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Assessment and Management of Flood Hazard for Tulkarm Area in Palestine

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Abstract

Flooding is an actual hazard at several watersheds in Tulkarm governorate of Palestine. The lack of integrated planning and appropriate preparedness leads to increased hazard of flood events. This study aims to develop a flood hazard map, using a group of parameters including slope, elevation, drainage density, precipitation, soil texture, land use/land cover, flow accumulation and population density. Analytic Hierarchy Process method and Geographic Information System software were utilized to add up weighted parameters. The result showed a flood hazard map with a 12.5 m resolution for Tulkarm study area categorized into five classes (in percentage): very low (2%), low (26%), medium (37%), high (28%) and very high (7%) flood hazards. Results were comparable with those of previous studies, and verifiable by ground truthing to examine the certainty of the results in three different locations in Tulkarm area. A group of interventions (structural and non-structural) were proposed for each flood hazard class so that competent authorities could better manage flood hazards. 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 hazard management from mitigation, preparedness, response and recovery.

Keywords

Assessment, Flood, Hazard, Intervention, Management, Palestine

1 Introduction

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 result in damages and significant losses in human lives, properties and the environment (UNDRR, 2025). 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 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.

According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2025), the "big five" disasters, namely floods, droughts, earthquakes, storms and heatwaves, have accounted for more than 95% of the direct globally-recorded losses in the past two decades. More recently, between 2000 and 2024, floods had become the most disaster frequent type of natural disaster in the world (WMO, 2024), causing dramatic life losses and property damages. Flood can be defined 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). In effect, flood is classified as one of the major risks that cause severe damage to the society and the environment (UNDRR, 2025).

In order to better assess the flood hazards, maps associated with potential risks for a specific area should be prepared. Collecting useful and relevant data can help key actors understand these risks and support their ability to decision making. Preparing flood hazard maps can be powerful to estimating and identifying the high, medium and low vulnerable areas to respond accordingly (Mudashiru et al., 2021). In the literature, hydrologists and scientists have recently studied and delineated flood hazards using different approaches and techniques, including the Analytic Hierarchy Process (AHP), the multi-criteria decision analysis (MCDA) and the Geographic Information System (GIS) (e.g., Arya and Singh, 2021; Gigovic et al., 2017; Hagos et al., 2022; Parsian et al., 2021; Rincon et al., 2018); Shadeed, 2019). Shadeed (2019) used these techniques to develop a coarser flood hazard map for the entire West Bank of Palestine. The results showed that 12 and 36% of the West Bank area, including Tulkarm, were of very high and high hazard levels to flood hazards, respectively.

Gigovic et al. (2017), for instance, studied the mechanism of introducing a GIS-based MCDA method to map hazard zones for flood-prone urban areas in Belgrade of Serbia. The study recommended using other parameters such as precipitation, soil texture, flow accumulation, and flow direction. Rincon et al. (2018), however, developed flood risk maps for four scenarios in the Don River Watershed in Toronto of Canada. They found that the demographic component was important to implement mitigation measures that decreased number of people affected after a flood event.

Parsian et al. (2021) assessed the flood hazard in western Iran using GIS and remote sensing datasets and nine variables. Almost 95% of the actual flooded areas were classified as very high and high flood hazard classes, indicating a high level of accuracy of the method. Arya and Singh (2021) also used GIS and remote sensing to delineate the flood hazard map in Uttar Pradish area of India and found promising results compared to the field. The methods used in the present study were selected after studying previous international studies of similar objectives taking into consideration their strengths to adopt and weaknesses to avoid.

At the global level, the interrelation between the hydrological cycle and the climate change is strong and evident (Francois et al., 2024). Therefore, climate change has negative impacts on the hydrological cycle, water security and freshwater availability (Francois et al., 2024). Flood hazards have recently increased in many places of the world due to climate change and population growth (Shamsudduha, 2025). Therefore, severe floods are expected in the future due to changing weather patterns associated with climate change (IPCC, 2023b; UNDRR, 2025; WMO, 2024).

As for the population in 2025, Tulkarm governorate is projected to accommodate 213,049 people of which 73,616 live in Tulkarm city (PCBS, 2021). In 2023, the registered live births approached 5,257 of which 2,697 were males (PCBS, 2024), indicating a high population growth concentrated in a small area. This high population density leads to scarcity in water, land, food and energy resources as well as environmental deterioration due to higher consumption and waste production of these resources. This is really challenging to the management of water resources system, in particular, as water is indispensable to all living organisms.

While flood might cause life losses and property damages, it constitutes an abundant source of surface water if collected and stored properly, and an alternative source of groundwater replenishment if managed well. Israel controls all water resources, including surface and groundwater, and limits their usability and accessibility to the Palestinian communities (Amnesty International, 2009; Anayah et al., 2021, Mason et al., 2012; World Bank, 2018). It is no secret that Israel also controls water and wastewater services and limits the development of the inadequate infrastructure to these services across the Palestinian communities (Anayah et al., 2021).

Unlike large basins, studying the flood hazards in small-scale basins, plays a vital role in improved flood risk management and assessment and faces distinct challenges. These basins present unique challenges because of limited data availability and rapid hydrologic responses to flood events. The competent authorities (e.g., municipalities and local councils) typically operate with limited resources, constrained infrastructure and scarce data and information, which differ remarkably from larger basins.

On January 2013, an unprecedented rain storm of approximately 260 mm in three consecutive days had hit Tulkarm area in the Northern West Bank, flooded most streams and rivers, and resulted in drowning three innocent people in different areas of the city (Hawajri, 2016; Shadeed, 2019). This extremely heavy storm led to high volume of rainwater accumulating in areas of inadequate drainage systems where rainwater and wastewater shared the same pipes and damaged infrastructure such as roads, bridges and buildings.

The continuous rainwater mixed with wastewater overflows intensified the negative consequences of flood to property losses, environmental pollution and health risks of the local community in Tulkarm area (Hawajri, 2016). The flash flood in January of 2013 hit the northern West Bank, in particular Tulkarm and Qalqilya cities that share the same geographic and climatic characteristics, yet the damages in Qalqilya city were limited to economic losses of properties and family displacements only (Hawajri, 2016). This calls for immediate interventions and prompt actions from governmental and other competent entities to address flood hazards in these specific areas.

