Soil Erosion Assessment via RUSLE model and GIS and RS (Case study of the Mujib Basin)

د. شذا حسين كساب الرواشدة[(1)]* | م. اسراء فواز العايد[(2)]
أ. د. ايمن عبدالكريم عايد الطعاني[(3)] | د. زبيدة علي بركات العدوان[(4)]

Abstract

This study aims to identifying areas with high sedimentary output in Wadi Al-Mujib. It investigate the hydrological content of the Wadi Al-Mujib Basin area, estimate the sediment output density and identify the hydrological criteria that affect. In addition, the vegetation cover and its relationship to the intensity and processes of soil erosion are also studied based on a GIS and RS techniques. The Digital Elevation Model (DEM) within ArcGIS was employed to infer the basic factors involved in the RUSLE model through spatial and hydrological analysis. Our findings revealed that there is significant erosion in various areas of the Wadi Al-Mujib Basin area, with the highest rate of sedimentary output ranging between 45–60 tons/hectare annually and covering an area of 149 km^2.The findings provide evidence that parts of the northern and western regions with the highest average recorded rainfall may also have the highest rates of soil erosion and sedimentary output. As a result, the basin is more consistent with being a central drainage environment for many long valleys in some regions of Jordan's Centre and south. This would be extremely effective in preventing soil erosion and thus benefit significantly from future water gathering plans.

Keywords: Sedimentary Output, Geographic Information System (GIS), Remote sensing, Wadi Al-Mujib Basin, RUSLE, Hydrological Content.

الملخص

تهدف هذه الدراسة إلى تناول المحتوى الهيدرولوجيّ لمنطقة حوض وادي الموجب وتقدير حجم الناتج الرسوبيّ باستخدام نموذج (RUSLE) إضافة إلى التعرّف على الخصائص الهيدرولوجيّة باستخدام تقنيات أنظمة المعلومات الجغرافيّة (GIS) والاستشعار عن بعد (RS) ومن ثم تحديد المناطق ذات الناتج الرسوبيّ العالي في منطقة حوض الموجب، كما تهدف دراسة الغطاء النباتيّ وعلاقتها بعمليات انجراف التربة.

وللوصول إلى النتائج المرجوة تم الاعتماد على نموذج الارتفاعات الرقميّة (DEM) وكذلك الاعتماد على برنامج (Arc GIS) حيث تم استخدامه في التحليل المكانيّ والهيدرولوجيّ واستنباط العوامل الأساسيّة الداخلة في نموذج (RUSLE).

وقد تبيّن من خلال النتائج وجود انجراف مرتفع في مناطق مختلفة في منطقة حوض الموجب، حيث تراوح أعلى معدل للناتج الرسوبيّ بين 45 – 60 طن / هكتار سنوياً، وبلغت هذه المساحة 149 كم2 من منطقة الدراسة، وتم إنشاء خريطة للناتج الرسوبيّ في منطقة الدراسة، وبيّنت الدراسة أيضاً أنّ جزءً من المنطقة الشماليّة وجزءاً من المنطقة الغربيّة والتي ترتفع فيها نسبة الأمطار كانت أعلى معدلات الانجراف والناتج الرسوبيّ

(1) قسم التاريخ والجغرافيا، كليـة الآداب، جامعة الحسين بن طلال، معان، الأردن.
(2) قسم هندسة مساحة وجيوماتكس، كليـة الكرك الجامعية، جامعة البلقاء التطبيقية، الكرك، الأردن.
(3) قسم الجغرافيا التطبيقية، كليـة الآداب والعلوم الانسانية، جامعة آل البيت، المفرق، الأردن.
(4) قسم هندسة المساحة، كليـة الهندسة، جامعة آل البيت، المفرق، الأردن.
* الباحث المستجيب: shatharawashdeh38@gmail.com

للتربة ، كذلك يعدّ الحوض بيئة تصريف مركزيّة للعديد من الأودية الكبيرة والرئيسة في بعض مناطق الوسط والجنوب من المملكة الأردنيّة الهاشميّة، وأوصت الدراسة بتحديد المناطق الجغرافيّة التي تتجمع فيها المياه والتي تكون ذات فعالية عالية في حدوث الانجراف للتربة والاستفادة من التجمعات المائية، واستغلال الرواسب المنبعثة من خزان السد فيها للزراعة.

1. Introduction

Water basins are one of the dry valley systems and significant environments in hydrological studies (Hamdey, 2015). Soil erosion is one of the most important elements that are addressed in the study of these environments. It is considered as indication for environmental degradation that affects the formation of the soil and its suitability for agricultural production. Soil erosion is caused by two main factors: water and wind. The soil erosion accounts for approximately 85% of global land degradation, reducing crop yields by approximately 17%, affecting soil fertility initially and resulting in long-term land abandonment (Singh & Panda, 2017).

Parameters that affect the soil erosion and equations for estimating it have been developed and employed to predict the soil loss. Universal soil loss equation (USLE) developed by Wischmeier and Smith (1978) , and the revised universal soil loss equation RUSLE developed by Renard et al. (1996) are common equations for the erosion modeling. (Dutta ,2017)

one of the main disadvantages of USLE is that it doesn't take the spatial context into account in the erosion estimation beside the large amount of assets and time needed to prepare the input factors to run the model in a new environment. RUSLE was developed to overcome such limitations to estimate soil erosion and investigate its spatial distribution, RUSLE model have been in a GIS environment. (Efthimiou et al., 2014)

Soil erosion is one of the most important elements addressed in the study for its symptom of environmental degradation that affects directly the formation of the soil and its suitability for agricultural production. As a result, estimating sedimentary output is critical to determining its impact on water resources, soil, and agricultural and water projects (Panditharathne et al.,2019). Some human activities such as overgrazing, stone quarries, incorrect plowing, incorrect urban sprawl and other influential factors have increase the problem and result in mitigating the vegetation cover, increase the susceptibility to soil erosion, and deposition in dams that affect their storage efficiency (Al-Zayoud Hisham, 2017). As a country suffering from water lack, dams in Jordan are an important strategic resource for meeting water shortages (Abdel Hamid, 2019).

The Mujib Valley Basin is located in a semi-arid environment with low vegetation cover and high erosion, which causes increased water erosion and has an impact on the storage capacity of the Mujib Dam (patils, 2014; Maysoon et al., 2021).

RUSLE was developed by the US Department of Agriculture and is used as a decision support system in soil conservation and land use planning (Renard, 2015). It investigates the characteristics of the vegetation cover in the study area and their relationship to the soil erosion process in the study area. An analysis of the hydrological and morph metric characteristics of the Mujib Basin area using GIS and RS was implemented; and a map of the rate of sedimentary output and its spatial distribution was produced.

