# WATER EROSION MODELLING IN THE ALGERIAN STEPPE ZONES: CASE OF LAGHOUAT PROVINCE

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## ABSTRACT

Water erosion is a complex environmental phenomenon that affects many countries around the world. In this paper, remote sensing data, and environmental and climatic indicators are used to map the soil erosion extent in the Laghouat steppe region in central Algeria. This area is characterized by low rainfall of limited duration and high intensity. As a result, the vegetation cover is low and soil abrasion is remarkable. Using the EPM erosion potential model, satellite data provides information on environmental indicators such as slope, soil, vegetation cover, and climatic factors such as annual precipitation and temperature. The results show that the average soil losses modeled by the EMP are calculated at 28 t/ha/year representing a range from 0.52 to 340 t/ha/year. Statistical analysis of these results also determines the highly correlated factors that control water erosion in this area, including slope, rainfall, and soil sensitivity.

**Keywords:** EPM, GIS, Soil, Cartography, Arid, Laghouat.

## Introduction

Water erosion is an environmental phenomenon that affects several regions of the world. It leads to soil and vegetation degradation, particularly in arid and semi-arid regions. The main causes of soil erosion in Algeria are directly linked to climatic and geomorphological conditions and human activities such as overexploitation of natural resources, overgrazing, deforestation, and overexploitation of agricultural land (Mihi *et al*., 2022). Land degradation in drylands is manifested by a deterioration of vegetation cover, soils, and water resources. It results in a reduction in the biological potential of the land and its capacity to support the populations living there (Benguerai, 2011).

In Algeria, more than six hundred thousand (600,000) hectares of steppe areas are vulnerable to desertification (Ali, 2009). They are exposed to recurring droughts and increasing anthropogenic pressure due to overgrazing and the exploitation of land unsuitable for crops. For several decades, the process of degradation of all components of the ecosystem has intensified. The fauna and flora, the plant cover, the soil, and its elements are facing a hydrological imbalance due mainly to soil erosion (Nedjraoui & Bedrani, 2008).

The most affected areas are the densely populated ones, where the pressure on the land is the highest. More than 12 million hectares are subject to water erosion causes significant soil losses and leads to the siltation of dams. Consequently, the loss of fine soil elements is estimated at 120 million tons of sediment per year and landslides are estimated at 16.6 million $m^3$/year (Aissaoui & Ghazi, 2023).

The rate of soil erosion is controlled by natural factors such as precipitation, soil properties, topography, vegetation cover, watershed morphology, drainage network, and land use practices, as well as human activities (Daneshvar *et al*., 2012). Nowadays, the assessment and monitoring of soil water erosion are key factors in understanding the extent and evolution of this environmental phenomenon (Mosaid *et al*., 2022; Dey *et al*., 2024). Several indicators can be used to quantify it, such as loss of soil productivity, decrease in plant biomass, decline in water quality, and desertification (Lamb, 2011).

Despite recent efforts by the United Nations, such as the Global Soil Erosion Mapping Project, there is still no coordinated supranational soil erosion monitoring program. To monitor the progress of water erosion and assess the results of control actions, space techniques such as satellite imagery are favored. Satellite data are collected from different sources, such as Landsat, Sentinel, and MODIS, which provide valuable information in the form of pixels on vegetation, soils, and other environmental indicators. They make it possible to develop more precise maps showing the progression of the phenomenon based on environmental indicator parameters. Large-scale desertification monitoring aims in particular to study and analyse changes in vegetation cover and soil quality. Thus, field studies can be conducted to assess the impact of erosion on local ecosystems.

Optimization of erosion parameters remains a major challenge because they cannot be measured directly in the field. Thus, modeling the erosion process with physical models is a major problem in optimizing erosion parameters that cannot be measured directly in the field. In the literature, several empirical models used to estimate soil erosion give promising results such as the model of (Wischmeier & Smith, 1978) also called the Universal Soil Loss Equation (USLE); the Water Erosion Prediction Project (WEPP) model (Laflen *et al*., 1991), WaTEM/SEDEM (Van Oost *et al.*, 2000), Rangeland Hydrology and Erosion Model (RHEM) (Nearing *et al.*, 2011), PanEuropean Soil Erosion Risk Assessment model (PESERA) (Kirkby *et al*., 2008) and le Erosion Potential Model (EPM) (Gavrilovic, 1988).