In effect, it is essential to delineate a flood hazard map that identifies the areas of high vulnerability to flooding, to set proper planning for the disaster before its occurrence, and to adopt effective approaches of response to such unfortunate events. This would help responsible authorities (e.g., municipalities and local councils) understand associated risks and create possible solutions. Innovative solutions should begin from the stage of planning and preparedness to confront these potential risks to the stage of response and recovery for the water resource management system.

The main importance of this research is to better understand the hydrologic system and associated risks of flood hazards in Tulkarm governorate. It is essential to set up action plan strategies in Tulkarm governorate for the competent authorities of the water resources management system to address flood risks. Handling flood risks necessitates the development of responsive strategies, emergency preparedness and preventive measures at all levels of water resources system management.

2 Description of the Study Area

Tulkarm governorate lies in the northwest of the West Bank of Palestine (Figure 1). Tulkarm climate can be generally described as a Mediterranean climate which varies between hot dry summer to wet cold winter with short transitional seasons (Shadeed, 2019). In Tulkarm, the precipitation is concentrated in the winter and spring months. In 2023, the annual precipitation was 615 mm (PCBS, 2023), which was close to the long-term annual average. The land use of Tulkarm governorate is classified into different classes, the primary four classes are cultivated and arable land, pasture and open land with no vegetation, pasture and open land with no significant vegetation cover and built-up area. Each one of these classifications occupies 67%, 20%, 11%, 2% from total area of governorate, respectively.

The runoff increases at impermeable surfaces, such as urban areas. Also, when vegetation cover is removed, such as deforestation, the amount and speed of surface runoff and the flood peak discharge increase (Francois et al., 2024; Ma et al., 2024; Tarboton, 2003). There are three different types of soil that exist in Tulkarm governorate: Terra Rossa, Brown Rendzinas and Pale Rendzinas and Grumusols. Also, the main water sources in Tulkarm governorate are divided into four types (PWA, 2017): (1) rainwater, (2) surface, (3) groundwater and (4) the bulk water imported from Israel water company.

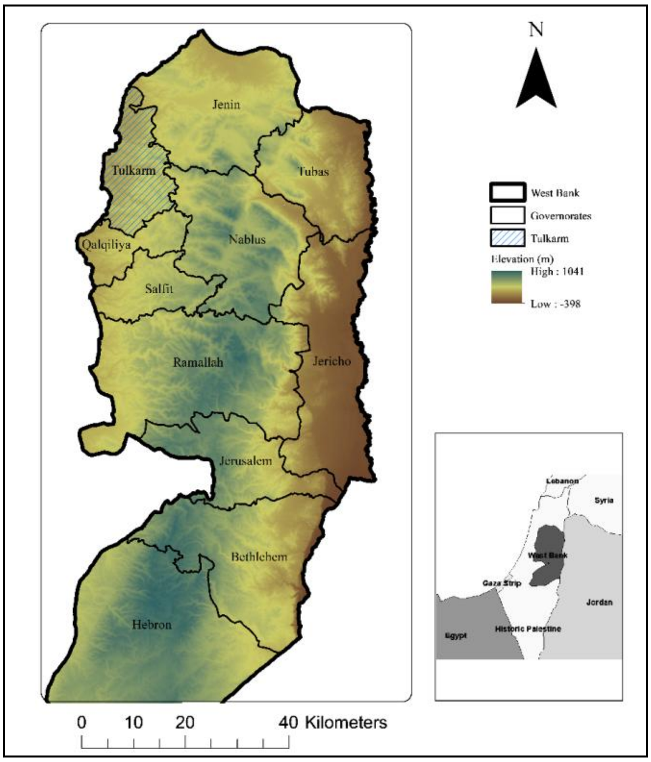

Figure 1: Tulkarm governorate in the West Bank of Palestine.

Hydrologically, the study area covers 35.4% of the watershed area; In terms of population, there is a large number of people live in Tulkarm area (~35%) compared to other parts of the governorate (PCBS, 2021). The selected study area covers 66% of the total area of Tulkarm governorate. Previous studies indicated that the study area is one of the most critical areas to flood hazards; and in the past, Tulkarm area had experienced severe consequences due to extreme flood events.

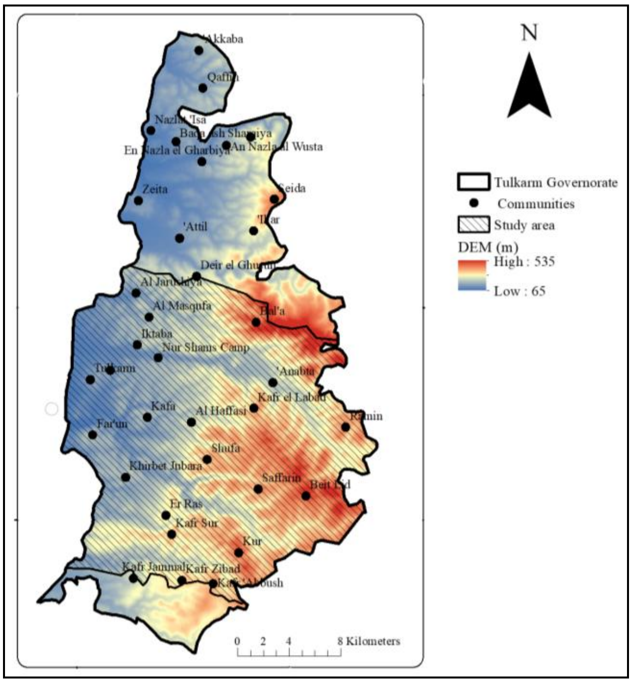

Figure 2: Study area of Tulkarm governorate with the digital elevation model (DEM) in the background.

3 Data and Methods

First, it is important to understand problems encountered in order to study the flood hazard and create efficient solutions for Tulkarm area. The first problem was how to delineate the precise boundaries of the study area. Looking to the literature, several scientific articles in the field of flood hazard management were reviewed in our study. The second part of data collection were interviews with multiple local experts and scientists in the field of study who knew the study area characteristics. In these interviews, a couple of questions were posed in terms of identifying the most concerning parameters that significantly affect flood hazards in the study area. Such parameters included as precipitation, surface slope, elevation, curve number, curvature of the outline, etc. In addition to the hydrological aspects, flood hazards may be affected by many physical and socioeconomic parameters such as political sovereignty, land use/land cover, proximity to roads, building materials, population density and others. Finally, the authors' self-reference from their professional experience was utilized to adopt the final set of parameters to consider in developing a reliable flood hazard map.

