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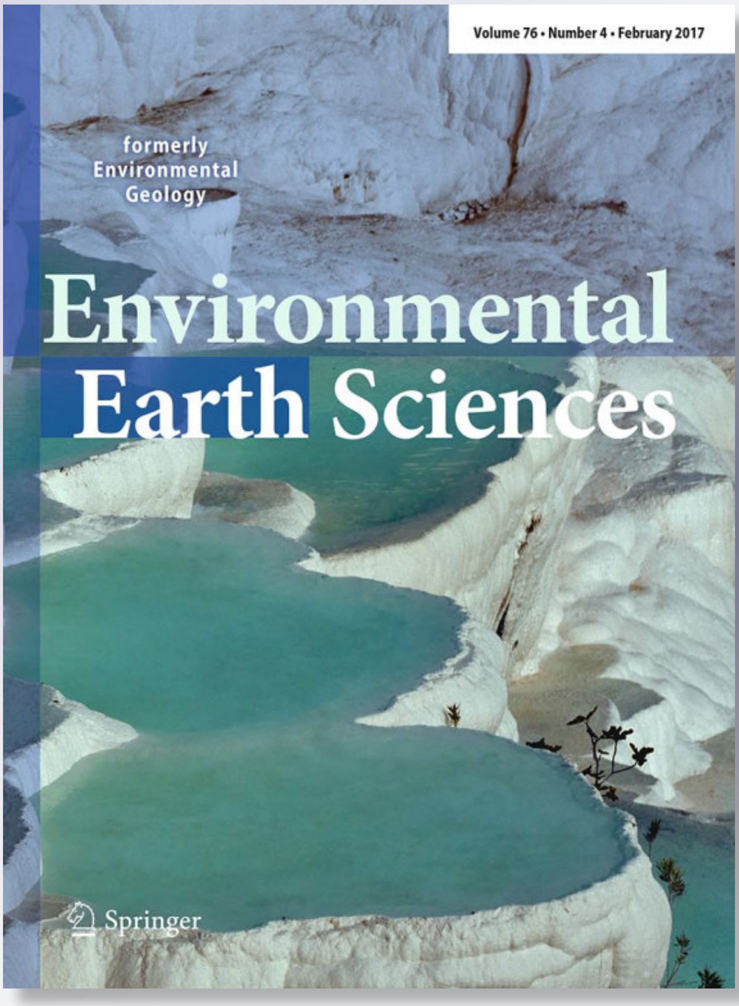
Environmental Earth Sciences

ISSN 1866-6280
Volume 77
Number 9

Environ Earth Sci (2018) 77:1-13
DOI 10.1007/s12665-018-7532-1



Environmental Earth Sciences (2018) 77:345
https://doi.org/10.1007/s12665-018-7532-1

ORIGINAL ARTICLE

Estimating of water erosion in semiarid regions using RUSLE equation under GIS environment

Case of Wadi El-Ham watershed in Hodna region, Algeria

Omar Djoukbala[1] · Mohamed Mazour[1] · Mahmoud Hasbaia[2] · Oussama Benselama[1]

Received: 9 November 2017 / Accepted: 30 April 2018

Abstract

Water erosion is one of the main forms of land degradation in Algeria, with a serious repercussion on agricultural productivity. The purpose of this study is to estimate the soil loss of Wadi El-Ham watershed in the center of Algeria, this study aims also to evaluate the effectiveness and reliability of the use of the Revised Universal Soil Loss Equation (RUSLE) under a Geographic Information System in this field. The RUSLE model involves the main factors of erosion phenomena, namely, rain aggressiveness, soil erodibility, topographic factor, land cover index and the anti-erosive practices factor. Using this approach, the specific erosion in Wadi El-Ham watershed is estimated as 5.7 (t/ha/yr) in the entire watershed area. This result is compared to the measured suspended sediment at the Rocade-Sud gauging station situated outlet the watershed. These data consist of 1293 instantaneous measures of the water discharge and the suspended sediment concentration recorded during 21 years. Through this comparison, the used approach of RUSLE under GIS estimates the soil loss in Wadi El-Ham in Hodna region of Algeria with an error of 7.5%. Consequently, the results obtained in cartographic format make it possible to target the areas requiring priority action for a larger scale analysis to find appropriate solutions to combat erosion and to protect the natural environment.

Keywords Soil erosion · RUSLE · GIS · Remote sensing · Algeria

Introduction

The water and soil are vital resources. In the arid region, they are experiencing a high degradation in quantity and quality by water erosion. The latter is a natural phenomenon that evolves with the anthropic evolution and the climate severity. Recent studies on the vulnerability to climate change in the Mediterranean region indicate a trend towards increased aridity which accelerating water erosion (Berkane and Yahiaou 2007; Souadi 2011). It is also worth mentioning that recent studies also alert for the negative impacts of certain land use changes on soil losses, water quality and soil fertility. Environmental land use conflicts, which occur when land use deviates from land capability (natural use), were found to amplify soil losses (Valle Junior et al. 2014; Pacheco et al. 2014), amplify nutrient exports with enhanced surface and groundwater quality degradation (Valle et al. 2014; Pacheco and Sanches Fernandes 2016), and amplify soil fertility decline through enhanced organic matter loss (Valera et al. 2016, 2017).

Soil erosion by rainfall and runoff is a widespread phenomenon in the many Mediterranean countries (Bou Kheir et al. 2001); it is a very complex phenomenon because of its irregular, random nature and its spatiotemporal discontinuity.

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The topographic and climatic factors, associated with the accelerated and sometimes anarchic urbanization, make of Algeria a favorable environment for the phenomenon of erosion.

Algeria is, therefore, one of the most threatened countries in the world by erosion. The annual losses of water due to siltation in dams are estimated about 20 million m^3 (Remini 2000). However, an average annual specific erosion ranging between 2000 and 4000 (t/km/year) (Demmak 1982), the intensity of water erosion varies from one area to another. The western region is the most affected, i.e., 47% of the whole area, similarly, (27%) and (26%) for the central and the eastern regions, respectively (Ministry of the Environment and Spatial Planning 2000).

In the scientific literature, several approaches are proposed to evaluate, quantify and predict erosion rates and sediment transport. These approaches are based on field observations, many modeling concepts, and sometimes both.

A lot of models are developed to study runoff, erosion process and sediment transport: (CREAMS) *the Chemicals, Runoff, and Erosion from Agricultural Management Systems* (Knisel 1980) and (SWRRB) *Simulator for Water Resources in Rural Basin* (Williams et al. 1985). Other types of models are interested not only in soil loss, but also the nutrient losses: (AnnANPSPL) *Annualized Agricultural Non-Point Source Pollutant Loading*, (ANSWERS) *Areal Non-point Source Watershed Environment Response Simulation* (Beasley et al. 1980) and (LISEM) *Limburg Soil Erosion Model* (De roo et al. 1996).

Models such as *the Universal Soil Loss Equation* (USLE) (Wischmeier and Smith 1978), *Griffith University Erosion System Template* (GUEST) (Rose et al. 1983), *the Water Erosion Prediction Project* (WEPP) (Nearing et al. 1989), *the European Soil Erosion Model* (EUROSEM) (Morgan et al. 1998), *Soil and Water Assessment Tool* (SWAT) (Arnold et al. 1998) and *Agricultural Non-Point Source Pollution Model* (AGNPS)(Young et al. 1989) are based on the description of the physical erosion process through a mathematical concept.

