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Estimation the Volume of Water Erosion for Jadida Valley Basin in Erbil, Northern Iraq

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Abstract

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This study examined the potential of predicting the volume of water erosion using the erosion probability model, which is one of the most widely used methods for assessing soil degradation within drainage basins. This research aimed to determine the surface areas subjected to erosion and the resulting sediment quantities during one year, after demonstrating the impact of various natural conditions on the basin using remote sensing technology, which was represented by modern satellite visuals with the introduction and analysis of these visuals in the context of geographic information systems, as well as the application of a set of mathematical equations. This study shows that locations with high topography are always subjected to torrential waters, resulting in significant erosion, as opposed to plain areas, where erosion is weak or non-existent. The amount of soil lost in the basin ranged from 0.056–6900 m³/km²/year, and also included places with minimal erosion (26.705%) While weak erosion was found in 43.890% of the entire to the basin, moderate erosion was found in 20.929%, severe erosion was found in 5.762% and very severe erosion was found in 2.713% which includes places with steep slopes and no vegetation. The annual average of water erosion in the basin is projected to be 797.434 m³/km²/year, with an annual volume of eroded soil in the basin of around 321129.861 m³/year, necessitating the development of a plan to manage drift and reduce the danger of water erosion in the basin.

Keywords: Water Erosion; Jadida Valley Basin; Gavrilović model; Soil

1. Introduction

The study of water erosion in drainage basins is crucial for determining the degree of sensitivity of the earth's surface as an important component of environmental assessment, as well as its direct impact on sovereignty and varied land uses. This is a typical natural phenomenon that affects drainage basins and is caused by a number of natural elements, including precipitation intensity, gradient, rock composition, vegetation cover, and soil type (Salahaldin et al., 2016). The incorrect use of agricultural regions, the alteration of the earth's surface, and the removal of vegetation cover from soil and rocks are all major factors in the spread of this problem. As the density of the vegetation cover declines, the risk of water erosion increases (Zorn and Komac, 2008).

The Gavrilović method is one of the most widely used methods for analyzing water erosion, which occurs when huge amounts of soil are swept away within drainage basins. It is an experimental and semi-quantitative method for estimating sedimentary revenue, determining the severity of water

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erosion, and identifying locations that are likely to be eroded (Al-Jubory, 2019). Slobodan Gavrilović developed the Gavrilović approach, commonly known as the erosion probability model (EPM), based on a field study of erosion in the Morava River drainage basin in Serbia in the 1960s (Gavrilović, 1972). The Gavrilović method began with the development of geographic information systems techniques; however, despite the availability of all GIS capabilities that allow the evaluation of each cell within the river drainage basin by calculating the materials moved through it, this method has not been completely exploited to date (Nevena et al., 2016).

Erosion processes are most commonly caused by large rainstorms, which result in the formation of water torrents on the earth's surface, causing erosion and the transfer of sediments from one area to another. However, due to the complexity of these processes, forecasting activities for these processes is difficult to date (Vanmaercke et al., 2010). This study came to demonstrate the phenomenon of land degradation that is exposed to the drainage basin of Wadi Jadida due to the different topography of the basin, the diverse land cover, and inappropriate agricultural practices such as excessive plowing of the soil and cultivation of lands with steep slopes. The current study aims to estimate the amount of soil water erosion within the Wadi Jadida basin, as well as to determine erosion areas and their areal distribution within the basin, using indicators from the EPM, which aims to provide an applied model for remote sensing and GIS techniques in calculating Erosion quantities, and by analyzing a set of satellite visuals for the indicators of this method.

There are no previous studies on the phenomena of water erosion in the study area, but there are numerous research studies on the same issue in Iraq that operated in various methods; For instance, the Wadi Zarawa basin in Sulaymaniyah underwent a qualitative and quantitative evaluation of water erosion study, with the qualitative evaluation of water erosion relying on the PAP/CAR model. According to the EPM, the amount of soil lost within the basin fluctuates between (314-2790) $\text{m}^3/\text{km}^2/\text{year}$, and the basin has varied levels of erosion, including mild, medium, severe, and extremely severe (Al-Mashhadani, 2020). Additionally, the (EPM) method was used to quantify soil erosion in the garmiyan region of the Kurdistan region of Iraq, and values for the (Z) drift coefficient were categorized as moderate to high. It is increasing northward due to an increase in height, slope, and precipitation rate, which generates a high land flow, and this is related to high drainage and the power of enormous river erosion, which causes erosion of the earth's surface, resulting in a big amount of sediments (Salahalddin et al., 2016). The types of water erosion were estimated in some basins of the Khanaqin district, including them; Erosion of raindrops and coverings and erosion of flumes and gullies. According to the classification of the Bergsma equation, he estimated the degrees of groove erosion, its activities, the rate of its impact, the number of sites impacted by each of these degrees, their areas, and the proportion of each of them (Entisar and Halah, 2021).

2. Study Area, Geographic Location and Geological Setting

Wadi Jadida Basin is located in the northern of Iraq, within the administrative borders of Erbil, coordinates extends from high mountainous areas northeast of Erbil to plain areas in the west, before draining the basin's water into the course of the Great Zab River. It has a length of 44160 km, an area of 402.704 km^2 , and a perimeter of 132.667 km, and it is confined between longitudes 44°13'30" – 43°43'30" East and two latitudes 36°21'0" – 36°12'0" North (Fig. 1).

The geology of the basin is being studied in order to identify its rocky and sedimentary formations as well as the extent to which these formations respond to water erosion processes. The basin is divided into two geological formations: the Bai Hassan Formation and the Muqdadia formation, which are made up of dammak rocks and a succession of soft claystone, sandstone, alluvial stone, and shale stone (Hagopian, 1976), and the modern Quaternary sediments spread in the middle of the basin and consist from different sizes that include boulder and round pebbles (cobbles), pebbles, clay soils, sand, silt and

clay vary in their spatial distribution and the degree of their response to water erosion when rain falls on the basin.

