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Qualitative Assessment of Water Erosion in Zawita Town in Dohuk Governorate within Kurdistan Region in Iraq, Using the (PAP/CAR) Model

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Abstract

The research aims to assess qualitative degradation and identify soil vulnerability and environmental sensitivity to detect and diagnose deterioration in the Zawita area within Dohuk Governorate, using the (PAP/CAR) model, which is linked to variables including (lithology - slope - soil protection factor - land cover and land use), derived from Landsat Oli 8 data, Dem, geological reports, as well as climate satellite data. A soil susceptibility map for degradation was prepared by intersecting the maps of lithology (soil type) and slope (direction, elevation), and producing a soil protection factor map from the plant map and land cover and land use map. The results revealed the spread of five categories of degradation (weak, very weak, moderate, severe, very severe), and it was found that water erosion is significantly influential, covering an area of 111.17 km2, representing 27.57% of the total area .

Keywords: *Erosion, PAP CAR Model, Rocks, Slope, Lost Soils.*

1- Introduction

The PAP/CAR model is one of the modern models used in studying water erosion, formulated for monitoring soil loss in the Mediterranean basin based on results obtained within the framework of cooperation between the Plan Bleu for the Mediterranean (PAM), the Food and Agriculture Organization (FAO), and the General Directorate for Environmental Preservation in Madrid (PNUE), within the program "Promotion and Protection of Soil in Coastal Areas of the Mediterranean Basin." The PAP/CAR model is considered one of the most effective models for calculating and evaluating qualitative water erosion because it relies on multiple variables that effectively contribute to water erosion and identify the most vulnerable and sensitive areas to erosion, as well as identifying areas less sensitive to erosion (PAP/CAR, 1998, p. 78).

The problem lies in the existence of water erosion in the Zawita district within Dohuk Governorate, Iraq, reflecting its impact on land use in the region. The research suggests that there are risks of water erosion in the Zawita district that can be measured using the PAP/CAR model. One of the main reasons for focusing on the area is the type of erosion and its implications on human activities by determining the geographic distribution and severity of erosion to prevent future risks.

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The Study Area: The Zawita district is geographically located in Iraq within Dohuk Governorate, northern Iraq, in the southwestern part of Dohuk Governorate. It is bordered to the north by the Duski district, to the east by the Sarsink and Atrosh districts, to the south by Dohuk city center, and to the west by the Zakho city center, Batil district, and Smeil center. Astronomically, it lies between longitude lines (42°18' to 51°42' E) and latitude lines (37°01' to 48°36' N). Its area is approximately 403.24 km2, accounting for 6.15% of the total area of Dohuk Governorate, which is 6,553 km2.

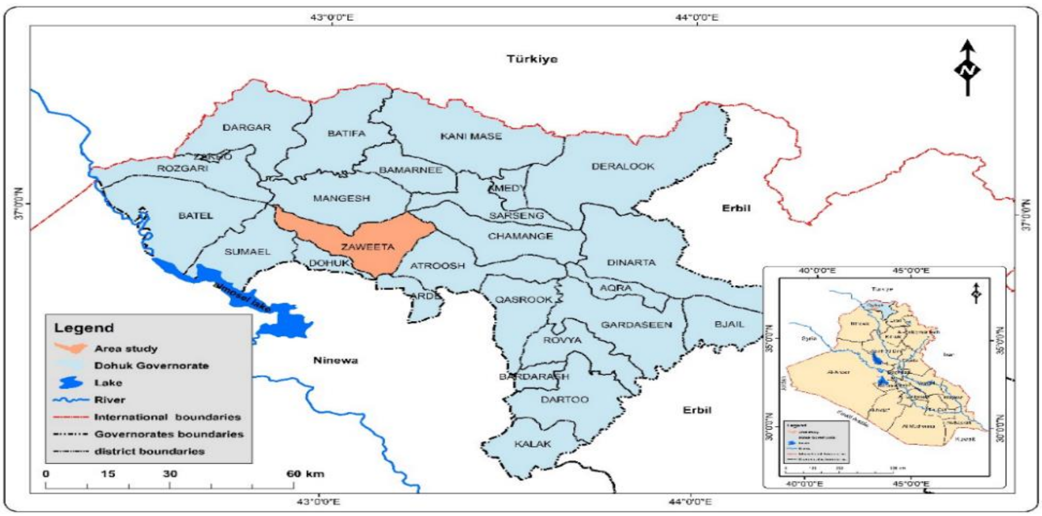

Figure (1): The Geographical and Astronomical Location of Zawiya District in Dohuk Governorate.

