Iraqi Journal of Science, 2023, Vol. 64, No. 7, pp: 3691-3704
DOI: 10.24996/ijs.2023.64.7.44

ISSN: 0067-2904

Mapping of Soil Erosion Using Remote Sensing and GIS: Case of The Oued Bouhamdane Watershed (North-East of Algeria)

Boubaker Khallef

Department of Earth Sciences, Institute of Architecture and Earth Sciences, University Abbas Ferhat, Sétif, Algeria

Received: 11/1/2022 Accepted: 5/3/2023 Published: 30/7/2023

Abstract

The northern region of Algeria is experiencing a real threat to the spatial extension of soil erosion. The Oued Bouhamdane watershed, part of this region, brings together all the natural and anthropogenic conditions that accelerate its degradation. This study is based on the use of remote sensing and GIS to map soil erosion in the Oued Bouhamdane watershed in north-eastern Algeria, using the Gavrilovic equation. The combination of data from different sources and field observation has made it possible to draw up a contextualized map of all the factors of soil erosion. Integrating the model into the GIS made it possible to give a first estimate of the annual volume of eroded soils, i.e., 14.57% of the total area of the Oued Bouhamdane watershed is affected, where soil losses are estimated on average at 941.13m^3/Km^2/year. This modest cartographic result is a perfect base for environmental monitoring and managing water resources in this watershed.

Keywords: Soil erosion; watershed; Remote Sensing and GIS; Oued Bouhamdane; Algeria.

1. Introduction

Water erosion is a set of physical processes (uprooting, transport, and deposition) variable in time and space [1]; it has become a relevant issue globally. This phenomenon has experienced a spectacular extension in recent years, causing increasingly worrying effects [2]. It is the leading cause of soil degradation and the deterioration of the water's geochemical quality [3]. Rapid changes in the landscape under the influence of certain factors such as climatic deterioration, fragile soils, steep slopes, degraded vegetation cover, overgrazing, deforestation, fires, poor management of agricultural work, sand extraction, and accelerated urbanization have contributed to the land exposure to erosion [4]. About six million hectares are exposed to active erosion in Algeria, especially in the northern region. The specific annual erosion is between 2,000 and 4,000 t/km^2/year, making Algeria the country most threatened by erosion. The average between one and two million m^3 is the volume of sediment collected from the basin and deposited in the sea for the basin's sole tributary to the Mediterranean [5]. The Oued Bouhamdane watershed, the subject of this work, brings together all the natural and anthropogenic conditions that predispose them to accelerated degradation.

Hence, erosion assessment reduces its negative effect, where water erosion modeling is a way to identify the soil degradation processes underway in the Oued Bouhamdane watershed. The Prosion Potential Method (EPM) lends itself to spatial interpolation, which makes it possible to obtain factors map and to spatialize the areas most sensitive to erosion. The choice

*Email: bokhallef@yahoo.fr

to apply the EPM to assess water erosion in the Oued Bouhamdane watershed is based on the socioeconomic importance of this watershed. The various applications of the EPM model in Algeria [6] and Morocco [7, 8] encourage using the EMP model. The second reason is that water erosion in this watershed has been assessed using other models [9], but the EPM model has not been used. This study aims to map areas vulnerable to soil erosion at the scale of the Oued Bouhamdane watershed located in northeast Algeria by applying the EPM model using remote sensing and geographic information systems.

2. Material and Methods

2.1. The study area

The Oued Bouhamdane watershed is an important tributary of the Seybouse. It originates in the semi-arid High Plains, on the southern reverse of the Tellian Atlas, and results from the junction of three important rivers; Oued Sabath, Oued Zenati, and Oued Sakkoum. It is located in the northeast of Algeria and occupies the western part of the Wilaya of Guelma, part of the Seybouse watershed. The study area is part of the territory of three departments: the southwest part of the department of Guelma, the east part of the department of Constantine, and the southern part of Skikda. It is limited to the North by the Constantinos watershed, to the South and Southeast by the Oued Cherf watershed, to the East by the Middle Seybouse watershed, and to the West by the Kebir Rhumel watershed (Figure 1).

