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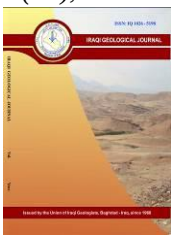

GIS-Based Spatial Distribution of Flood Hazards in the Chamchamal Basin, Sulaymaniyah, NE Iraq

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Abstract

Floods are natural disasters of a large scale that endanger human life. The reasons for the study are population increases and unplanned land use changes in the Chamchamal Basin. The current study's objective is to generate a flood hazard zone map for the Chamchamal Basin to support disaster risk reduction and land-use planning. To determine the flood hazard zones of the research region, an integrated strategy combining remote sensing, GIS, and the Analytical Hierarchy Process was applied. Eleven flood-influencing factors (Distance from Stream, Rainfall, Elevation, Topographic Wetness Index, Slope, Drainage Density, Flow Accumulation, Stream Power Index, Soil, land Use/Land Covers and Profile Curvatures were chosen specifically for this. The Chamchamal Basin was classified into five zones based on flood hazard areas. According to the findings, 32.2 km^2 (6.4%) of the basin has an extremely low flood risk. Low and moderate flood hazard zones cover approximately 85.8 km^2 (16.96%) and 159.5 km^2 (31.4%), respectively. Additionally, high and very high hazard zones cover 148.9 km^2 (29.5%) and 79.6 km^2 (15.74%), respectively. Planners may find great success in developing appropriate measures to lessen the hazard of flooding in the Chamchamal basin with the help of data obtained from this study.

Keywords: Chamchamal Basin; Flood hazard; TWI; Natural disasters; GIS

1. Introduction

Floods are natural disasters of a large scale that cause danger to human life (Bhattacharyya, 1997). There are several factors that cause flooding (Suppawimut, 2021). Heavy rainfall is one of the most important factors that lead to flooding (Kongmuang et al., 2020). The one of reasons for the flow of water during rainfall is the presence of seasonal valleys (Ali and Salih, 2022). The rainfall are accumulates in the discharge areas of basin. One of the most dangerous and critical threats facing humanity in the world is the phenomenon of climate change (Al-Gburi et al., 2022). The death percentage due to natural disasters, i.e. floods, is approximately 40% (Di Baldassarre et al., 2010). Floods cause total disruption to people's human and economic activities (Domakinis et al., 2020).

Changing climatic conditions and land use in urban areas increase sensitivity to flood hazards due to rapid population development or rapid urbanization (Jumadar et al., 2008). Floods occurred due to continuous rainfall, which leads to an increase at the surface water of the basin compared to its discharge. The increasing population of the Chamchamal basin leads to changes in land uses and land covers, and thus the surface water of the basin increases during long duration precipitation. The monitoring changes

in land uses and land covers are an important necessity for basins to reduce flood hazard (Ahmed et al., 2024). In most countries around the world, several methods are used, including remote sensing (RS) and the Geographic Information System (GIS), in addition to the Analytical Hierarchy Process (AHP) for the management and assessment of flood hazards.

The usefulness of remote sensing data is very important for monitoring flood hazards in detail because it enables real-time tracking of water flow and inundation areas (Zhao et al., 2014). The application of hydrological, along with RS and GIS, contributes to providing a solution to the problems of flood hazards for basins or watersheds (Nkonu et al., 2022). GIS are considered one of the ideal methods for identifying the natural conditions that affect the basin (Al-Gburi and Al-Tamimi, 2020). Hydrological researchers from all over the world are attracted to the phenomenon of flood hazards in order to better explore and manage floods (Khanday et al., 2022). The watershed map provides protection and scientific support in water management (Al-Gburi and Al-Tamimi, 2023). Mapping of hydrological basins using modern techniques and methods is essential in water resources management (Al-Gburi et al., 2022).

The lack of comprehensive flood risk studies in developing countries hinders effective disaster planning and mitigation (Kunze and Strobl, 2024). Therefore, more extensive studies are needed to address the flooding problem. Flood maps are one of the important tools for supporting government authorities by using reliable data to implement a strategy to protect against floods and mitigate their effects during the last ten years, significant changes have occurred at the Chamchamal basin due to the increase in human activities, such as building construction on the streams. For this reason, the chance of floods increases, thus causing human and economic losses. In many periods, especially in the winter and spring seasons, the basin are experiences floods. These floods play a major role in causing severe damage to farms and infrastructure.

Floods have caused damage throughout history (1954, 1988, 2006, 2019, and 2021); with the most severe occurring in the year 2006 and 2021. This damage was represented by drowning and water pollution due to the drifting of waste, in addition to the drifting of agricultural pesticides. Mapping the flood hazard at the Chamchamal basin is very important. Because no such study has been conducted previously at the basin. The flood hazard map is useful for detecting flood-prone zones because it provides accurate spatial information for planners in order to manage hazards. This study aims to map flood hazards in the Chamchamal Basin using RS and GIS to identify high-risk zones.

2. Study Area

The Chamchamal Basin is located at northeastern part of Iraq and west of Sulaymaniyah City. The basin is located between 3941050 - 3912970 latitude and 507657- 480334 longitude. The basin occupies an area of 506 km^2. The basin includes thirty-three villages. The boundaries of the Chamchamal basin are the Qara Hanjeer basin from the west, the Al-Khassa sub-basin from the northwestern. Basara basin from the northeast, and the Chia sur sub-basin from the north (Fig.1). Depending on tectonics, the Chamchamal basin is located at Low folded zone (Jassim and Goff, 2006). Structurally, the borders of the chamchamal basin Darbandi-Bazian-Sagram-Qaradagh Anticline from the eastern and Chamchamal North Anticline passes through the center (Sissakianet al., 2017). The Chamchamal Basin consists of five geological formations are (Gercus - Pila Spi, Fatha, Injana, Muqdadiyah and Bai Hassan) , their ages from the Eocene to Pliocene (Stevanovic and Marcovic, 2003) (Fig. 2).

