serious limitation for emergency management activities).**

			roads due to partial collapse of weak retaining walls located on street edges or on the near buildings. - Environmental degradation due to additional fuel consumption of the slow moving vehicles thus additional CO_2 emissions. **- Land sliding triggered events especially under weak road edges.**	- Environmental pollution due to the possibility of sewage and rain water mix-up. **- Land sliding triggered events especially near weak road edges and behind weak retaining walls.**	**- Heavy pavement erosion.** **- Severe land sliding triggered events.**

					Likelihood				
People	**Assets**	**Environment**	**Reputation**	**Impacts**	Very unlikely 1	Unlikely 2	Possible 3	Likely 4	Very likely 5
Multiple fatality	Extensive damage	Massive effect	International impact	5 Severe		**Scenario #5 (65cm<h<85 cm)**			
Single fatality	Major damage	Major effect	National impact	4 Major			**Scenario #4 (45cm<h<65cm)**		
Major injury	local damage	Localized effect	Considerable effect	3 Moderate			**Scenario #4 (45cm<h< 65cm)**	**Scenario #3 (25cm<h< 45cm)**	
Minor injury	Minor damage	Minor effect	Limited impact	2 Minor				**Scenario #2 (5cm<h< 25cm)**	
No injury	No-Slight damage	No-Slight effect	Slight impact	1 Insignificant					**Scenario #1 (1cm<h< 5cm)**

Figure (5.2): Multi Risk Rating Matrix for Intensive Rainfalls that Could Lead to Flooding Events in Nablus City

5.3.3 Risk Analysis and Evaluation for Snowing Hazard

The last hazard is the snowing hazard, which is the least probable hazard. It can be identified based on various parameters as mentioned in Chapter 4. The suitable standard for the analysis process is the site parameter. Therefore, the snowing hazard is divided into 5 proposed scenarios based on the depth (d) of the accumulated snow in roads in centimeters (cm) as shown in Table 5.4. Each scenario is also described based on the depth of accumulated snow and the multi risk rating matrix is described in Figure (5.3).

From Figure (5.3), it is shown that scenario #1 (1cm<d<5cm) is likely to happen, and has insignificant impact over the transportation network (green color). It may cause some interruption for the traffic flow and some vehicles may slip due to the icy layer formed due melting of shallow snow layer if the road not salted.

However, scenario #2 (5cm<d<20cm), is likely to happen and has minor impact on the transportation network (yellow color). It will result in reduction in road surface friction, which negatively affects the driving conditions, thus slippage of vehicles, reduction of road capacity, and increasing the travel time due to partial closure of roads due to snow accumulation.

For scenario #3 (20cm<d<35cm), which is possible to happen, is classified to have moderate impact on transportation infrastructure (orange color). It will result in total closure of roads in mountainous areas, thus roads capacity reduction, in addition to roads closure in other areas due to fallen objects.

While for scenario #4 (35cm<d<50cm) it could have moderate impact on the transportation infrastructure (orange color). It will result in deterioration of roadway network performance, cracks formation on the surface layer of the roads, possibility of pavement erosion, and collapse of weak road sides and road layers failure due to snow accumulation, which generates high weight on roads.

The last one, scenario #5 (d>= 50cm), which is unlikely to occur, but has severe impact, as it will cause the road network to be totally inaccessible, if the snow removal process is insufficient.

It should be mentioned that the time at which the snow storm occurs can impact its effects. A storm during a working day rush hour is more difficult to resist than the storm during a weekend. Also high winds conditions during the snow storm can add up to a depth many times more than what actually fell, as the wind will result in drifting snow. Finally, the temperature at the time of the storm will also affect the nature of its results, as if the storm is accompanied with low temperatures, the required removal effort will increase and therefore long periods for roads closures and serious restrictions for emergency activities.

Table (5.4): Snowing HI & the Probable Hazardous Events in the Transportation Network in Nablus City

Proposed scenarios	**Scenario #1 (1cm<d<5cm)**	**Scenario #2 (5cm<d<20cm)**	**Scenario #3 (20cm<d<35cm)**	**Scenario #4 (35cm<d<50cm)**	**Scenario #5 (d>= 50cm)**
Description	Light snow	Moderate snow	Strong snow	Extreme snow	Exceptional snow
Potential hazardous events on transportation network	- No direct effect on people. **- Traffic flow interruption**. **- Vehicles slippage due to the icy layer formed by the melt of shallow snow layer.**	**- Reduction in road surface friction, which negatively affect the driving conditions / vehicles slippage.** **- Reduction of road capacity and increasing in the travel time due to partial closure of roads.** **- Occurrence of Property Damage Only (PDO) crashes due to the glaring light of vehicles.** **- Occurrence of serious chain collision accidents, which leads to human injuries.** - Environmental pollution due to more car fuel consumption.	**- High traffic disturbance with high accident rates due to snowfall accumulation.** **- Traffic movement constraints due to snow fog and accumulation.** **- Total closure of roads in mountainous areas, thus roads capacity reduction.** **-Roads closure due to fallen objects (ex. electricity poles and trees).**	- No accessibility for specific locations/ people may be trapped in these locations. **- Deterioration of roadway network performance.** **- Cracks formation on the surface layer of the roads.** **- Possibility of pavement erosion.** **- Collapse of weak road sides and road layers failure due to snow accumulation,** thus failure in underground networks leading to environmental pollution. **- Roads closure due to failure of weak retaining walls and the fallen objects (ex. electricity poles and trees).** **- Moderate land sliding triggered events especially under weak road edges.**	-Similar hazardous events like scenario #4, but in a stronger way. **- The road network will be totally inaccessible.** **- Cracks formation on the top layers of the roads.** **- High possibility of pavement erosion.** - Severe damages for properties and infrastructures. **- Serious land sliding triggered events especially under weak road edges and in areas with steep slopes.**

					Likelihood				
People	**Assets**	**Environment**	**Reputation**	**Impacts**	Very unlikely 1	Unlikely 2	Possible 3	Likely 4	Very likely 5
Multiple fatality	Extensive damage	Massive effect	International impact	5 Severe					
Single fatality	Major damage	Major effect	National impact	4 Major		**Scenario #5 (d>= 50cm)**			
Major injury	local damage	Localized effect	Considerable effect	3 Moderate			**Scenario #4 (35cm<d< 50cm)**		
Minor injury	Minor damage	Minor effect	Limited impact	2 Minor			**Scenario #3 (20cm<d< 35cm)**	**Scenario #2 (5cm<d< 20cm)**	
No injury	No-Slight damage	No-Slight effect	Slight impact	1 Insignificant					**Scenario #1 (1cm<d<5cm)**

Figure (5.3): Multi Risk Rating Matrix for Snowing Hazard in Nablus City

5.4 Resilience Assessment Process

The previous section reflects a wide range of potential natural hazard scenarios that Nablus City could be exposed to. A number of them had previously happened in the city and some of them are unlikely to happen, but all of them must be understood to help identify where to focus further efforts. HI tables show that the consequences of natural hazards would not only affect the transportation network itself, the effects will extend to reach all parts of network as it is a complex integrated infrastructure system. The results of the risk assessment help in initiating the resilience assessment, which is explained in the following two sections.

The first section measures the desired level of resilience of Nablus City transportation infrastructure based on risk assessment results. The second section measures the existing level of resilience for it.

5.4.1 Desired Level of Resilience for Nablus City Transportation Infrastructure

Within the previous multi risk rating matrices, the scenarios with the highest risk were illustrated. This help in building a multi hazard risk matrix (Figure 5.4) combining the three identified hazard, in which from this matrix, the desired level of resilience against each hazard would be specified through the translation of the resulted risk to desired level of resilience as shown in Table 5.5.

					Likelihood				
People	**Assets**	**Environment**	**Reputation**	**Impacts**	Very unlikely 1	Unlikely 2	Possible 3	Likely 4	Very likely 5
Multiple fatality	Extensive damage	Massive effect	International impact	5 Severe			**Seicmic hazard**		
Single fatality	Major damage	Major effect	National impact	4 Major			**Siesmic hazard**		
Major injury	local damage	Localized effect	Considerable effect	3 Moderate			**Snowing hazard**	**Intensive rainfalls leading to flooding events**	
Minor injury	Minor damage	Minor effect	Limited impact	2 Minor			**Snowing hazard**	**Intensive rainfalls leading to flooding events**	
No injury	No-Slight damage	No-Slight effect	Slight impact	1 Insignificant					

Figure (5.4): Resultant Multi Hazard Risk Matrix for Nablus City

Table (5.5): Desired Level of Resilience for Nablus City Transportation Infrastructure against Natural Hazards

Hazard type	Risk level	Desired level of resilience
Seismic hazard	Very high	Very high
Intensive rainfalls leading to flooding events	High-Moderate	High-Moderate
Snowing hazard	High-Moderate	High-Moderate

The process of translating the resulted risk score to desired level of resileince was based on the concept that the risk level is the opposite of the resilience level. Figure (5.5) illustartes this concept through the adopted two scales for risk and resilience.

