Estimation of soil loss using RUSLE model for Sebou watershed (Morocco)

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Abstract In the current study, the revised universal equation of soil losses (RUSLE) is implemented, to assess the risk of water erosion in the Sebou watershed (Morocco). The calculation of erosion requires a huge amount of information and data from various sources available in different formats and scales. Therefore a geographic information system (ArcGIS 10.2) was used, which allowed ease and considerable time savings in the organization and processing of spatial data showing the effects of each factor affecting soil erosion. This erosion is influenced by topography, rainfall, soil properties, the conditions of crop management, and finally conservation practices. The average annual soil loss was calculated by multiplying these five factors. The results show that 78.83 % of the study area has a low risk of erosion, 17.36 % medium risk, 3.04 % high risk and 0.77 % a very high risk.

Keywords Erosion · RUSLE · Risk · Basin · Sebou · GIS

Introduction

Soil erosion by water runoff, whose origin is in the action of water on an area deprived of vegetation cover, is perhaps the most important process of degradation, because it is irreversible and generally of great magnitude (Honorato et al. 2001).

There are several factors that increase water erosion which are: rainfall, soil type, slope, vegetation type and

presence or absence of conservation measures. The direct consequence of soil erosion is the declining productivity due to the loss of nutrients, physical deterioration, decrease of soil thickness, and in extreme cases, total loss of soils. Hence the importance to estimate the potential of this erosion to implement preventive measures against such losses (Morgan 1997). These results will be used for territorial planning.

Study area

The Sebou watershed, located north west of Morocco between parallels 33° and 35° north latitude and 4°15' and 6°35' west longitude, covers nearly 40,000 km². It is bounded to the north by the southern front of the Rif mountain chain, the south by the Middle Atlas mountains, to the east by the corridor Fez-Taza, and West to Atlantic Ocean (Fig. 1).

Materials and methods

There are various methods that consider soil erosion in watersheds, these methods vary from simple to more complex and differ in their need for data input and their ability to predict erosion.

The universal soil loss equation (USLE) proposed by Wischmeier and Smith in (1978) was the most widely used model in predicting the loss of soil. It is described by the following Eq. 1:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where A is the estimated average soil loss in ton/ha/year, R is the erosivity of rainfall in mj mm/ha h year , K is the

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Fig. 1 The study area (AHBS 2011)

soil erodibility factor in ton ha h/ha mj mm, LS is the topographic factor integrating slope length and steepness (LS) dimensionless, C is the cover-management factor, dimensionless, and P is the support practice factor, dimensionless.

After further research, the USLE was improved, which led to the development of the revised universal equation of soil losses (RUSLE) which has the same equation as USLE but with several improvements to verify the factors. The manual of agriculture No. 703 (Renard et al. 1997) published by the United States department of agriculture (USDA), describes this equation in detail. Its advances include:

- Introduction of new algorithms for calculation,
- New erosivity values of rainfall-runoff (R),
- Development of a soil susceptibility term erosion periodically variable and alternative estimation methods when the monogram is not applicable.
- A new method to calculate the cover-management factor (C), using the sub-factors that include prior land use, crops, soil cover (including rock fragments on the surface) and roughness ground.
- New forms of estimating factors slope length and steepness (LS) which consider the erosion percentages grooves and inter-grooves.

- The ability to adjust the LS factor for variable shape slopes; and new conservation practices values (P) for crops in alternating strips, use of grasslands and underground drainage.

R factor

R is the rainfall and runoff factor by geographic location. The greater the intensity and duration of the rain storm, the higher the erosion potential (Stone and Hilborn 2012).

The R factor is the index presented by Wischmeier and Smith (1978), and is defined as the product of the kinetic energy of a storm and its maximum intensity during a 30 min interval (Eq. 2)

$$EI30 = (Ec) \times (I30) \quad (2)$$

where $EI30$ is the erosivity index for an event in mj.mm/ha/h, Ec is the total kinetic energy of rain in mj/h, and $I30$ is the maximum intensity of rain in 30 min in mm/h.