3. Materials and Methods

A flood risk map for Chamchamal Basin was prepared by applying a modern scientific method using GIS version 10.4 and RS coupled with AHP. The map was prepared for the total basin by 11

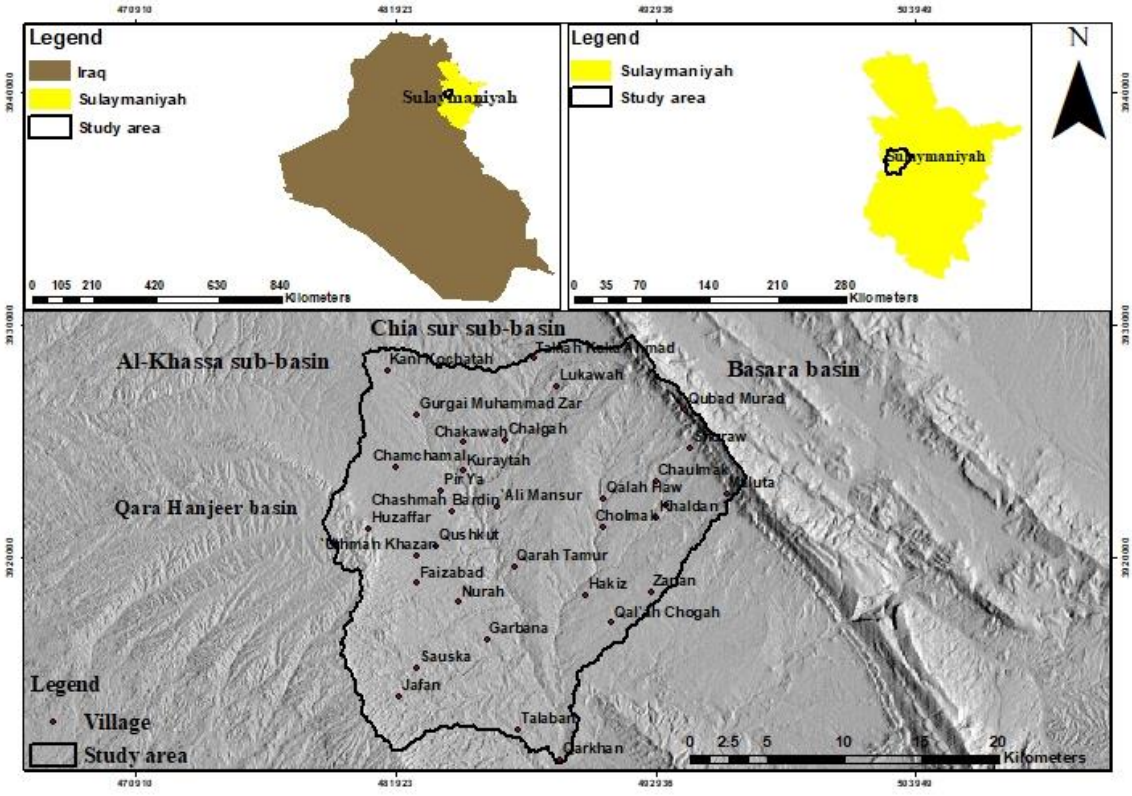

Fig. 1. Location of the Chamchamal basin

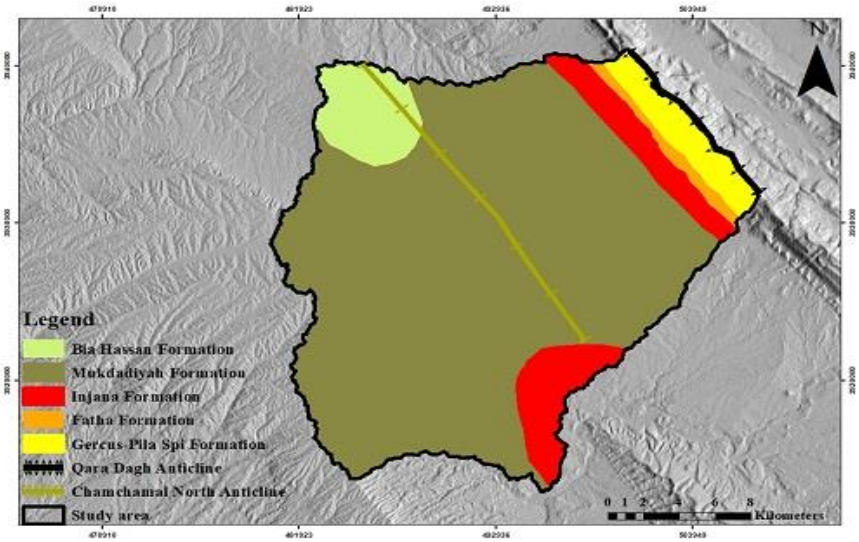

Fig. 2. Geological map of the Chamchamal Basin

Harmonized Global Soil Database HWSD (Nachtergaele et al. 2008), land use/land covers (LULC), and Profile Curvatures (PC). The rainfall data were sourced from (NASA Power).

Land use and Land covers were sourced from Environmental Systems Research Institut (ESRI). Eight parameters, included (E, TWI, S, DD, FA, SPI, distance from stream and PC) were derived from the Digital Elevation Model DEM (12.5 m) scale derived from using the USGS website. The study considered that these data are suitable for preparing a flood risk map at Chamchemal basin. It is possible to use more parameters for basins with larger areas. After determining the parameters for the Chamchamal Basin, the matrix was prepared using the AHP method (Wind and Saaty, 1980) (Table 1).

Table 1. Scale of relative importance according to Wind and Saaty (1980)

Importance	Definition
9	Extreme significance
7	very strong significant
5	very significant
3	moderate significance
1	Similar significance
8, 6, 4 and 2	In between values

In the second step, each factor was represented by a specific weight (Table 2). In the third step, 5 categories were determined for all maps after they were rated to produce the flood hazard map, depending on the following equation (Dutta et al., 2003):

$$FHI= \Sigma\ W.R = W_{DS}.R_{DS} + W_R.R_R + W_E.R_E + W_{TWI}.R_{TWI} + W_S.R_S + W_{DD}.R_{DD} + W_{FA}.R_{FA} + W_{SPI}.\ R_{SPI} + W_{SO}.R_{SO} + W_{LULC}.R_{LULC} + W_{PC}.R \quad (1)$$

Where: W and R = the weight and rating of the parameters. A flood map was produced as shown in the flowchart (Fig. 3).