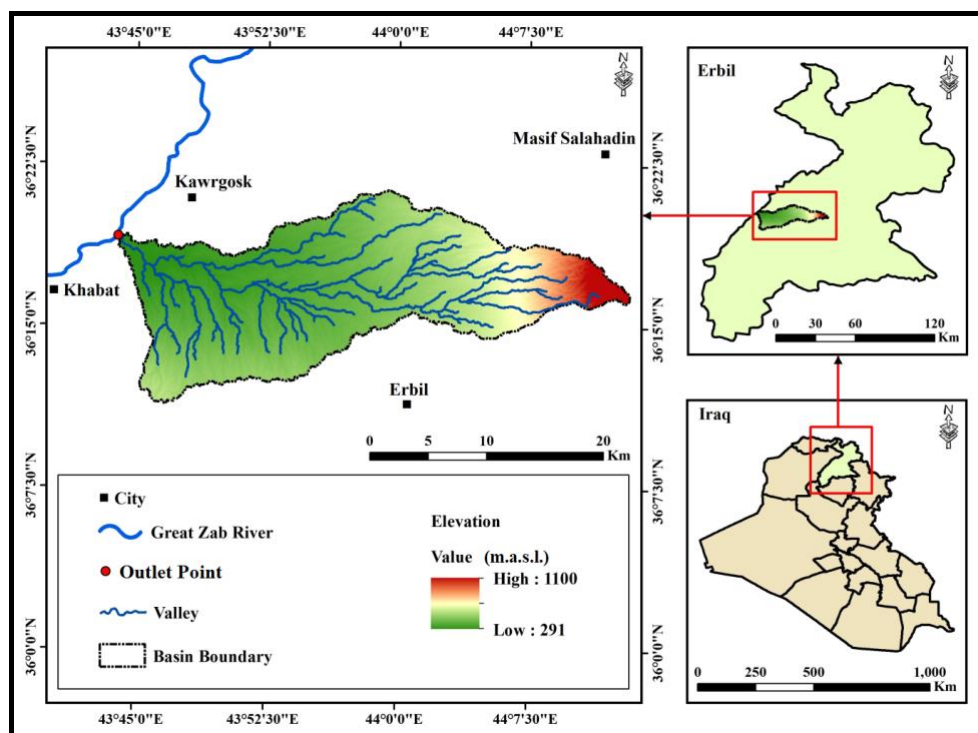


Fig.1. Location map of the study area

3. Materials and Methods

The Gavrilovi model is based on the analytical method and is one of the models suitable for estimating water erosion in damaged areas and major mountain basins (Globevnik et al., 2003), as well as a quantitative mathematical model that is dependent on a set of variables within the drainage basin and takes into account (rock composition, soil, vegetation cover, slope, Rainfall and temperature), and using a set of mathematical equations contained within the GIS software (Fig. 2). After analyzing the satellite visuals captured by the satellite (Landsat 8), the digital elevation model (DEM), soil and rock data, rainfall and temperature data, The annual soil erosion can be calculated using the equations proposed by Gavrilović in (1972) based on the EPM model:

$$W = T * H * \pi * \sqrt{Z^3} \quad (1)$$

Where :

W : The volume of soil erosion ($\text{m}^3/\text{km}^2/\text{year}$)

T : The coefficient of temperature ($^{\circ}\text{C}$)

H : The annual rainfall (mm)

Z : Erosion intensity

π : 3.14

$$T = \sqrt{\frac{C}{10} + 0.1} \quad (2)$$

Where :

C : The mean annual temperature ($^{\circ}\text{C}$)

$$Z = Y * Xa * (\psi + \sqrt{Ja}) \quad (3)$$

Where :

Y : The soil erodibility coefficient

Xa : The soil protection coefficient

$$Xa = (XaNDVI - 0.61) * (-1.25) \quad (4)$$

NDVI : Normalized difference vegetation index

ψ : The erosion coefficient of watershed

$$\psi = \sqrt{\frac{TM3}{Qmax}} \quad (5)$$

TM3 : Third range

Qmax : Maximum radiation value

Ja : The slope coefficient of watershed

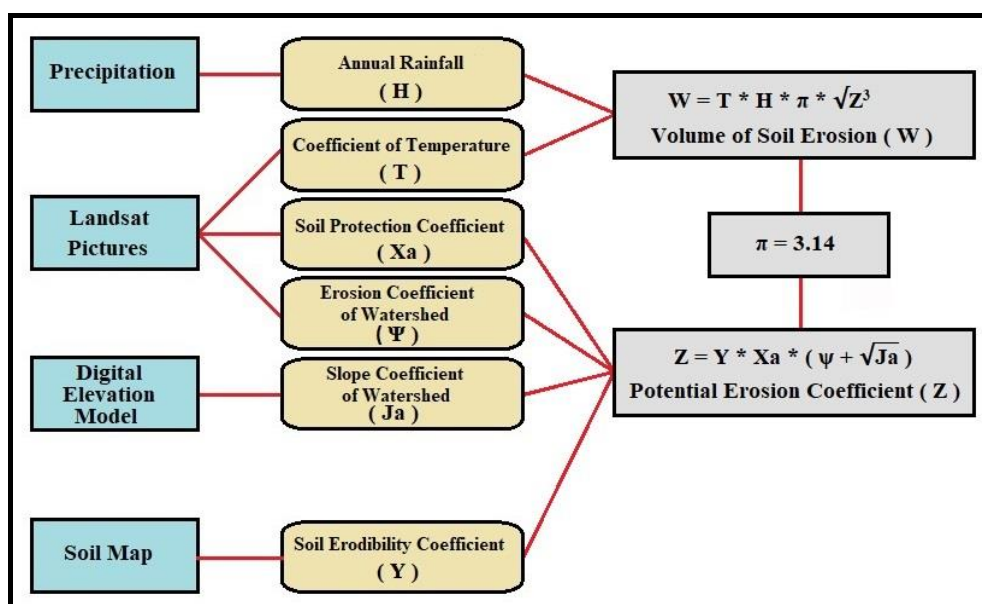


Fig. 2. The flowchart shows the application diagram of EPM

4. Results and Discussions

4.1. Basin Soil

Soil is a natural resource formed by the physical and chemical weathering of brittle rocks, particularly sedimentary rocks. Climate elements and the topography of the earth's surface have an impact on soil. It takes thousands of years to form and loses its components due to rapid water erosion, and the rates of formation do not compensate for this (Schultz et al., 2014). It was based on the classification map (FAO) in the study of the basin's soils with a scale (1:5000000), which is one of the world's most recent soil classifications (FAO, 2016). As shown in Table 1 and Fig. 3, the basin contained two types of soils: Chromic Vertisols and Calcic Xerosols. Soil, with its various qualities, influences the quality of water flow, particularly the size of its grains and its permeability. Clay soils are more useful in raising the amount of water erosion than loamy clay soil because they have low porosity and permeability, which prevents or minimizes water intrusion into the ground, It increases the amount

of rainfall that flows on the surface of the earth, which causes the flow its to become stronger and faster, especially in the study area's mountainous regions.

