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Utilizing Remote Sensing and GIS Techniques for Flood Hazard Mapping and Risk Assessment

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Abstract

In this paper, a comprehensive flood hazard map for the vicinity of King Talal Dam in Jordan, utilizing advanced remote sensing (RS) and GIS methodologies, is developed. Key geographical and environmental factors, encompassing terrain slope, elevation, aspect, proximity to water streams, drainage density, and land use/land cover, are integrated to highlight areas with increased flood risk. This study, by employing a novel theoretical approach, harnesses the synergistic capabilities of RS and GIS to collect and analyze geospatial data. The Analytic Hierarchy Process (AHP) is applied to assign weights to various flood-conditioning factors, quantifying their relative importance in flood risk assessment. Through the weighted sum overlay technique, the aforementioned factors are integrated to categorize flood risk levels from very low to very high. This study successfully maps flood hazards, identifying areas near main water channels, ravines, and lower-elevation areas prone to flooding. This research provides a robust framework for flood risk assessment, contributing valuable knowledge to the fields of environmental management and disaster mitigation. It underscores the importance of continuous monitoring and updating of flood hazard maps to accommodate changing land use, climate, and hydrological conditions. The innovative application offers crucial insights for urban planners and policymakers, emphasizing the need for proactive strategies in flood-prone areas and serving as a model for similar geographical regions.

Keywords: Flood Hazard; Flood Risk; AHP; GIS; Remote Sensing; DEM; Weighted Sum Overlay.

1. Introduction

Natural disasters arise from the confluence of natural hazards, such as volcanic eruptions, earthquakes, landslides, and floods, and anthropogenic (human-caused) activities. While the intensity and frequency of natural disasters are increasing globally, the Asian region experiences a disproportionate share of these events, leading to significant losses in human life, infrastructure, stability, and economic progress. Floods, characterized by the inundation of land by a large body of water, stand as the most prevalent and destructive natural disaster, posing a constant threat to life and property. Over the past three decades, floods have caused hundreds of thousands of fatalities globally, alongside widespread infrastructure destruction, economic disruption, and annual economic damages estimated in the millions [1]. Notably, nearly half of all flood events between 1985 and 2003 occurred in Asia [2]. This vulnerability is further amplified by the interplay between human activities. While growing populations residing downstream of rivers exacerbate flood damage, human interventions upstream, such as deforestation and land-use changes, are contributing to the increased size and frequency of floods themselves.

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Due to their catastrophic nature, the investigation of floods and their effects on society has long been a major topic of interest for the academic community, especially for hydraulic engineering experts. The main focus of the literature has been on fluvial floods (i.e., riverine), such as the prediction of their occurrence and inundation extent [3-5], the forecasting at the continental and global scale [6], and the assessment of their effects on agriculture [7, 8], aquatic habitats [9], the built environment [10], people's health [11], and the economy [12], as well as the development of adaptation strategies [13]. More recently, flash floods have also attracted the attention of the global community due to the occurrence of very catastrophic events around the world. Such floods are characterized by intense and high-velocity flows generated either by extreme rainfall at nearby higher grounds in a short amount of time or by the sudden release of water from dams and levees. They can be very catastrophic for the built environment [14, 15], such as transportation infrastructure and bridges, due to the large hydraulic loads [16]. Moreover, flash floods can cause cascading hazards, including landslides, debris flows, or water flows with entrained debris [17–21], with the latter leading to the generation of impulsive forces several times higher than the hydraulic ones applied to structures [16], a fact that increases the likelihood of destruction.

Within the domain of flood risk management, a paramount concern for the scientific community lies in the development of robust methodologies for flood-induced damage assessment [22] and the evaluation of flood vulnerability and risk [23]. To inform effective flood planning and preparedness strategies, various approaches have been utilized, drawing upon a diverse range of data sources. These sources commonly include hydraulic data, topographic maps, digital elevation models (DEMs), land use/land cover maps, inundation maps, and population density data. Broadly categorized, flood risk assessment methodologies can be classified as quantitative or qualitative [24]. Quantitative approaches aim to quantify flood hazards through the use of numerical modeling, often expressing risk in terms of exceedance probabilities or anticipated losses. Conversely, qualitative methods rely on expert judgment and incorporate a wider range of factors influencing flood risk. These methods are frequently employed for the construction of composite risk indices, combining various indicators [25]. Notably, some qualitative approaches integrate ranking and weighting systems, blurring the lines and potentially qualifying them as semi-quantitative [24]. While quantitative methods generally yield more precise results, they often necessitate substantial data acquisition, detailed morphological information, and the implementation of sophisticated numerical models. This can pose challenges in resource-constrained settings. Qualitative and/or semi-quantitative approaches, on the other hand, offer greater ease of implementation within Geographic Information Systems (GIS) and demonstrate enhanced flexibility in handling heterogeneous data, adapting to data availability [26, 27].

Numerous case studies underscore the practical applications of integrating RS and GIS for flood risk management. For instance, Dano et al. [28] applied these technologies in Perlis, demonstrating how they can support cross-border flood management initiatives. Similarly, Waseem et al. [29] focused on urban areas, where the combination of RS and GIS informed the development of urban planning strategies to minimize flood risks.

A range of studies have demonstrated the effectiveness of remote sensing and GIS techniques in flood hazard mapping and risk assessment. Antzoulatos et al. [30] and Psomiadis et al. [31] both utilized a combination of satellite imagery and GIS data to assess flood hazards and risk levels on the Sperchios river catchment in Central Greece. Kettner et al. [32] highlighted the potential of synthetic aperture radar data in overcoming limitations such as cloud cover and nighttime and the development of a 'one-stop-shop' portal for flood prediction and monitoring. Alarifi et al. [33] applied remote sensing and GIS techniques to delineate flash flood-vulnerable areas in southwestern Saudi Arabia, using a multicriteria decision-making technique and analytic hierarchy processes. These studies collectively underscore the value of remote sensing and GIS in enhancing our understanding of flood hazards and risks and in supporting effective flood management and relief efforts.