Source: General Authority for Survey, Map of Iraq at a Scale of 1/1000000; And Using Arc GIS 10.8.

2- Tools and Methods Used

Table (1): The Following Tools and Methods Were Used in the Research.

Tool Used	Scale	Year	Source
Geological Map	1:250000	2000	Ministry Of Industry and Minerals, General Authority for Survey and Mineral Investigation
Topographic Map	1:100000	2000	Ministry Of Water Resources, General Authority
Digital Elevation Model DEM	30×30	2014	Https://Www.Usgs.Gov/Centers/Eros/Science/Usgs-Eros-Archive-Digital-Elevation-Shuttle-Radar-Topography-Mission-Srtm-1
Visible From the Landsat Oil 8 Satellite	30×30	2023	Https://Earthexplorer.Usgs.Gov/
Satellite Climate Data	Processing And Analyzing Rainfall Data to Determine Its Impact on Water Erosion	2023	Https://Power.Larc.Nasa.Gov/Data-Access-Viewer/
Arc GIS 10.8	Processing, Displaying and Transmitting Data and Building Water Erosion Models	2014	Https://Www.Esri.Com/En-Us/Arcgis/About-Arcgis/Overview

3- Databases and Practical Procedures

First: The Susceptibility of Soil to Erosion

The susceptibility of soil erosion is directly related to the lithology of the study area, as there is an inverse relationship between lithology and soil erosion susceptibility. The higher the lithology, the lower the susceptibility of the soil to erosion, making it weak, and vice versa. Additionally, it is directly linked to the slope factor. Therefore, the soil erosion susceptibility map is the result of integrating the lithology map and the slope map. The model is built by combining the coefficients of the two previous maps in the ArcGIS software environment. Below is an explanation of both lithology and slope in the study area to extract the coefficient of soil erosion susceptibility.

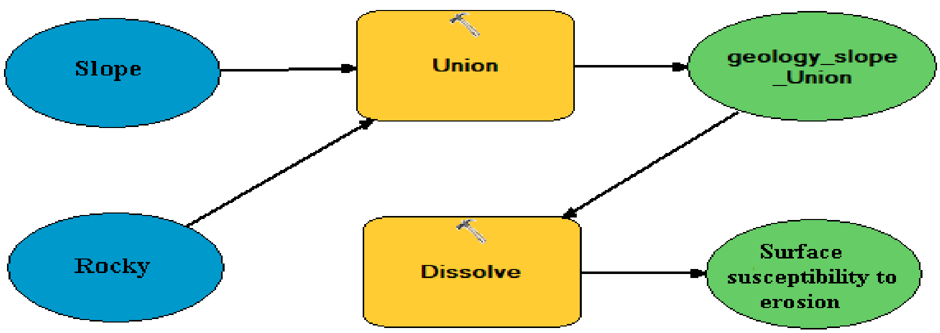

Figure (2): Building a Soil Erosion Susceptibility Map Model According to the PAP/CAR Model.

Source: Based on Arc GIS 10.8 Model Builder.

1. Lithology Factor (Geological Structure)

Several rock units are exposed with ages ranging from the Mesozoic to the Cenozoic eras, and these formations are arranged in a stratigraphic sequence from oldest to youngest, as illustrated in Figure (3) and Table (1). The Umbu Formation represents one of the formations of the Cretaceous period from the second era, with an area of 135.57 km², making it the largest area of rock exposures in the Zawita district. The Umbu Formation is part of the Lower and Middle Cretaceous era (Talabani, 1978, p. 70). Its components consist of limestone with marl and chalk, characterized by consistent and highly cohesive texture with a high silica content (Qarah Ghouli, 1968, p. 81). The presence of carbonate minerals makes it susceptible to chemical weathering. The exposed Akra Formation consists of thick layers of carbonate rocks and limestone, with a mixture of back-reef and fore-reef coral reefs, with a thickness of approximately 200 m and a depositional environment characterized as a coral reef or continental shelf environment (AlMusawi, 2007, p. 9).

The Shiranish Formation, belonging to the Cretaceous era, covers an area of 132.17 km². It is composed of blue-gray marl interleaved with limestone, with marl predominating. The limestone layers are hard, crystalline, and well-bedded, with a thickness of 225 m, and the depositional environment is deep marine (Sadeq, 1977, pp. 104-107).

The Khurmala Formation dates to the Paleocene era, covering an area of 33.93 km². It consists of well-bedded limestone layers interbedded with marl and limestone, with all these deposits intercalated with sandstone and conglomerates. The formation's thickness ranges from 50 to 60 m, and the depositional environment is an open marine environment.