2. Methodology

The descriptive and spatial data were employed in an analytical approach. Quantitative and cartographic methods to calculate the sedimentary output remote sensing (RS) and GIS techniques help in data from several formats and sources were integrated in a GIS and RS based procedure to create a soil erosion model in the positive basin area. Refer to table (1) a digital elevation model (DEM) for the study area with an accuracy of 30 m obtained from the USGS website; a soil map of Jordan (National Soil Map and Land Use Project, 1993). Land satellite images dated 19 August 2018 with a resolution of 30 m; and precipitation information in the study area.

Table 1. The materials and sources used in the study

	Materials	Sources	Year of Publication
1	Digital Elevation Model DEM (30 m)	USGS	-
2	Landsat images	-	2018
3	Precipation information	Experts Opinions, Literatures	Up to 2023
4	Soil map	National Soil Map and Land Use Project	1993
5	Arc GIS 10.3	-	-
6	Microsoft Office Excel	-	-

2.1 Study Area

The Mujib Basin is situated between longitudes 35.5 and 36.5 east and latitudes 30.7 and 31.9 north in the governorates of Al-Asimah, Karak, and Madaba. The basin covers an area of approximately 6500 km^2. The Mujib Basin is one of Jordan's most important basins due to its large size and its containment of many of the country's major valleys, as presented in Figure (1). Mujib Basin is a deep canyon watershed that enters the Dead Sea at an elevation of -430 meters above sea level and rises to 1273 meters. Deep canyons and incised streams cover about 3014 km^2 (42% of the total area) (Al- Husban, 2011; Odeh&Salameh, 2005; Alhusban&Almanasyeh, 2017).

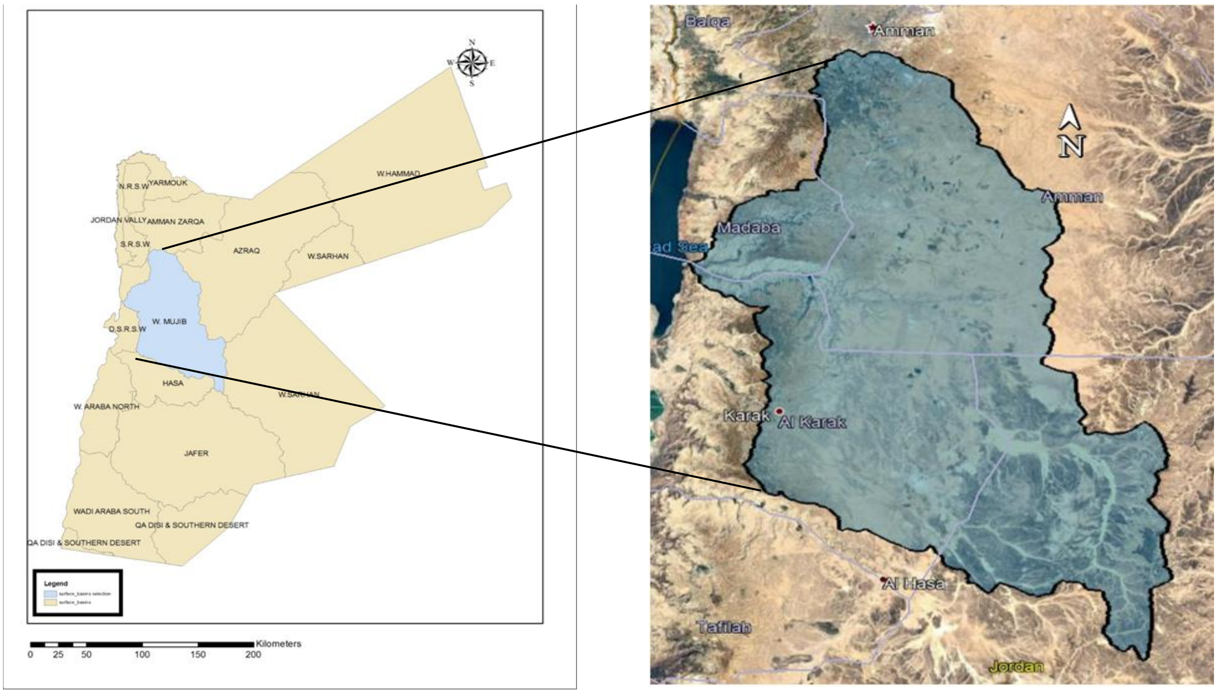

Figure 1. Study Area

2.2 Programs and Techniques

Processing and analysis were carried out using software and techniques. The following programs were used in the study to obtain the necessary analysis and treatment: Arc GIS 10.3, Erdas Imagine 2014, and RUSLE model. The following elements was included in the RUSLE model:

- Factor K is a soil erosion factor because each soil type has an erosion factor calculated based on the chemical composition of the soil. A map with points distributing each type of soil and its erosion factor is created, which is then converted into a grid raster data.

- Factor R is the factor concerned with analyzing the rain readings and their average in each of the study areas, and it is calculated by creating an digital elevation map so that the height represents the rainfall rate in the station area and then converting it into a network information raster.

- Factor C is the factor that represents the vegetation cover, uncultivated soil distribution areas, and urban areas, and it is calculated by classifying satellite images, converting them into linear information vectors, and then entering the soil erosion coefficient for each type of classification and converting them into raster information.

- Factor P is the factor of the effect of topography on soil erosion, where the higher the slopes, the higher the effect on soil erosion, and it is calculated by deducing the slopes from the digital elevation model DEM and then classifying the slopes within their impact from low to high and then storing them in a network information layer.

- RUSLE is a novel and advanced method for forecasting soil erosion and erosion. The Raster Calculator is used to combine and multiply the previous factors based on their effect in the final model to obtain a network information layer that shows the susceptibility of soil to erosion throughout the study area (K.G. Renard, 1997).

3. Results

Table 2 shows soil erosion factors K in the study area. The map below depicts the geographical distribution of soil types in the study area.

