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Extraction of soils affected by erosion processes from topographic indicators of the northern basins feeding the Khabur River using RS and GIS

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Abstract
Topographical characteristics such as elevation, regression, sediment type and geological formations, as well as soil types and characteristics, affect the degree to which the soil is exposed to erosion risks. As a result of the study area being located in a region with a complex geological and topographical formation, the soils there are exposed to processes of erosion, transport and deposition due to the variation in their natural characteristics, causing several problems, most notably soil erosion and environmental risks. Therefore, the spatial relationships between these natural factors will be found and models of soil types will be prepared according to their physical and chemical properties. The ability of basins to withstand river erosion and then transport sediments will be determined in order to improve integrated environmental management processes.Soils affected by erosion were identified using topographic indicators, specifically the SPI (Saturation Intensity Index), the TRI (Top Roughness Index), and the STI (Soil Transport Intensity Index). The relationship between topography and water catchment was also examined using the TPI (Topographic Location Index).This research aims to achieve integrated soil management and water resource development by mitigating erosion risks. It utilizes GIS and RS (Resource Surveying) techniques to determine the spatial distribution of soils affected by water erosion in the northern basins feeding the Khabur River.
Keywords: Topographic Indicators; Topographic Roughness Index (TRI); River Sediment Transport Capacity Index (STI); River Power Index (SPI); Topographic Position Index (TPI)1.

Introduction

Topographic indices derived from high-resolution digital elevation model (DEM) have improved the construction of topographic models for watersheds, as they reflect topographic features that are crucial in hydrological responses affecting soil properties and stability. Topographic indices are widely used in soil science and hydrology, as they predict surface water flow paths, water accumulation, sedimentation volume, soil erosion processes, and soil moisture conditions (Larson et al., 2022).Topographic indicators reflect the relationship between soils and the topographic nature of the basin, through which soil characteristics and problems are identified. Topography controls the spatial variation of hydrological conditions and natural hazards, as it affects the spatial distribution of soil moisture, thickness, and fertility. Therefore, topographic indicators were used to describe the spatial patterns of soil moisture, as it is a crucial factor in soil cohesion and the richness of natural vegetation, which limits its susceptibility to erosion. Thus, a number of topographic indicators will be used to detect and identify soils affected by erosion processes in the study area.

1.1. Site Description

The geographical location of the study area is in the far north of Iraq, in the region that occupies the northwestern corner of Duhok Governorate within the boundaries of Zakho District Figure 1. It lies within a high mountain region consisting of mountain ranges with steep regressions and complex terrain surrounding multiple valleys that together form the northern basins of the Khabur River. It is bordered to the east by Amadiya District, to the north and northwest by Turkey, and to the south by Duhok District. Astronomically, it extends between latitudes (25-31°) and (48-30°) north, and longitudes (38-45°) and (10-46°) east. It consists of eight secondary basins that extend from north to south and southwest, all of which drain into the Khabur River. The area of the study area is (548,669) km2. The study area has a temperate climate, with temperatures beginning to drop during the winter months, reaching freezing point in some months. The lowest recorded temperature for January was -6.74°C during the period from 2012 to 2023. Temperatures then rise during the summer months, reaching 21.71°C in July. Precipitation occurs in the form of rain and snow. Rainfall begins in September and continues until June, but the largest amount falls during the winter months due to the frequent occurrence of low-pressure systems from the Mediterranean Sea. The total rainfall in January reached 668.24 mm. In spring, the highest total rainfall was recorded in March (796.89 mm). Rainfall is less in autumn due to the infrequency of low-pressure systems, and there is no rainfall during the summer. Figure (1) shows the location of the study area on a map of Iraq (researcher's work).

