Rainwater Flood risk assessment in Zaatari Refugees Camp- Jordan: Towards Sustainable Solutions

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Abstract

Refugee settlements are frequently located in isolated and remote areas, characterized by poor-quality land and harsh climatic conditions. Zaatari camp in Jordan has suffered and continues to suffer from rainwater floods every winter. This study uses GIS analysis to assess flood risk in the camp, revealing that 61.1% of the area is moderately risky, while 0.84% and 22.42% are very high and high-risk zones respectively. The highest risk areas are near the camp boundary. This study recommends a structural intervention and first-class priority at the entrance area of the camp as it is located within a high-risk area and is of vital importance from a functional standpoint.

These recommendations range to areas within high-risk zone in (1, 2, 7, 12) districts, to moderate risk zone in (4,8,11) districts with precautionary and preventive measures. In addition, some structural solutions can be implemented in several stages. This research is significant not only for managing flood risk in Zaatari but also for providing a replicable methodology for similar humanitarian settlements worldwide.

Keywords: Zaatari refugee camp, Rainwater floods, Flood risk assessment, Sustainable development, GIS.

Introduction

Urban environments worldwide are increasingly facing the impacts of climate change, with extreme weather events such as intense rainfall posing significant threats to infrastructure, public health and community well-being[17]. Refugee camps, which often experience rapid and unplanned urbanization, exemplify the vulnerability of urban areas to climatic disruptions, particularly rainwater floods[2,14]. The Zaatari refugee camp in Jordan, evolving from a temporary settlement to a structured space resembling an urban environment, serves as a microcosm of these challenges, highlighting the interplay between rainwater floods and urban resilience[12].

Sustainable development, a concept developed 30-40 years ago, emphasizes balancing social, economic and environmental factors to meet current needs without compromising future generations. Sustainable urbanism advocates for maintaining, repairing and upgrading urban areas to sustain quality of life[19]. The relationship between urban form and resilience is intricate, with urban form elements exhibiting resilience attributes like persistence, adaptability, or transformability in response to disturbances.

Vulnerability, the intricate relationship between individuals and their environment in the face of potential hazards, is seen from two perspectives. One views vulnerability as a pre-existing condition emphasizing exposure to hazards, while the other sees it as a complex interplay of physical exposure, social dynamics, resilience and adaptive capacities[5]. The integration of sustainable development and vulnerability is crucial in settlement planning[21]. Hasan and Ghafoor[15] introduced the concept of water urbanization, integrating water management with urban planning.

Sustainable development and vulnerability to disasters, particularly floods, are interconnected. Sustainable practices can mitigate vulnerability while disasters can hinder sustainable development. Achieving a balance is essential for creating resilient communities that can thrive despite environmental challenges. Recent technological advancements, including remote sensing and GIS, enhance the precision of vulnerability and risk assessments, providing valuable insights for informed decision-making in disaster management and sustainable development initiatives[21].

Floods pose significant economic and social challenges in rapidly growing metropolitan regions worldwide, necessitating urgent attention due to the potential amplification of adverse impacts from climate change and population growth. Further research is imperative, focusing on the locational attributes of localized flooding and the role of the built environment in exacerbating or mitigating adverse impacts[30]. Flood resilience relies on three urban form elements: type of development, buildings and open/green spaces, with urban development concentrated on suitable land while avoiding flood-prone areas. High-density developments may increase surface runoff due to high impervious surface cover, necessitating a balance between neighborhood and city scales in devising runoff/flood mitigation strategies.

Factors affecting surface water flows in camp sites depend on soil conditions, terrain slope (topography) and land usage, with vegetation playing a key role in water retention and soil infiltration[1,32]. Effective surface water drainage and storm water management are crucial in refugee camps to ensure safe access for vehicles and pedestrians, advocating for comprehensive planning for secondary drainage systems[32]. Sustainable drainage systems (SuDS) and techniques like filter media roofs, soakaways, rainwater harvesting, swales,

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bio-retention systems and detention basins promote sustainable and resilient surface water management.

Several studies have examined rainwater flooding and hydrological aspects in the Zaatari refugee camp, proposing solutions like sanitary drainage systems and trenches to drain rainwater in specific areas[6,7,16,24,25]. Despite implemented solutions, some areas still experience flooding during the rainy season, underscoring the need for sustainable solutions suitable for urban expansion[16]. Rain-induced flooding in the Zaatari camp necessitates a comprehensive study to understand the dynamics and consequences. The research delves into the impact of rainwater floods in the Zaatari refugee camp, proposing sustainable solutions using geographic information system (GIS) analysis to assess rainwater flood risk and to propose strategies to manage these risks.

GIS is a powerful tool for mapping, determining rainfall distribution patterns and comprehending the spatial dimensions of these events[9,18]. This research is significant for enhancing the resilience of the Zaatari refugee camp and offers a replicable methodology for assessing and mitigating rainwater floods in similar urban settlements globally. By bridging environmental science and refugee camp management, the study contributes to environmental urban planning concepts, promoting resilient urban development.

