GLL

Geomatics, Landmanagement and Landscape No. 1 • 2025, 199–216

ISSN 2300-1496 https://doi.org/10.15576/GLL/200350

Research paper

Received: 5.12.2024
Accepted: 20.01.2025
Published: 31.03.2025

Flood susceptibility assessment using GIS-AHP and morphometric analysis in the El Malabiod Watershed, Northeastern Algeria

Rayene Sirine Ramdani[1, ✉] 0009-0002-4673-1135
Chemseddine Fehdi[1] 0000-0002-6319-3837
Nour El Houda Gueraidia[1] 0000-0003-4119-828X
Saida Gueraidia[2] 0000-0001-6041-7201
Sami Hafnaoui[2] 0009-0001-9807-0335

[1] Water and Environment Laboratory, Echahid Cheikh Larbi Tebessi University, Tébessa, Algeria
[2] Laboratory of Sedimentary Sets and Mineral and Water Resources of North Eastern Algeria, Echahid Cheikh Larbi Tebessi University, Tébessa, Algeria
✉ Corresponding author: ramdani.rayene-sirine@univ-tebessa.dz

Summary

This study aims to assess flood susceptibility in the El Malabiod watershed in Algeria, using a combined approach of morphometric analysis, land use/land cover mapping, soil texture mapping, and the Analytic Hierarchy Process (AHP) method. Morphometric analysis quantified the geomorphological characteristics of the basin, such as slope, drainage density, and relief, which influence the hydrological behavior of the basin. Concurrently, land use/land cover and soil texture maps were integrated to provide a comprehensive view of surface factors affecting flood susceptibility. These criteria were synthesized into a flood susceptibility map, identifying areas of high, moderate, and minimal risk, thereby facilitating flood risk planning and management. The results show a significant correlation between high susceptibility zones and historically recorded flood events, confirming the validity of the adopted methodology. This work provides a valuable tool for local decision-makers and water resource managers, assisting in the implementation of flood prevention and management measures, and optimizing land use planning in the El Malabiod basin.

Keywords

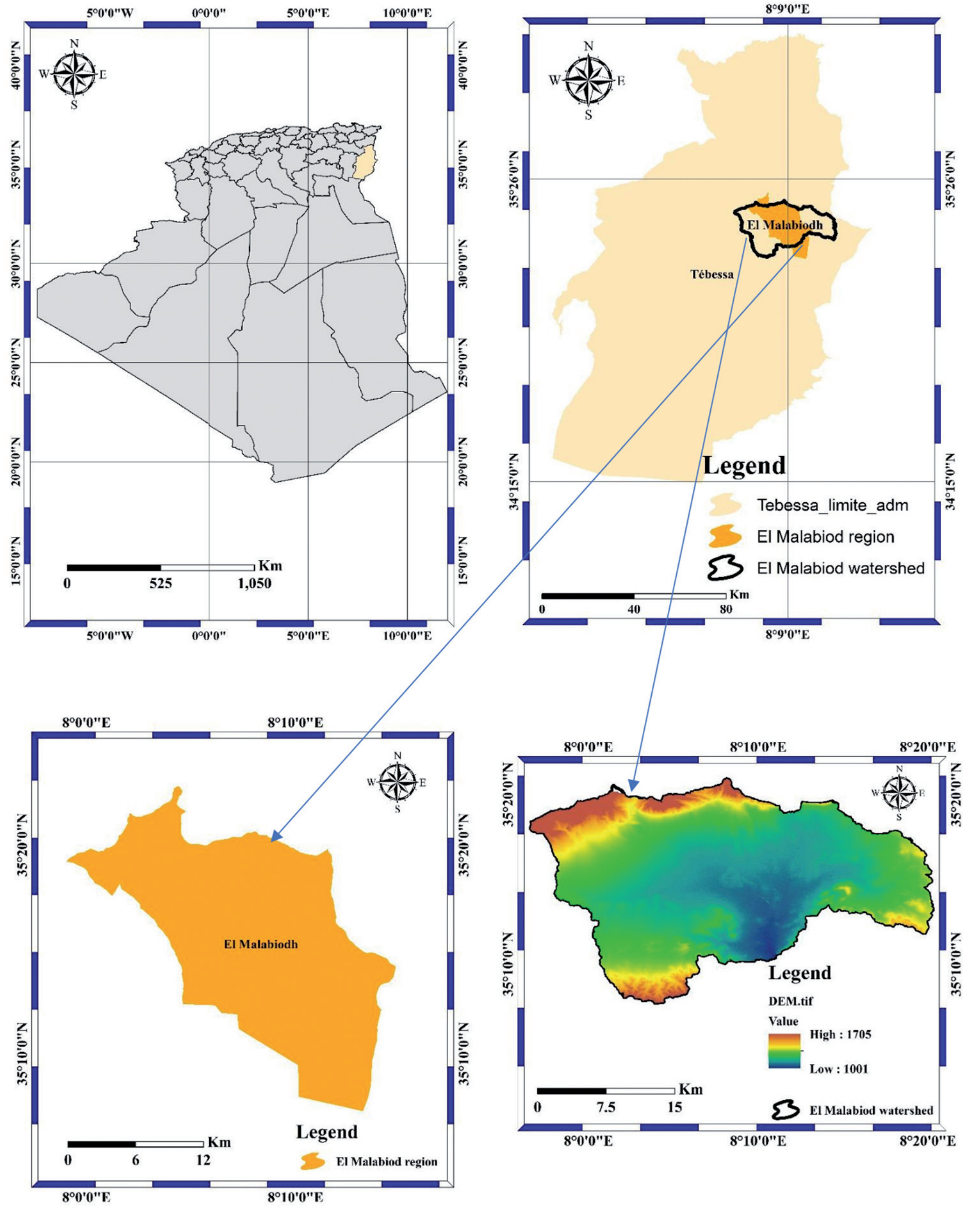
Analytic Hierarchy Process (AHP) • El Malabiod watershed • geographic information system • flood susceptibility • morphometric analysis

