Geo-spatial Assessment of Flood Vulnerability Areas of the Gaza Strip Towards Preparedness and Humanitarian Response Planning

Eshtawi, T.,[1] Abdellatif, M.[2] and Matar, D.,[3]
[1]Engineering and Information System Department, University College of Applied Sciences (UCAS), Palestine, Email: teshtawi@ucas.edu.ps
[2]Data Bank Unit, Palestinian Water Authority (PWA), Palestine, E-mail: mahlatif@yahoo.com
[3]Environmental and Social Office, UNRWA, Palestine, E-mail: dalya.matar@yahoo.com

Abstract

Nowadays, flood and drought will become more common as climate change causes. Due to climate change consequences, flood occurrence and its impact on Gaza people have been of great concern to the Palestinian water authority, as it has a negative influence on various humanitarian and social issues. The hazards and damages resulted by flooding cause loss of life, property, displacement of people and disruption of socioeconomic activities. This research focuses on assessing Gaza Strip vulnerability to flooding using analysis of GIS-based spatial information. Not only did it consider the physical-environmental flood vulnerability, it also investigated social flood vulnerability aspects e.g., population densities. Soil and slope were considered to have the highest weight in the vulnerability mapping, as they represent the main factors in urban hydro-ecosystem structure. The long term average rainfall, a climate function factor, has the lowest weight, because it could be considered as a threat factor in addition to a vulnerability factor. This research demonstrates that urban area and population density as strong factors influencing flood vulnerability for humanitarian and saving life purposes. The findings of Geospatial analysis were used to map vulnerable areas likely to be affected in the event of flood hazard and suggest future interventions and related adaptation strategies in Gaza areas for flood mitigation.

1. Introduction

Flood impact is one of the most significant disasters in the world causing losses of life and damage properties. Increasing population growth leads to more urbanization, more impervious area and less infiltration that has increased human vulnerability to floods. The Mediterranean region is identified as one of the main climate change hotspots due to water scarcity, concentration of economic activities in coastal areas, and reliance on climate-sensitive agriculture (Zachariadis, 2016). The Gaza Strip is located on the south-eastern coast of the Mediterranean Sea with a land area covering 365 km^2. Gaza Strip has a lack of water, mainly a consequence of the semi-arid climate. The flood in the Gaza Strip may occur due to continuous heavy rainfall overs short period of time, man-made activities, improper construction of roads and buildings, pool-related infrastructure particularly, insufficient stormwater drainage system, and many more reasons. The result due to flood is very much known and associated with suspected climate changes that may increase the potential and severity of floods. Gaza Strip was exposed to extreme flood, during the period from 10th December to 14th in the year 2014, caused negative effects on the daily life of Gaza people and their economic activities, revealed a deficiency in existing fragile stormwater infrastructure, poor housing, and the electricity crisis. Therewith, Gaza is a typical example of a coastal region under pressure of land use changes threating the urban water resilience in different aspects. Flood is one crucial issue has been raised dramatically since few years. Proper development planning is urgently needed to solve these problems and to ensure a sustainable water environment in future. Improving the information base and providing appropriate management indicators are essential steps to support proper development planning processes (Eshtawi et al., 2014). Currently, the geographical information system (GIS) is one of the most important tool used for geo-assessment process of flood vulnerability. Physical and Environmental components of flood vulnerability have been mentioned in different recent researches, which consider the susceptibility aspect to hazard (Hazarika et al., 2016; Frigerio and de Amicis, 2016, Elsheikh et al., 2015; Abah, 2013; Kundu and Kundu, 2011).

However, an area that could be classified as highly vulnerable under the socio-economic aspect may not have a higher degree of flood vulnerability under the physical environmental classification. This research demonstrates both physical-environmental as well as social aspects of vulnerability that can effectively be combined to get a more reliable flood vulnerability map.

