

## Modeling Soil Erosion Using RUSLE and GIS – A Case Study of Korifla Sub-Watershed (Central Morocco)

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### ABSTRACT

Soil loss is a problem that contributes to land degradation in many countries and Morocco is no exception. Our study focuses on water erosion in Korifla, a sub-basin of the Bouregreg watershed in northern Morocco. The objective is to quantify erosion using the RUSLE method which is based on five factors: Runoff erosivity, soil erodibility, cover factor, topography and conservation practices. These are processed by remote sensing and a geographic information system. The soil loss map shows that on an area of 1838 km<sup>2</sup>, erosion is estimated to be between 0.00 t/ha/year and 27.61 t/ha/year. The cumulative effect of the factors R, K, LS, C, and P are both the origin of this erosion and its spatial distribution.

**Keywords:** erosion, GIS, RUSLE, LANDSAT, MNT, KORIFLA.

### INTRODUCTION

Soil erosion is one of the main processes leading to land degradation (Koch, 2013), its rates are ten to fourteen times higher than soil formation rates worldwide (Pimentel, 2006) nearly 10 million hectares of agricultural land are lost to soil erosion each year (Amiri, 2019; Cedrà, 2017). The transported sediment affects human activities, such as the sedimentation of reservoirs for irrigation and drinking water purposes (Vörösmarty, 2003). In Morocco, water erosion is the main threat of soil degradation (Ouallali, 2016; Jazouli, 2017) several studies have used methods to assess soil loss from water erosion, the USLE method was developed mainly for soil erosion estimation in croplands or gently sloping topography. With its revised (RUSLE) and modified (MUSLE) versions. RUSLE has been adopted in several countries in the world as an equation of soil loss giving the best results in planning soil and water conservation in a sustainable manner (Kalambukattu,

2017; Tesema, 2020) and surface erosion models based on RUSLE are widely accepted and increasingly used for applications spanning field, catchment, national, and even global scales (Borrelli, 2017). For this study, the objective is to estimate water erosion in the Korifla sub-basin and to consider the soil loss map as a decision tool to implement soil conservation measures so remote sensing and Geographic Information Systems (GIS) are becoming more important tools in interactive decision support and operational planning for risk management operations (Bou Kheir, 2006; Gliz, 2015). In the framework of the present work we propose an estimation of water erosion in the Korifla sub-catchment. This is achieved by combining the Geographic Information System (GIS) and remote sensing with the Revised Universal Soil Loss Equation (RUSLE), it allows evaluating the extent of erosion by integrating several parameters such as runoff erosivity, soil erodibility, cover factor, topography and conservation practice.

## STUDY SITE

The study area is a sub-basin (SBV) of the Bouregreg catchment; it is located in the north-west region of central Morocco.

The study area lies between latitude 33°0'0" N and 33°55'0" N, longitude 6°25'0" W and 6°55'0" W. The area of the (SBV) is 1838 km<sup>2</sup> while Bouregreg has an area of approximately 10,000 km<sup>2</sup> which means that SBV Korifla constitutes 18% of the total area of BV Bouregreg and the elevation varies between 59 m and 981 m. The Oued Korifla covers an area of 1900 km<sup>2</sup> and originates on the western flank of the middle Atlas mountains, and then flows through central Morocco to the Sidi Mohamed Ben Abdellah dam located a few kilometers from Rabat (Bounouira, 2007). Administratively, the study area includes 15 communes, either totally or partially (Fig. 1).

The climate is Mediterranean, average annual precipitation values for the period between 1997 and 2017 range from a minimum of 383.16 mm to 424.81 mm.

## METHODS AND MATERIALS

### Methods

The RUSLE equation (Renard, 1997) is generated from five factors (Fig. 2): Runoff erosivity R, soil erodibility K, cover factor C, conservation practice P, topography LS.

GIS is the main tool of this study; thanks to ArcGis (version 10.3.1), the maps are georeferenced, digitized and interpreted. The first step of our work was the delimitation of the study area using the digital terrain model and identifying the outlet and then extracting the study area. Then, by integrating the maps and data, ArcGis was used to map and model the data set, and ENVI (version 5.3) was used in the remote sensing part to process the satellite image that would be used to determine the vegetation cover.