However, it should be noted that most of the soil erosion models currently in use were initially developed for small-scale assessments or using data from small experimental plots. Therefore, these models need to be fully evaluated and tested (Bezak *et al*., 2024). It should also be emphasized that most soil erosion modeling applications have been carried out using the Universal Soil Loss Equation (USLE) or its revised versions (eg. RUSLE model) (Borrelli *et al*., 2021).

Additionally, many modeling applications lack adequate model evaluation (e.g., lack of data for validation or evaluation) which can produce highly uncertain soil erosion estimates.

Given the limited number of soil erosion modeling applications in developing regions, Large-scale soil erosion modeling assessments are today often the only resource available for the most threatened regions to support policy decisions and implement mitigation strategies. Consequently, it is preferable to use multiple soil erosion models, rather than a single one.

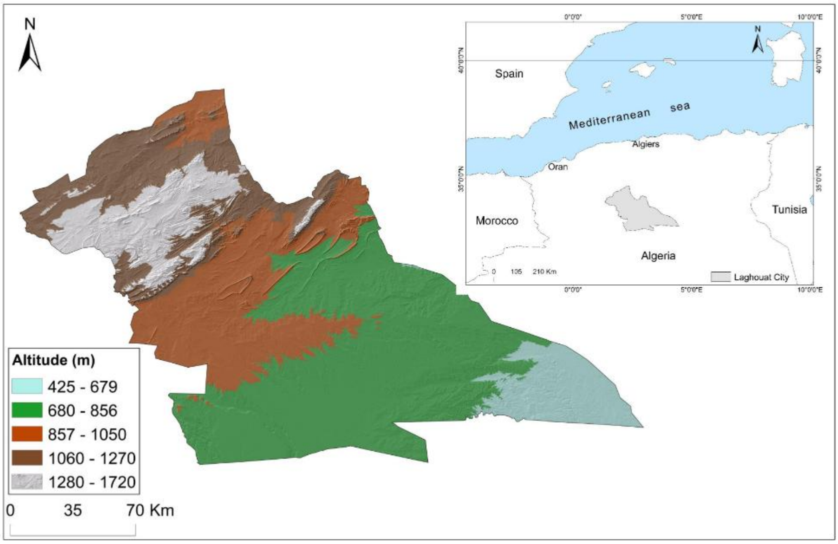
In this study, we are interested in quantifying the rate of water erosion in the wilaya of Laghouat in central Algeria. The choice of this study area was dictated by its geographical importance and its extent where the Saharan Atlas Mountains, the desert, the rocky ridges, and the palm grove meet, and this gateway to the desert is one of the regions most exposed to water erosion. The main objective of this study is to draw up maps of the extent of water erosion in the steppe zone of Laghouat by applying the empirical soil loss model (EPM). The modeling was carried out by mapping different factors such as annual precipitation, temperature, topography, and soil quality.

## METHOD AND MATERIALS

### Study area

Located in the heart of Algeria, 400 km south of the capital Algiers, the Wilaya of Laghouat covers an area of 25,000 km$^2$ and is a pastoral region near the M'Zi wadi (see Fig. 1). Laghouat was originally a sought-after oasis that stretched for nearly 3 km, and it is also home to the largest natural gas deposit in Africa.

**Fig. 1: Location of the study area**




The wilaya of Laghouat is composed of two distinct regions:

- The Saharan Atlas zone is characterized by altitudes ranging from 1,000 m to 1,700 m and slopes of 12.5 to 25 %. This zone in the northwest of the wilaya is made up of old forest massifs with an area of 47,000 ha, alfalfa beds covering an area of 315,000 ha as well as pastures and rangelands with an area of 1,531,000 ha.
- The Highland and Saharan Plateaus zone, are characterized by altitudes ranging from 700 to 1,000 m and slopes of 0 to 3 %. This zone is made up of vast steppe expanses with an area of 1,900,000 ha, a large part of which has been degraded by prolonged droughts.

The climate is continental in the northwest with rainfall ranging from 300 to 400 mm, snowfall and frost. In the Highlands region, the climate is Saharan and arid. Rainfall varies between 150 mm in the center and 50 mm in the south. Winters are characterized by frost and summers by high heat accompanied by sandstorms (Hamlat *et al.*, 2021).