Regarding previous studies, Khalaf et al., (2006) and Hamdan et al., (2007) assessed runoff taking into account the regional plan (2025) for the Gaza Strip and applying the rational runoff formula using GIS as an analytical tool. Aish et al., (2010) used the WetSpass model, under the umbrella of GIS, to evaluate groundwater recharge in the Gaza Strip. Hamad et al., (2012) investigated three different urbanization scenarios using the Automated Geospatial Watershed Assessment (AGWA) tool, which is a GIS-based model. Eshtawi et al., (2014) applied a new spatial evaluation for assessing the impact of urbanization for the semi-arid watersheds intersecting with the Gaza boundary using SWAT model. However, these comprehensive studies did not consider the humanitarian context in the modeling process as well as final conclusions.

2. Objectives

The main objective of this research is to derive a vulnerability map that shows areas in the Gaza Strip liable to flood, in order to estimate the potential affected population using a GIS-based multi-criteria decision approach. The specific research objectives are: (1) investigate spatially environmental-physical flood vulnerability aspects in terms of their susceptibility (illustrated by codes); (2) then, derive the highest vulnerable areas to flood considering the urban areas and their population density as a social vulnerability aspect. The results map shows the flood vulnerability classification based on the proposed method to the study area at the urban districts scale. The generated output, from vulnerability mapping, may be used as an effective tool for water sector planners, actors and humanitarian implementing agencies working in the Gaza Strip. The findings could be a reference point to guide them for recommending solutions that will help in minimizing the risk of flood and enable them to take proper decision in the right time before disaster occurrence.

3. Study Area

The Gaza Strip is a narrow coastal strip along the Mediterranean Sea of 365 km^2 area, with 40 Km long and on average 9 Km wide, in southern-western part of Palestine, located at Coordinates (31°25′N 34°20′E). The Gaza Strip includes five Governorates: North, Gaza, Middle, Khan Younis, and Rafah, as shown in Figure 1. Two million people reside on this narrow band of a semi-arid climate.

Figure 1: Gaza strip location map

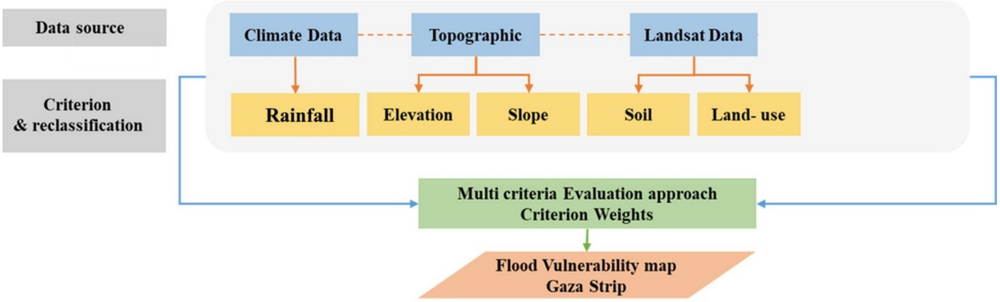

Figure 2: Flowchart of methodology

4. General Methodology

Eshtawi et al., (2016) conceptualized the relationship between water resources (water inputs) and the urban water system in the Gaza Strip, taking into account urban water budget (vertical and horizontal components), urban hydro-ecosystem function (water use), climate function, and urban hydro-ecosystem structure (soil, landuse, infrastructures) as well as human decision. This research derives a vulnerability map considering sensitive parameters of climate function, urban hydro-ecosystem structure, and human decision. The present research follows a GIS-based multi-criteria evaluation approach using criterion weights method and integrates: (1) rainfall (climate function); (2) topography/ slope, soil, and landuse; (3) population density to identify the flood-vulnerable areas as shown in the methodology flowchart in Figure 2.

The methodology developed in this research is divided into the following steps:

- Investigation of the main physical-environmental flood vulnerability criterions, namely rainfall, land use, soil and elevation.
- Criterions normalization. This process allows us to obtain dimensionless results to compare physical-environmental flood vulnerability criterions for different scales. So, for each criterion, the susceptibility was illustrated in terms of a code as illustrated in section 5.
- Intersection with the most susceptible districts considering their land use as well as population density as the main indicators for the social vulnerability.