Table 2. Soil erosion factors K

Type	k-Factor
Xerochrept	0.9
Torriorthent	0.8
Calciorthid	0.7
Camborthid	0.65
Torripsamment	0.55

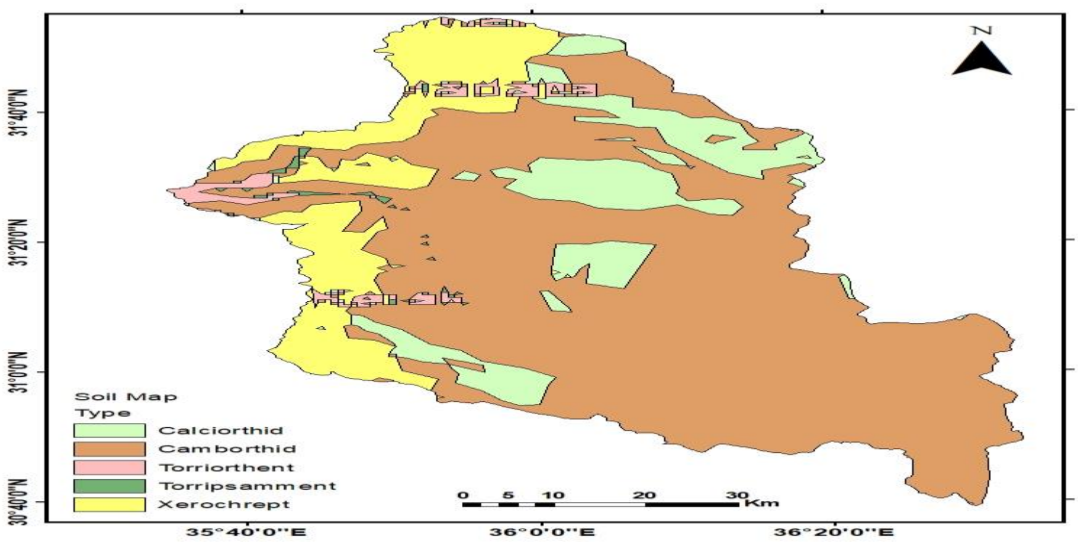

Figure 2. Soil type distribution in the Mujib Basin

The following map clarifies the distribution of K-factor for soil in the study area according to its susceptibility to erosion by using the erosion coefficient for each type of soil.

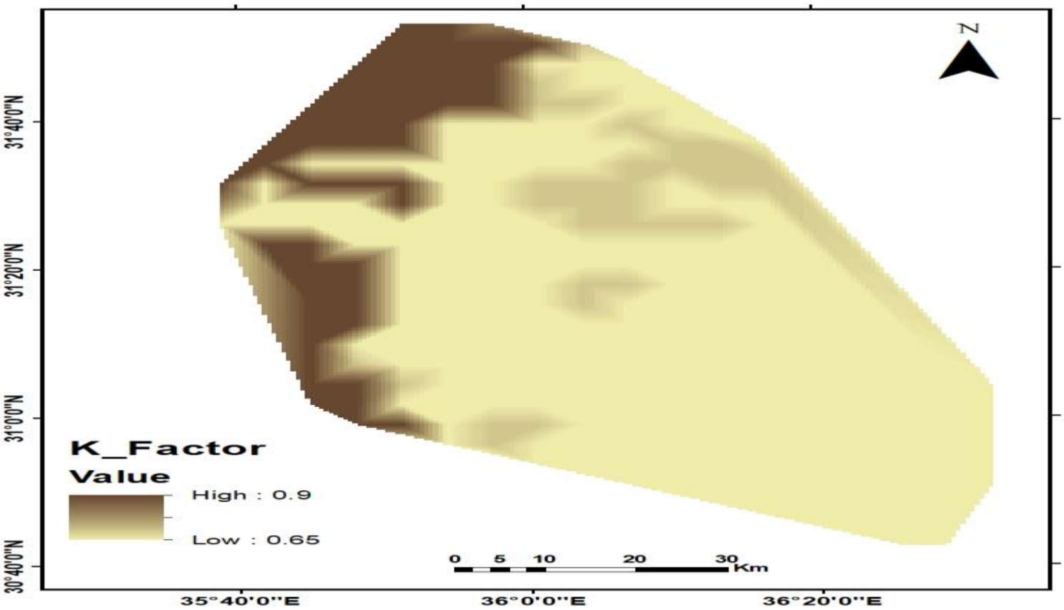

Figure 3. Erosion coefficient for each type of soil (K-factor) in Mujib Basin

Based on the map, the western and northwestern regions are the most prone to erosion due to the high rate of rain fall in them. This results in problems represented by the erosion of the soil in the form of sedimentary particles. It becomes polluted because it contains nitrogen and phosphorous, which may lead to the reproduction of algae when carried in water bodies and thus reduce water purity and deplete oxygen, as well as reducing the design energy of tanks. This necessitates ongoing maintenance operations. The remaining sub-soil is hard and rocky, making vegetation re-establishment difficult.

3.1 Annual rate of rainfall (factor R)

According to Table 3, the annual rainfall rate (factor R) was applied to the stations within the study area. Figure 4 shows the annual distribution of rainfall at the stations in the study region.

Table 3. Annual rate of rainfall (factor R) for the stations located in the study area

Station	Longitude	Latitude	Average ye
Arrabbah	35.738289	31.268277	337.2
Qatraneh	36.049613	31.250138	95.55
Queen alia	35.992905	31.722435	155.89
Rwaished	38.200672	32.508769	75.73

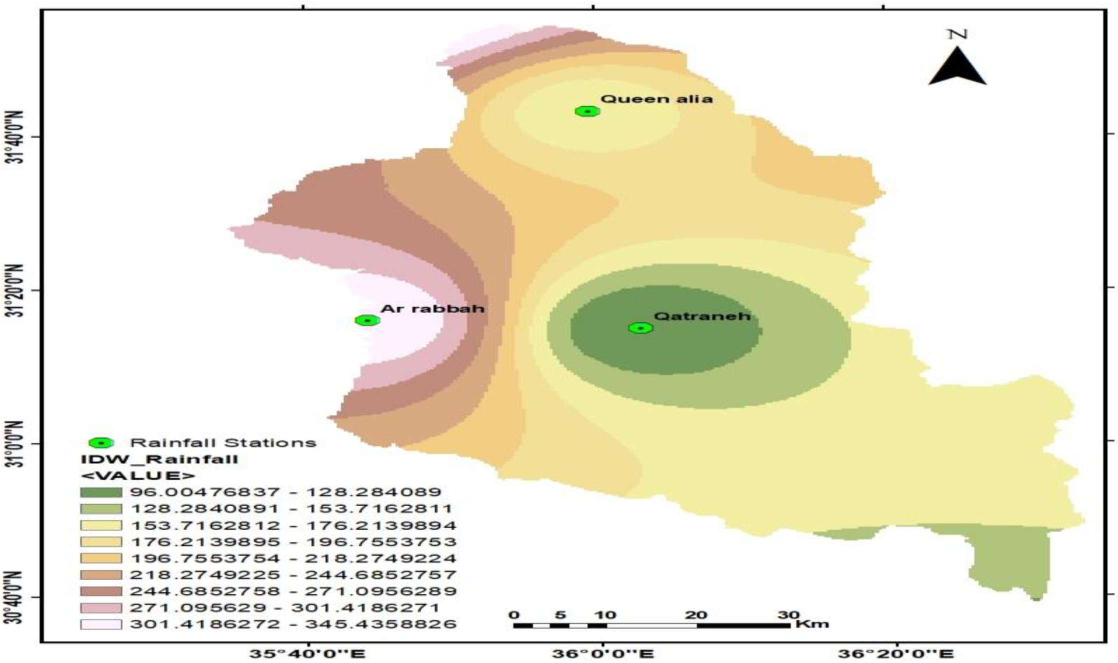

Figure 4. Annual rainfall rate (factor R) at stations in the study area

Figure 5 shows that the western and northwestern regions of the study area have the highest average rainfall, which is approximately 188 mm, while the northern and central regions have an average rainfall of approximately 120 mm.