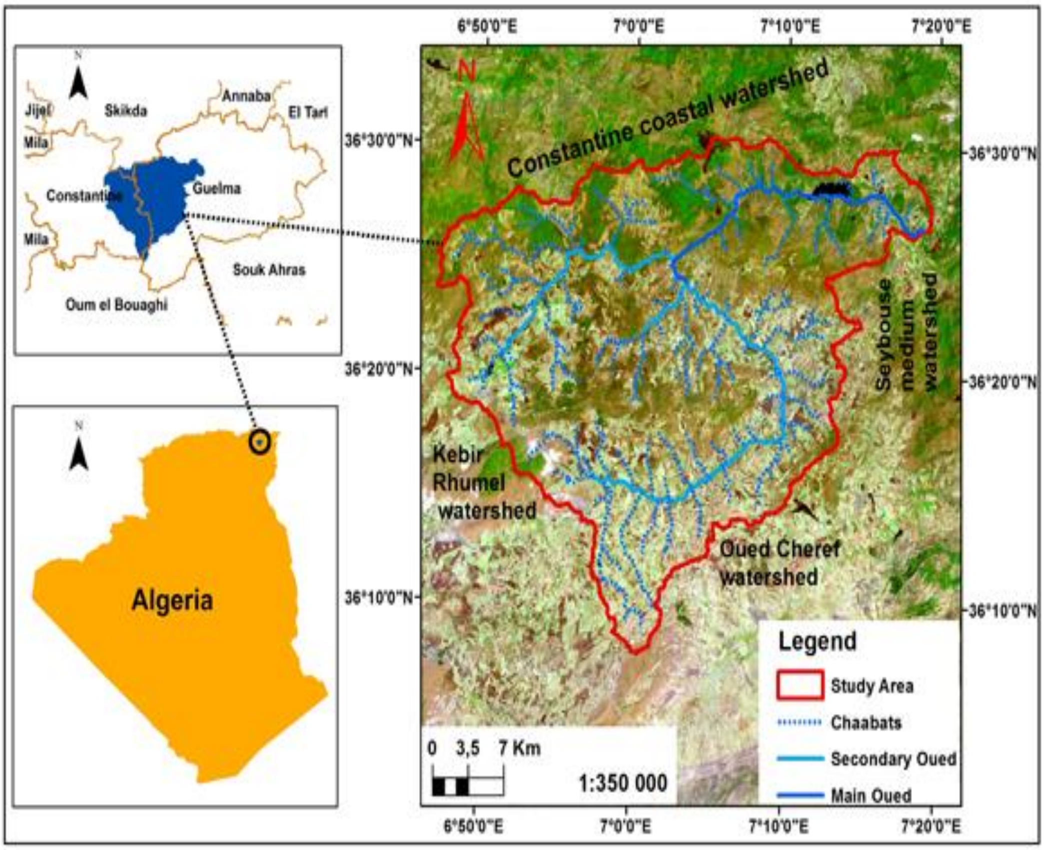

Figure 1: Geographical location of the Oued Bouhamdane watershed

It has an elongated shape and occupies an area of 1105 km². Its Gravelius Kc compactness index is equal to 1.72. It is drained by the Oued de Bouhamdane and its tributaries. The topography of the study perimeter is characterized by a significant altitudinal variation, ranging from 997m to 1237m at Djbel Oum Settas. From a lithological point of view, the Oued

Bouhamdane watershed encompasses a multitude of lithological formations composed mainly of Numidian sandstones, clays, marls, limestones, marly-limestones, shales, conglomerates, and surface formations. These facies ranging from the Quaternary to the Triassic, present variations in resistance of facies ranging from the hardest rocks represented by limestone and sandstone rocks to the tenderest clayey rocks (Bouguerra, 2018). The study area climate is the Mediterranean, characterized by a cold rainy winter and a dry and hot summer. Average annual rainfall ranges from 644 mm to 932 mm. The rainiest months are January, February, and March, totaling 237.63 mm, with a maximum rainfall of 81.92 mm recorded during February for 2009-2017. The average temperature is 18 °C; the minimum average temperature is 4.68 °C in February, while the maximum average is 36.81 °C in July. Natural vegetation in forests, scrub, rangelands, agricultural land, and bare and urban soil mainly represent land use.

2.2. Description of the EPM model

The Gavrilovic EPM model was designed in the 1950s by Gavrilovic for watersheds in the former Yugoslavia [8]. The method was developed to predict the annual erosion rates of soils of a set of erosion types (erosion in aquifers, erosion in gullies and ravines, and undermining of banks) for the management of control practices erosion [7,10, 11, 12]. It is based on mapping and combining six parameters; its formula is written as follows [13].

$W = T.H.\pi.\sqrt{z^3}$ (1) Where

W: Is the volume of soil erosion (m^3/km^2/year).

T: Temperature coefficient calculated by the following equation.

$T = \sqrt{\frac{t}{10} + 0.1}$ (2) Such that

t: Average annual temperature in (° C)

H: is the annual rainfall (mm),

π: is constantly equal to 3.14

$Z = Y.X_a.(\psi + \sqrt{Ja}$ (3) Where

Y: Soil erodibility coefficient.

Xa: Coefficient of soil protection of the watershed.

Ψ: Coefficient of type and extent of numerical equivalent erosion of visible and pronounced processes in the watershed.

Ja: Average slope of the study area in (%).

2.3. Data and materials used

This study is based on the equation developed by [14] using remote sensing data and geographic information systems. However, its application comes up against the availability and quality of data. In the case of the Oued Bouhamdane watershed, the data used were collected from a global online database. Also, the Hammam Debagh dam management provided a soil profile map to estimate the soil erodibility coefficient. The following Table summarizes the remote sensing data used. The pre-processing and image processing was carried out using ENVI 5.1 software, while the analysis, the combination of all the data, and the application of the model were carried out with ArcGIS 10.2.2 software. The images of the MODIS sensor (resolution of 926,62 m) and the RainSphere precipitation (25483m) resemble at a resolution of 30 m for a good combination with the other bands were used, thus avoiding any affection of the raster data during the calculation operations. The working resolution is 30 m, and the projection system applied to all our data is Transverse Mercator zone 32N.

