

Soil Erosion in Al-Adhaim River Basin, Central Part of Iraq

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How to cite this paper: Al-Ansari, N., Sissakian, V.K. and Elias, Z. (2025) Soil Erosion in Al-Adhaim River Basin, Central Part of Iraq. *Engineering*, 17, 207-221.

<https://doi.org/10.4236/eng.2025.173013>

Received: December 23, 2024

Accepted: March 18, 2025

Published: March 21, 2025

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Abstract

Al-Adhaim River is one of the main tributaries of the Tigris River, it has three main tributaries: Khassa Soo, Aq Soo, and Tuz Chia, all of which are seasonal streams. The course of Al-Adhaim River and its three tributaries flow in a very rugged topography, especially in the upper courses with high gradients. The exposed rocks in the catchment area are mainly soft claystone rocks with coarse conglomerate and sandstone, which are very easily eroded by the running water, especially during floods. We have used SRTM images of ground resolution of 3-arc-second (90 m) and a vertical resolution of approximately 10 m to divide the catchment area into 14 sub-basins using ArcGIS (Arc map). Moreover, many factors concerning soil erosion were calculated, such as drainage density, erosion intensity, erosion rates, and soil erodibility. We have found that the drainage density ranges between (0.26 - 0.39) km/km² with class Poor, the Erosion Intensity ranges between (264 - 387) m/km² with Very poor zone, the Erosion rates (K_e) ranges from (0.01 - 0.325), and the Erosion Coefficient ranges from (0.7 - 1.0).

Keywords

Erosion, Erosion Intensity, Drainage Density, Soil Erodibility, Al-Adhaim River

1. Introduction

The catchment (Basin) area of Al-Adhaim Basin occupies the central part of Iraq (**Figure 1**), with coverage area of 12323.390 km². We have chosen Al-Adhaim River for our study because it is a very erodible river and supplies the Tigris River with the maximum transformed loads as compared to the remaining tributaries [1].

Moreover, due to the diversity of the exposed rocks in the basin and diversity of topography, the basin extends into three different tectonic zones.

Al-Adhaim River consists of three main tributaries named: Khassa Soo, Tawooq (Aq or Daqooq) Soo, and Tuz Chai. The Tawooq Soo is the longest one and extends in the northern part of the catchment area within the High Folded Zone; there it is called Tinal Stream.

The three rivers meet and run parallel to Himreen Range; there it is called Wadi Ezghytoon (**Figure 1**). After crossing Himreen Range, it is called Al-Adhaim River (**Figure 1**). The length and width of the three main tributaries are 90 km (0.1 - 1.1), 178 km (0.1 - 1.4), and 138 km (0.1 - 1.0), respectively. The total length of Al-Adhaim River is 330 km and merges with the Tigris River northwest of Baghdad by about 70 km. Floods take place from November to May each year, as they are mainly fed by rainfall. However, during the last 2 decades, flooding events have been very rare due to drastic climate change.