The Balaspi-Avana Formation, belonging to the Eocene era, covers an area of 33.32 km². It consists of calcareous dolomite and well-bedded limestone, with green marl at the base. It is characterized by its varying thickness, ranging from thin to thick, with low permeability due to depositional conditions in chemical environments, making it solid rocks without fossils and not conducive to fluid accumulation unless fractured (Alani, 2010, p. 18). The thickness varies from 150 to 300 meters northeast of Zakho and 300 meters north of Batufa. In the Khabor area to the Zab area, its thickness ranges from 100 to 200 meters and sometimes reaches 215 meters (Khajik, 1995, p. 8).

The Anjana Formation consists of red and brown claystone, as well as red and brown sandstone and gritstone, covering an area of 28.96 km². The thickness of this formation ranges from 700 to 1200 meters. Overall, the Anjana Formation is characterized by its response to water erosion, especially in the claystone and gritstone layers, with environmental deposits indicating fluvial conditions.

The Fatha Formation, dating back to the Middle Miocene era, covers an area of 15.50 km². It consists of successive layers of gypsum rocks, claystone, and limestone, with inclinations of brown and leaden limestone, thin layers of leaden claystone, hard crystalline limestone, calcareous sandstone, with a thickness ranging from 1 to 150 meters. The depositional environment indicates a deep marine environment (Al-Azawi, 1982, p. 37).

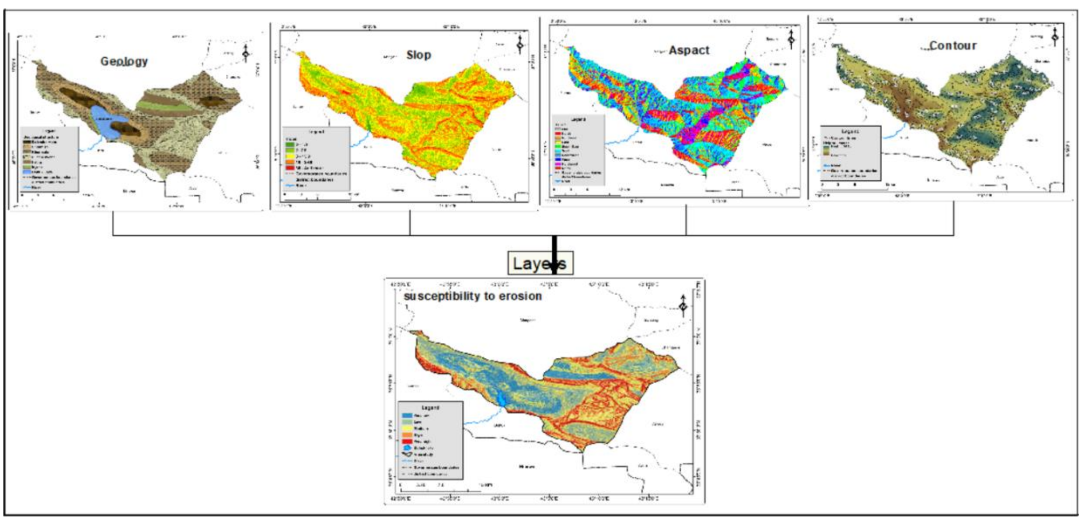

Figure (3): Erosion Potential Parameter Input.

Source

1. Ministry of Industry and Minerals, General Authority for Geological Survey and Mineral Investigation, Geological Map of Iraq, scale 1:250,000, for the year 2000, using the Arc GIS 10.8 program.
2. Depending on the digital elevation model and using the Arc GIS 10.8 program.

Table (2): Types of Geological Formations and Their Area in the Study Area.

Genesis	Time	Age	Area km2	The ratio %
Balambo Akre	Cretaceous	Early Late Cretaceous	135.57	33.62
Shiranesh		Late Cretaceous period	132.17	32.78
Khurmala	Triple	Paleocene - Eocene	33.93	8.41
Bellaspi Avana		Middle Eocene - Late Eocene	33.32	8.26
Anjana		Late Miocene	28.96	7.18
The slot		Middle Miocene	15.50	3.84
Dohuk Dam Lake	-	-	23.80	5.90
-	-	the total	403.24	100

Source: Based on Figure (3).