Table 1: Remote Sensing data used

Sensor	Acquisition date	Resolution (m)	Calculated factor
LandSat 8 OLI/TIRS	January 28, 2018	30	Xa, Ψ
	April 2, 2018	30	
	July 7, 2018	30	
	2018 ,October 11	30	
MODIS 11A2	January 01.09, 17, and 25, 2018	926,62	T
	February 02, 10,18and 26, 2018	926,62	
	March 06, 14,22, and2018 ,30	926,62	
	April 07, 15 and23,2018	926,62	
	May 01, 09,17 and 252018 ,	926,62	
	June 02, 10,18, and2018 ,26	926,62	
	July 04, 12, 20 ,and2018 ,28	926,62	
	August 05, 13,21, and2018 ,29	926,62	
	September 06,14, 22and 30,2018	926,62	
	October 08, 16, and2018 ,24	926,62	
	November 01, 09,17and 25, 2018	926,62	
	December 03, 11,19and 27, 2018	926,62	
Aster	November 17, 2011	30	Ja
RainSphere	July 01, 2019	25483	H

3. Results

The application of the Gavrilovic model (Erosion Potential Method) requires the calculation of the following factors:

3.1. Temperature coefficient

Temperature is an erosion factor in this model because it affects the water supply inside the soil. The maximum temperature increases evaporation and transpiration and leads to the appearance of cracks which make it possible to dismantle the clay formations in particular, and successive thermal variations allow the dismantling of the components of the rocks and surface formations [7]. Gavrilovic adopted temperature as an erosive agent in the EPM model. The temperature coefficient values are determined by equation No. 2, which takes the average annual temperature as the main parameter for calculating the coefficient [7,6]. In the absence of temperature data at the rainfall stations of the Oued Bouhamdane watershed, use was made of satellite images from the MODIS 11A2 Program. The annual average temperature is calculated from a series of MODIS 11A2 images (46 images) covering the 12 months of 2018. The temperature coefficient T is generated from the map of the annual average temperature obtained after a series of pre-processing and processing carried out on the images of the MODIS program under ArcGis software. Figure 2 shows that the temperature coefficient values vary from 20 to 26 ° C. The temperature gradually increases from north to south and from west to east in inverse relation to altitude (The temperature increases in the depressions and decreases in the altitudes). The exposure often explains these variations compared to sunshine, and the areas with southern exposure, are those most exposed to a high temperature.

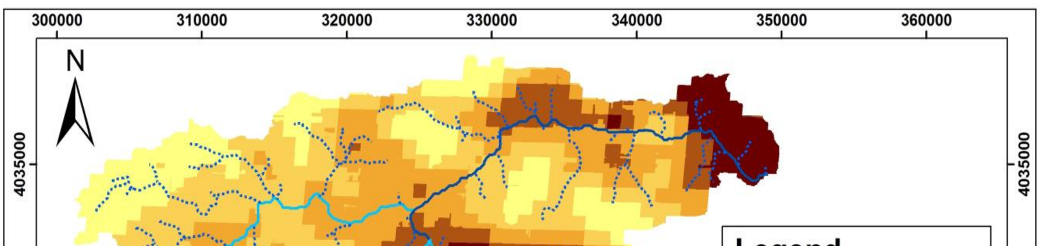

Figure 2: Map of the temperature coefficient

3.2. Average annual precipitation

In all places of the globe where water erosion occurs, atmospheric precipitation is the causative agent and the predominant factor of this phenomenon [15]. The precipitation is the main factor of water erosion in northern regions of Algeria; stormy rain showers erode large amounts of soil, especially in areas characterized by very steep slopes and zero plant cover low. The annual average precipitation map is produced from a GeoTIFF image of the pluviometric data (downloaded from the CHRS RainSphere site) covering 36 years of precipitation; then, the calculated values are interpolated by inverse distance weight (IDW). Figure 3 shows the spatial distribution of precipitation in the Oued Bouhamdane watershed. Average annual precipitation in the Oued Bouhamdane watershed ranges from 488 mm to 518 mm. These values follow an increasing gradient from South to North and West to East. The high values cover the northern part, while the low ones are in the part.