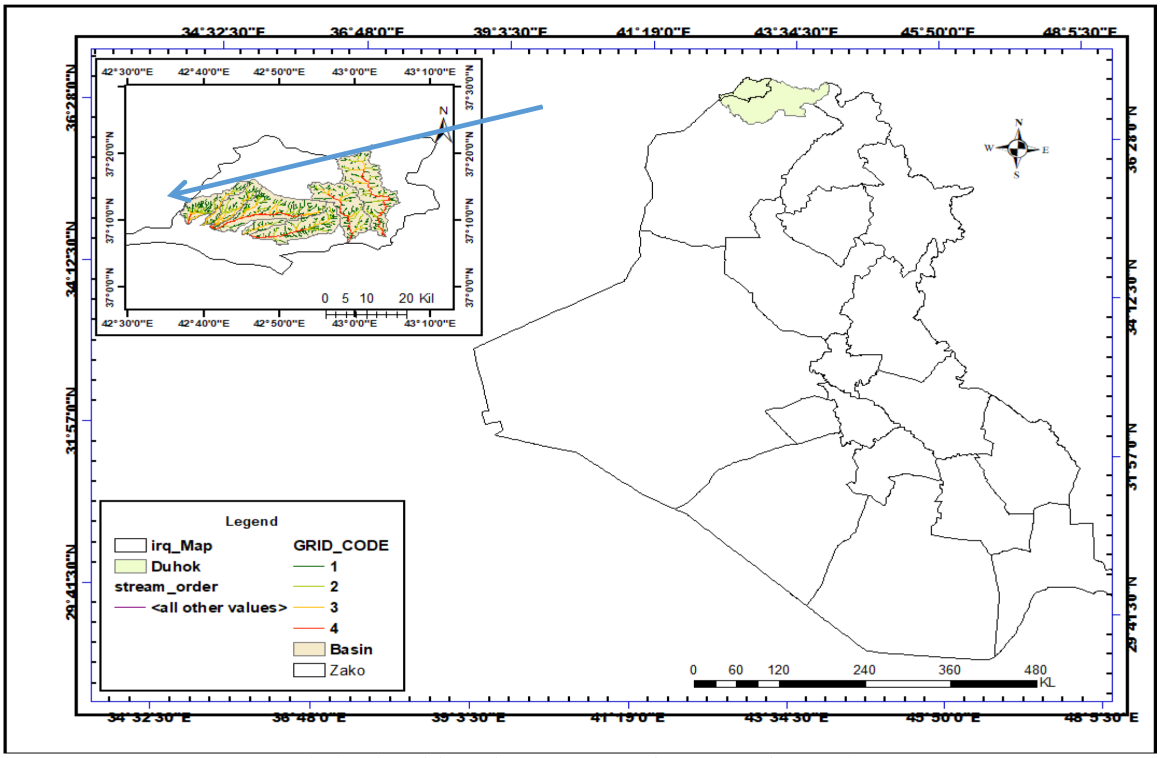

Fig.1. The location of the study area on a map of Iraq (researcher's work)

2. Materials and Methods

2.1 Data Collection

Topographic indicators are derived from the Digital Elevation Model (DEM) in a series of steps within ArcGIS software. The DEM is first imported into ArcMap, then the study area is mapped, and the Raster Calculator is used to apply the equation and extract the results. DEM data was obtained from the United States Geological Survey (USGU) (www.earthexplorer.usgs.gov) using radar imagery from the Aster Global DEM satellite. The layers with hazard-specific criteria were then incorporated: the regression layer, the flow direction layer, and the flow accumulation layer.

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2.1.1 Topographic Roughness Index (TRI)

The index is calculated using the equation (Eid, 2024):

TIR = (Smooth Area - Min R) / (Max R - Min R) (1)

Data required to calculate this index:

- Digital Elevation Model (DEM)
- Focal Statistics
  - Minimum Roughness (Min)
  - Maximum Roughness (Max)
  - Mean (Smooth Area)

2.1.2 Stream Power Index (SPI)

The Stream Power Index (SPI) can be calculated using the following equation (Yassin and Mohammed, 2024):

SPI = Flow Accumulation * Cell Size * Tan (Regression * 0.017453) (2)

When using the above equation to extract SPI values, the following data are needed:

- Dem of Study Area
- Flow Direction
- Water Accumulation Areas Flow Accumulation
- Regression Layer

2.1.3 Sediment Transport Index (STI)

The following equation was used to calculate this index (Eid, 2024):

STI = Power (Flow Accumulation / 22.13, 0.6) × Power(SIN(regression) / 0.0896, 1.3) (3)

Where:

22.13, 0.6 and 0.0896, 1.3 are constants

2.1.4 Topographic Position Index (TPI)

To calculate the TPI, it requires a high-resolution DEM. It is calculated in ArcMap software using the Focal Statistics and Minus tools in the toolbar.

3. Results and Discussion

3.1 Stratigraphic Sequence

From the geological map, it is clear that the study area exhibits a diverse geological sequences, consisting primarily of sedimentary rocks between the Triassic to the Miocene periods, in addition to Quaternary deposits (Khasbak, 1974). Sedimentary formations constitute the majority of the study basin due to their characteristics, which increase surface runoff, particularly in the upper reaches of the basin in areas with steep regressions.The study area lies within two distinct tectonic zones: the subduction zone in the north, whose southern boundary is represented by the main anticlines of the high fold zone, namely the Bakhair and Kara lines, which form the southern boundary of the Arka and Matin anticlines, the closest to the subduction zone; and the high fold zone in the south (Al Musawi, 2007), as shown in Figure (2) and Table (1).Solid limestone and dolomite rocks form mountain ridges and peaks, and most of the region's formations are of a lake origin, with the exception of the Bakhtiari Formation and the Quaternary deposits, which are of a riverine environment. Many geological formations of varying hardness are exposed on the surface of the region, ranging in age from the Early - Middle Triassic to the Quaternary sediments. Quaternary Sediments. The Mirga Mir formation is considered the oldest formation exposed in the study area and dates back to the Second Time (Early - Middle Triassic). It consists of marly limestone, soft crystalline limestone, and oil shale. The thickness of the formation is (200 m) and the height is (135 m). The depositional environment is shallow marine (Saffa F. A, 2008.) () It has an area of (0.225 km2) and a percentage (0.046%). Also, the Geli Kana formation appears along the Geli Kana valley. It consists of dolomite with bands of dolomitic limestone, followed by hard limestone alternating with green shale and yellowish-brown marl in the lower part. The thickness of the formation is (575 m) (Al Musawi, 2007) It reached an area of (35.161 km2) in percentage (6.408%). The Kura Chine and Baluti formations have a total area of (47,239) km2, and a percentage of (8,609%). The Jurassic formations appear, including the Sehkaniyan, Sarki, Sargelu, Naokelekan, Barsarin, and Chia Gara formations, which together constitute a very small area amounting to (4.612) km2, and a percentage of (0.840%), then followed by the Cretaceous formations, which are (Sarmord, Mergi, Agra-Bekhme, Shiranish), which together constitute a small area (15.876). km2, and percentage (2.893%) and consists of limestone and marl. Then the formations of the third time, Eocene Early, including the formations (Pila Spi, Gercus), which together constitute an area of (38,565) km2, a percentage of (7.1%), and consist of limestone, red claystone, and stratified dolomite. The Miocene (Fatha) formations cover the area at the feet of the mountains and are composed of mudstone and limestone, making up an area of (13,251) km2, and a percentage of (2.415%), and the (Injana) formation consisting of sandstone, clay, and limestone, reaching an area of (18,206) and a percentage of (3.318%). While it represents the formation of the Pliocene era (Mukdadiyah Late Miocene - Pliocene), it consists of sandstones, siltstone and clay, and some sandstone horizons are paved with gravel. It is the largest formation, covering an area of (172,436) km2, and a percentage of (31,245%). The Pliocene - Pleistocene Bai Hassan formation, which is the most recent formation of the Tertiary period, is covered with Quaternary sediments and consists of conglomerates lined with coarse brown sandstone and mudstone. The thickness of the formation is greatly variable, and the thickness of the formation is about (100 - 200) m. The origin of this formation is a riverine environment (Varoujan K. Sissakian, 1998) () The area of the formation in the study area is (61,752 km2), with a percentage of (11.25%).