1. Introduction

Flooding is an inherent component of the hydrological cycle and a commonly occurring natural hazard on a global scale, resulting in significant negative impacts on human populations, infrastructure, ecological systems, and financial stability [Bobbili et al. 2023]. Floods are primarily caused by heavy rainfall in most river basins [Nikita et al. 2024]. However, flooding has the potential to cause loss of life, displacement, and ecological damage, all of which can threaten economic development. Flooding is one of the most prevalent natural disasters, often leading to catastrophic outcomes and affecting approximately 170 million individuals globally each year [Kowalzig 2008, Mezgebe et al. 2018]. Flood hazard analysis involves studying the natural physical event of a certain intensity, characterized by a specific probability of occurrence in space and time, which has the potential to cause damage to the built environment and human lives [Hamid et al. 2019]. Furthermore, it is anticipated that by the year 2050, flood occurrence rates and intensities will increase because of climate change projections, changes in land use patterns, and population growth. Flash floods, despite their negative impacts, can also have positive aspects and contribute to sustainable development in several ways in many regions. For instance, flash floods can recharge groundwater aquifers, thereby increasing water availability in areas with limited water resources [Al-Qudah 2011]. Hydrological studies play a critical role in both scientific research and practical applications. For example, they are operationally used to predict floods, assess water resources, and manage various aspects of the environment. Scientifically, these studies provide in-depth insights into watershed behavior through careful analysis of relevant parameters. Flood hazard mapping produces clear and easily interpretable charts and maps, enabling planners to identify high-risk areas and prioritize mitigation efforts. Flood risk, defined as a measure of vulnerability to damage and loss from flooding, is typically estimated by considering physio-climatic, hydrodynamic, economic, social, and ecological factors [Shuayb 2023]. Remote sensing and Geographic Information System (GIS) approaches have proven highly effective in estimating flood risks. In recent years, advanced GIS techniques have been developed to improve watershed management and the characterization of drainage networks [Gaurav et al. 2022]. Understanding the geo-hydrological behavior of a dynamic basin requires a detailed morphometric analysis of canal networks. Beyond these methodologies, this study integrates data on the watershed's geology, geomorphology, climate, and current and historical structures through hazard and vulnerability assessments, GIS overlay analyses, multi-criteria decision-making (MCDA) procedures, and the fuzzy method. MCDA combined with GIS is a set of techniques used to analyze and integrate geographic data with user preferences to enhance decision-making [Abdullahi 2013]. In this study, the MCDA method will be employed, as it is widely used to spatially represent flood vulnerability assessments due to its flexibility in evaluating diverse and overlapping criteria [Abdullahi 2013].

2. Study area

The study area encompasses the El Malabiod watershed, as represented on the topographic maps (Tébessa sheet 206 and El Malabiod sheet 235) at a scale of 1:50,000.



Source: Authors' own study

Fig. 1. Location map of the study area

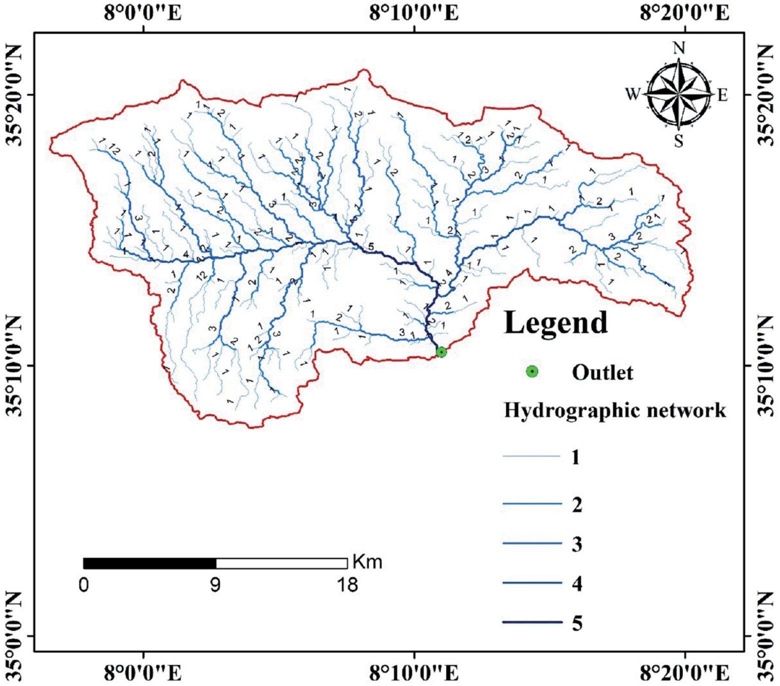
This region, located in the northeast of Algeria (Fig. 1), covers a total area of 512 km² with a perimeter of 128 km. The El Malabiod basin is situated in a semi-arid zone, bordered by limestone ridges to the north and south, a mountain range to the east that includes the Essif mountain on the Tunisian side, and a Turonian hill with light alluvial deposits to the west. To the north, the watershed boundary, delineated by the Doukane, Anoual, and Bouroumane mountains, also separates the major drainage basins of Mèllegue (northern slope) from Melguigh, to which the study area belongs [Rouabhia 2006]. The topographic and lithological characteristics of the rock outcrops, combined with the geometry of the sub-basin, play a crucial role in determining the hydrological behavior of the region, influencing both water drainage and retention. Land use in the El Malabiod watershed is distributed among agricultural areas, livestock grazing zones, forests, human settlements, and water resources, reflecting the diverse functions and activities within the region.

Intensive agriculture in the El Malabiod basin can lead to soil degradation, water pollution, and biodiversity loss, making the transition to sustainable farming practices essential to preserve both the environment and the health of local populations. A geomorphological study of the El Malabiod region reveals various formations and features that influence the distribution of groundwater resources. The watershed is primarily composed of Cretaceous formations such as marls and marl-limestones, which are frequently affected by tectonic phenomena, including faults and folds. Karstified limestones play a key role from a hydrogeological perspective [Abdelkader 2006]. The Miocene basin is characterized by deposits such as red clays, sands, and sandstones, which form a significant aquifer due to their high permeability. The tectonically driven hills can also contribute to the replenishment of the Miocene aquifer. The wadis, shaped by erosion, often expose Upper Miocene rocks. Although Quaternary alluvium is present, it does not have a significant hydrogeological role in the region. The main sources are primarily located near the interface between the Cretaceous rocks and the Miocene deposits.