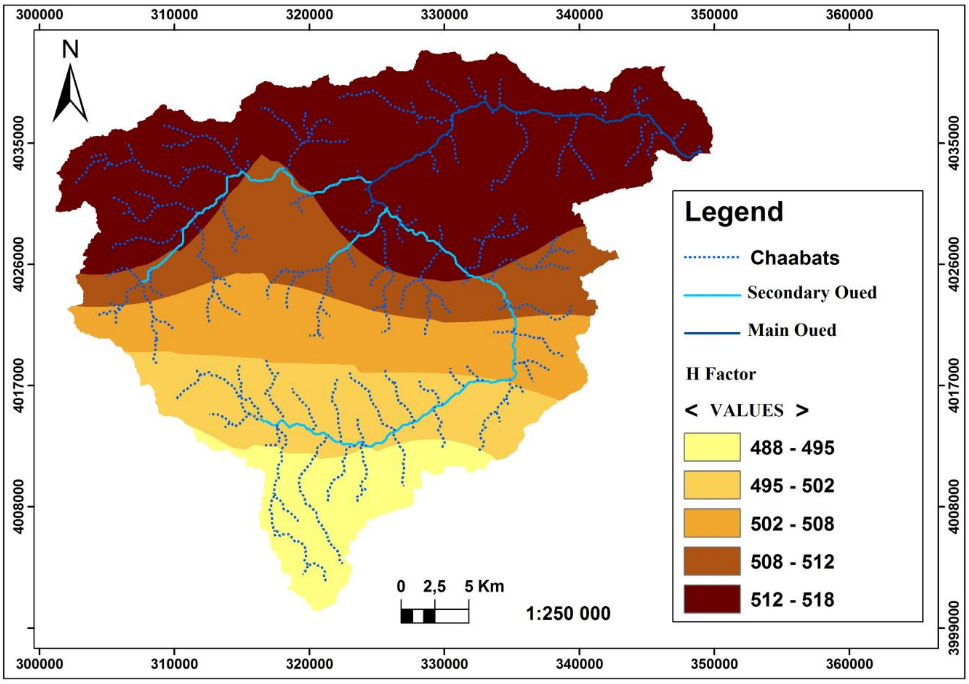

Figure 3: Map of average annual precipitation

3.3. Soil protection coefficient

The soil protection coefficient (Xa) (depends on land use and vegetation cover) numerically expresses the protection of an area against soil erosion [11]. According to[14], the values of (Xa) vary as a function of land use by vegetation (Table 2). For the Oued Bouhamdane watershed, this soil protection coefficient is estimated from satellite images from the Landsat 8 OLI / TIRS program.

Table 2: Values of soil protection coefficients[16]

Type of land use	(Soil protection coefficient (Xa
Dense mixed Forest, dense medium Forest	0.20 - 0.05
Pine and grass forests next to streams	0.40 - 0.20
Degraded Forest and Pasture	0.60 - 0.40
Damaged pasture and cultivated land	0.80 - 0.60
Bare soil without vegetation cover	0.10 - 0.80

The primary satellite images of the research represent the four seasons of 2018. The method is based on the Normalized Difference Vegetation Index (NDVI) calculation. Indeed the (Xa) is the inverse of (NDVI); according to [16], it is necessary to transform the values of (NDVI), whose minimum value becomes 0.9 and the maximum value becomes 0.01 [8]. The transformation equation N °4 corresponding to the soil protection coefficient (Xa) calculation is extracted from that proposed by [7]. The approximate values of the soil protection coefficient (Xa) at the level of the Oued Bouhamdane watershed are extracted from the vegetation index by mean normalized difference using the following equation. The soil protection coefficient (Xa) (depends on land use and vegetation cover) numerically:

$\mathrm{Xa} = (\mathrm{NDVI} - 0.4661) * (-1.622)$ (4) Where

NDVI: is the normalized difference vegetation index calculated by the following formula:

$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{R})/(\mathrm{NIR} + \mathrm{R})$ (5) Where
NIR: Near infrared channel (B5) for Landsat8 OLI / TIRS
R: Red channel (B4) for Landsat8 OLI / TIRS

Applying the N°4 made it possible to obtain approximate values of the coefficient of protection of the soil Xa varying from 0.01 for the zones with a dense vegetal cover and 1 for the zones with zero vegetal cover or bare ground (Figure 4). These values are listed in descending order according to the plant cover. This variation explains the protective role of vegetation and land uses in reducing or increasing the severity of soil amputation. The dense forest areas are well protected, and the soil protection coefficient registers values below 0.35. However, the protection decreases in the rangelands and reforestation areas, reaching values between 0.35 and 0.53. The values of this coefficient exceed 0.53 in the zones corresponding to agricultural land and bare soil.

3.4. Soil erodibility coefficient

The soil erodibility coefficient (Y) expresses its sensitivity to water erosion and depends on its intrinsic properties: texture, structure, and permeability. It is determined for a given soil by the following equation [17]:

$Y = \left(2{,}1 * M^{1{,}14} * 10^{-4} * (12 - a) + 3{,}25 * (b - 2) + 2{,}5 * (c - 3)\right)/100$ (6) Where

The following formula calculates M:

$$\mathrm{M} = (\%\ \text{fine}\ sand + silt) * (100 - \%\ clay) \quad (7)$$

a: is the percentage of organic matter.
b: is the permeability code.
c: is the structure code.

The soil erodibility coefficient (Y) was extracted from the soil profiles for the present study. The values calculated for each localized soil profile are then interpolated by the IDW (Inverse Distance Weight) interpolation method for the spatialization of this coefficient over the entire territory of our study area (Figure 5). The erosion process coefficients are classified into five categories, ranging from 0.18 for hard soil erosion resistant to 0.34 for soil without resistance to erosion. The study area generally has a high to very high erodibility (0.28-0.34), covering 67.78% of the total area of the study area, followed by low to very low erodibility (0.18-0.25) with 24.16% and the average (0.25-0.28) with 8.05 % of the total area of the study area.

