

Application of the Erosion Potential Method to the Wadi Mubarak Basin in Aqaba Governorate, Jordan

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Received on 20 March 2024; Accepted on 23 August 2025

Abstract

This study evaluates soil erosion and sediment yield in Wadi Mubarak Basin, located along the Aqaba Back Road in southern Jordan. The basin significantly impacts floodwater volumes and sedimentation levels. During intense, short-duration rainstorms, erosion leads to fatalities and infrastructure damage through box culvert and bridge blockages, leading to road deterioration and traffic disruption. The study employed the Erosion Potential Method (EPM), also known as the Gavrilovic Method. Key EPM parameters include the soil erosion coefficient, annual precipitation, and temperature coefficient. The soil erosion coefficient is based on the average slope coefficient, the erosion type and extent coefficient, soil protection coefficient, and the soil erodibility coefficient. Erosion intensity within the basin ranges from moderate to severe. Annual soil erosion is excessive in large Wadi beds within main channels ($>42,000 \text{ m}^3/\text{km}^2/\text{year}$), accounting for about 0.5% of the total catchment surface area. The findings help to understand the spatial distribution of erosion across the basin and serve as a foundation for further research and environmental management programs.

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Keywords: Gavrilović, Erosion Potential Method; Soil Erosion; Wadi Mubarak; Sedimentation; Soil Protection Index.

1. Introduction

Natural geomorphic processes, such as soil erosion, lead to the loss of topsoil due to the effects of runoff and precipitation. This separation and loss of soil particles occur through rainsplash or indirectly through sheet, rill, or gully erosion. Gully erosion has serious issues as its formations are deep, elongated, and narrow (Ali et al., 2016). Volumes of eroded material can be very destructive when large, as they may travel long distances. In most cases, erosion rates are higher on steep, long slopes (Tavares et al., 2021). In Jordan, soil erosion is caused by different natural and human factors. There are environmental effects of social, economic, and ecological implications (Al-Sababhah & Al maqablah, 2023).

The Wadi Mubarak basin is a highly sensitive watershed that determines sediment volumes and flood discharge. Moreover, Wadi Mubarak has a transport zone that redirects heavy traffic and cargo to the east of Aqaba city. Thus, it improves the city's environment and protects coastal resort areas.

Nevertheless, the Wadi Mubarak basin presents significant challenges to infrastructure and human security due to intense, short-duration precipitation. These storms tend to exceed the drainage capability. This leads to obstruction of box culverts and bridges, thereby damaging roads and shoulders and leading to a major inconvenience in traffic movement and accessibility. This has been evidenced by the historical occurrence of floods.

On 21 March 1991, there was a major flood which had an estimated 6-7 year period of return following the completion of the road construction but before the official opening of

the road, resulting in widespread destruction of the new infrastructure. In December 1993, another flood caused further damage (Farha, 1999). The recurrent floods are a testament to the need for robust infrastructure solutions to reduce the current number of threats posed by the Wadi Mubarak basin.

The presence of sparse vegetation cover is also a factor contributing to extensive soil erosion and sediment transport downstream (Thneibat, 2010) and the efficiency of engineering structures regarding these hazards. This work has been achieved through the analysis of remote sensing data, field work, laboratory work and field measurement, by utilizing standard techniques such as, (GPS). Critical factors in the infrastructure planning should be surface erosion and sediment yield (Dragičević et al., 2017) various methods for erosion intensity and sediment production assessment have been developed. The necessity for better model performance has led to the more frequent application of the method sensitivity and uncertainty assessments in order to decrease errors that arise from the model concept and its main assumptions. The analysis presented in this paper refers to the application of the Gavrilović method (Erosion Potential Method). The selection of models and parameter specifications of soil erosion requires accurate estimation. Over the last several decades, scholars have developed different empirical and physically based techniques of measuring erosion intensity and sediment production (Marouane et al., 2021). They depend on the input data required to perform their application (Deilami et al., 2012).

The most widely used empirical model for estimating soil erosion is the Universal Soil Loss Equation (USLE)

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(Wischmeier and Smith, 1978). Since its creation, other models have been developed, such as RUSLE (Renard et al., 1991) has been the workhorse of erosion prediction and conservation planning technology in the U.S. and even worldwide. In 1985, at a meeting of U.S. Department of Agriculture (USDA, MUSLE (Williams, 1975), PSIAC (Pacific Southwest Inter-Agency Committee, 1968), WEPP (Water Erosion Prediction Project), SWAT (Soil and Water Assessment Tool), and EPM (Gavrilovic, 1988; da Silva et al., 2014). These models were developed and are still used today. The hilly topography, sparse vegetation cover, and prolonged droughts and erosive precipitation events increase land degradation in the study area (Ali et al., 2016).