### Data type and source

The data are collected from several sources (Table 1). The Ls factor requires a DEM, the

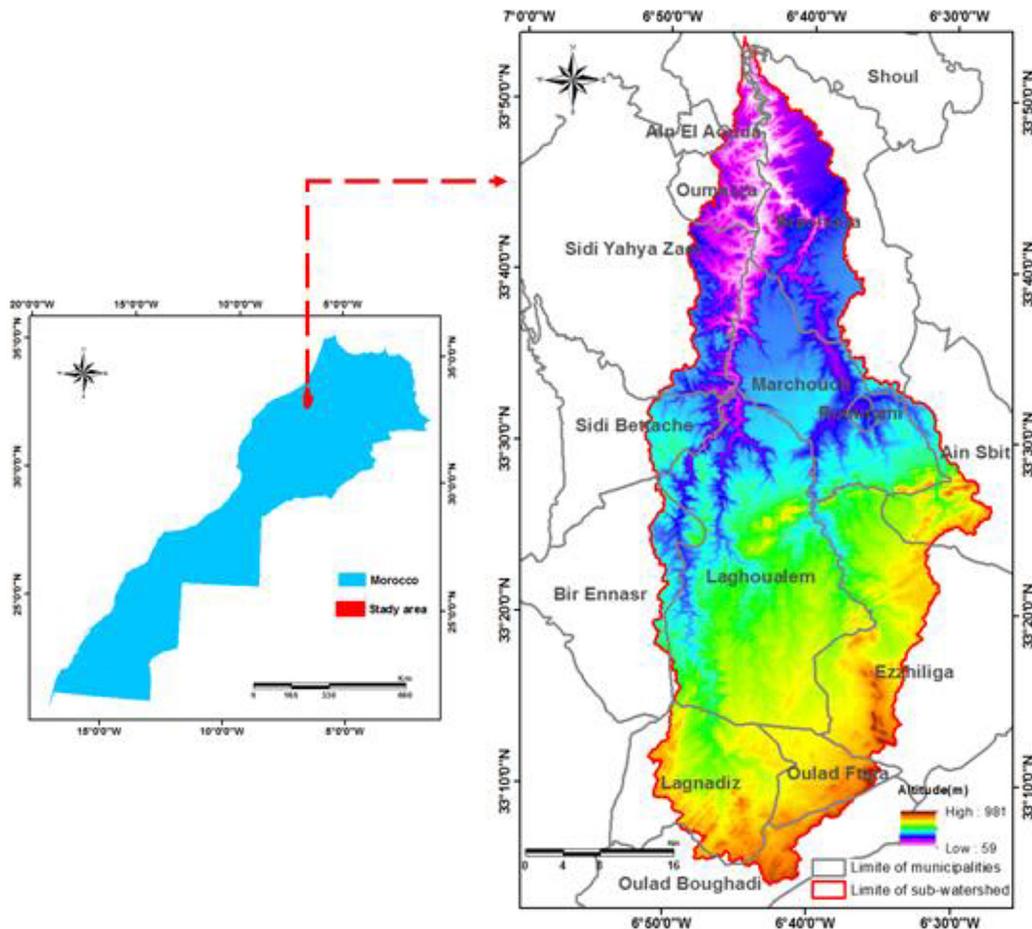


Figure 1. Location of the municipalities in the sub-basin and the elevation model

