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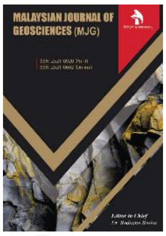

RESEARCH ARTICLE

ASSESSMENT OF SOIL EROSION BY RUSLE MODEL USING GIS: A CASE STUDY OF CHEMORAH BASIN, ALGERIA

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ABSTRACT

Soil erosion by water is one of the major sources of land degradation. Erosion contributes to the temporary or permanent lowering of the productive capacity of agricultural land and sedimentation of dams. The purpose of this study is to assess soil loss rate using a GIS/RUSLE approach at the Chemorah basin by focusing on two catchments, namely, Reboa and Soultez. The assessment of soil erosion aims thus to identify the lands more prone to erosion which are vital for erosion management process. RUSLE model supported by GIS software is to predict the spatial variability of erosion occurring in the Chemorah basin and its sub-basins. Five inputs such as rainfall erosivity, soil erodibility, slope and length of slope, plant cover and anti-erosion practices, are used in the model to compute the erosion loss rates. The mean annual soil loss in Chemorah river basin is estimated at 7.52 T/ha/year, and varying between 3.78 T/ha/year in Soultez catchment and 6.06 T/ha/year in Reboa sub-basin. The study shows that low erosion (≤ 7 T/ha/year) covers 52% and high to very high erosion (> 7 T/ha/year) which does not exceed 23% of the Chemorah basin area. The results indicate that Reboa catchment faces the greatest risk of soil erosion compared to Soultez one, with contributions of 44 % and 32 % of their basin areas respectively. Use of the erosion factors' information coupled with GIS/RUSLE program can help to design the appropriate land management to minimize soil erosion in the basin.

KEYWORDS

Chemorah basin, soil erosion, RUSLE, GIS, mapping.

1. INTRODUCTION

Soil erosion by water is a serious global problem that threatens land productivity and environmental quality (Montanarella et al., 2016; Montgomery, 2007). Meanwhile, concerns and problems related to erosion by water are reported worldwide; especially countries in the Maghreb appear to be under severe threat. This is largely attributable to the huge pressure on the land, often in combination with a lack of suitable land management practices, raising awareness among farmers, and application of proper policies to mitigate soil erosion (Haregeweyn et al., 2017; Fenta et al., 2020). Obviously, in developing nations, soil erosion is most threatening because of its multitude adverse transformation/dissection of the landscape, such as decreased soil fertility and crop production, muddy floods and siltation of reservoirs (Bastida et al., 2018; Haregeweyn et al., 2017). Being a work function, soil induced by erosion action is subject to several processes, which include detachment of particles from aggregates or soil mass, entrainment of detached particles, redistribution of soil over the landscape, and deposition of soil in depressional sites.

A study indicated that 33% of the soils around the planet were affected by processes of degradation (Lal, 2015). In India, about 53% of the total land area is prone to erosion and were estimated about 5,334 metric tonnes of soil being detached annually. In Mexico, 76% of the territory is affected to some degree by water erosion, 26.37% to moderate, and 37.06% to low erosion (Bolaños et al., 2016) and the main causes are urbanization, agricultural and livestock activities (Aguirre et al., 2017). In Ethiopia, the problems of soil degradation and low agricultural productivity are severe in the rural highlands, mainly caused by water erosion due to rugged topography, mismanagement of land resources, and loss of vegetation cover. Recent study estimated the rates of soil erosion as 20 $Mg\,ha^{-1}\,year^{-1}$ on currently cultivated lands and 33 $Mg\,ha^{-1}\,year^{-1}$ on formerly cultivated degraded lands (Adugna et al., 2015; Dagnachew et al., 2020). Mediterranean soils are particularly prone to erosion because of the marked topography (45% of the region has slopes greater than 8%), the high rainfall concentration in autumn and winter on arable cropping lands, the presence of poor, shallow and skeletal soils, and sparse natural vegetation. Overgrazing and deforestation can greatly accelerate soil erosion. (García-Ruiz et al., 2013; Raclot et al., 2016).

In most developing countries such as Algeria, there is no consensus on the extent and severity of land degradation by soil erosion as well as its impacts (Haregeweyn et al., 2015). In Algeria, erosion is a major problem; its intensity varies from a zone to another zone. It is recognized by colonists and agronomists that soil erosion in this country is an environmental problem since the year 1930. More than 180 million tonnes of sediments are evacuated into the sea each year reducing thereby the dams' lifetime (Remini et al., 2015). The deposition level increased these

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years due to the fact of the highly-catchment basins erosion, especially at the East of the country where the erosion affected almost 40% of all lands (Khanchoul and Khanchoul, 2019).

Studies erosion in northeastern Algeria were carried out on determining some overall sediment transport rate on an annual basis. The studies by Khanchoul and Khanchoul (2019) have treated the phenomenon of erosion in a watershed during a number of years. Their work was based on measured data of concentration and water discharge in order to evaluate mean annual sediment yield. The importance of the sediment discharge in Bouhamdane catchment has been underlined in a study of erosion by Khanchoul et al. (2010) and Louamri et al. (2013) and they used measured water discharge and sediment concentration to quantify the sediment yield in the basin and estimate the siltation of the Debagh Dam, located at its outlet. A study of the hydro-sedimentary flow using modelling in Soultez and Reboa semi-arid catchments were undertaken by Balla et al. (2017). The approach adopted for the quantification of sediment transport has consisted on researching the best regressive models to represent the statistical relation between the sediment discharge and the water discharge.

In recent years, the use of GIS and remote sensing for erosion assessment has proved to be a reliable tool (Ganasri and Ramesh, 2016), when combined with empirical/semiempirical models (Pal and Shit, 2017). The USLE model of Wischmeier and Smith is the most commonly used empirical model, The Revised Universal Soil Loss Equation (RUSLE) with its integration to geographic information system (GIS) became a widely applied empirical model used for the assessment of the annual loss of soil due to water erosion (Ali and Hagos, 2016). In Algeria, there is a number of research studies pertaining to the peril of soil erosion at various spatial and temporal scales that have used the RUSLE models (Bouguerra et al., 2017; Hallouz et al., 2018; Koussa and Bouziane, 2019; Khanchoul et al., 2020).

