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ASSESSMENT OF SOIL EROSION IN THE BOUSSELLAM WATERSHED, ALGERIA: INTEGRATED APPROACH USING THE EROSION POTENTIAL METHOD (EPM) AND GIS

Abstract: Land degradation is a growing concern, exacerbated by recent climate change. Water erosion emerges as a crucial tool to address this issue. This study focuses on estimating soil loss from water erosion in the Boussellam valley watershed, a part of the expansive Soummam basin in northeastern Algeria, characterized by a semi-humid to humid climate. Covering an expanse of 4,301 km² with a perimeter of 420 Km, the basin's assessment incorporates often-overlooked factors such as temperature. Utilizing Geographic Information System (GIS) in conjunction with GAVRILOVIC's EPM (Erosion Potential Method) model, erosion projections for the year 2022 have been generated. The findings reveal that the entire Boussellam watershed experiences an average erosion rate of 8.50 tonnes per hectare annually. However, it is evident that the current protective measures implemented by decision-makers are suboptimal. To pinpoint the most vulnerable areas, GIS was employed to map and subsequently categorize them into five levels of erosion intensity: low, moderate, medium, high, and very high. These detailed maps will enable more precise and tailored interventions by decision-makers to effectively safeguard the regions most impacted by erosion.

Key words: erosion, EPM, GIS, Boussellam watershed, Algeria

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Introduction

Soil erosion is considered one of the natural phenomena that threaten ecological balance, and it has become increasingly dangerous in recent decades due to current climate changes. According to Borelli et al. (2017), According to the FAO-led Global Soil Partnership20, arable lands around the world lose 75 billion tonnes (Pg) of soil annually, translating into an estimated $400 billion in lost revenue. More than 88% of global land degradation is caused by soil erosion (Benselama et al., 2018).

Particularly susceptible to water erosion, which can be caused by a variety of reasons (soil slope, vegetation cover, human activity), are semi-arid environments. Algeria recorded that around 20 million hectares of land were affected by erosion (Mazour & Roose, 1996), and the Algerian Ministry of Agriculture reported that 50 million hectares of land were subject to erosion (Benselama et al., 2018).

Particles of soil are carried and deposited downstream alternatively topsoil particles break off from one location and deposit in a new one, causing water erosion. Arable land is where soil particle separation occurs most frequently, which has a detrimental impact on soil fertility as well as agricultural and economic output. As a result, the Food and Agriculture Organization (2017) estimates that 7.6 million tons of production are lost annually.

Rainwater-borne soil particles also become silt in dams and other places. All decision makers are urged to seek a proper assessment of soil erosion in order to obtain satisfactory results and take strategies and measures to reduce erosion and preserve the integrity of fertile soils from disappearing.

For soil assessment there are currently many different models used around the world, some simple and other more complex, and from a diagnosis of a body of literature we have revealed that the universal equation soil loss (USLE) (Wischmeier & Smith, 1958), including its modifications (MUSLE, RUSLE) (Wischmeier & Smith, 1978) are the most used in Algeria, for example (Ahmed et al., 2021; Benchettouh et al., 2017; Benselama et al., 2018; Djoukbala et al., 2018; Goumrasa et al., 2021; Sahli et al., 2019; Toubal et al., 2018).

While the EPM model has been widely applied in some countries and in many watersheds to estimate soil erosion in a GIS and remote sensing environment, in Algeria (Zeghmar et al., 2022) in Morocco (Sadiki & Mesrar, 2012; Zahnoun et al., 2019) in The Iranian State (; Shahabi et al., 2016; Tangestani, 2006), in Northern Greece (Efthimiou et al., 2016), in Montenegro (Spalevic et al., 2015).

The objective of this work is to assess soil erosion in the Oued Boussellam watershed in northeastern Algeria using the Erosion Potential Model (EPM). The EPM method is chosen for its applicability in GIS and remote sensing environments, and its successful use in various other regions around the world.The novelty of this study lies in its focus on a specific watershed in Algeria, where soil erosion is a significant concern. The availability of data required by the EPM model, coupled with advances in GIS applications and easy access to remote sensing data, allows for accurate mapping of susceptibility to soil erosion. This study aims to determine the spatial distribution of potential soil erosion in the Oued Boussellam valley, providing valuable information for decision-makers to implement measures and strategies to reduce erosion and preserve fertile soils in the region.