At the research site, a few sediment gauging stations limit the ability to predict and evaluate watershed erodibility, thereby complicating the prioritisation of soil conservation in erosion and sediment yield assessment. Alternative models that are quantitative include the EPM. EPM, which has been used extensively in the Balkan countries, is effective in estimating the erosion rates, especially in the arid and semi-arid areas (Tavares et al., 2021). Although it is used in various settings, it was designed for dry and semi-arid areas of the southwestern United States and Iran (Yousefi et al., 2014).

The EPM was developed to calculate erosion coefficients, the measure of the erosion rates, and the mean annual sediment yield. Slovenia and Croatia have used the Gavrilović method to forecast soil erosion and the number of sediments at the basin level (Amini et al., 2010). The EPM is a suitable method of estimating erosion and sedimentation. The leading EPM parameters are the coefficient of soil erosion (z), the amount of precipitation per year (H) and the temperature coefficient (T). The soil erosion coefficient involves the mean slope coefficient (Ja), the soil protection coefficient (Xa), the erosion type and extent, and the soil erodibility coefficient (Loucks et al., 2005; Elbadaoui et al., 2023; Efthimiou et al., 2016; Jamal, 2020).

Gavrilović's method is straightforward and adaptable enough that the researcher can obtain significant results without relying on extensive historical data or complex modeling. It also provides a foundation for understanding erosion patterns and developing management strategies. In this context, the method uses annual parameters such as yearly precipitation and temperature data from King Hussein Airport in Aqaba, slope gradient and length measured from topographic maps, soil properties from geological maps, and land use data from the Aqaba Special Economic Zone maps. Notably, additional coefficients were calculated using empirical methods and tables developed by Gavrilović.

Soil erosion and sedimentation are not primary inputs to the planning process considered by regional development planners, and the focus is usually on flood hazard assessment. Planners rarely consider the dynamic nature of Earth's surface processes, including geomorphological processes, such as soil erosion, flooding, and increased sedimentation in hydraulic infrastructure (Farhan, 1999).

The goal was to reduce the errors in assessing soil erosion

and sedimentation and to develop effective control strategies (Uddin et al., 2016). These advancements in GIS and remote sensing facilitate more precise calculation of EPM factors (soil erodibility, soil protection, slope, temperature, and precipitation) through spatial analysis techniques.

2. Materials and Methods

2.1. Study Area

The study area, located in Aqaba Governorate (Figure 1), lies between latitudes $29^{\circ}24'46.77''N$ and $29^{\circ}30'48.40''N$ and longitudes $34^{\circ}58'35''E$ and $35^{\circ}7'0''E$. The basin covers 65 km² with elevations ranging from 0 to 1250 m above sea level.

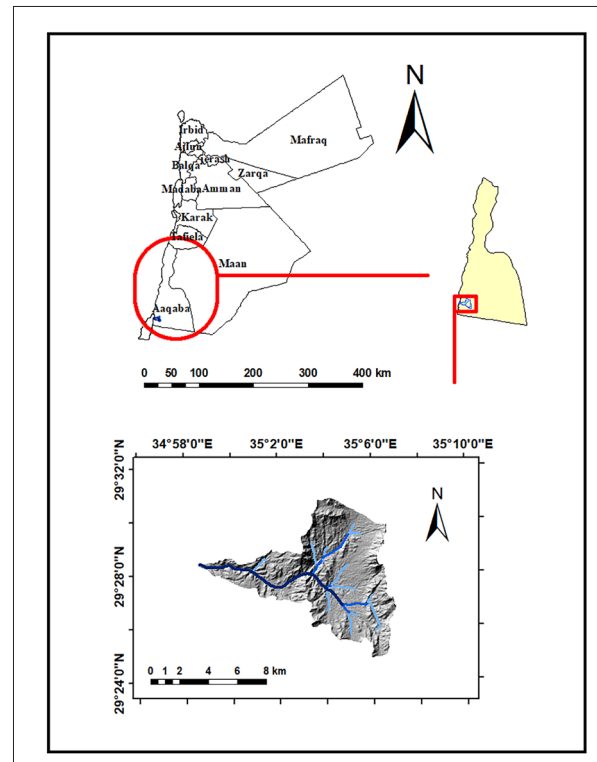


Figure 1. Location map of the study area in Aqaba, Jordan

2.2. Climatic data

Climate change in Jordan has led to shorter precipitation seasons with reduced precipitation frequency. Although most meteorological stations record decreasing precipitation trends, some locations experience extreme precipitation events (Salahat and Al-qinna, 2015; Oroud, 2011). Minor climate variations may lead to substantially different geomorphological responses (Saqqa & Atallah, 2013).