Table 1. Characteristics of the basin soils

Value	FAO Soil	Hydrologic Group	Texture Type	SNAM	Area (km ²)	Percent (%)
1	Chromic Vertisols	D	Clay	Vc1-3a-3276	285.066	71
2	Calcic Xerosols	D	Clay - Loam	Xk28-b-3300	117.638	29
Sum					402.704	100

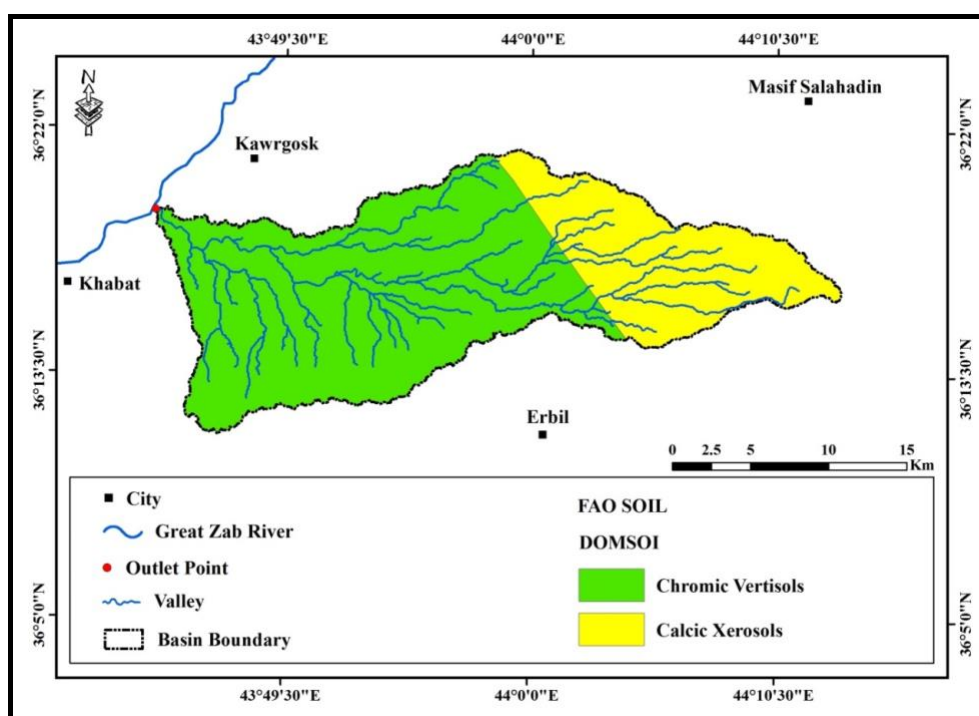


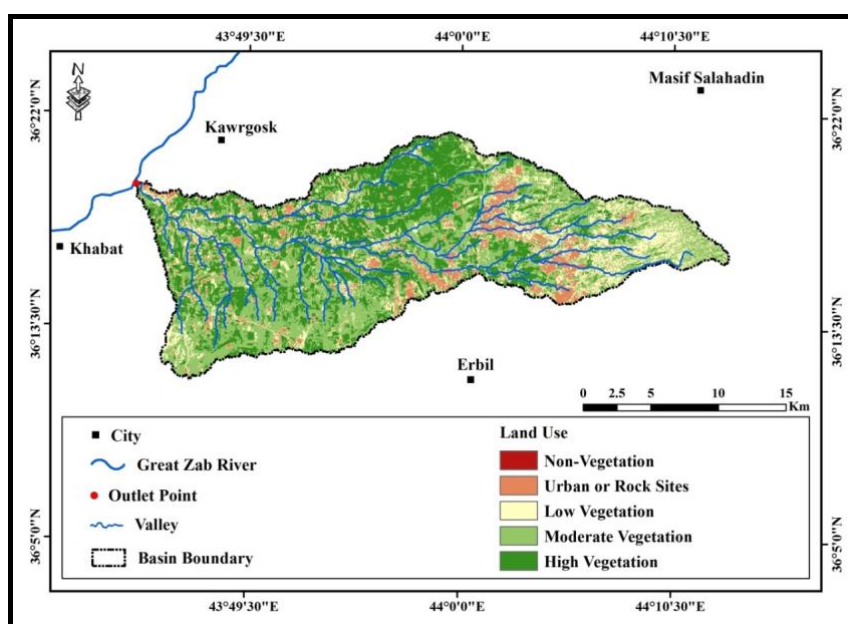
Fig. 3. Type of soils of the basin

4.2. Land Cover for Basin

Remote sensing technology is used within the GIS environment to determine the land cover of the basin using a set of modern satellite visuals, as the land cover plays a significant role in the variation in the quantities of sediments resulting from erosion and is dependent on changing the values of the soil protection factor according to the Gavrilovic model (Solaimani et al., 2009). The drainage basin's vegetation cover varies from region to another (Fig. 4) and works to reduce the intensity of erosion by protecting the soil from falling rains. Unlike areas covered by vegetation, areas devoid of it are vulnerable to erosion processes. By analyzing satellite images of the study area, the percentage of each land cover parameter was calculated (Table 2). It was found that the plain areas of the basin have a very high percentage of vegetation cover (90%), and this means that the amount of sediment resulting from it will be less than in the mountainous areas.

Table 2. Percentages and area of land cover for basin

Value	Land Use	Area (km ²)	Percent (%)
1	Non-Vegetation	0.038	0
2	Urban or Rock Sites	38.353	10
3	Low Vegetation	71.263	18
4	moderate Vegetation	168.083	41
5	High Vegetation	124.967	31
Sum		402.704	100

**Fig. 4.** Land cover of the basin

4.3. Precipitation

Rainfall plays a significant role in erosion processes and is regarded as the primary natural element for its occurrence, due to its relationship with slope, vegetation cover, geology, and soil, as rain showers sweep large amounts of soil, particularly in areas with steep slopes and little vegetation cover. Due to the lack of climatic stations near the study area, rainfall data was collected from ten climatic stations on the global website Power Data Access Viewer (NASA) during the period 2011-2020 (Table 3). Where annual precipitation within the drainage basin ranges from 422.598 – 569.113 mm, and where the amount of rainfall increases as we travel east (Fig. 5).