Because of the limitations of the data (rain intensity and rain gauges registers), the Eq. 3 generated by Cortés (1991) was selected and expressed as follows:

$$Y = 2.8959X + 0.002983X^2 \quad (3)$$

where Y represents the annual index of rainfall erosivity in mj mm/ha h year , and X is the annual average precipitation in mm .

The annual rainfall data for the period 1973 to 2013 were collected from the hydraulic agency basin of Sebou (AHBS).

R factor map (Fig. 2) indicates that the values range between 1527 and 7963 mj mm/ha h year .

K factor

K is the soil erodibility factor; it is the average soil loss in tons/hectare for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22.13 m and slope steepness of 9 %. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting

K, but structure, organic matter and permeability also contribute (Stone and Hilborn 2012).

In our study we used the harmonized world soil database (HWSD) version 1.2 (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009). The HWSD is composed of a raster image file and a linked attribute database. The raster database consists of 21,600 rows and 43,200 columns, of which 221 million grid cells cover the globe's land territory.

Each grid cell in the database is linked to commonly used soil parameters, namely, organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class, and granulometry. HWSD allows soil compositions to be displayed or queried in terms of user-selected soil parameters.

Fig. 2 Spatial distribution of R factor

The HWSD Viewer allows soil association compositions to be displayed or queried in terms of user-selected soil parameters, and it provides a geographical tool to query and visualize the database. For modeling, the HWSD and its geographical layer can directly be read or imported by common GIS and Remote Sensing software.

Table 1 k_{usle} Values

Dominant soil	k
Leptosols	0.17
Luvisols	0.15
Calcisols	0.17
Planosols	0.17
Kastanozems	0.16
Vertisols	0.14

The calculation of this factor is made as follows according to Williams' (1995) Eqs. 4–8:

$$K_{usle} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \quad (4)$$

$$f_{csand} = \left(0.2 + 0.3 \times \exp^{-0.256 \times ms(1-msilt/100)} \right) \quad (5)$$

$$f_{cl-si} = (msilt/(mc + msilt))^{0.3} \quad (6)$$

$$f_{orgc} = (1 - 0.25 \times orgc + \exp^{3.72-2.95 \times orgc}) \quad (7)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \frac{1-ms}{100}}{\frac{1-ms}{100}} + \exp^{-5.51+22.9 \times (1-ms/100)} \right) \quad (8)$$

where K_{usle} is the erodibility factor, Ms is the % sand, $Msilt$ is the % silt, Mc is the % clay, and $Orgc$ is the % organic matter.

Fig. 3 Spatial distribution of k factor

The values of the K factor (Table 1; Fig. 3) were multiplied by 0.1317 to be processed in the International System of Units (ISU). Ton Ha hr h/ha mj mm.

LS factor

LS is the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the “standard” slope steepness of 9 % and slope length of 22.13 m. The steeper and longer the slope, the higher the risk for erosion (Stone and Hilborn 2012).

We used a digital elevation model (DEM) with 30 m resolution obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM Validation Team 2009). The calculation and spatialization factors L and S based on

DEM data required several pretreatments. Initially, filling the sinks of the digital terrain model was performed to remove slight imperfections in the data. Several steps, using spatial analysis functions in raster mode, have subsequently been completed. The first step is the creation of a raster of flow direction from each cell to its neighboring cell of lower altitude. This determination of the direction of the theoretical river system flows then calculates a raster layer of accumulated flow to each cell. The second step is to calculate the slope in degrees for each cell. The Eqs. (9–13) (Velásquez 2013) used to calculate in ArcGIS 10 are:

$$F = \frac{\sin(\text{slope} \times 0.01745)/0.0896}{3 \times \text{power}(\sin(\text{slope} \times 0.01745), 0.8) + 0.56} \quad (9)$$

$$M = “F”/(1 + “F”) \quad (10)$$

Fig. 4 Spatial distribution of LS factor

$$L = \frac{\text{power}((\text{flowaccumulation} + 900), (M + 1)) - \text{power}(\text{flowaccumulation}, (M + 1))}{\text{power}(30, (M + 2)) \times \text{power}(22.13, M)} \quad (11)$$

$$S = \text{Con} \left(\begin{array}{l} \text{Tan}(\text{slope} \times 0.01745) < 0.09, (10.8 \times \text{Sin}(\text{slope} \times 0.01745) + 0.03), \\ (16.8 \times \text{Sin}(\text{slope} \times 0.01745) - 0.5) \end{array} \right) \quad (12)$$

$$LS = "L" \times "S". \quad (13)$$

The results of LS factor (Fig. 4) show that most of the basin presents values ranging from 0.03 to 8.4.