Materials and Methods

Study area

The Oued Boussellam sub-basin is located in the north-central part of Algeria and is part of the grande Soummam basin. Oued Boussellam is the main hydrographic axis of the Oued Boussellam sub-basin. It descends from the Meghris mountains, north of Sétif, to one of the largest valleys in Algeria, Oued Soummam. The study basin is located between longitude: 5° 20' 00'' and 5° 25' 00' E and latitudes 36° 10'00'' and 36° 15'00' N. It has an estimated surface area at 4301 km² and a perimeter of 420 km. The study area is characterized by heights of over approximately 1745 m and an outlet of 164 m, with an average height of approximately 932 m. The study basin is characterized by a humid climate in the northwest and dry in the southernmost regions, and it includes large agricultural areas with fertile lands devoid of vegetation. All these conditions have made this watershed a land. It is still exposed to strong erosion dynamics dominated by a dense hydrographic network. The eastern and southern slopes are considered the most susceptible to water erosion due to the steep slope and the intensity of aggressive rains that occur on the uncovered areas with clay soils, while the lower areas are constantly exposed at risk of surface runoff.

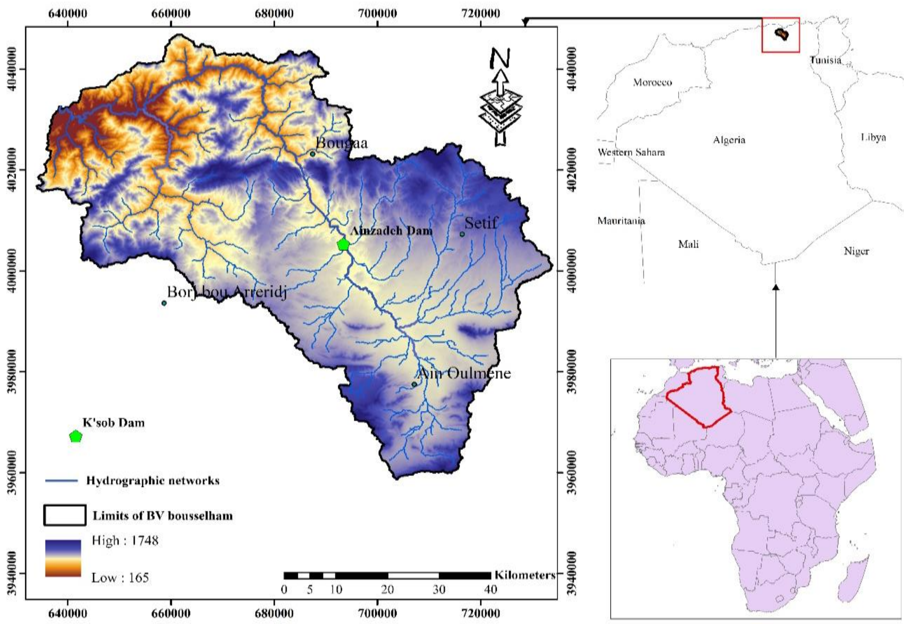

Fig. 1. Localisation of the Oued Boussellam watershed

Method and Procedures

Gavrilović developed the "probable erosion method" for the EPM model in the Serbian Morava River catchment in the 1950s (Dragičević et al., 2016). Then, in order to manage erosion control measures, a method was established to predict annual soil erosion rates for various types of erosion, including erosion in ravines, plots and valleys (Blinkov & Kostadinov, 2010). This method aims to assess soil water erosion by combining hydro erosion factors based on precipitation volumes, temperature, susceptibility to soil erosion, soil protection, types of erosion and slopes.

As all data relating to the model parameters and the similarity of the physical characteristics of the watershed are available, we will test the ability of this model to predict erosion in the Oued Boussellam watershed. In order to apply the Gavrilović model, all parameters required for the application of the empirical model in GIS must be mapped and integrated. Because GIS can process data quickly and efficiently, the parameters used in remote sensing research and data collected from many sources have become useful tools for managing natural resources and conducting disaster research (Pham et al., 2018). For this reason, researchers mainly use this software to evaluate and calculate soil erosion. (Belasri & Lakhouili, 2016). The work was carried out in accordance with the procedures indicated in the flowchart below (Fig. 2).

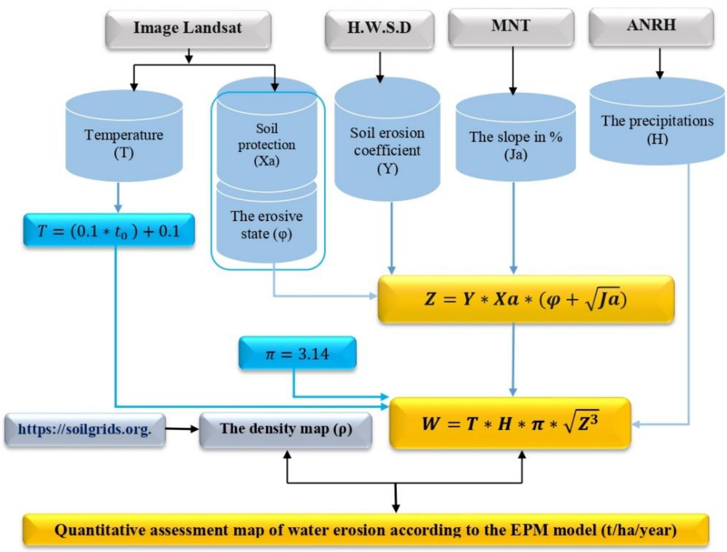

Fig. 2. Flowchart of the adopted methodology

The six parameters slopes, precipitation, temperatures, soil erodibility, erosion types and soil protection are combined to represent erosion in the equation:

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

where:

W : Estimated average annual soil losses ($m_3/km^2/year$). The values will subsequently be converted into t/h/an;

T: temperature coefficient, expressed as follows:

$$T = (0.1 * t_0) + 0.1 \quad (2)$$

Or: to: average annual temperature in °C

H: average annual precipitation (mm);

Z: erosion coefficient.