The aim of this study is to estimate the soil degradation in the whole area of Wadi El-Ham watershed using RUSLE under a Geographic Information System (GIS), and also to determine and plan accurately the spatial distribution of the erosive potential of soil at Wadi El-Ham watershed.

The Revised Universal Soil Loss Equation (RUSLE) is one of the most widely used methods in the Mediterranean region (Toumi et al. 2013), Algeria (Tahiri et al. 2016), Morocco (Fernández and Vega 2016), Spain (Karamesouti et al. 2016), Greece (Mancino et al. 2016), Italy (Abdo and Salloum 2017), Syria (Demirci and Karaburun 2012) and Turkey. It presents an easier implementation, in addition to the availability of the required data.

The study area

The Hodna basin with a drainage area of 26000 km^2 is the fifth large basin of Algeria. It is an interior endorheic basin, located at 150 km in the south of the Mediterranean coast.

The Hodna basin constitutes a transition zone between two large mountain chains, the Tellian Atlas chain, represented by the east–west Hodna Mountains. It reaches the summit of the Djebel Tachrit Guetiane in 1902 m and represents a declining altitude to the west to 1000 m; the Saharan Atlas chain constitutes the southern limit of the basin with altitudes do not exceed 1200 m (Table 1).

In this study, we are focusing on the Wadi El-Ham watershed, which is one sub-basin of the large basin of Hodna, it is located northwest the Hodna and occupies the whole area of this part. Geographically, Wadi El-Ham watershed is located between 35°15′ and 36°15′ north latitude and between 3° and 4°15′ east longitude. It drains an area of 5594 km^2 (with a perimeter of 492 km) to the gauging station Rocade-Sud installed at the outlet of the basin (Fig. 1).

Materials and methods

RUSLE model description

Erosion prediction models are useful tools for analyzing soil erosion and establishing a plan for soil erosion mitigation. The USLE model (Wischmeier and Smith 1978), with its revised version of RUSLE (Renard et al. 1997), is the most used model around the world in this field.

Moreover, the need for a USLE update, as users requested more flexibility in modeling erosion with new conditions,

Table 1 Morphometric characteristics of the Wadi El-Ham watershed

Parameters	Unit	Value
Aria A	km²	5594.29
Perimeter P	km	492.27
Index of compactness IC	–	1.843
Maximum altitude Hmax	m	1823
Minimum altitude Hmin	m	441
Mean basin elevation Hmean	m	747.82
Altitude to 95%	m	650
Altitude to 50%	m	861
Altitude to 5%	m	1235
Length of the rectangle Lrec	km	220.80
Width of the rectangle lrec	km	25.34
Length of the main river l	km	112
Drainage density Dd	km/km^2	1.341
Hydrographic density f	km/km^2	1.338

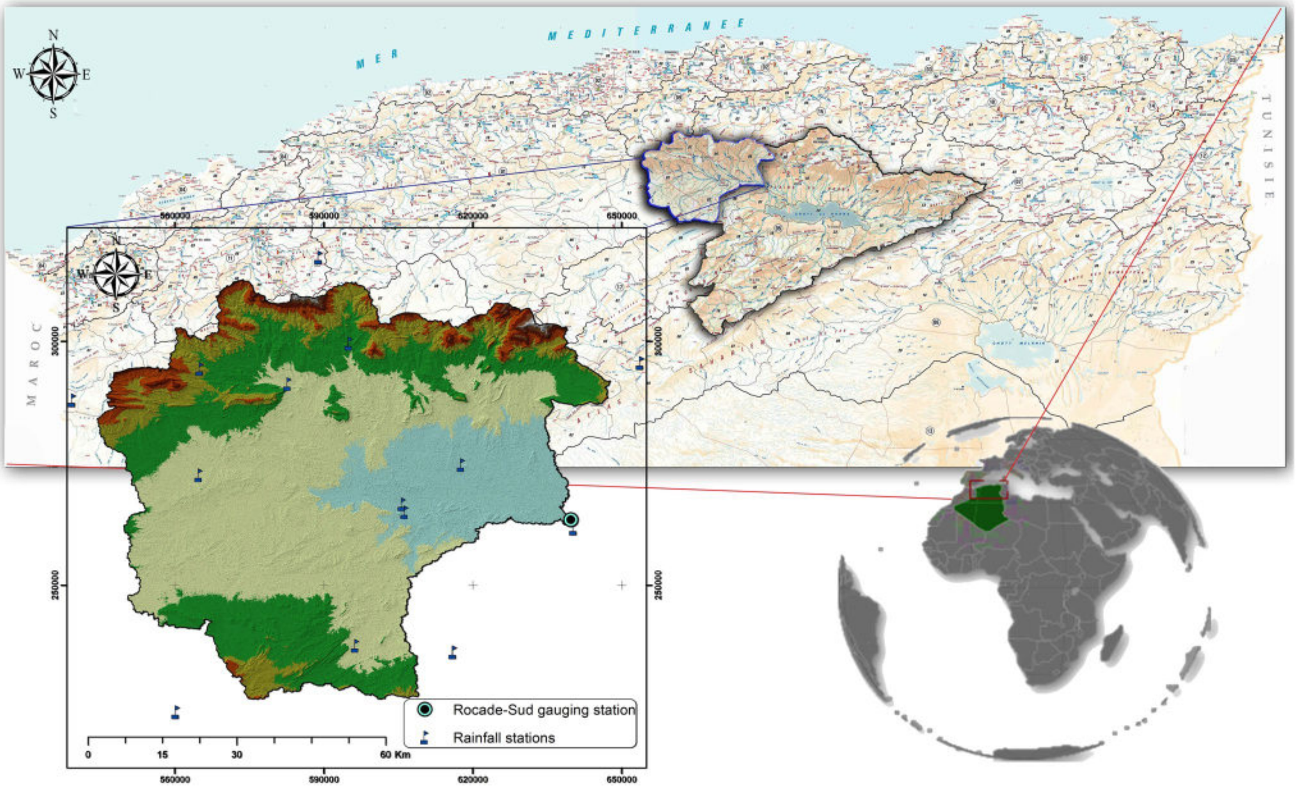


Fig. 1 Location of the study area

which obviously did not work well within the standard USLE version (Wischmeier 1976).

This model carefully demonstrates the spatial heterogeneity of soil erosion, and because it is suitably developed under geographic information systems, it has been the most commonly used model for soil erosion prediction (Feng et al. 2010; Tang et al. 2015).

The relation expresses the RUSLE equation:

$$A = R \times K \times LS \times C \times P, \tag{1}$$

where A is the specific soil loss (t/ha year), R represents the rainfall erosivity factor (MJ mm/ha/h/yr), K is the soil erodibility factor (Mg h/MJ/mm), LS is the non-dimensional topographic factor, C is the cover management factor and P is the soil conservation practices factor.