The upper layers cover Quaternary Sediments (Pleistocene - Holocene), which are modern deposits dating back to different periods that vary in size and composition, ranging from clay, silt, sand, and gravel. They cover low-lying areas such as valleys and floodplains and consist of slope deposits, flood deposits, and the remaining older soils that are coarse of gravel. They all constitute an area of (122,560 km2), with a percentage of 122,560 km2. (22.335%), and the most widespread are slope sediments.

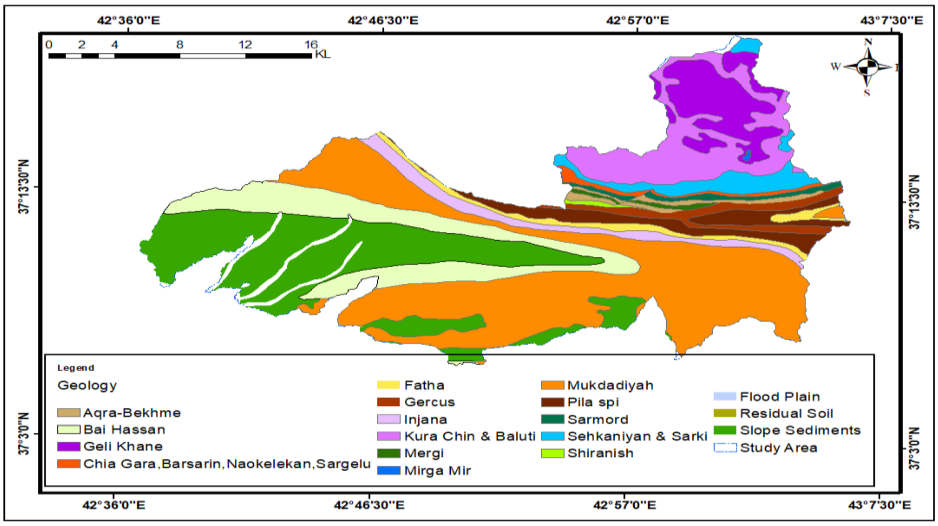

Fig.2. Geology of the study area

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Table 1. Sequence of geological layers in the northern Khabur basins

Period	Epoch	Age	Formation/Sediments	lithology	Area km^2	Ratio%
Quaternary	Holocene		Flood plain Sediments	Silt, clay, sand		
	Holocene		Residual soils	Clay with fragments of limestone rock		
	Pleistocene		Slope Sediments	Fragments of rock cemented together by calcareous materials	122.560	22.335
Tertiary	Pliocene	Late	Bai Hassan	Clay stone, Sand stone, Silt stone	61.752	11.25
		Late	Mukdadiyah	Sandstone and gravel, siltstone, claystone	172.436	31.425
	Miocene	Late	Injana	Clay stone, Sand stone, Silt stone	18.206	3.318
		Middle	Fatha	Gypsum, siltstone, claystone, marl, limestone	13.251	2.415
	Eocene	Late	Pila Spi	Stones	25.428	4.706
		Early	Gercus	Red stones	13.137	2.394
	Cretaceious	Late	Shiranish	Marl,limestone, marli-limestone	1.216	0.221
		Late	Aqra- Bekhme	Limestone	6.797	1.240
			Mergi	Limestone and marl	2.265	0.412
		Early	Sarmord	Limestone and marl	5.598	1.020
Mesozoic	Jurassic	Late	Chia Gara	Sandstone, marl, shale	4.612	0.840
			Barsarin			
			Naokelekan			
			Sargelu			
		Early	Sarki	Sandstone and oil shale	18.409	3.394
		Early	Sehkaniyan	Sandstone and oil shale		
	Triassic	Late	Baluti	Sandstone, oil marl	47.239	8.609
			Kura Chin	Oil shale and limestone		
		Middle	Geli Khana	Marl, limestone, claystone	35.161	6.408
		Early	Mirga Mir	Sandstone, marl, oil shale	0.255	0.046

3.2 Topography and Elevation Categories: Geomorphologically, the study area is primarily mountainous and rugged, with the exception of small sections around Zakho south of Mount Al-Bakhair and the area between Mount Al-Mateen and Mount Kara.

The basin in the northern highlands extends longitudinally in a northeast-southwest direction, encompassing, in part, the uplift zone in the north and the anticlines in the majority of the basin. This results in a variety of topographical features and, consequently, elevation categories, creating a complex topographical environment characterized by steep and moderate regressions, as well as high and low areas. The highest elevation in the region is at 2050 meters above sea level in the far north, characterized by the centers of anticlines where contour lines converge. The contour lines then diverge, and the elevation gradually decreases until it reaches its lowest point at the mouths of the basins feeding the Khabur River (450 meters above sea level). These areas are plains formed by alluvial deposits and fan deposits formed by the regressions at the foot of the highlands in the southwestern and central regions. Geomorphologically, the region is divided into two main parts. The first part consists of flat terrain, including mountainous and undulating plains in the northwest and southwest. The second part consists of a mountainous region that increases in elevation towards the north (Sissakian, 1996) (see Table 2 and Figure 3).