The study area has a hyper-arid climate with low mean annual precipitation and moderately high temperatures. According to the King Hussein International Airport station (1980-2018), the annual average temperature at the location is $24.8^{\circ}C$, and the annual precipitation is 23.4 mm.

2.3. The EPM

The Gavrilović Method, also known as the EPM method, is commonly used in watershed and land degradation studies in mountainous, dry, and semi-arid regions. It is calculated using Equation (1). The method is straightforward and requires minimal data, making it suitable for countries with limited data availability and offering an advantage over more

complex approaches (Efthimiou et al., 2016). This technique was chosen for the study because it is simple and convenient. It was used to evaluate soil erosion and sediment yield, as well as to examine its spatial distribution in the Wadi Mubarak Basin along the Aqaba Back Road in southern Jordan. To the best of the researcher’s knowledge, this method has not yet been applied in Jordan. The work followed the steps outlined in the flowchart (Figure 2), based on the method developed by Gavrilović.

$$W = T * H * \pi * \sqrt{Z^3} \tag{1}$$

W = Average annual soil erosion (m³/km²/ year)

T = Temperature coefficient

The temperature coefficient (T) is calculated by Eq.2.

$$T = \sqrt{\left(\frac{t^0}{10} + 0.1\right)} \tag{2}$$

Where t^0 = the mean annual temperature (°C)

H = Average annual precipitation (mm)

Z = soil erosion coefficient (dimensionless) can be calculated from Eq.3.

$$Z = Y * Xa * (\varphi + \sqrt{Ja}) \tag{3}$$

Where:

Y = Soil erodibility coefficient (dimensionless).

Xa = Soil protection coefficient (dimensionless).

φ = coefficient of type and extent of erosion (dimensionless).

Ja = Average Slope coefficient (%)

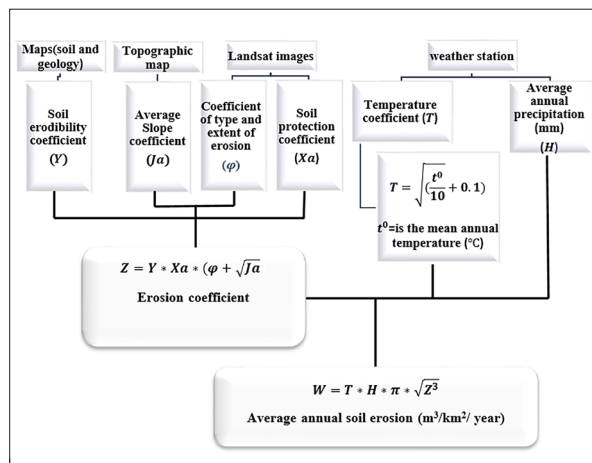


Figure 2. Flowchart which explains the various processes involved in the computation of sediment production.

2.3.1 Temperature and precipitation parameters

Gavrilović incorporated temperature in the EPM because thermal variations contribute to material weathering and rock formation breakdown (Marouane et al., 2021) In Morocco, the watersheds have very significant soil wastes, related to various physical and anthropic factors. The Oued Inaouene watershed is concerned because of its location in the eastern part of the Saïss basin, between the Middle Atlas and the Pre-Rif, where water erosion is more accentuated.

This basin covers a total area of 3597.13 Km² and it is marked by a semi-arid climate with relatively abundant (989.68 mm). Precipitation significantly influences water erosion, with intensity, duration, and frequency all playing a role. High-intensity precipitation events, though shorter, are more erosive than low-intensity ones due to increased flow energy (Elbadaoui et al., 2023).

2.3.2 Soil Protection Coefficient (Xa)

The soil protection coefficient, representing an area’s erosion protection effectiveness, is determined by the land use and vegetation cover coefficients. These coefficients, reflecting land type and erosion control measures (especially in agriculture), are considered a single factor in assessing soil protection (Elbadaoui et al., 2023). The soil protection coefficient in the study area was derived from the land-use map (Figure 3).