The objective of this study is to estimate the soil erosion by applying the RUSLE along with the Geographic Information Systems (GIS) in the locality of Chemorah catchment with its Soultez and Reboa sub-basins. The ongoing lack of sufficiently detailed information on soil erosion risks in the Chemorah catchment has posed a major challenge towards reducing soil erosion, where land degradation in forest areas, a loss of biodiversity and a decrease in soil nutrients available for crops are detected. There is therefore a need for the identification of critical areas most susceptible to water erosion to guide effective conservation planning.

2. STUDY AREA

The study two catchments, Reboa and Soultez wadis, belong to the Chemorah basin (755 km²), which are located in the Aurès region, northeast of Algeria (Figure 1). There areas are 327 km² and 207 km² respectively. The two wadis flow into the Koudiet Medouar Dam, having water capacity of 20 Million m³.

Figure 1: Location map of the Chemorah basin

The Chemorah basin belongs to the semi-arid Mediterranean climate with wet and cold winter, hot and dry in summer. The precipitations are very irregular and are characterized by intense rainstorms. The mean annual rainfall is equal to 330 mm in Soultez sub-catchment and 458 mm in Reboa basin for the period from 1985 to 2016. The rainy months are observed from September to February. The autumn (October and November) and winter seasons are characterized by high storm events with rains exceeding 30 mm an hour. The mean monthly temperatures vary between 6°C and 24°C with a mean annual value of 16°C.

In the Aurès region of Algeria, a series of mountains are widespread over the area where elevations may reach 2328 m as in Mahmel (2320 m) and Ras er Rih (1920 m) mountains. Meanwhile, it is interesting to notice that the Reboa catchment is more mountainous than Soultez sub-basin. The lithology of the study catchments was done using geological maps of 1:50,000 in scale. The lithological analysis of the two basins has revealed the existence of several rocks whose surface formations are distinguished firstly by quaternary formations, dissected by gullies at different places. These formations occupy 54% and 34% of the basins of Soultez and Reboa respectively.

The sandstone and clay outcrops of Miocene age are mainly observed at the center of Chemorah basin; they occupy 22% and 18% of the of Soultez and Reboa catchments. These rocks include the reliefs of Amrane, Timagoult, Koudiat Safia which are home to important landslides. The marly limestone occupies mainly the Reboa basin from east to west, with an area of 35% (114 km²). The gully erosion is dominant at the weak marly formations. Other less resistant lithologic formations are present in the two catchments such as clay (Cretaceous); series of marl, conglomerate and limestone (Miocene). The resistant rocks such as limestone are less spread, found only in the Reboa catchment (with 17 km² or 5% of its basin area).

It is obvious that the pedogenetic processes and the formation of soils can be compromised by the rapidity of sedimentation phenomena, so it important to present its terrestrial skeleton regarding the two basins operated by the different erosive processes. Four soil types are distinguished: (1) poorly developed mineral soils (Lithosol, Regosol): they are recent and distinguished by a slight degree of weathering of the minerals and a low organic matter content (Figure 2). These soils constitute the finest materials and the organic matter quickly disappears from regosols when these soils settle on soft materials (clays, marls, sands, etc.) and from lithosols when these soils meet on hard materials; (2) calcimagnesic soils and brown soils: these soils are rich in Rendzine but poor in humus. They are soils recently rejuvenated by erosion. These are deep soils and rich in clay. This richness in clay influences the decarbonation processes; (3) calcimagnetic soils with calcareous crusts: these are relatively thin and hard formations, extended on surface formed generally by the progressive accumulation of limestone due to leaching; (4) poorly developed alluvial soils: they are considered as alluvial soils where their deposition in the alluvial plain is made by rivers and streams. These soils are fertile, rich in silt and well fed in water; (5) poorly developed mineral soils: they are found on sloping areas where the rate of erosion prevents the in situ development of a fully formed soil profile.

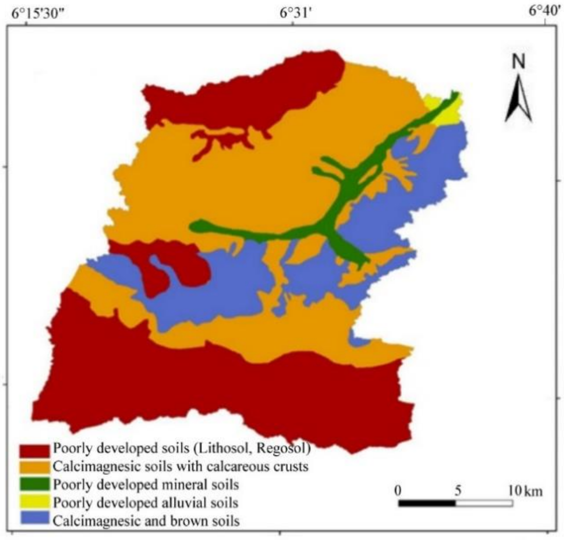

Figure 2: Soil type map of the study catchments

Slope as a topography factor also plays an important role on soil erosion (Smith and Wischmeier, 1958). It is therefore necessary to understand the relationship between slope gradient and soil erosion for rational planning of land use in a catchment, particularly in hilly areas (Zhang et al., 2015). The slope distribution map of the two study catchments was created using Digital Terrain Model (DTM) and Arcgis 10.4. Soultez catchment has shown a significant distribution of slopes from 3 to 10%, which is equal to 41% of its area against 27% in the Reboa basin; while the steep slopes (>15%) are less dominant in the first basin (with 19%) but more extended in the second one (with 49.50%). Slopes less than 15% occupy the same basin areas with 15% of their surface extension. It seems from the slope map that the Reboa catchment has the steeper slopes, which may favour soil erosion.