To develop the flood hazard map, several parameters were utilized, each was obtained from reliable open-source geospatial data providers in the period from September to December 2022. The DEM, used to derive both slope and flow accumulation, was downloaded from the NASA Earthdata Search Portal (https://search.earthdata.nasa.gov), which offers high-resolution elevation datasets with 12.5 m suitable for topographic and hydrological analysis. Land use/land cover, soil texture, precipitation and population density data were obtained from the Geomolg portal (https://geomolg.ps), which provides updated spatial information in Palestine. These sources ensure that the flood hazard mapping process is based on accurate, up-to-date, and regionally appropriate geospatial data.

GIS software has the power to integrate data from the various sources and formats into a common platform and make it readily available for analysis and downstream applications. Then, the raster data for the final set of parameters of interest was developed. Each raster data was categorized into five different hazard classes based on its vulnerability to flood hazard. The AHP pairwise comparison matrix, however, was applied according to Satty's scale of relative importance to assign weights for the different parameters. The relative importance of the parameter was determined in a scale from 1 to 5, by comparing the significance of the parameter to the other parameters. In order to check the weights of the parameters and the consistency of the comparison matrix, a consistency ratio, which is the popular method, was calculated.

The flood hazard map was developed by reclassifying each parameter from 1 to 5 according to its vulnerability to flood hazard. For instance, class number 5 indicated to the very high vulnerability to flood hazard, while class number 1 indicated to the very low vulnerability to flood hazard. The weighted overlay summation was applied within the GIS environment in order to multiply the scored values by the raster's weight of importance and add the resulting cell values together. As a results, the flood hazard map was produced and the most vulnerable areas were identified. All classes of vulnerability to flood hazard would be identified for future applicability and decision making.

Ground truthing was utilized in order to compare the results of the flood hazard map with the ground realities at certain locations in Tulkarm area. In effect, the flood of January 2013 which resulted in catastrophic consequences in Tulkarm governorate was utilized for this purpose. This method was applied in three different locations that were dramatically hit by the flood of January 2013 in Tulkarm governorate. This method was used to check the accuracy of the resulted flood hazard map to categorize the locations at which human casualties took place.

In order to precisely evaluate the hazard of floods in the study area, the parameters of concern and interest should be carefully selected. Essentially, the selection of potential parameters for analysis depended on the literature review, the experts' opinions through in-person interviews and the self-reference judgement from authors' professional experience. First, the authors reviewed recent published articles that had used multiple parameters in the AHP method to map the flood hazard such as Arya and Singh (2021), Gigovic et al. (2017), Hagos et al. (2022), Parsian et al. (2021), Rincón et al. (2018), Shadeed (2019) and Zeleňáková et al. (2018). After examining previous studies and conducting the interviews, we reached the decision to identify eight significant parameters affecting the flood hazard. These parameters were the slope (degree), elevation (m), drainage density (km/km^2), precipitation (mm/year), soil texture, land use/land cover, flow accumulation (pixel) and population density (person/km^2).

The AHP is one of the MCDA methods that organize the parameters of effect into a hierarchical framework (Papaioannou et al., 2015). This method is used to handle controversial issues of conflicting parameters, 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 steps: identify the problem to clarify the goals, built the hierarchical structure with decision elements (criteria, detailed criteria and alternatives), conduct pairwise comparisons among decision elements and form comparison matrices, estimate the relative weights, check the consistency ratio of comparison matrices to ensure that the judgments of decision makers are consistent and determine the overall rating of the method (Lee et al., 2008; Papaioannou et al., 2015). The parameters were categorized on a scale of 1 (Equal importance) to 9 (Extreme importance), indicating the importance of each parameter.

After implementing the pairwise comparison matrix, the diverse weights of the parameters were computed as the weight of a particular parameter equals the mean value of each row. It should be mentioned that this step was preceded by finding a new matrix that contained new values from dividing each cell by summation of each column. Then, the consistency ratio (*CR*) was calculated and found to be less than 0.1 which was consistent according to the recommended value of Youssef and Hegab (2019). As shown in Equation (1), the *CR* is equal to the consistency index (*CI*) divided by the random index (*RI*) which is computed as shown in Equation (2):

$$CR = CI / RI \qquad \text{Equation (1)}$$

$$CI = (Lambda - n) / (n - 1) \qquad \text{Equation (2)}$$

where *CR* is the consistency ratio, *CI* is the consistency index, *RI* is the random index, lambda is the division of weighted sum value over criteria weight and n is the number of parameters. As for the *RI*, it is taken from a specific table according to the n value (Youssef and Hegab, 2019). In the present study, *CR* equals 0.029 which is less than 0.1, and therefore, the assigned weights of parameters shown in Table 1 could be successfully used in the flood hazard calculations.

Table 1: Normalized flood hazard parameters using AHP pairwise comparison matrix.

Parameter (Symbol) (Unit)	*P*	*E*	*S*	*DD*	*FA*	*ST*	*LU/LC*	*PD*	Weight (%)
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

After calculating the weights of each parameter using the AHP method, we categorized every parameter into five classes according to the probability of flood and the vulnerable areas, giving each class a score of risk from one to five. The score one indicated the very low vulnerability to flood hazard, and the score five indicated the very high vulnerability to flood hazard. Table 2 indicates each parameter influencing the flood hazard with its classes and scores.

Table 2 indicates the scoring system and classes for the eight parameters of interest to the present study; slope (*S*), elevation (*E*), drainage density (*DD*), precipitation (*P*), soil texture (*ST*), land use/land cover (*LU/LC*), flow accumulation (*FA*) and population density (*PD*).

Table 2: Scoring system and classes for each parameter influencing the flood hazard.