Slope

Studying slopes is crucial in geomorphological studies due to their susceptibility to erosion, deposition processes, and the variation in topographic features, which lead to different forms of slopes and their degrees of steepness (Abu Al-Einen, 1966, p. 335). The area is divided into five slope categories according to the classification by Zink (Ahmed, 2003, 2013), which illustrates the spatial values of slopes. The first category starts with a low slope angle ranging from (0 - 1.9°), covering an area of 8.60 km², representing 2.13% of the total area of the region. These areas include plains and valleys, constituting the smallest areas of the region as shown in Figure (3) and Table (2). The second category encompasses foothill areas where the slope angle ranges from (2-7.9°), covering an area of 104.52 km², representing 25.92% of the total area of the region. The third category includes moderate slopes with angles ranging from (8-15.9°), predominantly representing low folds with an area of 157.54 km², accounting for 39.07% of the total area, making it the largest category in the Zawita district. The fourth category represents high folds with slope angles ranging from (16-29.9°), covering an area of 118.91 km², representing 29.49% of the total area. These areas are relatively high, experiencing increased water erosion activities, evident in material movement on slopes, especially during heavy rainfall. The fifth and last category includes high mountainous areas with slope angles exceeding (30°), covering an area of 13.67 km², representing 3.39% of the total area. These lands are extensively dissected due to active geomorphological processes, leading to rock mass movements and landslides in the region, making them more susceptible to water erosion.

Table (3): Slope Degrees and Their Area According to Zink Classification in the Study Area.

	Degrees of Decline	Area km2	The ratio %
1	0 - 1.9	8.60	2.13
2	2 - 7.9	104.52	25.92
3	8 - 15.9	157.54	39.07
4	16 - 29.9	118.91	29.49
5	And more – 30	13.67	3.39
-	the total	403.25	100

Source: Based on Figure (3).

- **Slope Direction**

Determining the directions of slopes is important for identifying the direction of material movement on the slope and determining the slopes that receive large amounts of rainfall and snowfall, which follow the direction of the slope. From Figure (3), the directions and their areas were extracted from the study area, as shown in Table (3), which illustrates the slope directions distributed across the area. Accordingly, the southeast direction recorded the highest percentage, reaching (18.35%) respectively, followed by the south direction with a percentage of (14.63%), while the flat surface percentage was (13.28%) respectively. The east and northwest directions were (11.55%, 11.17%) respectively, while the north direction was (8.63%) respectively. The southwest, northeast, and west directions had lower percentages in the study area, but they were close to each other, recording (7.80%, 7.41%, 7.19%) respectively.

This variation and differences in direction percentages can be attributed to ancient tectonic movements that led to the formation of highland areas, as well as ongoing geomorphological processes that have altered some slope directions in the study area. It can be inferred that the slope direction plays a significant role in water erosion occurrence, intensity variation, and associated risks, as slopes facing rainfall experience more water erosion compared to slopes representing rain shadow areas where rainy weather systems do not reach, thus losing a significant amount of moisture.

Table (4): Direction of Slope and Area in the Study Area.

	Direction	Space	Ratio
1	Flat	53.55	13.28
2	North	34.80	8.63
3	Northeast	29.87	7.41
4	East	46.57	11.55
5	Southeast	73.99	18.35
6	South	58.99	14.63
7	Southwest	31.45	7.80
8	West	28.99	7.19
9	Northwest	45.05	11.17
-	**Total**	**403.25**	**100**

Source: Based on Figure (4).

Cantor line

Contour lines were included as a means of enhancing and clarifying the slope aspect in the study area, illustrating mountain ranges in terms of elevation and extension. The importance of studying the topographic aspect lies in the variation of elevations, slope degrees, inclination, and the response of rocks to geomorphological processes. Studying elevations is significant due to their impact on all processes occurring on the slopes. The study area exhibits clear ruggedness and high elevations, as observed in Figure (3), which shows that the contour lines of the area range between an elevation contour of (593) meters above sea level, appearing in scattered areas, especially to the south and southwest of the study area, gradually increasing in elevation until reaching an elevation of (1448) meters above sea level, representing the peaks of the high mountains in Zawita district.

Based on the above, soil erosion susceptibility coefficients were extracted by integrating the geological form with the slope form. Analysis of Figure (3) reveals spatial variation in soil erosion susceptibility within different parts of the study area. This variation is attributed to factors causing erosion. Soils with very low susceptibility are widespread in large parts of the study area, mainly on gently sloping terrain with low ruggedness compared to other parts. Next is the category of soils with low susceptibility to erosion, which is largely adjacent to the previous category, predominantly occurring on the edges of the previous category. Then, soils with moderate susceptibility to erosion are concentrated in the western side of the study area, occupying a very small area compared to other categories.

The last two categories, represented by soils with high and very high susceptibility to erosion, overlap with each other and are largely distributed on the outskirts of the study area, particularly in the eastern and southeastern parts. Additionally, their distribution coincides with the most rugged areas, making the soil in these areas the most susceptible to erosion when sufficient rainfall occurs.