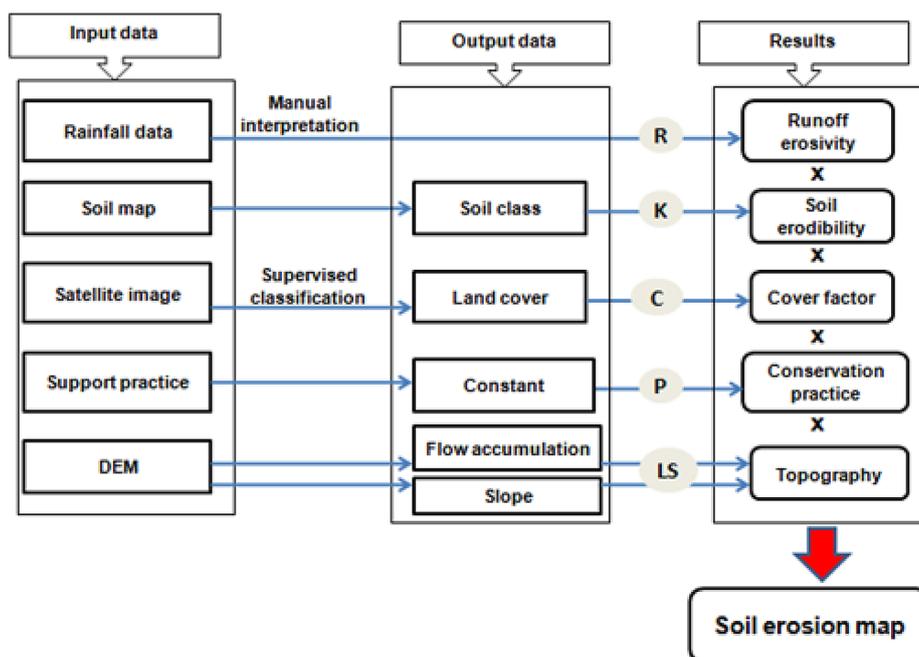


Figure 2. Descriptive diagram of the methodology

Table 1. Data sources and description

Type of data	Source	Description
ASTER DEM	www.earthexplorer.gov	30 m resolution
Landsat 8 OLI	www.earthexplorer.gov	Multispectral bands: 30 m Date: 20/03/2020
Rainfall data	Hydraulic Bassin Agency of Bouregreg and Chaouia	Period between 1997 and 2017
The soil map of central Morocco	The soil map of central Morocco	Scale :1 /50000, Edition 2001

one used for this study at a resolution of 30 m, while the C factor requires remote sensing, because the OLI image is first processed with the ENVI software. The source of the R factor data is seven meteorological stations for the period between 1997 and 2017 that have been used to interpolate the data, the K factor is derived from the soil map of the region and then the data set is interpreted using ArcGis and for the factor P conservation practice is bibliographic data validated after field visits.

### Description of RUSLE model

RUSLE model has been extensively applied for estimating sheet and rill erosion rates (Zerihun, 2018). The RUSLE (Renard, 1997) model was computed using (Equation 1):

$$A = R * K * LS * C * P \quad (1)$$

where: *A* – commuted soil loss per unit area per year ( $t \cdot ha^{-1} \cdot year^{-1}$ );  
*LS* – the slope length and steepness factor (dimensionless),

*K* – the soil erodibility factor ( $t \cdot ha \cdot MJ^{-1} mm^{-1}$ );  
*R* – the rainfall erosivity factor ( $MJ \cdot mm ha^{-1} \cdot h \cdot year^{-1}$ );  
*C* – the cover and management factor (dimensionless);  
*P* – the support practice factor (dimensionless).

### Rainfall erosivity factor (*R*)

Rainfall erosivity is one of the most important input parameters for describing erosive processes and proposing conservation measures using soil erosion prediction models (Panagos, 2017; Yue, 2020), it reflects the effect of rainfall intensity on soil erosion and requires detailed, continuous precipitation data for its calculation (Wischmeier, 1978).

Changes in rainfall pattern and hydrological cycle are the significant determinants of drought, causing land and forest degradation (Stocker, 2014).

In this study, the formula of (Arnoldus, 1980), it takes into consideration the average monthly

and annual rainfall; this choice is justified by the availability of rainfall data for the catchment area. The formula is expressed by (Equation 2):

$$\text{Log}(R) = 1.74 \log \sum \frac{P_i^2}{P} - 1.29 \quad (2)$$

where:  $R$  – the rainfall aggressiveness index (units·year<sup>1</sup>);  
 $P_i$  – average monthly precipitation (mm);  
 $P$  – average annual precipitation for the observation period (mm).