Factors of the models:

R factor

R is called factor of rain or index of rain "erosivity", is one of the important factors influencing the rate of soil loss, The rainfall erosivity factor (R) can be defined as an aggregate measurement of the amounts and intensities of individual rain storms over the year and is related to total rainfall (Hermassi et al. 2017).

The factor of rainfall erosivity is calculated from several formulas, proposed by Wischmeier and Smith (1961) and can only be applied in areas equipped with autographic recorders, and then, by the method of Arnoldus (Cormary 1964) based on the monthly precipitation or of the index of Fournier.

The lack of continuous pluviograph data relating to rainfall intensity motivated the application of the equation established by Wischmeier and Smith (1978) to derive the R factor. To calculate this factor, we used the data of the monthly rain, and the annual rainfall using the formula of Arnoldus (Cormary 1964) which is presented in the form:

$$\log R = 1.74 \log \sum_{i=1}^{12} \frac{P_i^2}{P} + 1.29, \tag{2}$$

where P_i is the monthly precipitation and P is the annual precipitation (mm).

In this study, the annual and monthly precipitations were recovered from 14 rainfall stations for a period between 25 and 30 years. R values were calculated and interpolated over the whole watershed area using a geostatistical model.

K factor

The soil erodibility factor represents the cohesion and strength of soil vis-à-vis the erosion.

The soil erodibility factor (*K*) in the RUSLE equation is an empirical measure, which expresses the inherent susceptibility of a soil-to-water erosion as determined by intrinsic soil properties.

The *K*-factor is related to soil texture, organic matter content, permeability, and other factor (% silt plus very fine sand, % sand, soil structure), basically, it is derived from the soil type (Wischmeier et al. 1971).

In our study, we used the harmonized world soil database (HWSD) version 1.20 (Fao 2012). The HWSD is composed of a GIS raster image file linked to an attribute database in Microsoft Access format. More 16000 different soil-mapping units are recognized in the Harmonized World Soil Database (HWSD).

The raster database consists of 21600 rows and 43200 columns of with 221 million grid cells covering the globe's land territory, which are linked to harmonized attribute data (Fao 2012).

The use of a standardized structure allows linkage of the attribute data with GIS to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic carbon, pH, water storage capacity, soil depth, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry).

In this study, the values of the *K*-factor were calculated using the following formulas proposed by Neitsch et al. (2011).

$$K_{\mathrm{USEL}} = K_w = f_{\mathrm{csand}} \cdot f_{\mathrm{cl-ci}} \cdot f_{\mathrm{orgc}} \cdot f_{\mathrm{hisand}}, \tag{3}$$

where f_{csand} is a factor that lowers the *K* indicator in soils with high coarse-sand content and higher for soils with little sand; $f_{\mathrm{cl-si}}$ gives the low soil erodibility factors for soils with high clay-to-silt ratios; f_{orgc} reduces the *K* values in soils with high organic carbon content, while f_{hisand} lowers the *K* values for soils with extremely high sand content,

$$f_{\mathrm{csand}} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_{\mathrm{s}} \cdot \left(1 - \frac{m_{\mathrm{silt}}}{100}\right)\right]\right), \tag{4}$$

$$f_{\mathrm{cl-si}} = \left(\frac{m_{\mathrm{silt}}}{m_c + m_{\mathrm{silt}}}\right), \tag{5}$$

$$f_{\mathrm{orgc}} = \left(1 - \frac{0.25 \cdot \mathrm{orgC}}{\mathrm{orgC} + \exp\left[3.72 - 2.95 \cdot \mathrm{orgC}\right]}\right), \tag{6}$$

$$f_{\mathrm{hisand}} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_{\mathrm{s}}}{100}\right)}{\left(1 - \frac{m_{\mathrm{s}}}{100}\right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_{\mathrm{s}}}{100}\right)\right]}\right), \tag{7}$$

where m_{s} is the percent sand content (0.05–2.00 mm diameter particles), msilt is the percent of silt content (0.002–0.05 mm diameter particles), mc is the percent clay content (< 0.002 mm diameter particles), and orgC is the percent of organic carbon content of the soil layer (%) (Table 2).

LS factor

The topography plays a significant role in soil–water erosion. The topographic factor (*LS*) represents the effects of slope length (*L*) and slope steepness (*S*) on the erosion of a slope. The effect of topography on the erosion is calculated throughout the length of slope (*L*) and the degree of slope (*S*), and usually is represented by merging of these two factors into one factor (*LS*) (Perovic et al. 2016).

The *LS* factor in RUSLE represents the ratio of soil loss on a given slope length and steepness to soil loss from a slope (Wu et al. 2012).

Table 2 Estimation of *K*-factor in Wadi El-Ham watershed

Soil sample	MS (sand) top soil %	msilt (silt) top soil %	MC (clay) topsoil %	orgC oraganic carbon %	F_{csand}	$F_{\mathrm{cl-si}}$	F_{orgC}	F_{hisand}	K_{usle}	K
LC	64.3	12.2	23.5	0.63	0.20	0.72	0.98	0.983	0.1393	**0.01834**
BK	81.6	6.8	11.7	0.44	0.20	0.74	0.99	0.718	0.1054	**0.01388**
I	58.9	16.2	24.9	0.97	0.20	0.76	0.93	0.994	0.1394	**0.01836**
XK	48.7	29.9	21.6	0.64	0.20	0.85	0.98	0.999	0.1659	**0.02185**
YK	63.5	17.9	18.7	0.26	0.20	0.81	1.00	0.986	0.1585	**0.02088**
YH	50.4	29	20.6	0.3	0.20	0.85	1.00	0.999	0.1694	**0.02231**
ZG	47.8	8.5	43.8	0.38	0.20	0.58	0.99	0.999	0.1151	**0.01516**

Bold indicates the soil erodibility values

The Digital Terrain Model (DTM) generated from the ASTER DEM (2017) (30 m resolution) was used to generate the *LS* factor. From the ASTER DEM image, the slope was derived using GIS software.

In the framework of our study, we used the formula developed by Wischmeier and Smith (1961) which has been used by several authors (Rodriguez and Suárez 2010; Hajji et al. 2017) for the calculation of topographic factor (*LS*).

$$\mathrm{LS} = \left(\text{Flow accumulation} \times \frac{\text{Resolution}}{22.1}\right)^{m} \times \left(0.065 + 0.045 \times S + 0.0065 \times S^{2}\right), \quad (8)$$

where '*S*' is the slope (%) and '*m*' is a parameter relative to each class of slope (Wischmeier and Smith 1978) (Table 3).

C factor

The vegetal cover factor (*C*) is considered as the second major factor (after topography) controlling soil erosion (Benchettouh et al. 2017). The factor *C* indicates the degree of soil protection by vegetation cover. The latter intercepts the rainfall, increases the infiltration and reduces the rainfall kinetic energy before influencing the soil surface (Mhangara et al. 2012). Soil erosion decreases exponentially with the increase in vegetation cover (Jiang et al. 2015).

In the RUSLE models, the cover factor (*C*) is an index, which reflects, based on the land use, the effect of cropping practices on the soil erosion rate. This factor is used to express the effect of vegetation cover of the watersheds. The Normalized Difference Vegetation Index (NDVI) is one of the most commonly used methods to determine the *C* factor.