M Amen et al. [34] utilized remote sensing and GIS techniques to map flood-prone areas and assess flood vulnerability. This study in Duhok, Iraq, used the analytical hierarchy process (AHP) to identify high-susceptible zones, while the study by Madi et al. [35] in the Tamanrasset Valley watershed, Algeria, integrated the HEC-RAS 1D hydraulic model with GIS to generate flood maps for extreme river flood events. Kumar and Jha [36] also employed GIS for flood risk mapping in the Kosi River Basin, Bihar, India, using an empirical approach that integrated AHP and thematic layers. Chakrabortty et al. [37] took a different approach, using machine learning algorithms in a GIS platform to delineate flood hazard risk zones in the Kangsabati River basin, West Bengal, India. These studies collectively demonstrate the effectiveness of remote sensing and GIS techniques in flood hazard mapping and risk assessment.

GIS is instrumental in analyzing spatial data, modeling flood hazards, and assessing vulnerabilities. By integrating topographical, hydrological, and socio-economic datasets, GIS enables the detailed spatial analysis required for risk assessment. Chan et al. [38] highlighted how GIS-based models could identify flood-prone areas and evaluate potential impacts on communities and infrastructure, guiding mitigation and preparedness strategies.

The synergy between RS and GIS technologies provides a comprehensive approach to flood hazard mapping and risk assessment. A study by Efraimidou & Spiliotis [39] exemplifies the integration of RS-derived flood extents with GIS-based vulnerability analyses to develop detailed risk maps. These integrated approaches facilitate targeted risk reduction interventions, optimizing resource allocation for flood defense, and emergency response planning. Satellite-derived remote sensing data plays a crucial role in characterizing landscape features, particularly land cover and land use. High-resolution imagery facilitates the identification of infrastructure and buildings within flood risk zones, enabling vulnerability assessments and potential loss estimations. Consequently, the systematic integration of remote sensing data offers a valuable tool for monitoring susceptible areas and mitigating future devastation. This study proposes the incorporation of diverse geospatial datasets using a map factor approach to generate an easily interpretable and readily available flood risk map.

1.1. Study Area

Al-Balqa Governorate is situated to the northwest of Amman, the capital of Jordan. It spans roughly 1100 square kilometers. Its geographical coordinates are 32°11′24″N in longitude and 35°48′05″E in latitude, as depicted in Figure 1. The primary function of the local dam is to capture and store rainwater during the winter season. This dam plays a crucial role in irrigating approximately 17,000 hectares of land and sustaining the livelihoods of about 120,000 residents. Over the years, the population of Al-Balqa Governorate has witnessed a significant increase, rising from 491,709 in 1996 to 518,600 in 2018 according to the Department of Statistics [40].

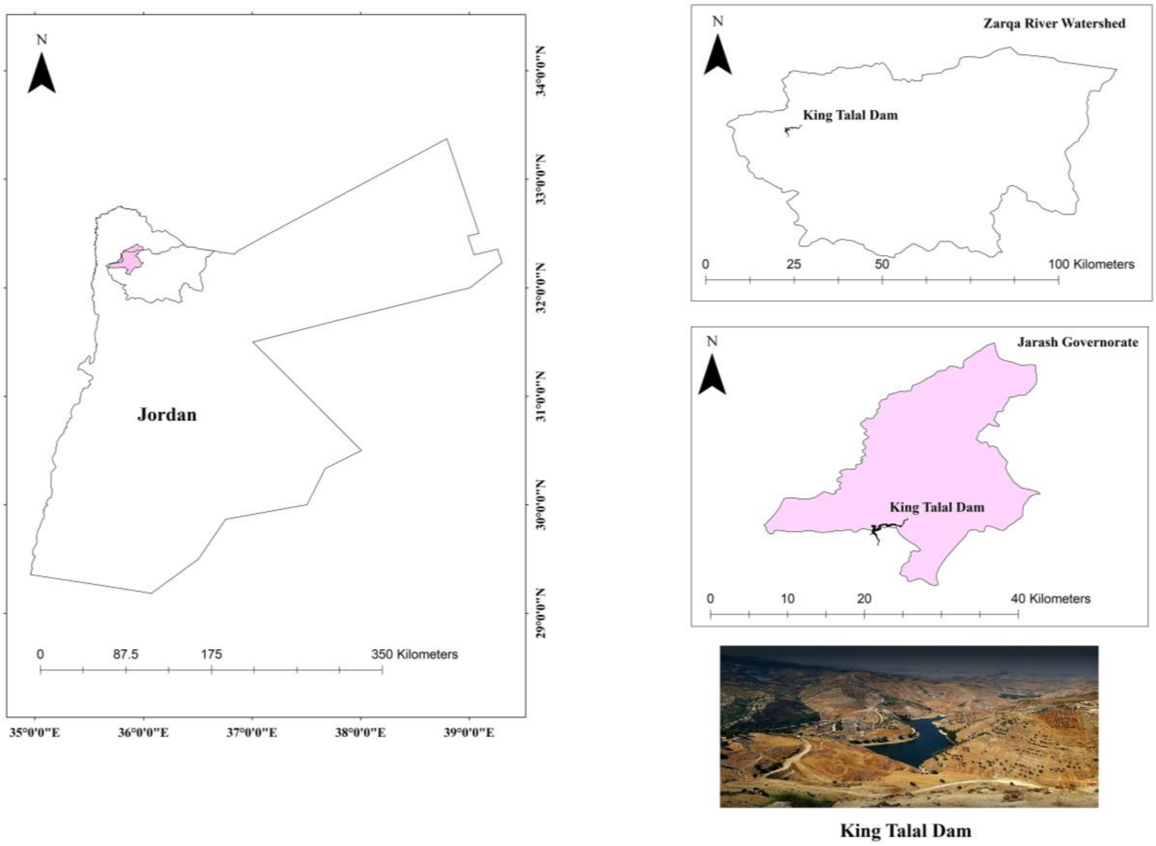

Figure 1. Location map of the study area

The northern to southern highlands of Jordan, known for being densely populated, are pivotal for the nation's agriculture and biodiversity. These areas, as reported by Makhamreh [41], benefit from a comparatively moderate climate, especially when contrasted with the warmer Jordan Rift Valley to the west and the desert regions to the east and south [42].