Parameter (Symbol) (Unit)	Class	Score
Slope (S) (degree)	≤5	5
	5< S ≤10	4
	10< S ≤15	3
	15< S ≤20	2
	>20	1
Elevation (E) (m)	≤100	5
	100< E ≤200	4
	200< E ≤300	3
	300< E ≤400	2
	>400	1
Drainage Density (DD) (km/km^2)	<1	1
	1< DD ≤2	2
	2< DD ≤3	3
	3< DD ≤4	4
	>4	5
Precipitation (P) (mm/year)	<450	1
	450< P ≤500	2
	500< P ≤550	3
	550< P ≤600	4
	>600	5
Soil Texture (ST)	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 (LU/LC)	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 ≤ 100000	2
	100000< FA ≤ 150000	3
	150000< FA ≤ 200000	4
	>200000	5
Population Density (PD) (person/km^2)	<100	1
	100< PD ≤ 400	2
	400< PD ≤ 700	3
	700< PD ≤ 1000	4
	>1000	5

After categorizing the eight selected parameters into five classes, eight rasters were created at which a score value from one to five was assigned for each cell (12.5×12.5 m). Using the ArcMap 10.5 software, the final step was to apply the overlay weighted sum tool that overlays several raster data. This was conducted by multiplying each raster by its given weight and summing them up as depicted in Equation (3):

$$\text{Flood Hazard Map} = \sum_{i=1}^{i=8} W_i \times S \qquad \text{Equation (3)}$$

where W_i is the weight of each parameter i so that summation of the weights equals 1, and S is the score of each cell in the raster.

4 Results and Discussion

The results found were interesting to researchers as well as policy and decision makers in the study area. Findings were further discussed and compared with those of previous studies from the literature, in addition to the ground truthing which supported what was found in the present study.

4.1 Deliverables of the present study

As shown in Figure 3, each of the eight parameters was mapped based on the calculated scores, and categorized into five classes that indicate the vulnerability of that parameter to flooding. For example, the land use/land cover map showed the classification of land use/land cover for the Tulkarm study area. The different classifications of land use/land cover were categorized into five classes. As everybody knows, the flood vulnerability increases at built up areas and decreases at areas of pasture and open land with no vegetation and forests.

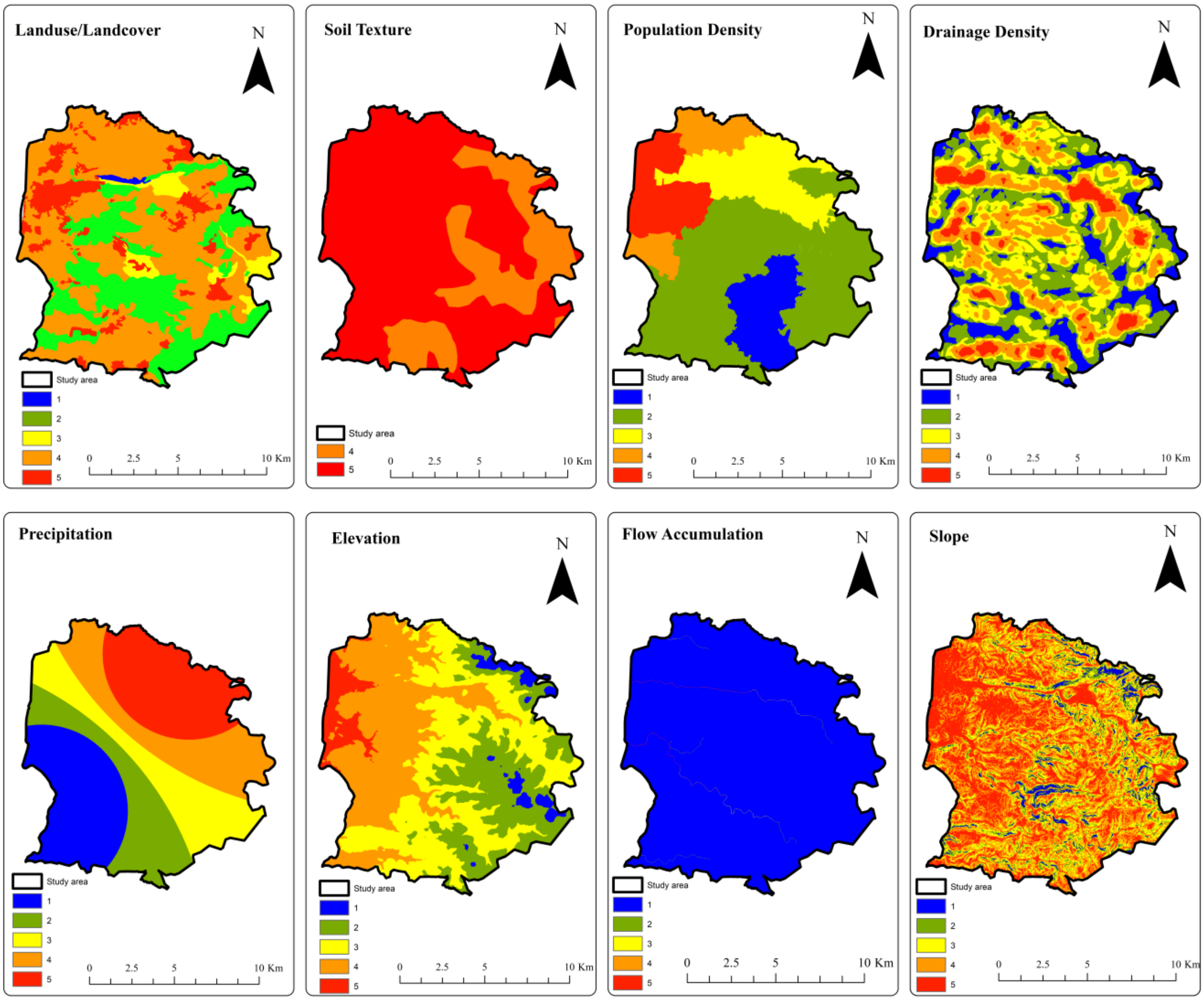

Figure 3: The scored raster maps for each parameter of the study area in Tulkarm governorate.

As for the population density, the map was categorized into five classes based on the population numbers for each community. The classes ranged from 100 to 1000 person/km^2, as it showed the greatest concentration of the possibility of flooding in the center and north of the study area. As a result, the vulnerability to flooding was directly proportional to the population density.