### Erosion Potential Model (EPM)

The original name EPM was developed by Slobodan Gavrilovic in the 1960s and 1970s following field research in the Morava River catchment in Serbia (Gavrilovic, 1988). The model has been frequently applied in Mediterranean regions especially in North Africa, Italy and Greece (Abdullah *et al*., 2017; Aleksova *et al*., 2023; Dominici *et al*., 2020; Efthimiou *et al*., 2016). Gavrilović (1988) proposed an empirical relationship to quantify the annual volume of soil loss produced by surface erosion given by the following equation:

$$W = T \, . \, H \, . \, \pi \, . \, Z^{1.5} \qquad [1]$$

Where W is the volume of soil produced by water erosion in ($m^3/km^2$/year), H is the annual rainfall (mm), T is the temperature coefficient given by the following equation:

$$T = ( 10 / t \;\; + 0.1 )^{0.5} \qquad [2]$$

Where t is the average annual temperature (°C). This formulation is only valid if t is greater than -1°C. The erosion coefficient (Z) reflects its intensity and depends on four important factors that control the evolution of erosion, namely: soil exposure, topography, vegetation cover and land use. The Z factor is given by:

$$Z = Y \, . \, Xa \, . \, ( \psi + J^{0.5} ) \qquad [3]$$

Where Y is the soil erodibility coefficient, Xa is the soil protection coefficient, ψ is the coefficient of erosion and development of the river network, J is the average slope (%) of the watershed. Table 1 gives an arbitrary classification of the erosion coefficient (Z) according to (Gavrilovic *et al*., 2008).

**Table 1: Classification of the Z coefficient (Gavrilovic *et al*., 2008)**

| Erosion Class | Description | Z value | Average value |
|---|---|---|---|
| Class V | Very low | < 0.2 | 0.1 |
| Class IV | Low | 0.20 – 0.40 | 0.3 |
| Class III | Moderate | 0.40 – 0.70 | 0.55 |
| Class II | High | 0.70 – 1.00 | 0.85 |
| Class I | Very high | > 1.00 | 1.25 |

## RESULTS AND DISCUSSION

### Climate data

The annual precipitation of ten years of observation used in the EPM model for mapping water erosion in the wilaya of Laghouat is of the TRMM type. The raster map of the factor (H) was generated by a spline interpolation between ten stations (see Fig. 2a). As for the annual mean temperature (t), we calculate it from band 10 of the Landsat 8 satellite image for a ten-year observation period.

### Soil erodibility coefficient (Y factor)

The soil erodibility coefficient (Y) can be expressed as the inverse value of the soil resistance to erosion due to the erosive force of precipitation (Efthimiou & Lykoudi, 2016). The lithological coefficient influences the geomorphology of an area and controls the erosion processes because the erodibility of the soil is very dependent on it. Consequently, it influences the speed of the erosion processes. In this study, the data for estimating the soil erodibility coefficient were obtained by examining the soil map of the study area. Five classes are proposed (see Fig. 2c) ranging from (0.139) to (0.173) indicating a soil that is fairly resistant to erosion. The results obtained were analyzed taking into account the soil sensitivity classification table proposed by (Bolline & Rosseau, 1978). It can thus be seen that the calculated values of Y indicate that the soil in the study area is fairly resistant to erosion.

**Table 2: Description of the erodibility coefficient Y given by (Bolline & Rosseau, 1978)**

| Description | Y value | Average value |
|---|---|---|
| Highly erosion-resistant soil | < 0.10 | 0.05 |
| Soil fairly resistant to erosion | 0.10 à 0.25 | 0.17 |
| Soil moderately susceptible to erosion | 0.25 à 0.35 | 0.30 |
| Soil fairly susceptible to erosion | 0.35 à 0.45 | 0.40 |
| Soil very sensitive to erosion | > 0.45 | 0.50 |

**Soil protection coefficient (factor Xa)**

The soil protection coefficient was calculated using the modified NDVI (XaNDVI), based on the methodology proposed by (Zorn & Komac, 2009), the modified Xa factor is given by the following equation (Chaaouan *et al.*, 2013):

$$Xa = -1.15 \; ( XaNDVI - 0.61 ) \qquad [4]$$

Table 3 groups together a classification of the soil protection coefficient (Xa) proposed by (Gavrilovic, 1988). According to the cartographic analysis of the soil protection coefficient, it is revealed that Xa fluctuates between 0.028 and 1.0 (cf. Fig. 2d).