Material and Methods

Zaatari refugee camp, established in 2012 to accommodate Syrian refugees fleeing the Syrian war, has become the largest Syrian refugee camp in the world, hosting around 84,000 people, over half of them are children. The camp, divided into 12 districts, includes 32 schools, 8 health facilities and 58 community centers. More than half of the families have a member with a disability and 42% have at least one member with a chronic illness. Over the past decade, caravans have replaced tents, transforming the camp into a more permanent settlement. Despite facing significant challenges, the residents of Zaatari have actively contributed to the camp's development, creating a vibrant community that resembles a city. They have set up markets, cultivated gardens and brought life to the desert environment, underscoring the need for sustainable development strategies that align with the evolving urban landscape created by the refugees themselves.

The camp features three entrances: one for vehicles and organizational staff, another connecting refugees to the main street and a third for trucks and machinery. The first two entrances are prone to flooding, evidenced by a major flood in 2019 that overwhelmed drainage systems and led to tragic drownings. Heavy water accumulation near the solar energy project and in the southwestern part of the camp further exacerbates flood risks. The camp is surrounded by earthen berms that along with reused street gravel and exposed soil, contribute to water pooling and muddy conditions after rainfall.

To mitigate flood risks, trenches and drainage channels have been constructed, though they require regular maintenance. The camp also implements an annual emergency winterization plan. Surrounding land use zones hold potential for agricultural development which could enhance the camp's sustainability. Addressing these infrastructural and environmental issues is crucial for the safety, resilience and sustainable development of Zaatari refugee camp. The study area, located within the Amman-Zarqa basin (AZB) east of Mafraq city, spans 3,739 km² in Jordan and 310 km² in Syria. It is a crucial groundwater basin in Jordan, acting as a transitional zone from semi-arid highlands in the west to arid desert in the east.

The region experiences arid to semi-arid conditions with mean annual precipitation ranging from 100 mm in the east to about 300 mm in the southwest, characterized by short, intense rainfall during the rainy season. The Zaatari refugee camp, established in this area, occupies a nearly flat terrain that forms a natural soil pan used for cultivation. This location choice, driven by emergency needs, overlooked natural drainage patterns, leading to annual flooding of homes, schools and shops within the camp. A significant stormwater emergency required UNICEF and the Water Authority of Jordan (WAJ) to use emergency wastewater tanks to manage excessive rainfall. They successfully pumped accumulated rainwater to a wastewater treatment plant and isolated the emergency tanks afterward.

Additionally, awareness sessions were conducted regarding the winterization plan and rainwater drainage cleaning. AlAyyash[6] noted that the camp's establishment altered the area's hydrology, causing flooding. The construction of an earth wall around the camp prevents runoff from entering natural watercourses, while the dense arrangement of metal houses and compacted pathways covers about 50% of the area. These changes increased the curve number (CN) values, leading 82% to 614% rise in runoff depth, trapping more floodwater within the camp. The study suggested constructing drainage channels along natural watercourses, connected to major watercourses next to the camp through culverts under the earth wall, to mitigate flooding.

In contrast, a study by Obeidat and Awawdeh[24] on groundwater quality around the Zaatari camp found that approximately 96% of sampled wells were of good to excellent quality, suitable for drinking. About 95% of the water samples were classified as freshwater and 67% were categorized as hard to very hard water.

To study the flood risk (FR) and to analyze its parameters, a set of hydrological and environmental data was collected from various sources. The main data sources included the Ministry of Water and Irrigation (MWI) for historical rainfall records from eight stations (Rihab, Mafraq Airport, Bal'ama, Khaldiya, Wadi Dhuleil Nursery, Sabha and Subhiyeh, Um El-Jumal, Khirebit Es Samra) covering the period from 1979 to 2019.