3. Methodology

3.1. Analysis of hydrographic network

The delineation of the drainage network can be achieved using an automated method known as hydrological evaluation. This method proves valuable in various planning efforts, particularly those focused on flood risk reduction, ensuring water supplies for agricultural purposes, or recharging underground aquifers. The research area was extracted from the processed DEM. The direction of water flow from each cell to its adjacent cells was determined, considering water accumulation, which represents the number of cells, or the amount of water drained by each cell. We adjusted the resolution of the streams based on a specific threshold. A lower threshold value increases accuracy but also enlarges the resulting file size. The threshold remains flexible and can be adjusted. Subsequently, we converted the raster file of the watercourses into vector format, transforming the data into a polyline layer that defines the watercourses in the study area. The hierarchy of streams was defined in six levels, with level 5 being the highest (Fig. 2). These levels were converted from raster to vector format for further processing, and the resulting vector layer was consolidated using the grid code field. A unique symbology was applied to this layer, highlighting higher-level watercourses with thicker segments, making it easier to distinguish between distinct levels of stream hierarchy. A point dataset was created within the same metric coordinate system, with a point marked at the confluence of a 6th-order stream. By referencing this location and the flow direction layer, the watershed associated with this point was identified. To conduct an in-depth morphometric analysis of this watershed, it was necessary to convert it from raster to vector format, resulting in the creation of a polygon layer. Only stream segments entirely within this watershed were isolated and symbolized for visibility (Fig. 2). The delineation of all hydrographic basins in the study area has been completed. The raster file of hydrographic basins was converted into a polygon layer to facilitate easier morphometric analysis. Drainage congestion is one of the main factors leading to floods. When drainage density is high, the flow rate increases significantly [Shuayb 2023], which increases the likelihood of flooding. We combined elevation and water density to create flood risk maps. As water density increases, flooding worsens. The flow density map of the study area was created using the 'Line Density' tool in ArcGIS 10.8. To calculate line density, the total length of all streams and rivers in the region was divided by the total area. This step was performed to assess water density in the study area.



Source: Authors' own study

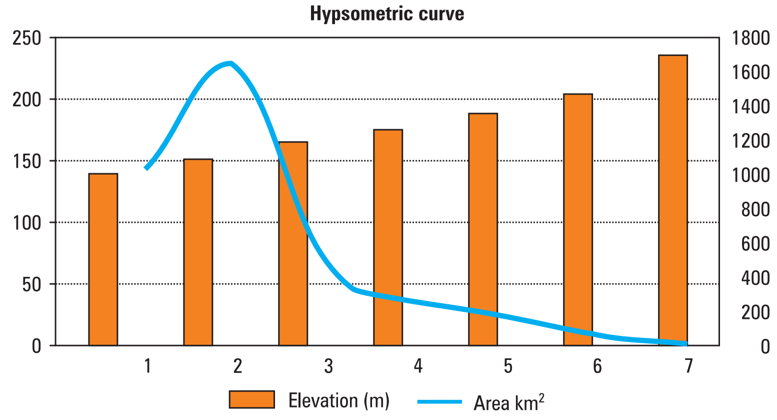
Fig. 2. Hydrographic network of study area

3.2. Morphometric analysis

Morphometric analysis is a study method that examines surface phenomena of the Earth mostly based on quantitative data. It involves measuring and assessing the characteristics of watersheds, such as their shape, size, relief, and drainage network. These measures provide a better understanding of the dynamics and function of river basins. The morphometric characteristics of hydrographic basins are linked to natural factors such as geological structure, climate, topography, and vegetation cover. Additionally, morphometric analysis plays a key role in water resource management, flood prevention, and environmental risk assessment. It is also employed to investigate the effects of climate change and human activities on hydrographic basins, providing valuable tools for the planning and sustainable management of territories. The morphometric analysis was conducted for the hydrographic basin and the rivers extracted within it. Morphometric analysis allowed for the determination of drainage density, surface, perimeter, width and length of equivalent rectangle, hypsometric curve, average slope, overall slope index, specific gradient, time of concentration and water flow velocity. Drainage density quantifies the extent of division and expansion of the river system within a certain. The calculation involves dividing the cumulative length of the watercourses by the surface area of the drainage basin. This statistic quantifies the attributes of water that flows across the land surface in the basin, which are affected by factors such as climate and terrain. A high drainage density signifies effective water movement, whereas a low density implies the existence of hindrances that hinder or obstruct the water flow. The benefit of defining the length and width of the equivalent rectangle is that it simplifies geometry. They provide a simplified representation of the original polygon, which can make it easier to analyze and visualize geographic data as well as calculate equivalent air pressure.

The hypsometric curves (Fig. 3), which show the points of equal height on a topographic map. They make it easier to study the land's shape and navigate by showing the hills and valleys. They also help with urban planning by assessing natural hazards. For managing natural resources, they are especially important because they show where sensitive areas are and help geological studies understand how the land's structure and history have changed over time. The average slope is commonly used to characterize the roughness of the terrain and is crucial for understanding the morphology of the landscape. The global slope index indicates the irregularity of the terrain at a regional or local scale, which can be useful in a variety of geoscience and environmental applications. The specific elevation gain is significant in hydrology because it estimates the amount of potential energy available for water flow and erosion processes. The concentration time is crucial in hydrology for estimating the response of a watershed to precipitation and for the design of drainage systems and stormwater management.

The velocity of water flow is determined by a number of factors, including the slope of the terrain, the roughness of the surface, the depth of the stream, the viscosity of the water, and the transverse section of the stream bed. It might vary significantly from one location to another and under different situations.



Source: Authors' own study

Fig. 3. Hypsometric curve of El Malabiod watershed

3.3. Generation of flood risk mapping using GIS

To lower the chance of flooding or to adapt to and lessen the damage caused by flooding, regional flood tracking is necessary. Using satellite images, flood maps can be made instantly. After the flood limit has been determined, it can be used to find out how high the water is during a flood. The Finnish Environment Institute [2015] states that a flood hazard map shows how storms might affect a place.