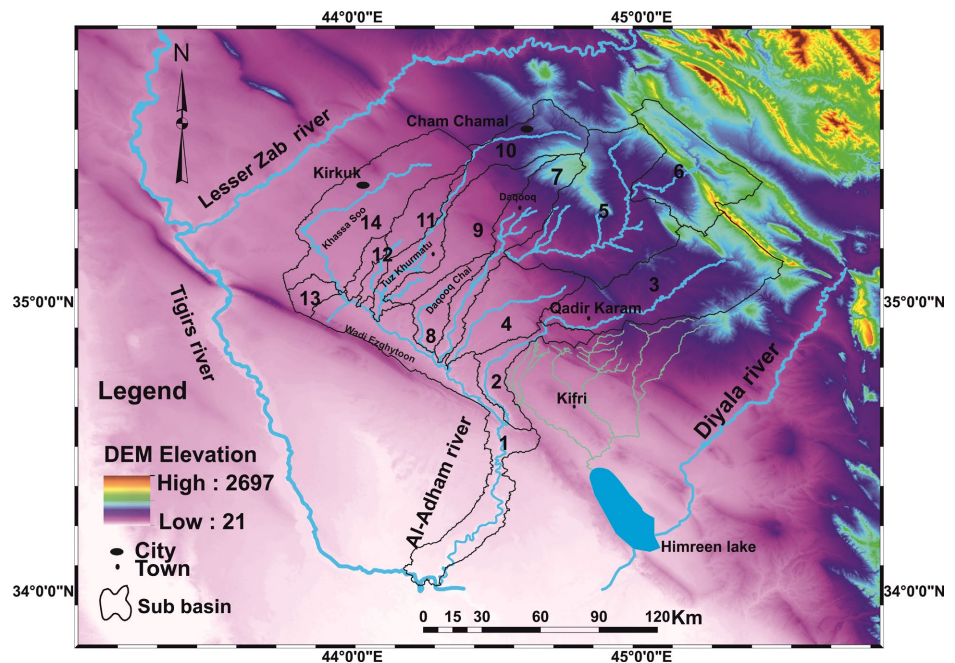


Figure 1. Location of catchment area of Al-Adhaim River divided into 14 sub-basins.

Recently, Adhaim Dam was constructed in 20,000, it is a multi-purpose embankment dam about 133 km northeast of Baghdad. The purpose of the dam is flood control, hydropower and irrigation. The dam has decreased load supply to the Tigris River as well as decreased erosion capacity downstream of the dam.

Research concerning soil erosion in Iraq and particularly in Al-Adhaim River Basin is very rare. The pioneer work of [1] is the most comprehensive performed work as soil type and erosion are concerned. According to Gibbs (1954) in [1], the Adhaim river was the main contributor of sediment. In 1938, the Tigris River carried 24 million m^3 , with 10 million m^3 being carried during the peak flood. [2] studied the climate change impact on the water resources of Al-Adhaim River. [3]

studied the impact of climate change on soil erosion in India, and we have adopted many parameters from their study. [4] carried out statistical analysis of the relation between tectonics and drainage behavior in India, and we have adopted many parameters from their study. [5] studied the rainfall-runoff modelling in Al-Adhaim River Basin to indicate the curve number. [6] studied modification of the spill way in Al-Adhaim Dam and presented Land-Use and Land-Cover (LULC) map (**Figure 2(a)**), and a spatial distribution of sediment sources (S S) map in the Adhaim watershed (**Figure 2(b)**).

The aim of this study is to indicate the drainage density, the erosion intensity, the erosion rates, and the erosion coefficient in Al-Adhaim River Basin. Besides, indicating galley erosion by total gully lengths, sheet erosion per erosion intensity, soil erodibility, and soil types and erosion rates.

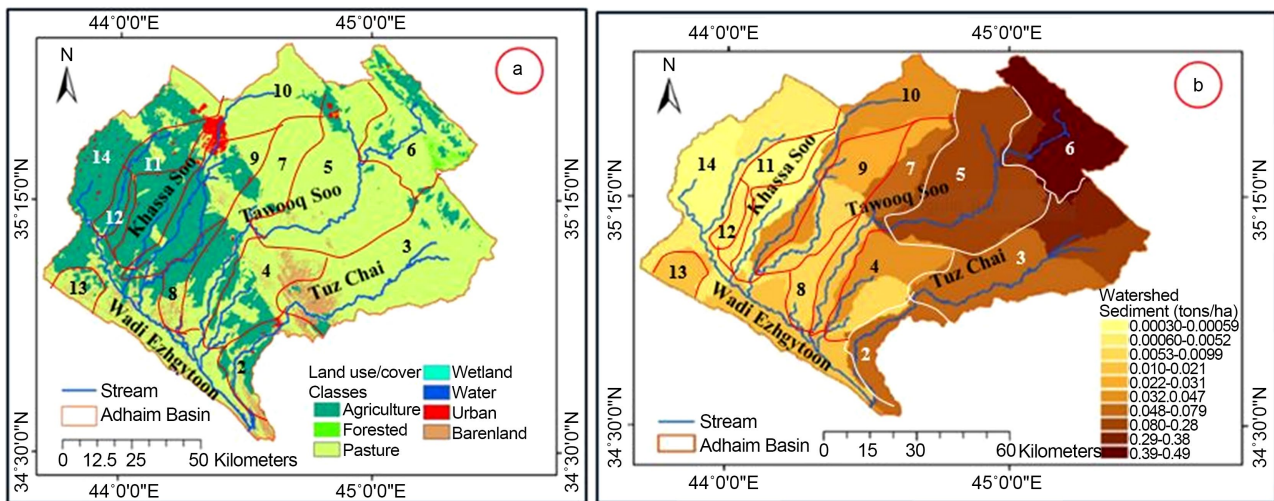


Figure 2. (a) Land-use and land-cover map, (b) Spatial distribution of sediment sources in the Adhaim watershed map (both modified from [6]). The limits of the 14 sub-basins are imposed by the authors.

