



**An-Najah National University
Faculty of Graduate Studies**

ASSESSMENT OF FLOOD RISK AND MANAGEMENT FOR TULKARM AREA

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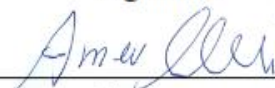
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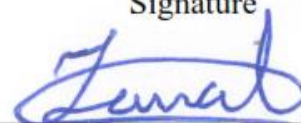
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Dedication

To my parents and to all my dear family members

Acknowledgments

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My parents, husband, sisters, brother, friends and my daughter Raya; thanks for your support and encouragement. I am thankful to all of you for your love, support and assistance.


Declaration

I, the undersigned, declare that I submitted the thesis entitled:

ASSESSMENT OF FLOOD RISK AND MANAGEMENT FOR TULKARM AREA

I declare that 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.

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ASSESSMENT OF FLOOD RISK AND MANAGEMENT FOR TULKARM AREA

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Abstract

Flooding is an actual risk at several watersheds in Tulkarm governorate of Palestine. The lack of integrated planning and appropriate preparedness lead to increased risk of flood events. This study aims to develop a flood hazard map, using a group of parameters: slope, elevation, drainage density, precipitation, soil texture, land use/land cover, flow accumulation and population density. Analytic Hierarchy Process method and Geographic Information System program were used to weighted parameters. The result showed a flood hazard map with a 12.5 m resolution for Tulkarm study area categorized into five classes (percentage): very low (2%), low (26%), medium (37%), high (28%), very high (7%). Results were compared with previous studies from the related literature and verified using ground truthing to examine the certainty of the results in three different locations. A group of interventions (structural and non-structural) were proposed for each flood hazard class so that competent authorities could better manage flood risks. Some of these interventions for high flood vulnerable areas are, applying heavily-engineered structural measures and regular maintenance of rainwater culverts and valley streams. Mapping the flood hazard is an integral part during phases of flood risk management from mitigation, preparedness, response and recovery.

Keywords: Assessment; flood; hazard; Management; risk.

Chapter One

Introduction

This chapter introduced a general background of Tulkarm governorate, considering a group of previous studies. Also, represent the research problem, study hypothesis, importance of the study, research objectives, some thesis terminology and thesis outline.

1.1 Background

There are many definitions of the term disaster. The expression disaster refers to an accident that affects a community and causes serious disruption to its functional facilities. It is also known that disasters resulting in significant losses in human lives, properties and the environment. The disaster has a spatial dimension, as it happens in a specific location and affects a certain area. Disasters can be classified based on their nature into two types. Natural disasters, which are related to natural phenomena that are beyond human control, such as floods, earthquakes and others. Man-made disasters are related to human activities such as water pollution, wars and others.

The lack of proper planning for the disaster leads to severe effects on society, and influences the wheel of growth, development and legislation. The existence of an easy, flexible and achievable plan, that defines duties and responsibilities of each stakeholder, contributes to the disaster risk reduction. The disaster risk management process includes a set of steps, beginning with planning for the disaster, evaluating its risks, determining its acceptable levels, preparing and organizing to reduce its effects and finally examining the plan and lessons learned.

In order to better assess the risks, maps related to the potential risks for a specific area should be prepared. Collecting useful and relevant data can help in understanding these risks and support the ability to decision making. Preparing flood hazard maps can help in estimating and identifying the high, medium and low vulnerable areas to respond accordingly. In addition, these maps can also assist in determining the specific risk at a

certain location and strengthening our preparedness appropriately for any future mitigation.

Tulkarm governorate is located northwest of the West Bank of Palestine. The governorate has an area of about 268 km², with a total population of around 198,856 people projected for the mid of the year 2021 (PCBS, 2021). Tulkarm climate can be generally described as a Mediterranean Sea climate which varies between hot dry summer to wet cold winter with short transitional seasons (Shadeed, 2019). Precipitation is concentrated in winter and spring months and the quantity of precipitation in Tulkarm from the beginning of the year 2022 till 14 March is 613 mm (PCBS, 2022).

In 2013, a flash flood that occurred in Tulkarm caused the death of three persons and flooded many areas in the city (Shadeed, 2019). This was due to the continuous precipitation in the presence of poor drainage systems and urban planning of buildings. It is necessary to delineate a flood hazard map identifying the areas that are more vulnerable to flooding, set proper planning for the disaster before its occurrence, and adopt scientific methods of response with effective management of unfortunate events. This will help municipalities and responsible authorities to suggest possible solutions to potential risks in each region according to its own circumstances and the factors to which it is exposed. Innovative solutions should begin from the stage of planning and preparedness to face potential risks to the stage of response and recovery.

1.2 Literature Review

Flood can be defined by the Oxford English Dictionary as “an overflowing or irruption of a great body of water over land in a built up area not usually submerged” (Jha et al., 2012). Flooding is considered as a natural phenomenon; it is classified as one of the major risks that cause severe damage to the environment and society.

Disaster risk management is a basic and important need which is an integral part of sustainable development of societies. The primary goal of disaster risk management is to preserve the property of human beings, now and in the future. According to the Hyogo framework for action, the disaster risk reduction is a national and local priority (Elboshy et al., 2019). One of the main objectives of flood risk assessment and management is to reduce the negative impacts on human health, the environment and economic conditions associated with floods in the local community. The European Union (2007) states that planned and consistent actions from the community would add a considerable value and enhance the overall level of flood protection. This is a major step of flood risk management which includes flood prevention, protection and mitigation.

The disaster risk management cycle is separated into several stages, which are: mitigation, preparedness, response, recovery (Twigg, 2015). First of all, to minimize the effects of disasters we need to apply the mitigation procedures, some of general applications are, risk assessment; public education, land use management; building use codes and safety rules and preventive healthcare.

The second part of the phases is preparedness, which means planning how to respond for disaster, such as readiness plans; emergency exercises/training, emergency communication systems, evacuation plans; emergency personnel resource inventories/contact lists; mutual aid agreements and public information/education and warning systems. After that come the stage of response, efforts to reduce the risks arising from disasters. Search and rescue; Rescue in an emergency. Such as assistance to refugees with transportation, temporary shelter, and food, to establishing semi-permanent settlement in camps and other locations. Final step is recovery which means, bringing society back to its normal situation. By applying short- and long-term measures include, restoring critical life support systems to minimum operating standards, temporary housing, public information, health and safety education, reconstruction; counseling programs; and economic impact studies, grants, and Medicare.

Risk management analysis for flood hazard depends highly on flood hazard mapping (FHM) (Mudashiru et al., 2021). Many published papers have studied flood hazard using different techniques and software. Geographic Information System (GIS) decision support systems have been used in various parts of the world. GIS offers the ability to integrate data from many sources into a common platform and make it easily available and understandable to various stakeholders.

Shadeed (2019) used the Analytic Hierarchy Process (AHP) method and the GIS software to develop a flood hazard map for the West Bank, Palestine. Multiple variables including runoff curve number, rainfall depth, flow accumulation, surface cover, distance from drainage network, and population density had been considered and different weights had been assigned according to their impacts on the flood. The results showed that 12, 36, 29, 15, and 8% of the West Bank were of very high, high, medium, low, and very low hazard level to flood hazards, respectively. As for Tulkarm city, it is classified as an area of high to very high flood hazard intensity. This rank results from the heavy rainfall, rising runoff potential, high population density, and low surface elevations.

It is worth to mention that the AHP is a method of multi criteria decision analysis, used to compute weights of different criteria. Gigović et al. (2017), for instance, studied the mechanism of introducing a multi-criteria GIS methodology to map hazard zones for flood prone urban areas. They considered six criteria that affect floods in urban areas (i.e., elevation slope, distance to sewage network, distance from water surface, water table, and land use). These factors were tested by experts using three scenarios of the AHP. The result indicated that the highest level of compatibility with historical data on floods was provided using the application of AHP with interval rough numbers scenario.

Rincón et al. (2018), however, developed flood risk maps for four scenarios in the Don River Watershed in Toronto. Potential variables were given various weights using the AHP method and multi-criteria analysis using the GIS environment. The major result from this research was that we can simply get a flood hazard map without using hydraulic

and hydrological models, just by digital elevation model (DEM), census data, streams, land use/land cover, and soil type layers.

Parsian et al. (2021) assessed the flood hazard in the western area of Iran using multiple GIS and remote sensing datasets. The variables considered were the DEM, slope, rainfall, distance from main rivers, topographic wetness index, land use/land cover, soil type, normalized difference vegetation index, and erosion rate. A fuzzy analysis and AHP had been conducted giving weights to the different variables in order to produce a flood hazard map with five levels of vulnerability areas. The results of this study declared that 95% of the actual flooded areas were classified as very high and high flood hazard classes in the produced hazard map. This indicates a high level of accuracy in the (Parsian et al., 2021) method of FHM.

Biswas et al. (2018) reviewed methodologies for FHM in different areas around the world. They discussed different techniques of flood risk assessment and mapping such as satellite imagery, GIS, and ERDAS IMAGINE. The ERDAS IMAGINE is the world's leading geospatial data authoring system, incorporates geospatial image processing and analysis, remote sensing, and GIS capabilities into a single powerful, convenient package. Scientists had used other techniques such as the Hydrologic Engineering Center's-Hydrologic Modeling System (HEC-HMS), the Hydrologic Engineering Center's-River Analysis System (HEC-RAS), and the Modelling System for Rivers and Channels. The results noticed from the reviewed literature confirmed that integrating HEC-RAS model with GIS is the most suitable technique to get a flood map, which raises awareness of people living in vulnerable areas.

The rational method is a simple and effective method, used to calculate the surface runoff from rainfall values. Kencanawati et al. (2021) used the rational method to determine the peak discharge from rainfall. The goal of this field study was to use field measurements to correct a simple hydrological formulation and develop a numerical rainfall model based on rainfall simulation, infiltration, land use/land cover, and flow parameters. The study focused on the hydrological cycle, and it was based on field data collection. Kencanawati

et al. (2021) estimated the runoff coefficient using a modified rational approach, which is an extension of the rational method.

There are different methods to compute runoff from rainfall data, of which one of the most popular is the Soil Conservation Service Curve Number (SCS-CN) method. Shadeed & Almasri (2010) evaluated flow modeling in the West Bank catchments, using the SCS-CN method with GIS techniques. In this study the composite CN of the West Bank catchments was calculated. The main benefit of using GIS in rainfall-runoff modeling is that it allows for more precise resolution and catchment characterization.

Maps represent a direct and powerful tool to express the spatial distribution of the flood risk than any other forms of presentation (Merz et al., 2007). Maps provides important and detailed information about the locations, vulnerability and assessment of risks. Risk maps are an important step for stakeholders and decision makers in order to assist planning for disaster risk reduction, raise ability to avoid their occurrence and reduce their impacts.

Flood risk maps provide an effective information tool. They are considered a valuable foundation for defining tasks and making decisions related to flood risk management. These maps show the potential negative consequences associated with different flood scenarios, including information on potential sources of environmental pollution as a result of floods (European Union, 2007).

There are significant differences between a flood hazard map, a flood vulnerability map and a flood risk map. Flood hazard maps are important for understanding the dangerous situation in an area. These maps are characterized by type of flood, its depth, speed and extent of water flow and the direction of flood. Flood hazard maps are prepared based on flood frequencies or specified return periods in light of the presence of historical flood events during the past periods (Jha et al., 2012).

Flood vulnerability map, however, are based on two major factors; the location of the element at risk and vulnerability of those elements to different aspects of the flood. There

are different concepts of vulnerability and there is no agreed understanding of this term (Merz et al., 2007). Yet, flood risk map is a combination between flood hazard map and flood vulnerability map (Aksha et al., 2020). In effect, the flood risk map represents a spatial integration of the flood hazard, flood exposure and the associated level of vulnerability.

The misconception among scientists in the definitions of flood vulnerability map, flood hazard map and flood risk map (e.g., Shadeed, (2019); Hagos, (2022); Zelenáková, (2018); Papaioannou, (2015)) might lead to variable outputs and outcomes. Therefore, there could be a misunderstanding to explain the results of such flood disaster management studies. This misinterpretation might lead to wrongful assessment of flood risks and associated consequences.

1.3 Research Problem

Floods are considered one of the natural disasters that occur frequently in different parts of the world (Shadeed, 2019), which are classified as hydrological hazards and pose a great danger to different parts of life. Given climate change and precipitation variability, there is a greater chance of flooding and other hydrologic disasters. When runoff of water accumulated with larger amounts, the poor capacity of existing drainage system to discharge water away or infiltrate it into soil may result in urban flood that might lead to people injuries and deaths as well as property losses. When cities develop, size of population and number of buildings increase, and therefore, the need for a proper urban planning becomes greater. This increases surface runoff and raises the risk of flooding amongst many other negative impacts.

Floods have many impacts on societies, of which the most important are health effects. This includes direct health effects such as chemical pollution, hypothermia, injuries caused by debris, and death due to drowning during flood events, and the indirect health effects include infectious diseases, malnutrition, poverty-related diseases, and diseases associated with displaced population (Du W, FitzGerald GJ, Clark M, 2011). In addition,

there are economic effects of the floods, such as the loss of properties, stopping the operation of industries and many commodities, and the costs of removing destruction and reconstruction (Adeel et al., 2020). There are a lot of environmental effects of flood such as destroying crops in farms, ruining wildlife habitats, and polluting water bodies. Furthermore, there are a social impact on people resulting from loss of lives and properties, causing life stresses, and lasting psychological impacts.

1.4 Study Hypothesis

In this study, the researcher has developed two major research hypotheses:

a. For the hydrologic system:

- Null hypothesis: Tulkarm governorate is not exposed to flood risks
- Alternative hypothesis: Tulkarm governorate is exposed to flood risks

b. For the water resource management system:

- Null hypothesis: No action is needed to manage water resources in Tulkarm governorate regarding flood events
- Alternative hypothesis: Immediate actions are required to better manage water resources in Tulkarm governorate regarding flood events

1.5 Study Importance

Flood risks have recently increased in many places of the world due to population growth and climate change. There is a dire need for studies that support reducing flood risks in a developing country such as Palestine. This cannot be achieved without a deep understanding and analysis to parameters affecting flood risks and a sustainable management that is built on a proper assessment. Due to the expected climate change, unplanned urbanization, rapid change in land use and different parameters that affecting on disaster. The risks are becoming more severe and critical and this requires better planning and management to minimize the consequences.