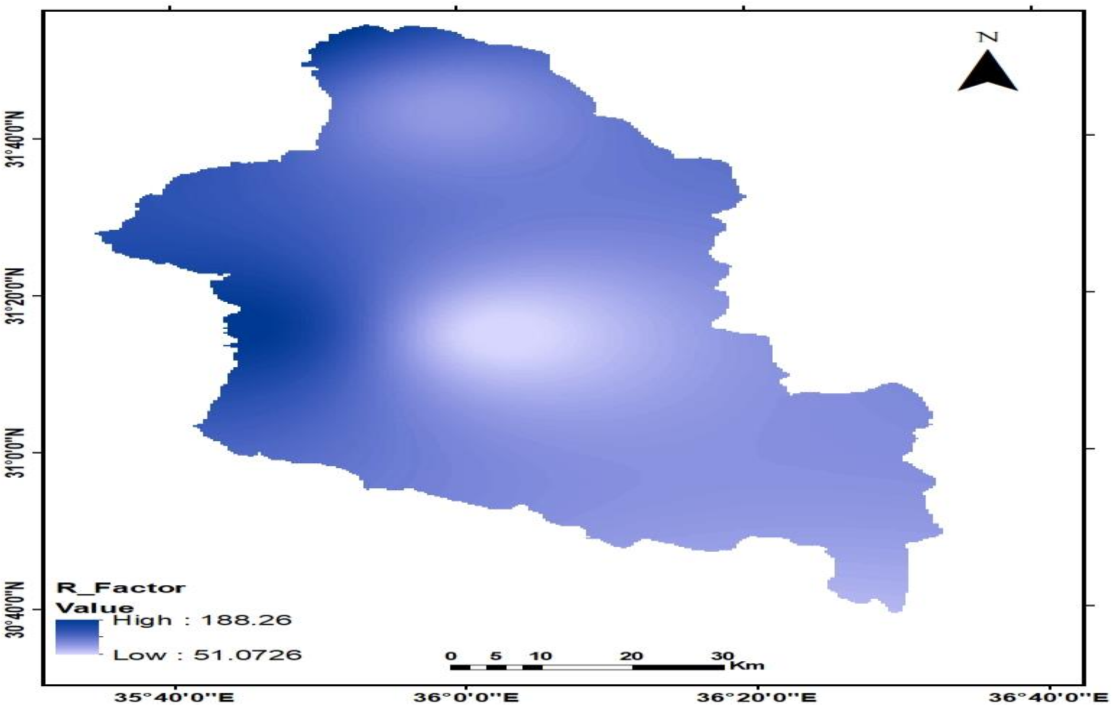

Figure 5. Annual rate of rainfall (factor R) in the Mujib Basin

3.2 Vegetation cover and land use Factor C

The presence of vegetation cover has the greatest impact on soil erosion because it is considered an important factor in RUSLE model calculations. Land satellite images were used to create a land use map in the Mujib basin area.

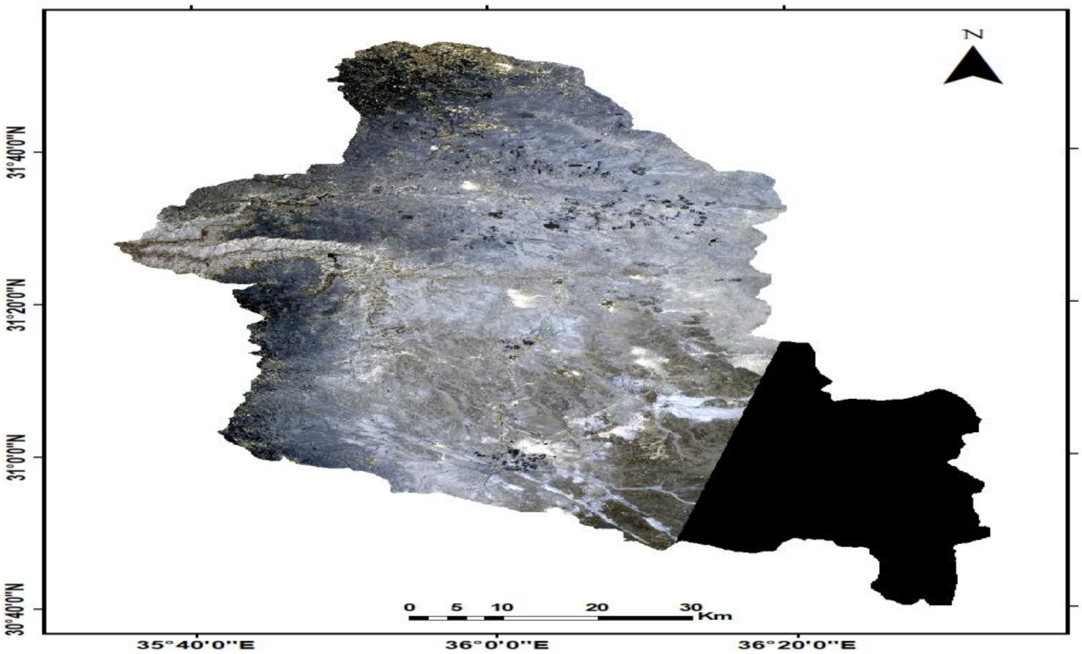

Figure 6. Satellite images from Land sat for Mujib Basin

Figure 7 depicts land uses in the study area using the directed classification technique on satellite images to clarify and identify cultivated areas, residential areas, water bodies, and unused areas in the Mujib Basin area.