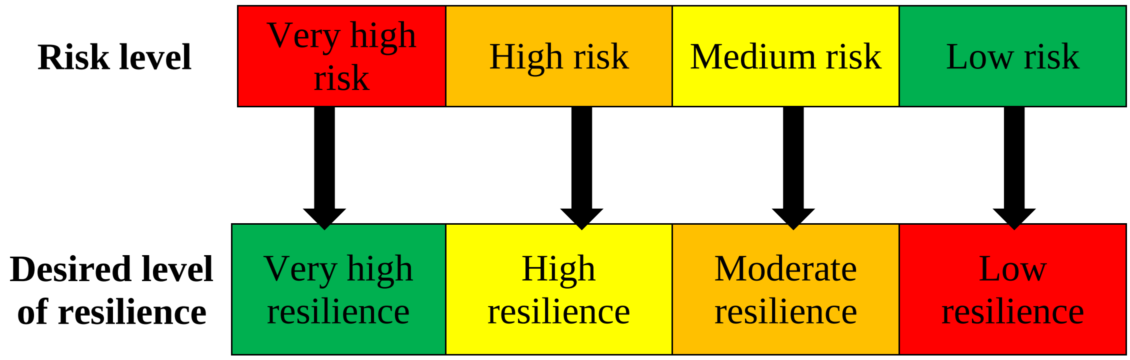

Figure (5.5): The Concept of Translating Risk Levels to Desired Level of Resilience

5.4.2 Resilience Assessment for Nablus City Transportation Infrastructure

This section illustrates proposing a qualitative framework for measuring the current resilience of the transportation infrastructure against the identified natural hazards for Nablus City at a macro-scale level.

Spreadsheets with a number of measurement categories related to the selected dimensions and principles is developed. Each dimension is evaluated through a set of principles, and each principle is evaluated through a set of measures, which have number of measurement items. This is done through giving each item a score of (0=low resilience, 1=moderate resilience, 2=high resilience, 3=very high resilience). This will give the overall resilience score for each dimension, which will lead to the overall current resilience score.

The two main evaluated dimensions are the technical and the organizational dimensions, as they are the only dimensions to be utilized in measuring the resilience of transportation infrastructure.

Table 5.6 illustrates the principles and the measures used to evaluate the technical resilience, and Table 5.7 illustrates the principles and the measures used to evaluate the organizational resilience.

Table (5.6): Principles and Measures for Technical Resilience Evaluation

Principles	Measures
Robustness	Maintenance, renewal, design (standard and codes)
Redundancy	Awareness of redundancy issues (exposure and vulnerability), network redundancy, alternate routes
Safe to fail	Design, detection tools

Table (5.7): Principles and Measures for Organizational Resilience Evaluation

Principles	Measures
Leadership and culture	Leadership, awareness, decision making
Networks	Internal resources, external relationships, leveraging knowledge
Change readiness	Communication and warning, information and technology, emergency planning strategies, recovery and response priorities

The scores for the measurement items were assigned by 18 expert persons through the in-depth interviews with the stakeholders who are responsible of the management and safety of Nablus City's CIs as included in **Appendix D**. Nine stakeholders were interviewed as following:

1. Head of Nablus Municipality and Nablus Municipality Engineering Department.
2. Head of the Emergency Committee and Emergency Committee Coordinator.
3. Director of the Fire Department and the representative of the Emergency Committee on it.
4. Head of the Red Crescent and the representative of the Emergency Committee on it.
5. Director of Nablus City Civil Defense and the Risk Management Unit on it.
6. General Director of the Electricity Company and the representative of the Emergency Committee on it.
7. General Director of the Telecommunications Company, Engineering Department and the representative of the Emergency Committee on it.
8. Director of Nablus City Police Department and the Director of the Traffic Department.
9. Director of the Public Works Directorate.

Through the interviews, a review by the researcher about the main topic of the assessment spreadsheets was performed, a discussion about each item was conducted, and finally a score for each item was assigned.

Table 5.8 summarizes the results for the assessment; full assessment spreadsheets are included in **Appendix (D)**.

As shown in the table, the result of the assessment shows that the technical resilience has a score of 1.21, which is in the range of moderate resilience, while the organizational resilience has a score of 1.68, which is in the range of high resilience.

The current overall resilience score is 1.45, which means Nablus City transportation infrastructure has a moderate resilience against natural hazards.

Table (5.8): Summary of Resilience Scores

Score	Low resilience 0.00-0.50	Moderate resilience 0.51-1.50	High resilience 1.51-2.50	Very high resilience 2.51-3.00

	Dimension	Principle	Principles average score	Dimension average score	Total resilience score
Summary of resilience assessment	1. Technical resilience	Robustness	1.76	1.21	1.45
		Redundancy	0.93		
		Safe to fail	0.94		
	2. Organizational resilience	Leadership and culture	1.64	1.68	
		Networks	1.71		
		Change readiness	1.69		

It is concluded that there is a gap between the desired level resilience, which was measured in the previous section and the current level of resilience for the seismic hazard as it requires a very high level of resilience. Therefore, interventions are required to improve the score, both in the technical and organizational sense.

While for the intensive rainfalls, which could lead to flooding events, and the snowing hazard, the current score is on the begining of the range required, as these hazards require moderate to high level of resilience. Therefore, interventions must be firstly addressed for the technical resilience, then further improvement must be addressed to the organizational resilience.

The spreadsheets also clarified the weaknesses aspects related to each dimensions, in which further interventions and improvements must be specifically addressed. These are with the red color (low resilience) and orange color (moderate resilience).

In the technical dimensions, the weaknesses are in the following measures:

1. Redundancy issues (exposures and vulnerabilities).
2. Lack of plans to establish diversions to alternate routes when failure of critical link occurs.
3. Significant losses for the city transportation network when exposed to the major scenarios of natural hazards.

4. Lack adaptation of safe to fail design, which relates to minimize the disruption for other parts of the infrastructure when one component of the integral system fails.

5. Lack of failure detection tools.

While weaknesses in the organizational resilience are:

1. Lack of natural hazards maps and risk profiles.

2. Lack of protected budget and budget plans to reduce the risk result from natural hazards and their impacts on the transportation network.

3. Insufficient equipment for emergency and response activities.

4. Lack of coordination and responsibilities allocation between stakeholders during the event.

5. Lack of database platforms for natural hazards.

6. Insufficient post event recovery plans.

7. Absence of early warning systems, which help in allowing time for reaction before the hazard.

5.5 Building Resilience of Nablus City Transportation Infrastructure

As shown in the previous section, there is a clear difference between the desired and the current level of resilience against the identified natural hazards; methods on how to increase the level are illustrated on this section.

For achieving this goal, there must be a better understanding for the causes (threats) of these hazards, the factors that could lead to increasing the risks resulted, and the control and the adaptation measures (proactive and reactive) that could prevent or mitigate the threats, and the consequences of the resulted hazardous event must be proposed. This is done using the Bow-tie models as shown in the following three sections.

Bow-ties show that there is a wide range of prevention and mitigation measures that could be adopted to reduce the risk resulted from these hazards on the transportation infrastructure and to increase the resilience against these hazards. These are summarized in the following paragraphs for each hazard.

5.5.1 Increasing Resilience against Seismic Hazard

Figure (5.6) shows various measures to be adopted against seismic hazards as follows.

Measures to be adopted before the event:

1. Existence of national disaster management plans / sufficient preparedness.
2. Existence of efficient alarming system.
3. Emergency management plans and contingency funding.
4. Risk assessment and scenario planning.

5. Compulsory seismic design codes.

6. Existence of seismic database platform.

7. Increase education and awareness between people towards seismic hazards and how to react when these event occurs.

8. Maintenance of roads through redesign the vulnerable parts and through add admixtures for the existed old cracks.

9. Strict monitoring and control measures for the implementation of roads, buildings and retaining walls.

Measures to be adopted during and after the event:

1. Efficient crisis design making.

2. Effective coordinated emergency response.

3. Training emergency teams efficiently to be ready for response.

4. Existence of sufficient emergency equipment.

5. Existence of sufficient recovery and evacuation plans.

6. Pre-identification of priority routes; which should have quick emergency response; these routes must be the ones that lead to strategic structures such as hospitals and evacuation sites.

7. Efficient debris removal management for the partially or totally closed roads.

8. Pre-determination of alternative roads for emergency use.

9. Sufficient environmental emergency response for the places that could suffer from environmental pollution due to the hazard occurrence, which requires specialized trained teams. This could be done through pollution containment and area insulation in these places.

In the case of seismic hazard occurrence, if these measures are suitably addressed, the after effect of the seismic hazard could be reduced because such hazard can’t be prevented but could be controlled by these measures.