The main importance of this research is to better understand the hydrologic system and associated risks in Tulkarm governorate. It is essential to set up action plan strategies in Tulkarm governorate for the competent authorities of the water resource management system to deal with flood risks and adopt effective response methods.

1.6 Study Objectives

The following points are the key objectives of this research:

1. Design a flood hazard map for Tulkarm governorate taking into account the different parameters associated with flood.
2. Develop action plan strategies and interventions for municipalities and competent authorities to better plan and manage flood risks.

1.7 Study Terminology

There are some definitions must to be clarified and described in disaster risk reduction:

By definition, any normal dry land that becomes submerged in water for a certain period of time can be said that the area is subject to flooding (Senarathne, P.C., Ekanayake, Evangeline, Perera, 2006).

Vulnerability: is described as the conditions and circumstances of the governorate specified by physical, social, economic and environmental factors or processes which increase the susceptibility to the impacts of hazards (UNDRR, 2020).

Hazard: can be defined as a phenomenon, human event, or substance that leads to human and material losses, disrupts the economic and social system in the governorate and has a negative impact on the environment. Hazards may be natural such as hydrometeorological hazards like floods, or happened from human activities and choices (UNDRR, 2020).

Natural hazard: is defined as natural operation or phenomenon that may cause injury to humans and damage their assets, loss of livelihoods and services, social and economic disruption or environmental damage (Debele et al., 2019).

Hydro-meteorological hazard: is a process or phenomenon naturally occurring of atmospheric, hydrological or oceanographic that may cause negative influences of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (Debele et al., 2019).

Risk: has two distinctive connotations; one is defined as the result of multiplying the vulnerability of a community or governorate by the source of the hazard. But, the other defined as the value of severity of hazard multiplied by the probability of occurrence the hazard (UNISDR, 2009).

Disaster: is a defect in the work system of the entire society resulting high losses and negative effects on lives and material properties, which exceed the capacity of society to face them (UNISDR, 2009).

Risk assessment: is a methodology to define the nature and extent of risk by evaluating the potential hazards (their location, intensity, frequency and probability) and existing conditions of vulnerability by drawing maps and assessment of capacities (UNISDR, 2009).

Resilience: The ability of a system, group or community exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the impacts of hazards in a timely and effective manner, by maintaining and repairing its necessary infrastructure and functions through risk management (UNISDR, 2015).

Disaster risk management: can be defined as a holistic approach that includes recognizing threats due to hazards by analyzing the threats as well as understanding the vulnerability factors. Also, evaluating the capacity and resilience of societies and improve strategies to reduce future risks (Nirupama, 2013).

Integrated flood risk management: means an approach including multiple stages of a disaster risk management cycle; prevention, protection, preparedness, response and recovery in order to assessment and management of flood risks to reduce the consequences, flood-related damage by the involvement of a broader range of decision makers, stakeholders and citizens (McCrory & Veeckman, 2017). Furthermore, integrated flood risk management needs the holistic development of a long-term strategy balancing present needs with future sustainability.

Structural measures: involve the application of engineered safety procedures to provide protection from disaster impacts or application of engineering techniques to achieve hazard- resistance and resilience in structures or systems (Peacock & Husein, 2011).

Non-structural measures: include a wide group of mitigation strategies that uses knowledge, practice or agreement to reduce risks and impacts e.g., through policies and legislations (Peacock & Husein, 2011).

1.8 Thesis Outline

Chapter one indicates a general background of Tulkarm governorate and a literature review, research problem, study hypothesis, importance of the study, research objectives, thesis terminology and thesis outline. Chapter two contains the study area characteristics including geography and topography, climate, water sources, land use/land cover, soil, geology and reasons for choosing the study area. In chapter three, the methodology was viewed and explained which consists of a brief introduction, delineating study area, choosing influencing parameters of flood hazard, AHP weights of parameters, classification of parameters according to flood hazard and build an indicator of flood hazard map. The results were explained, analyzed and discussed in chapter four starting from outcomes and deliverables, ground truthing, flood risk management and limitations. Finally, the conclusion and recommendation are given in chapter five.

Chapter Two

Study Area

The circumstances and reasons for choosing the study area of the present study are discussed in this chapter.

2.1 General Background

It is necessary to know the study area, determine its geography, topography, analyze its climate, water sources, rock formations, soil and distribution of land uses. To conduct the appropriate analysis for studying the flood risk for Tulkarm governorate.

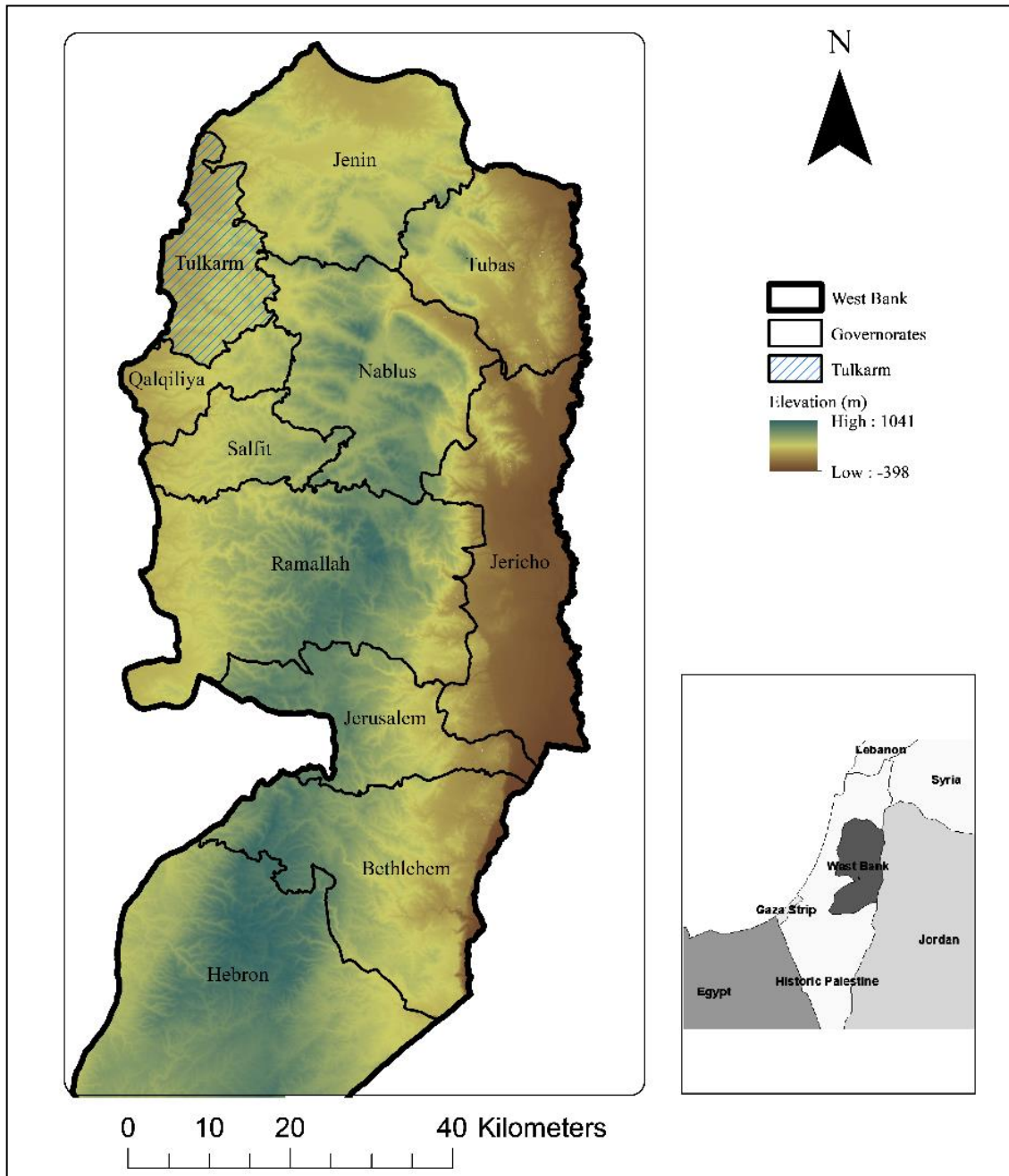
2.1.1 Geography & topography

Tulkarm governorate is located in the north western part of the West Bank of Palestine, and is governed by the Palestinian Authority. The governorate is bordered by Nablus governorate from the east, Qalqiliya governorate from the south, Jenin governorate from the north, and the Green Line separating Palestine and Israel from the west (Figure 1). The governorate has an area of about 268 km², with a total population of around 198,856 people as projected for the year 2021 (PCBS, 2021).

Tulkarm governorate ranges in elevation from high values in the north-east (around 414 m in Bal'a city) to low values (at the center of Tulkarm city of approximately 137 m above sea level). At a geographical latitude of 32°18'49" north of the equator, and longitude of 35°1'14" east of the Greenwich line (Bdair, 2012).

Figure 1

Tulkarm governorate in the West Bank of Palestine



2.1.2 Climate

Tulkarm climate can be generally described as a Mediterranean Sea climate which varies between hot dry summer and wet cold winter with short transitional seasons (Shadeed, 2019). The average temperature ranges from 8 to 16 °C in the winter, and from 23 to 31 °C in the summer (Diebel et al., 2022). As for the humidity, it varies from 40 to 70% in the summer, and from 70 to 85% in the winter (Bdair, 2012). The annual wind speed in Tulkarm governorate is 4.8 km/hr (Metrological General Directorate, 2018).

Precipitation is concentrated in the winter and spring months (from November to May) and the quantity of precipitation in Tulkarm till March 2022 was about 612 mm which is above the annual average precipitation 602 mm (PCBS, 2022).

2.1.3 Water sources

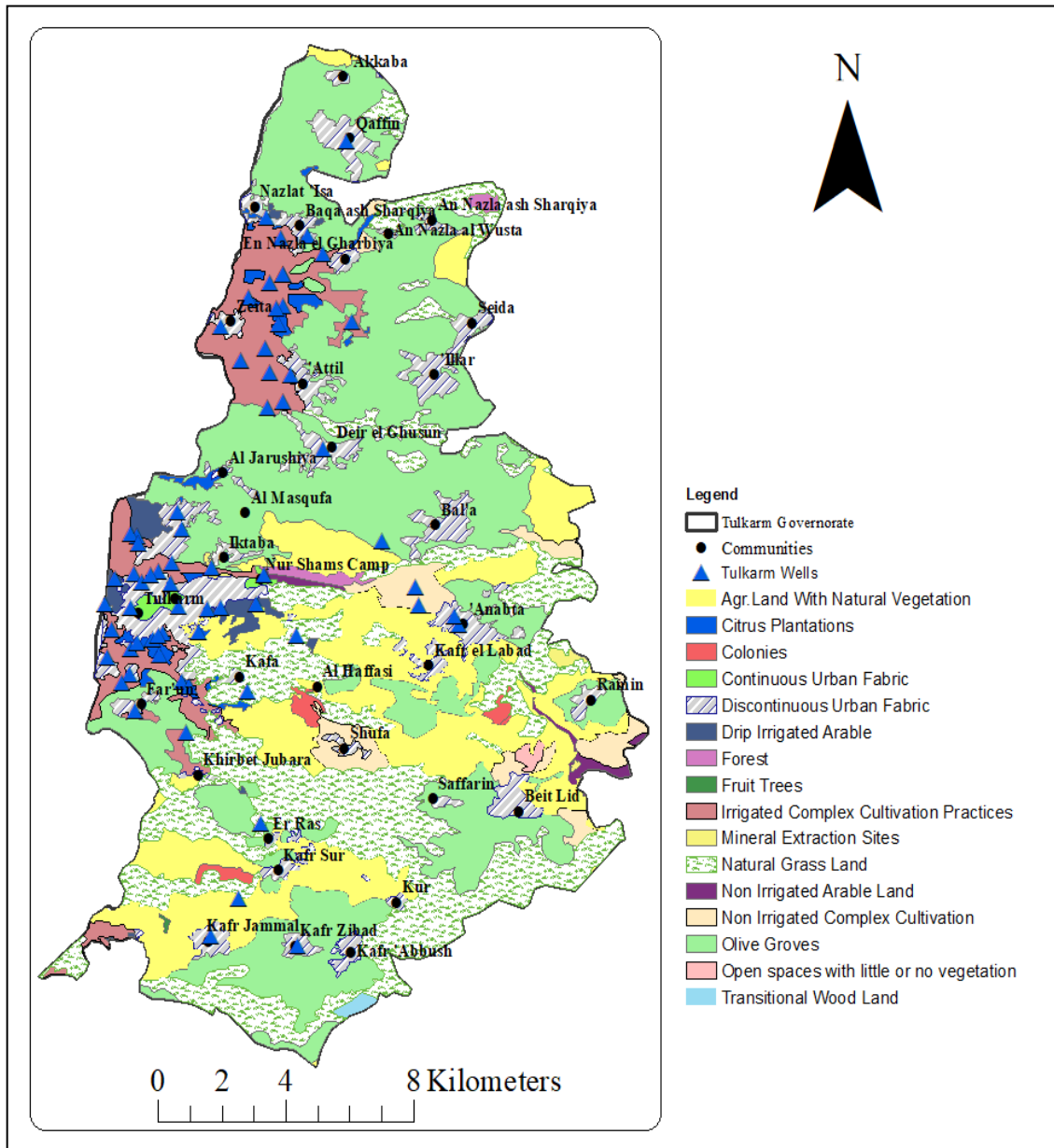
The main water sources in Tulkarm governorate are divided into four types (Palestinian Water Authority, 2017): (1) Rainwater which begins from November to May, (2) Surface water of temporary streams and springs including Zimmer, Abu Nar, Tin, Sukkar, Hamdan, Nimra and Assad valleys and (3) Groundwater from 67 wells (Ministry of Local Government, 2022) located in Tulkarm, Irtah, Pharaon, Shuwaiki, Attil, Deir Al-Ghussun, Nur Shams and Anabta as shown in Figure 2. (4) And one of the sources is the bulk water from Israel water company (Mekorot).