Table 3. Total annual precipitation for basin (mm)

Time interval	Number of stations	Longitude	Latitude	Annual rate
2011 – 2020	1	44.0625	36.3746	549.909
	2	44.3750	36.3746	570.690
	3	44.6875	36.3746	578.950
	4	44.3750	36.0624	491.602
	5	44.0625	36.0624	448.552
	6	43.750	36.3746	463.162
	7	43.750	36.0624	372.701
	8	44.6875	36.0624	466.014
	9	43.4375	36.0624	309.658
	10	43.4375	36.3746	430.023

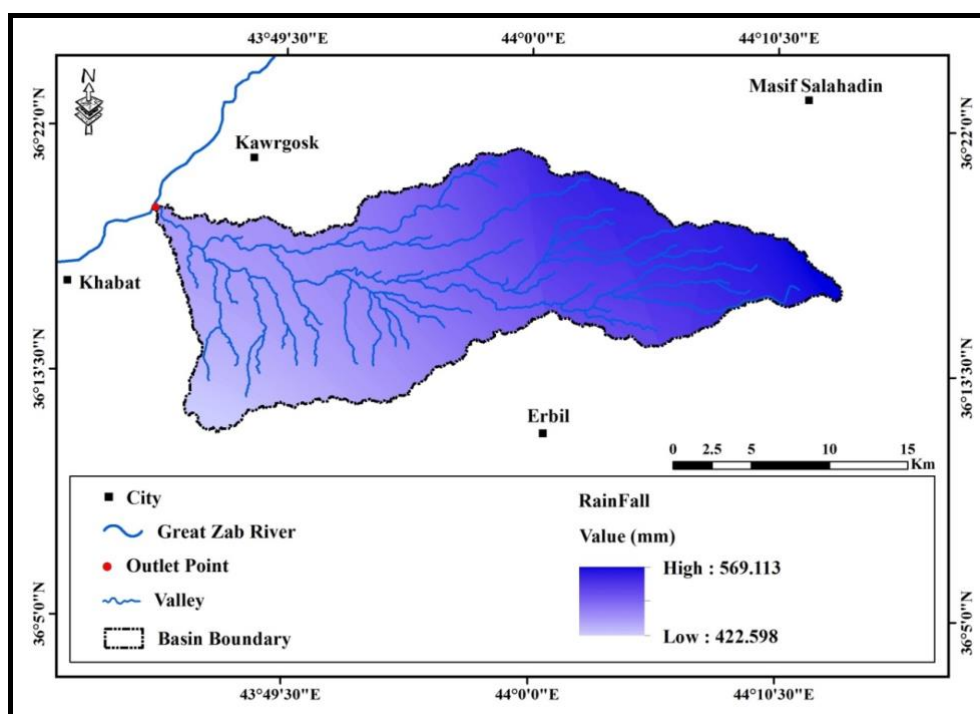


Fig.5. Annual precipitation map for basin

4.4. Temperature

Temperature is a significant element in the activity of erosion processes, with large variations in its values between seasons and daily rates during the day and night, since this fluctuation influences the components of soil and rocks, causing abrupt thermal changes in soil and rock masses. This causes it to peel, crack, and crush, making it more prone to erosion processes caused by falling rain and the ensuing flowing water, which causes heavy rain torrents of soil and rock pieces to form (Izeldeen and Jaza, 2011). Temperature data for the study area was obtained from (Nasa Power Data Access Viewer) website for the years (2011-2020), and it was discovered that there is a significant difference in maximum and minimum temperatures during the day and night, as well as a discrepancy in annual temperature rates (Table 4). Its temperature ranged between (21.245 - 36.678) degrees Celsius according on a recent satellite image for the year (2020) and through the (Arc GIs) software (Fig. 6).

Table 4. Average annual temperature for basin (C°).

Time interval	Number of stations	Max	Min	Median
2011 – 2020	1	33.582	8.745	21.163
	2	33.811	9.722	21.766
	3	33.219	8.952	21.085
	4	34.450	9.289	21.869
	5	33.805	10.261	22.033
	6	32.931	9.130	21.030
	7	33.996	9.977	21.986
	8	34.069	11.071	22.570
	9	31.910	10.2	21.055
	10	33.725	10.254	21.989
Average		33.549	9.760	21.654

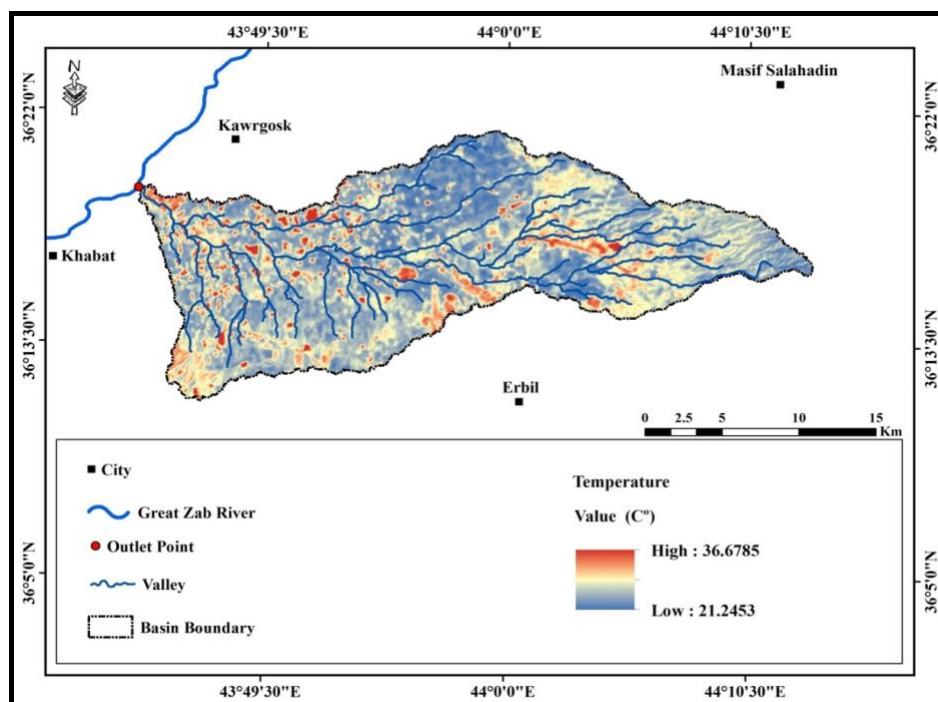


Fig. 6. Coefficient of temperature for basin

4.5. Qualitative Assessment of Water Erosion Using a Model (EPM)

The EPM model's application in estimating potential erosion is dependent on a large number of natural indicators of the drainage basin, including soil, rocks, slope, and vegetation cover, as well as field studies. Erosion levels are classified into five categories (Table 5) based on the value of Z which is calculated using equation No. 3.