Land use is one of the most important factors influencing soil erosion because of its effects on variations on some parameters such as surface roughness, organic content of soil, soil structure and infiltration rate. All of these factors make important contributions to the spatial and temporal dynamics of hillslope hydrology and sediment production, transport and delivery to rivers (Fiener et al., 2011). The predominant land use in both catchments are cultures (wheat and barley), exceeding 60% of area. The dense forest is less dominant, with only 10% in Soultez and 11% in Reboa; but the most permanent vegetation of forest and shrubs (25%) is sparse and occupying the hilly areas. In addition, it is mainly found on poorly developed soils of sandstone and marly limestone on slopes greater than 15%. Both catchments have been during years damaged by livestock, fires during summer season, and overgrazing, leaving thus the soil exposed to different erosive processes.

3. MATERIAL AND METHODS

3.1 Data Sources

The major factors available that determine soil erosion rate are rainfall, the nature of the soil and vegetation cover. Critical data concerning these factors in the study area were obtained as follows: the work required the procurement of six 1:50,000 topographic maps with a 20-m contour interval, for the extraction of the digital terrain model (DTM) of the study catchment. Monthly rainfall data were obtained from 15 meteorological stations in Chemorah basin for 32-year period (1985-2016), provided by the National Meteorological Office and the National Agency of Hydraulic Resources. The rainfall datasets were used to develop the rainfall erosivity map. Information on lithology was extracted from four 1:50,000 geological maps that partially cover the study area of Chemorah catchment.

In addition, the used soil data are relatively scarce and result largely from a soil map of Algeria at a scale of 1:500,000 developed by Durand (1954) and Digital Soil Map of the World (2007) produced by FAO-UNESCO (1:5,000,000 scale), found at the following link: www.fao.org/geonetwork/srv/en/metadata.show?id=14116&currTab=distribution. Both maps were prepared to derive the erodibility K factor. The land use map was realized using satellite imageries of Landsat-8 from 2014 and Google Earth Professional images at high resolution. The ancillary data used in the present study included the use of agricultural and forest map of Chemoura basin at 1:50,000 conducted in 1986 (BNEF 1986) and substantial amount of field data collected to support image classification and validation.

3.2 RUSLE Parameters Modelling

Various types of soil erosion models ranging from simple empirical models (e.g., Revised Universal Soil Loss Equation) to complex process-based models have been developed to assess soil erosion by water. Process-based models require large amounts of input data and calibration routines. Furthermore, the poor data availability related to soil controlling factors constrain the application of these complex models at larger spatial domains (Haregeweyn et al., 2017). RUSLE-type models reduce the complex process-based models to a simple one while maintaining the main factors that influence the soil erosion process.

In the present study, the Revised Universal Soil Loss Equation (RUSLE) model is applied to estimate soil erosion in Chemorah catchments concluding its Soultez and Reboa sub-basins. This model is revised version of the USLE model (Renard et al., 1991; Wischmeier and Smith, 1978). In previous studies, this model has shown remarkable flexibility for the available data and efficiency of the cartographic method in semi-arid zones in the Maghreb and Mediterranean countries (Khanchoul and Selmi, 2020).

Revised universal soil loss equation is an empirically based model that has the ability to predict the long-term average annual rate of soil erosion in a field slope as result of rainfall pattern, soil type, topography, crop coverage and management practices (Atoma et al., 2020). The estimates of the five parameters of soil loss are expressed as follows:

loss rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P) were used in the RUSLE model. The relationship is expressed as:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where (R) is soil loss rainfall erosivity factor, (K) is soil erodibility factor, (LS) is slope length and steepness factor, (C) is cover management factor and (P) is conservation practice factor. In order to identify the spatial pattern of potential soil erosion in the study areas, the considered erosion factors were surveyed and computed. Individual GIS files, relevant for the RUSLE, were built for each and combined on a cell by cell-grid modeling procedure in ArcGIS 10.4 (resolution of 30 m) in order to predict soil loss in a spatial approach (Atoma et al., 2020). All layers were projected with UTM Zone 31N using the WGS 1984 datum. The schematic representation of the methodology is shown in Figure 3.

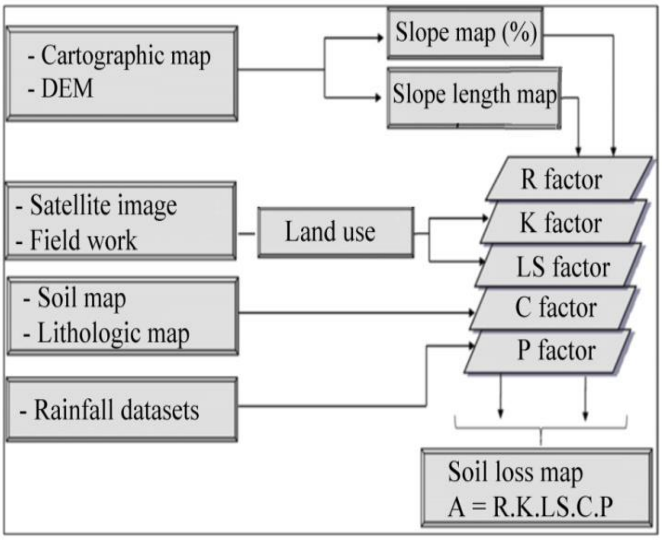

Figure 3: Flow chart methodology for soil loss assessment (Source: Khanchoul and Selmi, 2020)

3.2.1 Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) describes the erosivity of rainfall at a particular location based on the rainfall amount and intensity and reflects the effect of rainfall intensity on soil erosion (Koirala et al., 2019). The rainfall erosivity used in the RUSLE quantifies the result of rainfall impact and reproduces the quantity and rate of runoff factor (Gelagay and Minale, 2016). Its unit is expressed in MJ mm ha^{-1} h^{-1} $year^{-1}$. In this study, the created rainfall map was used to generate (R) factor. The rainfall map represents mean annual precipitation over the study area, produced from the meteorological stations around and in the study basins. The equation integrated to generate the R-factor is given by the simplified equation (2) used by Rango et Arnoldus (Gao et al., 2012) as follows:

$$\text{Log } R = 1.74 \times \log(P_i^2/P) + 1.29 \qquad (2)$$

Where R is the rainfall erosivity factor; P is the mean annual precipitation (mm); Pi is the mean monthly rainfall of the considered years (mm).