2.1.4 Land use/land cover

The land use of Tulkarm governorate is classified into different classes, the primary four classes such as cultivated and arable land, pasture and open land with no vegetation, or with no significant vegetation cover, Palestinian built-up area and other classes. Each one of these classifications occupies 67%, 20%, 11%, 2% from total area of governorate, respectively. Figure 2 show the classifications of land use/ land cover for Tulkarm governorate (Ministry of Local Government, 2017). The runoff increases at impermeable surfaces, such as urban areas. Also, when vegetation cover is removed, such as deforestation, that increases the amount and speed of surface runoff (Tarboton, 2003).

Figure 2

Land use/ land cover classifications of Tulkarm governorate



2.1.5 Geology

The geology of Tulkarm governorate consists of formations from Upper Cretaceous to Quaternary, covered by different sedimentary carbonate rocks such as limestone, dolomite, marl and chalk. The Cenomanian formation is composed of limestone, dolomite with chalk and marl, the Turonian formation consists of a series of massive, thick-to-thin bedded limestone to dolomitic limestone and dolomites with a thickness of approximately 70 - 130 m, the Cretaceous Rocks are composed of chalk from the Senonian formation and the Eocene formation mainly consists of chalk and limestone (Aliewi et al., 2013). The geological formations range in age from Senonian to Quaternary. Tulkarm is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk.(Khayat et al., 2012).

2.1.6 Soil

There are three different types of soil that exist in Tulkarm governorate:

1. Terra Rossa, Brown Rendzinas and Pale Rendzinas: This type of soil occupies the largest zone, about 185 km², representing 75% of the governorate area.
2. Brown Rendzinas and Pale Rendzinas: The total area of this soil type is 51 km² from the total area of the governorate.
3. Grumusols: This type of soil covers about 4 km² from the total area of the governorate.

2.2 Reasons for Choosing the Study Area

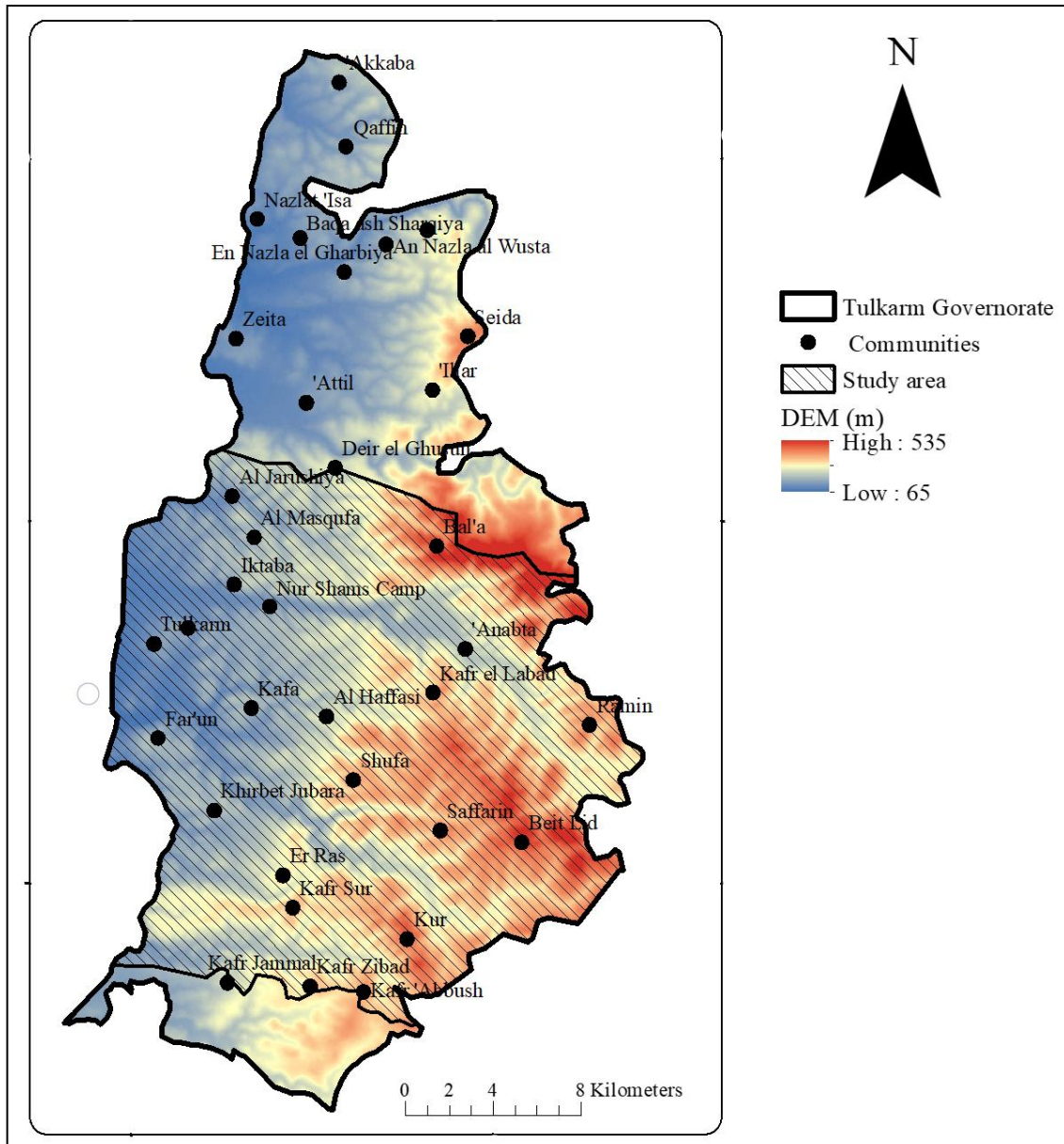
There are many reasons for choosing the study area as shown in Figure 3:

1. Politically, as we have no authority over the areas behind the apartheid wall and access to data is limited.
2. Hydrologically, the study area covers 35.4% of the watershed area.
3. In terms of population, There is a large number of people in Tulkarm area compared to other parts of the district. The selected study area covers 66% of the total area of Tulkarm governorate.

4. Previous studies indicated that the study area is one of the most critical areas to flood risks.
5. In the past, Tulkarm area had experienced severe consequences due to extreme flood events.

Figure 3

Study area of Tulkarm governorate.



Chapter Three

Methodology

Chapter three discussed the methodology that will be used to develop a flood hazard map for the study area in Tulkarm governorate.

3.1 Brief Introduction

The methodology that will be used in this study can be described in the following main points:

1. Understand the problem and the importance of studying the flood risk for Tulkarm area.
2. Define the boundaries of the study area, by making detailed information of Tulkarm area, spatially and temporally.
3. Collect data, by identifying the criteria that significantly affect the flood risk in the study area such as rainfall, curve number, surface slope, elevation, plan curvature, etc. In addition to the hydrological aspects, the flood risk might be influenced by some physical and socioeconomic aspects including political sovereignty, land use/land cover, proximity to roads, building materials, population density, and other criteria.
4. Identify sources of collected data such as the previous studies in the literature, Palestinian Centre Bureau of Statistics (PCBS), Palestinian Water Authority, An-Najah National University, and competent authorities such as municipalities, local councils, and other sources.
5. Conduct interviews with specialists, scientists, and scholars to study the situation of flood in the study area and the criteria of influence to flood hazard in selected municipalities and local councils.
6. Use Microsoft Excel and GIS programs to analyze the input data, by providing spatial layers for all criteria that affect the flood.

7. Build an AHP pairwise comparison matrix to give different weights for each criterion, using a range of scale from 1 to 5, and calculate the consistency ratio to check the weights of criteria are acceptable to use.
8. Utilize the Inverse Distance Weighting method to map the spatial distribution of input data (e.g., rainfall), that estimates each cell value by averaging the values of sample data points in the neighborhood of each processing cell.
9. Create the raster datasets of input data with all criteria considered in the GIS environment.
10. Reclassify the values in the input raster datasets using the weighted overlay summation process, multiply the scored values by the raster's weight of importance, and add the resulting cell values together to produce the output raster.
11. Produce a flood hazard map to identify the most vulnerable areas (i.e., very low, low, medium, high, very high).
12. Conduct a ground-truthing analysis in areas of different hazard classes.
13. Build the rainfall-runoff model using the runoff coefficient method to calculate runoff from rainfall equation (1):

$$Q = C i A \dots\dots\dots \text{Equation (1)}$$

where Q = runoff (m³/s), C = coefficient of runoff, which depends upon the nature of the surface, surface slope, and rainfall intensity, i = intensity of rainfall (m/s), and A = area of the catchment (m²).

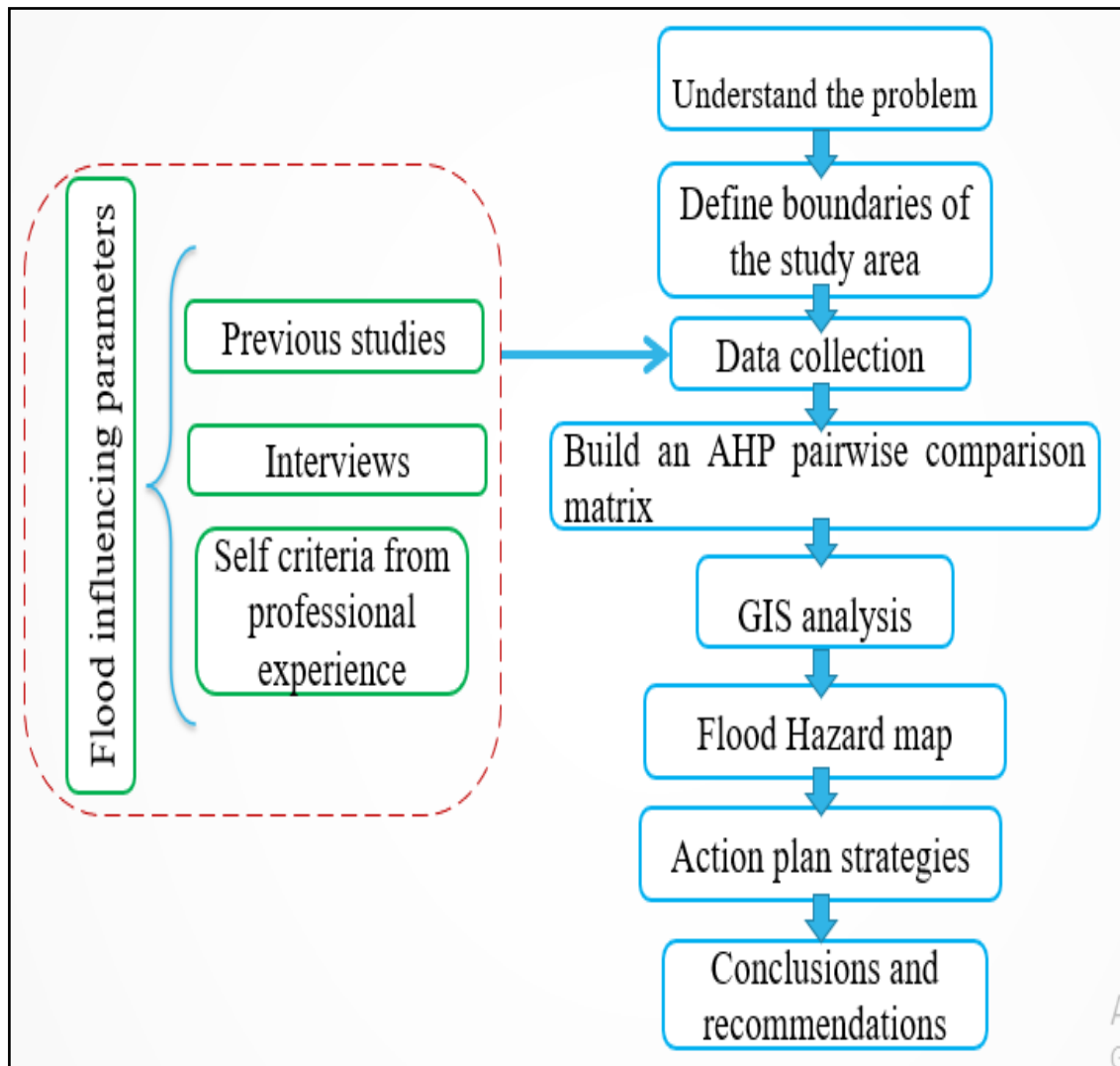
14. Create the runoff map showing the spatial distribution of runoff in the study area.
15. Compare the output of the flood hazard map with modeled results of the runoff method.
16. Analyze the flood hazard map to set up action plan strategies and interventions to improve preparedness plans, early warning system, and adjustment structures of flood risk.

17. Draw conclusions and recommendations.

The methodology used in this study to build the flood hazard map for the Tulkarm study area was arranged in the steps in this workflow chart as shown in Figure 4.

Figure 4

Workflow of study methodology



3.2 Detailed Methodology

To better understand section 3.1 which is summarized by Figure 4, the methodology needs to be further explained. First, it is important to identify challenges experienced and understand problems encountered in order to study the flood risk for Tulkarm area and create efficient solutions. Understanding the problem in a proper way is an integral part of its solution. The first problem we encountered was delineating the boundaries of the study area.

The boundaries of the study area are not only determined by political borders, they are also influenced by other factors. Data availability is one of the most sophisticated issues in a developing country, in particular Palestine. In addition, flood is one of the natural risks that are significantly affected by the hydrologic cycle of the study area. The spatial and temporal dimensions of the study have to be clearly identified earlier to any further analysis.