Table 5. Potential levels of erosion according for value Z (Gavrilović et al., 2006)

Value	Potential level of erosion	Z	Value Medium
1	Very high	1.01 - (>1.51)	1.25
2	High	0.81 - 1.0	0.85
3	Moderate	0.41 - 0.80	0.55
4	Low	0.20 - 0.40	0.30
5	Very low	0.01 - 0.19	0.10

Where it extracts indices values (Y , X_a , ψ) Relying on a set of tables drawn up by the scientist Gavrilović and it was later modified by a number of researchers (Stefanovic et al., 2004; Zorn and Komac, 2005). The potential erosion factor was extracted within the geographic information systems environment by integrating a set of indicators for applying a model (EPM):

4.5.1. Soil erodibility coefficient (Y)

It is a measure of the extent to which soil particles accept erosion, separation, and transport through rainfall and runoff on the earth's surface (Chadli, 2016), and it is influenced by soil texture and composition, organic matter, and permeability (Stone and Hilborn, 2012). The Soil Erodibility Coefficient was determined using the soil map (FAO) in comparison with (Table 6), Its value in the basin ranged between (0.22) as the lowest value and (0.30) as the highest value (Table 7), i.e. between

resistance Medium erosion in the upper part of the basin to resistance High erosion in the middle and lower part of the basin (Fig. 7).

Table 6. Characteristics of soil erosion coefficient values (Lazarevic, 1985; Vente and Poesen, 2005).

Value	Soil erodibility coefficient	Y	Value medium
1	Hard rock, erosion resistant	0.1 - 0.3	0.2
2	Rock with moderate erosion resistance	0.3 - 0.5	0.4
3	Weak rock, schistose, stabilized	0.5 - 0.6	0.55
4	Sediments, moraines, clay and other rock with little resistance	0.6 - 0.8	0.7
5	Fine sediments and soils without erosion resistance	0.8 - 1.0	0.9

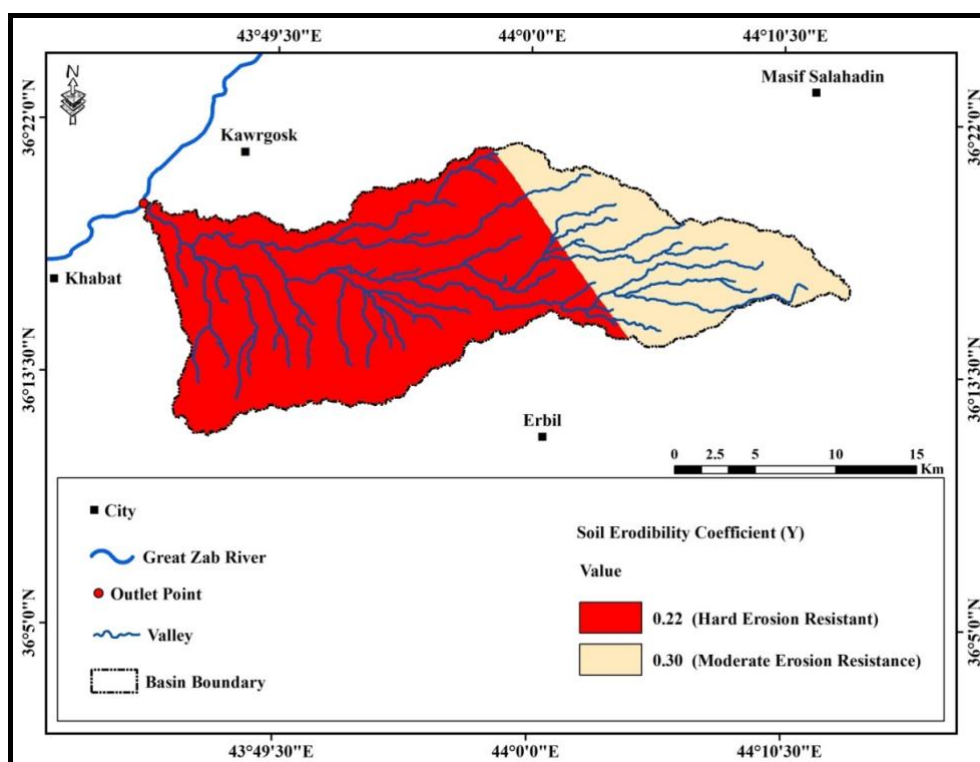


Fig. 7. Soil erodibility coefficient for basin

Table 7. Soil erosion coefficient for basin

Value	Texture Type	Soil composition			Y	Soil erodibility coefficient
		Sand	Silt	clay		
1	Clay	0 - 45	0 - 40	40 - 100	0.22	Hard Erosion Resistant
2	Clay Loam	20 - 45	15 - 52	27 - 40	0.30	Moderate Erosion Resistance

4.5.2. Soil protection coefficient (X_a)

According to the Gavrilović approach, the soil protection coefficient refers to plant land coverings that aid in soil stabilization by slowing the speed of water flow on the earth's surface, thereby increasing water penetration into the soil, and subsequently protecting the soil from erosion with flowing water (Al-Ghamdi, 2009). That is, the higher the vegetation density on the earth's surface, the better the soil

protection in the event of rainfall and the lesser the erosion processes. The value of this indicator in its relationship with soil loss was determined using satellite images (Landsat 8) and the criteria established by Gavrilović with a group of researchers (Table 8).