5. Data Sources, Collection and Coding

5.1 Soil Map

Soil type of the study area is one of the major indicators responsible for flood, which is taken into account in this research. In the Gaza Strip, there are around 11 soil types, which includes sand soil, loamy sand soil, sandy loam soil, loam soil, sandy clay loam soil, silty soil, silty loam soil, loam soil, clay loam soil, sandy clay soil, silty clay soil, and clay soil (Afifi et al., 2014). The west area is the sandy soil area located in the coastal sand dunes and most of it can be classified as medium to rough sand. In this research, using ArcGIS, the soil types were re-classified into seven categories according to their saturated hydraulic conductivity (Ks). Sandy soil takes code 1 (has the highest infiltration rate), whereas clay and Silty clay soils take code 7 (the lowest infiltration rate) as shown in Figure 3.

5.1.1Topography and drainage sope of area

Topography and the related slope are other indicators responsible for flood occurrence. The general topography of the study area ranges from zero to around 100-meter elevation. The digital elevation model (DEM) of the study area was created from 30-meter resolution Landsat imagery (USGS, 2020), and considered as the base to generate a slope map illustrated in Figure 4. Drainage slope was also reclassified in terms of low slope zones < 1% (having a potential for flooding) and zones with slopes > 1% (less vulnerable to flood). The drainage slope map was converted using ArcGIS from raster format to vector using different geo-processing tools.

5.1.2 Rainfall

Rainfall could be considered as a threat factor in some risk assessment processes more than vulnerability factor; however the researches deem that the long term average rainfall is a vulnerability factor suitable for the study area (as the northern areas have average rainfall around twice that of the southern areas). Accordingly, the average rainfall of around 30 years for 12 rainfall stations was considered in this research (PWA, 2020). Thiessen polygons were generated, whereas the average rainfall for each polygon was recorded (Figure 5). The lowest average rainfall has code of 1, whereas the highest average rainfall has code of 7.