Temperature coefficient (T)

Dry and semi-arid regions experience accelerated soil desquamation, and this is due to high temperature, which is considered one of the factors that affect the cohesion of rock and soil particles. Therefore, temperature was used as an erosion factor in the EPM model. By Gavrilović, and to extract the temperature coefficient in the system. Geographic information, and considering the lack of data at the study site, satellite image data downloaded from the USGS website was used, where monthly data for the year 2022 was used. By using ArcGIS we were able to create a map of average annual temperatures (Fig. 3), which represents the average annual temperature for the year 2022.

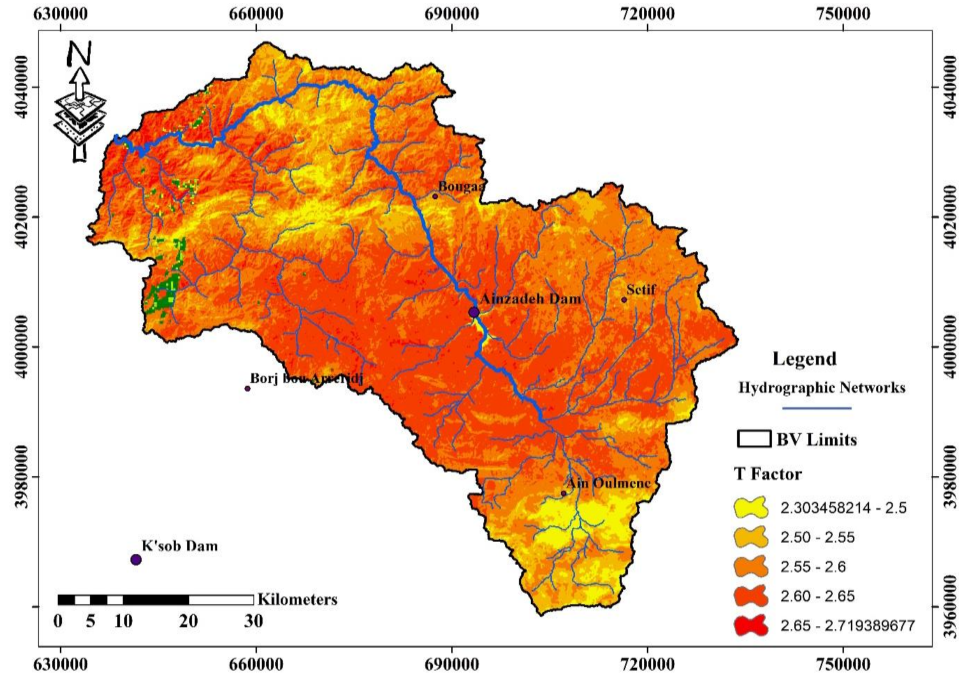

Fig. 3. Map of the spatial average annual temperature in the Oued Boussellam watershed

The factor of average annual precipitation (H)

Precipitation is considered one of the main factors of water erosion. The precipitation erosion factor (H) was estimated from rainfall data obtained from the Agency (ANRH), which are represented by monthly and annual data for approximately 18 stations from 1972 to 2013. The stations cover approximately the study area and on the basis of the proposed mathematical relationship (Meddi et al., 2016), H factor values were extracted independently for each station and distributed over the entire basin surface by kriging. And thanks to ArcGIS, we were able to create an H-factor map (Fig. 4), thanks to which we recorded that there is a precipitation gradient between stations distributed almost over the entire study area. Influence of heights and slopes which form barriers to the effects of the White Sea mean.