**Table 3: Classification of soil protection coefficient Xa**

| Description | Xa value | Average value |
|---|---|---|
| Mixed and dense forest, Sparse Forest with grove | 0.05 – 0.20 | 0.1 |
| Coniferous forest with small grove, bushy meadow | 0.21 – 0.40 | 0.3 |
| Damaged forest and bushes, pastures | 0.41 – 0.60 | 0.5 |
| Damaged pastures and cultivated land | 0.61 – 0.80 | 0.7 |
| Areas without vegetation cover | 0.81 – 1.00 | 0.9 |

**Slope coefficient (J factor)**

The slope coefficient was established using the digital elevation model (DEM) of the study area. Using a 30 m resolution DEM to generate and classify the slope factor (J). The slopes were reclassified into seven classes ranging from 0-5 to 50 %. The mean values of each slope class were assigned in Table 4 to determine the J factor (Gavrilovic, 1988). In the study area the J factor varies from 0 to 179 % indicating a highly variable topography (cf. Fig. 2e).

**Table 4: Slope classes and corresponding J factor**

| Slope class | Slope (%) | J value |
|---|---|---|
| 1 | 0 - 5 | 0.025 |
| 2 | 5 - 10 | 0.075 |
| 3 | 10 - 20 | 0.150 |
| 4 | 20 - 30 | 0.250 |
| 5 | 30 - 40 | 0.350 |
| 6 | 40 - 50 | 0.450 |
| 7 | > 50 | 0.600 |

**Erosion coefficient (ψ factor)**

The coefficient ψ represents the degree of influence of the erosion process in the watershed, in which the values range from 0.1 to 1 (Gavrilovic, 1988). In other words, the factor ψ indicates the resistance of the soil to erosion and also reflects the type and extent of erosion and subsidence (Bezak et al. 2024). It is calculated by the following equation (Zorn & Komac, 2009):

$$\psi = ( TM4 )^{0.5} / Qmax \qquad [5]$$

Where TM4 is band 4 of the Landsat 8 image, Qmax is the maximum radiance of band 4. The erosion coefficient in the Laghouat area is between 0.34 and 0.71 (see Fig. 2f), and classified according to Table 5.

**Table 5: Values of the erosion coefficient Ψ**

| **Type and extent of erosion** | **Ψ value** | **Average value** |
|---|---|---|
| Low erosion across the entire area | 0.1 – 0.2 | 0.15 |
| Erosion of watercourses over 20 to 50% of the area | 0.3 – 0.5 | 0.4 |
| Erosion of rivers, ravines and alluvium, karst erosion | 0.6 – 0.7 | 0.65 |
| 50 to 80% of the area is affected by erosion and landslides | 0.8 – 0.9 | 0.85 |
| The entire area is affected by erosion | 0.9 – 1.0 | 0.95 |