2. Data Used and Methodology

To indicate the required data and fulfill the aim of the current study, we have used satellite images of SRTM type with ground resolution of 3-arc-second (90 m) and a vertical resolution of approximately 10 m. We also have divided the catchment area of Al-Adhaim River into 14 sub-basins using ArcGIS (Arc map) (**Figure 1**) to calculate the area of each sub-basin and the stream lengths, and to impose the 14 sub-basins on the land-use land-cover map (**Figure 2(a)**) and the sediments source map (**Figure 2(b)**). Moreover, we have used different geological and topographical maps, and different published articles to calculate many factors concerning soil erosion, such as drainage density, erosion intensity, erosion rates, soil erodibility... etc.

We have calculated the drainage density according to the following equation:

$$Dd = Lu/Ba \quad [7]$$

where: Lu = Total stream length of all orders (km);

Ba = Area of the basin (km²).

The Erosion Intensity was calculated by the following equations:

$$AE = \Sigma L/A \text{ [8]}$$

where: AE = Erosion intensity;

L = Total length of the streams in the basin (m);

A = Total coverage area of the basin (km²).

We also have calculated erosion rate (K_k) and soil erodibility based on [3]. Based on [9], we have calculated erosion coefficient (Φ), sheet erosion and gully erosion; both were classified into 6 classes; each based on [4].

Although climatic factors (especially Rainfall) play a big role in the erosion intensity and rate; however, we didn't consider the role of the rain fall because the majority of the basin is located in the same climatic zone. Therefore, the amount of the rainfall is almost the same in the whole basin, which means it has the same effect on the erosion in the whole basin.

The study area is located in the central part of Iraq (**Figure 1**) and covers about 12323.390 km². Al-Adhaim River flows almost in the central part of the study area, whereas the three main tributaries are well distributed in the area (**Figure 1**).

3. Geological Setting

Three main aspects of the geology of Al-Adhaim River catchment area are briefed hereinafter.

3.1. Geomorphology

The main geomorphological units and geodynamical processes are briefed hereinafter.

3.1.1. Geomorphological Units

- Units of Fluvial Origin

Terraces (Pleistocene): Usually two stages of terraces occur along the courses of the three tributaries. The main components are carbonates, silicates, and rare igneous and metamorphic rocks. The thickness ranges from (1 - 5) m.

Alluvial Fans (Pleistocene): In the outlets of the three tributaries from highlands, three alluvial fans are developed. The main components are sandy silt, underlain by gravels of different sizes.

Alluvium: Alluvium sediments cover the western part of the Al-Adhaim Basin. They are in form sheet run-off, flood plain and valley fill sediments.

Valley Fill: The three tributaries of the Adhaim River are filled by thick sediments. The pebbles are of carbonates, silicates, and rare igneous, and metamorphic rocks. Other main valleys are filled by valley fill sediments. The thickness of these sediments varies between (<1 - 5) m. The sediments are largely quarried for sand and gravels, in the three tributaries.

Flood Plain: The three tributaries and the main valleys have developed considerable flood plains along their courses. Locally, two stages are developed, with

height difference of (1 - 2.5) m. The components of the sediments are fine sand, silt and clay, with very rare fine pebbles. The thickness of the sediments varies between (<1 - 3) m.

- Units of Structural-Denudational Origin

Dissected Slopes: These are not well developed in the studied area. They are well developed in areas built up by rocks of the Bai Hassan Formation. The dip slopes are densely dissected by valleys.

Anticlinal Ridges: They are well developed in the rocks of the Injana and Mukdadiya formations. Due to existence of alternation of hard and soft rocks, strike ridges and valleys are developed, with parallel drainage pattern.

Badlands: These are the very well developed in the studied area and cover large parts, mainly in areas built up by the rocks of the Bai Hassan Formation (**Figure 3**).



Figure 3. Typical badlands east of Kirkuk city; within the rocks of the Bai Hassan Formation.

Hogbacks and Cuestas: These are locally developed in the studied basin within the Fatha Formation. The alternation of the folded hard and soft rocks has developed typical flat tops, which in turn have developed successive hogbacks and cuestas.