The spatial distribution of average annual precipitation (P) in the study area was estimated using the kriging method of interpolation (Figure 4). In the process of interpolation, 28 year-rainfall for 15 rain-gaging stations are considered. It is observed that the highest rainfalls have occurred in Chelia and Foum el Toub regions and the lowest rainfalls have happened in Ali ben Tenoun and Tazoult regions.

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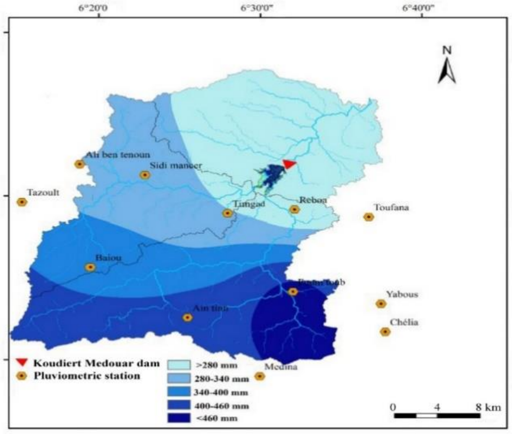

Figure 4: Rainfall distribution map of the study catchments

3.2.2 Soil Erodibility Factor (K)

Soil erodibility factor (K) indicates the sensitivity of soil or surface components to erosion, transportability of the silt, and the amount of runoff assumed an individual rainfall contribution as calculated in a standard condition (Narayan et al., 2018).

The main soil properties influencing the K factor are soil texture, organic matter, soil structure and permeability of the soil profile. Each uploaded satellite image was accompanied by a "DSMW" file offering all possible information on each layer in the form of a shapefile and Excel, giving thus the possibility to show the taken period of these coordinates' projection system, image quality and other information dealing with calibration. The used equation for K determination is that of Wiliams as follows:

$$K = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \quad (3)$$

With:

f_{csand}: is a factor that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand; f_{cl-si}: gives low soil erodibility factor for soils with high clay-silt ratios; f_{orgC}: reduces K values in soils with high organic carbon content; while f_{hisand} lowers K values for soils with extremely high sand content.

Where:

$$f_{csand} = [0.2 + 0.3 \times \exp[-0.256 \times m_s \times [1 - m_{silt}/100]]] \quad (4)$$

$$f_{cl-si} = [\, m_{silt}/(m_c+m_{silt})] \quad (5)$$

$$f_{orgC} = [(1 - 0.25 \times OrgC)/\, OrgC+\exp[3.72-2.95 \times OrgC]\,] \quad (6)$$

$$f_{hisand} = [1 - 0.7 \times [1-m_{silt}/100\,]/[1-m_{silt}\ 100\,]+\exp[-5.51+22.9 \times [1-m_s/100]] \quad (7)$$

with: m_s – the sand fraction content (0.05-2.00 mm diameter) [%]; m_{silt} – the silt fraction content (0.002-0.05 mm diameter) [%]; m_c – the clay fraction content (<0.002 mm diameter) [%]; orgC – the organic carbon (SOC) content [%]. The above formulas have allowed us to determine the K factor, presented in table 1.

Table 1: Distribution of K factor values in the study catchments

Soil unit symbol	Zo type	Yh type	Bk type
sand % arable layer	43.20	54.80	81.60
Silt % arable layer	24.60	20.60	6.80
Clay % arable layer	32.40	24.90	11.70
Organic carbon arable layer	0.40	0.53	0.44
f_{csand}	0.33	0.30	0.24
f_{cl-si}	0.78	0.79	0.74
f_{orgC}	0.99	0.99	0.99
f_{hisand}	1.00	1.00	1.00
K	0.26	0.23	0.18
K_{usle}	0.034	0.30	0.023
Soil sensitivity	Very low erodable	Low erodable	Moderately erodable

Zo: Orthic Solonchaks; **Yh**: Haplic Yermosols; **Bk**: Calcic Cambisols.

3.2.3 Topographic Factor (LS)

The topographic factor or Slope Length and Steepness Factors (LS) were created from two sub-factors: a slope gradient factor (S) and a slope-length factor (L); both of which are determined from the Digital Elevation Model (DEM). Slope-length and gradient is the important parameter in the soil erosion modeling (Koirala et al., 2019), in calculating the transport capacity of overland flow (Surface runoff). The L represents the effect of slope length on erosion and the S represents the effect of slope steepness on erosion (Ganasri and Ramesh, 2016). Therefore, the soil loss per unit area increases as the slope length increases but this loss increases more rapidly with slope steepness than it does with slope length. The slopes gradient and slope length factors were calculated from the DEM and combined to the result in the topographical factor grid, using the following equations (Gao et al. 2012):

$$L = (\lambda/22.13)^m \quad (8)$$

where, L = slope length factor, λ = slope length (m), m = slope-length exponent

$$m = F/\,(1+F') \quad (9)$$

$$F = \sin\beta\ 0.0896\,/3(\sin\beta)^{0.8} + 0.56 \quad (10)$$

where, F = Ratio of rill erosion to interrill erosion, β = slope angle (∘)

In ArcGIS, L is calculated as:

$$L = (flowacc+625)^{(m+1)} - flowacc^{(m+1)}\,/\,25^{(m+2)} \times 22.13^m \quad (11)$$

For slope gradient factor, the calculation is as:

$$S = Con((Tan(slope \times 0.01745) < 0.09),\ (10.8 \times Sin(slope \times 0.01745) + 0.03),\ (16.8 \times Sin(slope \times 0.01745) - 0.5)) \quad (12)$$

Final computation with $LS = L * S$

3.2.4 Cover Management Factor (C)

The cover management factor (C) was used to indicate the effect of cropping and management practices on erosion rates in agricultural lands. The role of vegetation canopy and ground covers on reducing soil erosion in forested regions varies with season and crop production system (Ganasri and Ramesh, 2016). The seasonal variation of C-factor depends on many factors such as rainfall, agricultural practice, type of crops etc.