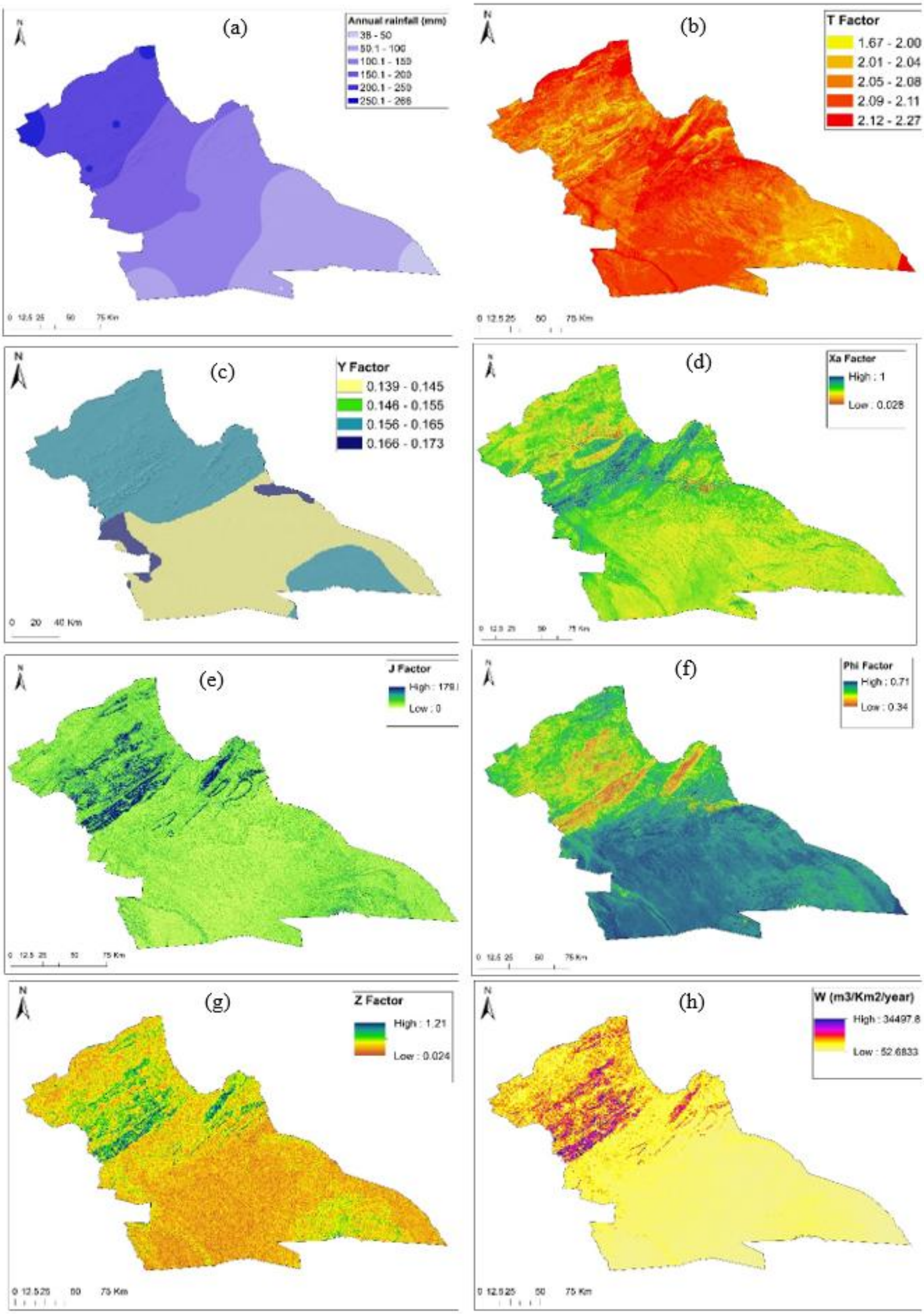
**Soil loss rate W**

By combining the seven factors of the Gavrilovic EPM model, we obtain the map of soil losses due to water erosion, with an overall average estimated at 28.10 t/ha/year. Soil losses are classified in Table 6. It can be seen that the erosive dynamics vary from one area to another, depending on the extent of influence of the different physical and anthropogenic factors (see Fig. 2h).

**Table 6: Classification of the calculated soil losses W**

| Intensity | Class (t/km$^2$/an) | Area (Km$^2$) | Area (%) |
|---|---|---|---|
| Very Low | 52-2050 | 16533.84 | 53.59 |
| Low | 2050-4030 | 7822.51 | 25.36 |
| Moderate | 4030-6500 | 4355.66 | 14.12 |
| High | 6500-11000 | 1624.25 | 5.26 |
| Very high | 11000-34000 | 514.40 | 1.67 |
| | Total | 30850.66 | 100 |

**Fig. 2: Mapping of erosion factors using EPM model**



Land losses greater than 52 t/km$^2$/year represent a class of very low erosive intensity and come from 53.59 % of the area of the zone, mainly occupying the southern part. The low intensity class from which land losses are less than 4030 t/km$^2$/year covers 25.36 % and is located in the center of the study area. 14.12 % of the wilaya of Laghouat is considered an area with high erosive dynamics. However, the class of very high soil losses (>11000 t/km$^2$/year) only occupies 1.67 % of the study area.