Fig. 1: Rain water flood

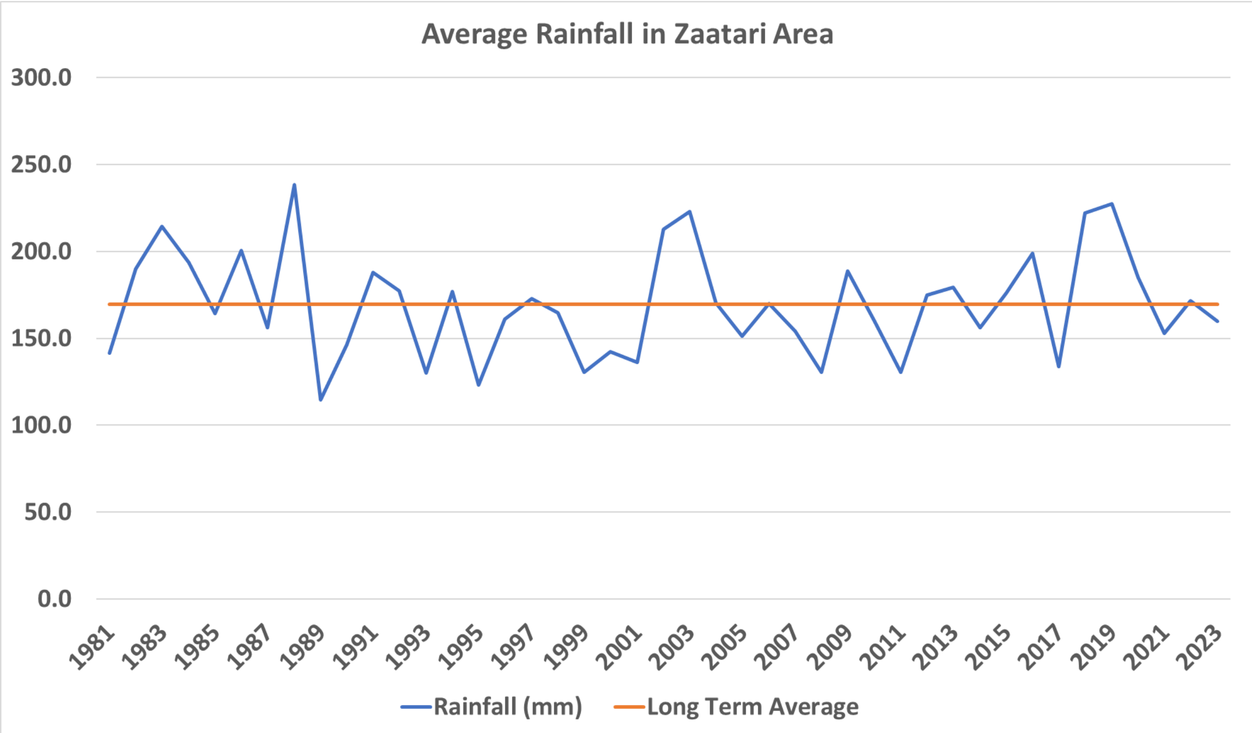


Fig. 2: Average rainfall in Zaatari area

Additional data were obtained from ALOS-PALSAR for a Digital Elevation Model (DEM) with a 12.5m spatial resolution, Landsat 8 imagery and the Google Earth Engine (GEE) platform for global soil textures and runoff maps. The long-term average rainfall was calculated for each station and these values were processed using ArcGIS software to produce the results shown in figure 2.

The process of estimating values at unknown points using known values at other points is known as interpolation[20]. ArcGIS software provides a set of tools for spatial data analysis and interpolation including the Inverse Distance Weighting (IDW) method available within its geostatistical analyst tools. In the IDW method, each point's weight is inversely proportional to its distance from the unknown point being estimated[26]. The general formula for inverse distance weighting is provided in eq. 1:

$$z_p = \frac{\sum_{i=1}^{n} \frac{z_i}{\mathrm{d}i^p}}{\sum_{i=1}^{n} \left(\frac{1}{d_i^2}\right)} \qquad (1)$$

where Z j is estimated value for the unknown point at location j, di j is distance between known point i and unknown point j, Z i is the value at known point I and n -n user is defined as exponent for weighting.

The Google Earth Engine (GEE) platform provides a comprehensive database of global spatial data. Historical rainfall data for the study area were downloaded from the GEE platform, utilizing the fifth generation of the European Centre for Medium-Range Weather Forecasts (ECMWF-ERA5) atmospheric reanalysis of the global climate. Figure 2 illustrates the annual rainfall fluctuations from 1981 to 2023. Notably, the long-term annual rainfall average was 169.6 mm/year. The highest recorded rainfall was 238.5 mm/year in 1988 while the lowest was 114.6 mm/year in 1989.

The Digital elevation model (DEM) provides a digital representation of the Earth's landscape on a two-dimensional surface. Typically generated from elevation data sourced from geographic maps and aerial photographs, DEMs offer a detailed portrayal of terrain. In this study, ArcHydro tools in ArcGIS software were used to process the DEM layer, delineating the stream network and catchment area. The DEM layer was also utilized to generate maps of slope, drainage density and the topographic wetness index (TWI).

Drainage density can be calculated using equation 2 while TWI can be calculated using eq. 3:

$$DD = \frac{L_s}{A} \tag{2}$$

where Ls is the total streams length and A is the total area[11].

$$TWI = ln\frac{a}{tan\, b} \tag{3}$$

where a is accumulation area per unit contour width and b is the slope angle[28].

To analyze land cover in the study area, a Landsat 8 (OLI) image, acquired on June 23, 2023, was downloaded from the USGS website. Spectral bands B1 to B7 were extracted and combined using the band composition tool in ArcGIS software, then clipped to the study area. Supervised image classification, utilizing the maximum likelihood algorithm, categorized the area into three main land cover classes: urban areas, crops and undeveloped areas.

The Analytical Hierarchy Process (AHP) was employed to determine weights for selected criteria through Pairwise Comparison (PWC). Using a comparison matrix, weights were calculated by extracting the eigenvector associated with the matrix's largest Eigen value and normalizing the sum of components to unity. The consistency ratio (CR) was used to validate the reliability and consistency of the judgments with a CR of 7%, indicating high consistency as it is below the recommended 10% threshold.