Table 2. Categories of Equal Elevation Lines, Their Areas (km²), and Percentages

Categories	Selected height category/m	Area / km^2	Percentage %
The first	620-540	256,18	%47
The second	810-630	106,56	%19
The third	1200-820	71,159	%13
The fourth	1600-1300	73,168	%13
The fifth	2200 -1700	41,256	%7,6
Total area km^2		548.6991	%100

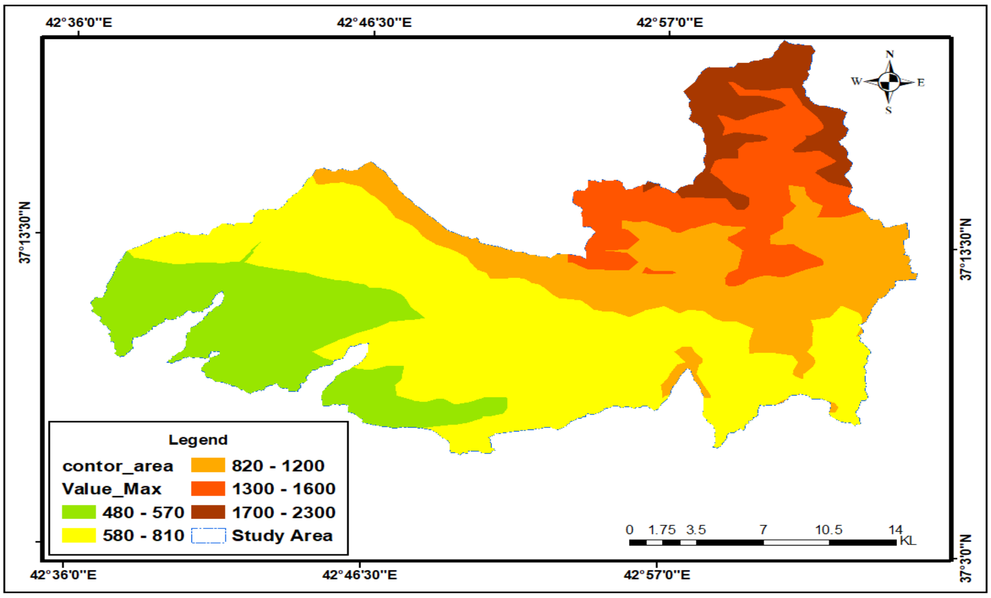

Fig.3. Elevation categories of the study area (Researcher's work)

3.3 Regression

The basin generally regressions from the north and northeast to the south and southwest towards the lower areas towards the basin outlets towards the Khabur River. This has concentrated surface runoff according to the different regression categories and thus its effect on the thickness and properties of the soil and its content of important mineral and organic materials for plants and the extent to which the soil retains moisture. From observing Figure (4) and Table No. (3), it appears that there is a clear variation in regression according to the topography of the region and the inclination of the layers. This is due to the nature of the inclination of the layers, the rock composition, and the difference in the type of rocks that were affected by the Alpine tectonic movements that formed the anticlines, ridges, and faults in the study area.

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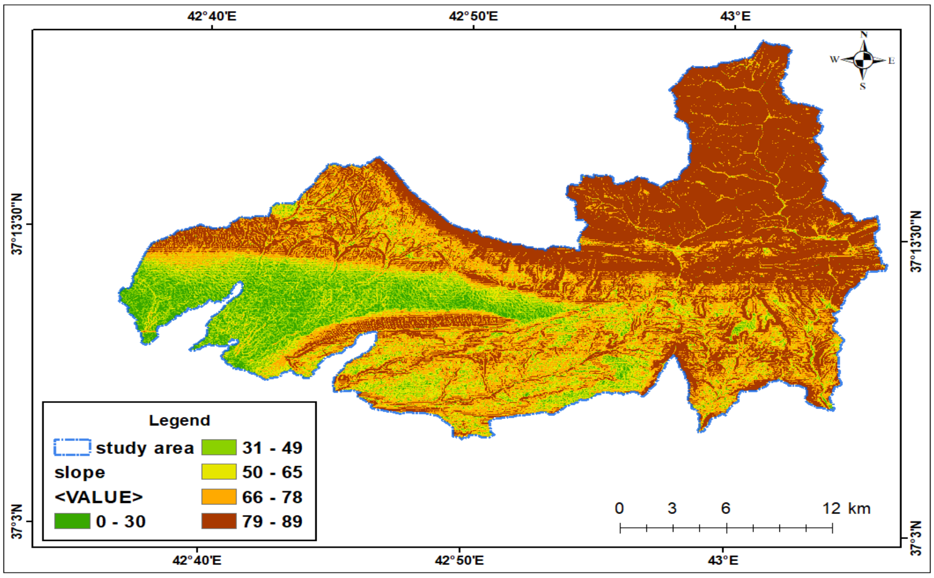

Fig.4. Regression degrees for the study area (researcher's work)

Table 3. Regression categories, their areas (km²), and their percentages%

Categories	Selected category/m	Area / km2	Percentage
The first	33-0	25,109	%4,6
The second	51-34	49,546	%9,4
The third	67-52	70,898	%13
The fourth	79-68	127,454	%23
The fifth	89-80	275,690	%50
Total area km^2		548.699	% 100