One of the most important components of early warning systems or ways to prevent and reduce future floods is flood hazard maps and analysis. This helps identify the most vulnerable areas based on their physical features that make them more likely to flood. Flood hazard mapping is an essential part of planning the use of flood-prone land and developing strategies to reduce the risk of flooding. Flood hazard mapping uses easy-to-read charts and maps to help planners identify high-risk areas and decide which safety measures to prioritize.

A flood hazard map is a valuable tool for assessing the amount of danger in a specific area. For centralized planning of development operations, the hazard map is essential and can also function as a decision support system (DSS). The goal is to generate a danger map that is comprehensible to users of all levels of expertise, including those who are not technically inclined.

3.3.1. Flood mapping using GIS

For identifying risk zones in accordance with specific geographic regions and managing flood hazards, GIS has become an appealing and efficient tool [Lawal 2011]. As a result, the system's substantial functionalities have facilitated the development of a cartographic representation of inundation hazards, with a particular focus on the areas susceptible to flooding. Geographic information is queried, graphically displayed, and stored in a database within a GIS. By overlaying or combining various geographical layers, it becomes possible to identify inundation risk zones, which can then be used to effectively manage flood-prone areas or implement mitigation measures.

The Analytic Hierarchy Process (AHP), introduced by Saaty, is a popular Multi-Criteria Decision-Making (MCDM) technique that has been frequently applied to tackle water resource decision problems. The goal of AHP is to provide decision makers with the option that best meets their objectives among several alternatives and criteria. This approach evaluates two criteria at a time using a pairwise comparison matrix, which assigns values indicating the relative importance of one criterion over another. It assesses a level of consistent judgment based on theoretical principles. The scale of relative importance ranges from one to nine, with one indicating equal importance and nine indicating extreme importance.

3.3.2 Analytic Hierarchy Process

This approach comprises the comparison of criteria, which also enables the evaluation of the relative relevance of two criteria simultaneously. The approach, known as Analytical Hierarchy Process (AHP), was introduced by Saaty in 1980. AHP is the best option because it can consider the relative importance of different elements. It provides a simple decision-making process that helps the decision-maker generate valid inferences [Rohit and Anju 2023]. It allows for the conversion of subjective estimates of relative significance into a linear set of weights. The criteria pair-wise comparison matrix accepts pair-wise comparisons as input and generates relative weights as output. Additionally, the Analytic Hierarchy Process (AHP) offers a mathematical approach to convert this matrix into a vector that represents the relative importance of the criterion. The Analytic Hierarchy Process (AHP) provides a methodical approach to decision-making by quantifying measurements, evaluating different possibilities, and establishing connections between these aspects and the ultimate purpose.

This method provides a logical foundation for making critical decisions [Hummel et al. 2014]. The Analytic Hierarchy Process (AHP) is a widely used decision-making model that incorporates multiple criteria. It is commonly employed to prioritize factors based on their relative importance [Kordi and Brandt 2012, Beskese et al. 2014]. AHP is particularly suitable for tackling decision-making problems that require the simultaneous evaluation of both quantifiable and non-quantifiable factors. Its widespread adoption can be attributed to its simplicity, user-friendly interface, and versatility.

3.3.3. Flood condition factor database

To assess the occurrence of flooding in the study area, it is crucial to identify the primary variables, and the precise locations affected. To this end, relevant data has been collected from multiple sources (Table 1). Flooding in the region is influenced by numerous factors, such as land use and soil texture, which can either exacerbate or mitigate water runoff. However, the most critical factors impacting flooding in this area are drainage density, slope, and elevation. It is worth noting that, due to the small size of the region, no rainfall distribution map is available. The area receives an average annual rainfall of approximately 200 mm.

Table 1. Sources of data

Primary data	Format	Year	Source	Extracted data
DEM	Raster	2020	Earth explorer https://earthexplorer.usgs.gov/	Hydrographic network, slope, elevation, drainage density, aspect, hillshade
Land use data	Raster	2020	USGS sentinel-2 10 m https://earthexplorer.usgs.gov/	Landuse/Landcover
Soil texture data	Raster	2015	ISRIC World Soil Information https://data.isric.org/geonetwork/srv/fre/catalog.search#/metadata/2a7d2fb8-e0db-4a4b-9661-4809865aaccf	Soil texture

Flood vulnerability characteristics have been categorized into five levels: very low susceptibility, low susceptibility, moderate susceptibility, high susceptibility, and very high susceptibility, with the latter being the most severe. This classification was established based on the importance of the contributing criteria. Table 2 outlines the a range of factors used in flood susceptibility mapping, along with their respective rankings.

Table 2. Classification and evaluation of causative factors

Flood causative criteria	Unit	Class	Susceptibility class ranges and rating	Susceptibility class ratings
Elevation	[m]	1001–1105 1105–1180 1180–1282 1282–1423 1423–1705	Very high High Moderate Low Very low	5 4 3 2 1
Slope	[%]	0–4.69 4.69–10.17 10.17–18.79 18.79–30.93 30.93–99.84	Very high High Moderate Low Very low	5 4 3 2 1
Drainage density	[km/km²]	0–3 4–5 6–8 9–10	Low Moderate High Very high	1 2 3 4

Table 2. cont.

Flood causative criteria	Unit	Class	Susceptibility class ranges and rating	Susceptibility class ratings
Soil type	–	Clay loam Sandy clay loam Loam Sandy loam	Very high High Moderate Low	5 4 3 2
Landuse/ Landcover	–	Bare ground Built area Crops Range land Trees Water	High Moderate Low Moderate Very low	2 3 4 4 1

3.3.4. Creating a flood risk map using ArcGIS

El Malabiod's flood susceptibility map was generated using the AHP model, which is based on five conditioning factors: drainage density, slope, elevation, land use and cover, and soil texture. According to the model, drainage density, slope, and elevation have the greatest influence on flood frequency in the region.