Considering the average land losses, we can confirm the results of studies carried out in semi-arid watersheds by applying the universal soil loss equation USLE, such as the Macta basin which produces on average (20.6 t/ha/year) (Semari & Korichi, 2023). The results also reveal a good correlation with the EMP model applied in other arid areas such as the Souss Basin in Morocco (Ahmed *et al*., 2019), and the Jouah Basin in Saudi Arabia (Azaiez, 2024).

**Weight of erosion factors on soil losses**

Empirical models translate the relationship between measured variables and evaluated by regression analysis. The uneven distribution of soil losses in the study area results from the high variability of the impact of each erosion factor. The statistical relationships between the different factors and the erosion dynamics show quite significant trends.

Table 7 shows a strong correlation between the erosion rate W and the erosion coefficient Z which is 0.88. The most influential factor in this coefficient is the slope, which seems to be the most determined in the erosive dynamics with a correlation coefficient of about 0.86. The precipitation H presents a significant correlation of the order of 0.65 before the soil erodibility factor Y which occupies the fifth rank with a correlation of 0.45. However, the erosion factors ψ which are in direct connection with the temperature present a negative correlation of -0.63.

**Table 7: Correlation matrix between soil losses and erosion factors**

| Layer | W | Z | PHI | T | Xa | Y | J | H |
|---|---|---|---|---|---|---|---|---|
| W | 1.00 | | | | | | | |
| Z | 0.88 | 1.00 | | | | | | |
| PHI | -0.63 | -0.49 | 1.00 | | | | | |
| T | -0.08 | -0.20 | 0.03 | 1.00 | | | | |
| Xa | 0.21 | 0.22 | -0.18 | 0.25 | 1.00 | | | |
| Y | 0.45 | 0.44 | -0.57 | -0.13 | 0.13 | 1.00 | | |
| J | 0.86 | 0.93 | -0.42 | -0.21 | 0.13 | 0.27 | 1.00 | |
| H | 0.65 | 0.33 | -0.67 | 0.11 | 0.08 | 0.47 | 0.26 | 1.00 |

## CONCLUSION

Water erosion is a major environmental problem especially in arid and semi-arid areas. It results from a natural imbalance in the dynamic interactions between several components in the ecosystem, namely: climate, soil, vegetation and man. It is a state that sets in under the combined effects of climate and entropic changes but also human activities applied to fragile soils and vegetation.

The main objective of this study is to apply the EPM erosion potential model to estimate soil water erosion and to study its spatial distribution in the Wilaya of Laghouat in central

Algeria. Such an important area represents a port region of the great Sahara and suffers from the effects of increasing desertification from one year to the next. This study confirmed that remote sensing and GIS techniques could be advantageous decision-support tools for the quantification of soil losses. The results indicate soil loss classes ranging from 52 to 34000 t/km$^2$/year with an average of 2800 t/km$^2$/year. The most dominant class is between 52-2050 t/km$^2$/year and covers more than half of the area of the Wilaya of Laghouat. However, the areas most affected by water erosion are concentrated in the center in the mountainous regions.

These soil loss results show a good correlation with other Algerian basins that have similar climatic and environmental characteristics, such as; Mina basin (11.2 t/ha/year), Boumahdane basin (11.18 t/ha/year), Sahouat basin (12 to 16 t/ha/year), Gazouana basin (9.65 to 11.33) and Macta basin (20.6 t/ha/year).

The EPM factors such as soil erodibility, soil protection, slope, temperature, and precipitation are important to control the erosion process. Statistical analysis of the results shows that the erosion rate is strongly related to the erosion coefficient Z and slope coefficient J with correlations of 0.88 and 0.86 respectively. EPM is weakly related to temperature in this arid zone hence the correlation coefficients are negative.

Erosion mapping by the EPM method has proven to be a useful tool for environmental monitoring and water resources management, which provides satisfactory results. In the face of these environmental challenges, the Algerian government has implemented several policies and programs to improve water management and vegetation protection. These policies include the rehabilitation of degraded lands, protection of forest areas, and construction of water storage infrastructure. However, despite these efforts, the steppe region in Algeria still faces major environmental challenges that require continued attention and effective measures to ensure sustainable management of natural resources.

## CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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