In this study, the Normalized Difference Vegetation Index (NDVI) data (period 2017) generated by Satellite Landsat 8 with a spatial resolution of 30 m were used to estimate the *C* factor and explain the effect of differences in vegetation cover on the loss of soil. NDVI was calculated from a combination of red and infrared bands.

To estimate the values of the *C* factor, some authors (Toumi et al. 2013) have used the regression between two extreme values of NDVI; the regression line found is given by

$$c = 0.9167 - \mathrm{NDVI} \times 1.1667. \quad (9)$$

Table 3 Value of '*m*' relative to each class of slope (Wischmeier and Smith 1978)

SLOPE (%)	*M*
> 5	0.5
3–5	0.4
1–3	0.3
< 1	0.2

P factor

P factor indicates erosion conservation practices on the annual soil loss from the watershed; it reflects the effects of practices that will reduce the amount of runoff and their velocity, thereby reducing the effects of water erosion.

According to Elaloui et al. (2017), the cultural contour in alternating strips or terraces, reforestation benches, mounding and ridging are the most effective soil conservation practices.

The values of *P* between 0 and 1, in which the highest value is assigned to areas with the absence of anti-erosive practice, the minimum value represents a good indicator of resistance to erosion; accordingly, lower the *P* value, the more effective the conservation practices.

Estimating sediment discharge

In this section, we use the instantaneous measurements of water flow discharge and suspended sediment concentrations carried out by the ANRH agency. The flows of Wadi El-Ham are controlled by the Rocade-Sud gauging station, located at the outlet of the watershed. According to Hasbaia et al. (2012), water erosion is evaluated on the basis of the annual flow of suspended matter A_s [t] by the following formula:

$$A_s = \frac{\left(Q_{i+1}\,C_{i+1}\right) + \left(Q_i C_i\right)}{2}\left(t_{i+1} - t_i\right), \quad (10)$$

where $\left(Q_i C_i\right)$ and $\left(Q_{i+1}\,C_{i+1}\right)$ are the liquid flow discharges corresponding to the suspended sediment concentration measured at times t_i andt_{i+1}, respectively.

The arithmetic sum of these elementary contributions during the year will constitute annual sediment yield. Similarly, the liquid yield generating the As flux is calculated as follows:

$$\mathrm{Al} = \frac{Q_{i+1} + Q_i}{2}\left(t_{i+1} - t_i\right). \quad (11)$$

Therefore, soil erosion is calculated by dividing the annual sediment yield As [t/yr] by the area of the basin A [km²] according to the following formula:

$$A_{ss} = \frac{A_s}{A}\ \left(\mathrm{t/yr/km^2}\right). \quad (12)$$

Fig. 2 gives a general idea of the functioning of the model that presents a summary of the used methodology.

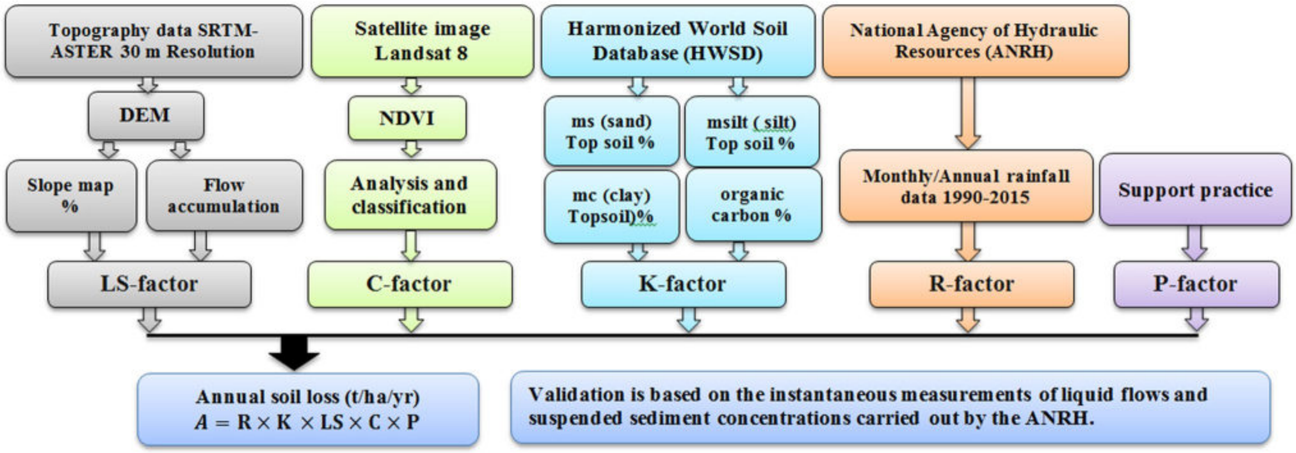


Fig. 2 Diagram of the methodology-adopted USLE–GIS approach

Results and discussion

The obtained results using the RUSLE model are summarized below.

Rainfall erosivity factor (*R*) map

The erosivity of rainfall in the Wadi El-Ham watershed varies from 45 to 70 (MJ·Mm/ha·h·an) (Fig. 3). The rainfall aggressiveness is experiencing an increasing gradient from the south of the basin to the north with a slight increase from east to west.

These *R* values exceeding 45 (MJ·Mm/ha·h·an) indicate that the entire Wadi El-Ham watershed area is subject to high-climatic aggressiveness. It is, therefore, deduced that the erosive power of the rains is important in this basin. The lowest *R* values presented by the class 45–53 (MJ·Mm/ha·h·an), focus on the lowland with a semi-arid climate, while the highest values are more than 53 (MJ·Mm/ha·h·an), focus on the mountainous areas of Wadi El-Ham watershed.

Soil erodibility factor (*K*)

The results obtained for the *K*-factor in the Wadi El-Ham watershed range from 0.0138 (t·ha·h/ha·MJ·mm) for the most resistant soils to 0.0223 (t·ha·h/ha·MJ·mm) for the soil that is least resistant to erosion. Soil are of medium susceptibility to erosion in that more than 80% of the basin has an erodibility index *K* greater than 0.02 (t·ha·h/ha·MJ·mm) (Table 4).

Fig. 4 shows the distribution of soil erodibility over the entire area of Wadi El-Ham watershed.

Topographic factor (*LS*)

The *LS* values range from 0.01 to 22.27. They were grouped into six classes (Table 5). The length and degree of inclination of the slope are determining factors in the erosion process. A reading of the map clearly reflects the topography of the watershed (Fig. 5). The values below 0.5 occupy the largest area of Wadi El-Ham watershed (83.8%), which corresponds to low elevation or lowland areas. The highest values, those exceeding 22 indicate rugged terrain with steep slopes. They occupy very limited areas not exceeding 1% of the basin, but with a distribution over the entire catchment area.

Since this parameter characterizes the functioning of the surface, it is therefore a good indicator of soil erosion in the watershed.

Vegetation cover factor (*C*)

The obtained *C* factor map (Fig. 6) shows that 98% of the watershed area has a very low vegetation cover and only 2% of the area is well protected with $C<0.5$. The values of *C* factor below 0.5 correspond to a dense forests, dense matorrals and arboriculture, however, the values between 0.5 and 0.9 are assigned to areas covered by low density, sparse forests and clear matorrals (Table 6).