**Soil erodibility factor (K)**

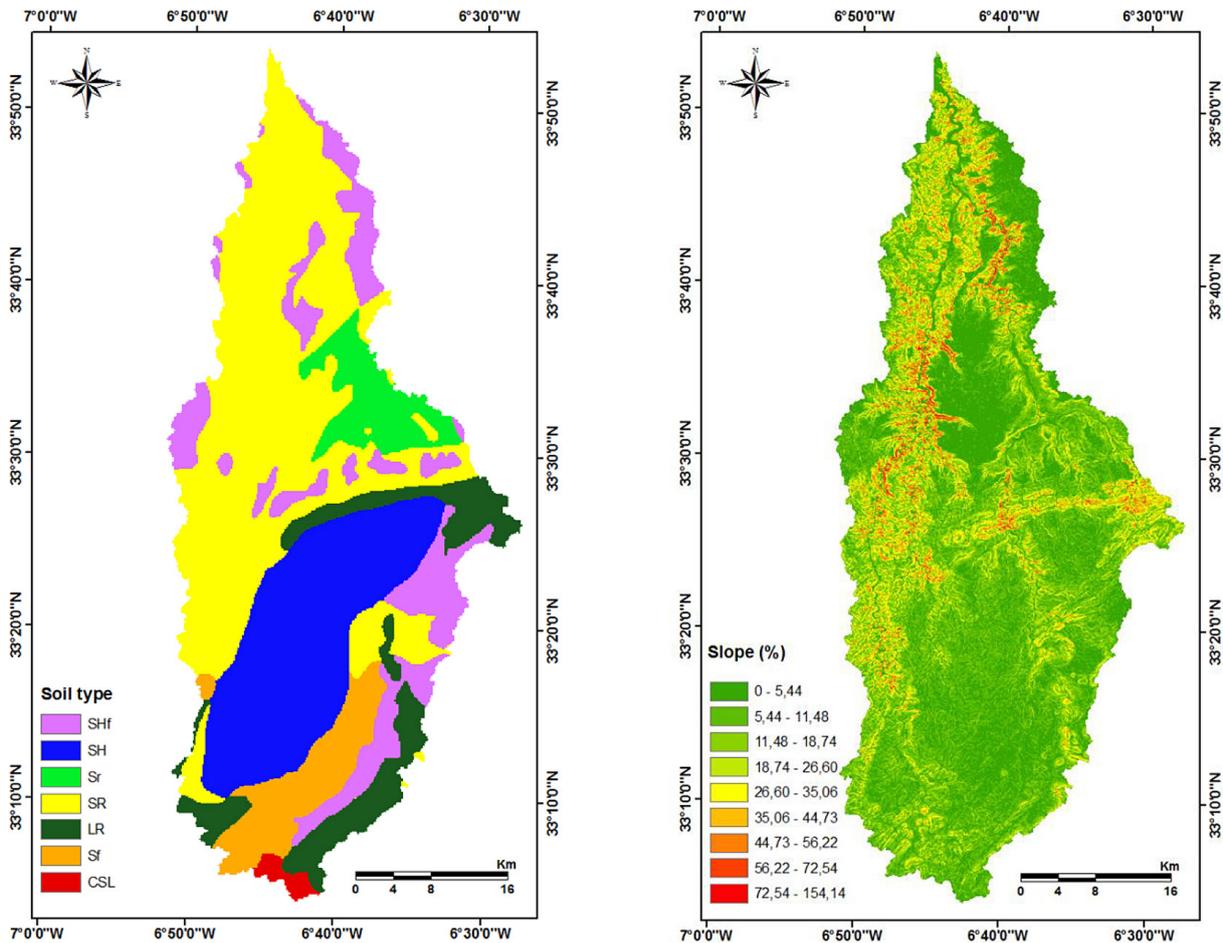
K factor reflects the physical and chemical properties of the soil, which determines the erodibility of a particular soil types (Renard, 1997), it's calculated (Equation 3) by the following equation (Wischmeier & Smith, 1978):

$$Y = 2.1 * M^{1.14} * 10^{-4} (12 - MO) + 3.25(B - 2) + 2.5(C - 3)/100 \quad (3)$$

where:  $M$  – (%Fine sand + silt) · (100 – %Clay);  
 $MO$  – percentage of organic matter;