As depicted in the elevation map (Figure 3), the classification ranged from 65 m to 535 m, whenever we moved to the left (when the elevation class was less than 100 m), the vulnerability to flooding increased. Hence, there was an inverse relationship between the elevation and the vulnerability to flooding. The slope map displayed the classification of slopes for Tulkarm study area, an inversely proportional between slope and flood vulnerability. This different classification was categorized into five classes. The flood vulnerability increased at small slopes. However, flood vulnerability decreased at high values of slope as depicted in the map.

In summary, Figure 3 shows the scored raster maps for the eight selected parameters that were calculated based on the AHP method. Accordingly, the flood hazard map was created using the eight rasters of selected parameters with a resolution of 12.5×12.5 m and the corresponding weights for the parameters. A flood hazard map for the specified watershed in Tulkarm governorate was produced as shown in Figure 4. The flood hazard map contained the five classes (percentage): very low (2%), low (26%), medium (37%), high (28%) and very high (7%) flood hazards. Building a flood hazard map determined the vulnerable areas and helped decision makers manage flood hazard in the designated watershed (Zeleňáková et al., 2018).

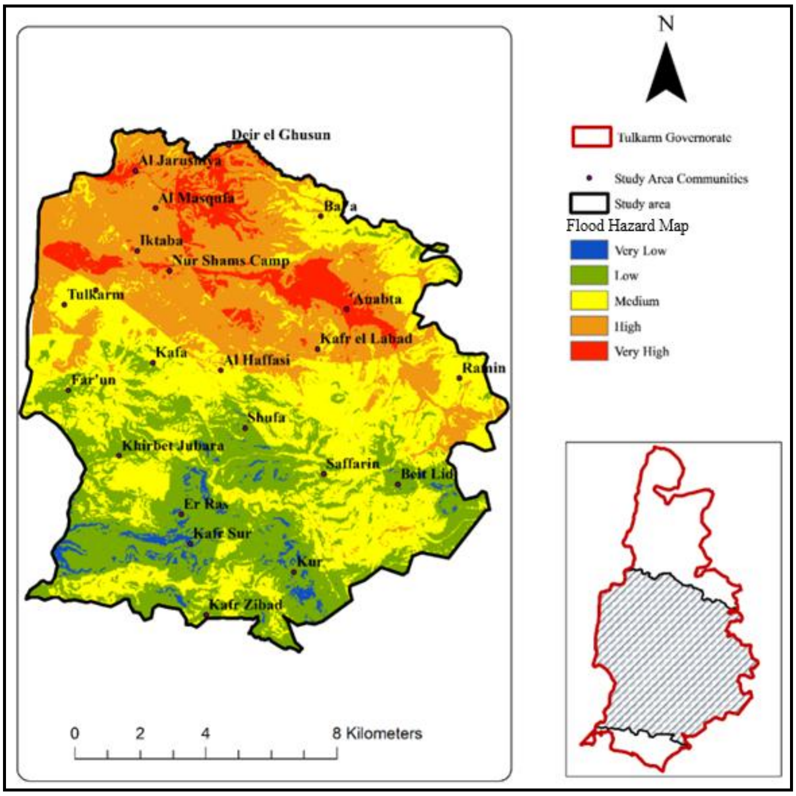

Figure 4: Flood hazard map of the study area in Tulkarm governorate.

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 4), as we moved from the south to the north, the flood hazard class increased gradually. Most regions in the north of the study area were categorized as high and very high vulnerable areas to flood. This could be clearly seen in Al Jarushiya, Deir Al Ghusun and Al Masqufa (Figure 4) which are located near wadi Esh Sham connecting to wadi Ammar as shown in Figure 5.

Also, the same hazard flood map showed extreme conditions at Iktaba, Anabta and Nur Shams camp, that lie in the area located along wadi Az Zeimar to wadi El Burj. It is important here to point out that the 2013 flood accident in which two women passed away took place in that particular area. This result was confirmed by what Shadeed (2019) had found in his study. This situation requires immediate action and rapid intervention from competent authorities. We also observed that Bal'a which has the highest elevation in Tulkarm governorate (Figure 2) was located within the medium to low flood hazard class.

In the middle of Tulkarm governorate, where Tulkarm city, Kafr El Labad, Al Haffasi and Ramin lie, the flood hazard class ranged from medium to high as noticed in Figure 4. While the flood hazard class extended from low to medium in the following communities; Far'un, Kafa, Shufa, Saffarin, Beit Lid, Khirbet Jubara and Kafr Zebad. In the south, Kafr Sur, Kur and Er Ras were classified as low to very low in the hazard to flood. Although wadi Et Tin and wadi Es Sahel are located around Er Ras and Kafr Sur communities, yet low hazard is noticed because of their high elevation and low population density. The elevation ranged from 200-400 m which is not low compared to altitudes in the study area (Figure 2). Most of these lands were pasture and open land with no vegetation (Figure 3).

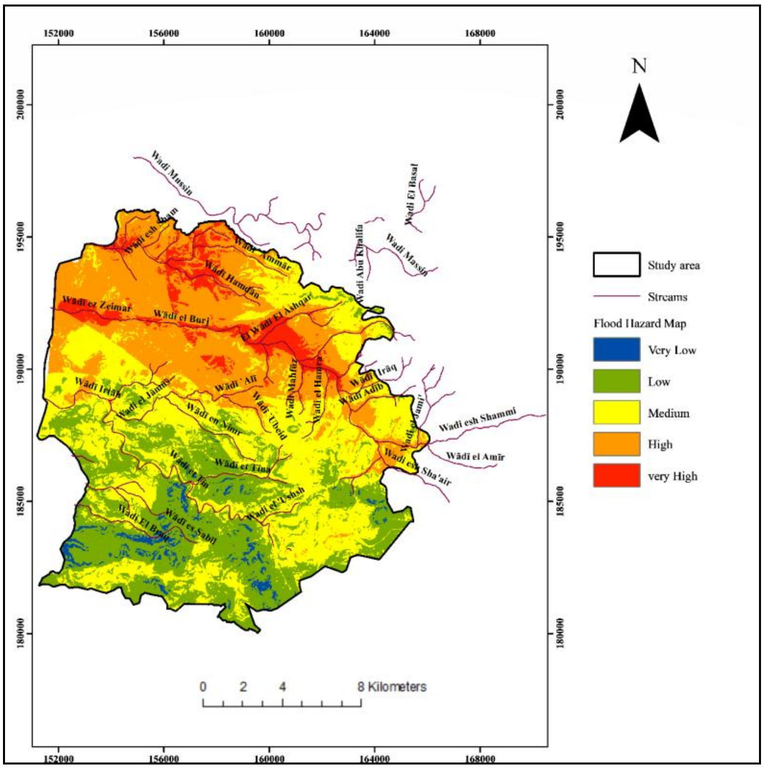

Figure 5: Streams and their extension in the study area.