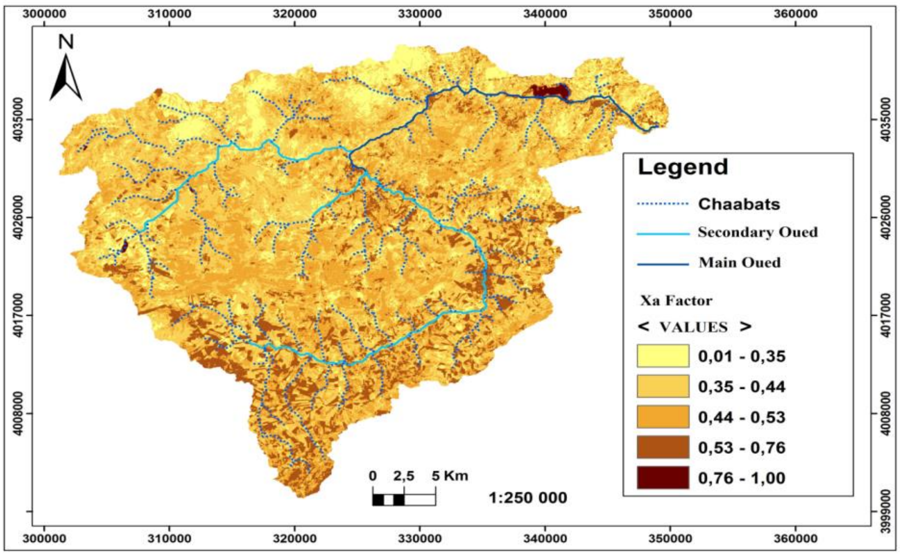

Figure 4: Map of the soil protection coefficient (Xa)

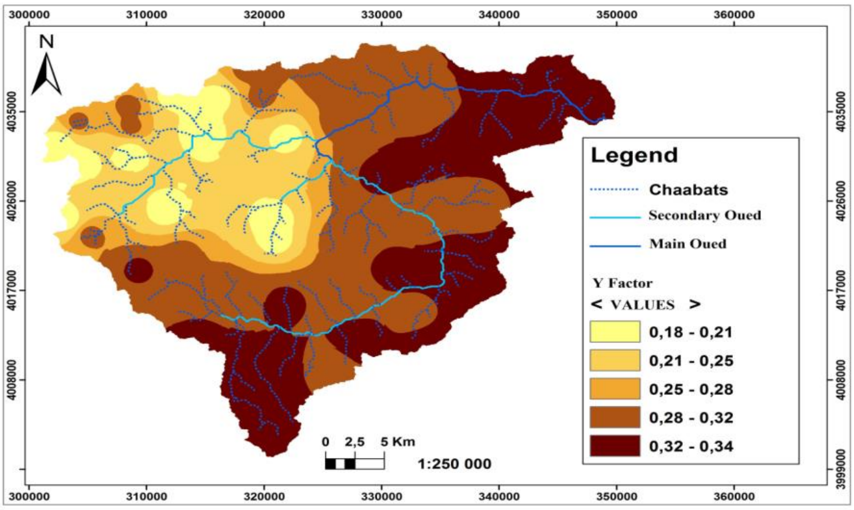

Figure 5: Map of the soil erodibility coefficient (Y)

3.5. Type and extent coefficient of erosion

The type and extent coefficient of erosion (φ) represents the degree of erosion process expressed in the basin, with its value between 0.1 and 1 [14]. The type and extent coefficient of erosion (φ) was calculated from satellite images used in the calculation of the soil protection coefficient (Xa), using the methodology proposed by [18] using the following equation (8): The type and extent coefficient of erosion (φ) represents the degree of erosion process expressed in the basin, with its value between 0.1 and 1 [14]. The type and extent coefficient of (φ) was calculated from satellite images used in the calculation of the soil protection coefficient (Xa), using the methodology proposed by [18] using the following equation (8):

$$\psi = \sqrt{\frac{B4}{Q_{max}}} \quad (8)$$ Where

B4: is the spectral band B4 for Lansat 8 OLI / TIRS.
Qmax: is the maximum radiance of the spectral band B4.
According to Gavrilovic, there are several types of erosion which vary according to the type coefficient and extent of erosion (Ψ) (Table 3)

Table 3 : Type of soil erosion as a function of (Ψ) (Argaz et al., 2019)

Type and extent of erosion	(Ψ) Coefficient
Little erosion in the watershed	0.1 - 0.2
Erosion in watercourses between 20-50% of the watershed	0.3 - 0.5
Erosion in rivers, ravines, and alluvial deposits	0.6 - 0.7
50-80% of the basin is affected by surface erosion and landslides	0.8 - 0.9
Entire watershed affected by erosion	0.9 - 1.0

The calculated average values of the type and extent coefficient of erosion (Ψ) from the four satellite images used are illustrated in Figure 6. The values of this coefficient in the Oued Bouhamdane watershed vary from 0.32 to 0.61, and Table 3 shows that the type of erosion was generally an erosion in watercourses between 20-50 % of the watershed. In contrast, erosion in rivers, ravines, and alluvial deposits was localized in the southern part of the watershed.