The crop management factor map (Figure 5) was prepared on the basis of land use cover map of the study areas. The land use is classified with five main classes, namely, water body, forest area, built-up land, agriculture land, shrubs and grassland based on the ground information.

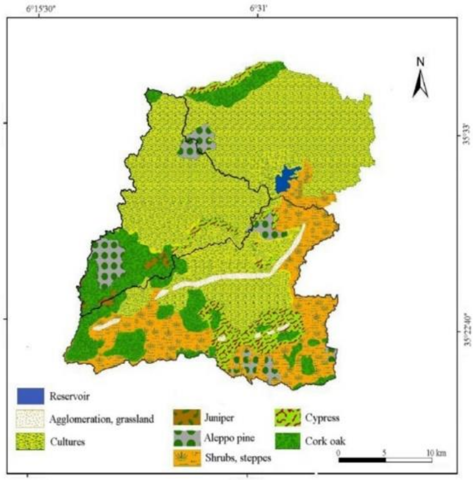

Figure 5: Land use and land cover map of the study catchments

These major land use features found in Chemorah basin were extracted from Landsat 8 image (Landsat ETM+ and ASTER image) using supervised classification method. The supervised classification method requires ground truth information for each land cover category that is collected using global position system (GPS) and trained the algorithm to extract the overall land cover. The overall accuracy of the supervised classification method is about 83%. The normalized vegetation index (NDVI) is the source of C factor values. The cover management factor is a dimensionless for each grid cell ranging from 0 to 1 under standard fallow conditions. The ratio between index C and NDVI is given by the following formula (Bouderbala et al., 2018):

$$C = \exp\left[-2\times\frac{\text{NDVI}}{1-\text{NDVI}}\right] \qquad (13)$$

The area associated with each land use classes were calculated and C-factor values were assigned. The land use-land cover map is reclassified based on C-factor value for the creation of the C-factor map.

3.2.5 Conservation Practice (P) Factor

The P-factor (dimensionless) represents the ratio of soil loss after implementation of a structural conservation measure to that from straight-row cultivation running up and down a slope (Fenta et al., 2020). P-factor values can be derived from satellite image classifications and reports of previous studies. The P-factor values are allocated over the land use/land cover map, according to the management practice (Ali and Hagos, 2016). It varies between 1 on bare ground without any anti-erosion protection at about 0.1, when on a low slope, ridging is practiced. The high percentage of low slopes in the Soultez catchment and high sleepness of the Reboa basin proves the scarcity of anti-erosion practices raised during field visits. However, due to the fact that there are no anti-erosion practices adopted throughout the study area, this factor was considered as a unit value equal to 1.

4. RESULTS

This study has used a modelling approach called the RUSLE based method to develop a detailed spatial assessment of the distribution of erosion risk across the Soultez and Reboa catchments using remotely-sensed data and GIS software.

4.1 USLE factor mapping

4.1.1 Rainfall erosivity factor (R)

The rainfall erosivity map based on annual data over a 28-year period clearly shows a decline from north to southeast (Figure 6). The values of R range from 25 to 82 MJ.mm.h^{-1}.y^{-1}. The mean annual value of R is equal to 48.4 MJ.mm.h^{-1}.y^{-1}. Figure 6 shows that the high degree of aggressiveness is observed mainly in the Reboa basin where R varies between 25 à 82 MJ.mm.h^{-1}.y^{-1}, while the Soultez basin has R-factor that varies between 25 and 66 MJ.mm.h^{-1}.y^{-1}. Timgad and Reboa, which belong to Reboa basin, are showing the least affected areas by rainstorms.

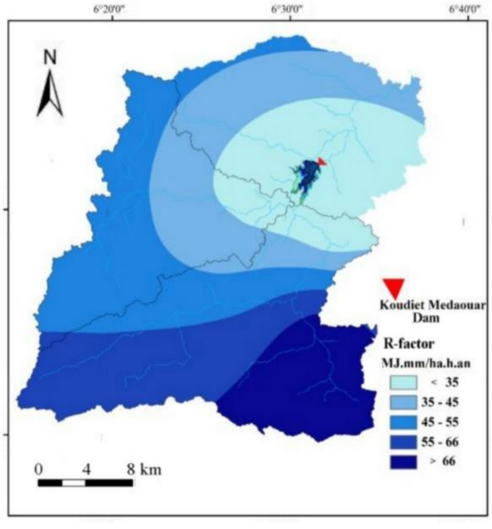

Figure 6: Spatial Rain erosivity (R) map of the study catchments

The lowest R values presented by the class 25 to 35 MJ.mm.h^{-1}.y^{-1} occupy almost 13% of the Chemorah basin and are mainly found on 70% of the flood plain towards the catchment outlet; while the highest values, more than 50 MJ.mm.h^{-1}.y^{-1} (45%) are observed at areas of the highest mountains of the basin, at Reboa catchment (Table 2). These results allow us to conclude that Chemorah basin and particularly Reboa one are generally subject to a significant erosive power.

Table 2: R-factor distribution in the Chemorah basin and its sub-basins

R-factor	> 35	35-45	45-50	50-66	> 66
Basin area (km^2)	96.50	64.00	257.5.	236.50	100.50
Basin area (%)	12.80	8.50	34.10	31.30	13.30

In general, the variation in rainfall intensity is probably due to variation in elevation and exposure, where the maximum elevations are 2320 m in the southern part (Reboa catchment), 1849 to 1920 m in the western part (Soultez catchment).