Data gathering, data will be collected according to different sources, starting with previous studies, different papers in the field of developing flood maps and flood risk management were pointed out in our study. The second part of data collection were interviews which conducted with a specific group of experts and scientists in this field (show Table 1), asking them a set of questions related to the subject of the study in terms of identifying criteria that significantly affect flood risks in the study area such as precipitation, curve number, surface slope, elevation, curvature of the outline, etc. In addition to hydrological aspects, flood risks may be affected by some physical factors. and socioeconomic aspects including political sovereignty, land use/land cover, proximity to roads, building materials, population density, and other criteria. Also, self-criteria from professional experience were relied upon to take and adopt the parameters that help in developing a flood hazard map.

Table 1*Specialists and scholars who were interviewed*

Interviewees (specialists and scholars)	Official Institutions
Dr. Jalal Dabeek	
Dr. Sameer Shadeed	An-Najah National University
Dr. Abdalhaleem khadr	
Dr. Reyad Awad	Tulkarm Municipality
Eng. Reem Mahajneh	Municipality of Kafriyat
Eng. Asem abuzeyadeh	Anabta Municipality
Rami Sweis	Civil Defense
Eng. Saededdein Odeh	Ministry of Local Government
Dr. Shaher zeyod	
Dr. Fathi Anayah	Palestine Technical University - Kadoorie

GIS program has the power to integrate data from various sources into a common platform and make it readily attainable to analyze the input data. For a better analysis, the raster data for the parameters that affect the flood have to be developed. Each raster data is classified into five different hazard classes based on its relation to flood risk.

AHP pairwise comparison matrix was applied according to Satty's scale of relative importance for giving weights to different parameters. Using a range of scale from 1 to 5, by compare the importance of each parameter. Calculate the consistency ratio which is the popular method to check the weights of parameters and to make sure that comparison matrix is consistent or not.

The flood hazard map is developed by reclassifying each parameter from 1 to 5 according to its vulnerability to flood. For instance, class number 5 indicates to the very high vulnerable areas, class number 1 indicates to very low vulnerable areas to flood. We have to apply the weighted overlay summation process enabled by GIS, multiply the scored values by the raster's weight of importance and add the resulting cell values together to produce the flood hazard map to identify the most vulnerable areas.

Ground truthing can be described as compare the facts and data explained in the maps with the ground realities at a location or in a place. This method was applied in different three locations that previously affected to flood in 2013 in Tulkarm governorate. Comparing the results of this study with the locations that already happened a death of people there. This method has been used to check the accuracy of the resulted flood hazard map. Some of the points that were explained need more details and presentation of the data, as this will be illustrate in the next sections.

3.3 Delineating Study Area

Using the ArcMap 10.5, the watersheds that correspond to the study area need to be accurately defined. To delineate the targeted watersheds, several steps are to be followed as shown in Figure 5:

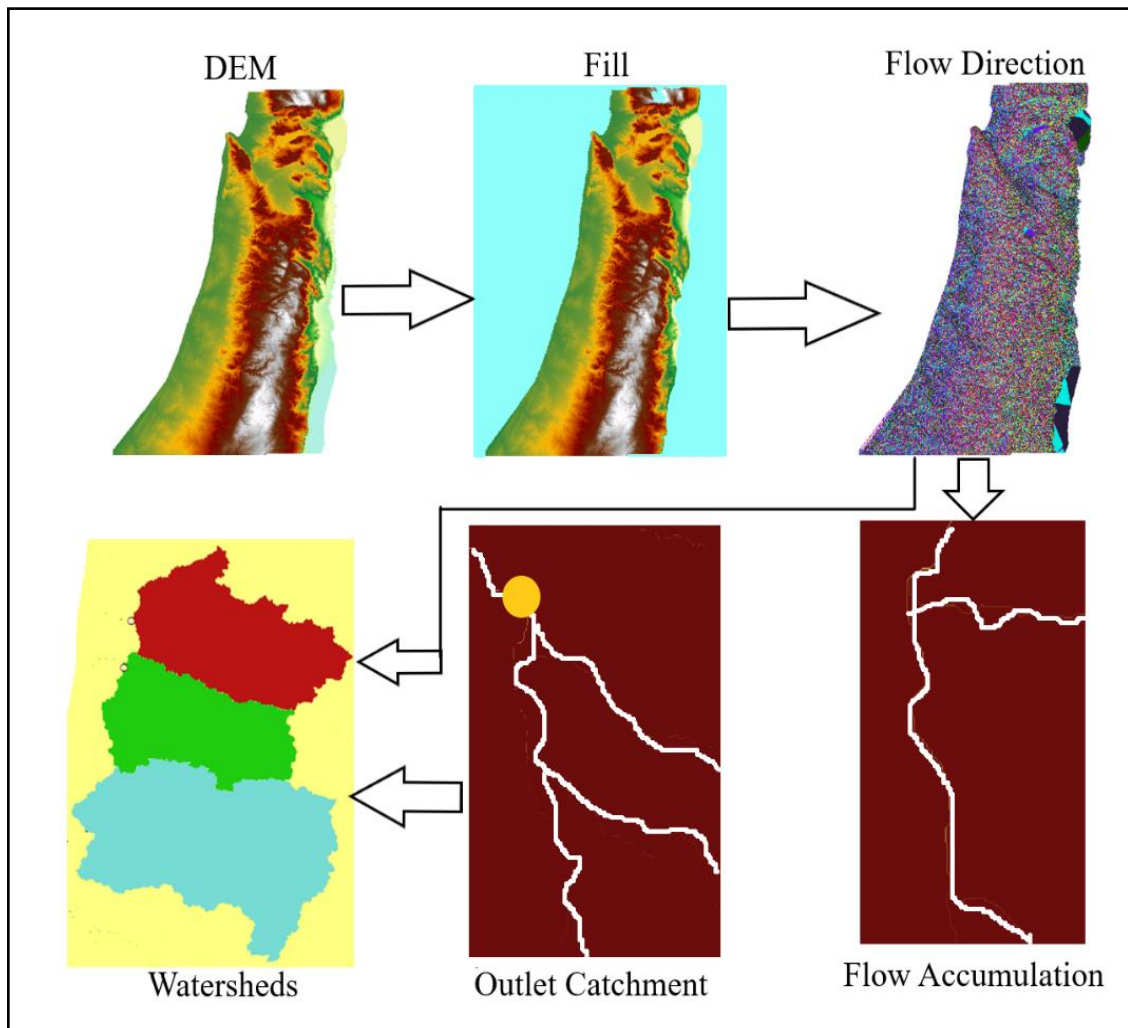
1. The “Hydrology” toolbox of the ArcMap 10.5 is utilized to accomplish this task.
2. The digital elevation model (DEM) raster of the highest resolution available from a reliable source is downloaded from EARTHDATA website [https://search.earthdata.nasa.gov/search?fs10=terrain%20elevation&fsm0=topography&fs20=digital%20elevation/terrain%20model%20\(dem\)&fst0=land%20surface](https://search.earthdata.nasa.gov/search?fs10=terrain%20elevation&fsm0=topography&fs20=digital%20elevation/terrain%20model%20(dem)&fst0=land%20surface)
3. The 12.5 m-resolution DEM of historic Palestine is selected for this purpose, given that the vertical accuracy is not available.
4. The “Fill” tool from the “Hydrology” toolbox is applied to remove any imperfections (or sinks) in the DEM.
5. The “Flow Direction” tool is implemented to trace the path of water flow in the grid from cell to cell based on the underlying terrain.
6. The “Flow Accumulation” tool is utilized to determine the number of upstream cells flowing into each particular cell in the grid.
7. The outlet point of the watershed needs to be specifically selected to determine the boundaries of the watershed, indicating total flow of water. Whenever the point is farther towards the flow direction (to the west across the Mediterranean Sea), the

greater total flow is. As we are restricted by the border with Israel, this aspect is taken into account to define the outlet point. Various outlet point locations were tested, to choose the appropriate watershed.

8. The “watershed” tool is used by entering the flow direction dataset as an input raster to get a new output dataset containing the specified watershed.

Figure 5

Steps to delineate Tulkarm governorate watersheds



3.4 Choosing Influencing Parameters of Flood Hazard

There are different parameters to select for evaluating the hazard of floods. It is an essential step for analysis based on the literature review, self-criteria from professional experience and the experts' opinions through in person interviews. From the literature review, Table 2 indicates a brief description for several article had recently used different parameters using the AHP method for flood hazard map.

Table 2

A brief description of parameters to consider for flood hazard map

Selected Parameters (percentage of weight factor)	Recent Studies						Expert Perspectives
	(Rincón et al., 2018)	(Zeleňáková et al., 2018)	(Shadeed, 2019)	(Parsian et al., 2021)	(Arya & Singh, 2021)	(Hagos et al., 2022)	
Slope (degree)	✓ (12-23%)	✓ (17%)	✓ (5%)	✓ (12%)	✓ (16%)	✓ (33%)	To be considered
Elevation (m)			✓ (8%)			✓ (25%)	Important
Drainage Density (km/km ²)			✓ (11%)		✓ (15%)	✓ (16%)	Important
Precipitation (mm/year)	✓ (36-42%)	✓ (49%)	✓ (22%)	✓ (18%)	✓ (27%)	✓ (7%)	The most important
Soil Texture		✓ (9%)		✓ (7%)	✓ (9%)	✓ (4%)	Relevant
Land Use/Land Cover		✓ (25%)	✓ (4%)	✓ (13%)	✓ (5%)	✓ (2%)	important
DEM (m)				✓ (16%)			DEM=Elevation
Flow Accumulation (pixel)			✓ (15%)				Important
Population Density (person/km ²)			✓ (2%)				To be investigated
Curve Number	✓ (8-12%)		✓ (31%)				CN must be derived from soil texture and land use. Not popular for risk managers.
Distance from Drainage Network (m)	✓ (13-23%)		✓ (3%)				Not recommended

After a deep reading of previous studies, we conclude a set of preliminary parameters: DEM, slope, elevation, land use/land cover, soil texture, curve number, rainfall distribution, distance from the drainage network and population density. According to Table 2, all of these studies used the slope parameter, which is an important factor to estimate. Furthermore, more than half of these studies used rainfall parameters. However, the demographic component is important to obtain for implementing mitigation measures that are aiming to decrease the number of people affected after a flood event (Rincón et al., 2018).

A number of interviews were conducted with knowledgeable experts from different institutions, the aim of these interviews was to familiarize the local experiences and identify the needs of the Tulkarm governorate in accordance with the objectives of this study. A group of knowledgeable experts working in the study field from different sectors of which two from governmental agencies (Table 1), three from local government units (LGUs) such as municipalities and five from academic institutions such as local universities. We asked about the nature and importance of the flood hazard at Tulkarm governorate, the causes of flood risk and the procedures and recommendations to be taken to mitigate such risk. Also, some questions were asked about selected parameters that affect the risk of flooding.

After examining previous studies and conducting interviews, we reached to the following eight parameters, slope (degree), elevation (m), drainage density (km/km²), precipitation (mm/year), soil texture, land use/land cover, flow accumulation (pixel), population density (person/km²).

3.5 AHP Weights of Parameters

Analytic Hierarchy Process (AHP) is one of the multi-criteria analysis (MCA) methods that organizing the parameters into a hierarchical framework (Papaioannou et al., 2015). This method used to represent an issue and develop weights for a different set of parameters and compare them in terms of importance, based on the judgment of the user.

The AHP procedure includes six essential steps: determine the problem, clarify the goals and results, built the hierarchical structure with decision elements (criteria, detailed criteria and alternatives), apply pairwise comparisons among decision elements and form comparison matrices, estimate the relative weights, check the consistency ratio of matrices to ensure that the judgments of decision makers are consistent and achieve overall rating of the method (Lee et al., 2008).

AHP process in the GIS environment is the most popular and powerful method especially in the problem of solving the weights of parameters, such as slope, elevation and precipitation for producing flood hazard maps, with a good level of precision (Gigović et al., 2017). The parameters are categorized on a scale of 1 to 9, indicating the importance of each parameter (Table 3).

Table 3

Satty's scale of relative importance for giving weights to different parameters

Intensity of importance	Degree of preference	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one factor over another	Experience and judgment slightly favor one activity over another
5	strong or essential importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	When compromise is needed

Note: (Hagos et al., 2022)

After implementing the pairwise comparison matrix, the diverse weights were computed as the weight of a parameter equals the mean value of each row. It should be mentioned that this step must be preceded by finding a new matrix that contains new values from

dividing each cell by summation of each column. We should calculate the consistency ratio (CR) that must be less than 0.1 (Youssef & Hegab, 2019), which is equal to the consistency index (CI) over the random index (RI) as follows in equation (2):

$$(CR=CI/RI) \dots\dots\dots \text{Equation (2)}$$

$$(CI = \text{Lamda} - n / n-1) \dots\dots\dots \text{Equation (3)}$$

where: CR is the consistency ratio, CI is the consistency index, RI is the random index, lamda is the division of weighted sum value over criteria weight and n is the number of parameters as shown in equation (3). As for the RI, it is taken from a table according to n value (e.g., (Youssef & Hegab, 2019)). In the present study, CR equals 0.029 which is less than 0.1, and therefore, the assigned weights of parameters showed in Table 4 can be successfully used in the flood hazard calculations.