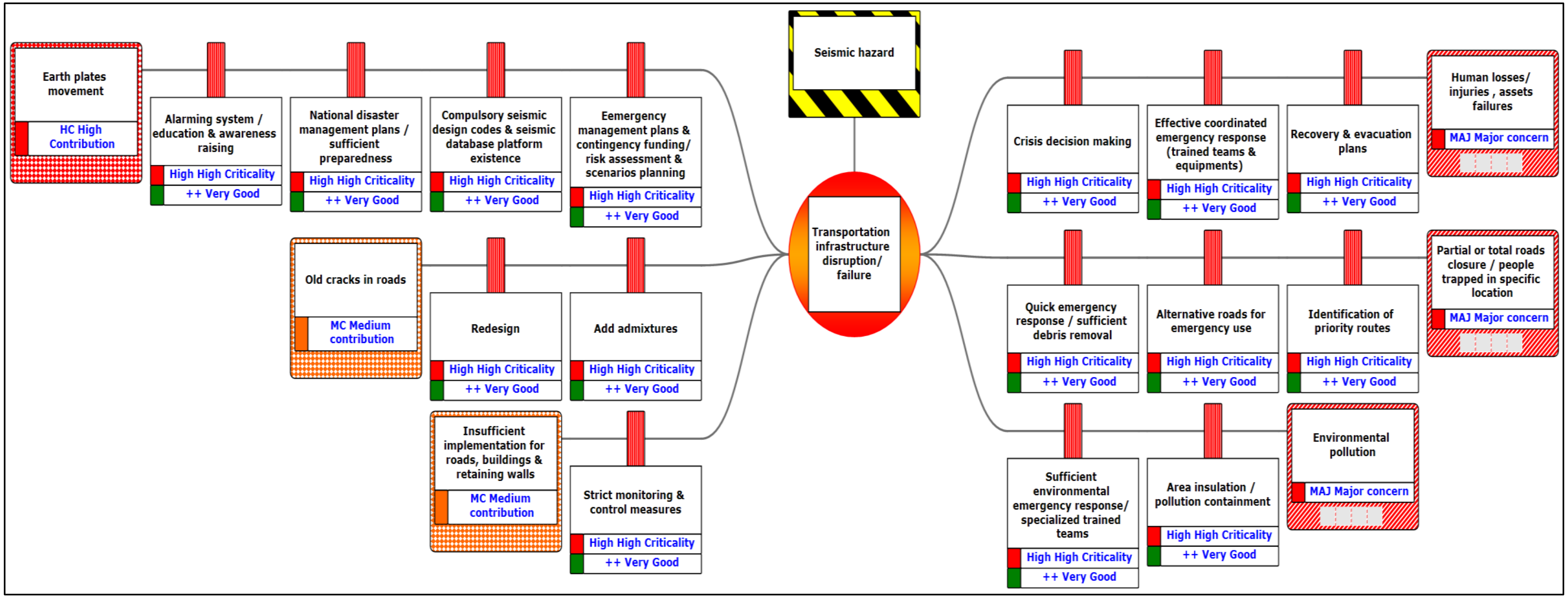

Figure (5.6): Bow-Tie Model for the Seismic Hazard for Nablus City

5.5.2 Increasing Resilience against Flooding events

Figure (5.7) shows various measures to be adopted against flooding events as follows.

Measures to be adopted before the event:

1. Existence of flood risk management plans / sufficient preparedness.
2. Efficient storm water management regulations and land use planning and zoning.
3. Sufficient storm drainage design and codes implementation.
4. Efficient weather forecasting systems.
5. Existence of efficient alarming system which allow time for reaction before the hazard.
6. Regular maintenance and checks for manholes and storm culverts.
7. Build flood database platform.
8. Increase education and awareness between people towards flooding events and how to react when these event occurs.
9. Appropriate implementation of sufficient storm drainage systems and right distribution of these systems.

Measures to be adopted during and after the event:

1. Effective coordinated emergency response.

2. Training emergency teams efficiently to be ready for response.

3. Existence of sufficient emergency equipment.

4. Existence of sufficient evacuation plans for risk areas.

5. Existence of sufficient recovery plans.

6. Pre-identification of alternative roads for traffic movements.

7. Planning of temporary flood proofing; ex. sandbags.

8. Sufficient environmental emergency response for the places that could suffer from environmental pollution due to the hazard occurrence, which requires specialized trained teams. This could be done through pollution containment and area insulation in these places.

9. Quick debris removal for roads, which could suffer from debris flow and could limit from the traffic movement.

10. Existence of detour roads that traffic could use.

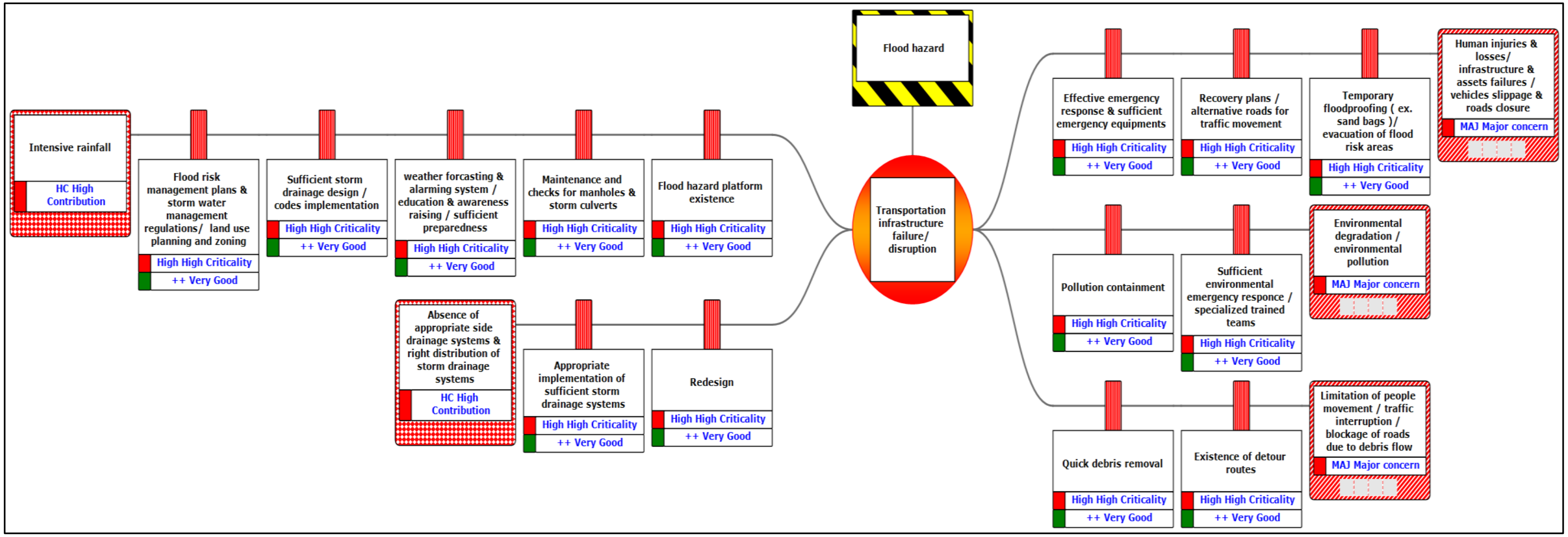

Figure (5.7): Bow-Tie Model for the Flooding Hazard for Nablus City

5.5.3 Increasing Resilience against Snowing Hazard

Figure (5.8) shows various measures to be adopted against snowing hazard as follows.

Measures to be adopted before the event:

1. Appropriate distribution of snow removal vehicles.
2. Sufficient preparation for sanding and salting operations, which could help in reducing the accumulation of the snow.
3. Efficient weather forecasting systems.
4. Existence of efficient alarming system, which allow time for reaction before the hazard.
5. Build snow database platform.
6. Increase education and awareness between people towards snowing hazards and how to react when these event occurs.
7. Protection for open areas against strong wind events that could happen through the snow storm, and result in drifting snow phenomenon.
8. Maintenance of roads through redesign the vulnerable parts and through add admixtures for the existed old cracks.
9. Redesign of roads with insufficient right of way/ insufficient road width.

10. Strict monitoring and control measures for the implementation of roads, buildings and retaining walls.

Measures to be adopted during and after the event:

1. Efficient response of related authorities.
2. Effective coordinated emergency response.
3. Training emergency teams efficiently to be ready for response.
4. Existence of sufficient snow removal and emergency equipment.
5. Pre-identification of priority routes (emergency snow removal routes) which should have quick snow removal; these routes must be the ones that lead to strategic structures such as hospitals and fire stations.

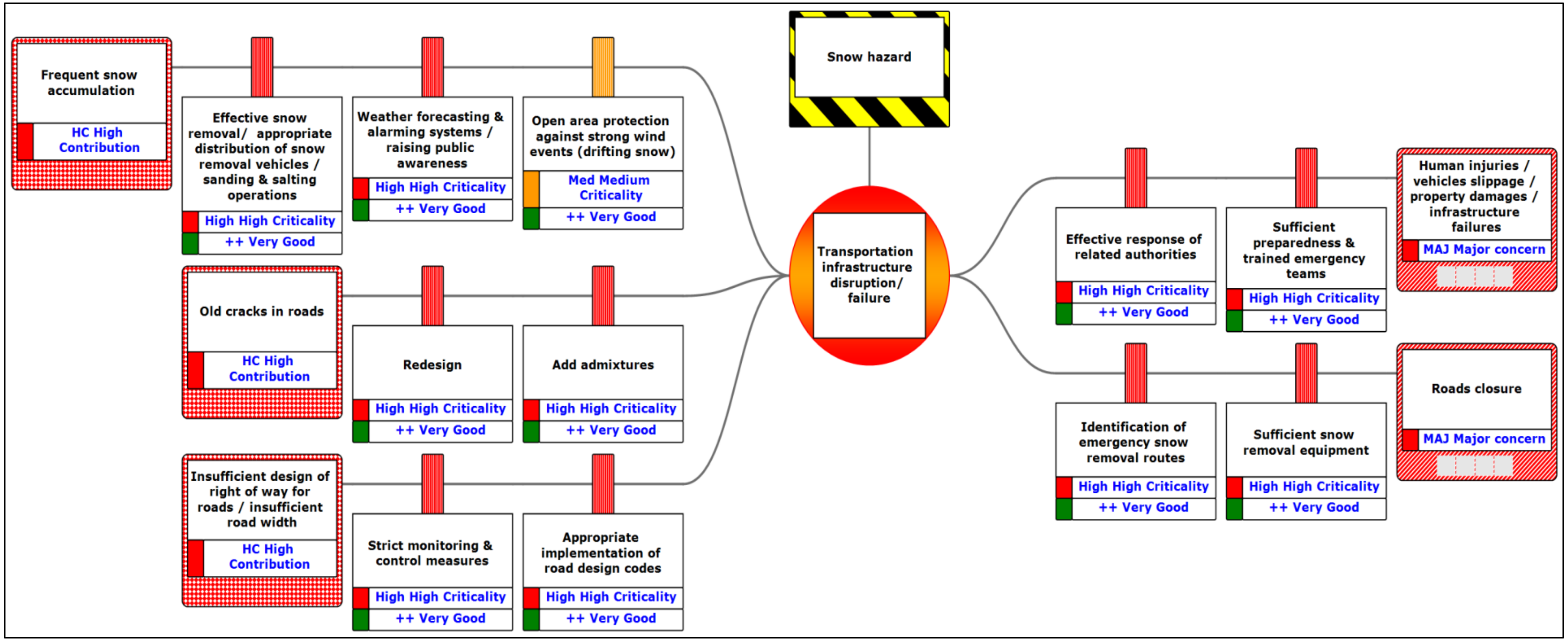

Figure (5.8): Bow-Tie Model for the Snowing Hazard for Nablus City

5.6 Summary of the Proposed Framework

One of the objective for this research is to develop a framework for assessing the resilience of the transportation network at macro-scale level. All the steps that have been taken to develop this framework were detailed in the previous sections. Figure (5.9) summarizes these steps and illustrates the developed framework.