4.1.2 Soil erodibility K-factor

After assigning K factors for the different soil types in the area, the resulting map was converted to a grid map of 30 m cell size taking K factors as values for the cells (Figure 7). The calculated K-factor in the Chemorah catchment varies from less than 0.0235 to 0.034 t.ha.h/ha.MJ.mm and has a mean value equal to 0.029 t.ha.h/ha.MJ.mm, which is relatively high (Figure 7).

The low values are mainly located in the extreme southern (represented by Reboa catchment) and northern parts of the Chemorah basin where soils are more marly and calcareous types with an increase in the amount of organic matter, providing high penetration amounts and abridging runoff (Khanchoul et al., 2020). Also, this class of low erodibility, covering 29% of the basin area, is more protected by vegetation where shrubs and forest are the dominated vegetation cover.

The high values are located in clayey soils, covering 45% of the basin area and are touching both study catchments with almost the same percentage. The modest to fairly high K values occupy most of the Soultez catchment and an important part of Reboa basin. These areas are mainly dominated by weak quaternary formations. The highest to moderate erodibility values indicate that the soils are highly vulnerable to erosion because they have low stability and low infiltration rate, which may lead to high runoff and soil loss.

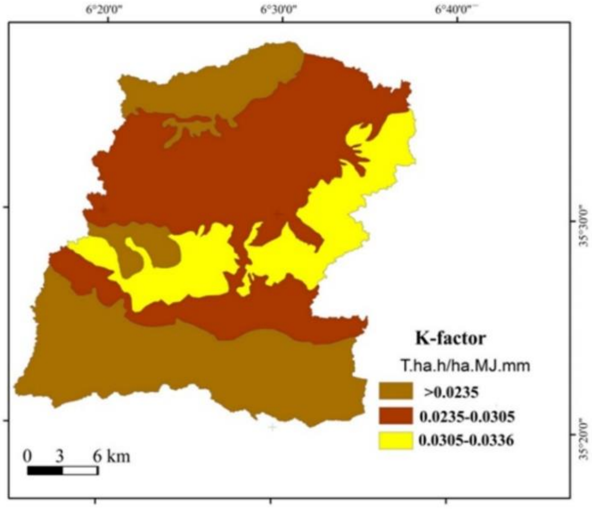

Figure 7: Soil erodibility K-factor map in the study catchments

4.1.3 Topographic factor (LS)

The topographic factor, which represents the influence of slope length and slope steepness on erosion process, was calculated by considering the flow accumulation and slope in percentage as an input. From the analysis, it is observed that LS-factor values vary between 0.03 and 328.55, with a mean of 5.18. The class 0 - 5 occupies the most dominant Chemorah basin area with 46%. The high LS values are present in only 5% of the basin area and highly represented by Reboa catchment (Figure 8).

These results are proportional to the soultez catchment topography, dominated by relatively flat surfaces where the low slopes are observed in 66% (≤ 10° of slope) against only 35% for Reboa catchment. The high LS values are attributed to the upstream Chemorah basin, particularly at Reboa upstreams, where the relief is high. These areas should be the most sensitive to sheetwash, rills and bank erosion processes.

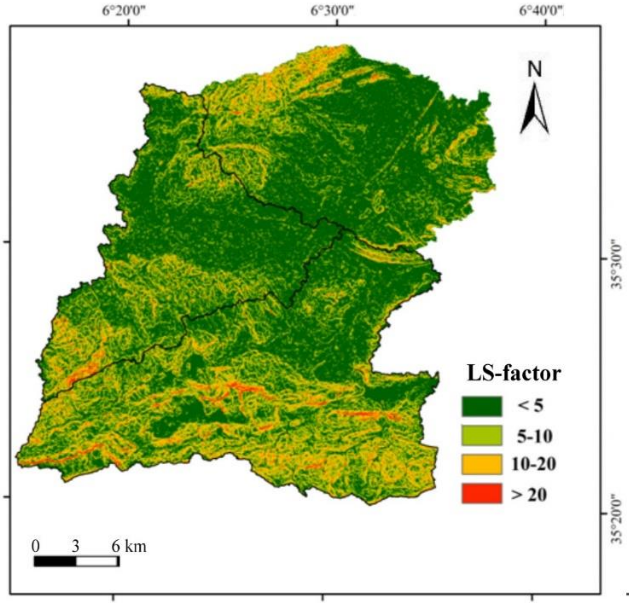

Figure 8: Map of the LS-factor in the study catchments

4.1.4 Crop management factor (C)

Information on land use permits a better understanding of the land utilization aspects of cropping pattern, fallow land, forest, waste landand surface water bodies,which are vital for developmental planning/erosion studies (Ganasri and Ramesh, 2016). In the present study, remote sensing and GIS technique have generated a thematic layer of land use and land cover of the Chemorah basin. The values of C-factor were introduced as a raster image corresponding to each land use that is determined from the tables of Wischmeier and Smith (1978) and Cormary and Masson (1963).