Table 4

Normalized flood hazard parameters using AHP pairwise comparison matrix

Parameters	P	E	S	DD	FA	ST	LU/LC	PD	Weights
Precipitation(P) (mm/year)	1	2	3	4	5	6	7	8	33.13%
Elevation (E) (m)	1/2	1	2	3	4	5	6	7	23.07%
Slope (S) (degree)	1/3	1/2	1	2	3	4	5	6	15.72%
Drainage Density (DD) (km/km ²)	1/4	1/3	1/2	1	2	3	4	5	10.59%
Flow Accumulation (FA) (pixel)	1/5	1/4	1/3	1/2	1	2	3	4	7.09%
Soil Texture (ST)	1/6	1/5	1/4	1/3	1/2	1	2	3	4.77%
Land Use/Land Cover (LU/LC)	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3.27%
Population Density (PD) (person/km ²)	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2.36%

3.6 Classification of Parameters According to Flood Hazard

After calculating the weights of each parameter using AHP method, we divided every parameter into five classes according the probability of flood and the vulnerable areas,

giving each class a score of risk from one to five; one indicates the very low vulnerable areas and five indicates the very high vulnerable areas to flood. Table 4 indicates each parameter with its classes and scores.

As depicted in Table 5, there are eight parameters of interest to the present study; slope, elevation, drainage density, precipitation, soil texture, land use/land cover, flow accumulation and population density. Table 4 indicates the scoring system and classes for each parameter.

Table 5*Scoring system and classes for each parameter*

Parameter	Class	Score
Slope (S) (degree)	≤ 5	5
	$5 < S \leq 10$	4
	$10 < S \leq 15$	3
	$15 < S \leq 20$	2
	> 20	1
Elevation (E) (m)	≤ 100	5
	$100 < E \leq 200$	4
	$200 < E \leq 300$	3
	$300 < E \leq 400$	2
	> 400	1
Drainage Density (DD) (km/km ²)	< 1	1
	$1 < DD \leq 2$	2
	$2 < DD \leq 3$	3
	$3 < DD \leq 4$	4
	> 4	5
Precipitation (P) (mm/year)	< 450	1
	$450 < P \leq 500$	2
	$500 < P \leq 550$	3
	$550 < P \leq 600$	4
	> 600	5
Soil Texture	Sand	1
	Sandy loam	2
	Silt loam	3
	Clay loam = Brown Rendzinas and Pale Rendzinas	4
	Clay = Terra Rossa soil & Grumusols	5
Land Use/Land Cover	Built-up area	5
	Cultivated land	4
	Arable land	3
	Pasture and open land with no vegetation	2
	Forest	1
Flow Accumulation (FA) (pixel)	≤ 50000	1
	$50000 < FA \leq 100000$	2
	$100000 < FA \leq 150000$	3
	$150000 < FA \leq 200000$	4
	> 200000	5
Population Density (PD) (person/km ²)	< 100	1
	$100 < PD \leq 400$	2
	$400 < PD \leq 700$	3
	$700 < PD \leq 1000$	4
	> 1000	5

After classifying the selected parameters into five classes, based on its affecting on flood risks, providing them a score value from one to five. For example, as for the slope parameter, when the slope is less than or equal to five degrees, the water will accumulate and result in surface water runoff. In this case, the slope class will take the score of five which means high hazard to flood. In addition, for the precipitation parameter, when the values less than 450 mm/year the scored value will be one. The final step using ArcMap 10.5, is to apply the overlay weighted sum tool that overlays several raster data, multiply each one by its given weight and sum them together as depicted in Equation (4):

$$\text{Flood Hazard Map} = \sum_{i=1}^{i=8} W_i \times S \quad \dots\dots\dots \text{Equation (4)}$$

where: W_i : is the weight of each parameter I so that $\sum W_i = 1$, and S : is the score of each cell in the raster.

3.7 Build an Indicator of Flood Hazard Map

Developing the rainfall-runoff map using the runoff coefficient to calculate runoff from rainfall as shown in Equation (5):

$$Q = C i A \quad \dots\dots\dots \text{Equation (5)}$$

where Q = runoff (m^3/s), C = coefficient of runoff, which depends upon the nature of the surface, surface slope, and rainfall intensity, i = intensity of rainfall (m/s), and A = area of the catchment (m^2).

While the runoff ratio for the West Bank is 2-3.2% of the rainfall according to Rofe and Raffety (1965) report (Anayah, 2006). Trying to perform a food risk map to multiply by our flood hazard map resulting in flood risk map as shown in Equation (6) (Aksha et al., 2020).

$$\text{Flood risk map} = \text{Flood hazard map} \times \text{Flood vulnerability map} \quad \dots\dots\dots \text{Equation (6)}$$

Chapter Four

Results and Discussion

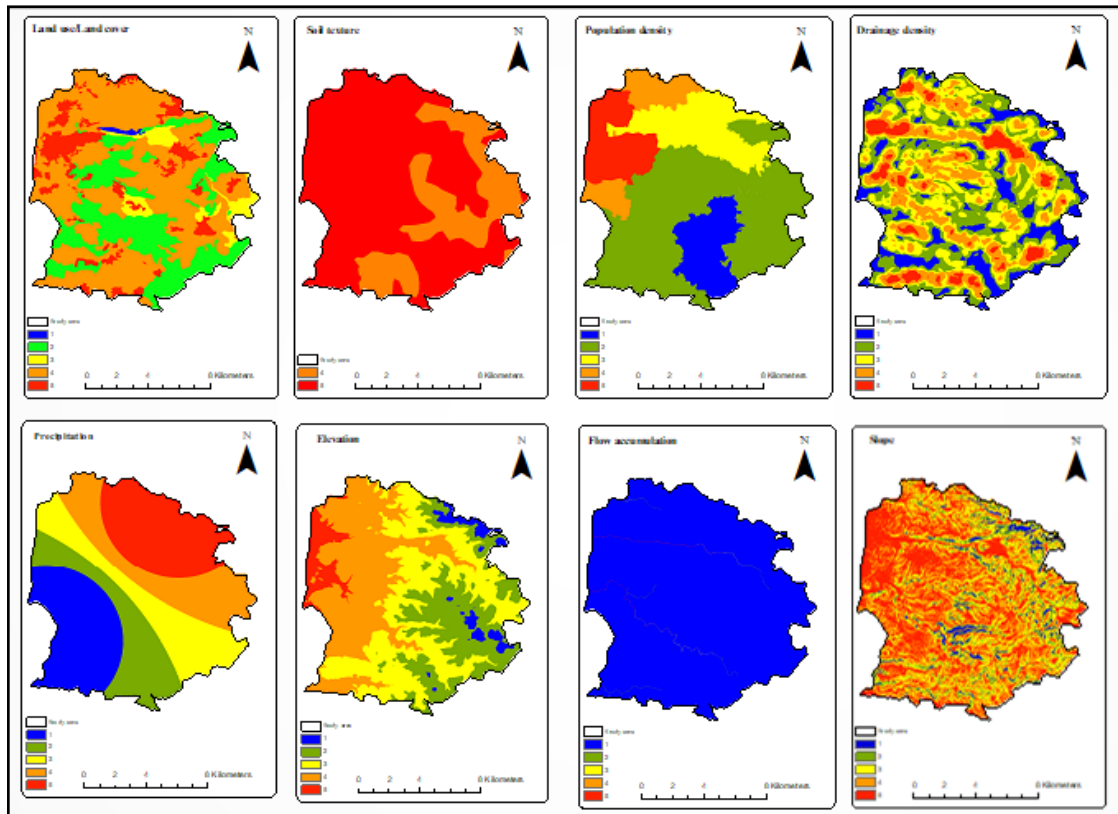
The results found are to be discussed in this chapter. The discussion includes comparison with results of previous studies from the literature, in addition to the ground truthing which supports our results.

4.1 Outcomes and Deliverables

According to the eight selected parameters with different weights depending on its importance that were calculated based on the AHP method as shown in Figure 6, the flood hazard map was performed using several rasters with a resolution of 12.5×12.5 m. A flood hazard map for a specific watershed in Tulkarm governorate was produced as shown in Figure 7, containing five categories indicate with each percentage (Table 6): very low (2%), low (26%), medium (37%), high (28%), and very high (7%). Building a flood hazard map with determine the vulnerable areas help decision makers to manage flood risk (Zeleňáková et al., 2018).

Figure 6

The scored raster maps for each parameter of the study area in Tulkarm governorate



As shown in Figure 6, eight parameters were mapped and each parameter was studied based on its relation to flooding, where each one was divided into five classes that indicates the vulnerability to flooding. For example, as depicted in the elevation map, the classification ranges from 65 m to 535 m, whenever we turn to the left (when the elevation class is less than 100 m) the vulnerability of flooding increases, so there is an inverse proportion between the elevation and the vulnerability to flooding.

In the population density, the map was classified based on the population numbers for each community, the classes range from 100 to 1000 person/km², as it shows the greatest concentration of the possibility of flooding in the center and north of the study area. As the relation between them is directly proportional.

The land use map shows the classification of land use/ land cover for Tulkarm study area. This different classification categorized into five classes. The flood vulnerability increases at built up area. In the other hand, flood vulnerability decreases at pasture and open land with no vegetation and forests.

The slope map displays the classification of slopes for Tulkarm study area, an inversely proportional between slope and flood vulnerability. This different classification categorized into five classes. The flood vulnerability increases at small slopes. In the other hand, flood vulnerability decreases at high value of slope as depicted in the map.

Figure 7

Flood hazard map of the study area in Tulkarm governorate

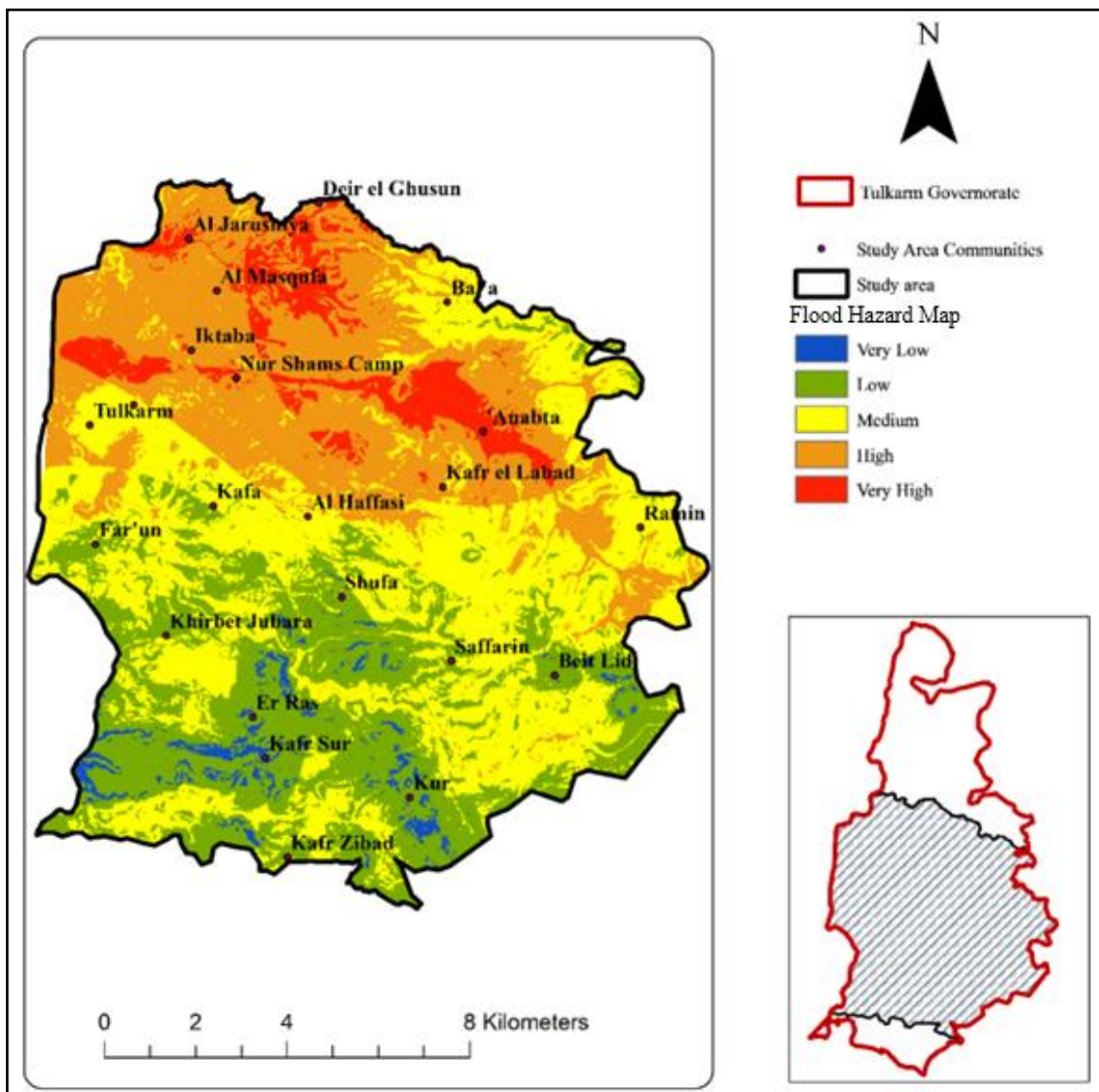
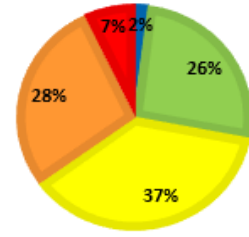


Table 6*Percentage of each flood hazard class*

Flood hazard class	Percentage (%)
Very low	2
Low	26
Medium	37
High	28
Very high	7