1. Drainage density

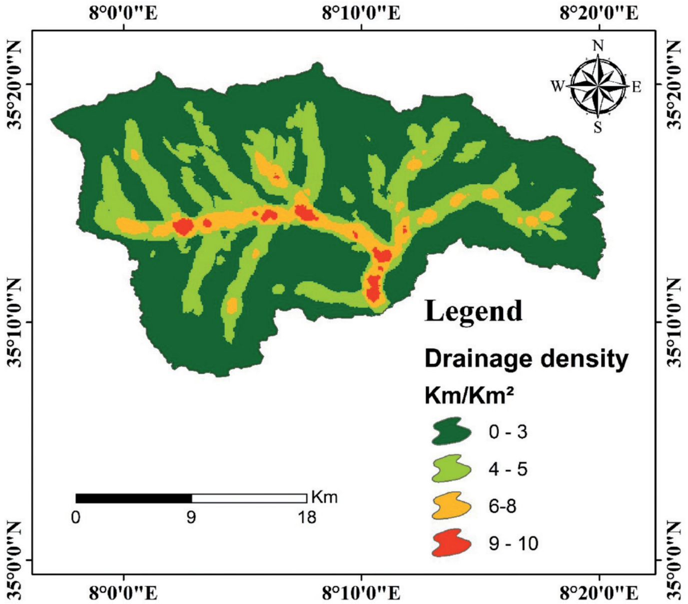
Drainage density is a dominant factor in the occurrence of inundation. When there is a high drainage density, the discharge rate becomes critical. The consequence is an increased probability of flooding. For flood hazard mapping, Dash, and Sar [Dash et al. 2020] utilized drainage capacity to incorporate the combined effect of elevation and drainage density. The 'Line density' tool in ArcGIS 10.8. was utilized to generate a drainage density map of the study area (Fig. 4) from stream network data, as flooding peaks increase with drainage density. The determination of line density involves the division of the sum of the lengths of all streams and rivers within a given catchment by the catchment's total area.

2. Slope

The slope is also thought to be a key factor that can cause flooding. It changes how easily drainage and flow can happen. The slope also changes the amount and speed of surface flow and the amount of groundwater that seeps into the ground. Using the surface analysis tool in ArcGIS 10.8, the Digital Elevation Model (DEM) was turned into a slope map. In the study area, the slope ranges from 0% to 49% (Fig. 5). These places, which have minimum slopes of less than 2% and are thought to be the most at risk, are mostly low-lying areas and riverbeds. Other than that, places with slopes higher than 16% (steeper slopes), which are usually hilly, are less likely to flood.

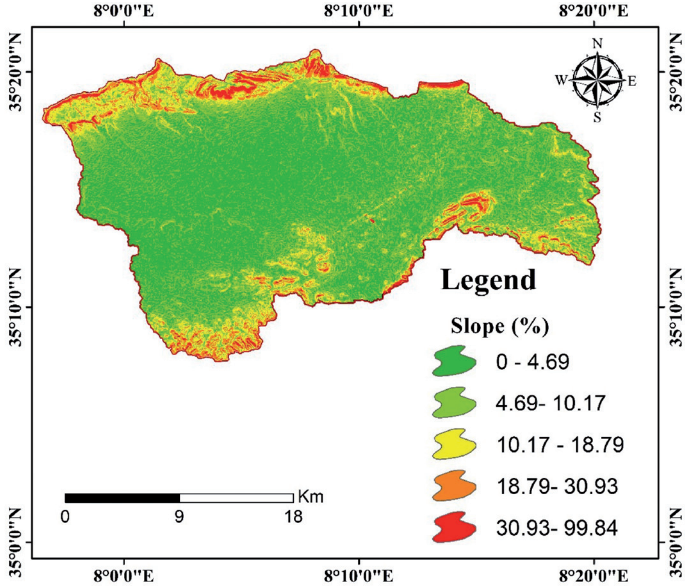
3. Elevation

As water moves from higher to lower elevations, lowland places are more likely to flood. Changing the type of DEM makes it possible to make the elevation map. The El Malabiod



Source: Authors' own study

Fig. 4. Drainage density map of El Malabiod Watershed



Source: Authors' own study

Fig. 5. Slope map of El Malabiod basin

watershed has a range of elevations, from 1002 meters to 1705 meters. The hilly side of the basin (Doukane and Boudjllel mountains) has the highest elevations, while the El Malabiod basin area has the lowest. Because of the high elevation and steep hill upstream, there are a lot of runoffs after it rains, which makes the water flow quickly downstream. A digital elevation model with a precision of 30 meters was taken from the USGS Earth Explorer and used to make the elevation map of the study area (Fig. 6).

4. Soil texture

Another crucial factor influencing hydrology is the soil structure. The porosity and permeability of soil directly impact the infiltration rate [Ullah and Zhang 2020]. Lithological units with higher permeability accelerate the infiltration phase, while impermeable layers increase surface runoff, potentially causing flooding. Porous rocks, such as loose sand, conglomerates, and others, facilitate the percolation of rainwater into the ground, thereby reducing the risk of flooding. Conversely, impermeable deposits, including marl, clay, gypsum, and similar materials, increase the risk of flooding by enhancing surface overflow. The soil map used in this study was obtained from ISRIC, representing the World Soil database at depths of 100–200 cm. The contents of sand, silt, and clay were projected using data from the Africa Soil Profiles Database (Fig. 7).