Within the administrative framework of Jordan, comprised of twelve governorates, Al-Balqa occupies the fifth position in terms of population size. Conversely, its land area ranks tenth amongst the governorates [43]. This disparity translates into a high population density, placing Al-Balqa fourth in the nation after Amman, Irbid, and Jarash Governorates. Geographically, the governorate borders the Jordan Rift Valley, incorporating sections of the Dead Sea shoreline along its southern boundary [43].

Several research initiatives in Jordan have focused on the trends of urban sprawl and the corresponding reduction in vegetation, as highlighted in studies by Al-husban [43], Al-Bilbisi [44], and Qtiashat et al. [45]. These studies collectively observed a decline in vegetation coverage across the study regions, alongside a sporadic pattern of urban growth driven largely by rising demands for residential land use. These investigations have pointed out that the noticeable decrease in agricultural and green vegetated areas can be directly attributed to rapid urbanization. This expansion has adversely impacted both agricultural fields and water catchments and increased the potential of floods in the area.

This work aims to bridge this gap by harnessing the power of satellite remote sensing data, combined with a multifaceted geospatial analysis approach, to develop a novel flood risk map that is both accessible and informative. Our approach builds on the foundational work of hydraulic modeling and risk assessment methodologies but seeks to innovate by offering a more integrated and spatially precise tool for flood risk management. By doing so, we address the critical need for enhanced tools in flood planning and preparedness, particularly in regions like Al-Balqa Governorate, Jordan, where the interplay of rapid urbanization and environmental changes poses heightened flood risks.

2. Material and Methods

This research employs a novel theoretical approach that harnesses the synergistic capabilities of Remote Sensing (RS) and Geographic Information Systems (GIS) for flood hazard mapping and risk assessment. Central to its methodology is the integration of RS and GIS to collect and analyze geospatial data, including terrain features and land use patterns, to identify areas at risk of flooding. The study innovatively applies the Analytic Hierarchy Process (AHP) to assign weights to various flood-conditioning factors such as slope, elevation, and proximity to water bodies, thereby quantifying their relative importance in flood risk assessment. The weighted sum overlay technique integrates these factors to produce a comprehensive map that categorizes flood risk levels from very low to very high. This approach not only demonstrates the utility of combining RS and GIS for environmental hazard evaluation but also emphasizes the importance of dynamic flood risk management—acknowledging the need for continuous monitoring and updating of flood hazard maps to reflect changing environmental conditions. By offering a holistic and adaptable framework, this research contributes significantly to the fields of environmental management and disaster mitigation, providing valuable insights for developing targeted flood risk management strategies.

To produce an easily readable and rapidly accessible flood hazard map of the study area, the methodology was performed by selecting six flood-conditioning factors: slope, elevation, distance to stream, drainage density, aspect, and land cover/land use.

Although different number of factors were utilized by previous relevant studies such as Withanage et al. [46] who used ten factors, Rudraiah et al. [47] who used twelve factors, Vojtek et al. [48] who used seven factors, and Costache et al. [49] who used twelve factors, this study used six factors based on their importance in identifying the flood hazardous maps and based on the availability of the data in Jordan.

The weights of the maps were adopted considering several parameters that control water runoff. In particular, the Digital Elevation Model (DEM) of the study area was used to extract slope, elevation, distance to stream, aspect, and hillshade. The land cover map was produced from a 10-meter Sentinel-2 satellite image. Figure 2 shows the flowchart of the work methodology.

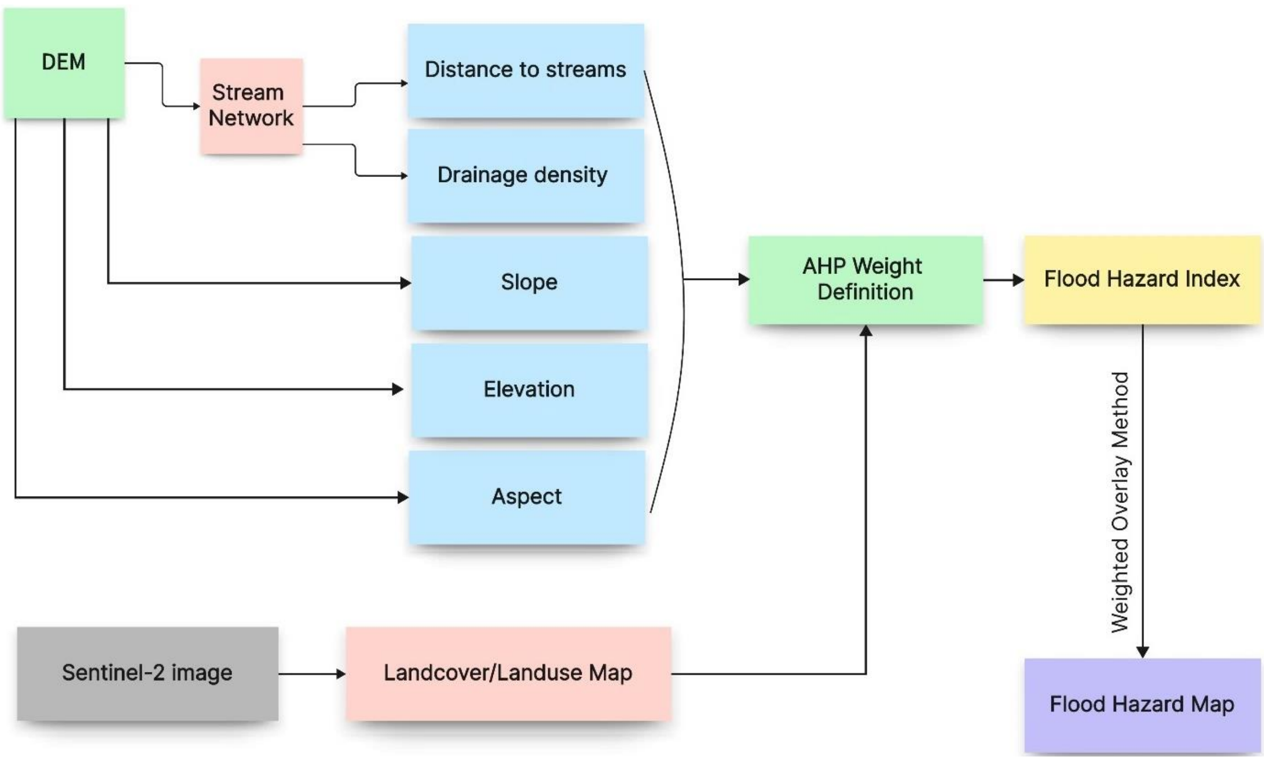

Figure 2. Flowchart of work methodology

2.1. Data Collection

A high-resolution Sentinel-2 satellite image acquired on March 21st, 2021, with a 10-meter spatial resolution, was utilized to generate a land use/cover map of the study area. Additionally, a 30-meter Digital Elevation Model (DEM) was incorporated. The DEM was validated using ground control points obtained through GPS observations. This comprehensive geospatial dataset facilitated the production of detailed thematic maps, including slope, elevation, drainage density, distance to streams, aspect, and hillshade. These parameters are recognized as crucial factors in the generation of flood hazard maps