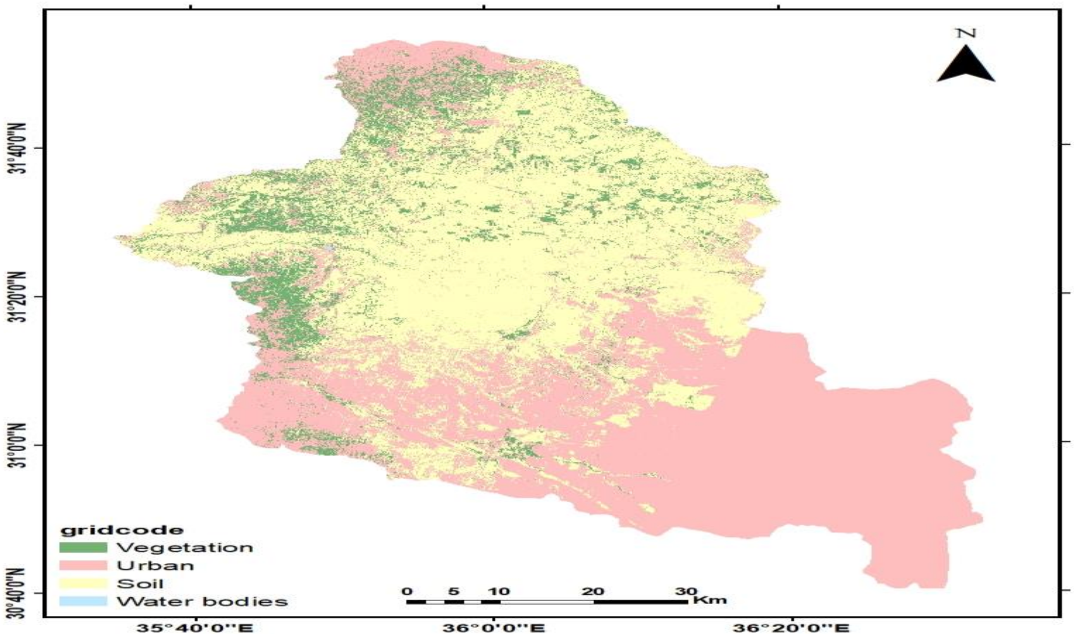

Figure 7. Land use in Mujib Basin

To obtain the effect of each common use in the classification, the layer was converted into an information network containing the special effect of each use on soil erosion, in order to produce a map of the impact factor of vegetation and urban cover. Soil erosion accelerates in the northern and northwestern regions, as well as the southern part of the study area, due to a lack of vegetation and urban cover.

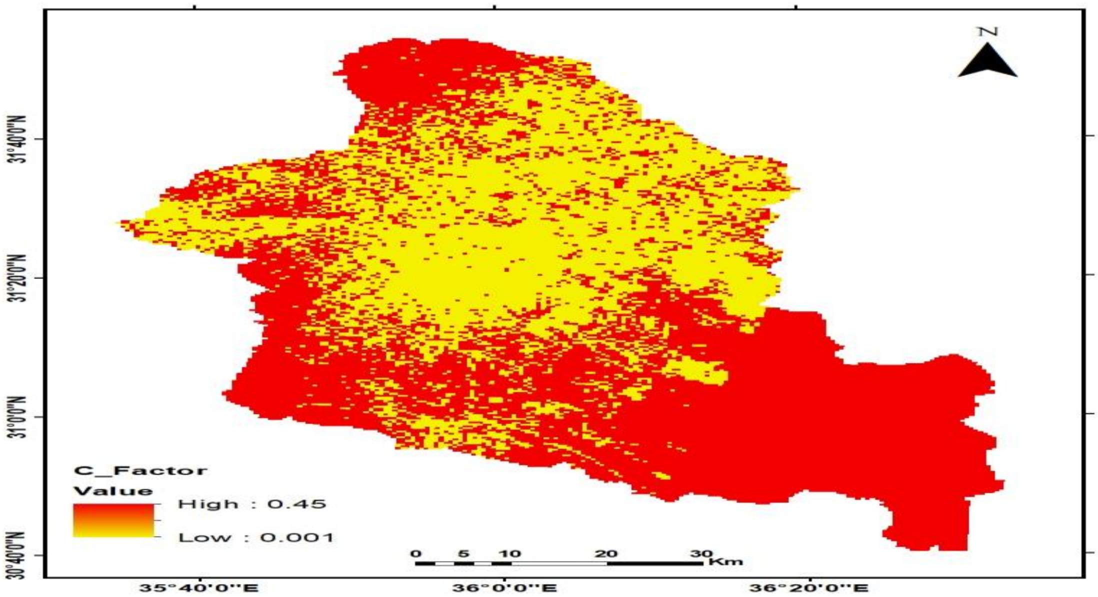

Figure 8. Soil erosion in Mujib Basin

3.3 The effect of terrain and slope on soil erosion (P Factor)

Topography and slopes are important in the study of soil erosion because they have a large impact on sedimentary output. The slopes of the Mujib Basin area and their impact on the soil coefficient were determined using the digital elevation model DEM. As shown in Figure 10, a slop map was created based on a DEM.