Secondly: Soil Erosion Protection Coefficients

Soil erosion protection coefficients are determined by integrating land use and vegetation cover forms (Figure 4). Therefore, it is necessary to analyze both land use categories and vegetation cover and determine the concentration of each category, as well as the area covered by each, in order to determine the soil erosion protection coefficients. The following provides an explanation of each of them.

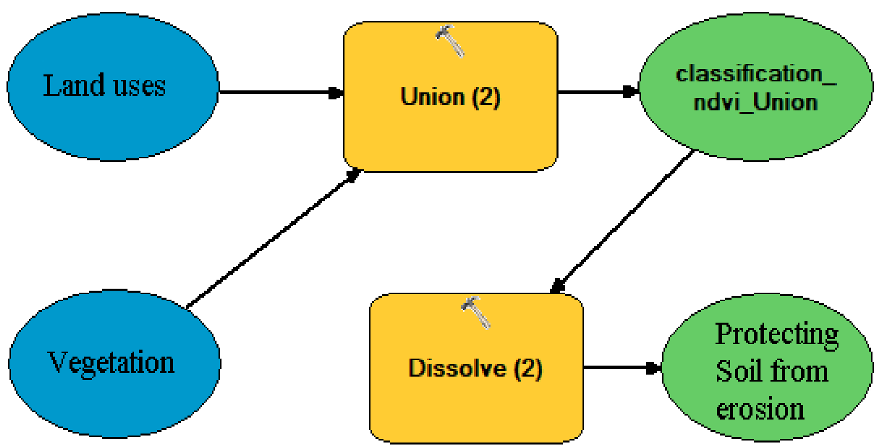

Figure (4): Building a Model of the Soil Protection Coefficient from Erosion According to the PAP/CAR Model.

Source: Based on Arc GIS 10.8 Model Builder.

1. Land Uses

Analysis of Figure (4) and Table (4) regarding land use in the study area reveals five categories of land cover. The largest category is barren land, covering an area of (258.09) km², accounting for (64.00) % of the total area. This category is the main cause of water erosion due to the lack of vegetation cover. Next is vegetation cover, with an area of (80.53) km², representing (19.97) % of the total area. This category is one of the most protective against water erosion. Dense forests come third with an area of (46.53) km², comprising (11.54) % of the total area. Urban land use, including residential areas and other urban patterns, covers an area of (17.20) km², accounting for (4.27) % of the total area and ranking fourth. Lastly, water cover, represented by Lake Duhok Dam, has the smallest area of (0.89) km², representing only (0.22) % of the total area.