Normalized difference vegetation index (NDVI), Normalized difference built-up index (NDBI), Normalized difference water index (NDWI), Bare soil index (BSI), and visible brightness were computed and implemented in the classification of the satellite map. Consequently, NDVI and visible brightness were selected for classifying vegetation and water, while Support Vector Machine (SVM) classification was applied to soil and urban areas due to significant overlap. This approach yielded highly satisfactory results, as verified against high-resolution RGB images. The multi-resolution segmentation algorithm, a region-growing technique with parameters set at 35 Scale, 0.8 Shape, and 0.5 Compactness using eCognition, was used to generate the image objects [50] as shown in Figure 3.

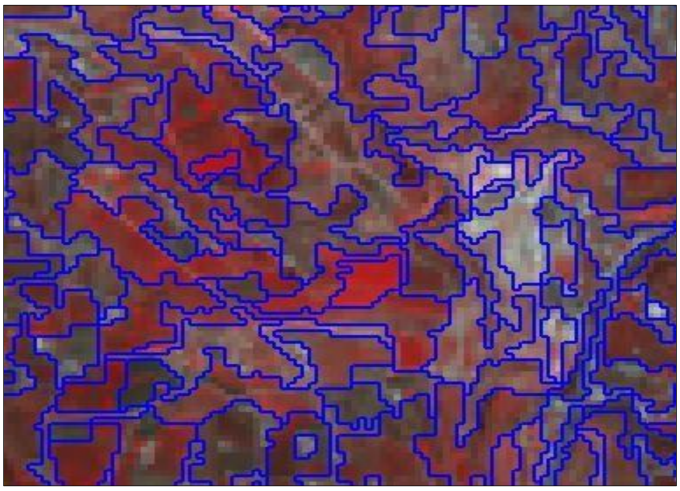

Figure 3. Result of Image Segmentation

The accuracy of the classified Sentinel-2 image was evaluated using a reference dataset. A common approach for accuracy assessment involves generating random points from ground truth data and comparing them to the classified data using a confusion matrix. This technique allows for the assessment of various image classification methodologies and training site selection strategies. Figure 4. illustrates an example of accuracy assessment using a very high-resolution (VHR) image. In this specific case, the accuracy assessment yielded an overall classification accuracy of 88.33% and a Kappa coefficient of 84.37%.

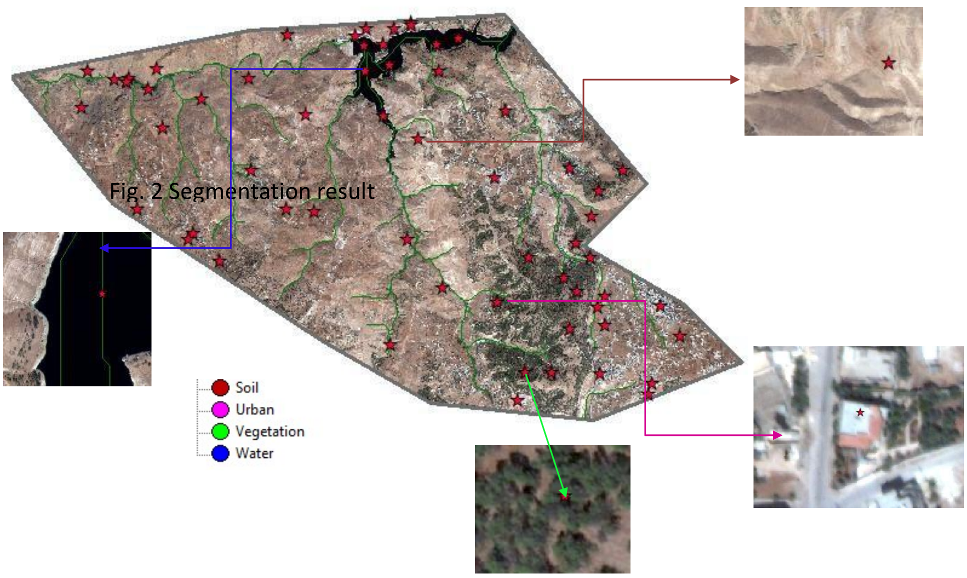

Figure 4. Accuracy assessment using VHR image

This study employed Geographic Information Systems (GIS) and geoprocessing tools to extract the stream network from a Digital Elevation Model (DEM) [51]. The extracted network was subsequently classified using Strahler's stream ordering system, where unbranched segments are designated as first-order streams. Confluences of two first-order streams generate a second-order segment, and this hierarchical process continues for higher order streams [52].

Following established methodologies from Strahler [52], Horton [53], and Schumm [54]. various linear and areal morphometric parameters were automatically computed. Drainage density (Dd), a key parameter reflecting stream network intricacy, was investigated in this study. Dd is influenced by climatic conditions, vegetation cover, underlying geology, relief, and landscape evolution processes [55]. Dd values typically range from 1 km/km² in highly permeable terrains to over 5 km/km² in areas with low permeability [46].

Generally, low Dd values are indicative of regions with resistant or highly permeable subsurface materials, dense vegetation cover, and subdued topography. Conversely, high Dd values are associated with weak or impermeable subsurface materials, sparse vegetation, and mountainous landscapes [47]. As shown in Figure 5, the spatial distribution and characteristics of stream segments within a watershed are influenced by a confluence of geological and hydrological factors. These factors include the underlying bedrock's lithology and structural organization, the density and composition of vegetation cover, the intensity and temporal patterns of precipitation, and the infiltration capacity of the soil. [51, 56].