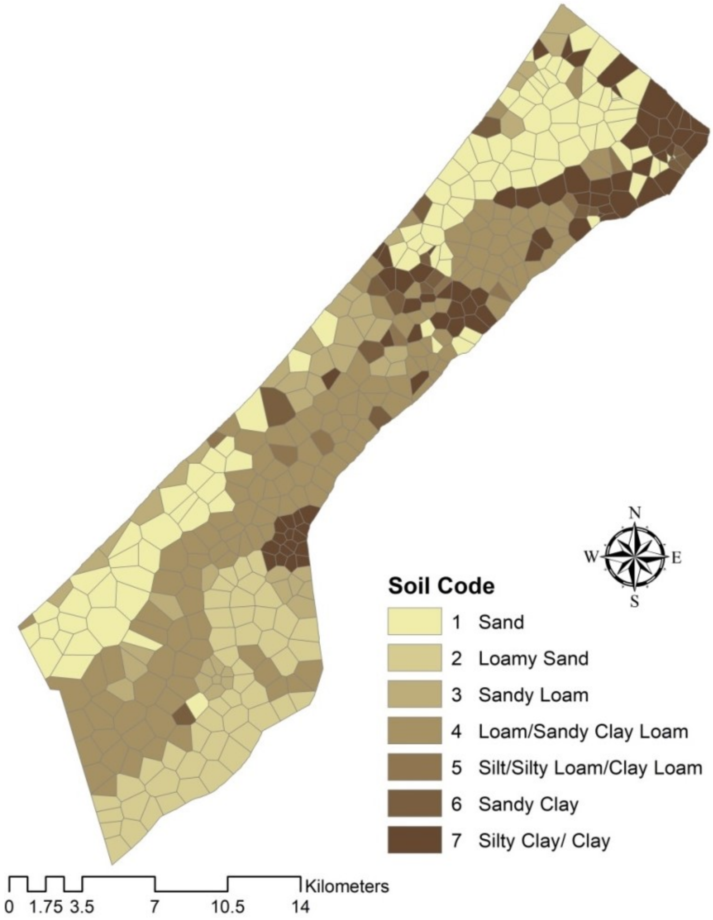

Figure 3: Soil types/code map of study area

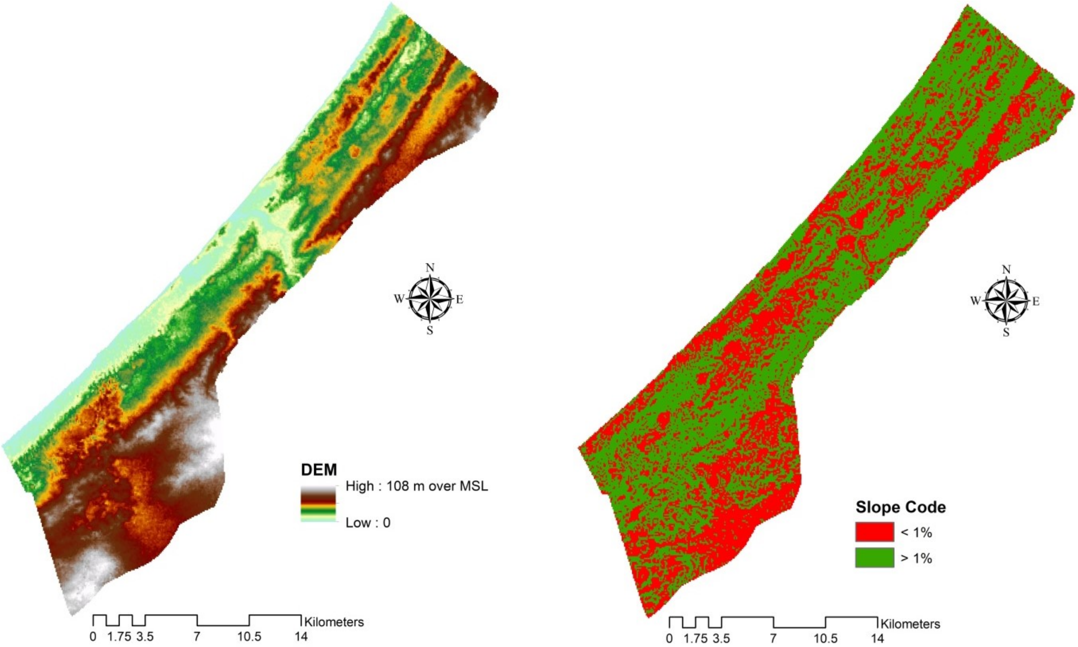

Figure 4: Data elevation model of study area

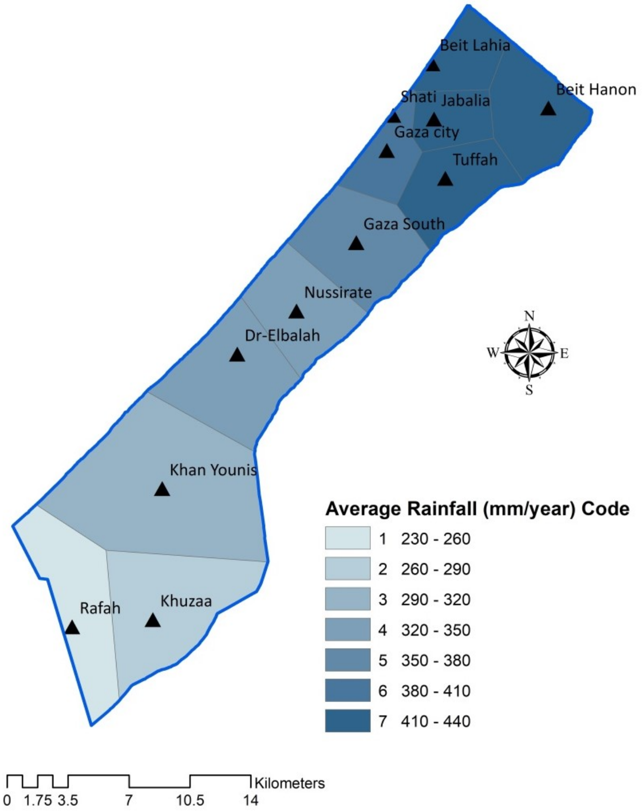

Figure 5: Long term average rainfall of study Area

Figure 6: Built-up area and the population density maps

5.1.3 Landuse

The research takes into account the flood vulnerability in the urban areas (built-up area). A digitized built-up area for the Gaza Strip was used to figure the final vulnerability map (Figure 6) (MoP, 2020). This map was developed based on a satellite image processing of the Gaza Strip (image resolution is 0.5 m).