The resulted framework includes six basic phases, in which each phase contains a number of steps in order to be performed. The core phases of this framework are the risk assessment in which without it, the desired level of resilience can’t be measured, and the resilience assessment in which developing the spreadsheets form the major challenge on it.

It should be noted that this framework is considered applicable to assess the resilience of any kind of critical infrastructure against any type of hazard it would be exposed to.

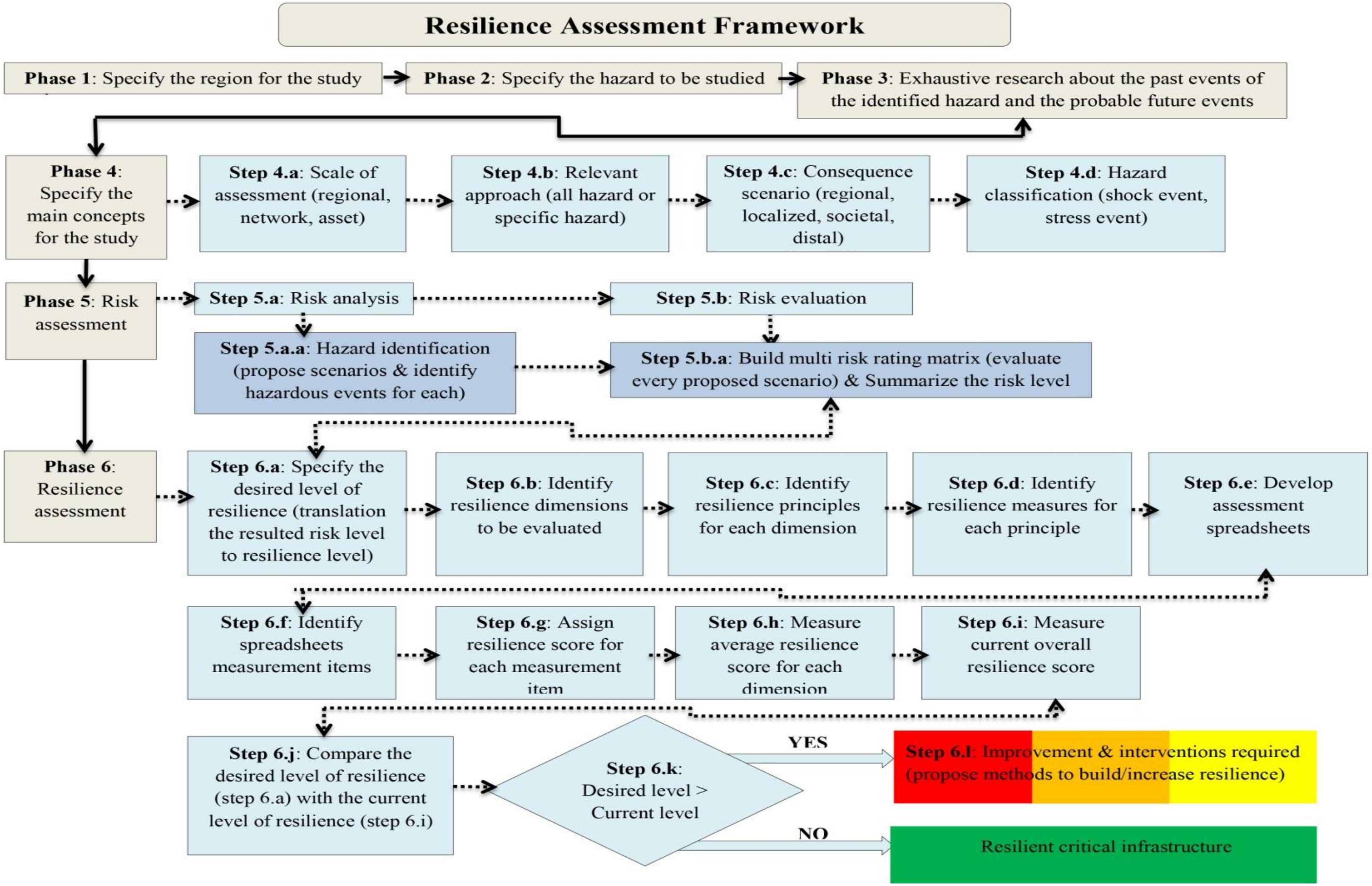

Figure (5.9): Proposed Framework for Resilience Assessment

Chapter Six

Conclusions and Recommendations

Chapter Six
Conclusions and Recommendations

6.1 Conclusions

Over the past decades, the Palestinian areas experienced various types of natural hazards such as earthquakes, snow, flood, and landslides with various levels of severity ranging from minor to disastrous. Nablus City transportation infrastructure is threatened to be exposed to serious risks that could result from these hazards. The integrity and safety of the transportation infrastructure could be achieved through building and increasing its resilience against these hazards. This research helps in qualitatively evaluating the resilience of Nablus City transportation infrastructure at the macro-scale level under various ranges of natural hazards scenarios. A multi hazard risk matrix was developed to evaluate the risk level resulted from each identified natural hazard (seismic, flooding, snowing) to reach for the desired level of resilience that must be exist for Nablus City transportation infrastructure to be resilient against these hazards. Afterwards; special spreadsheets were developed including specific measures to evaluate the existing level of resilience.

Based on the data collected and analysis, the followings are the main research conclusions:

1. The climate change has a significant effect on increasing the probability of natural hazard occurrence on Palestine as it is part of the Middle East. It is considered as a main contributor that would result in generating more extreme weather conditions.

2. Through the past decades, Nablus City as part of the Palestinian areas was exposed to a wide range of natural hazards scenarios ranging from severe and major events to moderate and minor events. Each has resulted in specific effects, which directly affect the transportation network.

3. Nablus City will encounter serious difficulties in the process of evacuation and emergency response through severe natural hazards events as it has certain peculiarity in terms of location, which clearly reflects on the transportation networks.

4. The risk assessment process forms a major part of the resilience assessment for the transportation network. It is highly overlapping through all the evaluation steps.

5. The resulted hazard identification tables introduced a wide range of potential hazardous events that Nablus City could be exposed to. A number of them had previously happened in the city and some of them are unlikely to happen, but all of them must be understood to help identify where to focus further efforts. Hazard identification tables show that the consequences of natural hazards would not only affect the transportation network itself, the effects will extend to reach all part of network as it is a complex integrated infrastructure system. These tables help in providing hazard and disaster information where and when it is needed and can be used for more detailed risk analysis and transport infrastructure protection.

6. The scenarios with the highest risk were illustrated through the multi risk rating matrices. This gives an overall risk pictures for decision makers to compare and evaluate these potential hazards scenarios, set priorities on what kinds of mitigations are possible, and set priorities on where to focus the resources and further study. The lack of preparedness and mitigation measures will lead to severe consequences on Nablus City transportation network especially in the case of seismic hazard.

7. The resulted multi hazard risk matrix combined the three identified hazards and demonstrated that the hazard with the highest risk that Nablus City would be exposed to is the seismic hazard, while the flooding and snowing hazards have a moderate to minor risk level.

8. The desired level of resilience against seismic hazard for Nablus City transportation infrastructure must be very high resilience, while a high to moderate level of resilience must exist against flooding and snowing hazards.

9. The main two resilience dimensions that were evaluated to reach for the existing level of resilience for the transportation infrastructure are the technical and the organizational resilience. The technical dimension was related to the physical characteristics of the transportation network and was evaluated through robustness, redundancy, and safe to fail principles. The organizational dimension was related to the capacities of the institutions and organizations to manage the physical

components of the transportation infrastructure, and plan and respond to any potential hazard event. It was evaluated through leadership and culture, networks, and change readiness principles.

10. Developing the assessment spreadsheets is a crucial part of resilience assessment and forms a major challenge in the resilience assessment process, as they must directly address the core issues for each identified resilience dimension through evaluating their main principles. These spreadsheets can't be answered by the researcher, instead they must be answered by the discussion with the stakeholders responsible for the management and the safety of the city's critical infrastructures.

11. Nablus City transportation infrastructure has a moderate technical resilience against natural hazards, while it has a high organizational resilience. It should be noted that the spreadsheets were answered by the responsible stakeholders based on their experiences and on the events they encountered in their lives. This would impact the quality of the final results.

12. The overall existing resilience for Nablus City transportation infrastructure is moderate resilience against natural hazards.

13. There is a gap between the existing level of resilience and the desired level of resilience. Therefore, interventions and improvements are required. For the seismic hazard interventions are required to improve the level of resilience both in technical and organizational sense. For the flooding and the snowing hazards, interventions must be firstly

addressed for the technical resilience of the transportation network, and then further improvement must be addressed to the organizational resilience.

14. The weaknesses that resulted in decreasing the existing level of resilience for Nablus City transportation network both in technical and organizational levels were explored through the assessment spreadsheets. This helps the decision makers to start mobilizing the efforts to set priorities on which aspects they would start working on to improve the current situation of the network.