Five experts in hydrology and urban planning were engaged to weight study parameters using AHP. A flood risk map was generated based on the AHP method. The assigned weight values and the consistency ratio confirmed that the experts' opinions were consistent and suitable for AHP analysis. The results of the pairwise comparison matrix (PWCM) processing are as follows:

λmax=7.57, CI=0.095, RI=1.32 and CR=CI/RI= 0.072

In the context of the analytic hierarchy process, λmax is the maximum Eigen value, CI is a measure of consistency and RI is a reference value used to assess the consistency of judgments. The study parameters including class, rank and weight, are detailed in table 1.

Illustration of a flow diagram outlining the methodology employed to generate the flood risk map is shown in figure 3.

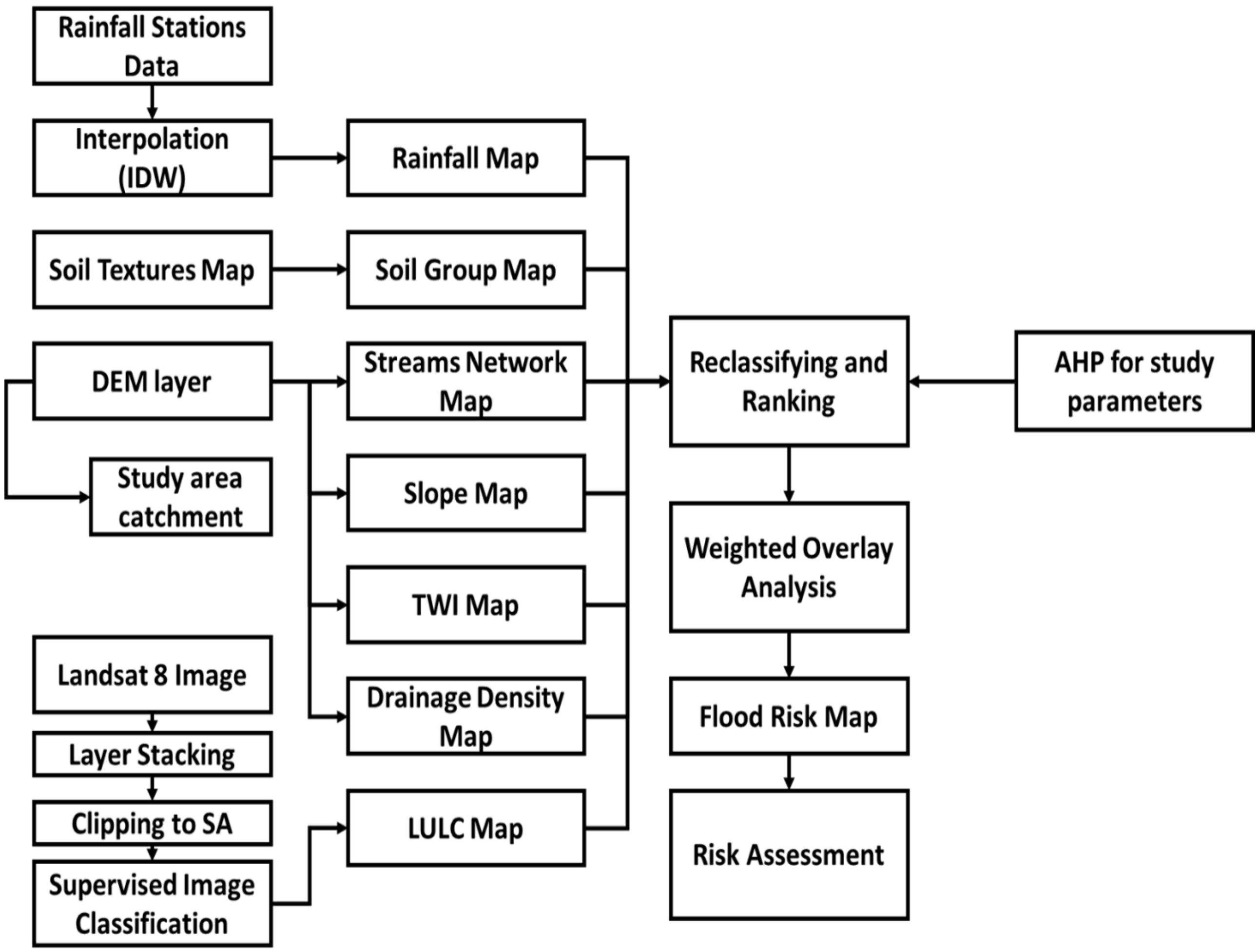


Fig. 3: Methodology flowchart

Table 1
Processing the study parameters

Criteria	Class	Rank	Weight %	Effect on runoff/flood
Rainfall	113-130	1	15	Rainfall is the primary parameter contributing to surface water runoff. An increase in rainfall values leads to higher expected runoff and greater flood risk. Consequently, the highest rainfall values were assigned the highest ranks, while the lowest values received the lowest ranks.
	131-145	2		
	146-160	3		
	161-175	4		
	176-195	5		
Distance to mainstreams	>100	1	21	The runoff magnitude is generally greater at the main streams of the stream network; this means more flood risk compared to the other streams. Accordingly, the areas close to these main streams were given a higher rank than the areas far away.
	51-100	2		
	26-50	3		
	11-25	4		
	0-10	5		
Drainage Density	0-4	1	8	Drainage density is directly linked to flood risk, as drainage density increases, so does flood risk. Therefore, the highest ranks were assigned to areas with the highest drainage density values.
	4.1-8	2		
	8.1-12	3		
	12.1-16	4		
	16.1-20	5		
Slope	0-3	1	10	Runoff is affected by slope by increasing its flow velocity in the cliffy areas, therefore, the highest slope values have the highest ranks in terms of flood risk.
	3.1-6	2		
	6.1-9	3		
	9.1-12	4		
	>12	5		
Soil Texture	Clay Loam	5	24	Soil texture impacts runoff and infiltration; clay soils generate more runoff, while sandy soils favor infiltration. Thus, coarse soils received lower ranks and fine soils received higher ranks.
	Sandy Clay Loam	4		
	Loam	3		
	Silty Loam	2		