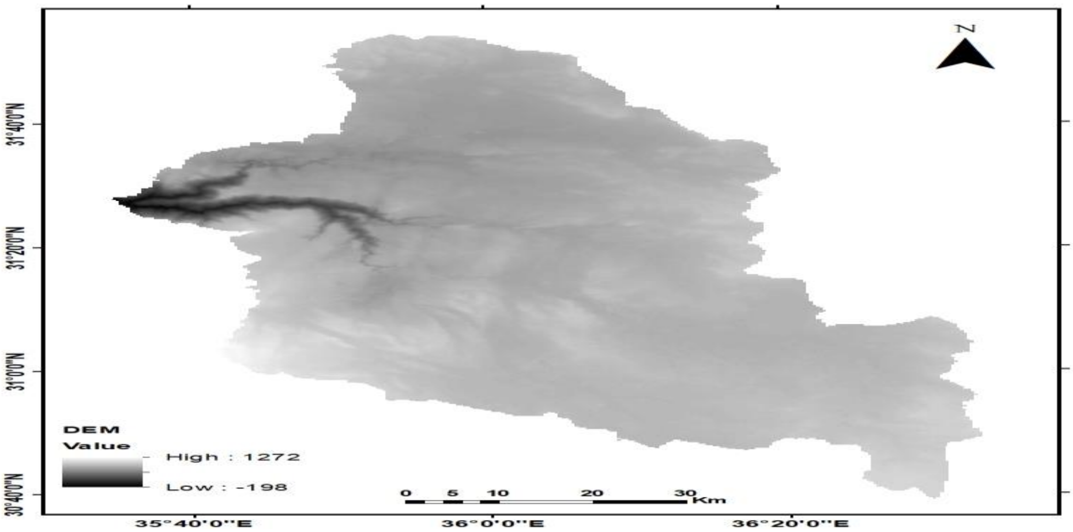

Figure 9. DEM digital elevation model for the Mujib Basin

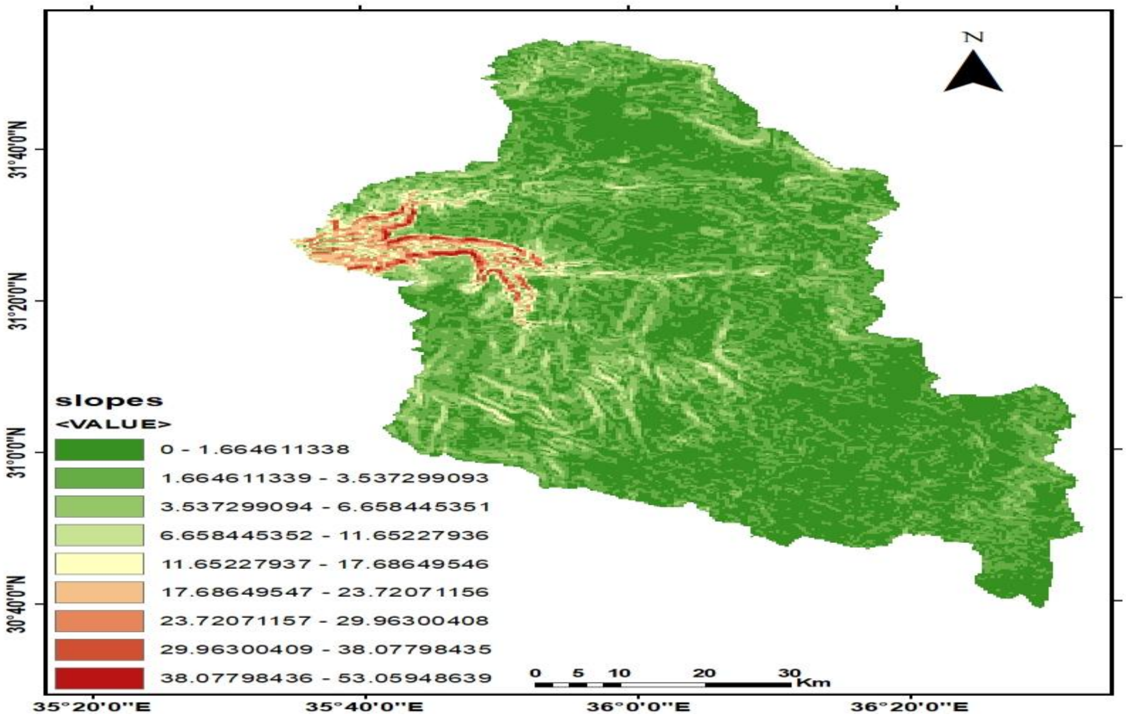

Figure 10. Slop map for the Mujib Basin

Table 4 shows M. Hashem (1997) classified tendencies based on their impact on sedimentary output rates. Figure 11 demonstrates the slop distribution after applying the factor P.

Table 4. Support practice factor (p)

Slope (%)	Contouring	Strip cropping	Terracing
0.0 – 7.0	0.55	0.27	0.10
7.0 -11.3	0.60	0.30	0.12
11.3 – 17.6	0.80	0.40	0.16
17.6 -26.8	0.90	0.45	0.18
26.8 >	1.0	0.50	0.20

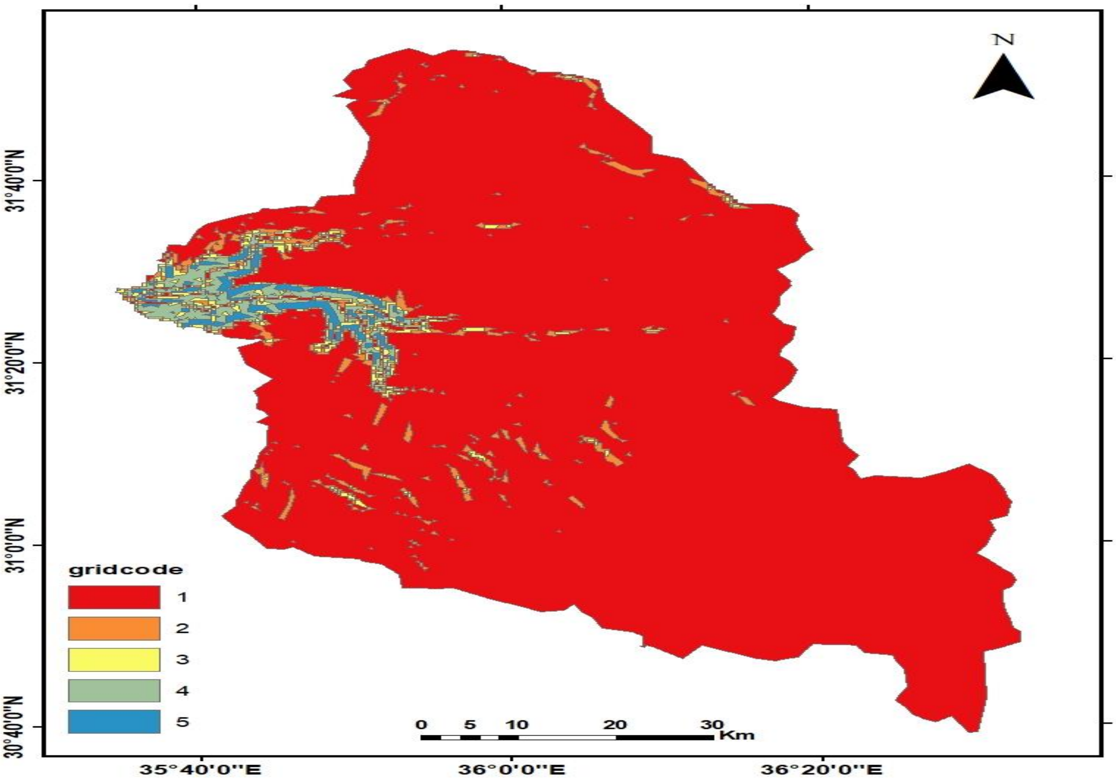

Figure 11. Distribution of the slop according to sedimentary effects in the Mujib Basin

The areas with the number 5 are the most inclined and the highest, followed by the areas with the numbers 4, 3, 2, and finally the areas with the number 1. When the table's influence values are applied to the classification of the slope, the following map of the sprocket impact factor is produced.