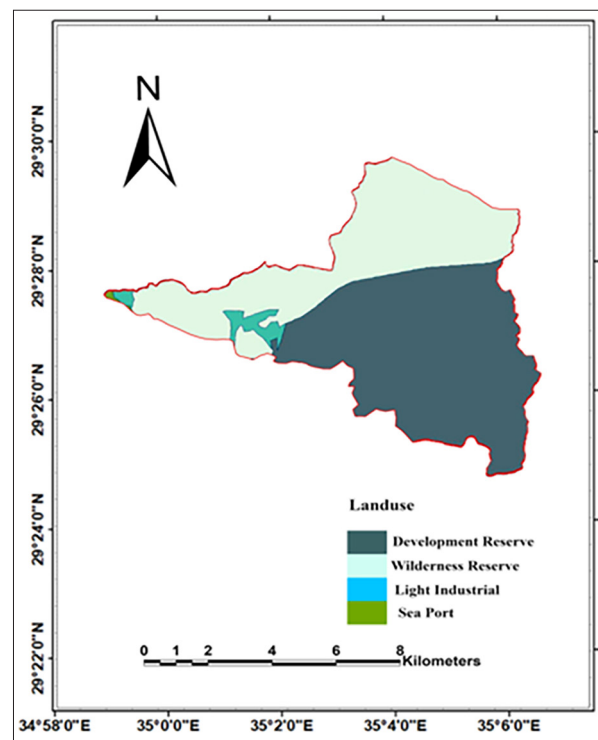


Figure 3. Landuse map of the study area as reported by Aqaba Special Economic Zone Authority.

2.3.3 Soil erodibility coefficient (Y)

Soil erodibility coefficient (Y) reflects a soil’s susceptibility to erosion based on watershed geology (Marouane et al., 2021) In Morocco, the watersheds have very significant soil wastes, related to various physical and anthropic factors. The Oued Inaouene watershed is concerned because of its location in the eastern part of the Saïss basin, between the Middle Atlas and the Pre-Rif, where water erosion is more accentuated. This basin covers a total area of 3597.13 Km² and it is marked by a semi-arid climate with relatively abundant (989.68 mm). The formula was used to obtain the soil erodibility coefficient (Y) in the study area using the geological map scale of 1:50000 (Figure 4).

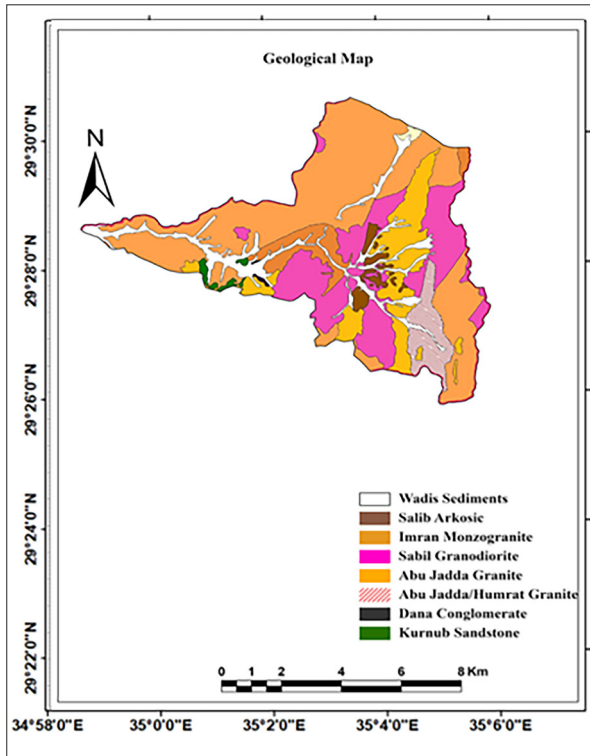


Figure 4. Geological map of the study areas reported by the Jordanian Natural Resources Authority.

2.3.4 Coefficient of Type and Extent of Erosion (ϕ)

The Coefficient of Type and Extent of Erosions (ϕ) was determined through field observation. The coefficients of erosion processes were classified into five categories with an interval between 0.1 and 1.0 (Efthimiou et al., 2016). The study area values were obtained using Landsat and field values (Figure 5).

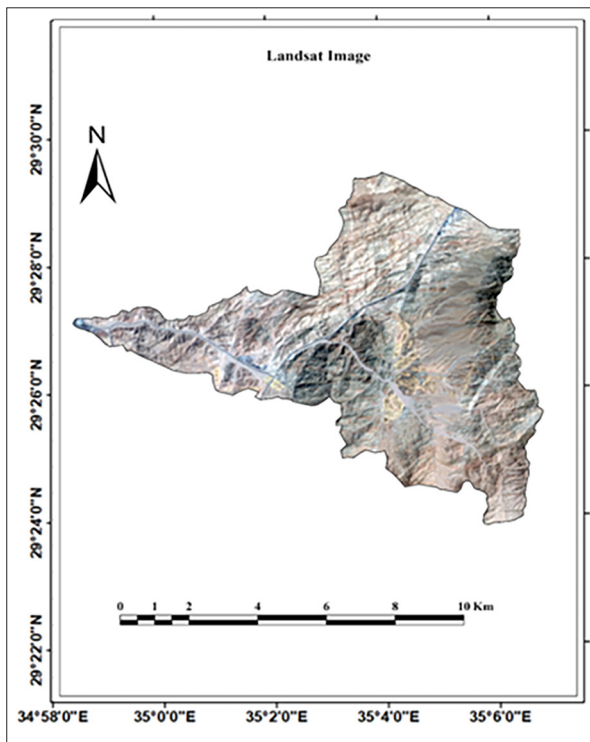


Figure 5. Landsat image of the study area, attained from the United States Geological Survey.