Shadeed (2019) found that Tulkarm governorate had high to very high vulnerable areas (13% of the West Bank area) which confirmed the importance of the present study. 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 represented approximately 35% of the study area. More than one third of the study area is considered a high percentage so that local government units (e.g., municipalities and local councils) should apply preventive measures and mitigate the hazard of flood. In the Hagos et al. (2022) study, the high and very high vulnerable areas represented 56% of the upper Awash River basin of Ethiopia which was also an extreme percentage to implement appropriate flood control strategies.

It was important to check the accuracy of the resulting flood hazard map using ground truthing to match the results on the ground. Three different case studies in the study area were chosen (Figure 6): location 1: at the east of the study area (the location where two women passed away in the flood of January 2013), location 2: at the middle of Tulkarm city (Shobaki junction at Far'un street) which had always been flooded with water in winter) and location 3: at Kherbit Jubara (where the death of a man in the flood of January 2013 took place). After matching the coordinates of the three case studies, it indicated realistic and correct results in each of the three locations which actually represented high and very high vulnerable areas to flood hazard.

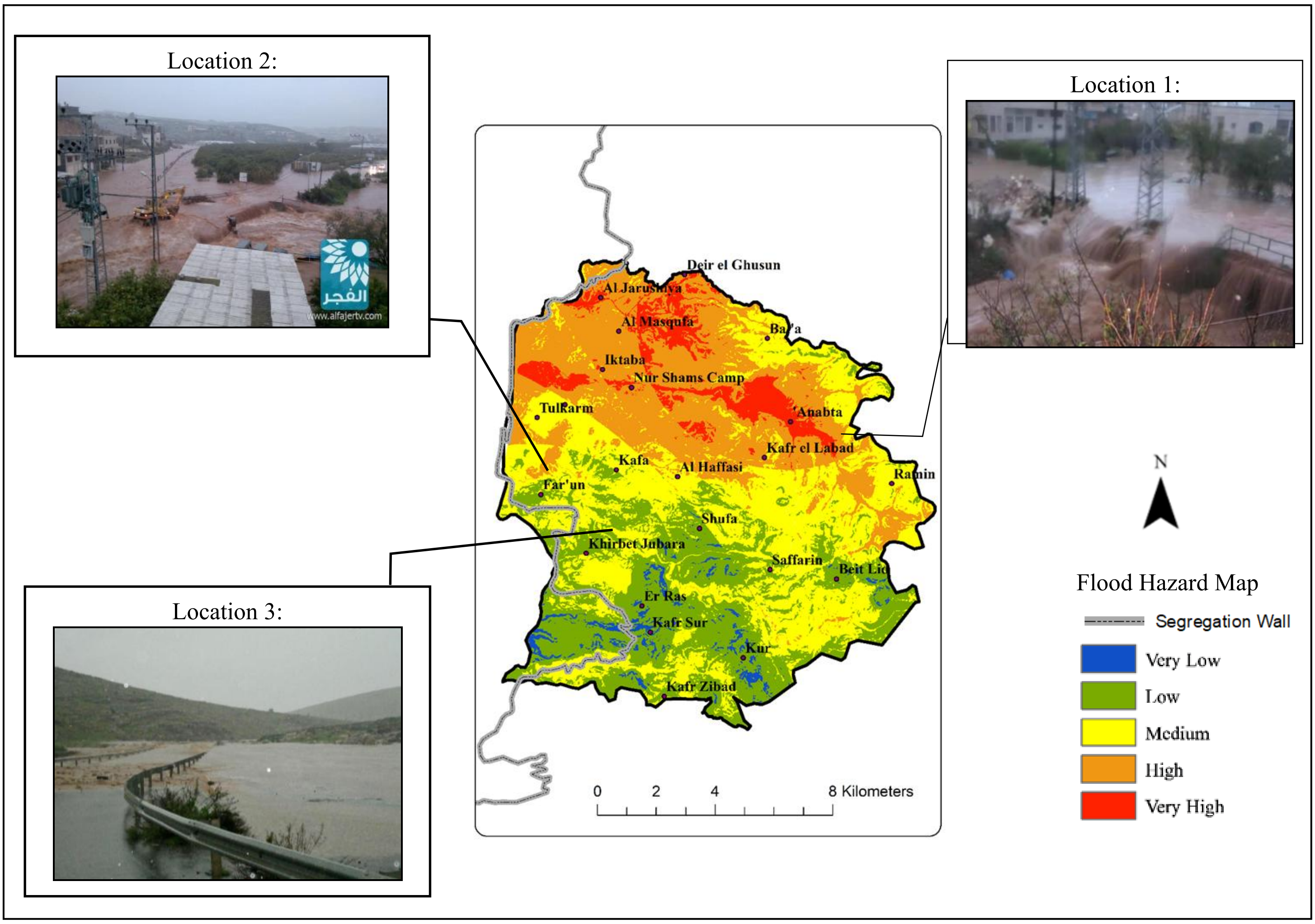

Figure 6: Ground truthing results and the segregation wall in the study area (Photos courtesy of Al-Fajer Al-Jadeed television of Tulkarm city and photographer Mohamad Al Sadlah).

4.2 Special constraining parameters in Palestine

As mentioned earlier, the Palestine case is unique as it has a special political, physical and socioeconomic constraints that no other country in the world shares. Among these constraints, Israel built a segregation wall in 2002 that isolated the Palestinian communities in the West Bank. The wall had destroyed, confiscated, or at least isolated thousands of dunums of residential and agricultural lands (Anayah, 2020). The segregation wall had impacted the Tulkarm and Qalqilya governorates the most among all West Bank governorates (ARIJ, 2015). Almost 50 groundwater wells with a total annual extraction rate of 6.5 million m^3 are isolated behind the wall or located in the buffer zone of the wall in which access to Palestinians is limited or prohibited (ARIJ, 2015). As shown in Figure 1, the flow of the surface water moves towards the west in Tulkarm area because of the difference in elevation.