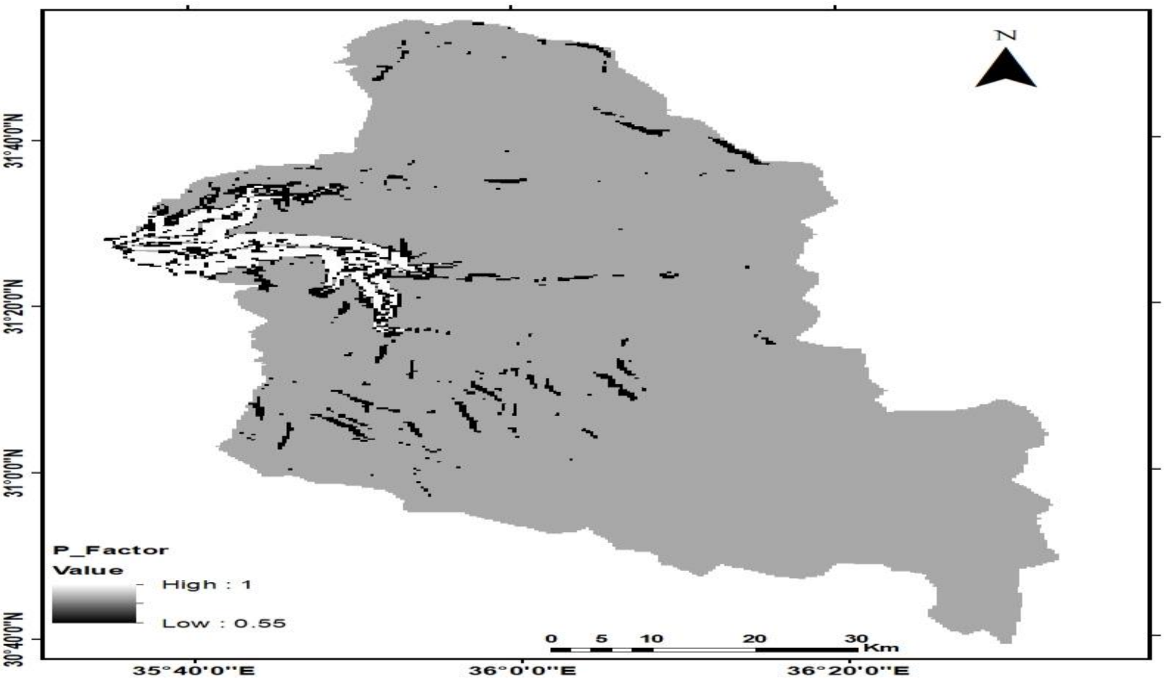

Figure 12. Map of terrain effects on the sedimentary

The western region has the highest terrain, the most rain, and the most soil erosion. When using the Raster Calculator tool to apply the map of the sedimentary output of the soil in the Mujib Basin according to the RUSLE model and implementing the RUSLE equation according to the following formula:

Factor A = Factor C ***** Factor P ***** Factor K ***** Factor R

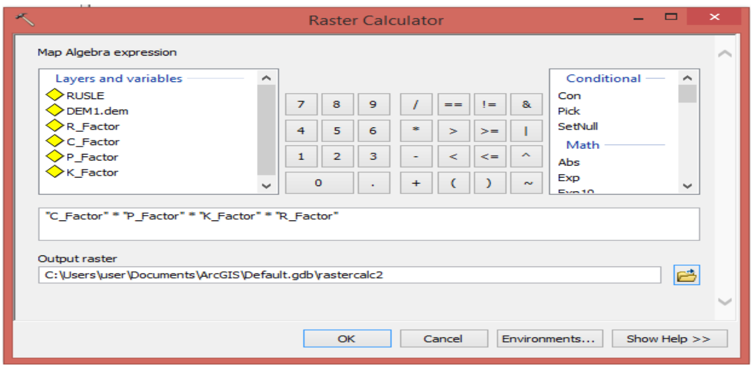

Figure 13. Raster Calculated

Figure 13 captures the result of estimating the sedimentary product of the soil in the Mujib basin. As shown in Figure 14, the process involves multiplying coefficients that affect primarily the sedimentary product in the basin (tonnes/hectare) and then classifying the sedimentary product using the classification standard deviation equation.