Topographic wetness index (TWI)	4-8	1	14	TWI indicates the amount of runoff likely to occur based on topographic parameters, higher TWI values indicate more runoff and flood risk and they've assigned to the highest ranks.
	8.1-12	2		
	12.1-16	3		
	16.1-20	4		
	20.1-24.1	5		
The Land Use and Land Cover (LULC)	Urban areas	5	8	Land cover significantly impacts infiltration and runoff. Urban areas, with zero infiltration, have higher runoff and flood risk, whereas undeveloped or crop areas experience lower runoff and reduced flood risk.
	Undeveloped	4		
	Crops	2		

Source: Author

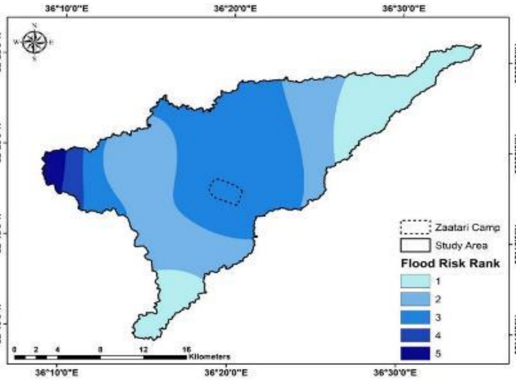
Results and Discussion

To apply the weighted linear combination (WLC) method effectively, it is crucial that the criterion layers share a consistent scale and units. Additionally, for further categorization, vector layers like roads, soil and stream order need to be converted into a raster format. The study parameter results after processing are shown in figure 4. The flood risk based on rainfall across the study area is depicted in figure 4-a. The highest flood risk areas are located in the central region where the Zaatari camp is situated and the western parts of the study area. The risk decreases toward the eastern and southern parts. This heightened vulnerability is attributed to increasing urban density and the expanding camp area, as discussed by AlAyyash[6].

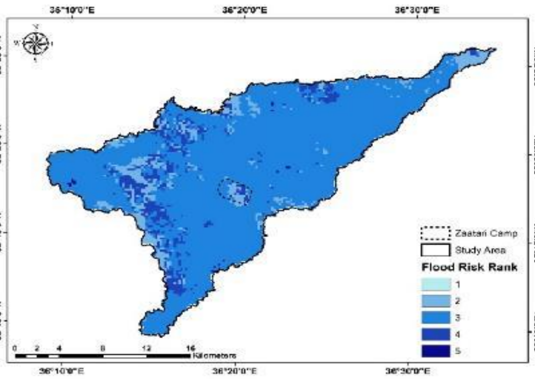
Figure 4-b classifies most of the study area as medium flood risk, primarily due to loamy soils which cover about 82.3% of the area surrounding the camp. Sandy clay loam soils represent approximately 7.8% and silty loam soils represent 9.7%.

While loam soil around the camp allows for moderate water infiltration, reducing flood risk, the presence of silty loam within the camp introduces complexities. The interaction of these soil types, combined with topography and human activities, significantly influences flooding dynamics.

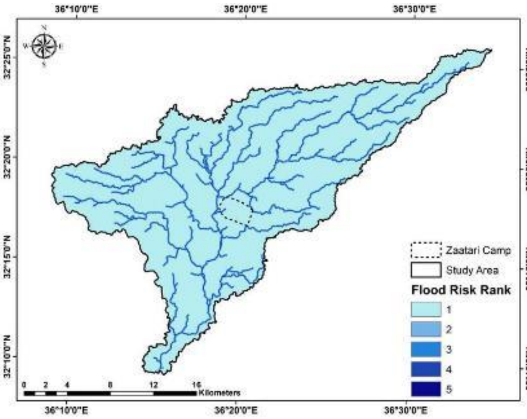
Figure 4-c illustrates the distance to main streams and the corresponding reclassified flood risk map. Streams originate in the north and northeast, flowing from the Syrian mountain (Jabal Al-Arab), traversing the camp and causing occasional flooding before continuing southwest. This classification helps identify areas with high flood risk, aiding in targeted risk management and land-use planning.