- Units of Denudational Origin

Pediments: These are present in different parts of the studied area, developed in form of thin belts surrounding the higher areas, slopes and ridges. Mainly consist of the pebbles derived from the Bai Hassan Formation or of carbonate rock fragments, well cemented.

- Forms of Solution Origin

These units include sinkholes, which are developed in gypsum and limestone beds. The sinkholes are developed in different shapes and sizes; usually (1 - 8) m in aperture size and (1 - 5) m in depth. Some small caves are developed with different sizes.

3.1.2. Geodynamical Processes

Land Slides: These formed along the cliffs of the Pila Spi Formation. The size of the

slid masses reaches up to a few hundred cubic meters.

Toppling: This is well developed along the hard sandstone ridges of the Mukdadiya and Injana formations, and partly along Pila Spi Formation. The size of the toppled blocks varies between ($<0.3 - 2$) m³.

Creep: This is a very rare phenomenon along the slopes of the Bai Hassan, Gercus, and Kolosh formations. Usually, step forms are developed, and the height of the steps ranges from (5 - 30) cm.

3.1.3. Weathering and Erosion

These phenomena are very active in Al-Adhaim River Basin. Different types of both phenomena with different agents are developed, they are described hereinafter, briefly.

- **Weathering:** The clastic rocks are the most common rocks, that are exposed in Al-Adhaim River Basin; therefore, mechanical weathering is more active. The presence of Badlands (**Figure 3**), which cover large parts of the basin is a good indication for the mechanical weathering, besides the dense drainage system. However, chemical weathering is active only in small parts, especially those covered by carbonates and gypsum of the Pila Spi and Fatha formations, respectively. In the former, the carbonate beds are cavernous and karstified, whereas in the latter, different karst forms are developed in gypsum beds, like sinkholes and caves.
- **Erosion:** The main erosion agent in Al-Adhaim River Basin is the water. The three main types of erosion are Gully, Rill, and Sheet. Gully erosion is well developed in the courses of the three main tributaries and other main valleys, where water gaps and gorges are developed. Rill erosion is developed on soft rocks, like claystone. Sheet erosion is well developed, especially in flat areas, when are covered by soil.

3.2. Stratigraphy

The exposed formations are presented in **Figure 4**, whereas the geological map is shown in **Figure 5**. The Quaternary sediments are described in more detail. All presented data are based on [10].

Formation	Age	Thick. (m)	General Description
Bai Hassan	Pliocene – Pleistocene	500 - 700	Coarse conglomerate and reddish-brown claystone
Mukdadiya	Late Miocene – Pliocene	400 - 600	Grey sandstone alternated with claystone; some sandstone beds are pebbly
Injana	Late Miocene	300 - 450	Reddish-brown sandstone, siltstone, and claystone, in rhythmic cycles
Fatha	Middle Miocene	250 - 450	Green marl, limestone, and gypsum in rhythmic cycles
Pila Spi	Upper Eocene	80	Well bedded limestone, dolostone and rare marl
Khurmala	Paleocene	50	Well bedded limestone
Kolosh	Paleocene	350	Black claystone, sandstone, and rare conglomerate

Figure 4. Generalized columnar section of the exposed formations in Al-Adhaim River Basin.

In Al-Adhaim River Basin, the following Quaternary sediments of the Pleistocene and Holocene ages are developed. These are:

Terraces (Pleistocene): These are developed along the courses of the Kassa Soo, Tawooq Soo, Tuz Chai, and Al-Adhaim River. The type of the sediments and their thicknesses are the same as those of the alluvial fans.