**Table 2.** Soil types and K-factor values

Soil type	Description	K-Factor	Area (%)
SR	Association – mediterranean red and brown soils (sometimes hydrompric), regosols	0.44	41.81
SH	Association – brown or red sandy soils, hydromorphic sandy soils (granite)	0.35	20.91
SHf	Hydromorphic sandy soils with iron concretions	0.4	13.95
LR	Lithosols and regosols (ridges)	0.0395	9.64
Sf	Brown forest soils	0.0057	7.16
Sr	Association – red floors and shooting on red material	0.45	5.74
CSL	Association – calcareous brown, steppe brown, lithosols and some red soils	0.0395	0.77



**Figure 3.** Spatialization soil type and slope

- B – soil permeability code (1 to 6);
- C – permeability class of the profile.

It represents the susceptibility of different soils to erosion, determined under standard unit plot conditions for both amount and rate of runoff (Bryan, 2000).

The soil type map (Fig. 3a) is derived from the soil map which is geo-referenced and digitize and according to (Heusch, 1970; Bollinne, 1978; Molla, 2017; Kacimi, 2020), the values of the K factor are presented in the (Table 2), the value of K varied from 0 to 1, where the previous proposed less and future indicates high vulnerability to erosion hazard correspondingly (Bewket, 2009).

#### Topographic (LS) factor

The geomorphology of the study area contributes significantly to soil erosion through slope length (*L*) and slope steepness (*S*) (Da Cunha, 2017; Ozsoy, 2012). The LS factor is estimated by applying the (Equation 4) developed by (Moore, 1986).

$$LS = \left( \text{Flow accumulation} \times \frac{\text{Cell size}}{22.13} \right)^{0.4} \times \left( \frac{\sin \text{Slop}}{0.0896} \right)^{1.3} \quad (4)$$

The DEM used in this study has a resolution of 30 m and the slope is in percent, Flow accumulation is calculated from flow direction. The slope is one of the most important topographical features affecting soil erosion (Guerra, 2017; Srinivasan, 1991).

Slope length and slope steepness is the other main factor for estimating the soil loss which measures sediment transport capacity of the flow (Moore, 1992). The numerical application of the LS equation allowed us to view the LS factor map, it can be computed using an ArcGIS Map Algebra Arc Toolbox (van Remortel, 2004; Tesema, 2020).

For our study, Slope (Fig. 3b) is in percent its value is between 0% and 154, 14%. According to the classification of (Dragicevic, 2016) the slope greater than 30% is classified high and the percentage greater than 40% is very high.

#### Cover management factor (C)

Poor surface cover promotes soil erosion, land degradation, and the elimination of habitat and biodiversity, as well as a rapid reaction to

rainfall and excessive runoff (Kiage, 2013; Ziadat, 2013). The Landsat OLI 8 was acquired on 20/03/2020 and covers the entire study area with resolution of 30 m.

The remote sensing part is implemented by the ENVI software (version 3.5) because we have to eliminate atmospheric disturbances that infiltrate the image quality and make corrections for accurate and correct results, this is by radiometric calibration and atmospheric corrections then NDVI (Normalized Difference Vegetation Index) is calculated by the (Equation 5) (Tucker, 1997) :

$$NDVI = \left( \frac{NIR - RED}{NIR + RED} \right) \quad (5)$$

where: NIR – surface reflectance in the near infrared.

The NDVI value is between -1 and 1 where -1 is a high vegetation index. However, the factor will use NDVI for the application of the (Equation 6) (Durigona, 2014):

$$C = \frac{-NDVI + 1}{2} \quad (6)$$

This equation applies on the map resulting from the ENVI software it is integrating in ArcGis. The map Algebra tool allows you to apply the equation is to get the C factor map.