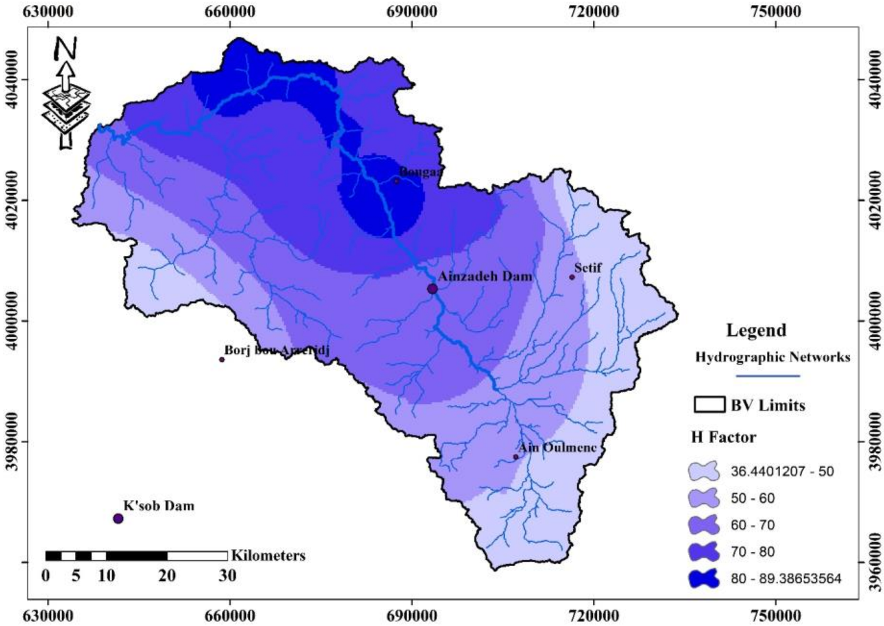

Fig. 4. Map of average annual precipitation (H) of the Oued Boussellam watershed

The erosion coefficient (Z)

To obtain the corrosion coefficient (Z), one must extract the four factors that control its development, namely (exposed rocks and soils, topography and vegetation/land use), then the corrosion coefficient (Z) can be calculated on the basis of equation 3:

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

Where:
Y: Soil erodibility coefficient. It depends on the rock, soil type and climate;
Xa: Soil protection coefficient against influences linked to atmospheric phenomena;
δ: Coefficient which expresses the type and degree of evolution of erosion processes visible in the watershed;
Ja: slope angle (%).

Convert the results of this model from $m_3/km^2/year$ to t/ha/year by applying the density equation:

$$\rho = m/V \quad (4)$$

Where:
m: the mass of the homogeneous substance occupying a volume V.

Soil protection coefficient (Xa)

It is known and disseminated among researchers (Jaafar, 2023; Salma et al., 2023; Zahnoun et al., 2019) in this field that the soil protection coefficient (Xa) is directly linked to the plant cover, which is considered one of the basic elements to protect soils from aggressive rains. The values of (Xa) vary depending on the land occupation by vegetation (Tab. 1) (0.1 for dense forests to 1 for rough terrain).

Tab. 1. (Xa) depending on land occupation by vegetation (Dragičević et al., 2016; Zorn et al., 2009)

The type of soil	Soil protection coefficient (Xa)
Dense and medium forests	0.05 – 0.20
Pine forests and grasses along streams	0.20 – 0.40
Pastures and farms	0.60 – 0.80
Bare ground without cover	0.8 – 1.00

Based on the methodology used by (Chaaouan et al., 2013; Marouane et al., 2021; Zeghmar et al., 2022) and depending on the application of the vegetation factor (NDVI) from monthly data for the year 2022 from the Landsat satellite obtained on the USGS website, the values of the soil protection factor index (Xa) was extracted according to the following equation:

$$Xa = (NDVI - 0.61) * (-1.25) \quad (5)$$

Where:
Xa: Soil protection coefficient;
$NDVI$: Adjusted vegetation cover factor.

From Figure 05, we see that the criteria of the soil protection index gradually evolve over the study area, where the values of Xa between 0.4 and 0.6 covered the southern region of the study area, which represents pastures and farms, while values of Xa < 0.4 reflect the presence of dense and medium forests, pine forests and forests.

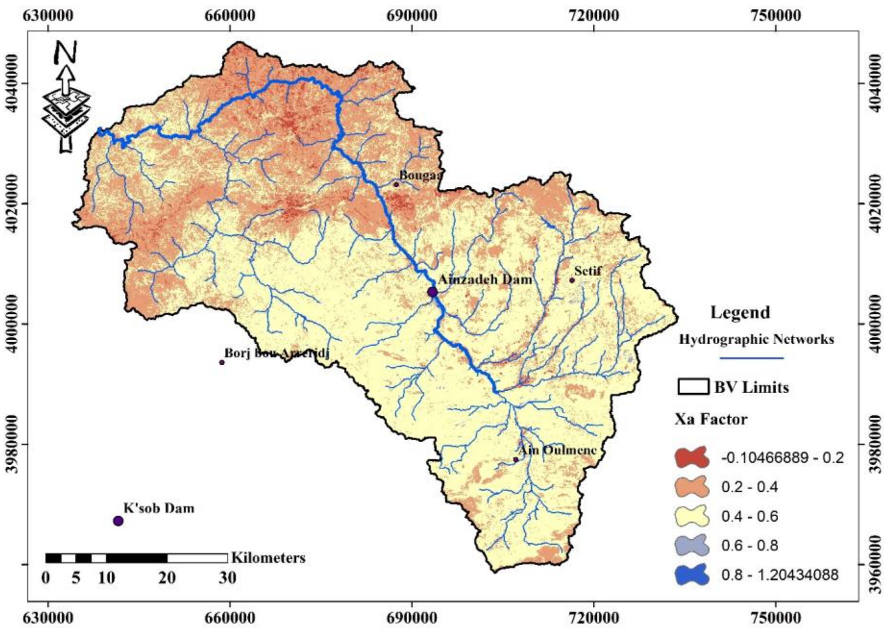

Fig. 5. Map of values (Xa) generated from the NDVI transformation

Soil erosion coefficient (Y)