Table 2. Weight potential factors for Chamchamal Basin

Factors	Weights
Distance from Stream	0.2385
Rainfall	0.1557
Elevation	0.1597
Topographic Wetness Index	0.1114
Slope	0.0900
Drainage density	0.0721
Flow accumulation	0.0512
Stream Power Index	0.0460
Soil	0.0320
land use/land covers	0.0242
Profile Curvatures	0.0190
Total	1

4. Results

4.1. Key Parameters Influencing Flood Risk in Chamchamal Basin

4.1.1. Distance from stream

In general, areas close to stream are more vulnerable to flooding than areas farther from stream. Areas near the stream become flooded when it rains, leading to floods (Reager et al., 2014). According to the map, the research areas of distance from the stream between 0 and 1072 m (Fig. 4A). The 200 m zone distance from the stream was given a rank of five because it is vulnerable to flooding even during small- to medium-sized floods; in contrast, the 800-1072 m zone was given a rank of one because of the exact opposite circumstance (Fig. 4B).

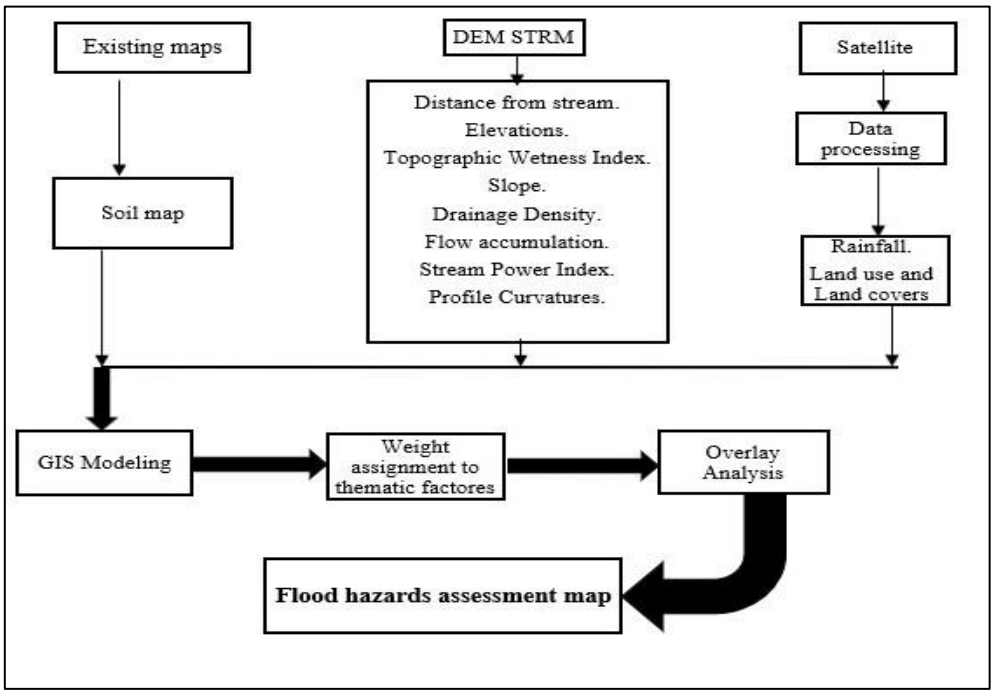

Fig. 3. Flow chart for flood hazards assessment map of the Chamchamal Basin

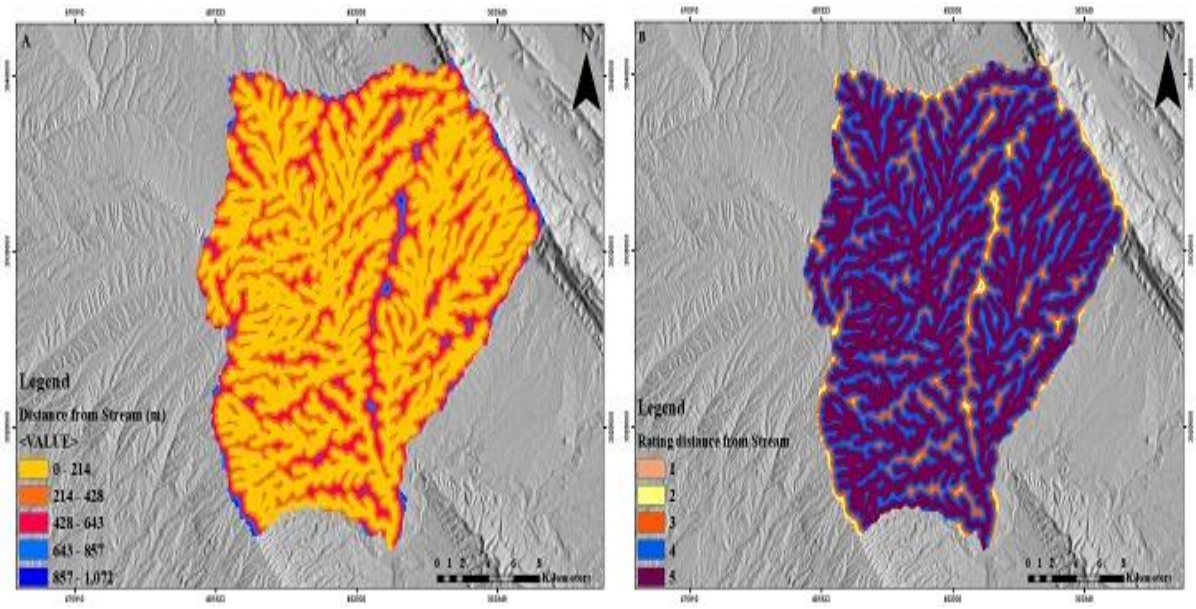

Fig. 4. A) Distance from stream and B) distance from stream rating of the Chamchamal basin.

4.1.2. Rainfall

One of the causes of the floods is heavy rainfall. Areas at risk of flooding are those that do not have natural runoff drainage. There is a direct relationship between the amount of rainfall and runoff; Because it is not possible for water to seep into the ground directly (Ouma and Tateishi, 2014). By using the IDW method, a rainfall map of the research area was created and then classified into five groups. According to the map, the research area's yearly average rainfall falls between 372 and 399 mm (Fig. 5A). The area's extreme south and south-western parts had the lowest concentration, while north region had the highest concentration.The places with the highest concentration of average annual rainfall were given higher ranks on the map, and the map was then categorized (Fig. 5B).