The value of this indicator ranged between (0.01 - 0.76) for the study area (Table 9), and there is a large variation in the value of this indicator, which explains the variation in the protective role of vegetation cover and soil uses in reducing or increasing the intensity of soil erosion within the drainage basin. It represents good soil protection and has a value less than (0.38), whereas rocky and barren areas devoid of vegetation have poor soil protection and have a value greater than (0.76), causing soil erosion when rainfall and water runoff within the basin (Fig. 8).

Table 8. Soil protection coefficient values (Lazarevic, 1985; Vente and Poesen, 2005)

Value	Soil protection coefficient	Xa	Value Medium
1	Mixed and dense forest - Thin forest with grove	0.05 - 0.2	0.125
2	Coniferous forest with little grove, scarce bushes, bushy prairie	0.2 - 0.4	0.3
3	Damaged forest and bushes, pasture	0.4 - 0.6	0.5
4	Damaged pasture and cultivated land	0.6 - 0.8	0.7
5	Areas without vegetal cover	0.8 - 1.0	0.9

Table 9. Soil protection coefficient for basin

Value	Soil protection coefficient	Xa	Area (km ²)	(%) Percent
1	Mixed and dense forest - Thin forest with grove	0.01	71.479	17.75
2	Damaged pasture and cultivated land	0.76	331.225	82.25
Sum			402.704	100

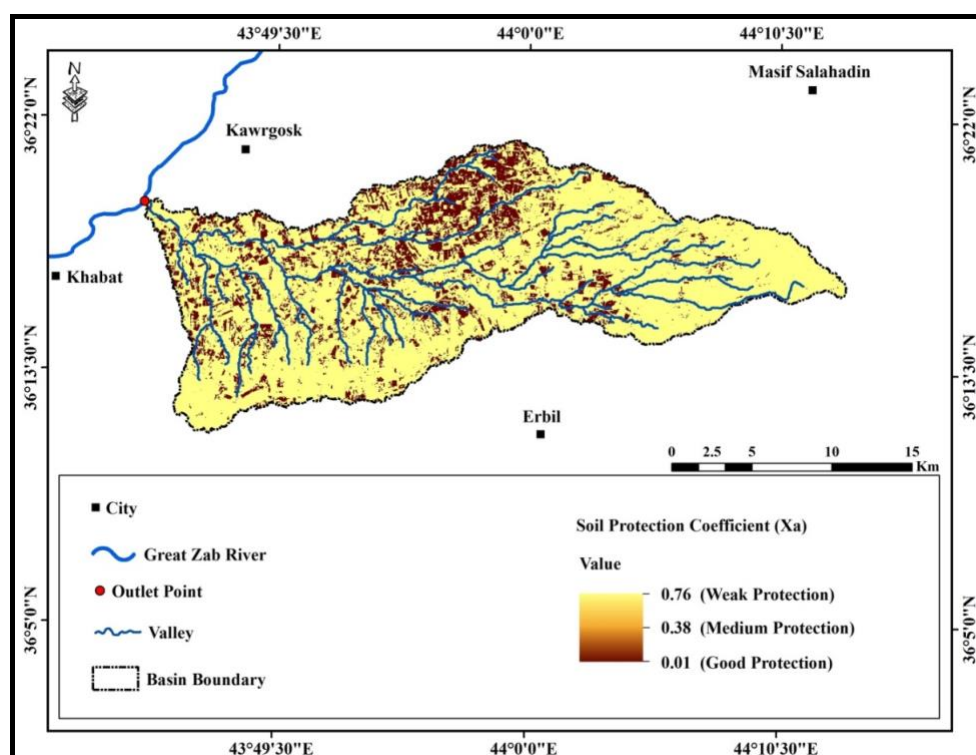


Fig. 8. Soil protection coefficient for the basin

4.5.3. Erosion development coefficient (ψ)

The values of this indicator vary depending on the size of the water basins, and its calculation necessitates a field study of the basin as well as the availability of high spatial accuracy satellite visuals (Jamal, 2015), and there is a special formula to measure this indicator by dividing the square root of the third range (TM3) by the maximum value of radiation (Q_{max}) (Milevski, 2008).

The value of this indicator was determined using Gavrilović's criteria and a group of researchers (Table 10). The value of this indicator ranged between (0.31) for areas with a low soil development coefficient, which included the majority of the basin areas due to the dense spread of vegetation, and (0.67) for areas with a high soil development coefficient, which included only a small portion of the drainage basin (Fig. 9).

Table 10. Characteristics of erosion development coefficient values (Lazarevic, 1985; Vente and Poesen, 2005).

Value	Erosion development coefficient	Ψ	Value Medium
1	Little erosion on watershed	0.2 - 0.1	0.15
2	Erosion in waterways on 20-50% of the catchment area	0.3 - 0.5	0.4
3	Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6 - 0.7	0.65
4	50-80% of catchment area affected by surface erosion and landslides	0.8 - 0.9	0.85
5	Whole watershed affected by erosion	1.0	1.0

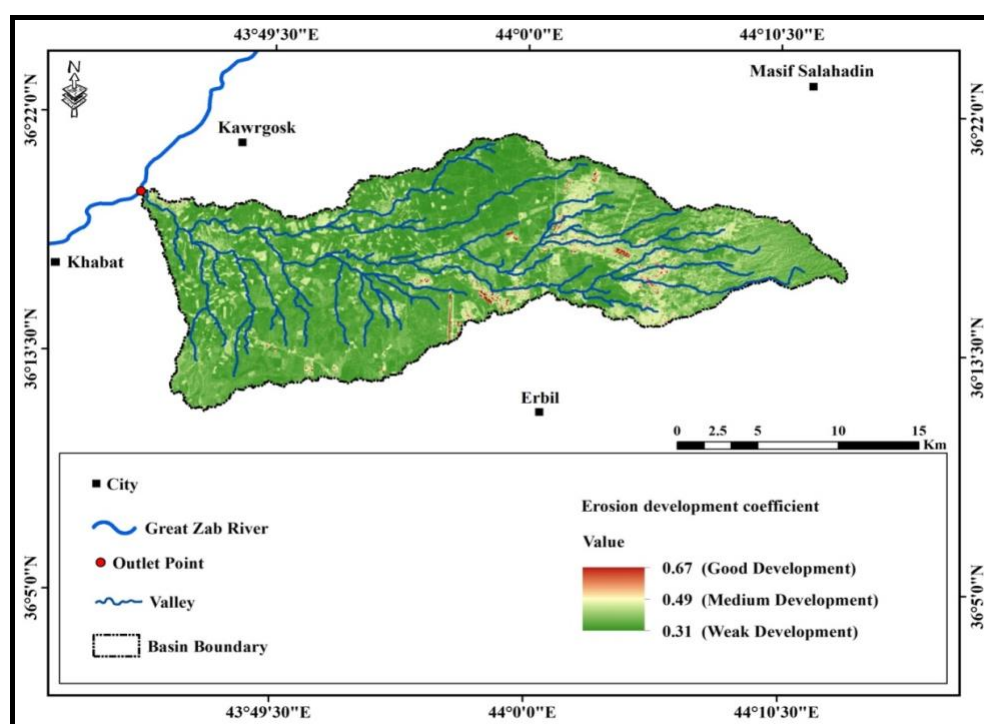


Fig. 9. Erosion development coefficient for the basin.