The influence of erosion processes is significantly affected by the soil erosion factor K, as quantified by its contribution (Kumar et al., 2016). Susceptibility to soil erosion varies depending on soil characteristics such as texture, structure, roughness, organic matter content and moisture levels. This parameter demonstrates the vulnerability of soil to water-induced erosion, determined by evaluating soil types against their erosion resistance attributes, encompassing texture, structure, organic composition, permeability and moisture content. For this investigation, soil data were sourced from the Harmonized World Soil Database (HWSD), using the World Soil Map, to establish the K factor (FAO & ISRIC, 2012; Nachtergaele et al., 2023). This comprehensive database offers detailed information on global soil parameters and serves as a raster platform for global soil mapping. Calculation of the K factor also involved the use of equations established from previous work (Benselama et al., 2018; Chadli, 2016).

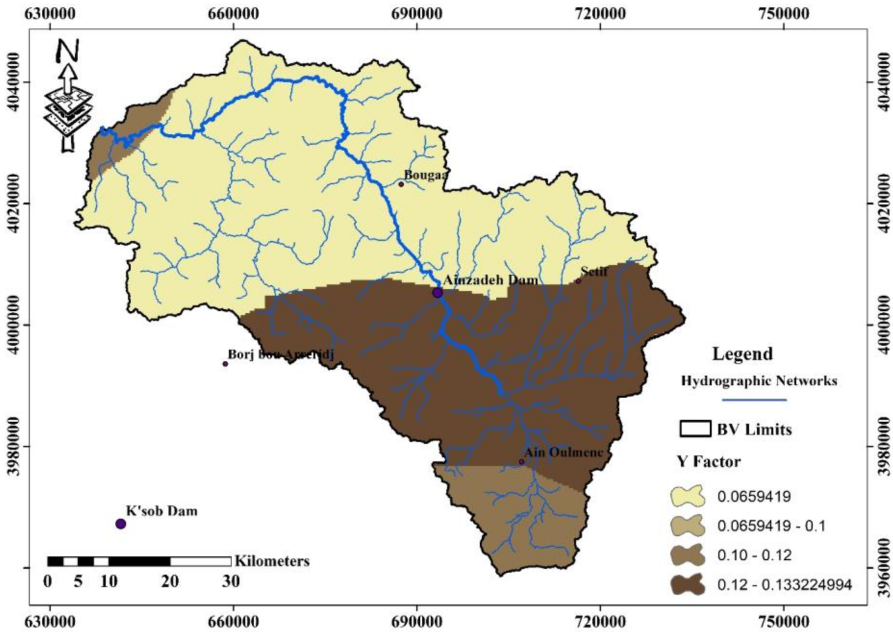

Fig. 6. Map Soil erosion coefficient (Y)

Coefficient of type and extent of erosion (φ)

The parameter φ serves as an indicator of the extent of erosion in the watershed, denoting values between 0.1 and 1.0 (Table 2, Figure 7), thus delineating the regions affected by erosion encompassing rivers, valleys, canyons, alluvial accumulations and the entire watershed (AbdulWahab et al., 2019; Zeghmar et al., 2022). The evaluation of the current erosion index (φ) was carried out using the methodology introduced by (Zeghmar et al., 2022; Zorn et al., 2009), with a calculation based on Landsat 8 satellite imagery. The calculation of the parameter φ is carried out using the following equation (5):

$$\delta = \sqrt{\frac{TM4}{Qmax}} \qquad (6)$$

Where TM4 band 4 of the Landsat 8 image, Qmax is the maximum radiance of band 4, erosion coefficient in the Oued Boussellam watershed ranging from 0.3 to 0.62.