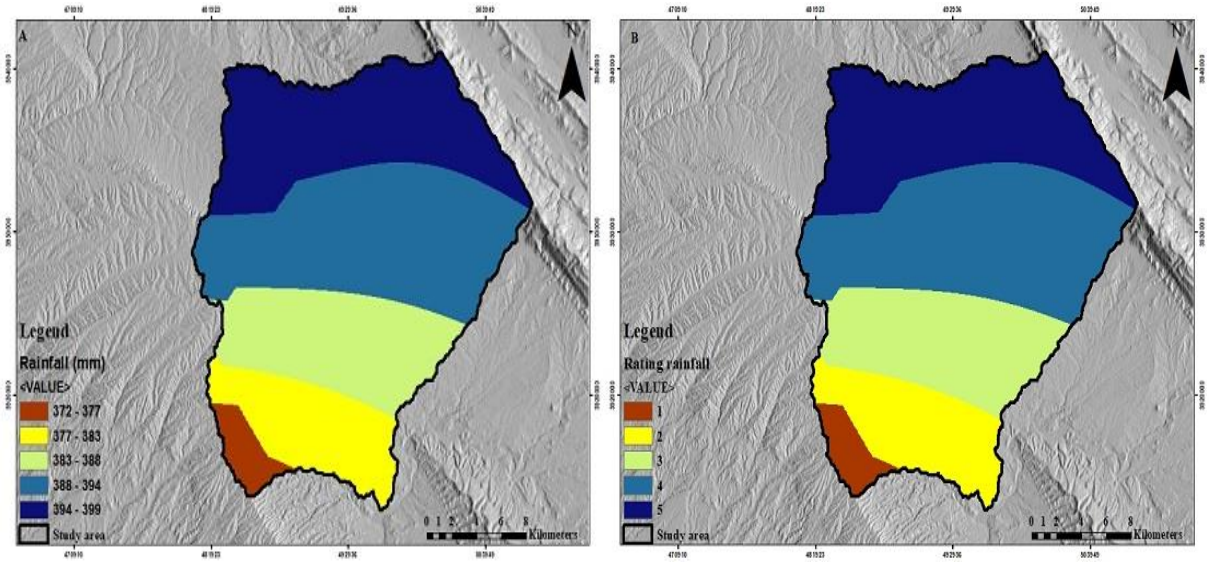

Fig. 5. A) Rainfall and B) rainfall rating of the Chamchamal Basin

4.1.3. Elevations (E)

Elevation essentially governs the normal flow of water (Xi et al., 2019). Elevation is one of the most important factors in studying floods, as floods cannot occur in areas of very high elevation. It is significant to note that low-lying and flat areas are more vulnerable to flood hazards because the water flows from high altitudinal zones to lowland areas, causing water to stagnate for an extended period of time that eventually results in a flood-like situation or inundation of the land (Raha et al., 2023). The work area's height varies from 458 to 1395 m, with higher elevations found in the northeast, north, and west parts (Fig. 6A).

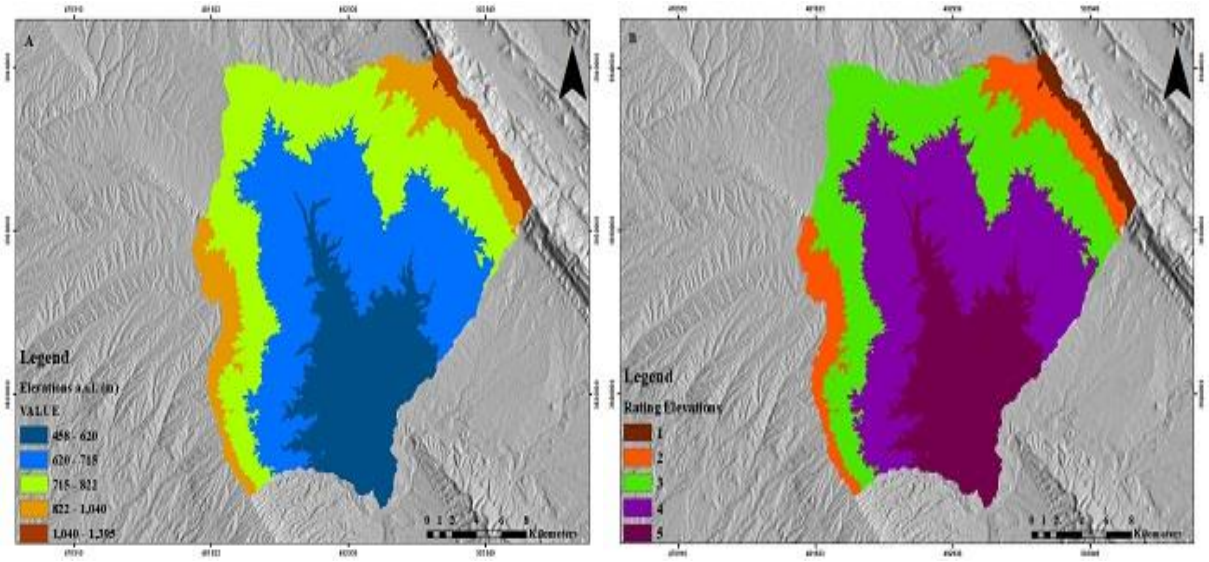

Fig. 6. A) Elevations and B) elevations rating of the Chamchamal Basin

The research area's elevations were split into five classes, with the lower-elevation locations being assigned a rank of five due to their greater contribution to the promotion of flood hazards (Fig. 6B).

4.1.4. Topographic Wetness Index (TWI)

TWI is the sum of the contributing area upstream per unit slope (Beven and Kirkby, 1979). It is used to control hydrological processes and soil moisture distribution. The study area's TWI values vary

from 3 to 22 (Fig. 7A). In the current study, locations with higher TWI values were given higher rankings, and vice versa (Fig. 7B).