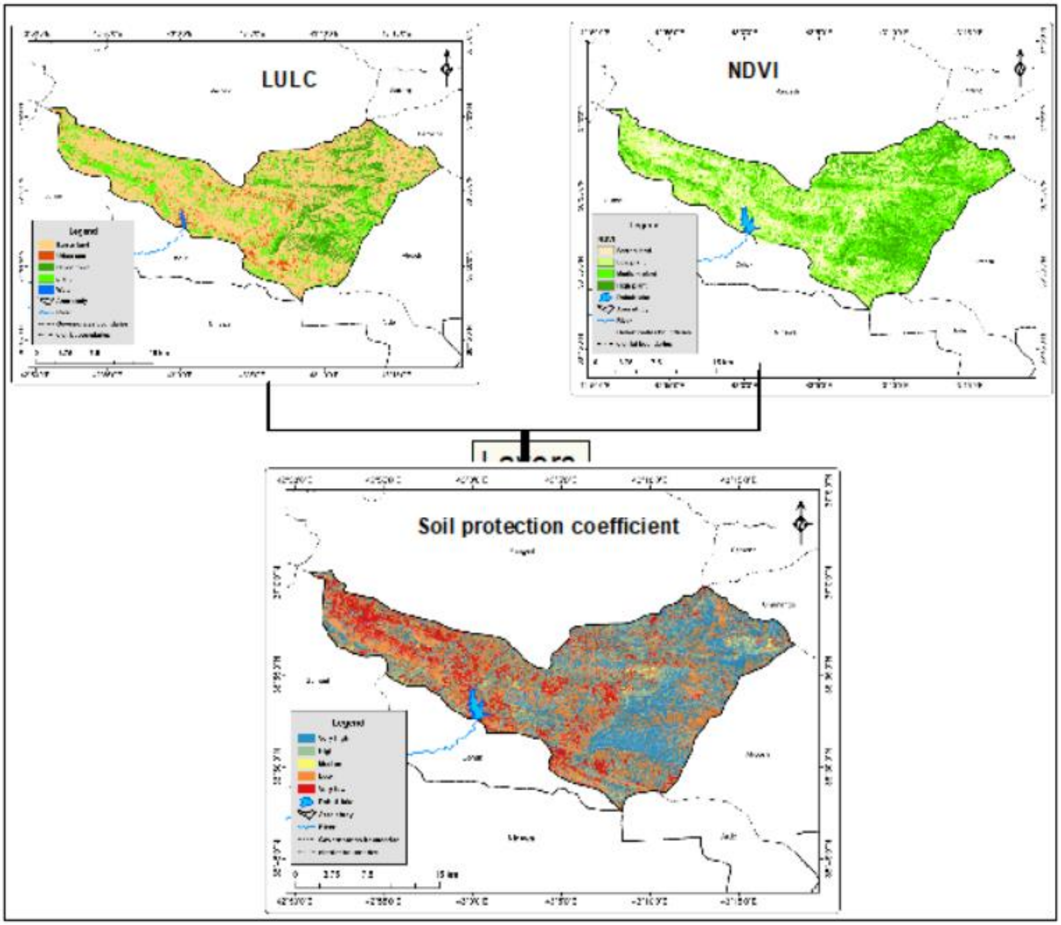

Figure (5): Soil Protection Factor.
Source: Based on analysis of satellite visuals (Landsat 8) for the year 2023, using Arc GIS 10.8 program.

Table (5): The Categories of Land Uses and Their Area in the Study Area.

The Categories	Area Km2	Rate %
Vegetation	80.53	19.97
Water	0.89	0.22
Dense trees	46.53	11.54
Urban Use	17.20	4.27
Barren Lands	258.09	64.00
Total	403.25	100

Source: Based on Figure (7).

2. Vegetation

Vegetation cover is one of the most crucial variables in assessing water erosion in any area.

This is because vegetation cover acts as a factor that either increases or decreases water erosion. The denser the vegetation cover, the more cohesive the soil becomes, resulting in reduced water erosion.

This is clear in the eastern and northeastern parts of the study area, as shown in Figure (4), where moderate to high-density vegetation cover is prevalent. This indicates that water erosion in these areas is minimal because vegetation obstructs fast-flowing water and makes the soil more cohesive. The combined area of these two categories (medium and high-density vegetation cover) is (78.95, 148.54) km², accounting for (19.58, 36.84) % respectively, as shown in Table.(6)

Conversely, when vegetation cover density decreases, as is the case with sparse vegetation cover, covering an area of (126.96) km² and representing (31.42) % of the total area, water erosion becomes more prevalent. Sparse vegetation cover is found scattered across various parts of the study area, including the central, southern, and southwestern regions, making the soil more susceptible to water erosion.

Barren land, which is completely devoid of vegetation cover, covers an area of (49.06) km², representing (12.17) % of the total area. This category is also scattered across different parts of the study area but is most concentrated in the northwestern region. These areas are highly susceptible to water erosion due to the lack of vegetation cover, leading to soil disintegration or water infiltration into the rock substratum, contributing to soil fragmentation and increased erosion hazards.

Table (6): Types and Density of Vegetation in the Study Area.

The Categories	Area Km2	Rate %
Barren lands (arid land)	49.06	12.17
Low density vegetation cover	126.69	31.42
Medium density vegetation cover	148.54	36.84
High density vegetation cover	78.95	19.58
Total	403.25	100

Source: Based on Figure.(8)

After identifying the characteristics, distribution, and area of each land use and vegetation cover category, the two maps were merged to produce a figure illustrating the soil erosion protection factor, which is one of the most important indicators necessary for deriving the water erosion model. Analysis of Figure (9) reveals that soil erosion protection is weak to very weak in the most intensively used areas or in barren areas with low vegetation cover density. It is noticeable that these two categories are prevalent in the western and northwestern parts of the study area .

Areas with moderate protection capability against erosion are spatially limited compared to other categories and often overlap with the severe and very severe categories in the eastern parts of the study area.

Severely and very severely protected soil areas are highly concentrated in the eastern and northeastern parts of the study area. They significantly correlate with areas of dense vegetation cover and dense tree cover, as well as with areas of moderate and high-density vegetation cover, which hinder and reduce the speed of runoff and promote soil cohesion due to dense vegetation cover. Consequently, these areas have a high erosion protection factor.