5.1.4 Population density

This research also considered the population density as one of the most effective humanitarian factors in identifying the flooding vulnerability, since the more-densely populated districts, the more lives are expected to be lost. A recent population density map (PWA, 2020 and PCBS, 2015) was re-classified into seven groups; the classification code is (Natural logarithm of the habitant/1000m^2 for each polygon/district +1) as shown in Figure 6. This figure depicts that districts in the Gaza city have the highest population density followed by districts in the north governorates.

6. Data Analysis and Vulnerability Mapping Process

On the basis of data processing as mentioned above, ArcGIS was the geo-processing environment to develop comprehensive maps. The flood vulnerability map was generated by integrating the thematic layers of slope, rainfall, and soil, then clipping the developed map by built-up area layer. Then, to derive the potential extreme flood map, the flood vulnerability map was clipped by the highest two population density polygons from the population density layer. The weighting method implemented here for each vulnerability factor is based on experts' opinion and previous studies addressing flood vulnerability. The summary of assigning weight to factors is shown in Table 1.

Furthermore, soil layer that characterized by 7 coding steps as well as slope (2 coding steps, 0 or 1) were considered as the most effective factors relate to flood vulnerability and each one has a weight of 40%, as shown in Table 1 and Table 2. Rainfall (7 coding steps) has a weight of 20% , whereas the built-up area and population density themes were considered for clipping the generated flood vulnerability map expressed by the following formula: (0.4 × soil code + 0.2 × rainfall code + 0.4 × 7 × slope code). According to the resulted weighted summation, the vulnerability code was derived and divided into 5 groups tabulated as in Table 3. Figure 7 shows the resulted Flood vulnerability map clipped by the urban area, whereas Figure 8 illustrates the potential extreme flood zones in the urban area reflecting areas with crucial needs for humanitarian response before and during disaster. Table 4 exhibits the potential flood locations in terms of governorates, cities, and districts. It reflects the relevant vulnerability code and vulnerable area in (Km^2) as well as the potential affected population.

Table 1: Vulnerability factors weights

Vulnerability factors	Weight (%)
Soil	40
Rainfall	20
Slope	40

Table 2: Vulnerability factors codes

Vulnerability calculation factors	Maximum code value	Minimum code value
Soil	7	1
Population density	7	1
Rainfall	7	1
Slope	1	0

Table 3: Vulnerability classification

Weighted summation range	Vulnerability code	Vulnerability classification
0.8 – 2.0	1	Low vulnerability
2.1 – 2.8	2	Reasonable vulnerability
2.9 – 3.5	3	Moderate vulnerability
3.6 – 4.3	4	High vulnerability
4.4 – 5.8	5	Extreme vulnerability