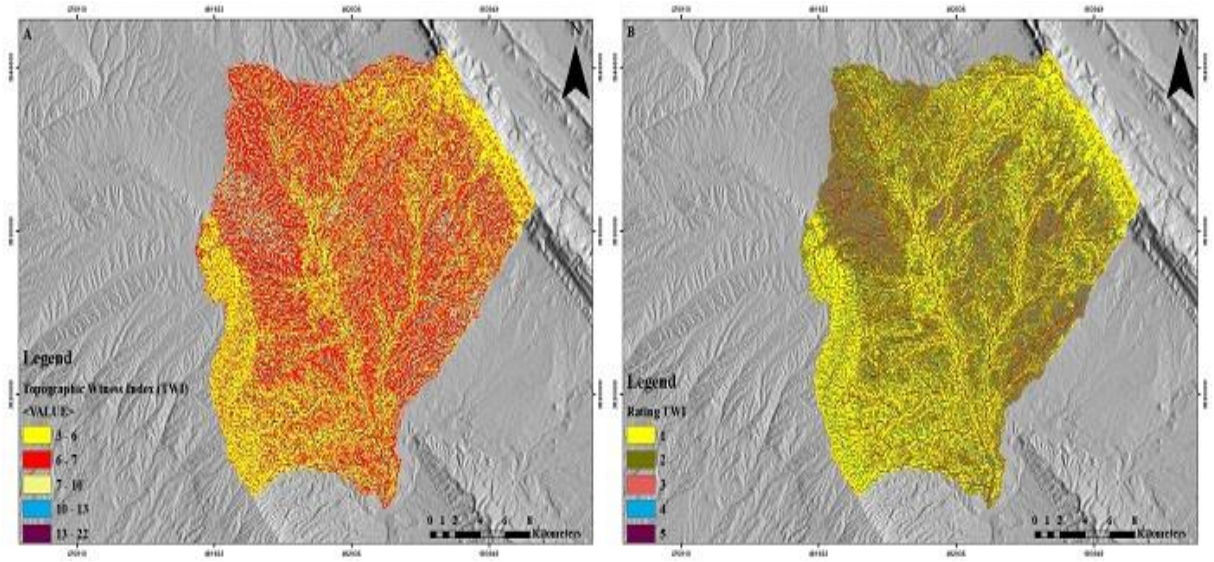

Fig. 7. A) Topographic Wetness Index and B) topographic Wetness Index rating

4.1.5. Slope

In any of the hydrological studies, slopes play an important role in surface water runoff (Das et al., 2018). The increase surface water flow is evidence of the presence of strong slopes, and thus leads to a reduction in the occurrence of flood. Generally, flat areas are flooded faster than areas with steep slopes (Tadesse et al., 2024). The value of the slopes at the basin ranges from 0 to 55.5 degrees (Fig. 8A).

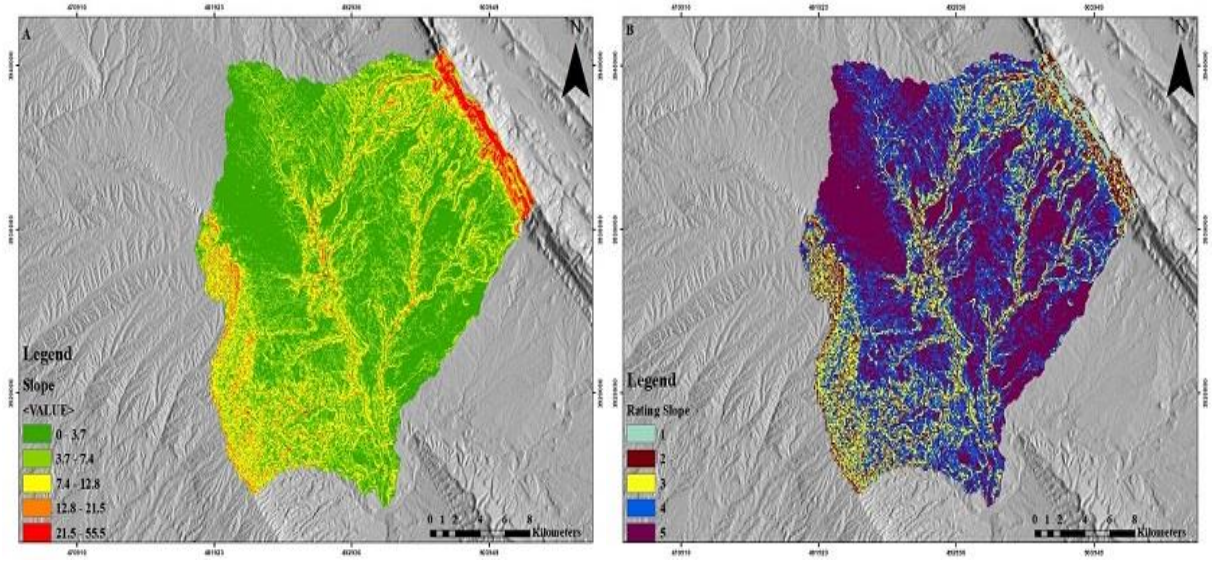

Fig. 8. A) Slope and B) Slope of the Chamchamal Basin

The Chamchamal Basin was divided into five categories according to the degree of slope, from (very low-very high). The highest-ranked flood areas included those with the highest slope, and vice versa (Fig. 8B).

4.1.6. Drainage Density

Drainage Density (DD) is important in distributing runoff and also controlling infiltration (Nkeki et al., 2022). The risk of flooding is most likely near the drainage network channel. Therefore, areas

located far from drainage channels are less at risk of flooding. The whole area is divided into five categories: extremely low (< 0-0.65 km/km^2), low (0.65–1.30 km/km^2), moderate (1.30–1.95 km/km^2), high (1.95–4 km/km^2), and very high (> 4 km/km^2) (Fig. 9A). In the current work, locations with higher DD values were given higher rankings, and vice versa (Fig. 9B).