4- Analyze and Discuss the Results

Potential Erosion According to the PAP/CAR Model

The stages of producing the water erosion map involve merging the soil erodibility map with the soil erosion protection factor map to ultimately produce a map showing potential water erosion degrees, as depicted in Figure.(5)

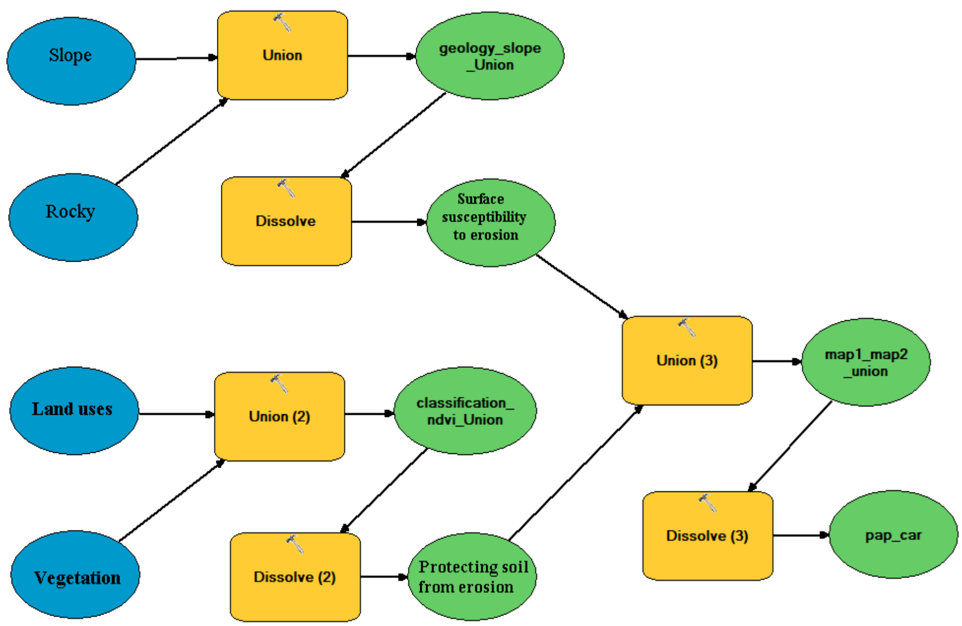

Figure (6): Building a Potential Erosion Model According to the PAP/CAR Model.
Source: Based on Arc GIS 10.8 Model Builder.

Through analyzing Figure (6) and Table (8) related to water erosion according to the (PAP/CAR) model, it becomes evident that water erosion varied according to degree and location. This can be illustrated as follows:

1. Very Weak Erosion

This category of erosion ranked second in terms of area after moderate erosion, recording an area of 110.21 km², representing 27.33% of the total area. It is spatially distributed in various parts of the study area, primarily in the central parts, with a smaller area in the northern and northeastern parts. This type of erosion occurs in areas characterized by gentle slopes and denser vegetation compared to other parts of the study area, resulting in very low soil loss.

2. Weak Erosion

Its area reached (104.38) km², accounting for (25.89) %. It is scattered in various parts of the study area. It is observed that this spread overlaps with the very weak erosion category because this category occurs under the same conditions as very weak erosion, i.e., in areas with high rock content, dense vegetation cover, and sometimes with gentle slopes. However, high rock content does not necessarily cause high erosion.

3. Moderate Erosion

Moderate erosion is one of the most widespread types of erosion, covering an area of (111.17) km², accounting for (27.57) %. This category of erosion is spread in scattered parts of the study area, particularly concentrated in the northwest, central, and southern parts, and it is noticed that this erosion category is spread in the areas with the least slope.

4. Severe Erosion

It is considered one of the dangerous erosion types that contribute to the increase in the amount of lost soil and its impact on people and houses within it. It is the least widespread category, ranking last with an area of (35.90) km², accounting for (8.90%) of the total erosion categories. It is spatially interwoven with very severe erosion due to the similarity in the conditions and factors causing both.

5. Very Severe Erosion

Very severe erosion is one of the most dangerous erosion types as it causes the highest amount of soil loss. Its area reached (41.59) km², accounting for (10.31) %. It is observed to spread spatially in the form of a strip extending from the northwest to the south and a very small portion of the northern parts. It also occupies some parts of the central area, characterized by a very high slope degree when matched with the slope gradient. Moreover, it records the highest amount of rainfall when matched with the spatial distribution of rainfall and is correlated with the distribution of the Belaspi-Avana formation, which is less rigid, making it susceptible to erosion, especially with the presence of suitable conditions, particularly rainfall, which is one of the main variables controlling water erosion.