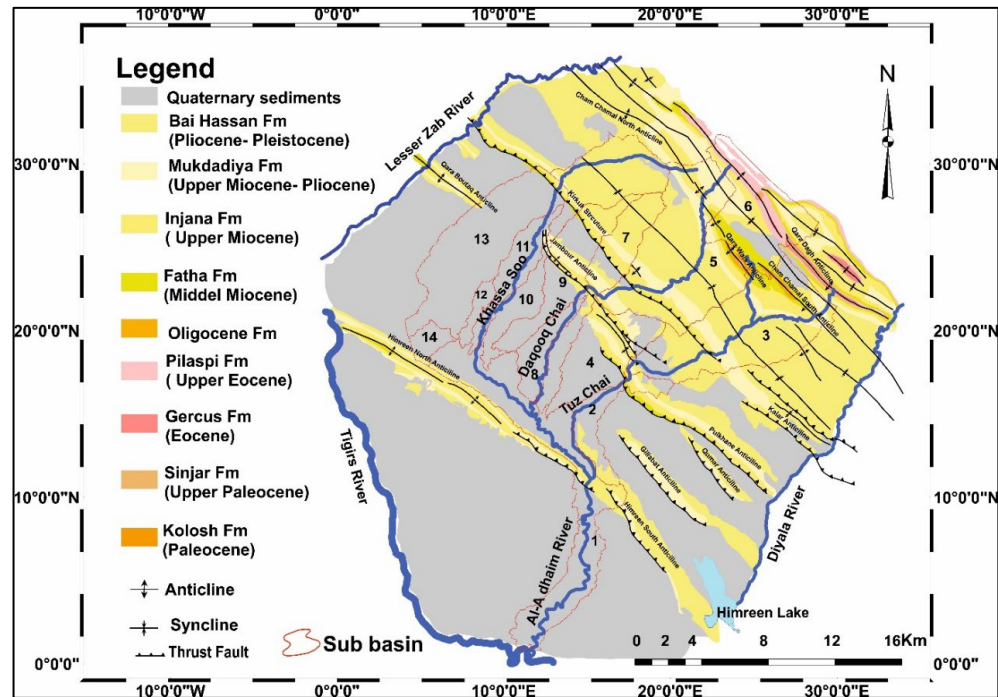


Figure 5. Geological map of Al-Adhaim River Basin and surrounding areas showing the 14 sub-basins (modified from [10]).

Polygenetic Sediments (Pleistocene-Holocene): These sediments are developed in the areas covered by the rocks of the Bai Hassan Formation, especially in topographically low areas. The main composition is pebbles with rock fragments of different sizes and types, mainly covered by a thin mantle of gypcrete. The thickness ranged from (1 - 10) m.

Alluvial Fan Sediments (Pleistocene-Holocene): The remnants of the alluvial fans are preserved in different parts of the studied area. They are in the form of small plateaus and/or mesas, covering the folded rocks of pre-quaternary formations. The main composition of the rock fragments and/or pebbles consists of different rocks in different shapes and sizes, which are cemented by calcareous and sandy cement. In the outlets of the three tributaries from the hilly and mountainous areas; alluvial fans are developed. However, the alluvial fans are almost vanished, this is attributed to erosion and man activities. The thickness is a few meters; locally it may attain even more than 10 m.

Valley Fill Sediments (Holocene): These sediments are very deposited in the courses of the three main tributaries of the Adhaim River, and usually consist of pebbles of different sizes which range from a few centimeters up to (15 - 25 cm)

and rock types, mainly limestones, dolomite, silicates, and rare igneous and metamorphic rocks. The thickness ranges from (<1 - 5) m, and maybe more.

Flood Plain Sediments (Holocene): These sediments are deposited along the three main tributaries of Al-Adhaim River; consist mainly of sand, silt, and clay. Some fine pebbles may rarely occur. The thickness varies between (<0.5 - 1.5) m, locally is more.

3.3. Tectonics and Structural Geology

Al-Adhaim River's basin extends mainly within the Low Folded Zone. However, the extreme northern and southern parts of the basin are within the High Folded and Mesopotamian zones, respectively. The three tectonic zones are part of the Unstable Shelf of the Arabian Plate (Jassim and Goff 2006). According to [11], however, the three zones belong to the Outer Platform of the Arabian Plate. The zones are part of the Zagros Fold-Thrust Belt. Many anticlines and synclines are developed within the basin area in NW-SE trend. The northeastern limbs are usually thrust over the southwestern limbs; accordingly, large parts of the anticlines are hindered below the thrust part. Some synclines are unique in the form of hanging synclines, like Khal Khalan and Taqaltu. The main anticlines in the basin are, from the north to the south: Qara Dagh, Darbandi Bazian, Aj Dagh, Qara Wes, Cham Chamal, Taq Taq, Kirkuk, Chia Surkh, Jambour, Pulkhana and Gilabat (**Figure 5**).