2.2. Analytic Hierarchy Process Selection Criteria

Flood hazard assessment typically incorporates various spatial factors that influence flood generation. These factors commonly include slope, elevation, proximity to streams, drainage density, land cover/use, and aspect. Each factor is represented by a raster layer, and these layers are subsequently classified based on their potential to contribute to flooding. This study employed an Analytic Hierarchy Process (AHP) to determine the relative importance of each factor. The AHP utilizes pairwise comparison matrices, where experts and local residents, with their understanding of the area's characteristics, assign weights to each factor based on its comparative importance to the others. A rating scale of 1 to 9 is used, with 1 representing a factor of minimal influence and 9 signifying a highly influential factor [57].

Table 1 illustrates the pairwise comparison matrix, formatted as a 6 × 6 matrix. In this matrix, the diagonal elements are uniformly set to 1, indicating equality when a factor is compared with itself. The matrix's structure allows for a systematic comparison of each row element against each column element to ascertain their relative importance, thereby determining the rating score. For instance, when considering the importance of Distance to Streams relative to Aspect, Distance to Streams is deemed significantly more important and is accordingly assigned a value of 7. Conversely, when focusing on the importance of Aspect, as represented by the corresponding row, the value is the reciprocal of the earlier comparison, resulting in 1/7 for Distance to Streams in this case. This reciprocal approach ensures a balanced and coherent evaluation of each factor's importance within the matrix. The weight of each factor is computed within the pairwise matrix based on Table 1 and reported as shown in Table 2.

Table 1. Parameters' relative importance values used for developing flood hazards map using AHP

Parameter	Distance to Streams	Slope	Drainage Density	Land cover/ Land use	Elevation	Aspect
Distance to Streams	1	3	3	6	5	7
Slope	1/3	1	1/3	3	3	3
Drainage Density	1/3	3	1	6	3	7
Land cover/ Land use	1/6	1/3	1/6	1	1/3	1/3
Elevation	1/5	1/3	1/3	3	1	3
Aspect	1/7	1/3	1/7	3	1/3	1

Table 2. Hazards parameters and corresponding weights

Parameter	Distance to Streams	Slope	Drainage Density	Land cover/ Land use	Elevation	Aspect
Weight	0.405	0.143	0.261	0.040	0.093	0.058

Evaluating the consistency of the eigenvector matrix generated for AHP is essential. The consistency ratio (CR) should not exceed 0.1 to have a consistent pairwise matrix [57]. CR calculated in this instance is 0.098, which falls below the acceptable threshold of 0.1. This indicates that the consistency of the weights within the matrix is confirmed.

This study identifies elevation as a key factor influencing flood susceptibility within the investigated area. Due to the gravitational force driving water flow from higher to lower elevations, low-lying regions are more susceptible to inundation during flood events. Conversely, areas situated at higher elevations typically exhibit a lower likelihood of flood occurrence. The generated elevation map was subsequently classified into five distinct classes (Figure 6). A detailed breakdown of these elevation classes, their corresponding weights assigned in the flood susceptibility analysis, and the calculated Consistency Ratio (CR) are presented in Table 3.

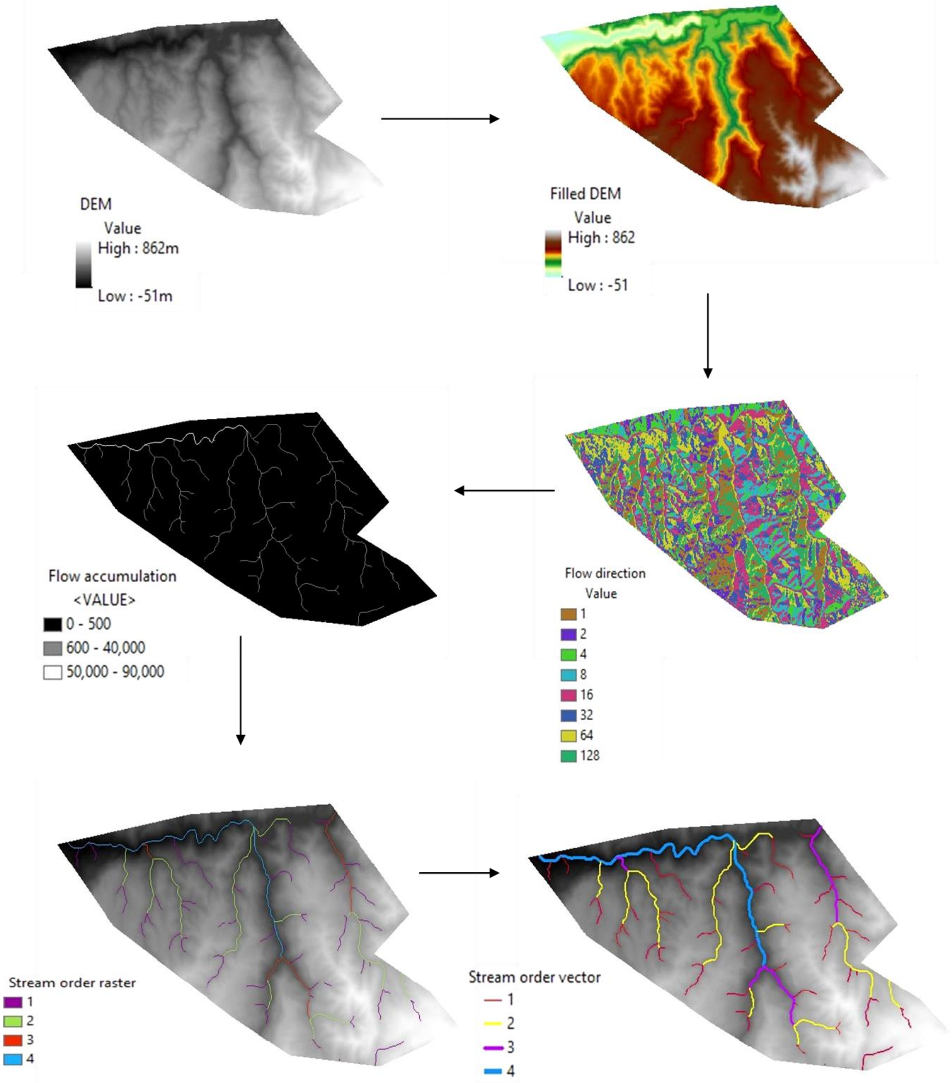

Figure 5. Workflow for the stream network extraction processing the DEM of the study area