3.4 Soil Types in the Study Area: The soils were classified according to the World Reference Baseline for Soil Resources (WRB), an international standard soil classification system adopted by the International Union of Soil Sciences (IUSS). This is one of the most recent and accurate classifications for soil types, providing consistent information on soil types worldwide based on specific criteria (soil component characteristics, formation factors, and soil management). This soil classification consists of (32) main soil groups and it has been completed and fanalized in 2006 (Al-Shammari and Al-Bu Ali, 2024). The WRB classification for the study area shows (6) soil types, as shown in Figure (5) and Table (4). Regosols was the most widespread soil type: these are poorly developed, loose, and fragile sedimentary soils that are susceptible to water erosion. They are found in areas with active topography and are of medium thickness as a result of their continuous exposure to erosion factors (IUSS, 2007). They cover an area of 227.94 km², representing 42% of the total area in the basin. Due to their fine texture, they facilitate rapid surface runoff and are distributed across wide areas, particularly in the northern, eastern, and central parts of the study region. Additionally, the high percentage of Calcisols (calcium carbonate soils) indicates soils containing large accumulations of clayey and wind-agglomerated lime deposits resulting from weathering agents rich in base. These soils contain a petrified calcareous horizon, and as is commonly known, lime has low resistance to water erosion. Vegetation cover is sparse, and these soils are suitable for extensive grazing and agriculture (IUSS, 2007). This species comprised 41% of the total area, covering 223.53 km². Other species, such as Kastanozems, Campisols, Leptosols, and Luvisols, also appeared, but at lower percentages.

Table 4. Soil classes according to the (WRB) system, their areas (km2) and their percentages%

No.	Class No.	Class code	Class name	Area / km2	Percentage
The first	5	CL	Calcisols	223,53	%41
The second	6	CM	Cambisols	92.269	%17
The third	15	KS	Kastanozems	0.641	%0.12
The fourth	16	LP	Leptosols	4.232	%0.77
The fifth	18	LV	Luvisols	0.0855	%0.016
The Sixth	24	RG	Regosols	227.94	%42
Total area				548,669	% 100

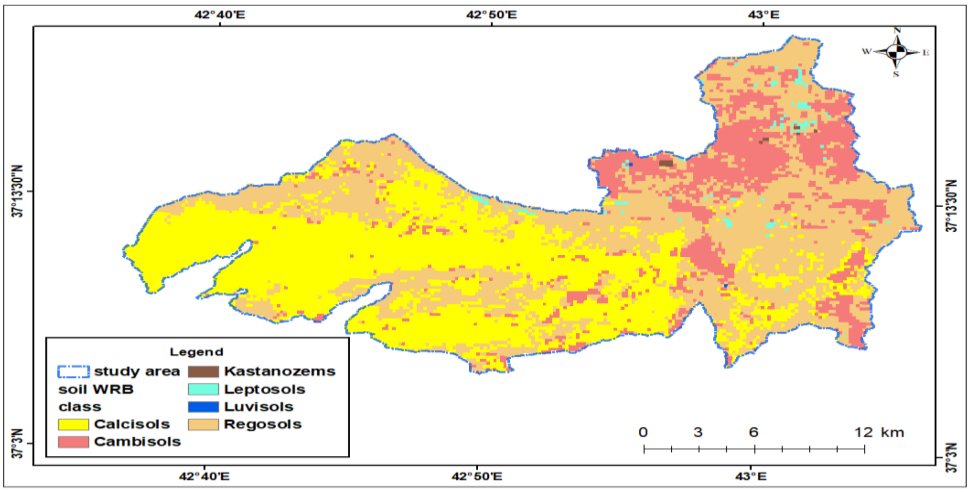

Fig.5. Soil types in the study area according to the International Soil Classification System (FAO/WRB) (Researcher's work)

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3.5 Extracting Erosion-Affected Soils from Topographic Indicators

*3.5.1 Topographic Roughness Index (TRI)*The TRI is a powerful tool for detecting topographic features that indicate the amount of sediment resulting from erosion processes. It utilizes topographic measurements to automatically identify regressions affected by erosion (Różycka et al., 2016). It is a geomorphological indicator that explains the complexity and variation of the surface, which is closely related to runoff speed, surface water drainage, and its distribution. This helps in understanding and assessing natural hazards. It also aids in understanding soil properties, as a rough surface can affect soil erosion, and rugged terrain increases geomorphological hazards (Eid, 2024).The index provides insight into the nature of topographic variation whether it is highly varied or minimally varied. This plays a significant role in the geomorphological processes activity, the soil properties, and the formation of landforms. The greater the variation in elevation and the steepness of the terrain, the more eroded the soil is. This led to increased soil erosion, resulting in thinner soils, higher sediment transport volumes, and increased environmental hazards. Soils on steep regressions are the most eroded areas in the basin, while those on flat areas are more stable and less eroded. Low-lying areas, such as valleys' streams, receive a greater volume of sediment.Figure (6) and Table (5) show that there is a variation in the values of the topographic roughness index (TRI), and this shows the roughness of the channel in the basin, as the highest value of the index was (0.888), while the lowest value of the index was (0.142). This variation was a result of the large variation in the values of elevations due to the rugged topography of the region in the northern basins feeding the Khabur River, which led to a spatial variation in the area and percentage of the index values, and then a variation in surface runoff and the amount of water discharge. The first category (0.42-0.14) was the lowest category, which means that it is a low-lying area where water collects and the amount of water discharge and sediments increases. It included the areas of the valley courses and the plains areas, so the water runoff of the drainage network was concentrated in it, as its area reached (81.12) km2 and the percentage of (14.78%). The values gradually increased in height, area, and percentage until they reached their highest value in the fourth category (0.89-0.58), with an area of (79.36) km2 and a percentage of (14.46%). The values of this category were spatially distributed over the steep areas in the highly complex terrain, and thus the surface runoff was severe, erosion was great, and the soil was thin.It is also evident that the rugged terrain in the basin represents the largest proportion, maintaining the moderately rough course in the second and third categories (0.43-0.49, 0.50-0.57), with areas of 195.82 and 192.4 km² respectively, together constituting 75.75% of the basin's area.