4.5.4. Slope coefficient of watershed (J_a)

The slope factor has a direct effect on water erosion processes because the greater the degree and length of the land's gradient, the greater the risk of erosion (Stone and Hilborn, 2012). The basin's slope

coefficient was extracted using the software (Arc GIS) and based on a digital elevation model (DEM) with a discriminatory accuracy of (14) meters (Fig. 10). According to the classification of (ITC), the slope of the basin was classified into five main classes, and the results showed The classification is that the majority of the basin's area ranges between (4.8-0) degrees and at a rate of approximately (85%), as it is flat to slightly sloping (Table 11).

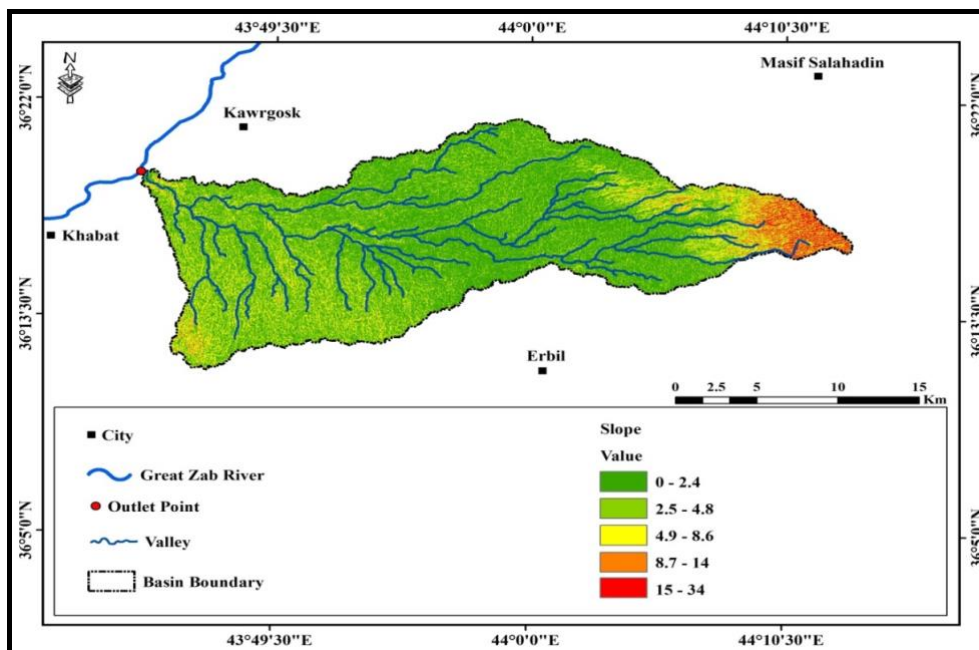


Fig. 10. Slope of basin.

Table 11. Slopes characteristics of the basin

Value	Slope class (%)	Description ITC	Area (km ²)	Percent (%)
1	0 - 2.4	Flat or almost flat	168.944	41.952
2	2.5 - 4.8	gently sloping	173.016	42.963
3	4.9 - 8.6	Sloping	44.427	11.0323
4	8.7 - 14	Moderately steep	12.072	2.997
5	15 - 34	Steep	4.245	1.054
Sum			402.704	100

After calculating the values of each soil erodibility coefficient, soil protection coefficient, erosion development coefficient, and slope, the erosion potential coefficient (Z) was calculated within the geographic information system environment by integrating all of the above indicators (Fig. 11) , It was found from the results of the qualitative evaluation of water erosion, according to the application of a model (EPM) and Table 5 about being (54.830%) from the area of the drainage basin is within the range of weak to very weak potential erosion, and by area (220.802) km², This range includes low-slope plains, which are characterized by dense vegetation cover, and medium erosion range form (31.116%) from the total area of the basin, and by area (125.306) km², This range prevails in areas with medium-altitude slopes near the water valleys, which run on the various river sediments. While the range of erosion included strong to very strong (14.054%) from the total area of the basin, and by area (56.596) km², Where this range is found in the upper parts of the basin, which is characterized by steep slopes and non-existent or very little vegetation cover, as the speed of the water current is very high in the stomachs

of mountain valleys descending from the peaks of the highlands and works on the erosion of fragile rocks and soil.