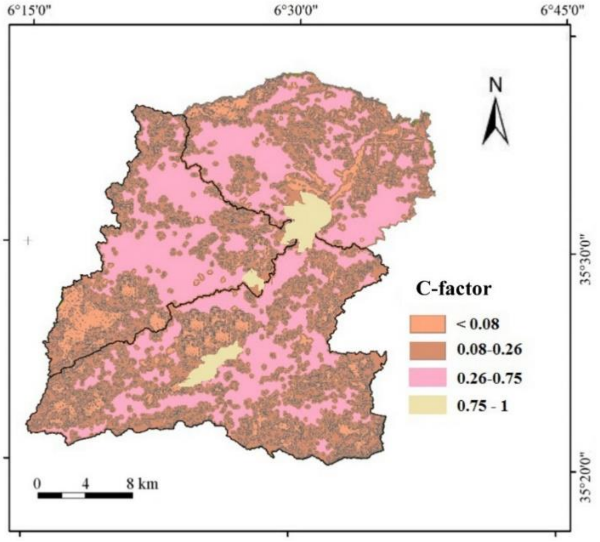

Figure 9: Crop management factor (C) in the study catchments

The C-factor values range between 0.05 and 0.99, with a mean equal to 0.61 (Figure 9). The map shows that the lowest values are located along most of the divide borders of the Reboa and Soultez catchments, which contain mainly forest and shrubs. The Chemorah basin has values that vary between 0.26 and 0.99, covering almost 49% of its area, and contains agricultural lands, shrubs and steppes. The moderate C values (0.08-0.26) occupy 30% of the basin and are somehow more distributed in the Reboa catchment. The spatial distribution of the C-factor confirms that the study area has been for a long time undergoing human activities land use and climatic changes which have led to the degradation of the forests and the transformation of these areas into cropland, induced grassland and steppes (Khanchoul et al., 2020).

5. DISCUSSION

The evaluation of land losses by water erosion, obtained by the multiplication of layers with a resolution presented by the RUSLE parameters and thematic maps, was carried out by the empirical formula of Wischmeier and Smith (RUSLE) with their databases using Arcgis 10.4 to produce soil loss rates. Each pixel of the resulting map had a unique value which corresponded to its possible erosive potential. Figure 10 indicates each pixel of soil loss gives a very reliable description of the potential erosion in the study basin. Thus, the estimates of the soil losses using RUSLE are theoretical and relatively reflect the reality of the Chemorah basin.

Figure 10 shows that the areas with a high soil erosion are found mainly in the south part of Chemorah basin, essentially at Reboa catchment. In order to be able to analyze and estimate the soil erosion rates, soil erosion values are grouped into four classes. The value of 7.00 T ha^{-1} yr^{-1} is used as the average tolerance limit for soil erosion (Sadiki et al., 2007).

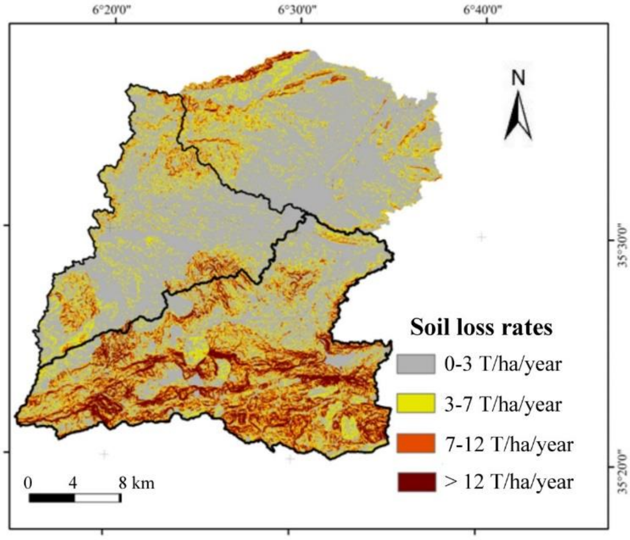

Figure 10: Soil loss rates in the Chemorah basin

It is known that soil losses are spatially related to vegetation, slope, soil types and rainfall maps, in a way where erosion bu water is dependent mostly on topography, permanent land cover such as forest and shrubs, runoff of the study region. Yet underlying geology may influence the efficacy of soil production and sediment transport on hillslopes. Usually, soil losses may be higher on moderate slopes. Mountain soils, often superficial, are mixed with various rock fragments, which will increase their resistance to the beat of raindrops and to the shear of runoff (Roose et al., 1993). In the dense forest region, the soil is permanently covered (C close to zero) and the rates of water erosion become practically zero.

The soil losses at the Chemorah basin vary from 0.0014 to 191.71 T/ha/year with a mean soil loss of 7.52 T/ha/year. The map in figure 10 shows that very low erosion potential belongs to soil loss of less or equal to 7 T/ha/year and which represents more than half (77%) of the total basin area. This is explained by the low values of LS factor and by the protective effect of the vegetation in the sloping areas of Soultez and downstream Chemorah basin rivers. Soil losses greater than 7 T/ha/year occupy only 23% of the total area and are located mainly in areas of steep slopes where the soil has fragile skin composed of marly and clayey formations. The erosion potential of this area can be distinguished by an intensity of high to very high.

Table 3 shows the results of the used factors related to RUSLE model and the computed soil loss in the Reboa and Soultez catchments.

Table 3: Results of the RUSLE parameters and the mean soil loss in the study catchments

Catchment	Values	R-factor	K-factor	LS-factor	C-factor	P-factor	Mean soil loss (T/ha/year)
Soultez	Min	25.00	0.0235	0.03	0.05	1	0.0014
	Max	81.62	0.0336	185.44	0.99	1	94.05
	Mean	58.75	0.029	6.29	0.61	1	3.78
Reboa	Min	27.75	0.0235	0.03	0.05	1	0.002
	Max	56.23	0.0336	83.75	0.99	1	191.71
	Mean	46.63	0.029	4.46	0.62	1	6.06

The minimum soil loss (< 3 T/ha/year) is observed at Soultez catchment (Figure 11), occupying 57% (118 km²) of its area. It can partly be explained by the slight slopes of this sub-basin comprising a larger alluvial plain (slopes < 3%). On the contrary, the maximum soil loss (> 12 T/ha/year) is seen at the Reboa sub-basin with 14% (45.92 km²) (Figure 11). It is high because of the steep slopes and the marly-clayey soils of the hills delimiting the sub-basin. However, the downstream alluvial plain presents a much lower erosion (< 7 T/ha/year). Moreover, the comparison of the soil loss greater than 7 T/ha/year shows that there is a significant difference in area of occupation between Reboa and Soultez sub-basins, they are 44% and 32% respectively. This implies that Reboa catchment is highly erodible; the mean soil loss in the Reboa sub-basin reflects this difference where the mean is equal to 6.06 T/ha/year, much higher than Soultez sub-basin (3.78 T/ha/year) (Table 3). However, this difference is less observed for soil loss less than 7 T/ha/year, where Reboa and Soultez sub-basins occupy 66% and 68% of their areas respectively.