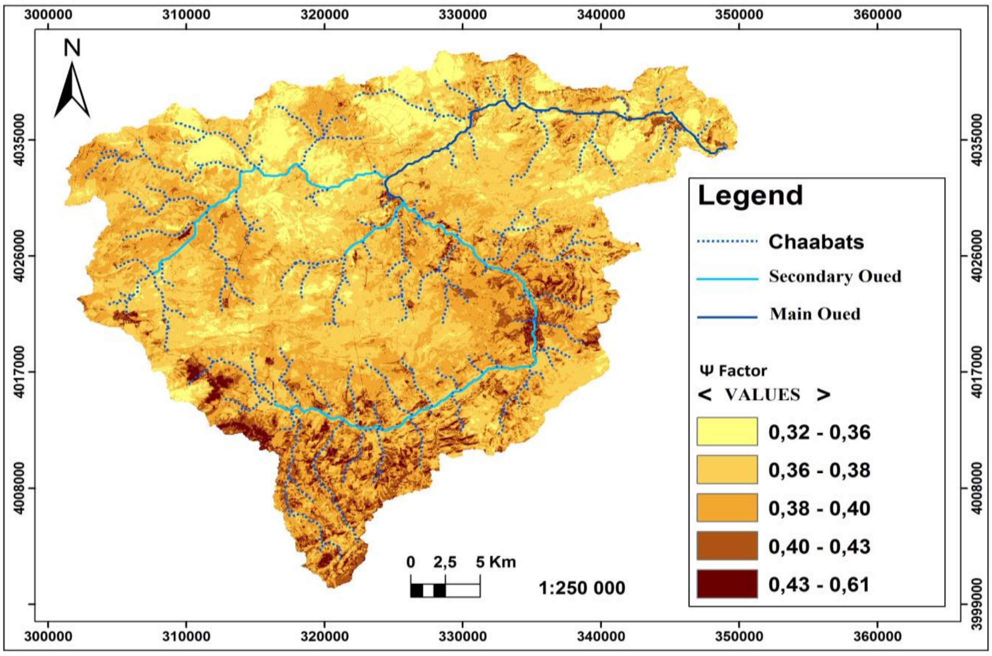

Figure 6 : Map of type coefficient and extent of erosion (Ψ)

3.6. Slope coefficient

Slopes are a critical parameter in the EPM model. The increase in flow velocity under the effect of slopes strongly causes erosion [7]. The slope coefficient was calculated using a digital terrain model (DTM) with a resolution of 30m (Figure 7). The slopes were reclassified into seven categories varying from <5 to > 50 %. The values of the class >50 % are located in the North (Djbel Taya), South-east (Djbel Oum Settas), and South-west (Djbel Ancel) parts corresponding to altitudes ranging from 1000 to 1300m. The values <5% generally occupy the south (plain of Tamlouka and Oued Zenati).

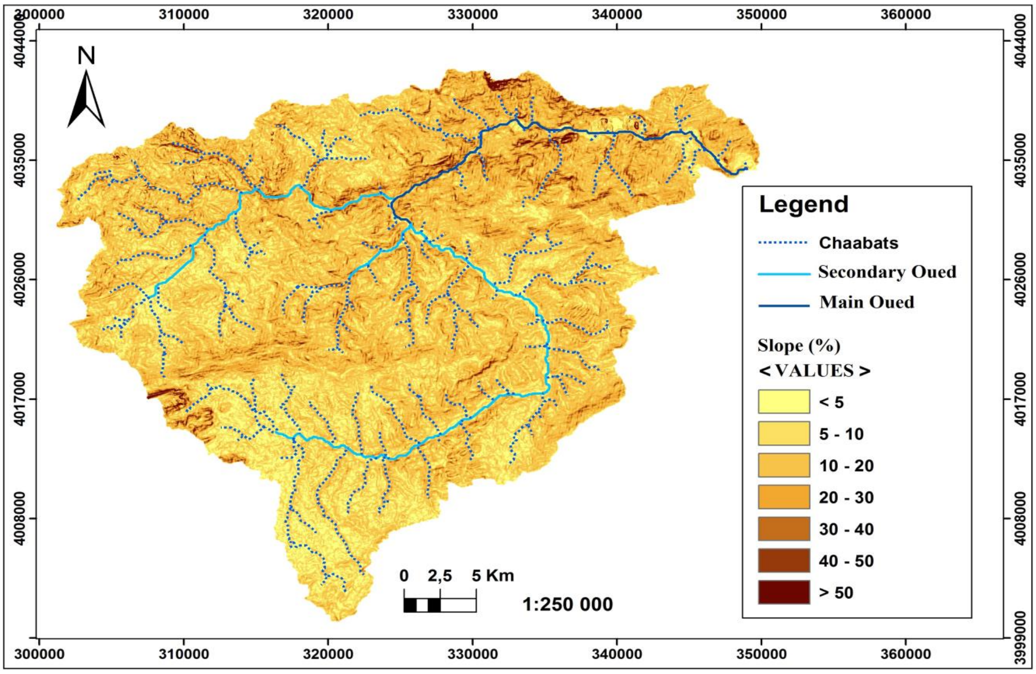

Figure7: Map Coefficient of slope Ja in (%)

3.7. Erosion coefficient

The coefficient (Z) indicates the probability of erosion in watersheds. This is one of the most essential factors in the Gavrilovic model since its calculation was based on several variables. It is instrumental in monitoring the evolution of erosion over time [7]. According to Gavrilovic, the erosion values were classified into five classes according to the Z coefficient (Table 4).

Table 4: The erosion class according to the coefficient (Z) [19]

Erosion Intensity	Value of the erosion coefficient (Z)
Very High	>1.5
High	0.80-1.00
Moderate	0.40-0.80
Low	0.20-0.40
Very low	0-0.20

The application of formula N °4 made it possible to calculate the factor Z, whose values were classified according to Table 4. Figure 8 shows that the very low to low erosion classes represented 33.85% of the total surface of the study area and were generally located in the North-west and South-west parts. The values of the middle class (0.40-0.80) occupy 58.91% more than half of the study area, spread over the entire catchment area, while the strong to extreme values represent only 7.24% of the total area is located mainly in the South, South-West, West, and North-West part.