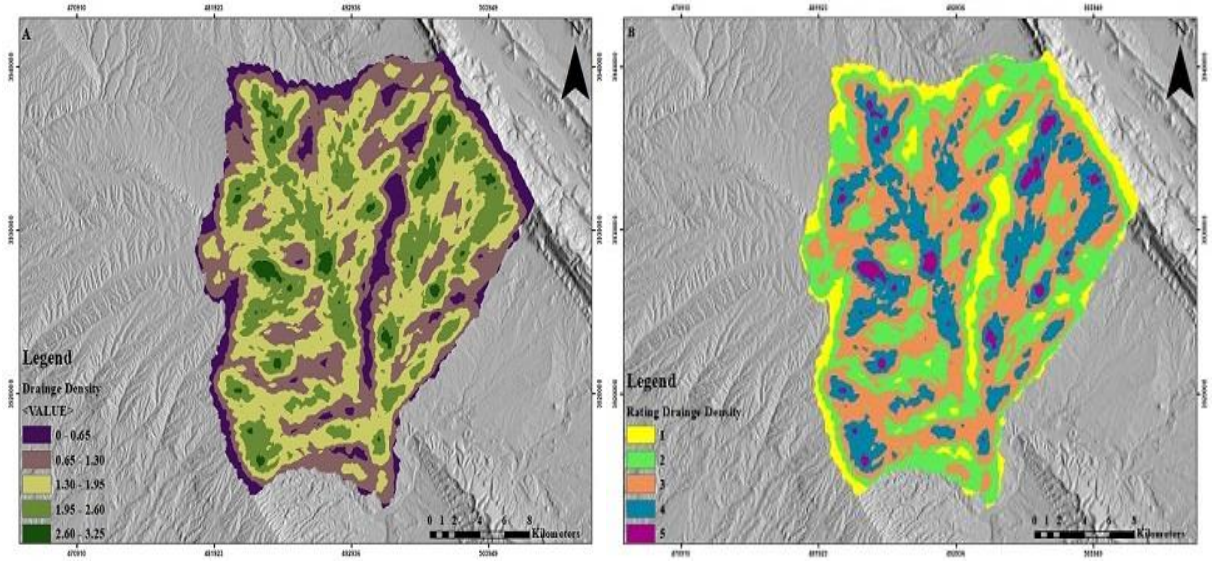

Fig. 9. A) Drainage density and B) drainage density rating of the Chamchamal basin.

4.1.7. Flow Accumulation

The FA is among the most crucial elements in reducing flood susceptibility zones. As long as the high-water accumulation zone's surroundings are present, flooding is a constant risk, FA is regarded as a crucial characteristic. The FA value in the current study between 0 to 495,6 (Fig. 10A).

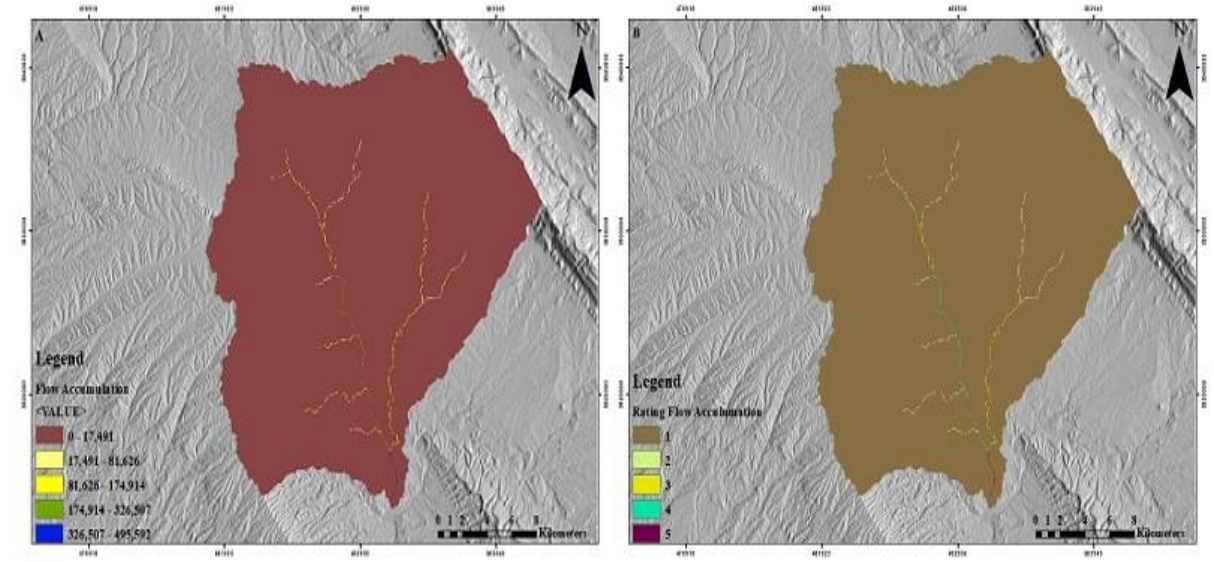

Fig. 10. A) Flow accumulation and B) flow accumulation rating of the Chamchamal Basin

In order to create a reclassified thematic map, the FA was divided into five classes, with a rank assigned to each class (Fig. 10B).

4.1.8. Stream Power Index

The SPI is a supplementary topographic component that defines and assesses the erosion power of a stream (Moore et al., 1991). The stream power index indicates water-induced surface runoff with

related erosional power (Wang et al., 2019). The SPI has a direct effect on flood occurrence since it rises with slope and highland Watershed area (Mirzaei et al., 2021). The stream power index value in the current study ranges from 0 to 2782 (Fig. 11A). A high SPI rate (5 rank) suggests rapid downstream water movement and a low chance of flooding, whereas a low SPI (1 rank) number indicates slow or stagnant water movement and a high probability of flooding (Fig. 11B).

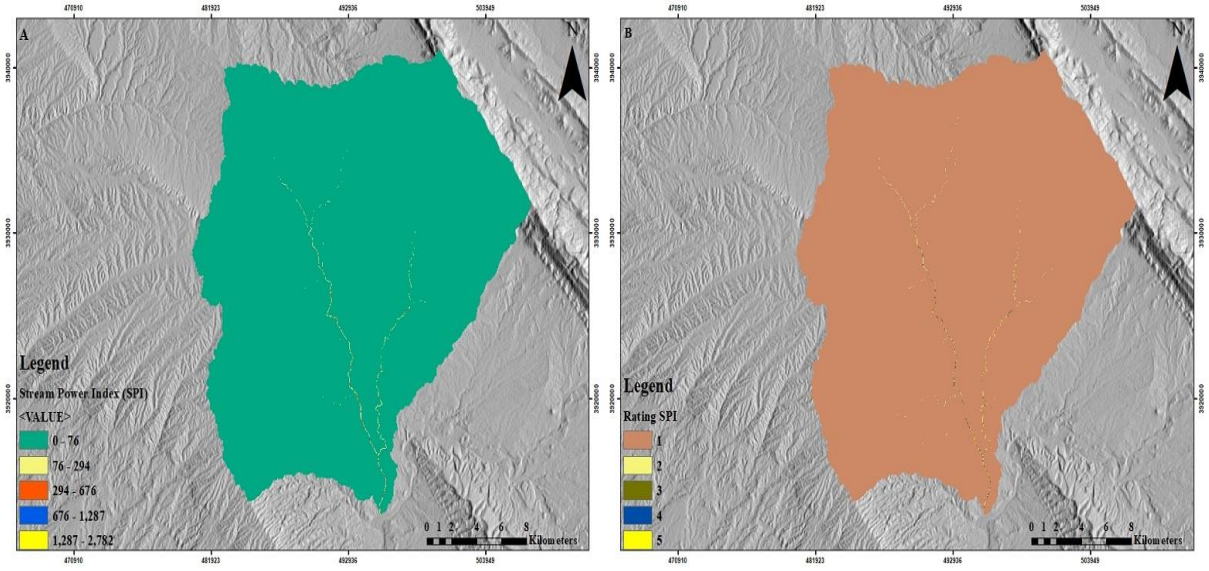

Fig. 11. A) Stream power index SPI and B) stream power index SPI rating of the Chamchamal Basin.