Tab. 2. Values of the EPM coefficient of the erosion coefficient

Coefficient of type and extent of erosion	Factor (φ)
Little erosion on the watershed	< 0.2
Erosion of watercourses in 20 to 50% of the watershed	0.2 – 0.4
Erosion of rivers, ravines and alluvium, karst erosion	0.4 – 0.6
50 to 80% of the watershed is affected by surface erosion and landslides	0.6 – 0.8
Entire watershed affected by erosion	0.8 – 1.0

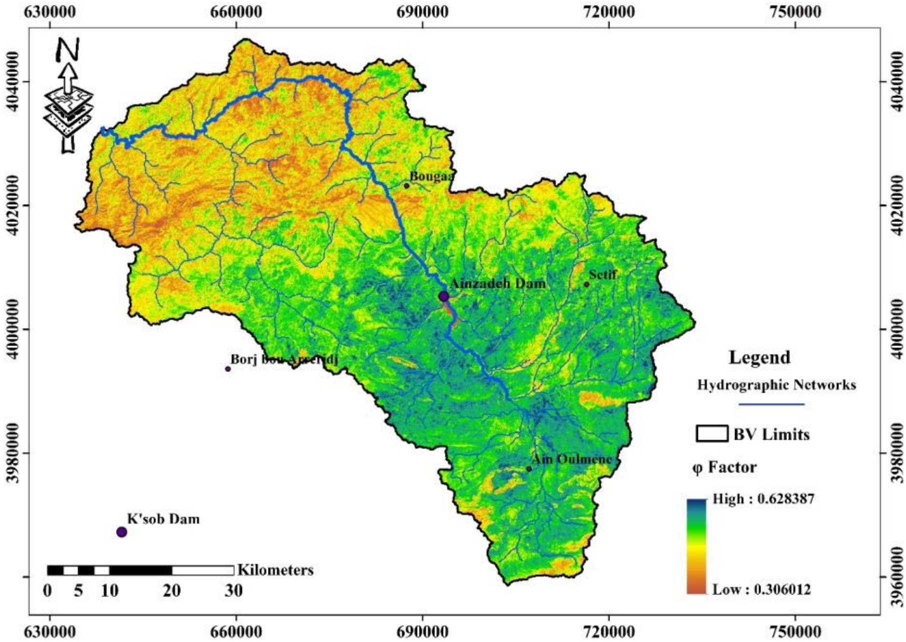

Fig. 7. Map of the existing erosion indicator (φ)

Slopes of the Study Area in Percentage (Ja)

The slope coefficient constitutes an essential parameter within the EPM model, meaning an important determinant contributing to increased soil sensitivity. This amplification of sensitivity is particularly pronounced under the influence of intense precipitation, favoring increased flow velocities through the synergistic interaction with the slope coefficient. The resulting result manifests itself in intensified erosion processes. The derivation of the slope coefficient involved the use of the digital elevation model (DEM) specific to the Oued Boussellam watershed region. A DEM with a resolution of 30 meters was used to calculate the slope parameter, carried out using ArcGIS software. The gradient values were classified into five classes ranging from 0% to 40% inclination (Zahnoun et al., 2019; Zeghmar et al., 2022), as visually shown in Figure 8. Examination of the class distribution reveals the concentration of steep slopes mainly in the north of the country. And west, a topographic feature attributed to the complex features of the drainage network and underlying terrain irregularities.

The slope categories (Figure 8) were divided into five categories. The low and very low categories, which represent less than 30%, are concentrated in the southern part, while conversely, the high and very high categories are concentrated in the northern half of the study area.

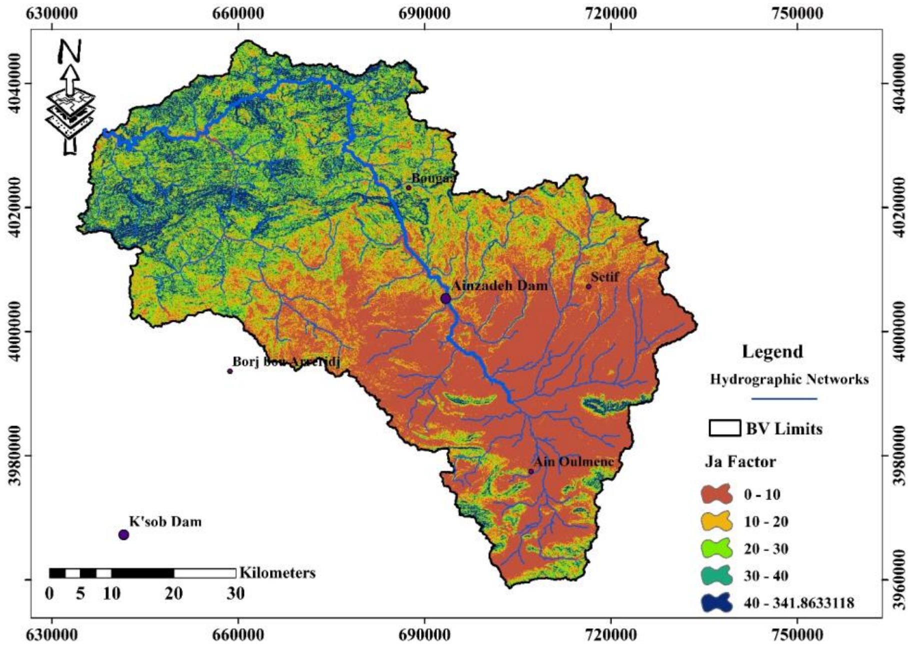

Fig. 8. Slope map Ja (%)