2.3.5 Average Slope Coefficient (%)

Slopes are one of the most important factors in the EPM Method. The erosion rate generally increases when surface water runoff occurs on steeper terrain with longer slope lengths (Tavares et al., 2021). Understanding the slope-erosion relationship is crucial for predicting erosion patterns and their landscape impacts (Elbadaoui et al., 2023). The slope map in the study area was derived from a topographic map at a scale of 1:25,000 (Figure 6).

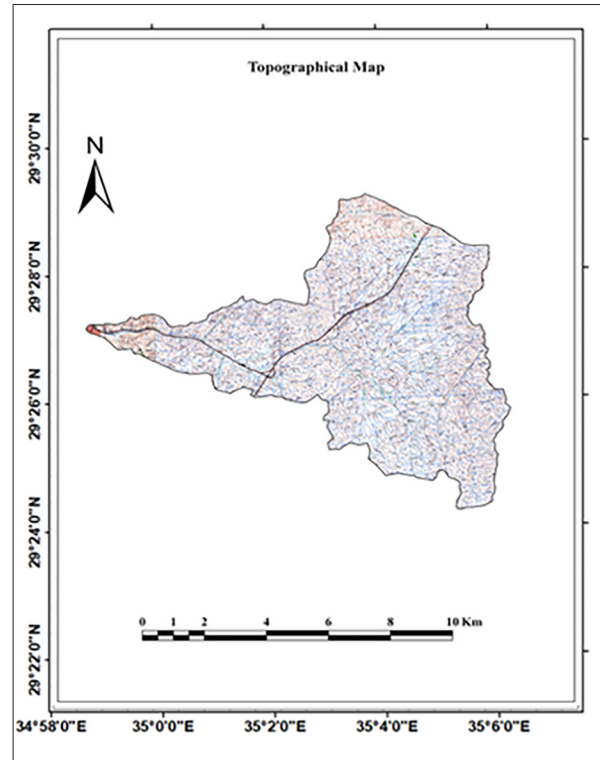


Figure 6. Topographical map of the study area attained from Royal Jordanian Geographic Center.

The coefficients X, Y, and ϕ values are presented in Table 1 and Figures 7, 8, 9, and 10; they are computed using tables proposed by Gavrilovic (1988) and reviewed by several researchers (e.g., Zemljic M, 1971; Globevnik et al., 2003; Fanetti and Vezzoli, 2007;Milanesi et al., 2015).

Erosion intensities are categorised as excessive, strong, medium, weak, very weak, or accumulating (Dragičević et al., 2017) various methods for erosion intensity and sediment production assessment have been developed. The necessity for better model performance has led to the more frequent application of the method sensitivity and uncertainty assessments in order to decrease errors that arise from the model concept and its main assumptions. The analysis presented in this paper refers to the application of the Gavrilović method (Erosion Potential Method; da Silva et al., 2014 ; Globevnik et al., 2003; Gavrilovic et al., 2004; Amiri, 2010; Tošića et al., 2012; Yousefi et al., 2014; Milanesi et al., 2015; Vacca and Dominici, 2015; Ali et al., 2016; Tadić and Šljuka, 2018; Jamal, 2020; Marko et al., 2022) geological, soil texture and land use types. The basin was subdivided into 5 sub-basins. Data required for this study were collected in part through published reports, whilst the remaining was derived by field surveys. Necessary maps in EPM models were

prepared in Autocad-2006 medium and were transported to IILWIS, after some revision. After constructing topologies for all polygons, we entered weightings for all layers within the Arc-View software. Combinations of all layers were managed thereafter. Coefficient of each factor was determined, and erosion intensity coefficient (Z).

Table 1. Descriptive factors used in the EPM method (Gavriloic, 1972; Lazarevic, 1985).

Soil Protection Coefficient	Xa
Mixed and dense forest	0.05-0.20
Thin forest with grove	0.05-0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20-0.40
Damaged forest and bushes, pasture	0.40-0.60
Damaged pasture and cultivated land	0.60-0.80
Areas without vegetal cover	0.80-1.00
Soil Erodibility Coefficient	Y
Hard rock, erosion resistance	0.1-0.3
Rock with moderate erosion resistance	0.3-0.5
Weak rock, schistose, stabilised	0.5-0.6
Sediments, moraines, clay, and other rocks with little resistance	0.6-0.8
Fine sediments and soils without erosion resistance	0.8-1.0
Coefficient Of Type and Extent Of Erosion	Φ
Little erosion on the watershed	0.1-0.2
Erosion in waterways on 20–50% of the catchment area	0.3-0.5
Erosion in rivers, gullies, and alluvial deposits, karstic erosion	0.6-0.7
of the catchment area is affected by surface 80%–50 erosion and landslides	0.8-0.9
The whole watershed is affected by erosion	1.0