Table 3. Paired comparison matrix of elevation parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Elevation (m)	0.093	>862m	0.03	0.071
		750-500 m	0.07	
		500-250 m	0.13	
		250-50 m	0.26	
		<50 m	0.50	

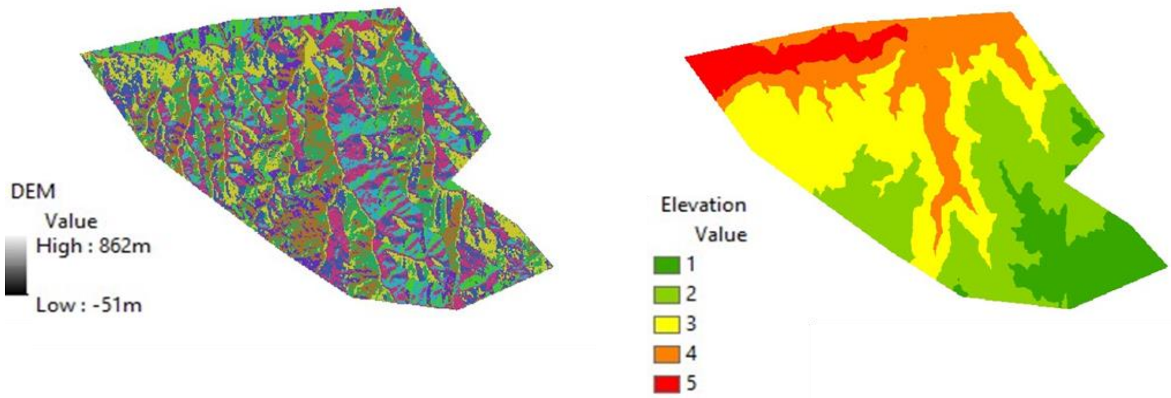

Figure 6. Elevation map classes of the study area

Within the domain of flood mapping investigations, slope emerges as a critical factor by virtue of its regulatory influence on surface water flow. The degree of slope governs both the volume of surface runoff and the intensity of water flux, which in turn, influences soil erosion and the rate of vertical percolation. Areas characterized by a lower slope exhibit a demonstrably higher susceptibility to flooding events. A detailed classification of slope categories and their corresponding weightings is presented in Table 4.

Table 4. Paired comparison matrix of slope parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Slope	0.143	Flat (0-2.26)	0.52	0.051
		Gentle (2.27-4.52)	0.27	
		Moderate (4.53-7.54)	0.13	
		Steep (7.55-11.8)	0.06	
		Very Steep (11.90-38.4)	0.01	

Drainage density, quantified as the total length of streams per unit drainage area (km/km²), reflects the efficiency of a basin's surface runoff network. Higher drainage densities indicate a greater capacity for rapid removal of precipitation via stream channels, thus corresponding to an increased susceptibility to flooding events. Figure 7 categorizes the drainage density of the study area, while Table 5. details the associated weightings assigned to each class.

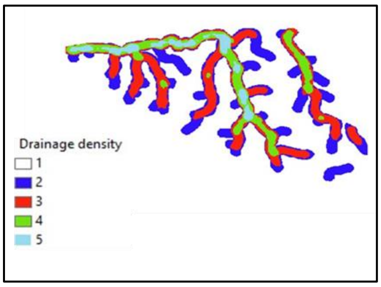

Figure 7. Drainage density map classes of the study area

Table 5. Paired comparison matrix of drainage density parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Drainage density	0.261	Very High (0.0470-0.0640)	0.50	0.047
		High (0.0300-0.0470)	0.26	
		Moderate (0.0130- 0.0300)	0.15	
		low (0.0068-0.0130)	0.07	
		Very low (0-0.0068)	0.02	

Land cover and land use (LCLU) data are critical parameters influencing surface runoff generation and potential flood hazards within a watershed. LCLU directly and indirectly impacts infiltration, evaporation, and surface runoff production. The study employed object-based image analysis techniques (Support Vector Machine [SVM] and rule-based classification) on Sentinel-2 satellite imagery to generate a land cover map. Implemented within eCognition software, a multi-resolution segmentation algorithm facilitated image segmentation. The resulting LCLU map classified the watershed into four primary categories: vegetation, water, urban areas, and soil (Figure 8).

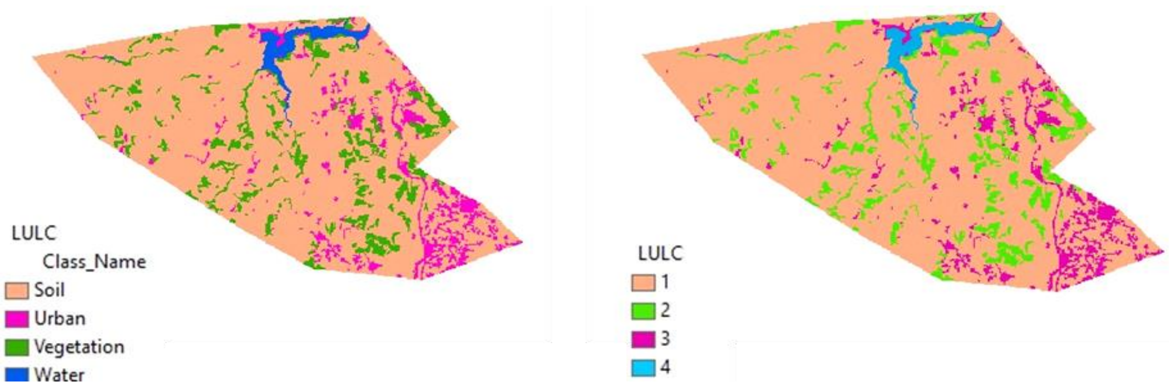

Figure 8. LCLU map of the study area

Urbanization significantly impacts flood sensitivity. Impervious surfaces like concrete and asphalt, common in urban settings, prevent water from naturally infiltrating the ground. This leads to higher surface runoff during heavy rainfall, increasing the risk of flooding. Additionally, urban drainage systems can sometimes be overwhelmed during extreme weather events, exacerbating flood hazards. The type of soil in an area is a major determinant of its flood sensitivity. Soils with high clay content, for instance, have lower permeability and thus absorb less water, leading to increased runoff and higher flood risk. Conversely, sandy soils with higher permeability can reduce flood risk by absorbing more water.