5. Land use/Land cover

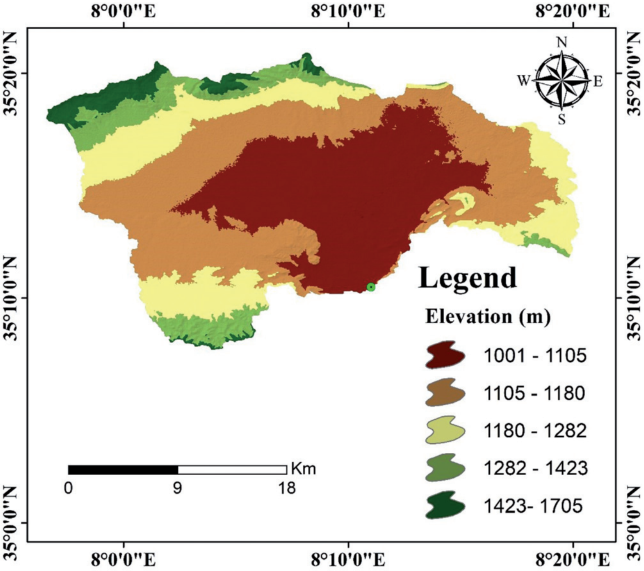
Water moves through various processes, including flow, diffusion, evaporation, and evapotranspiration, all of which are influenced by land use. Consequently, land use directly impacts flood risk [Alexakis et al. 2014]. Land use categories typically include soil deposits, residential areas, waterways, vegetation cover, bare land, and infrastructure such as roads [Al-Shabeeb 2016]. Changes in land use patterns and trends over time can significantly influence flood frequency [Dahri and Abida 2020]. Land use data for the study area were obtained from USGS websites at a 10-meter resolution. The data encompassed a wide range of land use types, including rangeland, bare ground, trees, water bodies, agricultural areas, and built-up regions (Fig. 8).

3.3.5. Weighting flood susceptibility factors

The following subsections present the study's results, including those derived from the Analytical Hierarchy Process (AHP) approach. The weights assigned to each city were utilized to generate the flood vulnerability map (Table 3).

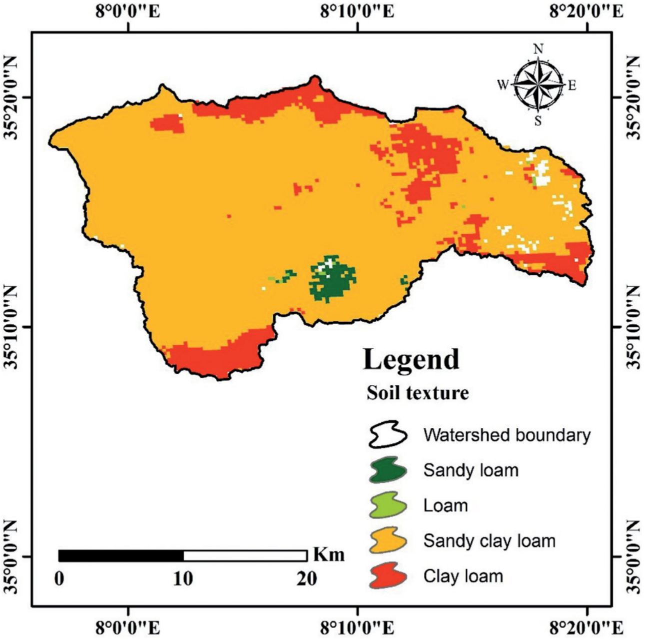
Table 3. Weighted results for each factor

Criteria	Weight [%]
Elevation	20
Soil texture	9
Slope	29
Lu/Lc	8
Drainage density	34



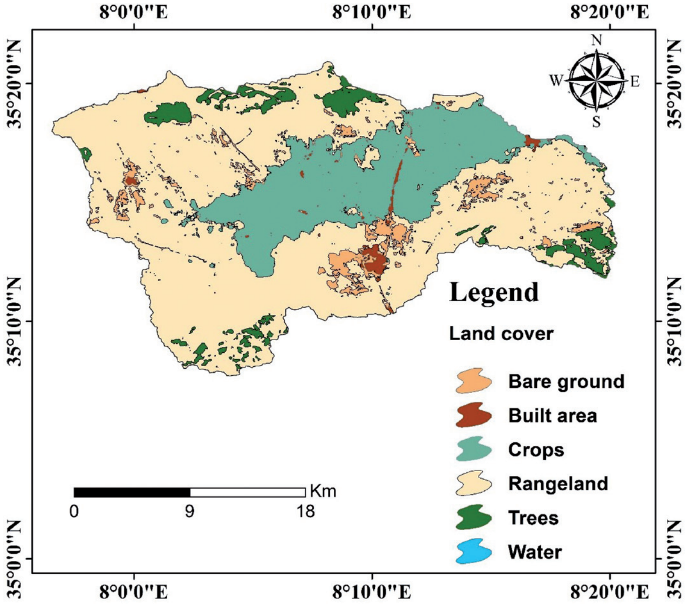
Source: Authors' own study

Fig. 6. Elevation map of El Malabiod Watershed



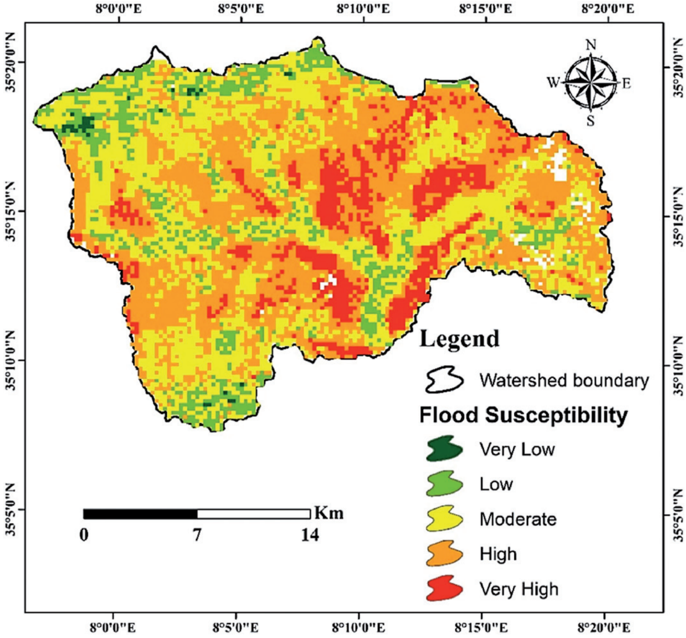
Source: Authors' own study

Fig. 7. Soil texture map of El Malabiod Watershed



Source: Authors' own study

Fig. 8. Landuse/Landcover map of El Malabiod Watershed



Source: Authors' own study

Fig. 9. Flood Risk Map Made with the AHP Analysis of El Malabiod Watershed

Figure 9 illustrates the vulnerability map produced from the AHP analysis. The map is categorized into five distinct levels: very low, low, medium, high, and very high vulnerability.