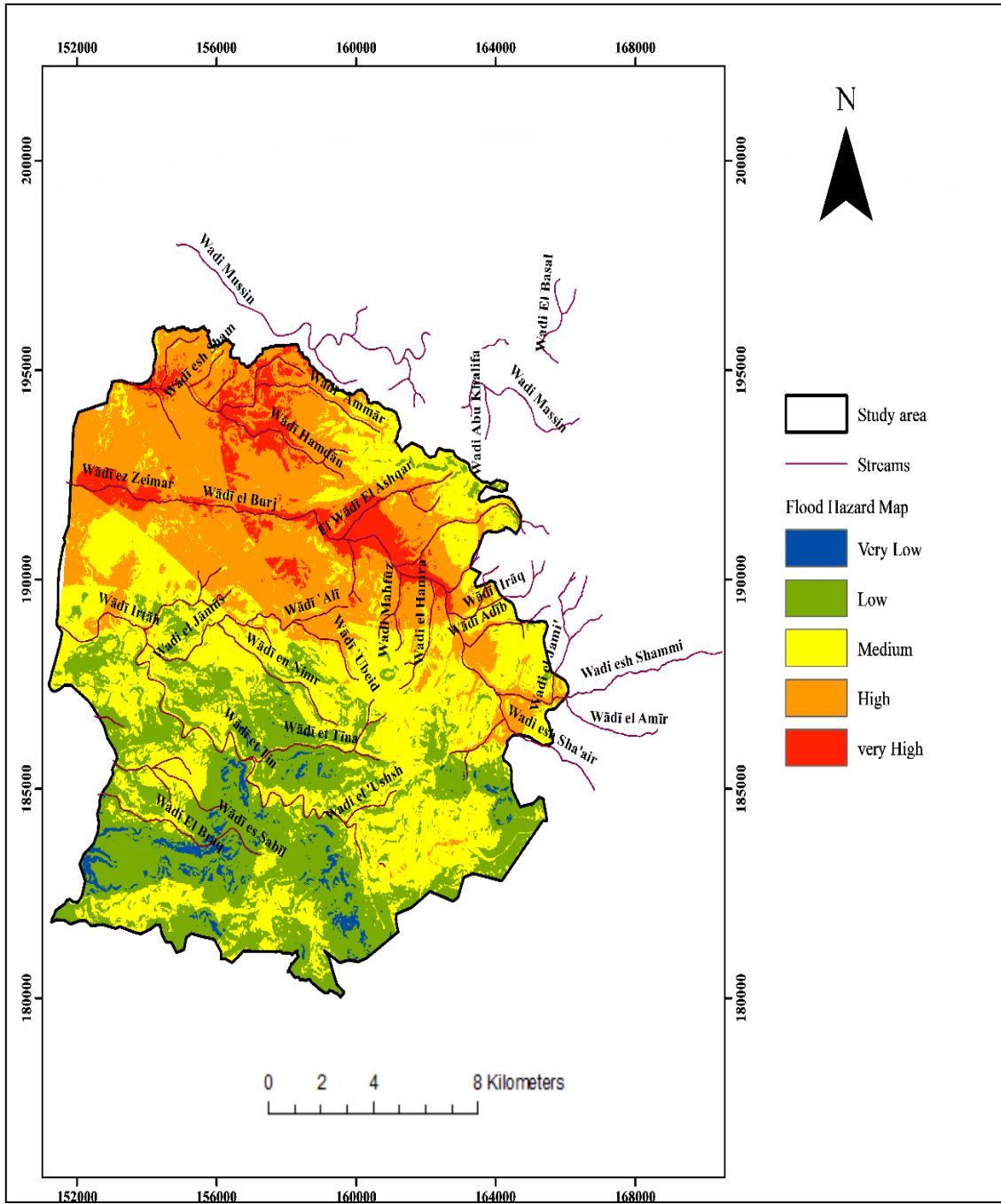


The study area is bordered to the north by Al Sharawyah region, to the south by Al Kafriat region and the city of Tulkarm and Anabta are concentrated in the middle which is called the eastern region. As depicted in the map (Figure 7), as we move forward from south to the north, the flood hazard class increases gradually, in the north of the map, most regions are highly vulnerable to flood. This can be seen in Al-Jarushiya, Deir Al-Ghusun and Al-Masqufa which is located their wadi Ash-Sham connecting to wadi Ammar as shown in Figure 8. Also, the same hazard flood map shows extreme conditions at Iktaba, Anabta and Nur shams camp, which is the area located along wadi Az-Zoumer to wadi Al-Burj. It is important here to point out the accident that took place there in which two women died (Shadeed, 2019) in 2013. This situation requires urgent and rapid intervention from decision makers. We also observe that Balaa is located within the medium to low class, because it has the highest value of elevation in Tulkarm governorate.

In the middle of Tulkarm governorate, where Tulkarm city, Kafr Al-Labad, Al-Haffasi and Ramin are located, the hazard class ranges from medium to high as we notice in the map. While the hazard class extents from low to medium in the following communities; Farun, Kafa, Shuffa, Saffarin, Jubara, Beit Lid and Kafr Zebad. In the south, Kafr Sur, Kur and Ar-Ras are classified as low to very low in the hazard to flood. Although wadi At-Teen is located around these communities, yet low hazard is noticed because of the low population density in that area. Also, the elevation ranges from 200-400 m which is not low compared to altitudes in the study area. Most of these lands are pasture and open land with no vegetation.

Figure 8

Streams and their extension in the study area

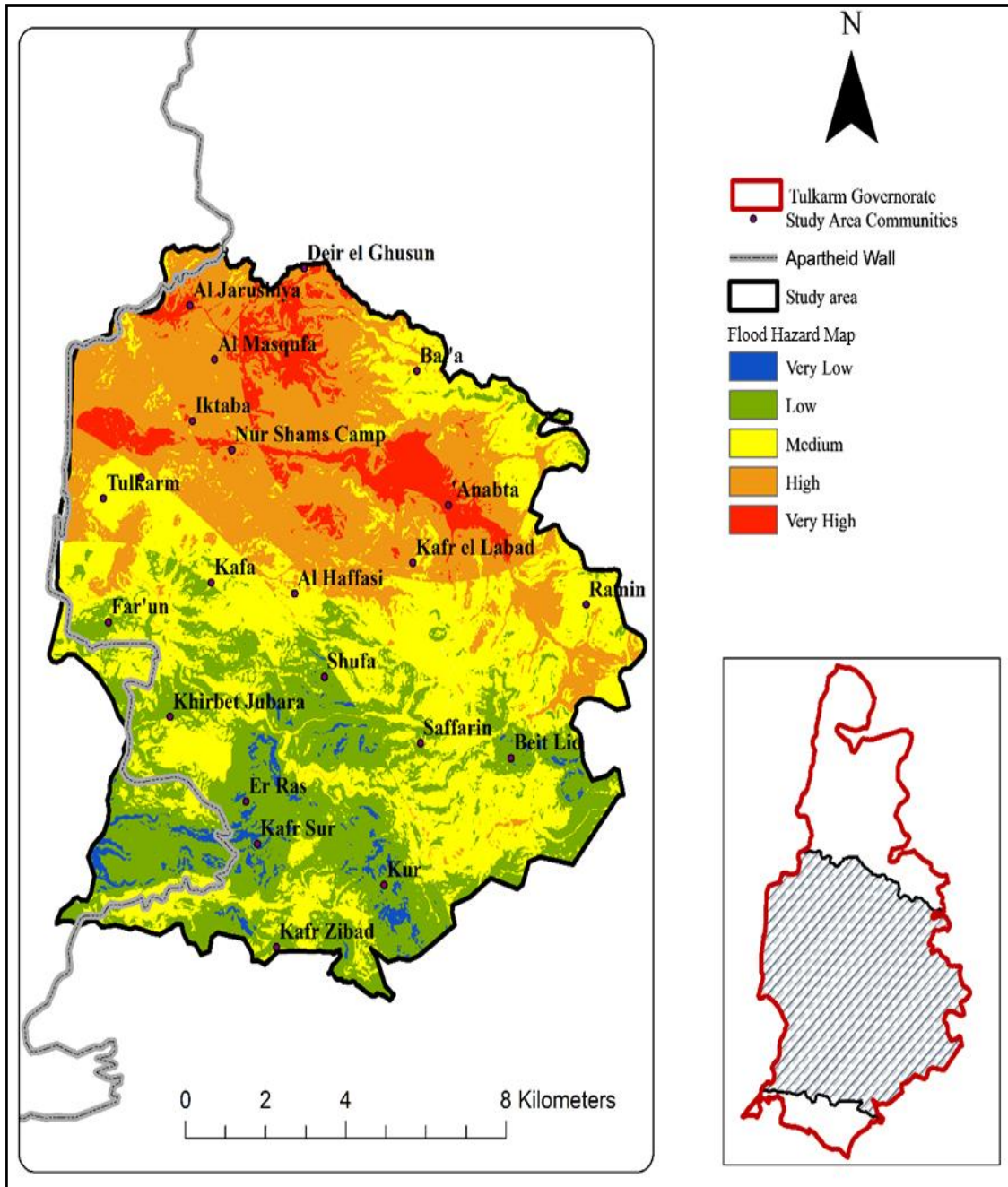


Shadeed (2019) found that Tulkarm governorate has high to very high vulnerable areas which indicates the importance of our study. The high to very high vulnerable areas approached 13% of in the West Bank area (Shadeed, 2019). It is worth mentioning that the resolution of the present study is 12.5 m which is higher than the resolution of Shadeed (2019) study which was 25 m. The high and very high vulnerable areas in the present study represent approximately 35% of the study area, which is a high percentage so that LGUs should apply preventive measures and mitigate the risk of flood. In the Hagos (2022) study, the high and very high vulnerable areas represent 56% of the upper Awash River basin of Ethiopia which is also an extreme percentage to implement appropriate flood control strategies.

It is important here to point out that these results appeared without considering the apartheid wall, where the presence of the wall acts as a barrier that its backwater leads to an increase in the class of hazard (Figure 9). Hence, the medium vulnerable areas will be high or very high with the existence of the wall (Ministry of Local Government, 2017). Tulkarm governorate is bordered to the south by the city of Qalqilya, which is very similar in terms of climatic conditions, soil, land use and elevation with Tulkarm governorate. As per what happened in 2013, when the apartheid wall gates were shut off by the authority of the Israeli occupation, runoff water accumulated in the low level areas caused a flood and resulted in losses of properties.

Figure 9

Apartheid wall in the study area of Tulkarm governorate



Based on a runoff ratio of 3.2%, a flood hazard map was developed by multiplying this ratio by the precipitation raster, resulting in a flood hazard map for the study area. As shown in Figure 10, the flood risk map was greatly affected by the precipitation map and there is no variability or distribution in the classes. This made the results inaccurate in terms of the common sense, and therefore, the so-called flood risk map will not be adopted

in the present study. As a result, we will stick to the flood hazard map to represent and demonstrate flood risk.

4.2 Ground Truthing

It is important to check the accuracy of the resulting flood hazard map using ground truthing to match the results in-situ. Three different case studies in the study area were chosen: location 1: at the east of the study area (the location where two women passed away in 2013), location 2: at the middle of Tulkarm city (Shobaki junction at Faroun street) which is always been flooded of water), and location 3: at Kherbit Jubara (where the death of a man in 2013 took place) (Figure 11). As shown in Figure 12, after matching the coordinates of all case studies, it indicates realistic and correct results appear in each location which actually represents the high and very high vulnerable areas.

4.3 Flood Risk Management

Floods are natural phenomena that can be controlled not prevented. To manage flood risk, we need to improve plans that focus on prevention, protection and preparedness (European Union, 2007). Flood hazard mapping should be performed routinely to monitor changes over time in the natural and social environments (Aksha et al., 2020). Mapping vulnerability enables competent authorities to delineate areas of the highest susceptibility and impact, in order to reduce vulnerability and promote capacity building (Jha et al., 2012). In addition, mapping flood vulnerability on a local scale gives accurate details and helps specialists in strategic planning and decision-making to reduce flood risks and increase community resilience (Membele et al., 2022).

There are two methods to control flood risk, structural adjustments which include flood water reservation structures, redirect the paths of flood waters, and modifications in some existing structures (Department of Homeland Security, 2016). The other method is non-structural called “soft solution”, the main goal of these measures is preparing for flooding, avoiding flooding, planning for and managing flood emergencies and recovering from flooding (Jha et al., 2012).

An integrated strategy usually needs joining between both structural and non-structural measures (Toshihiro, 2016). Some of the disadvantages of structural measures are high cost to perform and implement by governments. So, we need non-structural measures to control flood risk that generally need little cost and shorter time to apply. Table 7 describes various structural and non-structural measures used to manage the risk of flooding.

Table 7

Different structural and non-structural measures

Structural Measures	Non-Structural Measures
1. Conveyance	1. Flood awareness campaigns
2. Flood storage	2. Health planning and awareness campaigns
3. Drainage systems	3. Land use planning and flood zoning
4. Infiltration and permeability in urban areas	4. Flood insurance, risk financing, compensation and tax relief
5. Groundwater management	5. Solid and liquid waste management
6. Wetlands and environmental buffers	6. Emergency planning, rescue, damage avoidance actions and temporary shelter
7.	7. Business and government continuity planning
8. Flood defense	8. Early warning systems
9. Barrier and embankment systems for estuary and coastal flood protection	9. Evacuation planning
	10. Flood recovery and reconstruction
	11. Building design, resilience and resistance

Note: (Jha et al., 2012).

To use these several measures, experienced technical specialists should be consulted. Highly vulnerable areas need an urgent intervention from decision makers, to find a suitable solution for this situation. Figure 13 describes interventions for the different hazard classes. To ensure that flood risk is well identified and mitigated, it is important to have representation from sectors of the community including government agencies, LGUs, NGOs, united nations, private sector and others. Table 8 indicates different interventions and strategies for each tier of flood hazard class.