4.1.9. Soil

Soil is one of the important factors in producing a flood map. This is because soil plays a role in the runoff and filtration of water. Clay soil is impermeable to water, so runoff increases, leading to the possibility of the area being exposed to flooding (Pham et al., 2020). The two types of soil (clay and loam) that constitute the study region are represented in (Fig. 12A). The loam soil was ranked lower than the clay soil because it had a larger amount of sand (Fig. 12B).

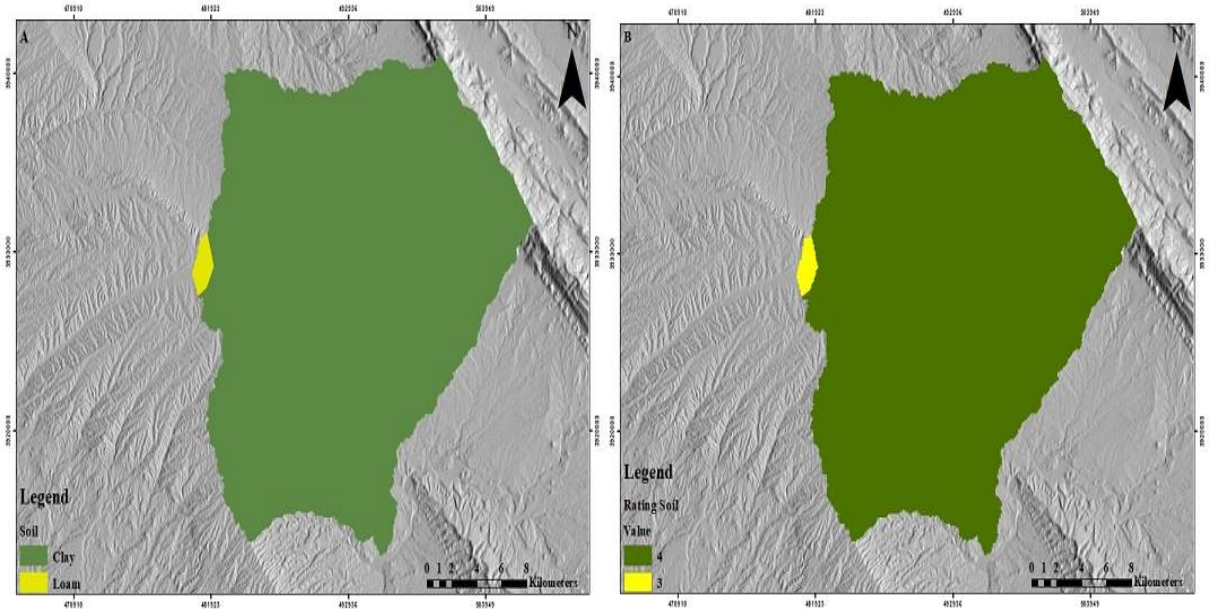

Fig. 12. A) Soil and B) soil rating of the Chamchamal Basin

4.1.10. Land Use and Land Covers

It was considered one of the indicators in applying the flood model (Hossain and Meng,2020). Runoff is affected by LULC, so it is considered an important factor or criteria in determining flood zones (Ramzi and Al-Gburi, 2022). The presence buildings are reducing infiltration and increases runoff. The presence of vegetation are leads to an increase in the recharge or infiltration process and a decrease in the runoff process. The study area included buildings, trees, water, grass, bare ground, crops, and scrub (Fig. 13A). The study region was very accurately classified into various land cover and land use categories, and among them, the highest rank, fourth and fifth, respectively, was assigned to the category represented by the stable area and water, while the second and third rank, respectively, was assigned to the vegetation and buildings category (Fig. 13B).

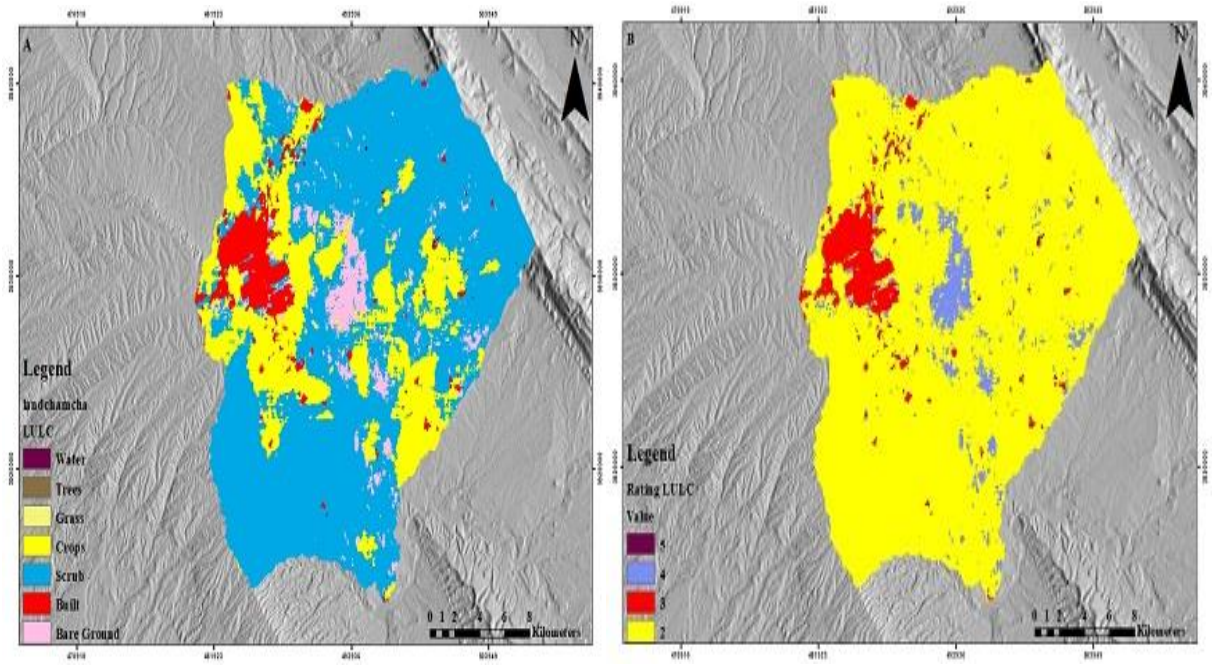

Fig. 13. A) LULC and B) LULC rating of the Chamchamal Basin

4.1.11. Profile Curvatures

These curvatures affect the velocity of flowing water in addition to the erosion and deposition processes. The PC is running parallel to the highest slope, and it mostly affects the flow across the surface's deceleration and acceleration. Whereas a convex contour (negative value) slows flow and so inhibits accumulation, a concave profile (positive value) speeds flow and so encourages the accumulation of water (Fig. 14A). Lower rankings were therefore allocated against negative curvature values in the current investigation, and higher ranks against positive curvature values (Fig. 14B).