4. Results and discussion

For conducting hydrological analysis, the digital elevation model (DEM) was processed using ArcGIS 10.8, specifically within the WGS 1984 UTM Zone 32N coordinate system to ensure accurate spatial representation.

The DEM for the study area was obtained by extracting data from a shapefile. This shapefile was meticulously created based on a high-resolution satellite image of the study area.

The extraction process involved delineating the study area's boundaries and ensuring that the elevation data accurately reflected the terrain's topography, which is crucial for hydrological modeling and analysis. This preparation allows for precise calculations of water flow, watershed boundaries, and other hydrological characteristics.

The analysis indicates that most watercourses in the area flow from north to south. The calculation of flow accumulation involved multiplying the number of cells that contribute flow to each specific cell. Following this, the resolution of these flow values was enhanced by applying a threshold greater than 1000. This procedure led to the generation of the flow vector.

The classifications of stream orders have been identified and converted into vector format. The results were then grouped according to the grid code, and a symbology was used to display the data. It has been observed that there are six classes of water courses, with class 5 being the highest (Fig. 2).

Based on the main hydrographic basins and order of flow layers, which were derived from the hydrological analysis, several morphometric characteristics were evaluated.

The surface and perimeter of the basin calculated using ArcGIS software are respectively 512 km^2 and 128 km. The equivalent rectangle has a width of 6.76 km and a length equal to 75.66 km.

To determine the hypsometric curve with ArcGIS, we start by preparing and classifying the data of rivers and digital terrain models (DTM). Next, we extract elevation data and calculate cumulative surfaces at different altitudes using tools like 'Zonal Statistics' and 'Surface Volume.' We export the results and plot the curve by placing the elevations on the x-axis and the cumulative surfaces on the y-axis (Fig. 3).

With an average slope of 9.29%, the average height of the ground changes 9.2 meters for every 100 meters of horizontal distance traversed. To rephrase, there is an elevation or dip of 9.29 meters for every 100 meters of horizontal movement.

A global slope index of 7.51 indicates the average slope of the topography or versant basin studied. This means that for every 100 meters of horizontal distance traveled, 7,51 meters rise or fall.

A specific elevation difference of 169.93 meters indicates an extremely steep terrain with very steep slopes. This has significant consequences for hydrology, natural risk management, land planning, and agricultural and forestry practices. It is a measure commonly used in mountainous regions or in terrains with steep geological structures.

Using the attributes table of the water course bed to get the sum of the water course lengths in kilometers and the hydrographic basin surface in square kilometers, the drainage density was calculated. Only 2.416 km/km² of drainage density indicates that water flow is uniform.

A concentration time of 3.67 hours for a watershed of 512 km² is short. This indicates that water moves rapidly across the watershed in response to precipitation. A short concentration time indicates that the watershed responds quickly to precipitation. This means that the flow rates in rivers increase rapidly following episodes of strong rainfall. Les bassins versants ayant des temps de concentration courts sont plus susceptibles de subir des inondations soudaines lors de fortes précipitations. Water resource managers must be vigilant from these risks and implement appropriate strategies to minimize potential damage.

A flow velocity of 2.80 m/s indicates the speed at which water moves within the stream. Such a flow velocity can lead to increased erosion of the stream banks and beds, which can have implications for the stability of the banks and water quality.

The AHP analyses reveal that the basin area is susceptible to both very high and moderate flooding. This area is characterized by low elevation, in contrast to the surrounding mountainous terrain, which acts as a barrier against flooding. The impermeable nature of the mountains hinders infiltration and leads to increased runoff.

The AHP analysis technique revealed that drainage density has the highest contribution to the occurrence of floods, followed by slope. Elevation has a moderate impact on flood occurrence, while soil texture and land use are the least influential factors.

5. Conclusion

The hydrological and morphometric analysis of the Malabiod basin, conducted using ArcGIS 10.8, provided critical insights into the region's topography and hydrodynamics. The study identified six stream orders, with significant elevation changes and an average slope of 9.29%, underscoring the steep and inclined nature of the basin. A rapid concentration time of 3.67 hours highlights the basin's quick hydrological response to precipitation, making it particularly prone to flash floods. The integration of DEM data, land use, and soil texture maps revealed that low-lying areas are most vulnerable to flooding, while the surrounding impermeable mountains exacerbate runoff by limiting infiltration. Drainage density emerged as the most significant factor contributing to flood risks, followed by slope, with elevation having a moderate influence. These findings emphasize the necessity of implementing targeted water resource management and flood prevention strategies. Priority should be given to enhancing drainage infrastructure, promoting reforestation in vulnerable areas to reduce erosion, and improving infiltration. Furthermore, the use of early warning systems and raising awareness among local communities can help mitigate the impacts of flash floods. In conclusion, this study provides a robust foundation for concrete actions aimed at strengthening water resilience and protecting the populations within the El Malabiod basin.

References

Abdelkader R. 2006. Vulnérabilité et risques de pollution des eaux souterraines de la nappe des sables miocènes de la plaine d'El Ma El Abiod Nord-Est Algérien. Thèse de doctorat es-sciences, Université Badji Mokhtar, Annaba.

Abdelkader R., Fethi B., Chemseddine F., Boumezbeur A., Boubaya D. 2010. Hydrogeochemistry of groundwaters in a semi-arid region. El Ma El Abiod aquifer, Eastern Algeria. Arabian Journal of Geosciences, 4, 973–982. https://doi.org/10.1007/s12517-010-0169-3

Abdelkader R., Fethi B., Nacer K., Larbi D. 2004. Vulnérabilité et risque de pollution des eaux souterraines de la nappe des sables miocènes de la plaine d'El Ma El Abiod (Algérie). Science et changements planétaires/Sécheresse, 15, 347–352.