Results and discussion

Erosion intensity coefficient (Z)

Using the assembled set of contributing factors described above, and following the integration of coefficient maps into a geographic information system (GIS) framework, a computational pathway emerges for the calculation of the erosion coefficient Z This pivot coefficient, synthesized from the fusion of data on soil sensitivity, slope, soil protection (Xa) and erosive state (Φ), finds its quantification rooted in equation (03). The magnitude of this coefficient serves as an indicator of potential occurrences of erosion in the watershed. The results derived from this initiative, as presented in Table 7, reveal a predominant prevalence of light erosion intensity in the study area, occupying the range of 0.2 to 0.4 on the coefficient scale of erosion. This light erosion category encompasses an area of approximately 2202.44 km^2, constituting 51.22 % of the total study area. The following categories include very light erosion, extending over 1304.14 km^2 (30.33%) followed by Moderate erosion (17.40 %), severe erosion (0.94%) and finally excessive erosion (0.11 %).

Tab. 3. Classification of Z coefficient values of erosion intensity

Potential erosion coefficient	Classes of (Z)	area	
		(km²)	(%)
Very low	< 0.2	1304.14	30.33
Low	0.2 – 0.4	2202.44	51.22
Moderate	0.4 – 0.7	748.33	17.40
High	0.7 – 1.0	40.27	0.94
Very high	> 1.0	4.90	0.11

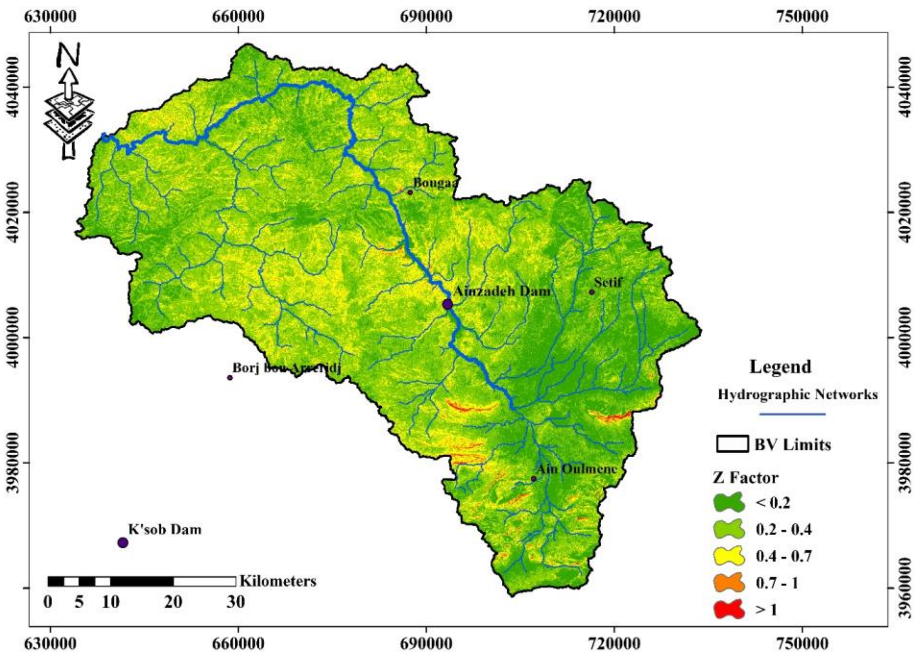

Fig. 9. Erosion intensity coefficient map (Z)

Average annual soil erosion (W)

Using equation (1) and taking advantage of the comprehensive data set and maps available to us, we can use the parameter Z, taking into account climatic factors (H and T), to estimate the annual loss of soil per unit volume of one cubic meter per square kilometer. Per year in the study area. This estimate takes into account spatial variations in the aforementioned factors. The results revealed significant spatial disparities in erosion rates, as illustrated in Figure 10. To facilitate a comparative analysis of the final results, we classified the intensity of soil loss into five distinct classes (as indicated in Table 4): "very low", "low", "moderate", "high" and "very high".

After creating the final map of erosion caused by water erosion using the EPM model (Figure 10), the calculated soil loss ranged from 0 to 13742 m3/km²/year, about 79.97% of the total area. The probability of soil loss ranged between low and very low, and about 6.75%. Of the total area represents the potential for “average” soil loss. From Figure 10, the very low possibilities of erosion are distributed throughout the entire study area, while the possibilities of high and very high soil loss are concentrated in the central and northern regions of the study area.