The spatial distribution map shows that areas most vulnerable to erosion attributed to the types of occupation of the naked ground; this class covers almost the entire watershed.

Factor anti-erosive practices (*P*)

Throughout Wadi El-Ham watershed, any significant conservation structures exist, what is more, agriculturists do not use conservation tillage practices, which became more

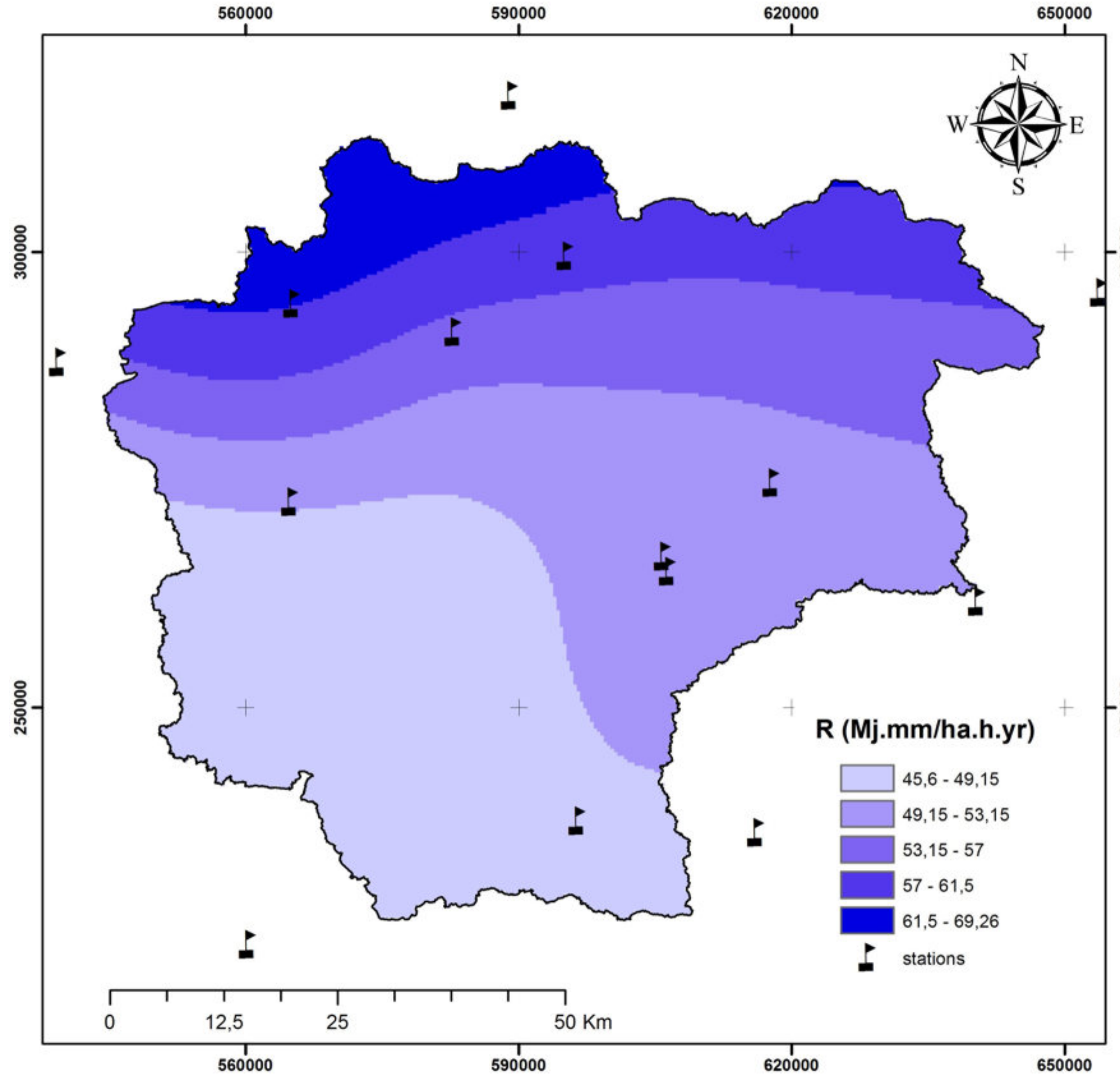


Fig. 3 Rainfall erosivity at 14 rainfall stations

Table 4 Distribution of *K* factor class in the Wadi El-Ham Watershed

Classes *K* factor	Area (ha)	Area (%)
0.013885	5630	1.01
0.015158	1006	0.18
0.018344	3866	0.69
0.018364	120,894	21.61
0.020875	68,153	12.18
0.021845	318,760	56.98
0.223069	41,121	7.35

important now than ever. The crops are mainly cereal, and plowing is rarely parallel to contour lines. In this specific situation, the value of 1 was allotted to the *P* factor in the entire watershed.

Potential erosion risk map with the RUSLE model (*A*)

Within the RUSLE, the erosivity of rainfall, the erodibility of soils, the vegetation cover and the topographic factor are four natural factors that determine the erosion process. The potential annual soil loss can be considered as the result of multiplication of these four factors. The combination and processing of these factors, under Geographic Information Systems (GIS) presented in detail above, have enabled the development of the potential erosion map of Wadi El-Ham watershed (Fig. 7).

The obtained map shows that the soil loss at the Wadi El-Ham watershed scale range from 0 to 17 (t/ha/yr), with an average value for the entire area of 5.72 (t/ha/yr).

This value provides information on the extent of the erosion phenomenon, particularly on steep slopes drained