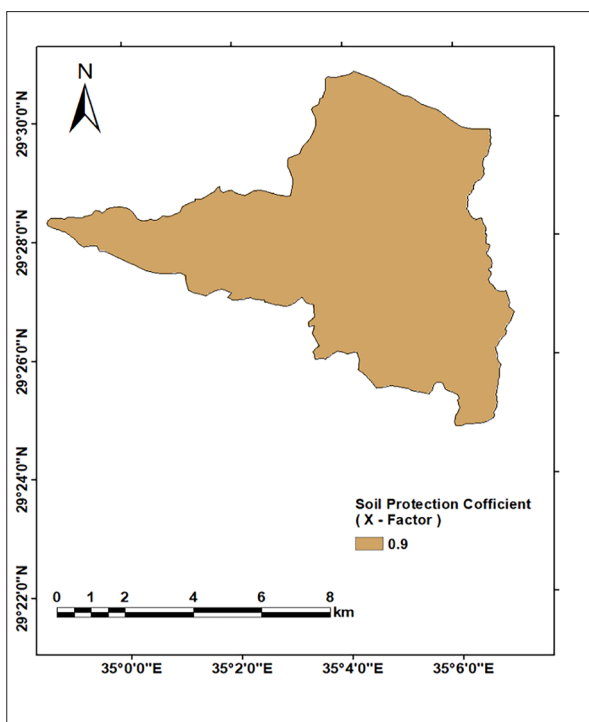


Figure 7. Soil protection coefficient (X)

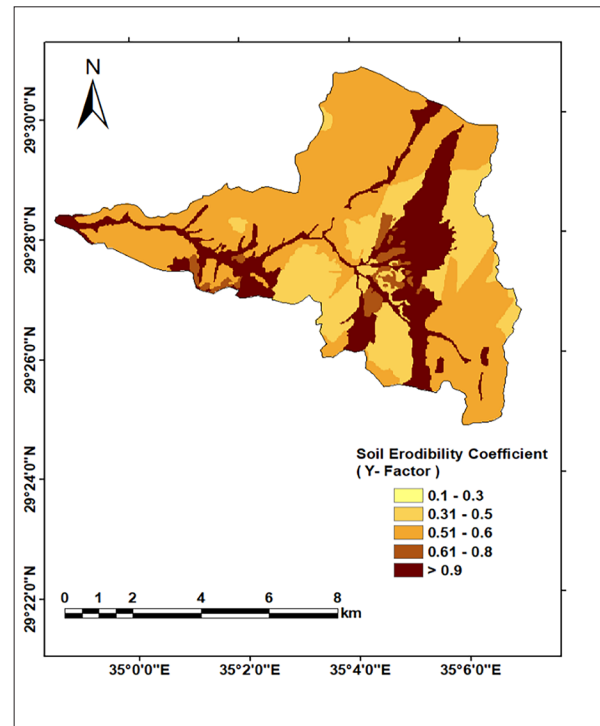


Figure 8. Soil erodibility coefficient (Y)

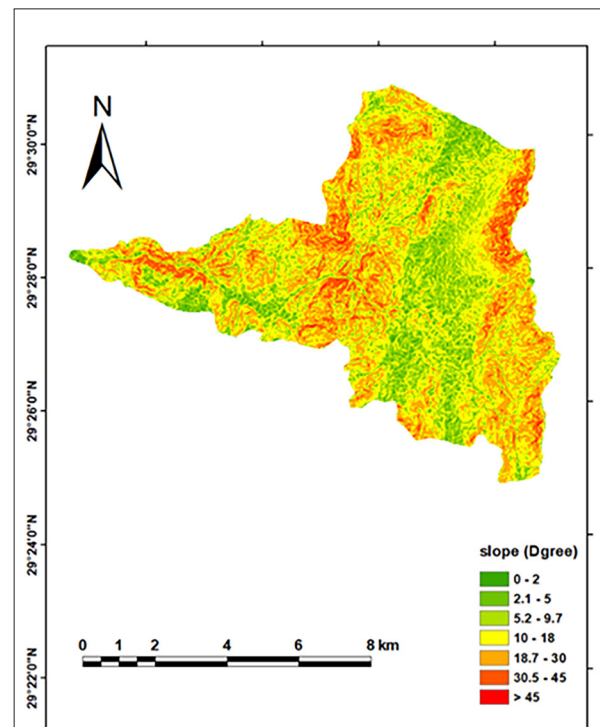


Figure 9. Average Slope coefficient (Ja)