Surface runoff, resulting from the topography and rocky nature of the basin in areas classified as high-value zones, has led to a concentration of drainage density in the main valley channels, where rainwater and snowmelt collect. This has increased environmental hazards, particularly in areas near populated areas within the basin. Furthermore, the narrowness, depth, and steepness of the watercourses in the upper basin result in high flow velocities and significant erosion of the valley banks. The smaller the runoff area, the greater the risk as a result of the force of the current of the water resulting from the narrow watercourse. In contrast, in the lower basin, the regression is less steep, therefore, the watercourses are wider, and the water volume increases, leading to water accumulation in the lower reaches of the basin and further exacerbating the risks. Therefore, it is evident that the study area is characterized by rough topographyleaded to rough watercourses due to the significant elevation differences. This has caused water to accumulate in the low-lying areas of the vally channels. Moreover, these low-lying areas are prone to significant sedimentation, impacting the feasibility of storage and dam projects.

*3.5.2 Stream Power Index (SPI)*This is a topographic index that relies on the topographic characteristics of a location to predict and estimate soil erosion rates in areas at risk of erosion within watersheds. It depends on the topographic features that determine the paths and movement of surface water (Danielson, 2013). SPI values increase with increasing flow velocity resulting from increased gradient and the volume of water contributed by the higher areas of the basin, thus increasing the risk of erosion. This index provides a value for calculating the erosive power of flowing water in the watershed, which helps determine suitable locations for soil conservation measures to reduce the impact of concentrated surface runoff and increased sedimentation (Thalacker, 2014).

The force of the watercourse is a significant indicator of the impact of water erosion on bedrock and soil. Soil is the covering directly exposed to the force and speed of water flow, which erodes the surface soil particles, threatening its thickness and carrying away a large quantity of soil, especially with high flow force. Factors contributing to the force of the watercourse include the ruggedness of the area, the steepness of the regression, and the volume of accumulated water.

Indicator values in the study basin range from areas with low values in the first category (0-0.016), indicating minimal erosion, to areas with high values in the fourth category (0.21-0.57), signifying high erosion. As illustrated in Figure 7 and Table 5, the force of the watercourse is concentrated in the main valley channels of the basin, within the highest value category. Large quantities of water from rainfall and snowmelt collect in these channels, flowing through the upper levels and then accumulating in the lower levels. The first and second categories had the largest area and percentage but the lowest index values. The first category comprised an area of (532.79) km² and a percentage of (97.1%), indicating high drainage but moderate stream strength. The third and fourth categories had the highest index values but the smallest area. The fourth category (0.21-0.57) had the highest index values and an area of (0.43) km², representing (0.58%), as it is located in areas with steep regressions and rugged terrain. Environmental risks are concentrated in this category due to the high stream strength index values, which promote soil erosion.

*3.5.3 Sediment transport index (STI)*This index helps identify areas prone to soil erosion and sedimentation in waterways. Watercourse sediments are transported towards the main river channel by surface runoff after soil erosion caused by rainfall in the upstream area, which increases water flow. Therefore, soil erosion and sediment transport increase and worsen with increasing gradient and water discharge volume (Tilahun and Desta, 2023).

The sediment transport process is related to the river's capacity to carry sediments and results from current strength and discharge density. The STI values in the study basin range from areas with low sediment transport capacity (0-0.53) to areas with high sediment transport capacity (2.9-3.6). As can be seen from the map in Figure (8) and Table (5), areas with high index values are concentrated in the lower and middle basins, specifically in the intermediate categories where water collects from the upper basin categories, increasing the volume of water discharge. Conversely, the river's capacity to carry sediment decreases in the lower categories with slower flow due to the gentler gradient, resulting in a greater volume of deposited sediment.There is a variation in the area and percentage of index values within the study basin. Low values are concentrated in areas with high gradients, indicating the river's high capacity for sediment transport. The first category (0-0.53) occupies the largest area and spatial percentage among the categories, covering an area of (500.32) km², representing (91.18%). This indicates the intensity of surface runoff in the upper basin. The highest category, the fourth (2.9-3.6), covers a small area of (21.63) km², representing (3.94%). It is evident that the river's ability to deposit sediment is determined in the main course of the valleys, and in the gently sloping areas near the estuaries. This indicates a high level of water erosion activity in the rest of the basin.

3.5.4 Topographic Position Index (TPI) The Topographic Position Index (TPI) is an algorithm used to identify the positions of topographic slopes and classify landforms. It measures the relative topographic position of a central point as the difference between the elevation at that point and the average elevation within a predefined location. It is one of the morphometric characteristics based on adjacent areas that is useful in topographic analysis, which is involved in the analysis and management of environmental and agricultural risks (De Reu et al, 2013).The Topographic position Index (TPI) technique is used to analyze and classify surface features, as well as to perform topographic analysis of landforms using pixel values relative to neighboring pixels via a Digital Elevation Model (DEM). It employs a multi-directional algorithm that favors spatial resolution. Biophysical and biological processes affecting terrain are linked to topographic position, such as plateaus, valley floors, hills, and plains, as well as soil erosion, sedimentation, and hydrological balance. Therefore, the TPI can be used to predict soil erosion (Alhusban, 2018).