15. Bow-tie models were built for each hazard, they help in proposing methods to improve the level of resilience. Measures to be adopted before, during, and after each natural hazard event were proposed. These methods concentrate on establishing disaster preparedness, coping and management plans, which emphasize on the preparedness and in developing hazard mitigation measures and strategies, and through increasing and promoting knowledge, risk wise behavior, and awareness towards such events. The measures involve an increase in the robustness of the transportation network as well as measures involving protection of the network. Roads inaccessibility during any emergency management activities could cause indirect damages to the operability of strategic structures, such as hospitals and fire stations, thus; increase the probability of losses.

16. The resilience assessment framework developed in this research could be used by decision makers as part of a municipal risk and resilience analysis and can be used and adopted on different scales to different critical infrastructures against various natural hazards scenarios. It could contribute to targeted investment in planning and design and facilitate preparedness actions in the event of failure.

17. The researcher concluded that there is a rapid growth of thinking and research pertaining to resilience of transportation infrastructures around the world, and that resilience assessment require new thinking and a departure from existing practices. On the other hand, resilience and risk assessment studies for transportation networks when exposing to disturbed events are marginalized in Palestine. As these studies help in providing a comprehensive picture for decision makers to choose appropriate emergency actions, feasible solutions, and improvement strategies for the current situation of the existing transport infrastructure in Palestinian cities.

6.2 Recommendations

The results of this research are valuable and can be developed to be comprehensive and reliable for decision makers and risk management experts. Based on the outcomes of this research, the following can be recommended:

1. There is an urgent need to increase the resilience of Palestinian transport infrastructure as part of the critical infrastructure integrated

system through adopting suitable control measures and increasing the communities' capacities and readiness to cope with natural hazards and their consequences at all levels. This will reduce the probability of the transportation infrastructure malfunctioning in the most efficient way in cases of disasters.

2. The outputs of this research are recommended to be adopted locally by Nablus City stakeholders to develop natural hazards mitigation, adaptation, recovery, and emergency plans.

3. Contingency funding plans must be suitably addressed.

4. Protected budget and budget plans must be found to reduce the risk resulted from natural hazards on the transportation network.

5. Increase the organizational resilience through improving their ability and speed to manage crises effectively, building risk management units in every organization to monitor and plan for potential natural hazards events, and improving the coordination and the responsibilities allocation between them.

6. Increase public awareness towards such events through emphasizing the safety measures. This could be done through education, knowledge, and training programs.

7. Build a national platform database for every natural hazard, containing the past events, time of every event, and effects and consequences. And

ensure that the relevant information will be accessible and available at all levels.

8. Further scenario planning for natural hazards events and their potential consequences on transportation networks should be explored by the relevant authority.

9. Identification of priority, emergency, and alternative routes, which should have quick emergency response in the time of the event. These may include providing access to critical community facilities (ex. hospitals).

10. Improve the prevailing construction system in the city to be more consistent with design codes. As the absence of spaces between the buildings will increase the risk level in the case of seismic hazards, and the narrow and the limited width of the roads will increase the risk level in the case of seismic, flooding, and snowing hazards.

11. Permanent maintenance and checks for the road network to improve the vulnerable parts that could fail during disturb events.

12. Strict monitoring for the design and implementation of roads, buildings, retaining walls, and storm drainage systems.

13. Implement warning systems and failure detection tools for each natural hazard.

14. Encourage critical infrastructure resilience related researches.

6.3 Recommendations for Future Work

1. The thesis provide a qualitative risk assessment for natural hazards that Nablus City would be exposed to, the outputs could be used to develop a quantitative risk assessment study for these hazards.

2. Investigate the expected impacts and consequences resulted from different climate change indicators and their potential effects on the transportation infrastructure.

3. Further detailed study for each natural hazard alone and its potential consequences on factors related to the transportation network, this could include studying the change in travel time, delay, level of service, demand, and capacity.

4. Divide Nablus City for a number of zones, and study each zone under natural hazards scenarios at the micro level.

5. Develop natural hazards maps and risk profiles for Nablus City and its zones.

6. Develop a framework to assess the resilience of the transportation network quantitatively.

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Appendices

Appendix (A)

Maximum Daily Rainfall / Month

For Nablus City (1955-2018)

Year	Month	Maximum Daily Rainfall/month (mm)
1955	01	13.5
1955	02	21
1955	03	21.8
1955	04	17.5
1955	10	3
1955	11	91.5
1955	12	59
1956	01	43
1956	02	16.5
1956	03	25
1956	11	11.4
1956	12	38.2
1957	01	31.9
1957	02	38
1957	03	34.5
1957	04	6.3
1957	10	49
1957	11	21.5
1957	12	73
1958	01	89
1958	02	5
1958	03	7.5
1958	04	18.2
1958	11	2.6
1958	12	9.9
1959	01	64.2
1959	02	67
1959	03	27.3
1959	04	0.3
1959	09	24.2
1959	11	16.6
1959	12	57.5
1960	01	64.2
1960	02	8.6
1960	03	51

1960	04	11
1960	11	28
1960	12	24.4
1961	01	28.3
1961	02	43.6
1961	03	14
1961	04	26.2
1961	05	4.9
1962	-	-
1963	-	-
1964	-	-
1965	01	44.6
1965	02	18.8
1965	03	23.6
1965	04	30.3
1965	10	16.9
1965	11	14.1
1965	12	41.4
1966	01	22.7
1966	02	47.6
1966	03	42.8
1966	04	0.6
1966	10	3.5
1966	11	5.8
1966	12	54.9
1967	01	58.2
1967	02	27
1967	03	48.5
1967	04	6.4
1967	10	14.3
1967	11	-
1967	12	29.5
1968	01	84
1968	02	29
1968	03	9.1
1968	04	5.8
1968	12	49.4
1969	01	36.6
1969	02	26.4
1969	03	27.6
1969	04	13.2
1969	10	11.6
1969	11	11
1969	12	22.5

1970	01	25.8
1970	02	26
1970	03	40
1970	04	15
1970	09	8.5
1970	10	3.2
1970	11	2.4
1970	12	31.2
1971	01	35.1
1971	02	27.3
1971	03	11
1971	04	81.7
1971	11	27.1
1971	12	35.9
1972	01	35.5
1972	02	43.2
1972	03	42.2
1972	04	19.1
1972	10	1
1972	11	12.5
1972	12	22.6
1973	01	55.8
1973	02	12.4
1973	03	50.2
1973	04	8.3
1973	05	11.2
1973	10	16.3
1973	11	66.2
1973	12	26.6
1974	01	67.9
1974	02	29.8
1974	03	10
1974	04	14.3
1974	11	18.7
1974	12	54.8
1975	01	21.3
1975	02	51.2
1975	03	39.2
1975	04	1.5
1975	09	15.1
1975	10	2.6
1975	11	62.7
1975	12	31.2
1976	01	23.4

1976	02	28.4
1976	03	52.9
1976	04	7.7
1976	09	0.2
1976	10	18.2
1976	11	66.8
1976	12	10.8
1977	01	64.7
1977	02	27.3
1977	03	36.3
1977	04	23.4
1977	05	1.5
1977	10	30.7
1977	11	1.7
1977	12	51.9
1978	01	46.2
1978	02	17.5
1978	03	28.7
1978	04	7.9
1978	10	8.3
1978	11	2.9
1978	12	41
1979	01	45.1
1979	02	6.3
1979	03	31.1
1979	04	5
1979	08	1.4
1979	10	14.1
1979	11	114.8
1979	12	54.9
1980	01	24.2
1980	02	37.3
1980	03	98.9
1980	04	12.8
1980	09	0.4
1980	10	7.7
1980	11	3.4
1980	12	74.5
1981	01	51.4
1981	02	43
1981	03	17.6
1981	04	11.2
1981	11	38.9
1981	12	8.4

1982	01	59.1
1982	02	45.3
1982	03	23.9
1982	04	2.6
1982	05	1.7
1982	10	10.3
1982	11	46.1
1982	12	52.8
1983	01	59.1
1983	02	67.2
1983	03	72.9
1983	04	6.4
1983	05	3.6
1983	09	0.9
1983	10	-
1983	11	30.9
1983	12	9.1
1984	01	44.9
1984	02	79.3
1984	10	19.3
1984	11	21.8
1984	12	38.9
1985	01	45.7
1985	02	52.9
1985	03	13.4
1985	04	20.5
1985	05	0.8
1985	10	14.4
1985	11	17.8
1985	12	10.5
1986	01	32.6
1986	02	58.2
1986	03	24.3
1986	04	21.4
1986	05	43.2
1986	06	0.2
1986	09	0.5
1986	10	15.9
1986	11	87.8
1986	12	53.2
1987	01	22.8
1987	02	19.3
1987	03	17.9
1987	04	1.7

1987	10	19.4
1987	11	21
1987	12	37.1
1988	01	27.5
1988	02	75.3
1988	03	22.6
1988	10	6.4
1988	11	46.9
1988	12	55.8
1989	01	24.4
1989	02	20.5
1989	03	30.8
1989	10	4
1989	11	36.2
1989	12	52.6
1990	01	35.7
1990	02	32.2
1990	03	28.7
1990	04	37.7
1990	10	2.6
1990	11	9.5
1990	12	8
1991	01	63.9
1991	02	17.1
1991	03	41.5
1991	04	21.8
1991	05	5.3
1991	10	8.4
1991	11	38.5
1991	12	86.2
1992	01	80.5
1992	02	78.8
1992	03	37.3
1992	04	4.4
1992	05	13
1992	11	50.6
1992	12	115.5
1993	01	39.5
1993	02	23.9
1993	03	17.5
1993	04	5.8
1993	05	15.3
1993	06	0.1
1993	10	6.7