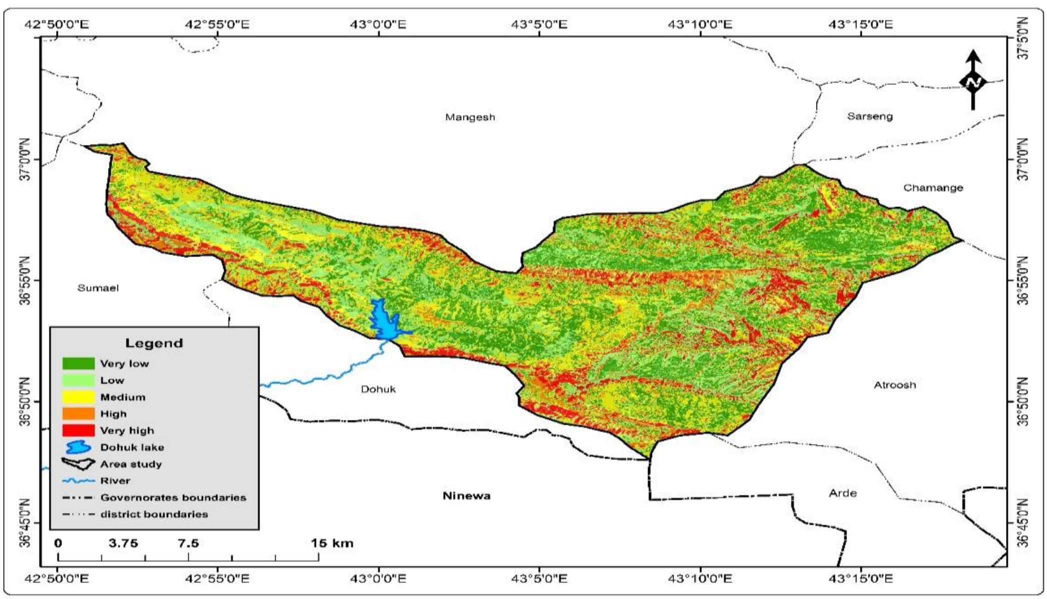

Figure (7): Types of Water Erosion According to the PAP/CAR Model.
Source: Based on Figures (3) and (5) Using Arc GIS 10.8.

Table (7): Types of Erosion and Their Area According to the PAP/CAR Model.

	Categories	Area km2	The ratio %
1	Very weak	110.21	27.33
2	Weak	104.38	25.89

3	Medium	111.17	27.57
4	Severe	35.90	8.90
5	Very intense	41.59	10.31
-	the total	403.25	100

Source: Based on Figure.(10)

Conclusions

1. The research revealed that soil erodibility resulting from the integration of lithological and topographic forms indicates the presence of five categories of soil erodibility, ranging from very low erodibility lands, which are widespread in large parts of the study area, corresponding to areas with few slopes and low ruggedness, to lands with severe and very severe erodibility, which are distributed at the edges of the study area, especially concentrated in the eastern and southeastern parts, corresponding to the most rugged regions.
2. The research showed that soil protection capability ranges from weak to very weak erosion in the most intensively used or barren areas with the lowest vegetation cover density, particularly in the western and northwestern parts of the study area. Lands with severe and very severe erosion, however, are concentrated in the eastern and northeastern parts of the study area, corresponding to areas with dense vegetation cover and moderate to high vegetation cover density, contributing to soil cohesion.
3. The results of the (PAP/CAR) model indicate that the category of very weak erosion ranked second in terms of area, covering an area of 110.21 km², accounting for 27.33%. It is spatially dispersed in various parts of the study area, generally concentrated in the central parts with a small area in the northern and northeastern parts. This erosion category occurs in areas characterized by gentle slopes and denser vegetation cover than other parts of the study area, resulting in very little lost soil quantity.
4. The category of moderate water erosion ranked first in terms of area, covering an area of 111.17 km², accounting for 27.57%. This erosion category is found in various parts of the study area but is particularly concentrated in the northwestern parts and other areas of the central and southern parts. It is noted that this erosion category is present in the least sloping areas.
5. Additionally, the category of very severe erosion is the most dangerous, causing the highest amount of lost soil. It covers an area of 41.59 km², accounting for 10.31%, and is spatially distributed as a strip extending from the northwest to the south of the study area, with a very small part in the northern areas. It also occupies some parts of the central area characterized by very high slopes when compared with the slope form first and its distribution is matched with the occurrence of the Belasbi-Afana formation secondly, which is the least rigid formation making it susceptible to erosion under suitable conditions, especially rainfall, one of the main variables controlling water erosion.

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