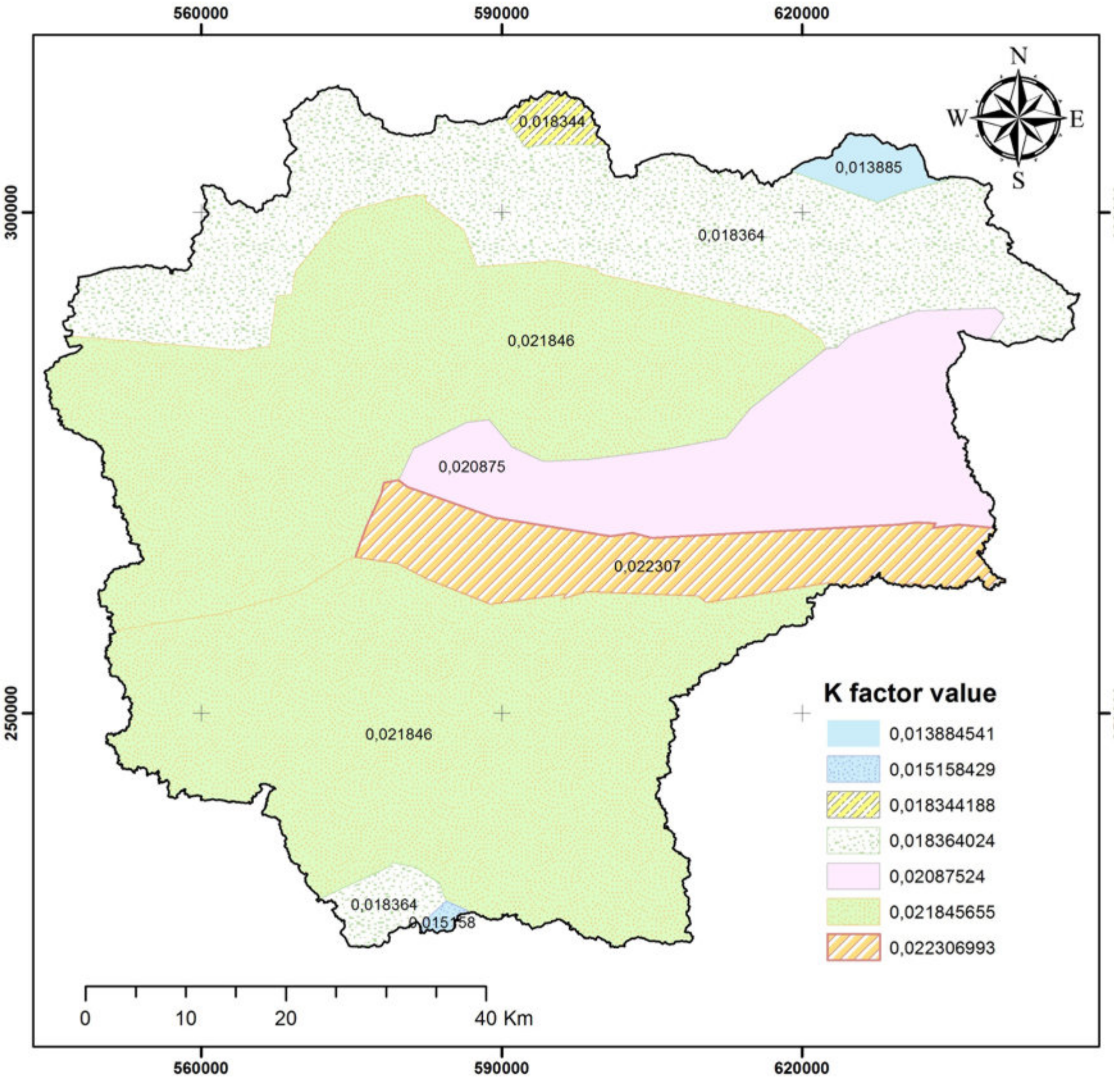


Fig. 4 The *K*-factor map of Wadi El-Ham watershed

Table 5 Distribution of *LS* factor class in the Wadi El-Ham Watershed

Classes *LS* factor	Area (ha)	Area (%)
0–0.25	31038.4	55.5
0.25–0.1	623.7	1.1
0.1 – 0.5	15227.4	27.2
0.5 – 1	5629.5	10.1
1–5	3302.7	5.9
5–22.7	120.9	0.2

by a dense hydrographic network. A low erosion is observed on flat surfaces.

The total solid yield in the Wadi El-Ham watershed is about 3.2 million tons of sediment. The erosion rates differ from one area to another, given the impact of different factors that control erosion.

To better visualize the results and to differentiate spatially between degrees of risk, the different units in soil loss were grouped into four classes. The areas at low risk of erosion with rates between 0 and 4 (t/ha/yr), occupying 54.3% of the total area, are distributed throughout the basin and generally follow the spatial distribution of low-altitude areas and gentle slopes.

The areas with an average risk that encompass classes with erosion rates between 4 and 7 (t/ha/yr) occupy 19.5% of the area and generally follow the distribution of elevations and slopes. They focus on areas where slope and altitude are averages. Similarly, the high-risk classes between 7 and 10 (t/ha/yr) occupying 16.3% of the basin area are mainly located in areas with a relatively high slope. The areas where the risk of erosion is very high > 10 (t/ha/yr) occupy 9.91%

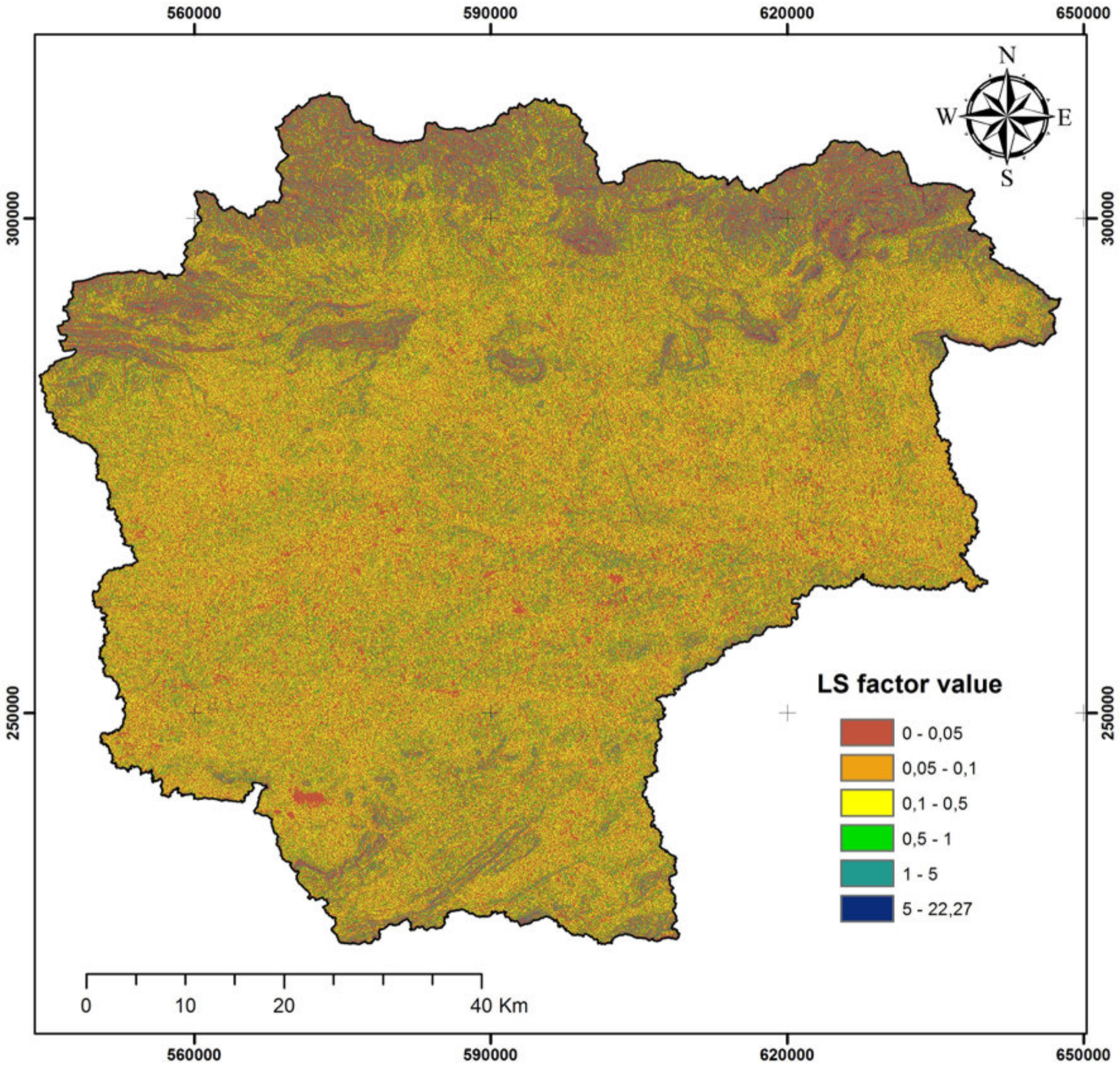


Fig. 5 The *LS* factor map of Wadi El-Ham watershed

of the total area and follow the steep slopes of the catchment (Fig. 8).