The topographic position index is an algorithm and was created by (Weiss 2001) that calculates the difference in elevation between a central pixel and the average elevation of a defined perimeter with a radius specified by the user. The TPI value expresses the intensity of the variation, as positive values indicate that the point is located in a higher position compared to its perimeter which means that the location is elevated and could be a series of hills. Conversely, negative values indicate that the point is located in a lower position compared to its perimeter which shows that the location may be a valley or a low-lying area. Flat lands e.g. plateaus and plains were indicated by zero values. Thus, high, low, and flat areas can be identified, and then units that are closely related to the flow can be identified (Trentin and Robaina, 2018).TPI is a valuable concept in remote sensing and GIS. It is used to describe the relative topographic position of a location within a terrain. It helps in understanding how a point or area relates to its surrounding terrain. It is very important on multi applications such as land-use planning, environmental and hydrological studies, and terrain analysis. Calculating the TPI requires a high-resolution DEM. TPI is done in ArcMap software using the Focal Statistics and Minus tools in the toolbar.

Based on this, areas characterized by soil erosion, high surface runoff areas, and water catchment areas can be identified to select the most suitable location for water harvesting projects.The index values in the studied basin area ranged from (173.594) to (-131.653). Map (10) and Table (9) show a variation in elevation values across the studied area, particularly between the northern, central, and southwestern parts of the basin. The higher elevations which represented by categories three and four, exhibited positive values. Category four refers to elevations of (48-170)m, covering an area of (31.39) km² and captured (5.72%). Category three (8.5-47) refers to hills with an area of (103.8) km² and representing (18.92%). Category one (130-25) refers to low-lying areas such as river valleys, covering an area of (36.54) km² and representing (10.27%). Category two (24-8.4) refers to flat areas such as plains or plateaus or relatively low elevation areas, which constituted a large area of the basin amounting to (357.17) km², with a percentage of (65.09%).

This variation in index values created a diverse topographic environment, influencing soil types ranging from shallow and thin to exposed and gravelly, according to the classifications of Iraqi soil exploration maps. Soil characteristics such as moisture and dryness, surface temperature, and vegetation cover also varied across the basin. Based on the above, the TPI index is important because it is used to determine the relative topographic position of a location within a terrain. This helps in understanding how a particular area relates to its surrounding topography, and thus has various applications in land use, topographic analysis, and water flow and its impact on soil properties and problems.

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Table 5. Variation in area and percentage of topographic indicators in the study basin4. Conclusions

Indicators		Indicator value	Area km^2	Percentage %
TRI		0.14-0.42	81.12	14.78
		0.43-0.49	195.82	35.69
		0.50-0.57	192.4	35.06
		0.58-0.89	79.36	14.46
STI		0-0.53	500.32	91.18
		0.54-1.7	12.78	2.33
		1.8-2.8	13.97	2.55
		2.9-3.6	21.63	3.94
SPI		0-0.016	532.79	97.1
		0.017-0.074	13.44	2.43
		0.075-0.2	2.15	0.39
		0.21-0.57	0.43	0.58
TPI	**Land geomorphology Categories**			
	Valleys	130- -25-	36.54	10.27
	Low regressions, shallow valleys and plains	24- -8.4	357.17	65.09
	Hills	8.5-47	103.8	18.92
	mountains	48-170	31.39	5.72

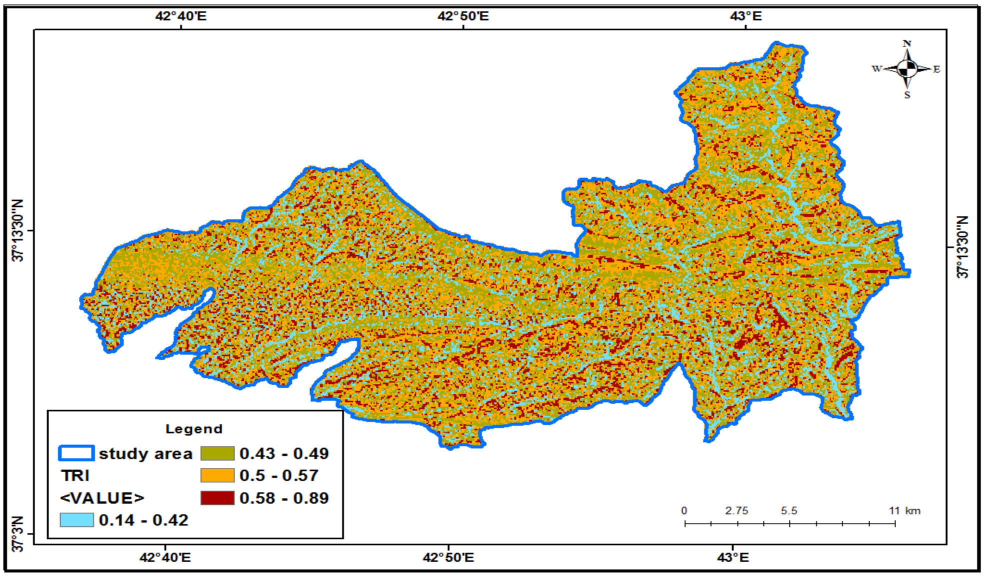

Fig.6.TRI (Tunnel Roughness Index) in the northern basins of the Khabur River (Researcher's work)