#### Conservation support practice factor (P)

The P factor is defined as the ratio of soil loss with a given surface condition to soil loss with up-and-down hill plowing (Vander-Knijff, 2000), its accounts for management practices that minimize the degradation potential of runoff through their impact on drainage networks, concentration of runoff, velocity of runoff and hydraulic forces on the ground (Ganasri, 2016). Soil conservation measures are often promoted as a solution to adapt to the projected increase of soil erosion under climate change (Amundson, 2015; Eekhout, 2019).

## RESULT AND DISCUSSION

### R factor estimation

Interpolation of annual and monthly 20 year average rainfall data from seven stations using the IDW tool resulted in the development of the Rainfall erosivity map (Fig. 4a).

The map shows that the R-factor varies between the value 68.73 MJ·mm·ha<sup>-1</sup>·h·year<sup>-1</sup> and

72.56 MJ·mm·ha<sup>-1</sup>·h·year<sup>-1</sup>. In addition (Table 3) raises that the class between 60, 00 and 71.00 MJ·mm·ha<sup>-1</sup>·h·year<sup>-1</sup> covers 70% of the area of the SBV Korifla.

### K factor estimation

The K-factor (Fig. 4b) ranges from 0.0057 to 0.45 t·ha·MJ<sup>-1</sup>·mm<sup>-1</sup> in the SBV Korifla. The minimum value (Table 2) is associated with the Brown Forest Soils while 41.81% of the area of the SBV Korifla is granted to the association: Red and Brown Mediterranean Soils (sometimes hydromorphic), Regosols and which is presented by the value of the K factor 0.44 t·ha·MJ<sup>-1</sup>·mm<sup>-1</sup>.

The K-factor values between 0.35 t·ha·MJ<sup>-1</sup>·mm<sup>-1</sup> and 0.45 t·ha·MJ<sup>-1</sup>·mm<sup>-1</sup> correspond to an area of 82.41% of the total Korifla SBV, which is in agreement with the soil types: SR, SH, SHf, Sr.

### Ls factor estimation

According to the map (Fig. 4c), LS is between 0, 00 and 64, 70 but up to 72.20% of the area is dominated by class 0-2 followed by value 0 with 27, 57%, the values of the remaining classes are presented in Table 4.

### C factor estimation

The C-factor's value varies from 1 in completely bare land to 0 in a water body or completely covered land surface (Mengistu, 2015).

For our study, the value of C is between 0.11 and 0.70 (Fig. 4d), with a percentage of 65.05% is only for class 0.40–0.50 as shown in Table 5.

### P factor estimation

The value P factor range 0-1 in which 0 values represent high-quality preservation practice and the value resembling one indicates poor protection practice (Morgan, 1998).

Due to the absence of anti-erosive practices in the study area, the value of the P factor is estimated at 1.

### Estimation of mean annual soil loss

The soil loss map (Fig. 5) obtained after applying the RUSLE equation by multiplying the factors (LS·C·K·R) allowed us to estimate an erosion of up to 27.61 t·ha<sup>-1</sup>·year<sup>-1</sup>.

The class of 0.5 and 2 constitutes 72.01% of the total area of the SBV Korifla (Table 6)

**Table 3.** R-factor classes and area

Classes R factor	Area (km <sup>2</sup> )	Pourcentage (%)
68.73–69.00	35.48	1.93
69.00–70.00	407.43	22.17
70.00–71.00	1288.92	70.00
71.00–72.56	105.14	5.72

**Table 4.** LS-factor classes and area

Classes factor LS	Area (km <sup>2</sup> )	Pourcentage (%)
0	506.45	27.57
0–2	1326.11	72.20
2–4	2.42	0.13
4–10	1.16	0.06%
10–64.70	0.46	0.02

**Table 5.** C-factor classes and area

Classes factor C	Area (km <sup>2</sup> )	Pourcentage (%)
0.11–0.30	30.98	1.68
0.30–0.40	605.67	32.93
0.40–0.50	1196.38	65.05
0.50–0.72	6.06	0.32

**Table 6.** Soil loss classes and area

Classes soil loss	Area (km <sup>2</sup> )	Pourcentage (%)
0	500.56	27.40
0–0.5	1315.68	72.01
0.5–2	9.25	0.50
2–27.61	1.35	0.07

according to the classification of (Haregeweyn, 2017), the erosion is very slight.