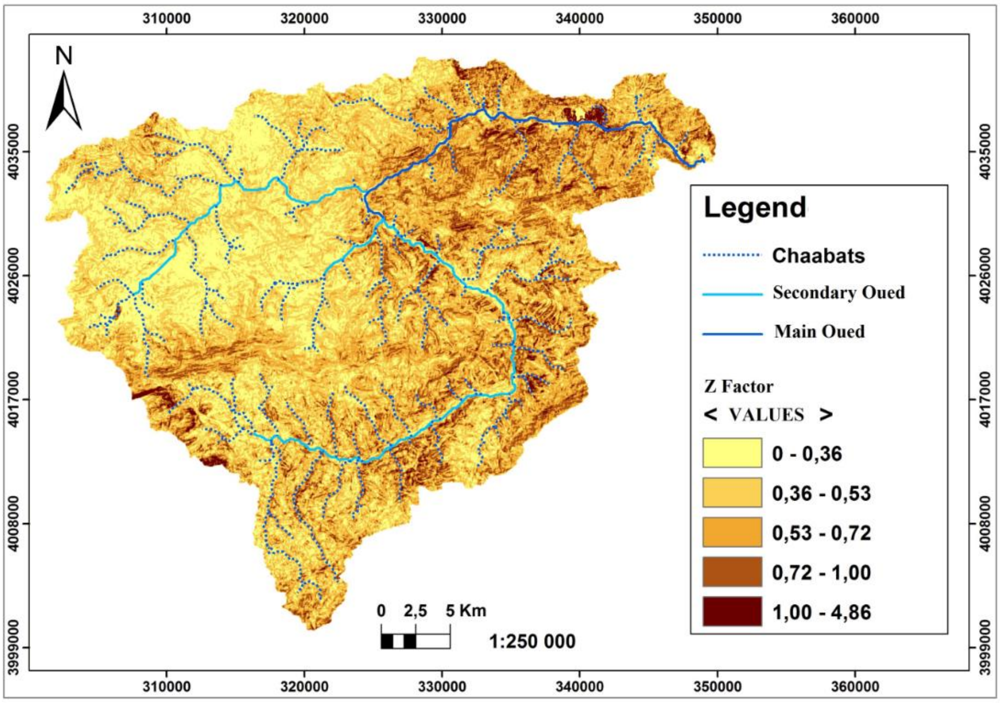

Figure 8: Map of the Coefficient (Z)

3.8. Estimated volume of soil erosion

According to [18], the low annual erosion rate is less than 500 m^3/Km^2/year, while the high rate exceeds 800 m^3/Km^2/year according to the Gavrilovic EPM model. Indeed [20] classified erosion by surface water according to the annual volume of eroded soils in six classes (Table 5).

Table 5: Erosion classes according to the annual volume of eroded soil

Classes of the annual volume of eroded soil ($m^3/Km^2/year$)	Erosion
< 50	Absence of erosion
50-500	Low erosion
500-1500	Moderate erosion
1500-5000	Generalized erosion
5000 - 20 000	High erosion
> 20 000	Very High erosion

The multiplication of layers representing the factors of the EPM model in matrix format (Raster) has made it possible to draw up at the level of the Oued Bouhamdane watershed the map of the annual volume of eroded soils, expressing the spatial distribution of the potential erosion values in $m^3/Km^2/year$. The result obtained, represented in Figure 9, watches erosion rates varying from 0.7 to 26,660 $m^3/Km^2/year$ distributed over the entire study area, with an average of around 941.13 $m^3/Km^2/year$.

This average value (941.13,$m^3/Km^2/year$) corresponds to the class (500-1500 $m^3/Km^2/year$), which expresses an average erosion rate (Table 5).