Table 4: vulnerable area and potential affected population

Governorate	**City**	**District**	**Vulnerability**	**Vulnerable Area Km^2**	**Potential Affected population**
North	Beit Hanon	Block5	Extreme	0.38	6825
North	Beit Hanon	Block3	High	0.34	7006
North	Beit Hanon	Block4	High	0.19	3682
North	Beit Lahia	Alkarama	High	0.03	369
North	Jabalia	Alnahda	Extreme	0.04	965
North	Jabalia	Alrawda	High	0.52	15466
North	Jabalia	Alsheikh Redwan	High	0.2	8629
North	Jabalia	Beit Lahia proj.	High	0.24	4077
North	Jabalia	Almanshia	High	0.13	2059
Gaza	Gaza city	Sabra	High	0.45	12179
Gaza	Gaza city	Remal (south)	High	0.65	14083
Gaza	Gaza city	Remal (north)	High	0.35	7418
Gaza	Gaza city	Tal Alhawa	High	0.2	5426
Gaza	Gaza city	sheikh eglean	High	0.1	1851
Gaza	Gaza city	Zaytoon	Extreme	0.66	8378
Gaza	Gaza city	Alnasser	High	0.23	8140
Gaza	Gaza city	Alshatea	High	0.19	6512
Gaza	Gaza city	Old city	Extreme	0.2	5043
Gaza	Gaza city	Ajdazda	Extreme	0.52	12241
Gaza	Gaza city	Torokmani	Extreme	0.42	4122
Gaza	Gaza city	Aldaraj	High	0.94	27235
Gaza	Gaza city	Tuffah	High	1.32	23447
Middle	Dr-Elbalah	Almahatta	Extreme	0.18	2242
Middle	Dr-Elbalah	Almuasker	Extreme	0.05	933
Middle	Dr-Elbalah	Albaraka	High	0.06	1496
Middle	Dr-Elbalah	Alsalam	High	1.69	15386
Middle	Nussirate	Alsedra	High	0.02	612
Middle	Nussirate	Alawda	High	0.01	94
Khan Younis	Khan	Albatn Alsamean	High	0.34	9003
Khan Younis	Khan	City center	High	0.14	3690
Khan Younis	Khan	Alkateba	High	0.28	2888
Khan Younis	Khan	Block3	High	0.04	328
Khan Younis	Khan	Alamal	High	0.03	687
Khan Younis	Khan	Almanar	High	0.06	560
Khan Younis	Khan	Altahrear	High	0.07	2214
Khan Younis	Khan	Block4	High	0.01	119
Rafah	Rafah	Aledari	High	0.96	16543
Rafah	Rafah	Aljunazna	High	0.29	5152
Rafah	Rafah	Alshabora	High	0.21	1945