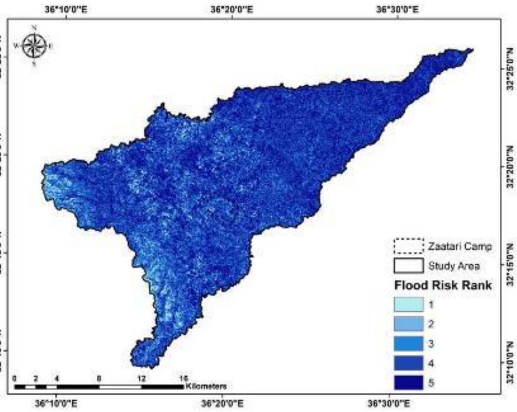
a- Rainfall



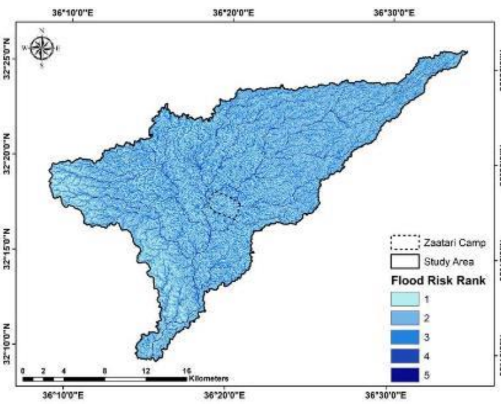
b- Soil Texture



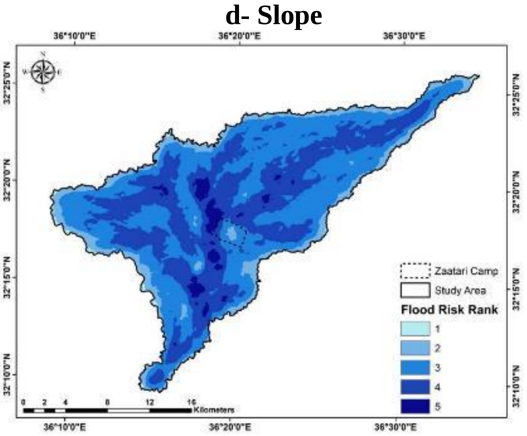
c- Distance to Main Streams



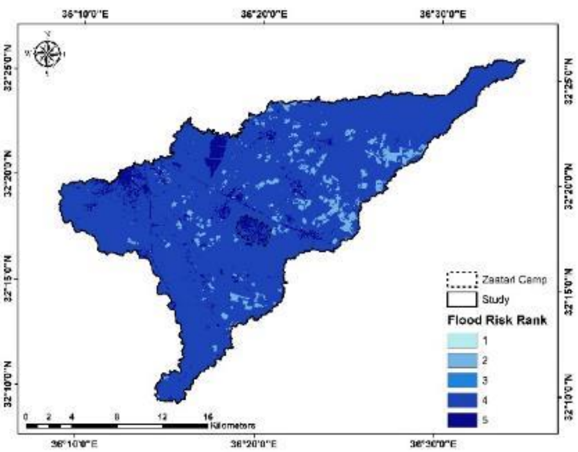
d- Slope



e- TWI



f- Drainage Density



g- LULC Map

Fig. 4: Flood risk maps of study parameters

Slope is a crucial factor in flood risk determination, affecting surface water runoff and flow. According to figure 4-d, about 63.2% of the study area consists of flat areas (slope <3%), making them vulnerable to rainwater accumulation and flooding. The Zaatari camp's flat topography particularly makes it susceptible to floods from upstream areas. The spatial distribution of Topographic Wetness Index (TWI) values across the study area is shown in figure 4-e. High TWI values, which form 1.9% of the study area, correspond to areas with increased wetness, indicating potential water accumulation or flow convergence zones. Low TWI values, covering 29.1% of the area, suggest drier locations with efficient water drainage or higher elevation. Figure 4-f shows that approximately 37.5% and 3% of the study area are classified as high and very high flood risk based on drainage density respectively.

The maximum drainage density value aligns with the central axis running from north to south and the northeast axis. This alignment corresponds with the surface runoff route passing through the camp, leading to flooding. Implementing water harvesting systems along this axis could mitigate floods and retain more water, aiding in water resource management and land-use planning. Finally, figure 4-g illustrates flood risk based on Land Use/Land Cover (LULC). The predominant land cover is undeveloped areas (approximately 88.8%), classified as high flood risk and urban areas (5.6%), classified as very high flood risk, mainly located in the central and western parts of the study area.

In summary, the central and western parts of the study area including the Zaatari camp, face the highest flood risks due to various factors such as rainfall, soil composition, slope, drainage density and land cover. Effective flood mitigation strategies including improved drainage systems and strategic water harvesting, are essential for managing these risks and ensuring sustainable land-use planning.

Flood Risk Map: The flood risk map analysis involved a thorough assessment of selected areas, categorized into sub-areas based on their flood risk levels: very high, high, medium, low and very low. Risk rankings were assigned on a scale from 5 to 1, with 5 representing the highest risk. As shown in figure 5, 61.1% of the study area is characterized by moderate risk. Very high and high-risk zones constitute 0.84% and 22.42% of the area respectively. The focus was on the highest risk areas near the camp boundary, transitioning from very high to high risk near the north boundary and decreasing to medium risk within the camp. This analysis considered topography, land use and hydrological characteristics, resulting in a comprehensive flood risk map that visualizes flood risk vulnerability across the study area. The map aids in strategic decision-making for flood risk management and preparedness.