4. Results

4.1. Drainage Density

Drainage density is defined as the ratio of the total length of channels of all orders in the basin to the drainage area of any basin [7]. The Drainage density as an index of closeness of spaces in a channel [7] is affected by many factors; climate, lithology, vegetation, and geological conditions of the area [12]. The characteristics of stream length are controlled by resistance to weathering, climate, vegetation, permeability of rock, etc. It is an indicator of the nearness of channel spacing, which provides measurable data about the average stream channel length for the whole basin. It can be calculated according to the following equation:

$$Dd = Lu/Ba [7]$$

where: Lu = Total stream length of all orders (km);

Ba = Area of the basin (km²).

According to Deju (1971) in [13], the drainage density is divided into three types depending on the Dd values: Poor (0.5), Medium (0.5 - 1.5), and Excellent (1.5). Whereas [4] considered that High drainage density refers to a basin with high relief accompanied by hard rocks, whereas low drainage density points to the reverse case indicating a basin with low relief and low surface topography. Reviewing the acquired data in **Table 1**; as far as the drainage density is concerned, we can see that all 14 sub-basins showed Poor drainage density since the values range from (0.26 - 0.39).

Table 1. Different calculated data at the 14 sub-basins of Al-Adhaim River Basin.

Sub-basin No.	Area (km ²)	Stream Length (m)	Drainage Density		Erosion Intensity		Tectonic Zone	Main Lithology
			Value (km/km ²)	Class (After Deju 1971)	Value (m/km ²)	Zone (After [8])		
1	1551.826	498860.687	0.32	Poor	321	Very Low	Mesopotamia	
2	419.619	127462.205	0.30		304		Low Folded	
3	347.786	526050.420	0.31		307		High Folded	
4	1368.579	299551.114	0.36		361		Low Folded	
5	57.663	578669.670	0.32		316		High Folded	
6	1776.464	728.137	0.26		264		Low Folded	
7	296.284	269970.426	0.38		379		High Folded	
8	723.192	100841.618	0.31		310		Low Folded	
9	324.819	296754.646	0.37		372			
10	796.738	311889.374	0.33		327			
11	953.566	152367.592	0.37		370			
12	411.505	43010.444	0.36		359			
13	119.954	56834.594	0.39		387			
14	146.894	493228.607	0.34		336			
14	1468.707	493228.607	0.34	336				

4.2. Erosion Intensity

Erosion intensity represents the ratio between the total length of a basin to its total area, it can be calculated by the following equations:

$$AE = \Sigma L/A \text{ [8]}$$

where: AE = Erosion intensity (average erosion);

L = Total length of the streams in the basin (m);

A = Total coverage area of the basin (km²).

Following the classification of [8] for the erosion intensity given in Table 2 and considering the acquired values of erosion intensity presented in Table 1, all sub-basins show Very Low erosion intensity.

Table 2. Classification of erosion intensity after [8].

Class	Erosion Intensity (m/km ²)	Erosion Zone
1	1 - 400	Very Low
2	401 - 1000	Low
3	1001 - 1500	Moderate
4	1501 - 2700	High
5	2701 - 3700	Very High
6	3701 - 4700	Extremely High
7	>4700	Very Extremely High

From reviewing the topographic and geological maps, besides satellite image interpretations, all 14 sub-basins exhibit Gully erosion. Considering the Gully erosion's classification given by [4] (Table 3) and comparing them with the estimated values of the erosion intensity (Table 1), then all 14 sub-basins show Slight erosion intensity because the erosion intensity ranges between (264 - 387) m/km² (Table 1 and Table 3).

The sheet erosion is active only in sub-basins Nos. 1, 12, and 14, in other sub-basins is less active; as deduced from the topographic maps at a scale of 1:100000 and geological maps of the same scale, besides interpretations of satellite images. We have considered the classification of [4] for the sheet erosion, which depends on the erosion intensity (Table 4). We have used the data of [6] (Figure 2(b)) and converted the used unit (ton/ha) to m³/ha. This was done by dividing the weight of the soil by the density, considering the average soil density is 1400 kg/m³.

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Table 3. Classification of the gully erosion by total gully length (after [4]).

Grade	Erosion Intensity		Verbal Assessment	Sub-basin No.
	(km/km ²)	m/km ²		
1	<0.10	<100	No erosion or insignificant erosion	
2	0.10 - 0.50	100 - 500	Slight erosion	1 - 14
3	0.5 - 1.0	500 - 1000	Moderate erosion	
4	1.0 - 2.0	1000 - 2000	Severe erosion	
5	2.0 - 3.0	2000 - 3000	Very severe erosion	
6	>3.0	>3000	Catastrophic erosion	

Table 4. Classification of the sheet erosion per erosion intensity (after [4]).