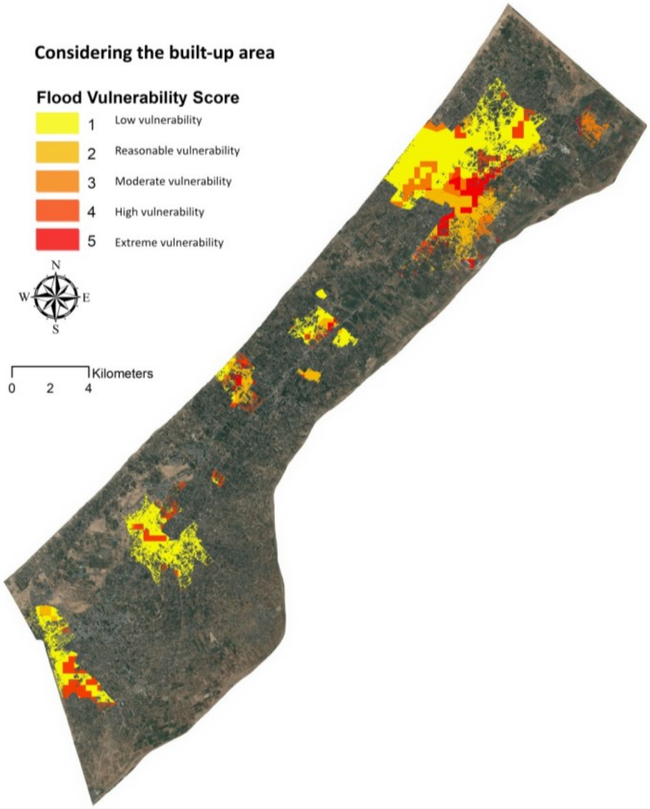

Figure 7: Flood vulnerability map

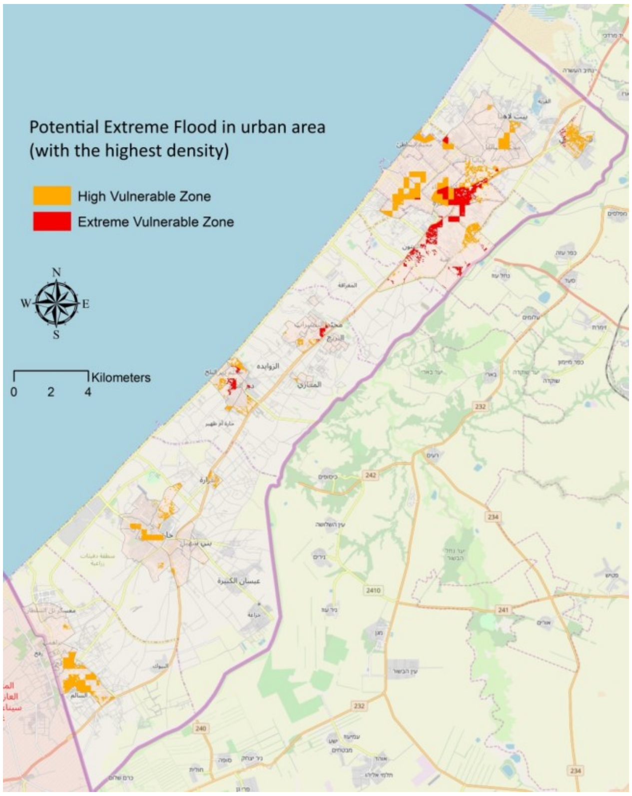

Figure 8: Potential extreme flood zones in the urban area

7. Results and Discussion

A GIS-based flood vulnerability map was created through a combined analysis of the digital elevation model (DEM), rainfall, and soil in the frame of population density and land use. This map was divided into five classes ranging from low to extreme vulnerability, as presented in Figure 7. Soil and slope were considered to have the highest weight (40% for each) in the vulnerability mapping, as they represent the main factors in urban hydro-ecosystem structure. The existing infrastructures of stormwater drainage in Gaza is not effective in general, so this factor was excluded from the mapping process. The long term average rainfall, a climate function factor, has the lowest weight (20%), because it could be considered as a threat factor in addition to a vulnerability factor. This research demonstrates that urban area and, in particular, population density as strong factors influencing flood vulnerability for humanitarian and saving life purposes. The vulnerability map shows that Almost 2% of households in the Gaza strip are extremely exposed to flood hazard, residing in 2.45 km^2 area. Most of them live in districts in the Gaza city, with a high population density. Also, the output illustrates that almost 10% of households in the Gaza strip are highly exposed to flood hazard, residing in 10 km^2 area and 25% of them concentrates in Gaza city.

In the vulnerability mapping, it was found that eight vulnerable areas, distributed over the Gaza strip, are identified as 'extremely vulnerable' to flooding risks and classified as very high-risk areas which requires immediate actions to improve the drainage systems, including the upgrading of existing storm water drainage infrastructure and creating linkages between drainage networks.

8. Conclusion and Recommendations

This study represents an exploratory step towards developing a new methodology for inexpensive, easily-read, rapidly-accessible charts and maps of flood vulnerability analysis based on topographical and demographical data. The study demonstrates the use of GIS and spatial technology to analyze and identify various flood-vulnerable areas, which need to be more focused on having various mitigation measures.Flood-affected areas of different magnitude have been identified and mapped using GIS Software. This means that there is a huge demand to increase the capacity of stormwater infrastructure facilities and the quantity and quality services.

The study explores that some districts characterized by high population density in the study area are classified and identified as very high vulnerable to flooding risk, and there is a need to give these vulnerable areas more attention from related local authorities and humanitarian implementing agencies to make immediate interventions to mitigate flooding risks and saving people lives. This research is innovative, as it quantifies the vulnerable population to be a guide for humanitarian interventions. It is also essential to find out the causes, reasons and measures in each high flooding risk area in the Gaza Strip to mitigate the flood situation in any given conditions and prepare a strategy for flood mitigation plan and management. In this context, the potential of decentralized natural solution (e.g., green infrastructure) is recommended to be a flood mitigation strategy to improve the system vulnerability and to add a natural hydro-ecosystem structure in the Gaza urban system working positively toward flood risk reduction.

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