The results obtained are values included in the estimation margin in previous work on the Bouregreg watershed because the rate of sediment transported, estimated at 967.664 tons each year, from the four sub-watersheds a real problem of filling the Sidi Mohammed Ben Abdellah dam (Mahé, 2014; Abdelhadi, 2022).

## CONCLUSIONS

The combination of a soil loss prediction model and a geographic information system, allowed us to give another dimension to the field information in the form of a numerical quantification, and spatialization of areas exposed to soil degradation risks in the Korifla basin. The results obtained allow decision makers to better plan intervention

strategies through the simulation of the surface condition and exposure of the study area to different hazards. The RUSLE equation was used to exploit the different factors (soil, climate, topography...) to produce an erosion sensitivity map that

determines the extent of soil loss in the region. For our study area, the results obtained show that the annual rate of soil loss is less than  $0.5 \text{ t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ . These results prove that the percentage of degraded lands is constantly increasing, which reflects

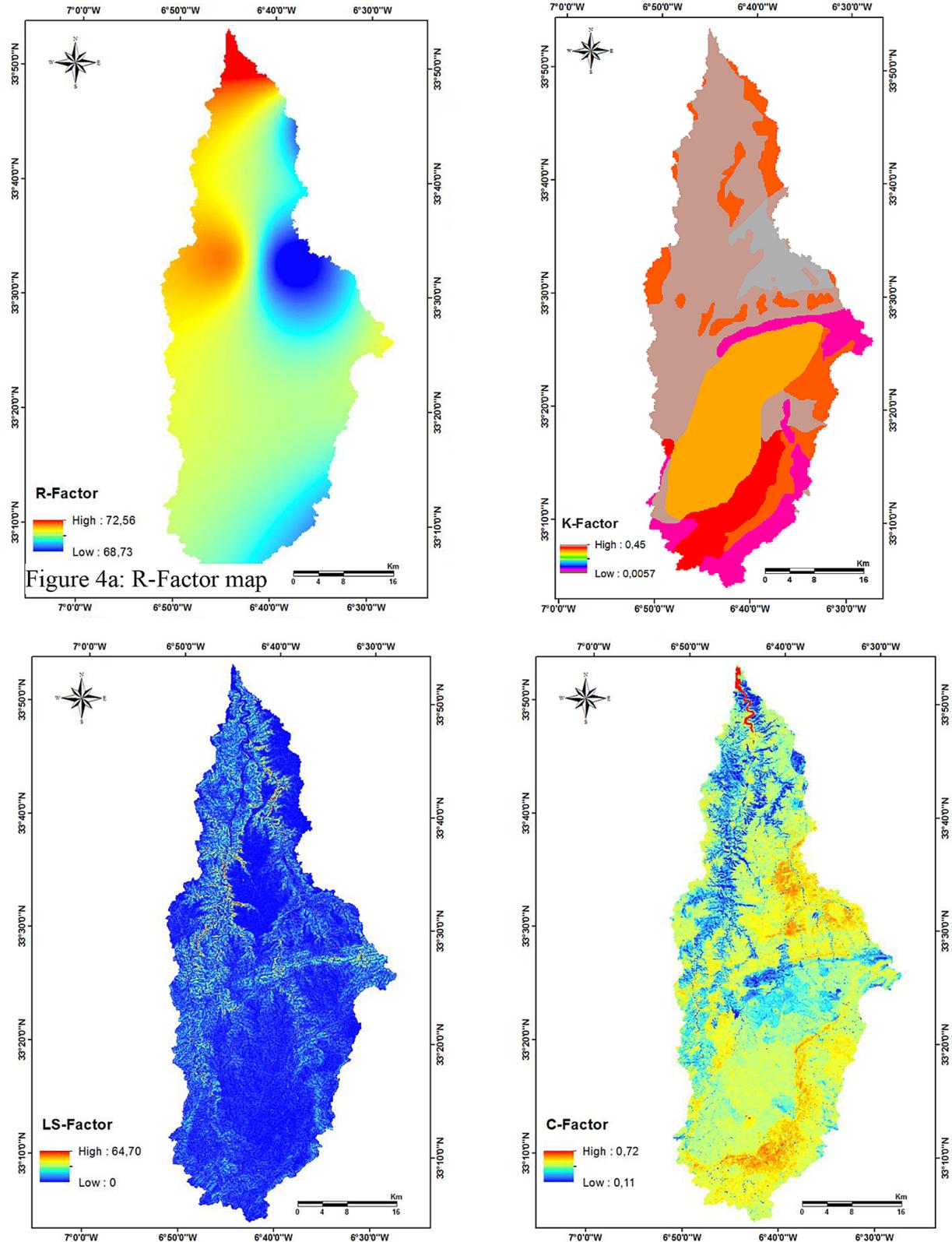


Figure 4. Spatialization of R, K, LS and C factors

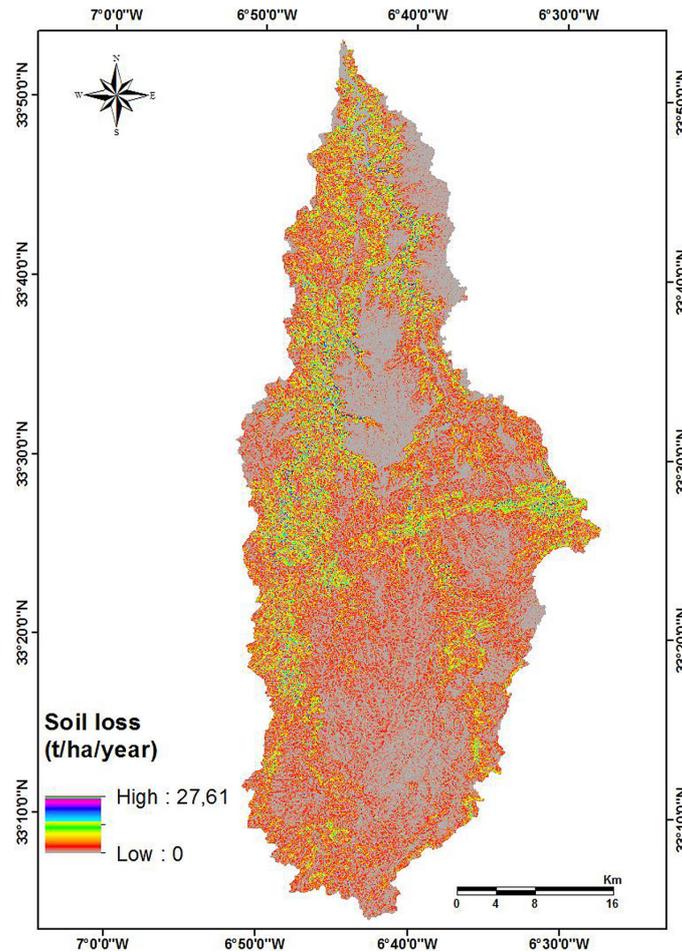


Figure 5. Soil loss map

the state of the different elements responsible for the accentuation of the erosive phenomenon (climate, soil, vegetation and human intervention).

This estimate is based on the combination of geographic information system and remote sensing. But these values must be put in their geographical context to add the values of the SBV belonging to Bouregreg in order to assess the risk of silting of the Sidi Mohamed Ben Abdellah dam and make the best decision of intervention. From all the results obtained, we can deduce the power of GIS tools and spatial remote sensing to better describe the space to facilitate the operation to the decision maker.

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