Grade	Erosion Intensity (m ³ /ha/year)	Verbal Assessment
1	<0.5	No erosion or insignificant erosion
2	0.5 - 5.0	Slight erosion
3	5.0 - 15.0	Moderate erosion
4	15.0 - 50.0	Severe erosion
5	50.0 - 200.0	Very severe erosion
6	>200.0	Catastrophic erosion

The used units by [6] start from (0.00030 - 0.00059) ton/ha to (0.39 - 0.4) ton/ha (Figure 2(b)), we have converted them to m³/ha the units, then the units will be

(0.00021 - 0.00042) m³/ha. Accordingly, when we compare the units with the classification of [4] (Table 4), then the result will be Insignificant Erosion Intensity.

We also have adopted the classification of [3] about the soil erodibility factor (K_k) and applied its details to the 14 sub-basins using the geological map (Figure 5) and other geological data. Accordingly, different soil erodibility factors were indicated in the 14 sub-basins (Table 5). Consequently, different erosion rates were indicated for the 14 sub-basins (Table 5).

Table 5. Soil erodibility factor at the 14 sub-basins (the factor values and definitions are from [3]).

No.	Soil Type	Erosion Rate	K_k	Sub-basins No.
1	Moderately-deep/soil of side slopes/fluvial	Slight erosion	0.01	1, 8, 11, 12 and 14
2	Moderately shallow/soil of side slopes	Moderate erosion	0.15	2, 4, 10 and 13
3	Shallow/soil of side slopes	Severe erosion	0.25	5 and 7
4	Very shallow/soil of side slopes	Very severe erosion	0.325	9
5	Soil at cliffs	Very very severe erosion	0.40	3 and 6

We also have adopted the classification of [9] for indicating the erosion coefficient depending on the slope, type of soil and/or rock, and drainage density of the 14 sub-basins. To indicate the slope and soil and/or rock type, we have used topographical and geological maps at a scale of 1:100000. The results showed that only the first four classes coincide with the status of the 14 sub-basins (Table 6).

Based on the soil types at the 14 sub-basins, different erosion rates were indicated (Table 7) by using the classification introduced by [3]. The results showed that the erosion rates differ from Slight to Very very severe rate of erosion. These erosion rates in the 14 sub-basins match better than any other previously presented erosion rates and/or intensities.

Table 6. Erosion coefficient in the 14 sub-basins (adopted from [9]).

No.	Explanation of Erosion Properties in Facies or Sampling Units	(ϕ)	Sub-basin No.
1	The area that immensely covered by head cut or gully erosion	1.0	3, 5 and 6
2	The area that covered 80% by gully erosion or rill erosion	0.9	4, 7 and 10
3	50 % of the area is covered by gully erosion or rill erosion	0.8	2, 9 and 13
4	The area that is immensely covered by surface erosion, mass movement, and with less Karst, gully erosion, and rill erosion	0.7	1, 8, 11, 12 and 14

The remaining erosion coefficients (ϕ) values from 0.6 to 0.1 do not match with the soil types at any of the studied 14 sub-basins.

Table 7. Soil types (after [3]) and erosion rates at the 14 sub-basins.

Sub-basin No.	Soil Type	Erosion Rate	K_f	Sub-basin No.	Soil Type	Erosion Rate	K_f
1	1	Slight	0.01	8	1	Slight	0.01
2	2	Moderate	0.15	9	3		
3	4	Very	0.325	10	3	Severe	0.25
4	4	severe		11	3		
5	5	Very very	0.40	12	1	Slight	0.01
6	5	severe		13	4	Very severe	0.325
7	3	Severe	0.25	14	2	Moderate	0.15

5. Discussion

We have considered soil and erosion types in this discussion. We didn't consider the climate factors, especially annual rainfall as erosion is concerned, because the basin area is under the same climate conditions, although the sub-basin No. 6 receives yearly slightly more rainfall.

We have studied different erosional aspects and compared them with the LULC and SS maps, besides the type of exposed rocks and/or sediments at each sub-basin. To facilitate the discussion, we have arranged a special table (Table 8) in which we presented the main discussed aspects.