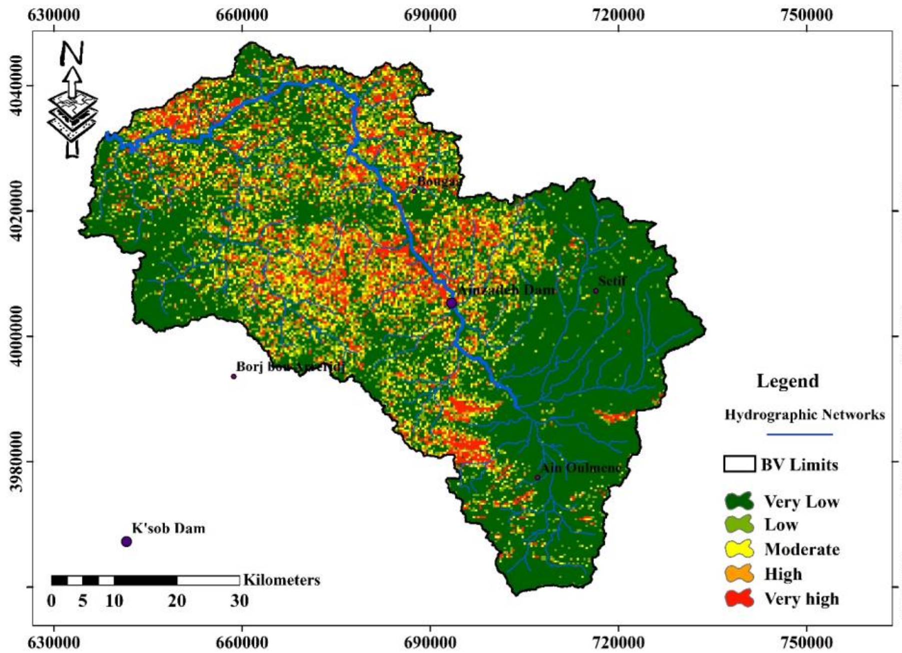

Fig. 10. Map for estimating soil loss (W) of the Oued Boussellam watershed

Tab. 4. Annual soil loss in the Oued Boussellam watershed

Annual soil loss	**Classes of (W) (m3 ha⁻¹ an⁻¹)**	**area**	
		(km²)	**(%)**
Very low erosion	< 1100	2839.84	66.04
Low erosion	1100 – 1500	598.88	13.93
Moderate erosion	1500 – 1800	290.44	6.75
High erosion	1800 – 2000	130.41	3.03
Very high erosion	> 2000	395.23	9.19

The obtained findings align with observations made across various watersheds in Algeria, particularly in the northeastern region. Notably, the study identified consistent patterns in Wadi Kebir Rhumel, where the erosion rate was measured at 17.92 mg·ha-1·p-1, and on the western-northern side of Wadi Bouhamdan, registering 941.13 m²/km²/year (Khallef et al., 2023; Zahnoun et al., 2019).

Moreover, there is a moderate level of concordance with comparable studies conducted in watersheds exhibiting similar climatic and environmental characteristics, albeit utilizing different models, including the RUSLE model. Specifically, congruent outcomes were observed in the northwestern region of Algeria, specifically in Wadi El Maleh (9 tons/hour/year) and Wadi Lahm (5.72 tons/ha/year) (Benselama et al., 2018; Djoukbala et al., 2018).

The present results also harmonize with research on water erosion assessments in other Mediterranean watersheds sharing almost identical climatic and environmental features with Algeria. In Morocco (Simonneaux et al., 2015), the High Atlas Mountains exhibited an average sediment production of approximately 515 m_3/km^2/year, while in Iran (Ebadati et al., 2022), a mountainous watershed in the Mediterranean Sea (central Pindos, Greece) recorded an average sediment production of about 161,236.5 m_3/year (Stefanidis et al., 2018).

The versatility of the EPM model allows for widespread application, empowering decision-makers to formulate strategic plans for effective interventions against water erosion. Its capability to identify and manage high-erosion areas enables the protection and prudent use of soil, guarding against the detrimental effects of water erosion.

Conclusion

In conclusion, our study successfully employed the Erosion Potential Method (EPM) along with Geographic Information System (GIS) tools and satellite imagery to generate a comprehensive map highlighting areas susceptible to soil erosion. The calculated average annual soil loss of 8.50 tonnes per hectare underscores the pressing need for effective erosion control measures in the Boussellam valley watershed. Moving forward, it is imperative to consider the following perspectives. Firstly, continued monitoring and regular updates of erosion vulnerability maps will be crucial for adaptive and sustainable land management practices. Additionally, integrating real-time weather data and climate change projections into erosion models will enhance the accuracy of predictions. Furthermore, collaborative efforts between researchers, policymakers, and local communities are essential to implement targeted erosion prevention strategies and ensure the long-term health and productivity of the region's soils. Comparatively, our findings align with the results obtained by (Sahli et al., 2019) in their study of the Soummam watershed, which utilized the RUSLE model and reported an average soil loss rate of 7.41 tonnes per hectare annually. This convergence of results underscores the validity and reliability of our approach, further emphasizing the importance of proactive erosion management in these critical watersheds.

Conflicts of Interest: The authors declare no conflict of interest.

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