The specific erosion calculated from Rocade-Sud gauging station data

Wadi El-Ham transports an average of 94 million m^3 of water and 2.97 million tons of sediment, i.e., a water erosion of about 5.30 (t/ha/yr). The latter value is among the highest in the world, and is an average value associated with significant variability; during the study period (21 years), the coefficient of interannual variation of Cv erosion are estimated to be 1.0.

The obtained results are relatively close to the specific erosion deduced from measured data of the gauging station of Rocade-Sud station. This outcome can be explained by the violent nature of the flows. More than 68% and 75% of the annual water and sediment yields, respectively, are observed during floods. Similar results are obtained in other Algerian watershed, for example, one flood at Upper Tafna catchment (Northwest of Algeria) caused by a severe storm generated 98% of the annual suspended load (Megnounif et al. 2003). The deposited portions of detached sediments can be rapidly compensated by erosion, which occurs in the hydrographic channels of the watershed during the flow. Hydraulically, the violent flows have always the tendency to saturate with sediment.

The current results are also compatible with other works on the evaluation of water erosion carried out in other Mediterranean watersheds having climatic and environmental characteristics that are similar. In Algeria, near our basin, the watershed area of K'sob records an average annual loss of 4.6 (t/ha/yr) (Benkadja et al. 2014); in Morocco (Simonneaux et al. 2015), the average output of the sediments

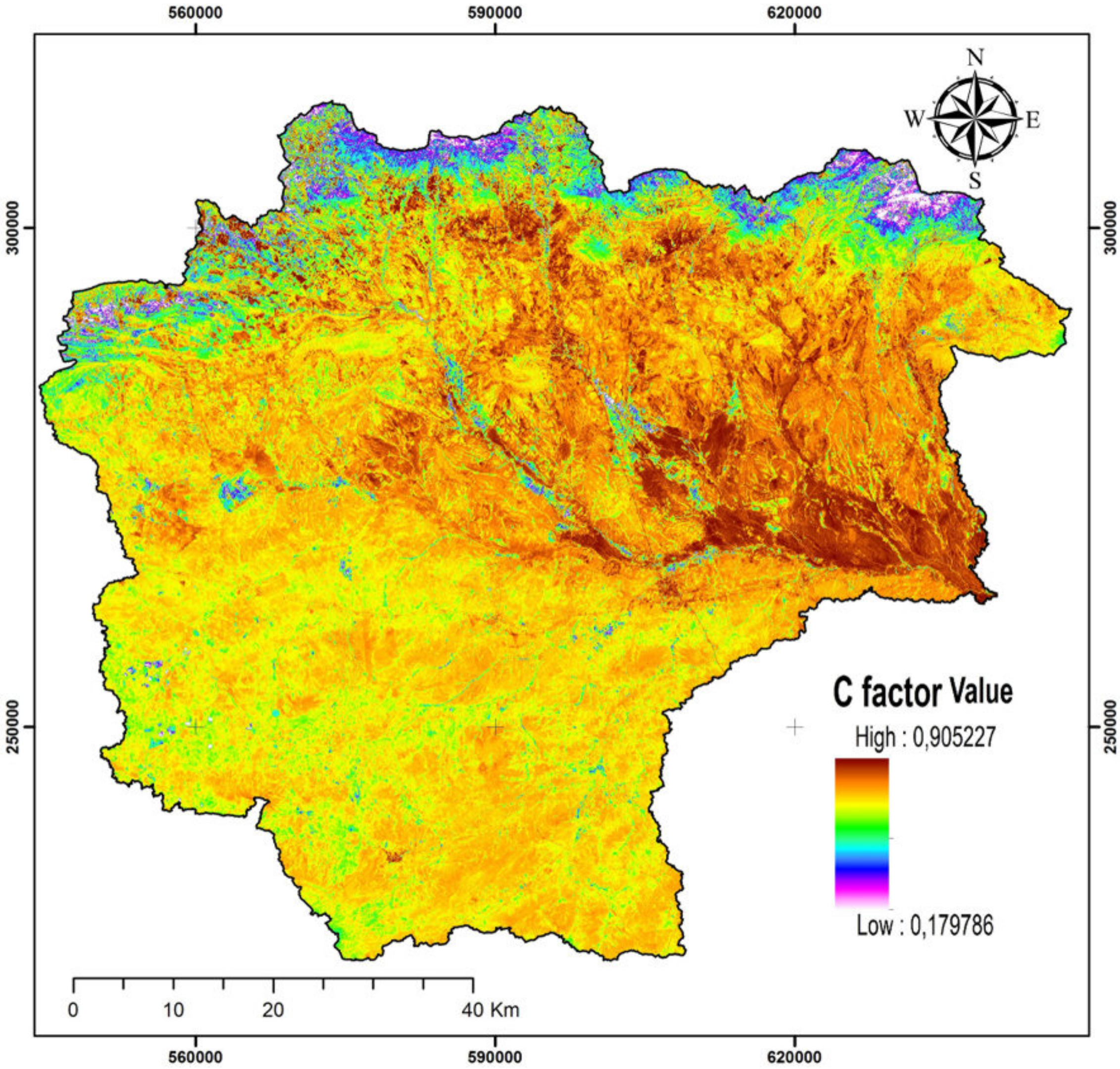


Fig. 6 The *C* factor map of Wadi El-Ham watershed

measured in the high mountains of the Atlas was approximately 4 (t/ha/yr).

In Italy, Mancino et al. (2016) found a loss of 8.5 (t/ha/yr) in the region of Matera (Basilicata, southern Italy), whereas Paroissien et al. (2015) estimated an average annual loss of 4.2 (t/ha/yr) with the watershed of the area of Languedoc (Peyne, France).