The achieved data about Erosion Intensity [8], Gully, and Sheet erosion [4] showed Very slight, Slight, and Insignificant values, respectively (Table 8). When comparing the type of the exposed rocks and the present soil types, besides the topography, most of the sub-basin (apart from sub-basins Nos. 3, 5, and 6) bear the same rock types and soil (Table 8). However, they showed the same erosion intensity, gully, and sheet erosion values. This means that the existing rocks and soil types do not affect the erosion, which is not acceptable. Moreover, the drainage density of all basins according to Deju (1971) showed Poor class, which is again not acceptable. These discrepancies of the mentioned values at the 14 sub-basins can be attributed to: 1) No detailed data exists about soil types at each sub-basin, 2) The accuracy of the used data to indicate the values of the three erosion aspects, and 3) Accuracy of the used DEM through which the coverage area and streams' length at each of 14 sub-basins were determined. Therefore, we will consider only the erosion rates (Table 8).

The acquired erosion rates, however, showed quite different estimates; according to [3] for the different 14 sub-basins. We have compared the acquired estimates with the type of the exposed rocks and present soil types at each sub-basin and the LULC, and SS maps (Figure 2), we have found a positive coincidence, not only in the estimated values but even the limits of the sub-basins which coincide with the SS map (Figure 2(b)). The rate of the supplied sediments (SS map, Figure 2(b)) when compared with the LULC map (Figure 2(a)) is low in sub-basins Nos. 8, 11, 12, and 14, and partly in sub-basin 9. This is attributed to the type of LULC which is agricultural (cultivated) lands; therefore, the erosion rate will be low and

accordingly, the sediments' supply will be low too. Moreover, the erosion rate ranges from Very Slight to Severe (Table 8). In the sub-basins Nos. 3, 4, 5, 6, 7, and 10 the erosion rates range from Very Sever to Very very Severe (Table 8). In the SS map (Figure 2(b)) the sediments supply map also shows a high range of sediments supply and the LULC map (Figure 2(a)) shows Pasture, which is arable lands and due to grazing then the erosion will be high. In sub-basins Nos. 2, 9, and 13, the erosion rates range from Medium to Very Severe (Table 8), therefore, the SS map (Figure 2(b)) shows moderate sediments' supply and the LULC map (Figure 2(a)) shows partly Pasture and partly Agricultural lands. The effect of the exposed rocks (Table 8) is clear in sub-basins Nos. 3, 5, and 6 (all types of rocks are exposed) and because there are anticlines with high dip amounts; therefore, the erosion rates will be Vey Sever to Ver very Sever, besides the sediments supply will be high (Figure 2(b)).

Table 8. Main rock and/or sediments' types and the values of the 7 erosion aspects.

Sub-basin No.	Soil Type [3]	Drainage Density (km/km ²)	Erosion Coefficient (ϕ)	Soil Erodibility Factor (K_f)	Erosion Rate [3]	Erosion Intensity [8]	Gulley Erosion [4]	Sheet Erosion [4]	Main Lithology [10]
1	1	0.32	0.7	0.01	Sl	Very slight	Slight	Insignificant	Alluvium
2	2	0.30	0.8	0.15	M				Claystone
3	4	0.31	1.0	0.4	VS				Sandstone
4	4	0.36	0.9	0.15	VS				Conglomerate
5	5	0.32	1.0	0.25	VVS				Gypsum
6	5	0.26	1.0	0.4	VVS				Limestone
7	3	0.38	0.9	0.25	S				Alluvium
8	1	0.31	0.7	0.01	Sl				Claystone
9	3	0.37	0.8	0.33	S				Sandstone
10	3	0.33	0.9	0.15	S				Conglomerate
11	3	0.37	0.7	0.01	S				Alluvium
12	1	0.36	0.7	0,01	Sl				Claystone
13	4	0.39	0.8	0.15	VS				Sandstone
14	2	0.34	0.7	0.01	M				Conglomerate

Sl = Slight, M = Medium, S = Severe, VS = Very Sever, VVS = Very very severe for soil Types [3] refer to Table 5.

6. Conclusion

The main conclusion about the soil types and erosion is that there is a positive relation between erosion rates and the: 1) types of exposed rocks, 2) present soil types, 3) LULC cover map, and 4) SS map. However, other calculated and/or estimated values of drainage density, erosion coefficient (ϕ), soil erodibility (K_f), ero-

sion intensity, gulley erosion, and sheet erosion showed a faint relation with the mentioned 4 aspects.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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