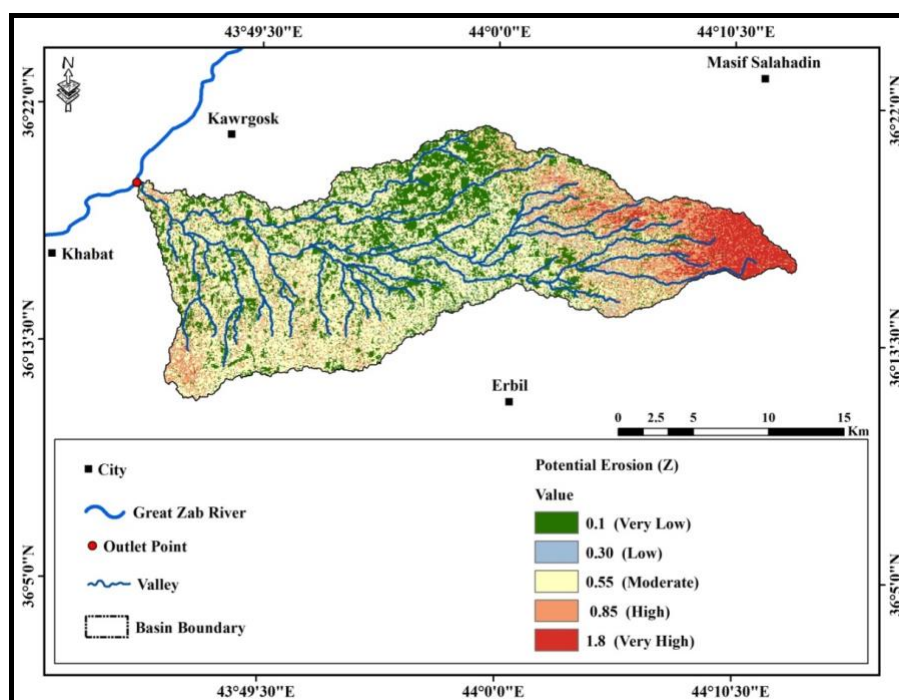


Fig. 11. Potential erosion of the basin

4.6. Quantification of Water Erosion Using a Model (EPM)

The erosion quantification methodology is based on a set of natural changes within the drainage basin that take into account (slope, vegetation, rocks, soil, precipitation, temperature), and the results obtained from this method were compared with the results of field measurements and found to be very similar (Gavriločić et al., 2006). The weak annual erosion rates are less than $(500) \text{ m}^3/\text{km}^2/\text{year}$, and exceeds high annual erosion rates $(800) \text{ m}^3/\text{km}^2/\text{year}$, according to the results of the EPM (Milevski, 2008). Water erosion levels are classed by the volume of soil lost (W) into six classes (Table 12) It is calculated using equation No. 1.

Table 12. Levels of water erosion according to loss soil volume (Zachar, 1982)

Value	Soil volume loss ($\text{m}^3/\text{km}^2/\text{year}$)	Erosion intensity	loss soil volume for basin	
			Area (km^2)	Percent (%)
1	< 50	Absence of erosion	107.542	26.705
2	50 – 500	Weak erosion	176.748	43.890
3	500 – 1500	Moderate erosion	84.282	20.929
4	1500 – 5000	Severe erosion	23.206	5.762
5	5000 – 20000	Very severe erosion	10.927	2.713
6	> 20000	Catastrophic	-	-

Varied size of the soil lost in the drainage basin and calculated in a way (EPM) from $0.056\text{--}6900 \text{ m}^3/\text{km}^2/\text{year}$ (Fig. 12), Where it included areas where there is no erosion approximately (26.705%) From the total area of the basin due to the levelness of the land and the density of high vegetation cover,

while areas with low erosion reached 43.890%, the areas with moderate erosion reached (20.929%), the severe erosion was within the limits of 5.762% and very severe up to 2.713%, which included areas with steep slopes and devoid of vegetation specifically the upper parts of the basin.

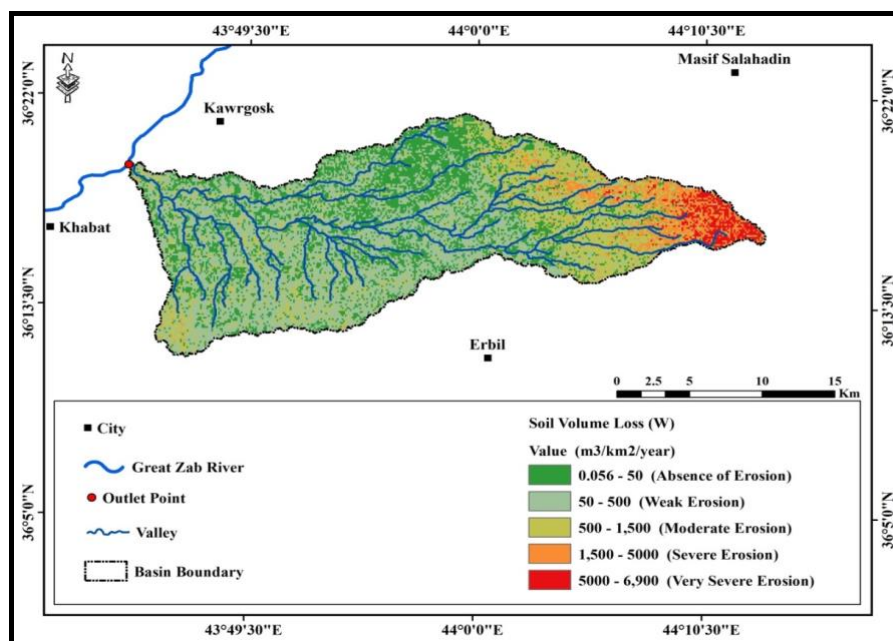


Fig. 12. Volume of soil erosion of the basin

The annual average of water erosion is estimated at about $(797.434) \text{ m}^3/\text{km}^2/\text{year}$, and this value expresses the average level of erosion compared to the table above, and the value has been multiplied by the area of the drainage basin to get the volume of the eroded soil from the basin, which amounted to about $(321129.861) \text{ m}^3/\text{year}$.

5. Conclusions

The application of EPM with the using of geographic information systems and remote sensing showed great possibilities in estimating the volume of water erosion within the drainage basin. Rainfall played a major role in soil erosion due to water erosion within the drainage basin. The terrain played an effective and influential role in the process of soil erosion, as the mountainous areas were characterized by severe slopes and a lot of rainfall, which resulted in severe to very severe levels of erosion, while the plain areas were characterized by few slopes that witnessed weak levels of erosion to the absence of erosion. The areas with high vegetation density represented good soil protection and its value was less than 0.38 while the rocky and barren areas devoid of vegetation had poor soil protection and its value was 0.76. The volume of soil lost in the drainage basin varied from $0.056\text{--}6900 \text{ m}^3/\text{km}^2/\text{year}$. The levels of erosion in the basin were classified according to the values of the potential erosion factor into five different categories. The first category included the absence of erosion at a rate of 26.705% of the total area of the basin, and the second category is low erosion at a rate of 43.890%, while the third category is medium erosion with a rate of 20.929%, the fourth category included severe erosion at a rate of 5.762%, and the fifth category was very severe erosion with a percentage of 2.713%. The annual average of water erosion was estimated at $797.434 \text{ m}^3/\text{km}^2/\text{year}$, and the annual volume of the eroded soil in the basin was about $321129,861 \text{ m}^3$.

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