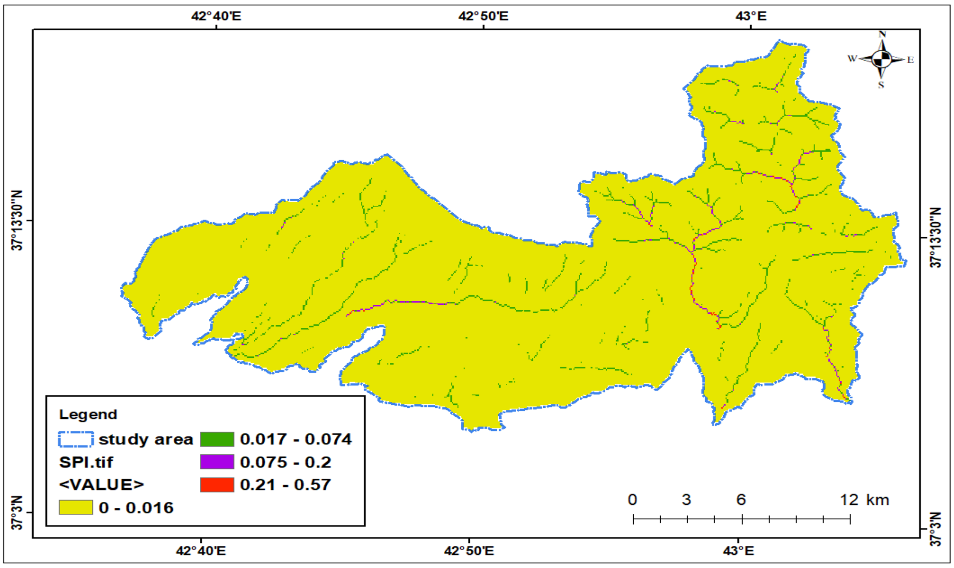

Fig .7. Stream Strength Index SPI in the northern basins of the Khabur River (Researcher's work)

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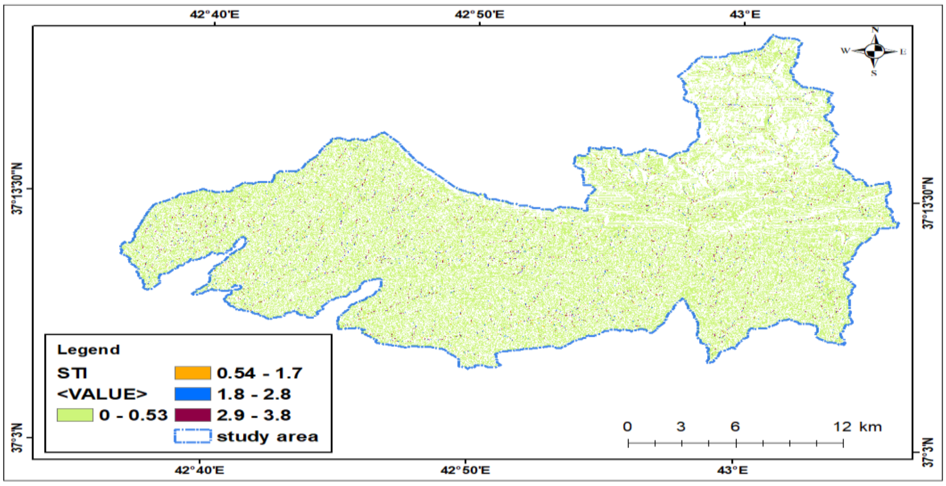

Fig .8. River Sediment Transport Capacity Index (STI) in the northern basins of the Khabur River (Researcher's work)

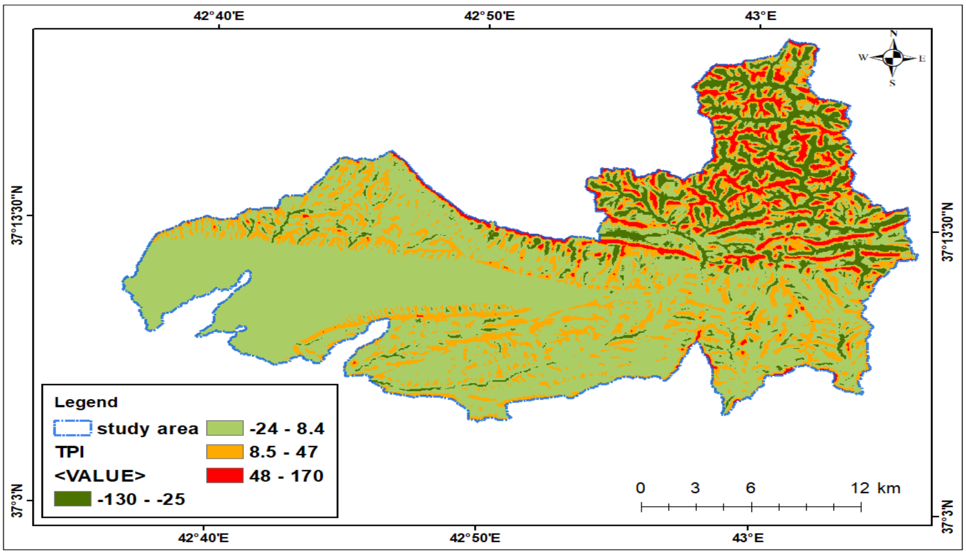

Fig .9. Topographic Location Index (TPI) in the northern basins of the Khabur River (Researcher's work)

4. Conclusions

1- The importance of calculated topographic indicators in detecting and spatially analyzing watersheds, soil moisture, topography roughness, elevation variations, stream strength, and sediment transport using remote sensing data and geographic information systems (GIS) has become clear, thus demonstrating their role in helping to avoid environmental risks and conserve water resources.

2- Analysis of the TPI revealed variations in elevation and diversity in landforms.

3- Analysis of the River's STI showed that the river's sediment transport capacity is concentrated in the areas located lower and middle basins, specifically in the third and fourth categories, where water collects from the upper categories and water discharge increases. Conversely, the river's sediment transport capacity decreases in the lower categories with slower flow due to the gentler gradient, leading to increased sedimentation.

4- Analysis of the SPI showed that stream power and water erosion are concentrated in the main channels with steep gradients and high discharges.

5- Analysis of the SRI showed that the studied basin is characterized by rough topography due to the significant difference in elevation between the source and the mouth.

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