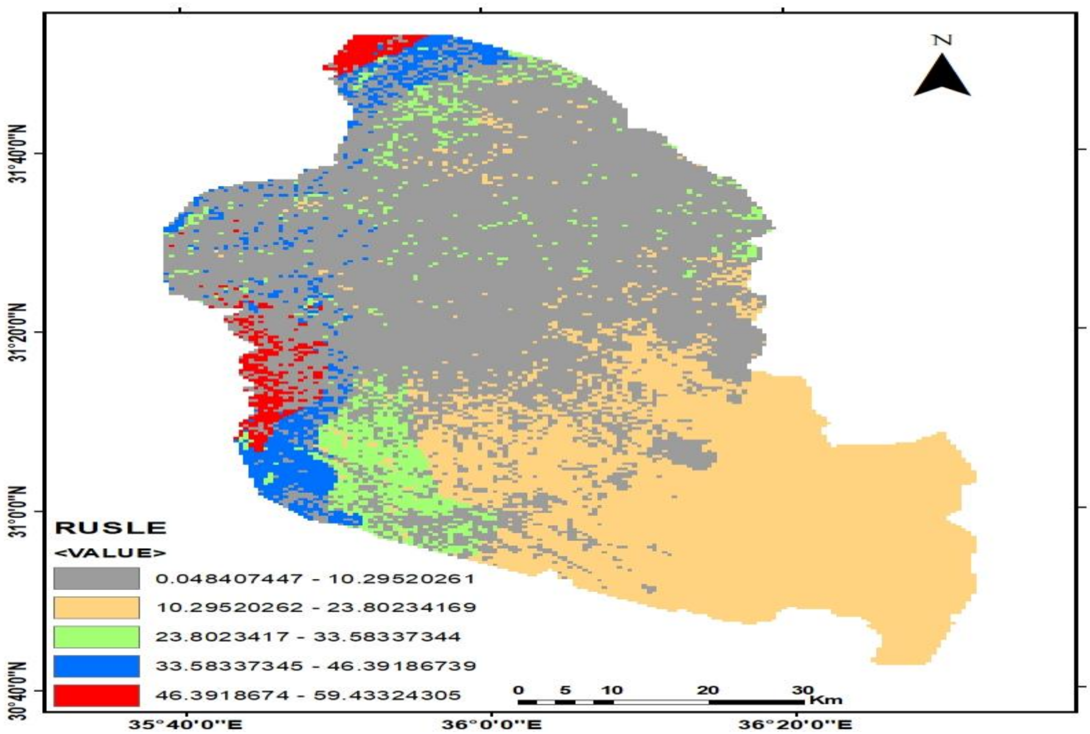

Figure 14. Estimation map for soil sedimentary products

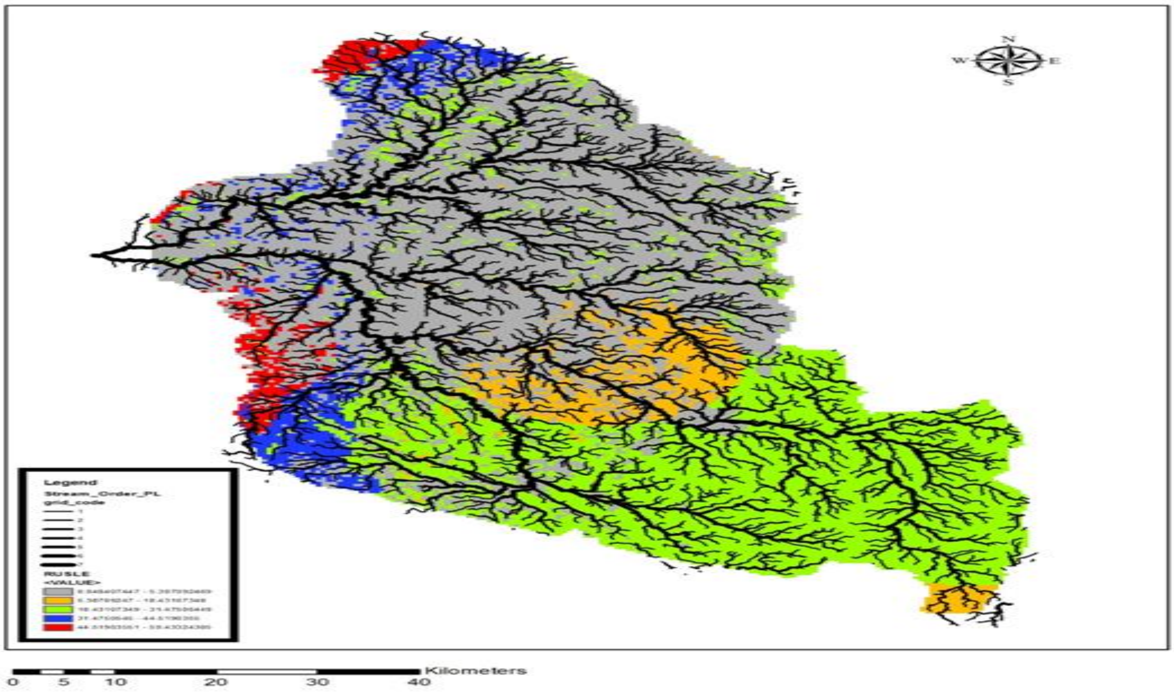

Figure 15. Estimation map for soil sedimentary products after applying the standard deviation equation

The rain factor influences soil erosion flow. Water erosion accounts for more than 56% of total sediment volume. The reddest areas are the rainiest and highest, with elevations of around 1272 m, as shown in Figure 9. Figure 10 shows that it used to have a slope ranging from 29 to 53 degrees, which explains the higher rate of sedimentary output. In addition, the type of soil and the width (thickness) of the valley's watercourse play a role in the sedimentary product, meaning that the thicker the number 7 in Figure 15 indicates that it carries a large sedimentation product due to erosion, transport, and sedimentation caused by the rise. The area of the study is 149 km^2 and is located in the western region, where the rate of sedimentary output ranged between 45 and 60 tonnes/hectare annually, as shown in Table 4. In the east, the sedimentary product decreases, as shown in Figure 15, due to the lower rank of the river valley course, which includes about 235.17 km2 (Figure 15), where it ranks third in terms of the amount of sedimentary erosion, which amounts to 18–31 tonnes/hectare annually, negatively affecting human activities (housing, agriculture,... etc.). The basin is also considered a central drainage environment for many large and main valleys in some of Jordan's central and southern regions due to its geographical location and topography. Table 5 represents the areas for each of the resulting classifications based on the standard deviation equation.

Table 5. Area of Sedimentary in the Mujib Basin

Sedimentary (tons/hectare)	Area (km^2)
0.04 - 5.38	3327.31
5.39 - 18.43	369.44
18.44 - 31.47	2138.54
31.48 - 44.52	280.46
44.53 - 59.43	149.28
residential areas (0)	245.17
Total	6500

The sediment sources in the study area included: erosion of agricultural land, forests, and waste; movement of soil mass due to landslides; stagnation and soil encroachment; erosion caused by flooding in water; and mining residues left on the ground's surface. The most significant issues associated with erosion and sedimentation are as follows: eroded soil in the form of sedimentary particles that became polluted; turbidity caused by sediment reduces photosynthesis; reduced reservoir design capacity; and eroded soil reduces areas of effective flow of drainage methods. If the waterways become clogged, the RUSLE model predicts a sediment volume of 7 million cubic meters in 2030, which represents approximately 22% of the dam's reservoir.

4. Conclusion

The RUSLE model was employed in many studies and its usage in erosion estimation allows identification of the most susceptible to erosion areas, constituting an important predictive tool for soil and environmental management in the study regions especially with aid of GIS and RS. (Amsalu and Mengaw, 2014), (Efthimiou et al., 2014), (Worodofa, 2011).

The previous studies have shown the different effects of the erosion factors (Worodofa, 2011). In (Amsalu and Mengaw, 2014) work, the aggregated effects of all parameters had been analyzed and soil loss from the area was calculated using RUSEL models, steeper slopes regions shows the highest degree of vulnerability against the erosion.

This study concludes the following based on the data and map analysis:

1. The erosion affects a wide range of areas in the Mujib basin, which serves as a central drainage environment for a large number of valleys.
2. The study area is distinguished by various sloping topographical features, as well as a lack of vegetation cover and the absence of a maintenance factor in the basin, all of which contribute to an increase in the basin’s sedimentary output.

3. The RUSLE model predicts a sediment volume of 7 million cubic meters in 2030. This is approximately 22% of the dam's reservoir capacity. These sediments have a negative impact on the efficiency and life of the hypothetical storage Al-Mujib dam.

4. Drift values increase at the basin's edges and decrease in the basin's centre and near the main valley.

5. The Mujib Basin area is prone to extensive erosion, which necessitates immediate attention and action to address the issue, particularly in urban areas.

6- Poor land management, fluctuation and high rainfall contributed to the high rates of erosion and the increase of sediment in the study area.

5. Recommendations

This study recommends the following:

1. Focusing on the planting of forest trees in various areas of the basin, particularly in areas with high erosion values, and the tendency to work on the maintenance factor through the construction of agricultural terraces and terraces.

2. Study the water quality of the Mujib Dam reservoir because the sediments may contain some chemicals that affect the quality of the water.

3. Constructing an artificial drainage network around the banks of the main valleys, as well as retaining walls and fence networks, to limit collapsing and lateral erosion in the valley. This reduces Mujib dam's storage efficiency.

4. Determining the geographical areas where water accumulates (hot spots), which are highly effective in causing soil erosion and benefiting from the water gatherings so that they become a water resource rather than a source of erosion and sedimentation in the study area.

5. Exploiting the sediments emitted from the dam reservoir for agriculture, as these sediments are soil rich in elements within the concept of sediment management.

6. Managing existing lands in and around the study area to stabilize the WadiMujib urban area.

7. Tightening control over the water coming from the valleys feeding the basin so that its use is rationalized, particularly in agriculture, through irresponsible surface irrigation

so that the water is utilized, which will positively affect the erosion and sediment processes in the basin.

8. Employ hydraulic suction pumps to remove sediment deposited at the bottom of the tanks.
9. Integrated management of natural water resources in the study area, as Jordan over consumes water, and application of the model to other bodies of water in Jordan.

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