Table 8*Interventions and strategies for each tier of flood hazard class*

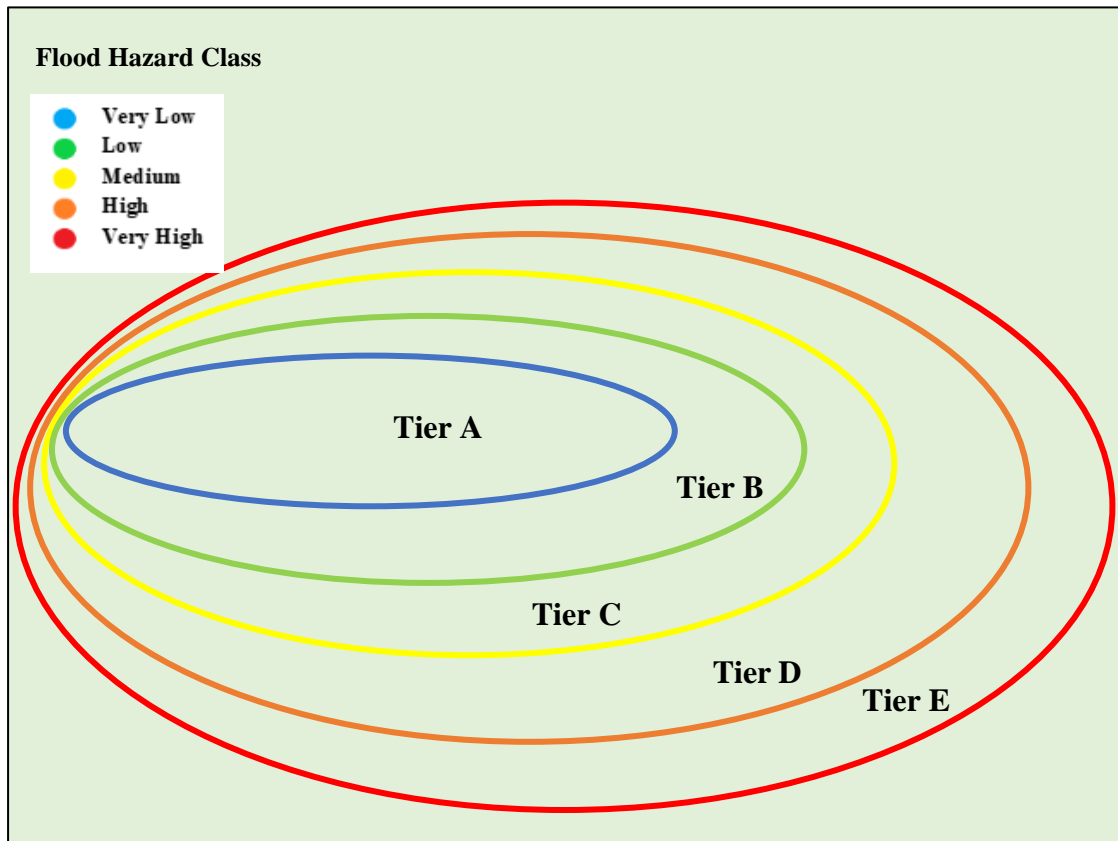
Flood hazard class	Tier	Interventions and strategies
Very low	A	<ul style="list-style-type: none"> • No active intervention ‘walk away’ • Preventive maintenance of rainwater sewers before winter frequently • Regular maintenance of rainwater culverts and valley streams
Low	B	<ul style="list-style-type: none"> • Preventive maintenance of rainwater sewers before winter frequently • Regular maintenance of rainwater culverts and valley streams • Continuation with existing and alternative actions to manage flood risk at the current class • Health planning and awareness campaigns about flood risks
Medium	C	<ul style="list-style-type: none"> • Taking further actions for remedial of the current class • Preventive maintenance of rainwater sewers before winter frequently • Continuation with existing and alternative actions to manage flood risk at the current class • Health planning and awareness campaigns about flood risks • Designing buildings with flood-resistant constructions in higher flood risk areas
High	D	<ul style="list-style-type: none"> • Taking immediate actions for remedial of the current class • Preventive maintenance of rainwater sewers before winter frequently • Regular maintenance of rainwater culverts and valley streams • Continuation with existing and alternative actions to manage flood risk at current class • Health planning and awareness campaigns about flood risks • Designing buildings with flood-resistant constructions in higher flood risk areas • Applying natural approaches of structural measures • Constructing new buildings according to flood resistance code • Flood insurance, risk financing, compensation and tax relief • Subsidizing insurance premiums for individuals’ businesses
Very high	E	<ul style="list-style-type: none"> • Preventive maintenance of rainwater sewers before winter frequently • Regular maintenance of rainwater culverts and valley streams • Continuation with existing and alternative actions to manage flood risk at the current class • Health planning and awareness campaigns about flood risks • Designing buildings with flood-resistant constructions in higher flood risk areas • Applying natural approaches of structural measures • Constructing new buildings according to flood resistance code • Flood insurance, risk financing, compensation and tax relief • Subsidizing insurance premiums for individuals’ businesses • Taking urgent and immediate actions at flood risk management levels from preparedness to recovery • Providing devices and equipment for rapid response to emergencies during flooding • Removal of informal settlements and other debris near the stream • Managing solid and liquid waste • Developing new legislation to enforce construction of new buildings in accordance with the flood-resistant code • Making special designs for the infrastructure of buildings adjacent to the floodplain • Preventing construction in highly flood vulnerable areas • Applying heavily-engineered structural measures

In the light of the discussion in Table 8, it is essential to highlight the following points:

- In the awareness and campaigns design, at all classes of hazard defining measurable goals are important by knowing the audience of these campaigns, using different communication such as television, newspaper, art competitions and threats. Ensure the implementation of these campaigns, and monitor public awareness.
- There should be soft interventions pre- and post-flood in order to enhance awareness of how to deal with floods, and for the effectiveness and success of hard interventions when applied.
- In order to implement these strategies and interventions, a group of targeted parties in flood risk management must be included; e.g., citizens, specialists, and official agents (decision-makers).
- There must be common factors or variables among the key actors of flood risk management.
- There must be an effective organizational structure that requires formal authorization, a series of effective policies that are realistic and depend on real-time information and a controlled system that is able to set things right and have the knowledge and skills to implement the work.
- Flood risk management requires the existence of effective plans based on procedures, laws and mechanisms to deal with potential floods during the three stages: before, during and after the flood.

Figure 13

Interventions for each hazard class



4.4 Climate change and its relation to flood

There are significant changes in the ecosystems in the areas of Asia, which result in many climatic, natural, social and economic changes. Climate change is increasing energy demands at a rapid rate. As a result, there is a large number of developing countries that are exposed to high degrees of energy insecurity which pose risks to industrial systems. These changes in space and time affected directly or indirectly the water use sectors and services (IPCC, 2022).

In addition, there are main expected impacts of climate change in the agricultural and food sectors. Furthermore, climate change affects infrastructure and causes direct losses as a result of damage to the transportation network, roads and power lines. It will lead to an increase in disease vectors and the possibility of infection, and thus, negative effects on human health and well-being (IPCC, 2022).

Disasters become more frequent and intense in the light of climate change. As during the past three decades, two-thirds of the world's disasters were caused by climate-related phenomena and the developing countries are the most affected by climate-related events (Rivera & Wamsler, 2014). Obviously, both climate change adaptation and disaster risk reduction (DRR) intend to decrease the influence associated risks of climate-related disasters.

Climate change has already changed the location, frequency and intensity of floods. As the climate warms, the nature of precipitation events (how often, how long, and how intense) will continue to change (IPCC, 2021). Therefore, more severe floods are expected as a result of the events of the unusual wet weather seasons that lead to greater amounts of precipitation in the future. As a result, even considering the many factors that generate floods, when weather patterns cause floods in a warmer future, those floods will be more severe (IPCC, 2021).

Due to the projected climate change, unplanned urbanization and quick land use change, the Asian urban areas are considered high-risk locations (IPCC, 2022). The presence of urban adaptation measures, for example adapting infrastructure (such as flood protection measures), helps mitigate the effects of climate change. Perception of risk, perceived self-efficacy, socio-cultural norms and beliefs, prior experiences of impacts, levels of education and awareness are factors that motivate adaptation actions (IPCC, 2022).

Planning for flood risk management and the existence of well-studied integrated plans help in the role of mitigating the effects of climate change and reducing the severity of its consequences (Few et al., 2004). Also, this represents a basic role in the goals of adaptation, mitigation and sustainable development simultaneously. Hence, mitigation can obviously reduce the impacts, which can be minimized even further with adequate adaptation strategies. Nowadays it is important to emphasize the risk management and preparedness towards the emergency response due to the increased risk posed by climate change. There is a necessity to move further toward risk reduction activities in flood (Few et al., 2004).

There is an obvious trend to integrate DRR activities with climate change adaptation measures to achieve the sustainable development goals. This can be achieved by urging national governments to improve strategies, conduct more studies and seek consistency across policies, institutions, targets, indicators and measurement systems for implementation (Dash & Akhter, 2023).

4.5 Limitations

The flood hazard map which was developed in the present study helps to reduce and mitigate flood risks if properly used. Regardless of the parameters applied in delineating the flood hazard map, previous studies in the literature (e.g., (Papaioannou et al., 2015; Zelenáková et al., 2018)), decision makers can take advantage of such maps to resolve issues that make the situation worse and the consequences higher.

Historical flood data should be recorded by the ministry of transportation which is in charge of meteorological data monitoring and management. Unfortunately, such data had never been available. We did not consider flood hazard map because of the low variability of results in a small area, so we stick to the flood hazard map that better represents the flood risk. More efforts are needed to create a flood hazard map to the study area, so that the flood risk can be assessed precisely and implemented properly.

Geographically, the study is specific to the Tulkarm region, limited to the area of watershed. Therefore, it should be expanded to develop a country-wide flood hazard map. The resolution of the DEM used in the present study (12.5×12.5 m) is another limitation. Soil map, land use land cover shapefile data should be updated to mimic the reality in the field.

It is also possible to increase the number of people interviewed to identify and study the factors affecting the flood. In addition, the possibility of changing the weights of the parameter used in this study by changing the important factor. This is crucial to conduct a sensitivity analysis and prioritize influencing parameter.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

This study has developed a flood hazard map with a high resolution of 12.5 m for a study area in Tulkarm governorate of Palestine. The hazard map has been created according to eight parameters; slope, elevation, drainage density, precipitation, soil texture, land use/land cover, flow accumulation and population density. Each parameter has its own weight based on the Analytic Hierarchy Process (AHP) pairwise comparison matrix. The Geographic Information System (GIS) program is an active environment to the weighted overlay tool to selected parameters used to improve a hazard map. It is essential to provide such a map for decision makers to create feasible solutions and mitigate flood risks.

In the last few years, Tulkarm governorate had experienced extreme flood risks that resulted in life and property losses. This did not happen to any other governorate in the West Bank and Gaza Strip, and different areas in the governorate experienced floods. The areal distribution of the flood hazard varies according to the different classes: very low (2%), low (26%), medium (37%), high (28%), and very high (7%). This situation requires immediate interventions from policy and decision makers to find effective solutions to the flood risk. A flood hazard map is an integral part of the flood risk assessment process. There is a dire need to conducting a number of interventions and actions that control flood risk during the phases of flood risk management for each vulnerability class.

A ground truthing was conducted for three different locations where previous flood occurred in 2013 in Tulkarm governorate. The ground truthing is to investigate how the results of the present study match the reality and to examine the validity of the findings compared to the field assessment. It is necessary to conduct proper flood risk management and utilize the produced flood hazard map in order to create the flood risk map. The maps are to be updated periodically to keep decision makers and officials informed of developments in high vulnerable areas. There is a set of structural and non-structural

interventions that must be carried out for each class of vulnerability. Increasing the flood resilience of the society is an important issue during all phases of flood risk management from mitigation, preparedness, response and recovery.

Climate change plays a major role in increasing the severity of floods and the severity of their occurrence. The application of mitigation and adaptation measures and strategies to manage flood risks reduces the severity of corresponding damages and consequences on societies and the environment.

5.2 Recommendations

Many recommendations can be drawn based on the results of the present study, which could be a key to new future studies, which are:

1. Developing a flood hazard map will help to produce a flood risk map.
2. Preparing an operation room to respond to the flood at the time of the event, for better management of flood risk.
3. Considering different parameters such as building material and building conditions, and changing the weights of the selected parameters using the AHP method to obtain different results that could benefit the current situation in Tulkarm governorate.
4. Setting up a well-sustained plan to be implemented for flood risk management in Tulkarm governorate.
5. Conducting raising awareness activities to study flood risk management in Tulkarm governorate by decision makers and the competent authorities.
6. Creating a flood resilience scorecard that helps communities to identify the actions that can decrease their vulnerability.

List of Abbreviations

Abbreviation	Meaning
AHP	Analytic Hierarchy Process
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
FHM	Flood Hazard Mapping
GIS	Geographic Information System
HEC-HMS	The Hydrologic Engineering Center's-Hydrologic Modeling System
HEC-RAS	The Hydrologic Engineering Center's-River Analysis System
PCBS	Palestinian Centre Bureau of Statistics
SCS-CN	Soil Conservation Service Curve Number

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Appendices

Appendix A

Photos of flood risk map, flood events in Tulkarm governorate in 2013 and ground truthing

Figure 10

Flood risk map of the study area in Tulkarm governorate.