Abdul-Lateef B., Abdul-Nasir M., Adekunle Isa H.-M. 2015. A fuzzy multi-criteria decision support system for evaluating subsea oil pipeline routing criteria in East Malaysia. Environmental Earth Sciences, 74, 4875–4884. https://doi.org/10.1007/s12665-015-4499-z

Abdullahi Elmi M. 2013. Managing Shared Basins in the Horn of Africa – Ethiopian Projects on the Juba and Shabelle Rivers and Downstream Effects in Somalia. Natural Resources and Conservation, 1, 35–49. https://doi.org/10.2495/RBM130121

Al-Qudah K. 2011. Floods as water resource and as a hazard in arid regions: A case study in southern Jordan. Jordan Journal of Civil Engineering, 5, 148–161.

Al-Shabeeb A.R. 2016. The Use of AHP within GIS in Selecting Potential Sites for Water Harvesting Sites in the Azraq Basin-Jordan. Journal of Geographic Information System, 8, 73–88. https://doi.org/10.4236/jgis.2016.81008

Ansari Z.R., Rao L.A. K., Yusuf A. 2012. GIS-based morphometric analysis of Yamuna drainage network in parts of Fatehabad area of Agra District, Uttar Pradesh. Journal of the Geological Society of India, 79, 505–514. https://doi.org/10.1007/s12594-012-0075-2

Bobbili Aravind Sai A., Ratnakar S., Pulakesh D. 2023. Near real-time flood inundation and hazard mapping of Baitarani River Basin using Google Earth Engine and SAR imagery. Environmental Monitoring and Assessment, 195, 1331. https://doi.org/10.1007/s10661-023-11876-5

Bourenane H., Bouhadad Y., Geuttouche M.S. 2019. Flood hazard mapping in urban areas using the hydrogeomorphological approach: Case study of the Boumerzoug and Rhumel alluvial plains (Constantine city, NE Algeria). Journal of African Earth Sciences, 160, 103602. https://doi.org/10.1016/j.jafrearsci.2019.103602

Bouaakkaz B., El Morjani Z.E.A., Bouchaou L. 2023. Social vulnerability assessment to flood hazard in Sous basin, Morocco. Journal of African Earth Sciences, 198, 104774. https://doi.org/10.1016/j.jafrearsci.2022.104774

Christopher O., Idowu A., Olugbenga A. 2010. Hydrological analysis of Onitsha Northeast drainage Basin using geoinformatic techniques. World Applied Sciences Journal, 11, 1297–1302.

Dash P., Sar J. 2020. Identification and validation of potential flood hazard area using GIS-based multi-criteria analysis and satellite data-derived water index. Journal Flood Risk Management, 13, e12620. https://doi.org/10.1111/jfr3.12620

Echogdali F.Z., Boutaleb S., Kpan R.B., Ouchchen M., IdBelqas M., Dadi B., Ikirri M. 2022. Flood hazard and susceptibility assessment in a semi-arid environment: A case study of

Seyad basin, south of Morocco. Journal of African Earth Sciences, 12, 104709. https://doi.org/10.1016/j.jafrearsci.2022.104709

Elkhrachy A., Zhang W. 2020. Methodology to map the flood hazards zones. Natural Hazards, 117, 2963–2987.

Gezahegn M.A., Suryabhagavan K.V. 2018. Developing Flood Hazard Forecasting and Early Warning System in Dire Dawa, Ethiopia. International Journal of Advanced Multidisciplinary Research, 5, 11–27. https://doi.org/10.22192/ijamr

Hummel N.A., Mészáros A., Ring D.R., Beuzelin J.M., Stout M.J. 2014. Evaluation of seed treatment insecticides for management of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), in commercial rice fields in Louisiana. Crop Protection, 65, 37–42. https://doi.org/10.1016/j.cropro.2014.06.025

Lahiri N., Arjun B.M., Nongkynrih J.M. 2024. Flood susceptibility mapping using Sentinel-1 and frequency ratio technique in Jinjiram River watershed, India. Environmental Monitoring and Assessment, 196, 103. https://doi.org/10.1007/s10661-023-12242-1

Lawal D.U., Matori A.N., Hashim A.M., Chandio I.A., Sabri S., Balogun A.L., Abba H.A. 2011. Geographic Information System and Remote Sensing Applications in Flood Hazard Management: A Review. Research Journal of Applied Sciences Engineering and Technology, 3, 933–947.

Mann R., Gupta A. 2023. Mapping flood vulnerability using an analytical hierarchy process (AHP) in the Metropolis of Mumbai. Environmental Monitoring and Assessment, 195, 1534. https://doi.org/10.1007/s10661-023-12141-5

Mohamed S.A. 2019. Application of satellite image processing and GIS-Spatial modeling for mapping urban areas prone to flash floods in Qena governorate, Egypt. Journal of African Earth Sciences, 158, 103507. https://doi.org/10.1016/j.jafrearsci.2019.05.015

Osman S.A., Das J. 2023. GIS-based flood risk assessment using multi-criteria decision analysis of Shebelle River Basin in southern Somalia. Discover Applied Sciences, 5, 1–17. https://doi.org/10.1007/s42452-023-05360-5

Taib H., Hadji R., Hamed Y. 2023. Erosion patterns, drainage dynamics, and their environmental implications: A case study of the Hammamet Basin using advanced geospatial and morphometric analysis. Journal of Umm Al-Qura University for Applied Sciences, 1, 1–16.

Taib H., Hadji R., Hamed Y., Bensalem M.S., Amamria S., Houda B. 2024. Evaluation of relative tectonic activity in a semiarid basin: Analysis of geomorphic indices and morphometric parameters in the Meskiana Watershed. Euro-Mediterranean Journal for Environmental Integration, 1, 1–16.

Tripathi G., Pandey A.C., Parida B.R., Kumar A. 2017. Flood inundation mapping and impact assessment using multi-temporal optical and SAR satellite data: A case study of 2017 flood in Darbhanga District, Bihar, India. Water Resources Management, 34, 1871–1892. https://doi.org/10.1007/s11269-020-02534-3

Varol M., Şen B. 2009. Assessment of surface water quality using multivariate statistical techniques: A case study of Behrimaz Stream, Turkey. Environmental Monitoring and Assessment, 159, 543–553. https://doi.org/10.1007/s10661-008-0650-6