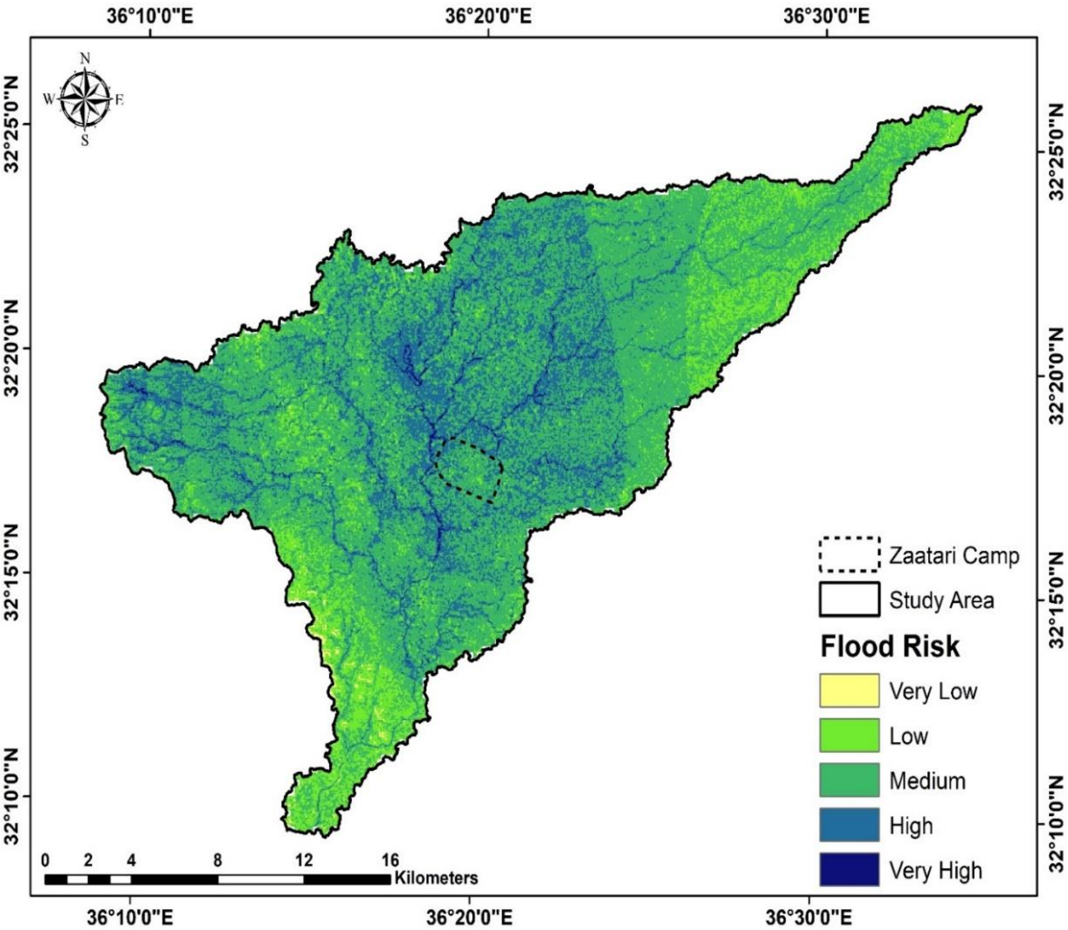


Fig. 5: Flood risk map

Notably, many hazard-prone areas were identified in the surrounding villages of Zaatari, Baij and Umm al-Jimal, highlighting the study's role in mitigating flood risks in these socio-economically vulnerable areas. By tracking water accumulations, drainage ditches direct water to the wastewater treatment plant (WWTP) southeast of the camp. This practice contradicts urban rainwater management principles and adds strain to the WWTP's capacity as noted by Tota-Maharaj[32].

The study emphasizes the need for effective flood risk mitigation not only within the camp but also in nearby villages, addressing socio-economic vulnerabilities and enhancing overall community resilience against flooding. This approach seeks to thoroughly evaluate flood risk and strengthen the community against environmental challenges. It is crucial not to overlook partial factors related to and arising from the camp's structure, as modifications to hydrologic responses in Zaatari can heighten flood vulnerability. Al-Ayyash[6] highlighted this issue in his study, which was further supported by Rainey et al[30]. This study reaffirms these findings by assessing the risks within the camp to address the pressing issue of rainwater-induced flooding in Zaatari refugee camp, outlined as follows:

A structural intervention is necessary at the entrance area of the camp due to its location in a high-risk zone and its critical functional importance. To improve safety, additional entry and exit points should be established in less hazardous areas, providing alternative routes during emergencies. Barriers, such as flood walls, levees, or berms, should be constructed around the gate area to protect them from floodwaters and environmental threats. Advanced drainage systems should be implemented around the gate to manage rainwater and prevent accumulation.