There are several advantages to integrating the model into a GIS, which allows an effective management of a significant amount of data related to the various factors of water erosion. This also guarantees the establishment of a synthetic chart of the losses in soil or potential erosion (t/ha/yr) and space distribution of the vulnerability to erosion of the various zones of the watershed area. This study confirms that RUSLE model provided a reliable result, even with a lack of data particularly detailed on soil type and precipitations. This method allows the decision makers and the managers

Table 6 Distribution of *C* factor class in the Wadi El-Ham Watershed

Classes *C* factor	Area (ha)	Area (%)
0.179–0.496	880	0.16
0.496–0.574	3700	0.66
0.574–0.628	7890	1.41
0.628–0.674	14380	2.57
0.674–0.715	22670	4.05
0.715–0.746	53320	9.53
0.746–0.772	161570	28.88
0.772–0.798	186570	33.35
0.798–0.916	108450	19.39

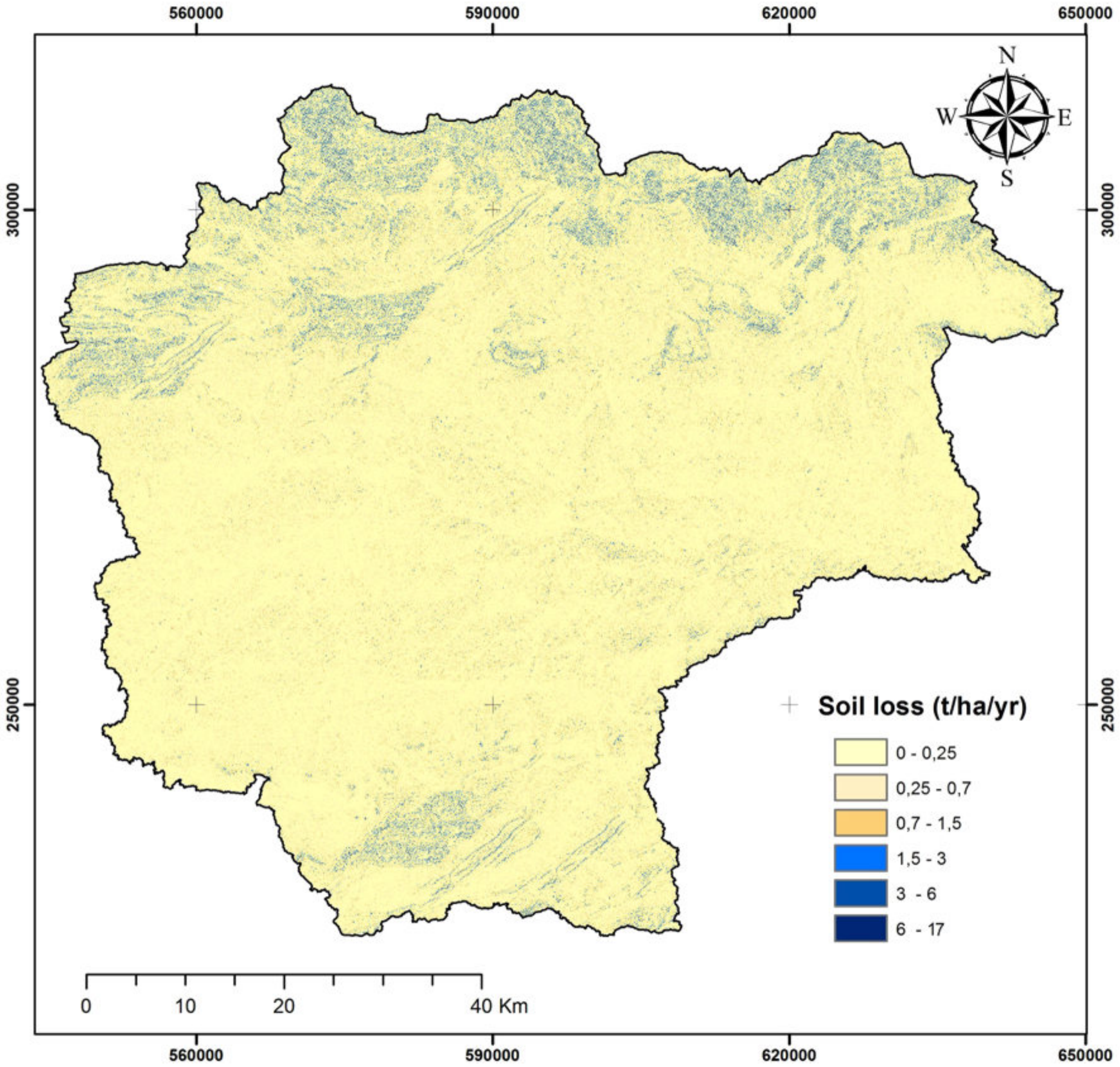
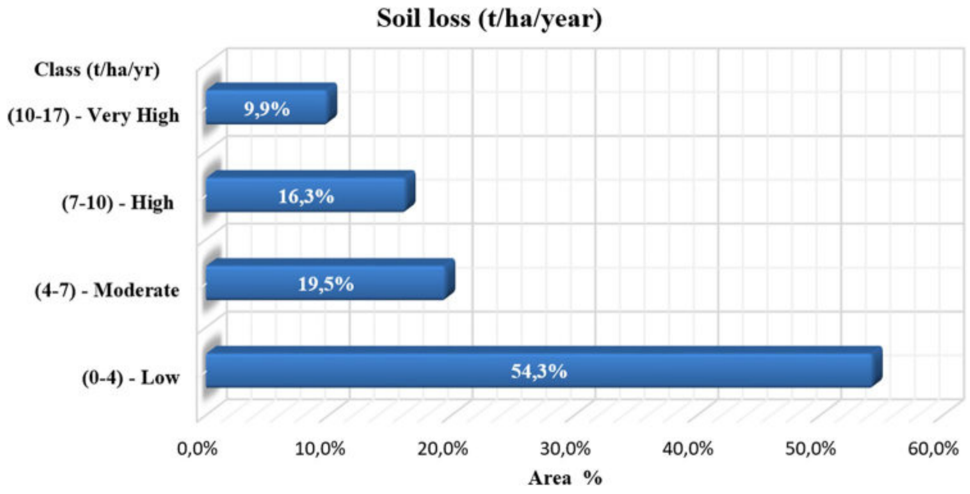


Fig. 7 Soil erosion map in the Wadi El-Ham watershed

Fig. 8 Histogram of soil loss proportions in the Wadi El-Ham



to plan for interventions to fight water erosion in the zones where the risk is high. It also makes it possible to manage the use of soil by facilities to protect it against the phenomena of water erosion.

Conclusion

The assessment of erosion risk and its spatial distribution at the watershed scale is still a real challenge to the scientific community. This study aimed to answer to this question in the Wadi El-Ham watershed north-central Algeria.

The Universal Soil Loss Equation is successfully used under Geographic Information System (GIS) environment. The obtained results show that Wadi El-Ham watershed loses almost 5.7 (t/ha/yr), on average. The spatial distribution of this erosive potential is presented in two classes: a moderate rate of erosion with losses varying from 4 to 17 (t/ha/yr), affects 45.7% of the watershed area, while the losses below 4 (t/ha/yr) cover 54.3% of the watershed.

To check the quality of RUSLE results, we have used the measured suspended sediment at the Rocade-Sud gauging station situated at the outlet of the watershed. These data consist of 1293 instantaneous measures of the water discharge and the suspended sediment concentration recorded during 21 years.

Wadi El-Ham transports an average of 94 million m^3 of water and 2.97 million tons of sediment, i.e., a water erosion of about 5.30 (t/ha/yr). This average value is associated with a significant variability, during the measured period (21 years); the interannual coefficient of variation is estimated to be 1.0.

Based on this measured soil loss, we conclude that the used approach (RUSLE) estimated the soil loss in Wadi El-Ham in Hodna region of Algeria with a mean relative error of 7.5%. This good quality of results can be explained by the violent nature of the flows and also because the major part (more 75%) of the erosion and sediment transport occur during flood periods.

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