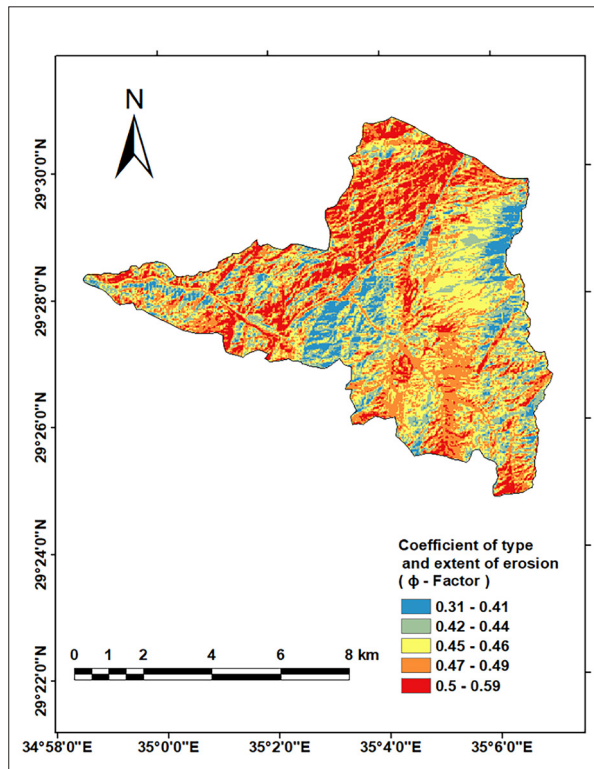


Figure 10. Coefficient of type and extent of erosion ().

3. Results and Discussion

Table 2 classifies erosion intensity using the non-dimensional coefficient Z, while Figure 11 shows its spatial distribution. Most of the basin area (83%, 54 km²) exhibits very low erosion intensity (Z < 0.2), followed by low (13%), moderate (2.4%), and high (1.1%) erosion intensities. Very high erosion intensity covers the smallest area (0.5%).

Table 2. The soil erosion intensity coefficient

Category	Erosion Intensity	Z value	Area (km ²)	Area (%)
I	Very low	<0.2	54	83
II	Low	0.21 – 0.40	8.4	13
III	moderate	0.41 – 0.70	1.6	2.4
IV	High	0.71 – 1	0.7	1.1
V	Very high	> 1	0.3	0.5

Analysis of results in Table 4 and Figure 12 shows that most of the basins experience severe to extreme erosion when compared with Zachar’s classification of sheet erosion based on soil removal intensity. Zachar identified six categories of water erosion based on the soil volume lost. Table 3 displays the erosion categories determined by Zachar based on erosion volume (Zachar, 1983). Erosion rates vary spatially within the basin depending on controlling factors.

Annual soil erosion reaches extreme levels in the main channels of large wadi beds (>42,000 m³/km²/year). The study area lacks vegetation cover, which makes the soils prone to erosion. Vegetation reduces the erosive force by dissipating the energy of erosive agents and increases water infiltration, which in turn reduces runoff. Main channels sloping wadi beds have sediments that have low soil resistance and steep side slopes. The granite underlying the Wadi Mubarak is

bare, and sandstone has been completely stripped away in over 90% of the catchment.

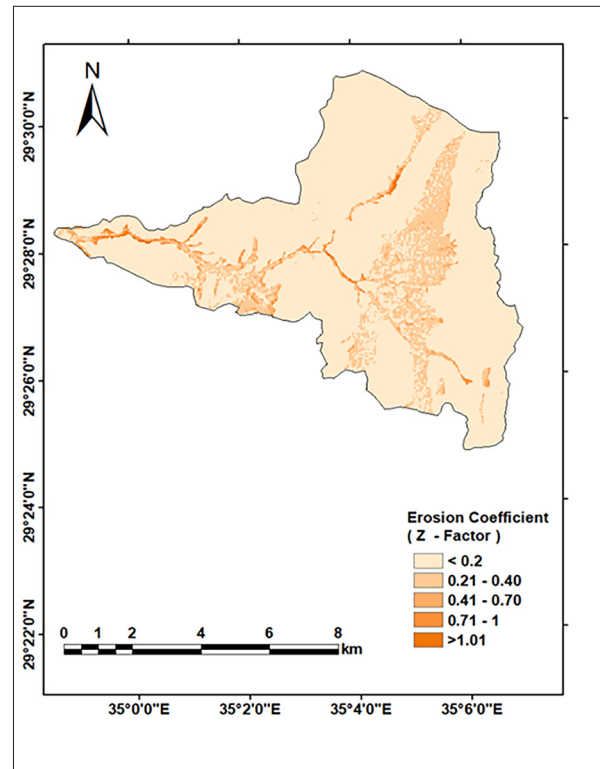


Figure 11. Spatial distribution of erosion intensity by using the Erosion Coefficient (Z).