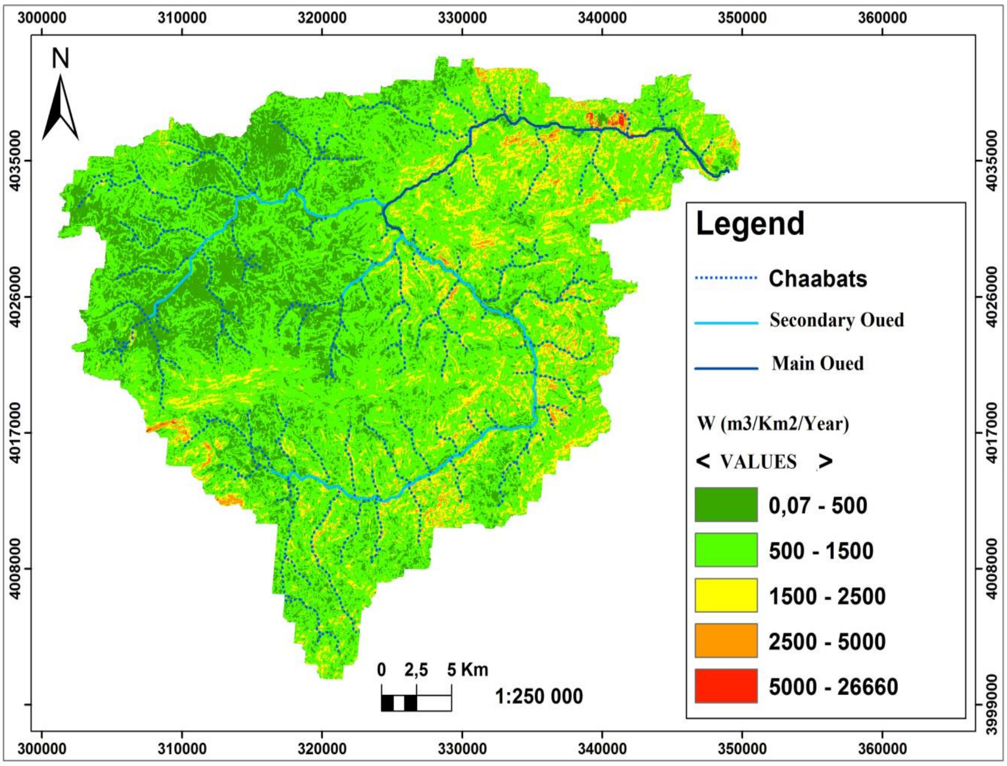

Figure 9: Map of the annual volume of eroded soils ($m^3/Km^2/year$)

Discussion

The study area generally represents low to medium erosion, i.e., 85.43% of the total area of the watershed, covers areas of dense vegetation cover, low to moderate slope, and erosion-resistant soils (in particular, the northwest part). The worrying and high values of the classes

(1,500-2,500 m^3/Km^2/year) and (2,500-26,660 m^3/Km^2/year) occupy 14.57% of the total area of the study perimeter, are distributed in the southern part, East and Northeast. These values reflect significant soil losses and are mainly localized in areas of zero to low vegetation cover, moderate to high slopes, soils with a low resistance to erosion, and southern exposure (higher temperature). To identify the factor responsible for this erosion, the different layers developed made it possible to correlate the factors of the EPM model and the annual volume of eroded soils obtained (Table 6).

Table 6: Correlation between the factors in the EPM model and the annual volume eroded

Correlation parameter	W	T	H	Y	Xa	ψ	Ja
W	1	0.14	0.03-	0.43	0,52	0.21	0.61
T	14. 0	1	0.45-	0.48	0.23	0.38	0.24-
H	0.03-	0.45-	1	0.34-	0.28-	0.41-	0.26
Y	0.43	0.48	0.34-	1	0.21	0.25	0.04-
Xa	0.52	0.23	0.28-	0.21	1	0.5	0.07-
ψ	0.21	0.38	0.41-	0.25	0.5	1	0.2-
Ja	0.61	0.24-	0.26	0.04-	0.07-	0.2-	1

The results obtained showed a strong correlation between the annual volume of eroded soils and the slope coefficient (Ja), Soil protection coefficient (Xa), and the coefficient of soil erodibility (Y) because these factors play the role of water erosion controllers. The annual volume of eroded soils showed a slight correlation with the type and extent coefficient of erosion (ψ) and the temperature coefficient (T), in addition to a very weak correlation with the average annual precipitation, which is very logical because these factors contribute to determining water erosion. In the absence of studies related to the application of this model (Erosion Potential Method) at the level of the study area or the scale of northern Algeria, the conversion of the result obtained per m^3/km^2/year into t/ha/year has become essential to make a comparison with that found by the RUSLE model (Revised Universal Soil Loss Equation).

The process of converting the average annual volume of loss 941.13 m^3/km^2/year to t/ha/year is 15.06 t/ha/year. Comparing this result (15.06 t/ha/year) with other studies recently carried out in this watershed using the application of the RUSLE model shows the reliability of the model applied (Erosion Potential Method). Indeed [9] finds that the average loss of soil by water erosion in the Oued Bouhamdane watershed reaches 11,18t/ha/year,[3], showed that the average soil losses in the Oued Bouhamdane watershed reach 13,63t/ha/year. For information, the Oued Bouhamdane watershed is fully included in the Oued Seybouse watershed. In the absence of quantitative data from in situ experimentation with water erosion in the study area, the result obtained on average 941.13 m^3/km^2/year, i.e. (13.63 t/ha/year on average) is close to that found by other researchers in this watershed using the application of a model other than that of EPM (Erosion Potential Method).

Conclusion

The main objective of this study was to apply the EPM model using remote sensing and the geographic information system to estimate the annual volume of eroded soils at the scale of the Oued Bouhamdane watershed. The result showed erosion rates varying from 0.07 to 26,660 m^3/Km^2/year with an average annual loss of 941.13 m^3/Km^2/year. This average value showed that this watershed was a favorable environment for the development of soil erosion processes; in fact, 14.57 % of the total area of the study area has values ranging from 1500 to 26,660 m^3/Km^2/year. This result is explained by the predominance of lithological formation with high erodibility (flysch, marls, alluvium, and sand) and degraded vegetation cover with steep slopes >24%. Field observations have shown that erosion is present and visible in the places visited. The correlation established between the annual volume of eroded soils and the factors of the EPM model shows that the slope coefficient (Ja), soil protection coefficient (Xa), and coefficient of soil erodibility (Y) control the process of soil erosion. In contrast, the rest of the factors contribute to the determination of this phenomenon. In addition, this study is an important database that can be used to protect and preserve the Oued Bouhamdane watershed by establishing an urgent intervention plan for the areas most affected by this phenomenon.

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