4.2. Flood Hazard Assessment Map

Based on the flood hazard map, which was divided into 5 categories using GIS from very low to very high areas; it covers an area of 32.2, 85.8, 159.5, 148.9 and 79.6 km^2 respectively (Fig. 15). Flood hazard areas include topography and slopes low, i.e., the water drainage area for the Chamchamal basin. On the contrary, the least dangerous areas that are characterized by the non- accumulation of water are those that have high of elevations and slopes.

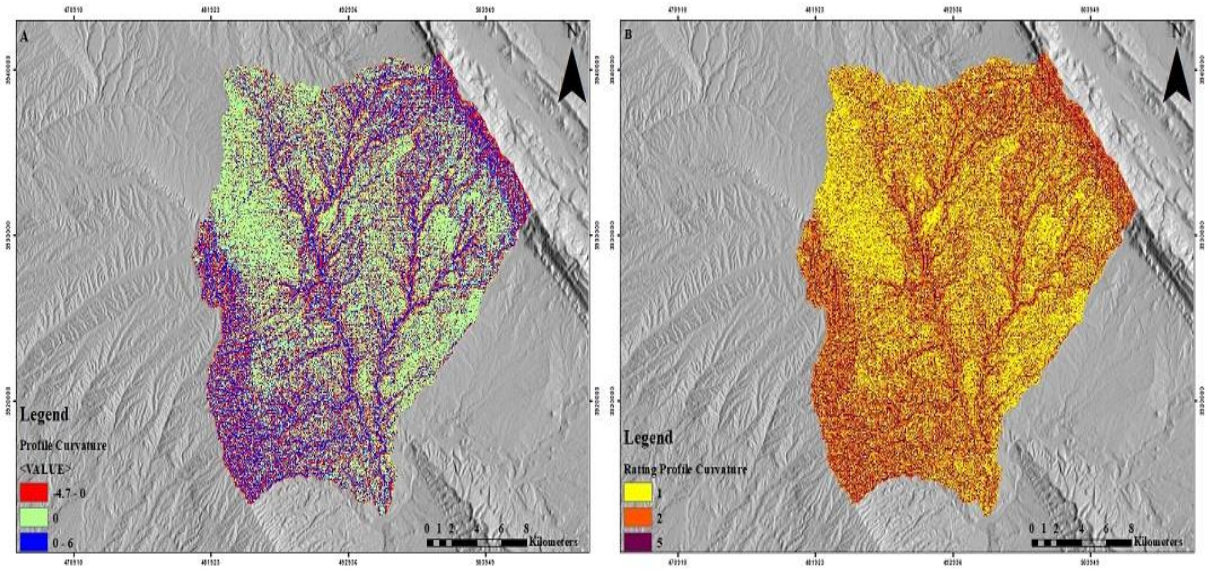

Fig. 14. A) Profile Curvatures (PC) and B) PC rating of the Chamchamal Basin

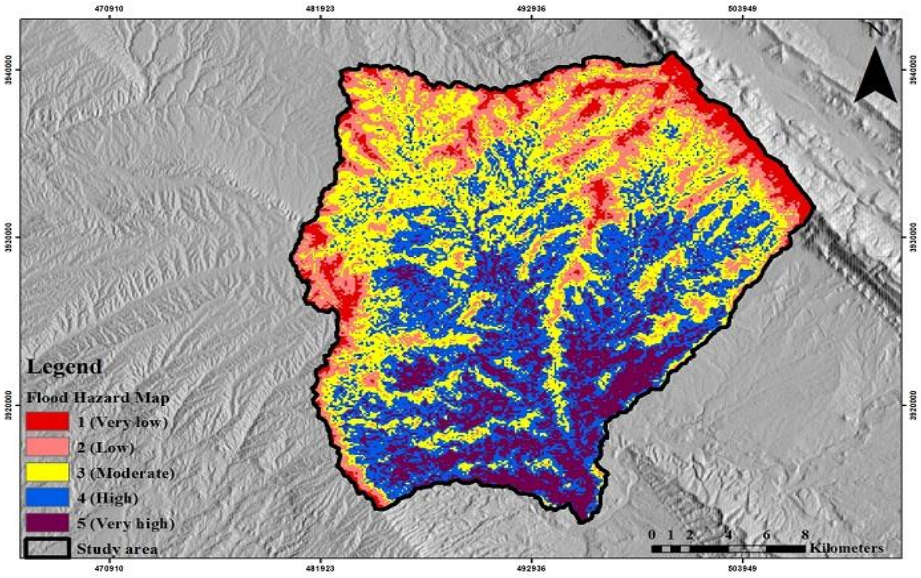

Fig.15. Flood hazard assessment map of the Chamchamal Basin

5. Conclusions

Modern techniques based on decision-making, RS, and GIS were used in this study. Based on the AHP, eleven factors were used by calculating the weights for each factor and also giving a rating weighted to the factors to produce a flood hazard map. These coefficients (11) were used for the first time in the Chamchamal Basin to determine the areas vulnerable to flooding. The results of the current study, which is characterized by accuracy and can be used with a reliable degree by the authority or responsible administration to reduce damage from flash floods, showed five flood vulnerable areas.The southern part is considered the most vulnerable area to floods, occupying approximately 29.5% high risk and 15.74% very high risk. While the moderate, low and very low areas occupy 31.4%, 16.96%, and 6.4%, respectively, for the Chamchamal basin. Authorities should focus on high-risk zones for mitigation measures like improved drainage and monitoring systems.

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