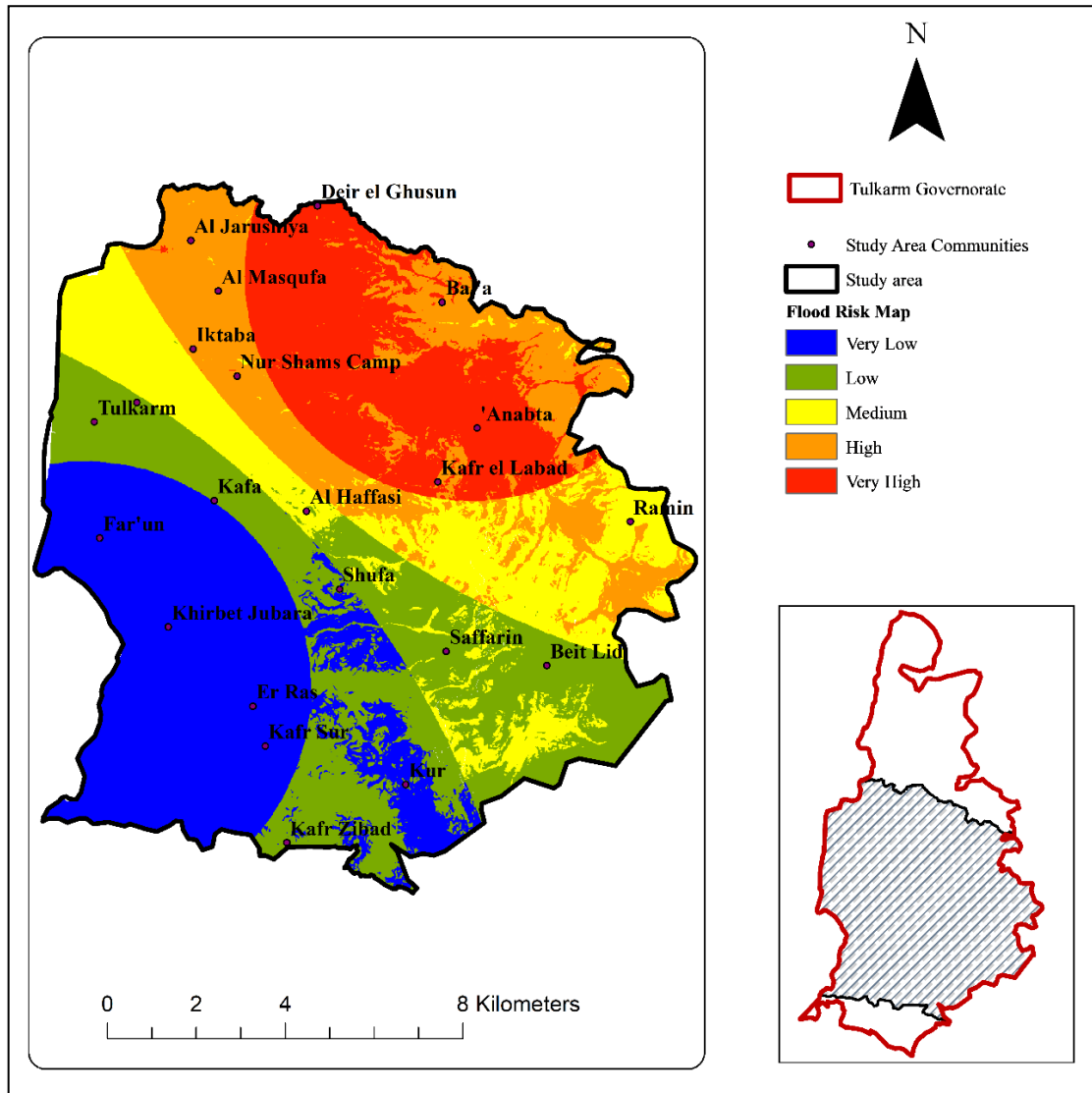


Figure 11

Photos of flood event in Tulkarm governorate in 2013 at: a. Location 1, b. Location 2, and c. Location 3

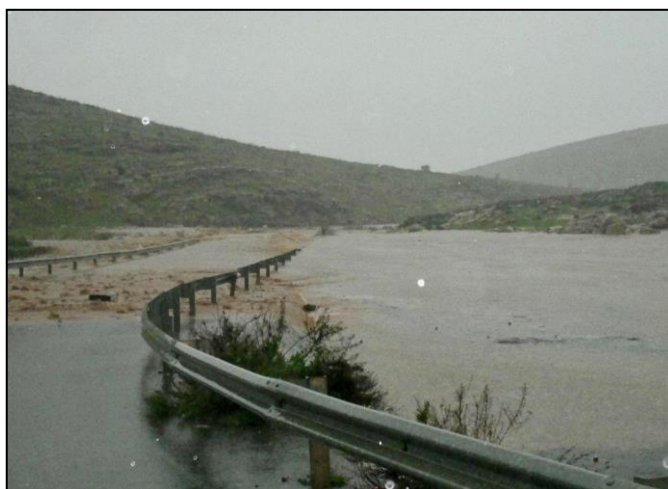
a. Location 1



a. Location 2



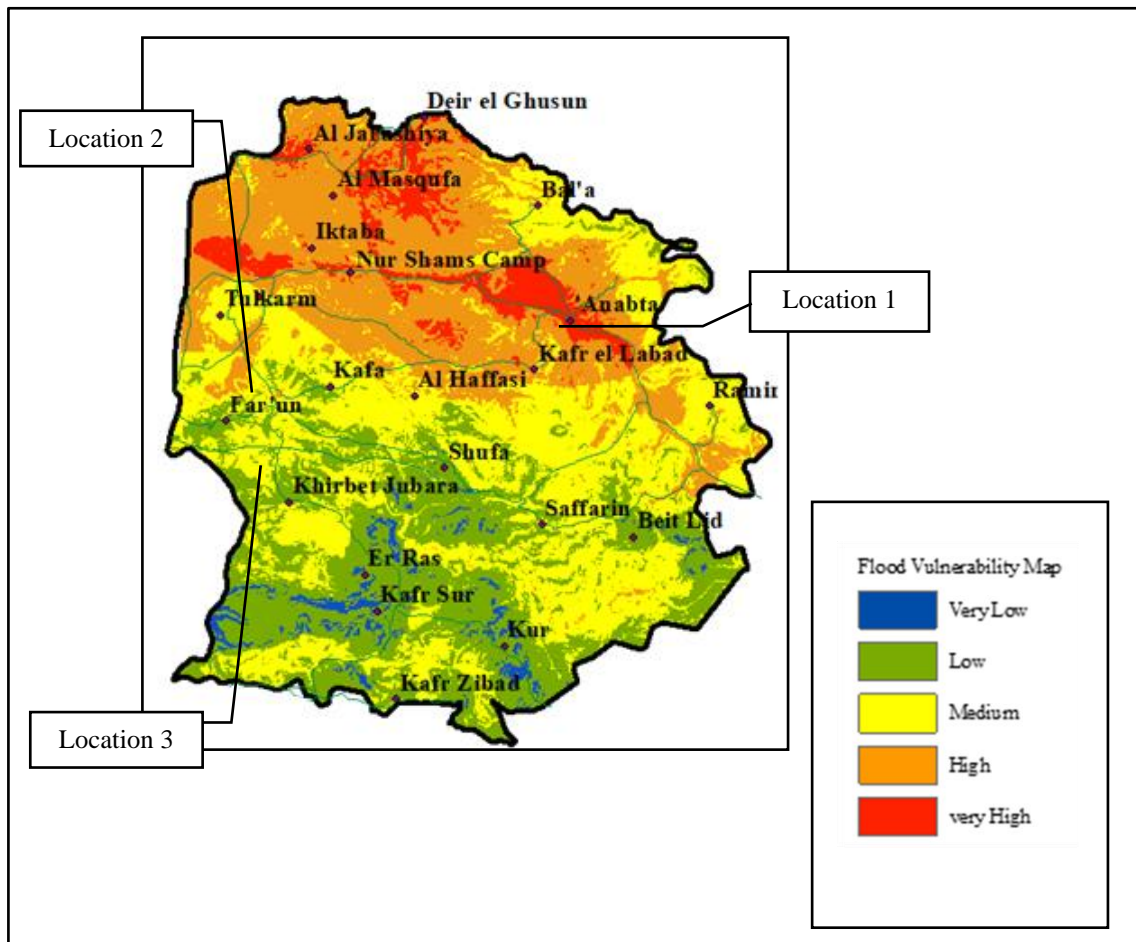
a. Location 3



(Source: <https://www.youtube.com/watch?v=bbcWht-nFM8>).

Figure 12

Ground truthing results



Appendix B

الاستبانة



جامعة النجاح الوطنية

كلية الدراسات العليا

برنامج إدارة مخاطر الكوارث

عزيزي/عزيزتي:

يتم اجراء دراسة بعنوان تقييم مخاطر الفيضانات وإدارتها في محافظة طولكرم، تهدف الى تصميم خريطة مخاطر الفيضانات لمحافظة طولكرم مع مراعاة المعايير المرتبطة بالفيضانات ووضع استراتيجيات خطة عمل للبلديات والسلطات المختصة لتخطيط وإدارة مخاطر الفيضانات، سوف أقوم بطرح بعض الأسئلة على حضرتكم المكونة من أربعة أجزاء أساسية، والتي تهتمنا في المراحل الأولى من الدراسة، تستغرق في المعدل من 10-12 دقيقة، وشكرا جزيلاً لحسن تعاونكم.

الباحثة: سجي صويص

المشرفان: الدكتور عنان الجبوسي والدكتور فتحي عناية.

➤ الجزء الأول: معلومات عامة:

- النوع الاجتماعي: ذكر أنثى
- المؤهل العلمي: دبلوم بكالوريوس ماجستير دكتوراه
- الخبرة العملية (عام): 1-3 3-9 10 وأكثر
- المؤسسة التي تعمل بها (يمكن اختيار أكثر من خيار):
 حكومية شبه حكومية أكاديمية خاصة

الجزء الثاني: طبيعة الخطر وأهميته

1. هل يوجد مخاطر طبيعية تتعرض لها محافظة طولكرم؟
 نعم لا
2. هل تعتقد أن خطر الفيضانات مهم ويؤثر على المحافظة؟
 نعم لا
3. هل تعلم بحادثة الغرق التي وقعت في محافظة طولكرم عام 2012 وتوفي فيها ثلاثة أشخاص بالغين؟
 نعم لا
4. على أي من الفئات المجتمعية الآتية يقع الخطر الأكبر للفيضان؟
 كبار السن (64 سنة فأكثر) متوسطو السن (15-64)
 صغار السن (أقل من 15) ذوي الاحتياجات الخاصة النساء

الجزء الثالث: أسباب الخطر

5. زيادة التجمعات السكانية للمحافظة سبب لحدوث الفيضانات.
 اوافق لا أوافق
6. لضعف التخطيط الحضري في المحافظة دور أساسي في زيادة خطر الفيضانات.
 اوافق لا أوافق
7. البناء العشوائي وغير المنظم في المحافظة يعتبر سبباً لزيادة خطر الفيضانات.
 نعم لا
8. يوجد تجهيزات مناسبة لفصل الشتاء في محافظة طولكرم تساعد في الحد من خطر الفيضانات.
 نعم لا
9. تقوم الجهات المسؤولة (مثل البلديات والدفاع المدني) بدورها اللازم في الاستعداد لموسم الشتاء
 نعم لا
10. قلة وعي المجتمع نحو التخلص من النفايات يعد سبباً لزيادة خطر الفيضانات
 نعم لا

الجزء الرابع: الحلول والتوصيات

11. هل يوجد إجراءات توصي العمل بها في المحافظة للتخفيف من خطر الفيضانات؟

12. هل توجد خطة عمل استراتيجية تساعد في الحد من مخاطر الفيضانات؟

الجزء الخامس (اختياري): العوامل التي تؤثر على خطر الفيضان في المحافظة

13. أي من العوامل التالية تعد مهمة في دراسة خطر الفيضان, وإذا أمكنك ترتيبها من حيث الأكثر أهمية؟

Selected Parameters	ترتيبها من حيث الأكثر أهمية	هل يعد هذا العامل مهم في دراسة خطر الفيضان؟	العوامل التي تؤثر على خطر الفيضان
Slope (degree)			الانحدار
Elevation (m)			الارتفاعات
Drainage Density (km/km ²)			كثافة الصرف
Precipitation (mm/year)			هطول الامطار
Soil Texture			تركيبية التربة
Land Use/Land Cover			استخدامات الأرض
DEM (m)			نموذج الارتفاع الرقمي
Flow Accumulation (pixel)			تراكم التدفق
Population Density (person/km ²)			الكثافة السكانية
Curve Number			رقم المنحنى
Distance from Drainage Network (m)			المسافة من شبكة الصرف الصحي

■ هل يوجد هناك عوامل أخرى تريد إضافتها إلى القائمة؟



جامعة النجاح الوطنية
كلية الدراسات العليا

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إشراف
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قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في إدارة مخاطر الكوارث، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس - فلسطين.

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الملخص

تشكل الفيضانات خطراً حقيقياً على العديد من مستجمعات المياه في محافظة طولكرم في فلسطين. يؤدي الافتقار إلى التخطيط المتكامل والاستعداد المناسب إلى زيادة مخاطر حدوث الفيضانات. تهدف هذه الدراسة إلى تطوير خريطة مخاطر الفيضانات، باستخدام ثمانية عوامل: الميلان، الارتفاع، كثافة الصرف، هطول الأمطار، قوام التربة، استخدام الأراضي / الغطاء الأرضي، تراكم التدفق والكثافة السكانية. تم استخدام طريقة عملية التسلسل الهرمي التحليلي (AHP) وبرنامج نظام المعلومات الجغرافية (GIS) للعوامل بحسب وزن كل منها. أظهرت النتائج خريطة مخاطر الفيضانات بدقة 12.5م التي نتج عنها خمس فئات لمنطقة الدراسة: منخفضة جداً (2%)، منخفضة (26%)، متوسطة (37%)، عالية (28%)، وعالية جداً (7%). تمت مقارنة النتائج مع الدراسات السابقة إضافة لعمل زيارات ميدانية في ثلاثة مواقع مختلفة لفحص مدى دقة النتائج والتأكد من فاعلية الخريطة الناتجة. تم اقتراح مجموعة من التدخلات (الهيكليّة وغير الهيكليّة) لكل فئة من فئات قابلية التعرض للفيضانات لمساعدة السلطات المختصة في إدارة مخاطر الفيضانات بشكل أفضل. تم اقتراح مجموعة من التدخلات (الهيكليّة وغير الهيكليّة) لكل فئة من فئات قابلية الإصابة للفيضان حتى تتمكن السلطات المختصة من إدارة مخاطر الفيضانات بشكل أفضل. بعض هذه التدخلات للمناطق المعرضة للفيضانات العالية هي، تطبيق تدابير هيكليّة شديدة الهندسة والصيانة الدورية لقنوات مياه الأمطار ومجاري الأودية. يزيد تقييم قابلية التعرض للمخاطر من مرونة المجتمع ويخفف من الآثار الصحية والبيئية للفيضانات.

الكلمات المفتاحية: الفيضان؛ المخاطر؛ الخطر؛ الإدارة؛ التقييم.