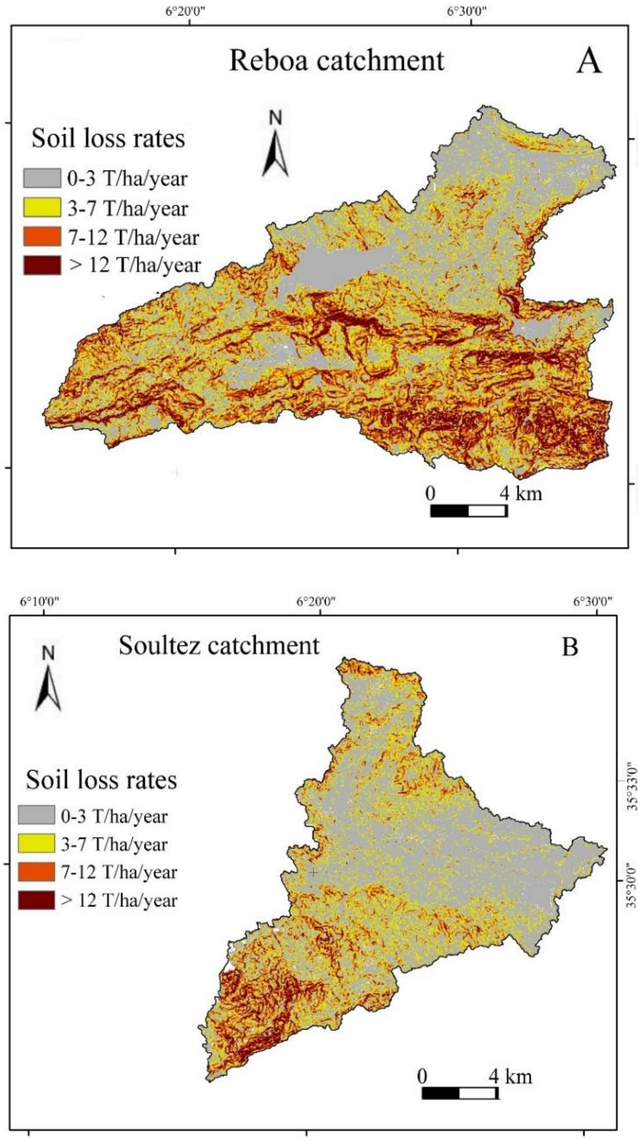

Figure 11: Soil loss rates in the Reboa and Soultez catchments

The total soil loss in lower Soultez region is found to occur near the 1st and 2nd order streams where the presence of weathered material is more (drainage density = 2.84 km^{-1}). It is also seen that the soil loss is more in the upper Reboa area where the drainage density and the thickness of the soil are more (drainage density = 2.73 km^{-1}). It is also observed that most part of the study area (Reboa and Soultez sub-basins) comes under moderate to high erosion category, which could be found in almost all areas, very high erosion occurs only in a few regions where the steep slope with barren land exists. High erosion occurs in the foothills where agricultural area and sparse shrubs and forest with moderate to high slopes exist.

The accuracy of the model may be further increased if statistical data (on crop composition, tillage practices, cover crops and plant residues) are available (Panagos et al., 2015). Taking into account its uncertainties, the RUSLE model can be used by policy makers at the Algerian and local level to run scenarios on crop rotation, land use and conservation practices.

6. CONCLUSION

Land degradation by soil erosion is an important problem in the semiarid-prone Chemorah region. Lack of good quality data and adoptable methods, combined with heterogeneity of environmental factors has pushed us to adopt RUSLE model with remote sensing and GIS to assess and map the spatial distribution of soil loss by erosion in the Chemorah basin with a case study in two catchments, namely Reboa and Soultez. The RUSLE model is found to be the most suitable modelling approach for estimating soil loss in the two catchments. The present study has revealed the role and change of land cover on accelerating the process of soil erosion. Such basic information is given to understand the land cover/land use relationship and to enhance the value of a land cover mapping for the planning and catchment management.

The mean soil loss using RUSLE is found to be equal to 7.52 T/ha/year; which leads to point that the Chemorah basin presents a moderate soil erosion loss. In fact, the erosion potential is tolerable in both study catchments, Reboa and Soultez, with means of 3.78 and 6.06 T/ha/year. In the Reboa sub-basin, the soil erosion is intense and localized in its upper zone at hills and piedmonts. On the other hand, this erosion is high and generalized over the northern sub-basin of the study area (downstream Chemorah sub-basin). With regard to the risk of erosion depending on land use during autumn and winter seasons, the majority of soil losse rates are found in sparsely vegetated areas and barren soils. In fact, the agricultural lands are also contributing in the soil erosion and thus cannot be neglected, concentrated in the central part of the Chemorah basin.

The RUSLE model can provide valuable assistance to be followed in decision making regarding the prioritization of the vulnerable zones that require protection and erosion control. Vegetal cover has to be highly taken in consideration because it is a parameter on which land use planning actions could be based to limit sensitivity to land erosion. Sustainable land management practices are urgently needed to reduce the rates of soil erosion located in the Chemorah basin to improve land productivity, farm program practices and to reduce Koudiat el Medouar reservoir siltation, located downstream from Reboa and Soultez wadis.

This approach might not have produced predicted maps with highest accuracy, but it has provided a quick, realistic and simple method for combining physical variables for mapping and monitoring the erosion potential of soil. . It is also strongly recommended that more developed technical approaches and solutions should be applied to solve similar sedimentation problems in other existing areas.

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