The question now whether there are increasing risks of flooding due to such political factors, and the answer is definitely yes. The segregation wall built by Israeli authorities to isolate the West Bank, particularly Tulkarm, might cause catastrophic damages to the human health and the environment in terms of flood risk. It is important here to point out that these results appeared without considering the segregation wall which exists at the western border of Tulkarm governorate (Figure 6). In fact, the presence of the wall (Figure 6) acts as a barrier that its backwater leads to an increase in the class of hazard. Hence, the medium vulnerable areas might be high or very high with the existence of the wall.

Tulkarm governorate is bordered to the south by the governorate of Qalqilya (Figure 1), which shares similar conditions in terms of climate, soil, land use/land cover and elevation. Therefore, Qalqilya is considered a twin city of Tulkarm city and both lie in the western north of the West Bank. As per what happened in the flood of January 2013, Israeli authorities shut off the waterway gates crossing the apartheid wall in the west of Qalqilya city. As a result, runoff water accumulated in the low elevation areas next to the apartheid wall, caused an anthropogenic flood, deteriorated the environment and resulted in economic losses and physical damages of several facilities and properties. Therefore, reasonable precautions and effective measures have to be taken to alleviate the flood hazard risk in these particular areas.

Considering the segregation wall to the parameters used to map the flood hazard in the present study is valuable and interesting as a political constraint, yet it adds more complexity and ambiguity to the picture and makes analysis and interpretation of results more challenging. Politically, the segregation wall is not the only parameter to consider, there are some Israeli settlements surrounding Tulkarm areas as well as lands and roads that are accessible to Israeli settlers only. All these assaults that take place on a daily basis are not quite easy to document or quantify as conditions on the ground change continuously and real impacts require in-place assessment.

4.3 Flood hazard management

Floods are natural phenomena that can be controlled not prevented (Shamsudduha, 2025). To manage flood hazard, we need to improve plans that focus on prevention, protection and preparedness (Wang et al., 2022). 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 hazards and increase community resilience (Membele et al., 2022).

There are two methods to control flood hazard, structural adjustments which include flood water reservation structures, redirect the paths of flood waters and modifications in some existing structures (Shuka et al., 2024). The other method is non-structural adjustments that are called “soft solution.” The main goals of these flood proofing measures are preparing for flooding, avoiding flooding, planning for and managing flood emergencies and recovering from flooding (Jha et al., 2012).

An integrated strategy usually joins both structural and non-structural measures for flood proofing. Structural measures are typically implemented by governments because of their high cost and long time to perform. Non-structural measures, however, can control flood hazard are they generally require lesser costs and shorter time periods to apply. To use these flood proofing measures, experienced technical specialists should be consulted first. Highly vulnerable areas to flooding need immediate interventions from competent authorities, to find suitable and feasible solutions. Table 3 indicates different interventions and strategies for each tier of flood hazard class.

Table 3: Interventions and strategies for each tier of flood hazard class.

Flood hazard class	Tier	Intervention and strategy
Very low	A	• Exercise no active intervention ‘walk away’ • Make preventive maintenance of rainwater sewers before winter frequently • Conduct regular maintenance of rainwater culverts and valley streams especially in the western parts of the city- Regular cleaning of wadis, such as Wadi Al-Zomar, to prevent blockage
Low	B	• Continue and enhance existing measures, such as rehabilitation of greywater systems • Conduct public awareness campaigns in schools and community centers on flood risks and proper behavior during flood events • Support community-based maintenance initiatives in vulnerable neighborhoods
Medium	C	• Require new buildings to implement flood-resilient designs, especially in areas like Shuweika and the central commercial zone • Improve road drainage systems on major streets (e.g., Nablus Street) to prevent water accumulation
High	D	• Apply nature-based solutions such as rain gardens in public parks • Update municipal building codes to include flood resistance standards for houses in low-lying areas like Irtah suburb • Activate a disaster insurance fund in collaboration with the Ministry of Local Government • Provide financial support or compensation to small businesses impacted by recurrent flooding
Very high	E	• Implement emergency measures, especially in refugee camps (e.g., Tulkarm Camp) during the winter season • Provide water pumps and transport equipment for rapid evacuation and response • Remove or relocate informal settlements from high-risk zones where possible • Manage solid and liquid waste to prevent clogging of drainage during floods • Enforce legal restrictions against construction near wadis and flood-prone areas • Design specialized infrastructure solutions (e.g., raised building entrances or protected utility boxes) • Apply advanced engineering solutions in future infrastructure projects

In the light of the interventions and strategies proposed in Table 3, it is essential to highlight the following points:

- In the design of planning and awareness campaigns at all classes of flood hazard, defining measurable goals is important by knowing the audience of these campaigns, using different communication channels such as television, newspaper, art competitions and social media. You have to ensure the implementation of these campaigns, monitor public awareness and assess reflections.
- 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 interventions and strategies, a group of targeted parties in flood hazard 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 hazard 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 the right way on the right time.
- Flood hazard 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.

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

4.4 Climate change and its relation to flood

In the West Bank of Palestine, the climate change is anticipated to impact the climatology and hydrology of the region by raising its temperature, reducing its precipitation, increasing its evaporation, decreasing its groundwater recharge, diminishing its spring flow and experiencing more frequent and intense extreme weather events (Faquseh et al., 2024; Mason et al., 2012). More specifically, climate projections in the eastern Mediterranean region reveal a reduction of 10 and 20% in annual precipitation by 2020 and 2025, respectively, with an increased drought risk in summer (UNDP, 2010). As for the annual average temperature, it is projected to rise from 2.6 to 4.8°C by 2100 according to several climate models and emission scenarios (UNDP, 2010). Similar projections of temperature and precipitation were found in the study of Mason et al. (2012). The water scarcity and ecosystem stability problems in the West Bank will get worse because of reduced surface water flow and depleting groundwater resources (Faquseh et al., 2024).