1993	11	7.2
1993	12	25.5
1994	01	41
1994	02	32.4
1994	03	59.9
1994	04	9
1994	10	8.6
1994	11	51.5
1994	12	54.6
1995	01	40
1995	02	45.9
1995	03	18.2
1995	04	16.9
1995	05	0.2
1995	10	1.2
1995	11	35.7
1995	12	15.5
1996	01	73.8
1996	02	101.8
1996	03	63.5
1996	04	8.7
1996	10	21
1996	11	8.1
1996	12	54.6
1997	01	74.8
1997	02	71.7
1997	03	62.2
1997	04	7
1997	05	29.8
1997	09	16.6
1997	10	10.3
1997	11	21.1
1997	12	33.4
1998	01	42.3
1998	02	32.6
1998	03	76.2
1998	04	3.8
1998	05	3.5
1998	09	0.9
1998	10	-
1998	11	1.7
1998	12	14.9
1999	01	53.3
1999	02	40.6

1999	03	13.5
1999	04	18.4
1999	10	-
1999	11	11.2
1999	12	13.2
2000	01	80.2
2000	02	40
2000	03	30.4
2000	04	0.3
2000	10	31.2
2000	11	3.2
2000	12	49.6
2001	01	46.9
2001	02	24
2001	03	8.4
2001	04	-
2001	05	30
2001	10	13.3
2001	11	30
2001	12	70
2002	01	68.9
2002	02	21.4
2002	03	29
2002	04	27.2
2002	05	18.8
2002	10	-
2002	11	-
2002	12	-
2003	01	-
2003	02	-
2003	03	-
2003	04	21
2003	10	2.2
2003	11	24.6
2003	12	44.5
2004	01	36.9
2004	02	67.9
2004	03	16
2004	04	7.3
2004	05	1.2
2004	10	0.4
2004	11	45.8
2004	12	30.9
2005	01	61.6

2005	02	95
2005	03	9.3
2005	04	5.5
2005	05	2.3
2005	10	4.4
2005	11	20.3
2005	12	-
2006	01	29.6
2006	02	67
2006	03	19.8
2006	04	53.6
2006	10	15
2006	11	19.5
2006	12	105
2007	01	43.3
2007	02	38
2007	03	41.8
2007	04	5.2
2007	05	2.5
2007	10	0.1
2007	11	31.5
2007	12	25.7
2008	01	72.6
2008	02	35.6
2008	03	3
2008	09	7.6
2008	10	13
2008	11	3.8
2008	12	76.8
2009	01	15
2009	02	60.9
2009	03	26.6
2009	04	12.9
2009	09	2.2
2009	10	19
2009	11	67.9
2009	12	41.5
2010	01	28.9
2010	02	74.6
2010	03	10.2
2010	04	0.1
2010	10	3.3
2010	11	-
2010	12	83.4

2011	01	30.6
2011	02	36.2
2011	03	46
2011	04	13.8
2011	05	18.1
2011	10	4
2011	11	42.5
2011	12	21.7
2012	01	50
2012	02	53.9
2012	03	74.8
2012	10	-
2012	11	-
2012	12	-
2013	01	106.7
2013	02	16.9
2013	03	3.3
2013	04	26.8
2013	05	2.8
2013	09	0.2
2013	10	13.5
2013	12	123
2014	01	2.8
2014	02	4.5
2014	03	36.2
2014	05	23.4
2014	10	16.4
2014	11	55
2014	12	7
2015	01	82.5
2015	02	55.9
2015	03	7.5
2015	04	25.2
2015	05	5.6
2015	10	7.6
2015	11	9.5
2015	12	48
2016	01	45.8
2016	02	43.6
2016	03	25.8
2016	04	22.7
2016	05	1.8
2016	10	0.1
2016	11	8

2016	12	73.8
2017	01	40
2017	02	35
2017	03	3.1
2017	04	2.3
2017	10	7.5
2017	11	9.2
2017	12	45
2018	01	60.5
2018	02	57
2018	03	4.5
2018	04	11.7
2018	05	2.6
2018	06	1.1
2018	09	0.5
2018	10	38.7
2018	11	21.2
2018	12	89.5

Source: (PMS, 2019)

Appendix (B)

Snow Fall Details for Nablus City (1997-2015)

Year	No. of snowing days	Starting from	Depth/ cm
1997	***	***	***
1998	2	1/11/1998	2--5
1999	***	***	***
2000	2	28/1/2000	10--15
2001	***	***	***
2002	***	***	***
2003	1	26/3/2003	0--2
2004	1	15/2/2004	0--2
2005	***	***	***
2006	1	28/12/2006	0--2
2007	***	***	***
2008	1	31/1/2008	0--2
2009	***	***	***
2010	1	12/12/2010	0--2
2011	***	***	***
2012	1	1/3/2012	0--2
2013	3	1/7/2013	0--2
	2	12/12/2013	15--25
2014	***	***	***
2015	3	1/7/2015	15--25
	2	20/2/2015	2--5

Source: (PMS, 2019)

Appendix (C)

Observed Failures, Effects, and Damages Resulted from Natural Hazards (Earthquakes, Intensive Rainfalls and the Resulted Flooding Events, Land Sliding, Snowing) Happened in Nablus City through the Past Years

C.1 Earthquake Hazard

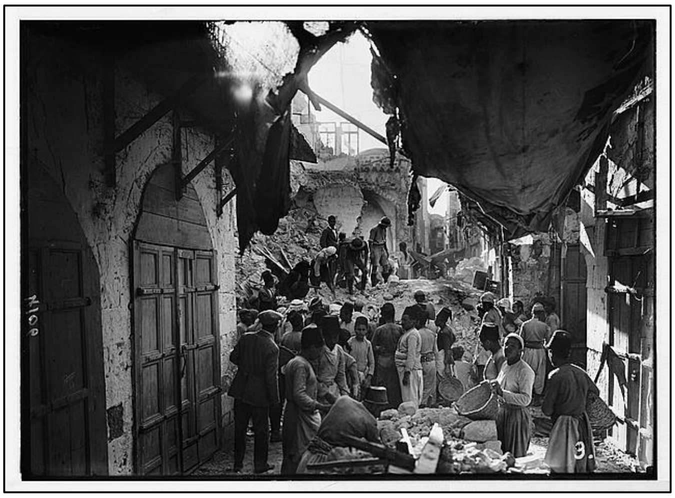

Figure (C.1): Blocked-Up Street in Nablus City, Choked by Fallen Houses Which Entombed Many Inhabitants in 1927 Earthquake

Source: (Palestineremembered, 2019)

Figure (C.2): The Aftermath of the Earthquake that Hit Nablus City in July 1927

Source: (Palestineremembered, 2019)

C.2 Intensive Rainfalls and The Resulted Flooding events

Figure (C.3): Partial Failure on the Road near Pioneer Baccalaureate School Due to the Intensive Rainfalls in January 2019

Source: (Nasrallah, 2019)

Figure (C.4): Inundation of Al-Maslakh Street Due to the Intensive Rainfalls in February 2019

Source: (Qamhia, 2019)

Figure (C.5): Flash Flood with Debris Flow in Al-Najah Old Street Generated by the Intensive Rainfalls in December 2018

Source: (Qamhia, 2019)

Figure (C.6): Partial Failure in Road 16 Due to the Intensive Rainfalls in December 2018

Source: By Researcher

Figure (C.7): Inundation of Al-Academia Street Due to the Intensive rainfalls in January 2013

Source: (Qamhia, 2019)

Figure (C.8): Stuck Cars and Cars Slippage in Al-Makhfeya Street Because of Street Inundation from the Intensive Rainfalls in January 2013

Source: (Qamhia, 2019)

Figure (C.9): Inundation of Ras Al-Ein Street Due to the Intensive Rainfalls in January 2013

Source: (Dooz, 2019)

Figure (C.10): Inundation of Al-Basha Street Due to the Intensive Rainfalls in January 2013

Source: (Dooz, 2019)

Figure (C.11): Traffic Interruption and Congestion in Faisal Street Due to the Intensive Rainfalls in January 2013

Source: (Dooz, 2019)

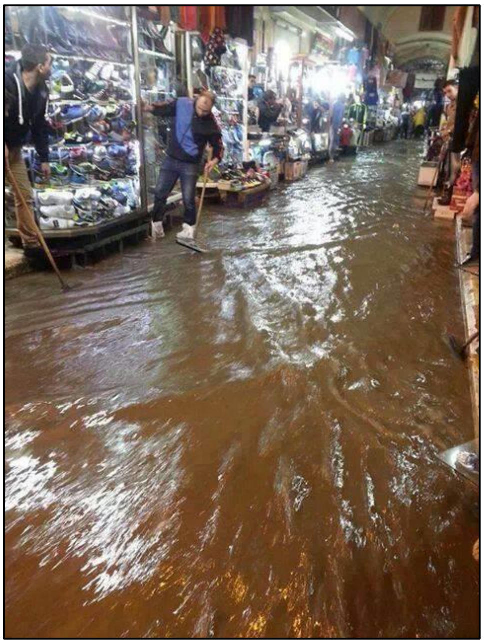

Figure (C.12): Closure of Khan Al-Tojar Street from the Flash Flood Generated by the Intensive Rainfalls in January 2013.

Source: (Qamhia, 2019)

C.3 Land Sliding Hazard

Figure (C.13): Mountain Slides on Aseera Street Due to the Intensive Rainfalls in March 2019.