Vegetation plays a crucial role in flood mitigation. Plants and trees absorb water, reducing surface runoff. Root systems help in maintaining soil structure, allowing for better water infiltration. In areas with sparse vegetation cover, there is an increased risk of flooding as there is less natural absorption and more surface runoff.

The proximity and characteristics of water bodies like rivers, lakes, and oceans also influence flood sensitivity. Areas close to water bodies are naturally more prone to flooding, especially if the water bodies are prone to overflowing during heavy rainfall or due to upstream activities. The nature of these water bodies, including their depth, flow rate, and capacity to contain water, also affects the flood risk. Paired comparison matrix of Land cover/land use classes is shown in Table 6.

Table 6. Paired comparison matrix of Land cover/land use parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Land cover/land use	0.04	Water	0.47	0.036
		Urban	0.36	
		Vegetation	0.19	
		Soil	0.11	

This study investigates the significance of proximity to streams in identifying areas susceptible to flooding. Areas in closest proximity to rivers demonstrably experience the most severe flood impacts. A paired comparison matrix detailing land cover/land use classifications is presented in Table 7.

Table 7. Paired comparison matrix of Land cover/land use parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Distance to streams	0.405	500-1000	0.67	0.043
		1000-2000	0.35	
		>2000	0.16	

The extracted aspect from the DEM helps us to explain why that area is more susceptible to flooding. The importance of aspect, or slope direction, in defining areas sensitive to flooding is quite significant but can vary based on geographic location, climate, and other environmental factors. Aspect determines how much sunlight an area receives, influences local microclimate, and affects soil moisture levels - all of which can impact flood risk. North-Facing Slopes: Tend to receive less direct sunlight, leading to cooler temperatures and potentially more moisture retention in the soil. This can sometimes lead to a higher risk of flooding, especially in areas with significant snowmelt. South-Facing Slopes: Typically receive more direct sunlight, which can result in drier conditions and potentially reduced flood risk. However, rapid snowmelt on these slopes can also increase flood risk during certain times of the year. East and West-Facing Slopes: Have varying exposure to sunlight depending on the time of day. East-Facing slopes are cooler and wetter in the afternoon while West-Facing slopes are cooler and wetter in the morning.

Table 8. Paired comparison matrix of Aspect parameter classes

Criteria	Weight	Sub-Criteria	Weight	CR
Aspect	0.058	N	0.442	0.078
		NE	0.321	
		SW	0.125	
		S	0.022	
		E	0.022	

3. Results and Discussion

This study employed the weighted sum overlay method to classify the study area into five hazard categories (very low to very high), as illustrated in Figure 9. These findings support the efficacy of utilizing remote sensing data in conjunction with relevant map factors for rapid and cost-effective hazard assessment.

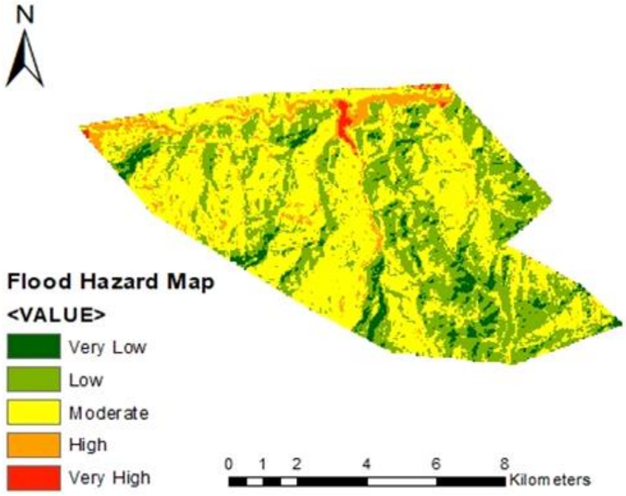

Figure 9. Flood Hazard Map of the study area

The study particularly integrates six thematic maps through GIS and AHP method to develop a comprehensive flood hazard map in the Vicinity of King Talal Dam in Jordan. These maps encompass slope, elevation, distance to streams, drainage density, land cover/land use, and aspect, each contributing distinctively to the flood risk assessment. The assignment of weights to each factor, grounded in extensive literature reviews and experts' opinions, refines the precision of the flood hazard evaluation.

The slope of the land influences the speed and direction of water flow. In areas with gentle slopes, water accumulates more easily, increasing the risk of flooding. Conversely, steeper slopes may facilitate quicker runoff, potentially reducing the duration of flood events but possibly increasing the risk of flash floods due to rapid water movement. In the vicinity of King Talal Dam, areas with gentle slopes may be at higher risk of sustained flooding, especially if these areas are also close to the dam's release mechanisms or natural water courses.

Elevation is a critical factor in determining flood risk. Low-lying areas are naturally more susceptible to flooding, as water flows from higher to lower points. In the context of King Talal Dam, the areas downstream or at lower elevations relative to the dam are at greater risk, especially during periods of heavy rainfall or when water is released from the dam. This can lead to the inundation of agricultural lands, settlements, and infrastructure located in these lower elevation zones.

Proximity to streams and rivers significantly influences flood risk. Areas located near streams, particularly those within the floodplain, are more likely to experience flooding. The flood risk increases with closer proximity to these water bodies, as they can overflow their banks during heavy rainfall events. For communities and infrastructure near King Talal Dam, especially those along the Zarqa River, understanding the distance to streams is crucial for assessing their vulnerability to flood events.

Drainage density reflects the extent of the river and stream network within a given area. High drainage density indicates a greater potential for surface runoff to concentrate and flow into these channels, increasing the risk of flooding. In the study area, regions with high drainage density around King Talal Dam might experience more frequent or severe flooding, as the existing channels are more likely to become overwhelmed during heavy precipitation events.