These are higher rates than those in Table Zachar. The ranges of 20000-41000, 8100-19000, and 2900-8000 cover (1.1%), (7.7%), and (38%), respectively. However, the largest area has a rate below 2,800 m³/km²/year (52%). The annual average erosion rate is estimated at 22,092 m³/km²/year. According to Zachar’s classifications, this value indicates a high level of erosion. Using this method, the highest and lowest erosion rates were 243 m³/km²/year and 163 m³/km²/year, respectively.

Table 3. Classification of sheet erosion and deflation by the intensity of soil removal. (Zachar, 1983)

Verbal assessment	Intensity of soil removal (m ³ km ² year ⁻¹)	Grade
No erosion. Insignificant erosion	50 >	1
Slight erosion	50 - 500	2
Moderate erosion	500 – 1500	3
Severe erosion	1500 – 5000	4
Very severe erosion	5000 – 20000	5
Catastrophic erosion	20000 <	6

Table 4. Annual soil erosion in the basin of Wadi Mubarak

Class	W (m ³ /km ² /year)	Area (km ²)	Area
1	<2800	34	0.52
2	2900 - 8000	25	0.38
3	8100 – 19000	5	0.077
4	20000 – 41000	0.7	0.011
5	> 42000	0.3	0.005

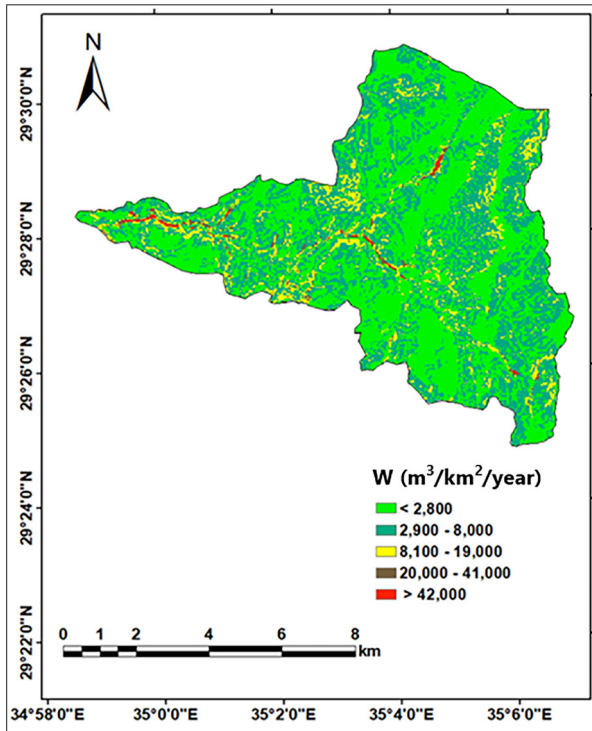


Figure 12. Annual erosion map of Wadi Mubarak

4. Conclusion

The primary aim of the study was to estimate soil erosion and to investigate its spatial distribution in the Wadi Mubarak Basin through the EPM Method. The research concluded that the EPM, when implemented with remote sensing and GIS

methods, can be used to examine soil erosion in places like the Wadi Mubarak Basin. The rate of erosion at the Wadi Mubarak basin was estimated using key factors, such as soil erodibility, soil protection, slope, temperature and precipitation. The highest soil erosion is (>42000 m³/km²/year), and the lowest soil erosion is (2800 m³/km²/year). The damaged hydraulic structures indicate a lack of knowledge of the geomorphic conditions at the design stage, as well as the use of inappropriate specifications during construction, especially at the road crossings (see Figure 13).

Erosion assessment methods are needed in the catchment as essential tools for decision-making and for the construction of relevant check dams to control surface runoff in the upper alluvial piedmont. These devices reduce the erosive energy of floodwater. Appropriate hydrological systems that have the capacity to allow flood discharge, such as riprap, gabions, as well as appropriate drainage, will mitigate the volume and velocity of runoff. Landslides and rockfall can be prevented by fences and terraces, which reduce water runoff and control sediment transport.

The use of AI should be implemented in the future to enhance mitigation. To simulate future climate (e.g., RCP4.5 and RCP8.5) projections, EPM can be used to project future erosion at the current temperature and precipitation to show a higher sediment yield at higher temperature conditions. Environmental Impact Assessments (EIAs) of infrastructure projects, like dams, roads, and mining activities can also integrate EPM. The approach supports the sustainability evaluation of the proposed development zone (Marko et al., 2023).



Figure 13. Undercut erosion at the base of the road

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