Source: (Qamhia, 2019)

Figure (C.14): Land Sliding Below Khalil Al-Nadi Street Due to the Intensive Rainfalls in January 2019

Source: (Nasrallah, 2019)

Figure (C.15): Retaining Wall Collapse and Soil Sliding Directly on the Road under Al-Jabi House Due to the Intensive Rainfalls in January 2019

Source: (Nasrallah, 2019)

Figure (C.16): Land Sliding in the Bottom Layers of Al-Ta'awon Street Due to the Intensive Rainfalls in December 2018

Source: (Nasrallah, 2019)

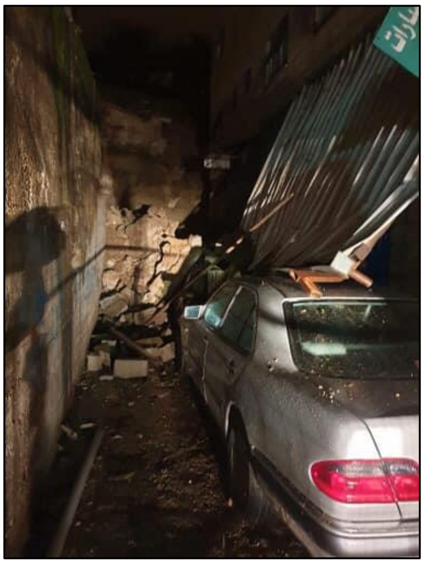

Figure (C.17): The Collapse of a Retaining Wall in Amman Street, Which Caused Two Cars to be Damaged Due to the Intensive Rainfalls in December 2018

Source: (Dooz, 2019)

Figure (C.18): Resulted Cracks on the Road from the White Mountain Landslides in 2018

Source: (Qamhia, 2019)

Figure (C.19): Boulder Wall Collapse in Al-Mabyad Street Due to the Intensive Rainfalls in December 2018

Source: (Nasrallah, 2019)

Figure (C.20): Road Collapsed Due to the Land Sliding of the White Mountain in Nablus City in 2005

Source: (Dabbeek, 2014)

Figure (C.21): Land Sliding in the White Mountain in Nablus City in 2003

Source: (Dabbeek, 2014)

Figure (C.22): Land Sliding in the White Mountain in Nablus City in 1997

Source: (Dabbeek, 1999)

C.4 Snowing Hazard

Figure (C.23): No Traffic Movement Due to the snowfall in Nablus City in 1992

Source: (Palestineremembered, 2019)

Figure (C.24): Roads Closure and No Traffic Movements Due to the Snow Accumulation in Nablus City in 2013

Source: By Researcher

Figure (C.25): Road Closure and Lack of Clarity for the Road Features Due to the Snow Accumulation in Nablus City in 2013

Source: By Researcher

Appendix (D)

Resilience Assessment Spreadsheets of Nablus City Transportation Network

Table D.1 Summary of Resilience Scores

Score	Low resilience 0.00-0.50	Moderate resilience 0.51-1.50	High resilience 1.51-2.50	Very high resilience 2.51-3.00

	Dimension	Principle	Principles average score	Dimension average score	Total resilience score
Summary resilience assessment	6. Technical resilience	Robustness	1.76	1.21	1.45
		Redundancy	0.93		
		Safe to fail	0.94		
	1. Organizational resilience	Leadership and culture	1.64	1.68	
		Networks	1.71		
		Change readiness	1.69		

Table D.2 Technical Resilience Assessment Spreadsheets of Nablus City Transportation Network
Based on the principles of robustness, redundancy, and safe to fail

Principle #1	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Robustness	Maintenance, renewal, design (standard and codes)	a- Processes exist to maintain Nablus transportation infrastructure (There is permanent maintenance for the infrastructure).	(3) Periodic inspection process for the transportation network and corrective maintenance completed annually.	//	1.63	1.76
			(2) Inspections and corrective maintenance completed when required.	//////		
			(1) Inspections or corrective maintenance completed, but with delays and backlog.	////////		
			(0) Inspections or corrective maintenance not completed.			
		b- Existence of applicable updated design codes, laws, and regulations that take into account the known natural hazards and the ones that are likely to occur.	(3) Codes, laws, and regulations exist, have been implemented, applicable and are up to date.	//	1.88	
			(2) Codes, laws, and regulations existed, not updated but implemented.	//////////		
			(1) Codes, laws, and regulations have been developed but not implemented.	////		
			(0) Codes, laws, and regulations don't exist.			

		c- Codes, laws and regulations related to the design and the implementation of buildings, roads and retaining walls are implemented and adhered to.	(3) Codes, laws and regulations are compulsory implemented and adhered to in all cases.	////	1.88	
			(2) Codes, laws and regulations are implemented and adhered to in most cases.	//////		
			(1) Codes, laws and regulations are implemented and adhered to in some cases.	//////		
			(0) Codes, laws and regulations are not implemented or adhered to.			
		d- There is supervision over compliance with codes, laws and regulations, especially with regard to land use laws and laws for the design and implementation of roads, buildings and retaining walls.	(3) Restrict supervision existed.	///	1.63	
			(2) Good supervision.	/////		
			(1) Minor supervision.	///////		
			(0) No supervision.	/		

Principle #2	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Redundancy	Awareness of redundancy issues (exposure and vulnerability), network redundancy, alternate routes	a- Exposure of the transportation network to seismic hazard.	(3) Very low - Low	//////////	2.44	0.93
			(2) Low - Medium	///		
			(1) Medium - High	///		
			(0) High- Very High			
		b- Exposure of the transportation network to flood and flash flood hazards.	(3) Very low - Low		0.56	
			(2) Low - Medium	//		
			(1) Medium - High	/////		
			(0) High- Very High	/////////		
		c- Exposure of the transportation network to snowing hazard.	(3) Very low - Low	//	1.50	
			(2) Low - Medium	////		
			(1) Medium - High	//////////		
			(0) High- Very High			
		d- Exposure of the transportation network to land sliding hazard (triggered land sliding events).	(3) Very low - Low	/	1.00	
			(2) Low - Medium	////		
			(1) Medium - High	/////		
			(0) High- Very High	//////		
		e- Vulnerability of the transportation network towards seismic hazard.	(3) Very low - Low		0.38	
			(2) Low - Medium			
			(1) Medium - High	//////		
			(0) High- Very High	////////////		
		f- Vulnerability of the transportation network	(3) Very low - Low		0.56	
			(2) Low - Medium			

		towards flood and flash flood hazards.	(1) Medium - High	/////////		
			(0) High- Very High	///////		
		g- Vulnerability of the transportation network towards snowing hazard.	(3) Very low - Low		1.00	
			(2) Low - Medium	///		
			(1) Medium - High	//////////		
			(0) High- Very High	///		
		h- Vulnerability of the transportation network towards land sliding hazard (triggered land sliding events).	(3) Very low – Low		0.88	
			(2) Low – Medium	///		
			(1) Medium - High	////////		
			(0) High- Very High	/////		
		i- Availability and capacity of alternate routes for strategic structures.	(3) Availability and capacity of unaffected alternate routes within the entire city.		0.75	
			(2) Availability of alternate routes which have much lower capacity, only for strategic structures (ex. hospitals) and for emergency activities.	////		
			(1) Ad hoc approach.	////		
			(0) No alternate routes.	////////		
		j- Existence of tested plans to establish diversions to alternate routes when failure of critical link occurs.	(3) Plans are well specified, tested and ready.		0.75	
			(2) Plans are specified, but not approved.	////		
			(1) Ad hoc approach.	////		
			(0) No plans.	////////		

		k- Loss is expected for the city transportation network when exposed to seismic hazard.	(3) No loss is expected.		0.25	
			(2) Ad hoc approach.			
			(1) Partial loss is expected in the city transportation network.	////		
			(0) Total loss is expected for large part of the city transportation network.	////////////		
		l- Loss is expected for the city transportation network when exposed to flood hazard / flash flood hazard.	(3) No loss is expected.		1.00	
			(2) Ad hoc approach.			
			(1) Partial loss is expected in the city transportation network.	////////////////		
			(0) Total loss is expected for large part of the city transportation network.			
		m- Loss is expected for the city transportation network when exposed to snowing hazard.	(3) No loss is expected.		0.81	
			(2) Ad hoc approach.			
			(1) Partial loss is expected in the city transportation network.	/////////////		
			(0) Total loss is expected for large part of the city transportation network.	///		
		n- Loss is expected for the city transportation network when exposed to land sliding hazard (triggered land sliding events).	(3) No loss is expected.		1.13	
			(2) Ad hoc approach.	//		
			(1) Partial loss is expected in the city transportation network.	//////////////		
			(0) Total loss is expected for large part of the city transportation network.			