C factor

C is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land (Stone and Hilborn 2012).

We used the land cover map Globcover 2009 World with 300 m resolution and 22 types of classes (Bontemps et al. 2011).

The values of the C factor (Table 2; Fig. 5) were obtained for each type of land use from the tables published in the manual for Erosion and Sediment Control in Georgia USA (Georgia Soil Water and Conservation Commission 2000), and USLE Fact Sheet, Ontario Ministry of Agriculture Food and Rural Affairs, Canada.

P factor

P is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross-slope cultivation, contour farming and strip cropping (Stone and Hilborn 2012).

The factor P (Table 3; Fig. 6) was prepared in the same way as the factor C from the GLOBCOVER map and tables established in USA and Canada.

Results and discussion

The raster map of A factor is obtained after the multiplication of the five factors (R, K, LS, C, P). The map of the resulting soil erosion was reclassified into 4 classes (Fig. 7) according to the classification proposed by the Food and

Table 2 C factor values

Land use class	C
Rainfed croplands	0.07
Mosaic cropland (50–70 %)/vegetation (grassland/shrubland/forest) (20–50 %)	0.07
Mosaic vegetation (grassland/shrubland/forest) (50–70 %)/cropland (20–50 %)	0.1
Closed (>40 %) broadleaved deciduous forest (>5 m)	0.001
Closed (>40 %) needleleaved evergreen forest (>5 m)	0.001
Closed to open (>15 %) mixed broadleaved and needleleaved forest (>5 m)	0.001
Mosaic forest or shrubland (50–70 %)/grassland (20–50 %)	0.1
Mosaic grassland (50–70 %)/forest or shrubland (20–50 %)	0.1
Closed to open (>15 %) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5 m)	0.001
Sparse (<15 %) vegetation	0
Artificial surfaces and associated areas (Urban areas >50 %)	0
Bare areas	0
Water bodies	0

Fig. 5 Spatial distribution of C factor

Table 3 P factor values

Land use class	P
Rainfed croplands	0.5
Mosaic cropland (50–70 %)/vegetation (grassland/shrubland/forest) (20–50 %)	0.5
Mosaic vegetation (grassland/shrubland/forest) (50–70 %)/cropland (20–50 %)	1
Closed (>40 %) broadleaved deciduous forest (>5 m)	1
Closed (>40 %) needleleaved evergreen forest (>5 m)	1
Closed to open (>15 %) mixed broadleaved and needleleaved forest (>5 m)	1
Mosaic forest or shrubland (50–70 %)/grassland (20–50 %)	1
Mosaic grassland (50–70 %)/forest or shrubland (20–50 %)	1
Closed to open (>15 %) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5 m)	1
Sparse (<15 %) vegetation	1
Artificial surfaces and associated areas (Urban areas >50 %)	1
Bare areas	1
Water bodies	1

Fig. 6 Spatial distribution of P factor

Agriculture Organization of the United Nations (FAO) in (1979) (Table 4).

The results show that 78.83 % of the study area has a low risk of erosion, 17.36 % medium risk, 3.04 % high risk and 0.77 % a very high risk.

Conclusion

The present study allowed us to quantify and map potential erosion throughout the Sebou watershed. Concerning management strategies to reduce soil loss,

intervention will focus only on the LS, C, and P factors, as the K and R factors cannot be changed (Stone and Hilborn 2012).

- For the LS factor, the management of terraces will reduce the length of the slope and consequently the soil loss,
- For the C factor, the choice of the types of cultivation and tillage methods will lead to reduction of erosion.
- For the P factor, conservation practices, such as culture against the slope, should be used to ensure that sediments are deposited close to their source.

Fig. 7 Spatial distribution of erosion risk categories

Table 4 Classification of erosion risk

Erosion rate in ton/hectare/year	Risk
<10	Low
10–50	Medium
50–200	High
>200	Very high

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