Land cover and land use play significant roles in flood dynamics. Urban areas, with their impervious surfaces, limit water infiltration, leading to higher runoff and increased flood risk. Conversely, vegetation can reduce runoff by absorbing water. In the area surrounding King Talal Dam, urban expansion and changes in land use can exacerbate flood risks, highlighting the need for sustainable land management practices that consider flood mitigation.

The aspect, or the direction a slope faces, can affect local microclimates and, consequently, flood risk. Slopes facing away from prevailing winds might retain more moisture, while those facing the winds could be drier. In the case of King Talal Dam and its surroundings, aspects could influence how certain areas respond to precipitation events, with some slopes potentially more prone to generating runoff that contributes to flood risks. By analyzing these six thematic maps in conjunction, researchers and policymakers can gain a comprehensive understanding of flood risks in the study area. This knowledge is crucial for designing effective flood mitigation strategies, such as targeted afforestation projects on vulnerable slopes, the construction of levees or flood barriers near key streams, and the careful planning of land use in flood-prone areas.

To compare the findings of the study on flood risk assessment in the vicinity of King Talal Dam in Jordan with existing studies or historical flood events, it's crucial to understand both the specifics of this study and the broader context of flood dynamics in the region.

Consistent with historical flood events and other studies in the region, this research confirms that areas at lower elevations and closer to streams or rivers are more prone to flooding. This is in line with the flood events that have historically affected Jordan, particularly in the Jordan Valley and areas adjacent to major watercourses [58]. Similar to findings in other regions of Jordan and comparable areas worldwide, changes in land cover and land use, especially urbanization, have been shown to increase flood risk due to decreased soil permeability and increased runoff. This matches historical trends in Jordan, where rapid urban expansion has led to more frequent and severe flooding in urban areas [59].

Like other studies conducted in semi-arid regions, this study underscores the role of vegetation and soil type in mitigating or exacerbating flood risk. Areas with sparse vegetation or impermeable soil types have been identified as more vulnerable, which aligns with observations from past floods in Jordan, where deforestation and land degradation have heightened flood impacts [60].

The study underscores the importance of continuously monitoring and updating flood hazard maps to maintain their accuracy and relevance amidst challenges such as limited data availability, climate change, and evolving landscapes due to urbanization. To overcome these challenges, it advocates for the integration of advanced remote sensing and GIS technologies, the application of the Analytic Hierarchy Process (AHP) for the dynamic weight assignment of flood risk factors, and the incorporation of community engagement and local knowledge. Furthermore, it recommends an adaptive management approach and collaboration with research institutions and governmental agencies to ensure flood hazard maps reflect the latest environmental changes and technological advancements. This comprehensive strategy aims to enhance flood risk management efforts by keeping flood hazard maps up-to-date, ensuring they are a valuable tool for planning and preparedness in the face of climatic and environmental shifts.

4. Conclusions and Recommendations

The study conclusively demonstrates the effectiveness of integrating GIS and AHP methodologies for flood risk assessment in the vicinity of King Talal Dam in Jordan. It successfully maps flood hazards by analyzing factors like slope, elevation, proximity to streams, drainage density, land cover, and aspect. The research underscores the heightened flood risks near main channels, particularly in lower elevations and areas with certain land cover types. Drainage density is highlighted as a crucial indicator of flood hazards due to its correlation with surface runoff and permeability. The methodology used in this study, integrating remote sensing and GIS technologies with the Analytic Hierarchy Process (AHP) for flood hazard mapping and risk assessment, is highly scalable and transferable to other geographic regions facing similar flood risks. Its reliance on widely available satellite imagery and GIS data, combined with the flexible, expert-driven weighting system of AHP, allows for adaptation to various landscapes and hydrological conditions. This makes it a robust framework that can be tailored to local specifics, such as topography, climate, and land use patterns, offering a valuable approach for regions worldwide seeking to enhance their flood risk management practices through accurate and up-to-date hazard mapping.

Key recommendations include the need for strategic flood management practices, especially in urban areas with high flood vulnerability. Implementing strategic flood management practices around King Talal Dam, such as advanced forecasting systems, green infrastructure, flood barriers, river channel management, floodplain zoning, community engagement, and integrated water resources management, can significantly enhance the resilience of urban and rural communities to flood risks. The study advocates for the use of remote sensing data and GIS in developing cost-effective, efficient flood hazard assessments. It also suggests the necessity for continuous monitoring and updating of flood hazard maps to incorporate changes in land use, climate, and hydrological conditions. Further research is recommended to refine the methodology by incorporating advanced climate modeling, sophisticated hydrological simulations, enhanced remote sensing, machine learning for data integration, local community input, and cross-disciplinary collaboration, which can significantly improve the maps' accuracy and utility in flood risk management and include more dynamic factors such as climate change impacts and urban development patterns. Collaboration with local authorities for the implementation of flood risk mitigation strategies is also advised, as local authorities are pivotal in implementing flood risk mitigation strategies, with their roles encompassing the collection and sharing of critical data, the development and enforcement of relevant policies, engaging and educating communities on flood risks, crafting and executing emergency response plans, and overseeing the construction and maintenance of flood mitigation infrastructure. They are also responsible for the continuous monitoring and adjustment of these strategies to ensure effectiveness while fostering collaboration with various stakeholders to ensure a unified approach. By leveraging the findings of flood risk assessments, local authorities can effectively safeguard communities, reduce the impacts of floods, and promote resilient urban planning and development practices.

5. Declarations

5.1. Author Contributions

Conceptualization, A.A. and N.N.S.; methodology, A.A. and N.N.S.; software, N.N.S.; validation, N.I.S., D.I., N.L., and Kh.A.; formal analysis, A.A. and N.N.S.; investigation, A.A. and N.N.I.; resources, N.N.S.; data curation, A.A. and N.N.S.; writing—original draft preparation, A.A. and N.N.S.; writing—review and editing, A.A., N.N.S., N.I..S., D.I., N.L., and Kh.A.; visualization, A.A. and N.N.S.; supervision, A.A. and N.N.S.; project administration, A.A. and N.N.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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