Principle #3	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Safe to fail	Design, detection tools	a. Is safe to fail design approach specified in design guidelines?	(3) Safe to fail approach is considered compulsory design for all assets.		1.31	0.94
			(2) Design codes and guidelines consider safe to fail approach implicitly.	///////		
			(1) Safe-to-fail approach is not included, but plans are to incorporate in near future.	///////		
			(0) Safe to fail approach is not considered.	//		
		b. Special programs are used to identify weakness, failure, and collapse locations in critical infrastructures during and after the event.	(3) Programs exist, tested and ready.	//	0.56	
			(2) Programs exist, but not approved.			
			(1) Ad hoc approach.	///		
			(0) No programs existed.	///////////		

Table D.3 Organizational Resilience Assessment Spreadsheets of Nablus City Transportation Network
Based on the principles of leadership and culture, networks, and change readiness

Principle #1	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Leadership and culture	Leadership, awareness, decision making	a. Is transportation infrastructure resilience against natural hazards a city priority?	(3) The city owns a well-defined, tested and ready plans and strategies to protect its transportation infrastructure against natural hazards.		0.81	1.64
			(2) The city owns plans and strategies to protect its transportation infrastructure against natural hazards, but not approved or tested.	///		
			(1) The city is in the process of setting up plans and strategies to protect its transportation infrastructure against natural hazards.	///////		
			(0) There are no plans or strategies.	//////		
		b. Does the city have knowledge of the main natural hazards that the city faces,	(3) City understands main natural hazards, and data updated permanently.		1.63	
			(2) City understands main natural hazards, and data are updated irregularly.	//////////		

		and their likelihood of occurrence?	(1) City understands main natural hazards, but data are not updated.	//////		
			(0) Hazards are not well understood.			
		c. Does the city owns natural hazard maps and risk profiles?	(3) Maps are available, well specified, and updated regularly.		0.56	
			(2) Maps are available, but not updated.	//		
			(1) The city is in the process of developing natural hazard maps and their risk profiles.	/////		
			(0) Maps are not available.	/////////		
		d. Community awareness sessions are held on how to deal during and after the event.	(3) Community highly involved and aware.	//////////	2.63	
			(2) Community moderately involved and aware.	//////		
			(1) Community involved and aware in the event time.			
			(0) No awareness.			
		e. The administrative capacity of the institution to deal with natural hazards.	(3) Very high – High	/////////	2.56	
			(2) High – Moderate	///////		
			(1) Moderate – Low			
			(0) Low - Very low			

Principle #2	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Networks	Internal resources, external relationships, leveraging knowledge	a. Over the city level, does the institution have budget plans and protected budget to reduce the risk of these natural hazards and their impacts on the transportation network?	(3) Budget plan is available and budget is protected.		1.13	1.71
			(2) Budget plan is available, but budget shared with other critical infrastructures.	////		
			(1) Plan is available, but no budget available.	//////////		
			(0) No budget plans.	//		
		b. Sufficient equipment are available to deal with risks arising from potential natural hazards (during and after the event), equipment needs are defined for range of hazard scenarios.	(3) Sufficient equipment are available, needs are defined, keyed to scenarios.		1.20	
			(2) Shortfalls in equipment, needs are defined, keyed to scenarios.	/////		
			(1) Shortfalls in equipment, needs are not defined.	/////////		
			(0) Major shortfalls in equipment, no needs defined.	//		
		c. Level of communication (pre-event) between stakeholders who are responsible of the management and safety of the city	(3) Very high - High	///	2.20	
			(2) High - Moderate	/////////////		
			(1) Moderate - Low			
			(0) Low - Very low			

		critical infrastructures.				
		d. Level of coordination (during the event) between stakeholders who are responsible of the management and safety of the city critical infrastructures.	(3) Very high - High		1.44	
			(2) High - Moderate	///////		
			(1) Moderate - Low	/////////		
			(0) Low - Very low			
		e. Existence of emergency operations center with participation from all agencies.	(3) Operations center exists, all agencies participate.	/////////	2.56	
			(2) Operations center exists but may have shortcomings.	///////		
			(1) Operations center exists, lack of participation.			
			(0) No operations center.			

Principle #3	Measures	Measurement (items measured)	Measurement Scale	Individuals Scores	Average Scores	Principle Average Score
Change readiness	Communication and warning, information and technology, emergency planning strategies, recovery and response priorities	a. a. Natural hazards that happened in the city, and their consequences basically on transportation network were documented during previous years.	(3) Documentation methodology and information platform exist,		1.40	1.69
			(2) Partial documentation and platform development.	//////		
			(1) Partial documentation, no platform.	//////////		
			(0) No documentation, no platform.			
		b. b. Emergency response plans are available to confront potential natural hazards.	(3) Complete plans exist, keyed to scenarios.	////	2.00	
			(2) Plans exist but with some significant gaps.	////////		
			(1) Plans being drafted.	////		
			(0) No plans.			
		c. c. Prevention measures (pre-event) are well defined to be taken to reduce the impact of natural hazards on transportation network.	(3) Sufficient prevention measures defined, keyed to scenarios.	///	1.81	
			(2) Some prevention measures defined, keyed to scenarios, but with gaps in definitions.	///////		
			(1) Prevention measures under development.	//////		
			(0) No prevention measures.			
		d. Lessons learned from past events of natural hazards happened on the	(3) Lessons learned are well specified, adopted, and keyed to scenarios.	////////	2.34	

		city to develop the mechanism of dealing with these hazards.	(2) Some lessons learned, keyed to scenarios.	//////		
			(1) Lessons learned, but not keyed to specific scenarios.	//		
			(0) No lessons learned.			
		d. e. Post event recovery plans exist and well defined.	(3) Plans exist and has contingency funding.		1.13	
			(2) Plans exist but have gaps and funding is not adequate.	////		
			(1) Plans being drafted and funding options are explored.	//////////		
			(0) No recovery plans.	//		
		e. f. Existence of early warning systems, where applicable.	(3) Warning systems exist for all known hazards and will allow time for reaction.		0.13	
			(2) Some hazards excluded (ex. earthquake) and warning time may not be adequate.			
			(1) Warning systems under development.	//		
			(0) No warning systems.	//////////////		
		f. g. Training exercises (emergency response exercises) are conducted for emergency teams to perform critical emergency response.	(3) Training programs are regularly implemented.	////////////////	3.00	
			(2) Training programs are rarely implemented.			
			(1) Training programs drafted but not yet implemented.			
			(0) No training programs.			

جامعة النجاح الوطنية
كلية الدراسات العليا

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إشراف
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أ. د. جلال الدبيك

قدمت هذه الاطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطرق والمواصلات بكلية الدراسات العليا، جامعة النجاح الوطنية في نابلس، فلسطين
2019م

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الملخص

لقد تم اعتبار القدرة على الصمود لشبكات الطرق كجزء من البنية التحتية الحيوية لأي مجتمع موضوعًا مهمًا ومجالًا هامًا يمثل طريقة جديدة لفهم سلامة وإدارة هذه الشبكات في ظل تعرضها لأي حدث مضطرب في العقود القليلة الماضية.

الهدف الرئيسي من هذا البحث هو إجراء تقييم وصفي لقدرة شبكة الطرق في مدينة نابلس على الصمود في مواجهة الاخطار الطبيعية التي من الممكن أن تتعرض لها المدينة من خلال تطوير إطار تقييم على مستوى المدينة كاملة. بحيث تتراوح هذه الأخطار من الأشد خطراً، وهو الزلزال، وأقل الأخطار احتمالاً، وهو خطر تساقط الثلوج ،إلى أكثر الأخطار احتمالاً، وهي الأمطار الغزيرة التي قد تؤدي إلى حدوث فيضانات، بالإضافة إلى خطر انزلاق التربة كحدث تابع محتمل لهذه الأخطار الطبيعية.

تعتبر شبكات الطرق في فلسطين جزءًا أساسيًا وهامًا من نظام البنية التحتية الحيوية الفلسطينية المتكامل، لأن هذه الشبكات هي السبيل الوحيد للتنقل بين وداخل المدن الفلسطينية لتقديم خدمات الطوارئ والإغاثة.

شكل الموقع الجغرافي لمدينة نابلس خصوصية معينة للمدينة من حيث الموقع. تنعكس هذه الخصوصية على شبكة الطرق في مدينة نابلس، بحيث تمتلك المدينة في معظم الحالات طرق ضيقة تمتد على الجانب الطولي من الجبال. بسبب درجات الانحدار الحادة في هذه المناطق الجبلية، فإن معظم الطرق في هذه المناطق لا يمكن من خلالها الوصول إلى الطرق الموازية

الأخرى، مما يعني أن إغلاق طريق واحد أثناء أحداث الاضطراب قد يتسبب في عدم إمكانية الوصول إلى طرق أخرى في نفس المنطقة. لذلك، فإن عملية الإخلاء والاستجابة لحالات الطوارئ خلال هذه الأحداث ستواجه صعوبات خطيرة.

تم تقسيم عملية تقييم القدرة على الصمود لشبكات الطرق في مدينة نابلس إلى ثلاث مراحل رئيسية: بناء التصور، وتقييم المخاطر، والتي تشكل جزءًا رئيسيًا من عملية تقييم القدرة على الصمود، وتقييم القدرة على الصمود. خلال هذه المراحل ، تم قياس المستوى المطلوب للقدرة على الصمود لكل خطر تم تحديده، ثم وضع جداول تقييم بيانات والتي تتضمن مجموعة من المقاييس المحددة المتعلقة بكل بُعد من أبعاد القدرة على الصمود لتقييم المستوى الحالي للقدرة على الصمود لشبكة الطرق.

بناءً على النتائج، تتمتع البنية التحتية لشبكة الطرق في مدينة نابلس بمستوى متوسط من القدرة على الصمود في مواجهة الأخطار الطبيعية. في حين يجب أن تمتلك شبكة طرق مدينة نابلس مستوى عالي جداً من القدرة على الصمود لمواجهة الخطر الزلزالي، ومستوى عالي إلى متوسط من القدرة على الصمود لمواجهة أخطار الفيضانات والثلوج. وهذا يعني أن الشبكة بحاجة إلى تدخلات وتحسينات لزيادة مستوى قدرتها على الصمود في مواجهة هذه الأخطار وللوصول إلى المستوى المطلوب.

تم استكشاف نقاط الضعف التي أدت إلى انخفاض مستوى القدرة على الصمود الحالي من خلال جداول تقييم البيانات. وذلك يساعد صانعي القرار على البدء في توظيف الجهود لتحديد الأولويات التي سيتم البدء في العمل عليها لتحسين الوضع الحالي للشبكة.

أخيرًا ، تم أيضًا اقتراح طرق حول كيفية زيادة مستوى القدرة على الصمود ضد كل خطر من خلال تدابير الوقاية والتخفيف والتكيف. بحيث يشتمل ذلك وضع خطط للتأهب للكوارث والتعامل معها وإدارتها وبناء قاعدة بيانات وطنية لكل خطر طبيعي، وزيادة المعرفة وتعزيزها والسلوك الحكيم للمخاطر والوعي بمثل هذه الأحداث.