There are significant changes to the ecosystems in the area of the Eastern Mediterranean, which result in many climatic, natural, social and economic impacts (Faquseh et al., 2024; Mason et al., 2012; UNDP, 2010). Climate change is increasing energy demands at a rapid rate (UNDP, 2010). 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, 2023a). In addition, there are major expected impacts of climate change on the agricultural and food sectors in Palestine (Faquseh et al., 2024; Mason et al., 2012; UNDP, 2010). More specifically, the agriculture sector is highly sensitive to climate variability and change in Tulkarm governorate, in particular rainfed agriculture (Mason et al., 2012). Furthermore, climate change affects infrastructure and causes direct losses as a result of damage to the transportation network, roads and power lines (UNDP, 2010; WMO, 2024).

Disasters become more frequent and intense in the light of climate change, representing climate vulnerability that threatens human security in Palestine (Mason et al., 2012). 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 (IPCC, 2023a, 2023b). Obviously, both climate change adaptation and disaster risk reduction intend to decrease the influence of associated risks of climate-related disasters (Shamsudduha, 2025).

The flood, drought, sea-level rise, rising air temperature and land degradation are globally recognized as the most common climate-related hazards (WMO, 2024). 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, 2023b). Therefore, more severe floods are expected as a result of the events of the unusual wet weather seasons that lead to changing 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, 2023b; Shamsudduha, 2025).

Due to the projected climate change, unplanned urbanization and quick land use change, the Asian urban areas are considered high-risk locations (IPCC, 2023b), particularly the Eastern Mediterranean area in which Palestine lies (Mason et al., 2012; UNDP, 2010). 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, 2023a).

Planning for flood hazard management and the existence of well-studied integrated plans help in the role of mitigating the impacts of climate change and reducing the severity of its consequences (Wang et al., 2022). Also, this simultaneously represents a basic role in the goals of adaptation, mitigation and sustainable development. Hence, mitigation can obviously reduce the impacts of climate change, which can be minimized even further with adequate adaptation strategies. Nowadays it is important to emphasis the hazard management and preparedness towards the emergency response due to the increased risk posed by climate change (Shamsudduha, 2025). There is a necessity to move further toward risk reduction activities in flood (Wang et al., 2022).

There is an obvious trend to integrate disaster risk reduction 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 and Akhter, 2023). In effect, assessment and management of flood hazard are crucial to sustain safe environments, promote prosperous economies and build resilient communities. In summary, it is well understood now that the Israeli appropriation of natural resources of Palestinians undermines their resilience to combat climate change and its impacts which are “inherently politicized” (Mason et al., 2012).

4.5 Practical relevance and potential applications of the work

It is significant to understand the natural water cycle and its hydrological processes in order to determine how best to plan and manage water resources and protect them from loss or pollution. It is therefore quite reasonable to assess the hazards that may result from unusual hydrological processes due to natural or anthropogenic attributes. Such hazard assessment studies are essential for the planning and management of water resources and the protection of the surrounding environment considering multiple spatial and temporal dimensions.

Owing to the scarcity of water resources in Palestine as a developing country of semi-arid Mediterranean climate that changes year after year, sudden extreme rainwater may result in severe flash flooding. Therefore, flood hazard management is a major challenge for policy and decision makers in the water and environment sector. The process of modelling these hazards and creating projected scenarios greatly help understand the system and mitigate their negative impacts. This enables the hazard management system to be more flexible, adaptable, and capable of absorbing the hazards and developing viable alternative solutions to sustain water and environmental resources. The willingness of key implementing actors such as municipalities and local councils to respond to such hazardous situations strengthens their ability to meet contemporary challenges such as climate change and enhances their resilience with accurate information and sound recommendations.

Studies to assess and manage flood hazards help communities identify strengths, weaknesses, opportunities, and challenges in managing natural hazards and normal disasters. This results in the use of available resources to build a sustainable and flexible hazard management system, in infrastructure, structure, and architecture, thereby reducing human and financial costs. Hazard management software tools can also be utilized to better predict potential consequences and ensure compliance with safety regulations. Once you identify and assess flood hazards, you will be able to control their threats to health and safety of the community members as well as to protect the environment. The accuracy in understanding the system forms the basis for enacting laws and setting standards regarding the proper regulation and management of natural resources and hazards.

5 Conclusion and Recommendation

This study had developed a flood hazard map with a high resolution of 12.5 m for a specified study area covering 66% of the total area of Tulkarm governorate in Palestine. The hazard map had been created according to eight influencing parameters; slope, elevation, drainage density, precipitation, soil texture, land use/land cover, flow accumulation and population density. Each parameter had 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 of the selected parameters used to develop the hazard map. It is essential to provide such a map for policy and decision makers to create feasible solutions and mitigate flood hazards.

In the year of 2013, Tulkarm governorate had experienced extreme flood hazards that resulted in life losses and property damages. This did not happen at the same degree to any other governorate in the West Bank and Gaza Strip, and different areas in the governorate experienced massive floods. This drew attention to study the flood hazard and to develop the map that exactly delineate vulnerable areas in Tulkarm. In the present study, the areal distribution of the flood hazard varied according to five different classes: very low (2%), low (26%), medium (37%), high (28%) and very high (7%) flood hazards. This situation requires immediate preventive and corrective interventions and strategies from policy and decision makers to find effective solutions to the flood hazard. A flood hazard map is an integral part of the flood hazard assessment process. There is a dire need to conducting a number of interventions and actions that control flood hazard during the phases of flood hazard 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 was 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 hazard management by utilizing the produced flood hazard map. The map must be updated periodically to keep decision makers and official agents 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 hazard management from mitigation, preparedness, response and recovery. Climate change plays a paramount role in increasing the severity of floods and the frequency of their occurrences. The application of mitigation and adaptation measures and strategies to manage flood hazards reduces the severity of corresponding damages and consequences on societies and the environment.

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. Preparing an operation room to respond to the flood at the time of the event, for better management of flood hazard.

2. Considering different parameters such as building materials and conditions, and changing the weights of the selected parameters using the AHP method to obtain different results that might better demonstrate the current situation in Tulkarm governorate.

3. Setting up a well-sustained plan to be implemented for flood hazard management in Tulkarm governorate.

4. Conducting raising awareness activities to study flood hazard management in Tulkarm governorate by decision makers and competent authorities.

5. Creating a flood resilience scorecard that helps the community to identify the actions that can decrease its vulnerability.

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Data access statement

Data will be made available on reasonable request.

Declaration of interests

The authors report no conflict of interest.

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