The second priority involves the districts (1, 2, 7, 12) while districts (4, 8 and 11) are in a moderate-risk zone with special attention needed for the southern edge of these two districts (Figure 6). To collectively mitigate flood risks during heavy rains, the integration of elevated platforms for shelter foundations, permeable surfaces for roads and walkways, strategically designed retention ponds and natural drainage channels aligned with the slope around the camp is essential. Additionally, paving streets may require a comprehensive planning study of the street network before implementing action plans. The drainage channels constructed along natural water courses as suggested by Al-Ayyash[6], have significantly reduced damage. However, their implementation highlighted the need for specific maintenance plans and possible enhancements, such as adding filters and tracking their structural capacity, as emphasized by Rainey et al[30] and Tota-Maharaj[32]. Alongside flood-resistant land use planning, incorporating vegetative buffer strips along water bodies, leveraging agriculture for soil stabilization and implementing rainwater harvesting systems are crucial components of a comprehensive flood risk reduction strategy.

Finally, collaboration with non-governmental organizations specializing in disaster risk reduction and engaging the community through training sessions on flood preparedness, evacuation routes, early warning systems and emergency winterization plans are essential for enhancing overall resilience and promoting sustainable development within the camp.

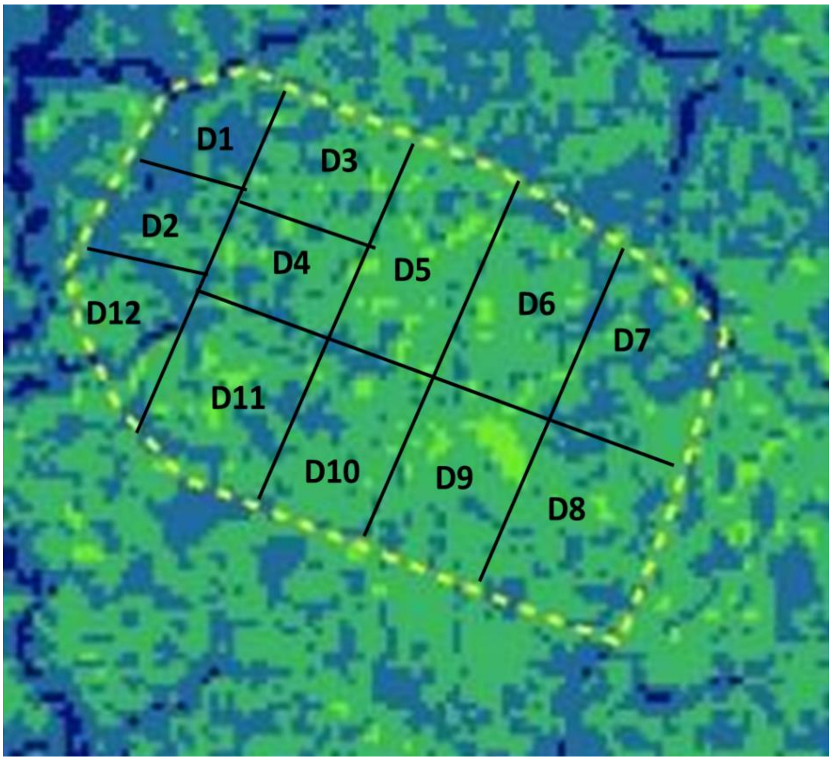


Fig. 6: Flood risk map

Conclusion

The rain water flooding in a simple word is a dynamic water feature which can be managed instead of facing as risk to integrate with sustainable and urban development akin to other urban water elements. The flood risk analysis not only contributes significantly to mitigating risks for the camp but also extends its impact to the neighboring villages, offering a comprehensive approach to address environmental challenges. The risk assessment reveals that the study area predominantly consists of moderately risky regions (61.1%), with very high and high flood-risk zones identified at 0.84% and 22.42% respectively which directly affect the corners of the camp's borders. Despite the region experiencing relatively modest precipitation percentages, the study's findings highlight surface runoff as the primary contributor to floods in the region.

Flood risk analysis helps in drawing up a comprehensive strategy to reduce flood risks, starting from solutions at the broader level to partial solutions within the study area, so that these solutions, their priority and the level of intervention are appropriate to the risk locations. This study recommends a structural intervention and first-class priority at the entrance area of the camp as it is located within a very high-risk area and it of vital importance from a functional standpoint. Then these recommendations range to areas with high-risk zone in (1, 2, 7, 12) districts, to moderate risk zone in (4, 8, 11) districts with precautionary and preventive measures. In addition, some structural solutions can be implemented in several stages. Future studies can conduct specialized hydrological assessment to implement more effective precise solutions.

This research, therefore, demonstrates the broader applicability and potential impact of our integrated GIS-based approach, emphasizing the transformative power of technology and comprehensive planning in creating environmentally resilient and socially conscious urban spaces. On the other hand, this research serves as a replicable methodology to direct the types of solutions and the priority of their implementation according to the assessment of risks and their relationship to function and urban use, providing a comprehensive framework for assessing and mitigating rainwater floods in similar humanitarian settings globally.

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