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Potential soil loss evaluation using the RUSLE/RUSLE-runoff models in Wadi Saida watershed (N-W Algeria)

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Abstract. Soil degradation has become a major worldwide environmental problem, particularly in arid and semi-arid climate zones due to irregular rainfall and the intensity of storms that frequently generate heavy flooding. The main objective of this study is the use of geographic information system and remote sensing techniques to quantify and to map the soil losses in the Wadi Saida watershed (624 km^2) through the revised universal soil loss equation model and a proposed model based on the surface erosive runoff. The results Analysis revealed that the Wadi Saida watershed showed moderate to moderately high soil loss, between 0 and 1000 t/km^2/year. In the northern part of the basin in the region of Sidi Boubkeur and the mountains of Daia; which are characterized by steep slopes, values can reach up to 3000 t/km^2/year. The two models in comparison showed a good correlation with R = 0.95 and RMSE = 0.43; the use of the erosive surface runoff parameter is effective to estimate the rate of soil loss in the watersheds. The problem of soil erosion requires serious interventions, particularly in basins with disturbances and aggressive climatic parameters. Good agricultural practices and forest preservation areas play an important role in soil conservation.

Keywords: RUSLE; RUSLE-runoff; soil loss; GIS; RS; Wadi Saida watershed

1. Introduction

The earthly system faces too many ecological problems that require real attention to ensure the future and sustainability of natural resources. One of the most important natural resources to preserve is the soil, which is an underestimated wealth. The accelerated loss of the arable layer due to the erosion of agricultural land has been recognized as a major threat to the world's soil resources. It is the principal cause of land degradation. Land degradation, loss of soil fertility and siltation of rivers are eco-environmental problems caused by soil erosion (Wang *et al*. 2018). Although, erosion is a physical process. Its global variability and frequency are taken into consideration where it influenced by other elements such as socio-economic, political and institutional factors (Morgan 2005). According to the report of status of the World's Soil

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Resources (2015), the most likely range of global soil erosion by water is 20-30 Gt/year, while erosion by tillage can reach about 5 Gt/year. Between 2000 and 2010, the correlation of land degradation by soil erosion shows that north African countries are the most affected among the studied countries (Wiebe 2003). Algeria is one of the countries most affected by soil erosion. The rate of erosion exceeds 2000 t/km^2/year in most of the watersheds of the Tellian Atlas.

It reaches 4000 t/km^2/year on the Dahra coastal chain and 5,000 t/km^2/year in the much-degraded basin (Remini *et al*. 2003). According to Achite and Ouillon (2016), the analysis of sedimentary transport in Algeria's north-western zone shows increasing values over the past 40 years due to climate change resulting in a change in the hydrological regime. The intensity of water erosion is 26% in the eastern part of the country, 27% in the central and 47% in the western part of the Algerian territory (Hallouz *et al*. 2018). At the watershed level, the two most important hydrological phenomena that can occur from rainfall procedures are surface runoff and soil erosion (Gajbhiye *et al*. 2014, Kayet *et al*. 2018). Physically, soil erosion defined as a detachment and transport of soil materials (Ellison 1947). The mechanical process is caused by the kinetic energy action of runoff, wind speed, morphometric characteristics and other external forces. Soil erosion is defined as the soil sensitivity to erosion process (SSSA 2008). Modelling information like soil type, land use, topography and climate data can provide an opportunity to identify areas affected by soil erosion problems (Doetterl *et al*. 2012, Van Oost *et al*. 2007). There are many models to study the soil erosion. Two of the most widely used models for estimating this phenomenon are: The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) (Wang *et al*. 2018). Six factors are included in the RUSLE model: Rainfall erosivity, soil erodibility, slope length and steepness, vegetation cove and management and supporting practices (Wischmeier and Smith 1949). In this current study, multi-sources data are used to generate the necessary parameters of the RUSLE model. The Soil Conservation Service Curve Number (SCS-CN) model is an empirical model used to estimate runoff. The advantage offered by this model is its simplicity and the diversity of the parameters used reflecting the function of runoff under the hydrological system. In large areas, the application of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques resolve the problem of data access and has allowed for the assessment of soil erosion and spatial distribution due to reasonable costs and greater accuracy.

Different studies have been carried out for the evaluation of the erosive runoff on the watersheds. The runoff considered as an erosion triggering factor. According to Gajbhiye *et al*. (2014), surface runoff and soil erosion are the two significant hydrologic reactions since the rainfall procedures on the watershed systems. This study has shown that a strong relationship between the surface runoff estimation and the sediment yield, which is proportional to the maximum erosion potential. Bui *et al*. (2019) reported a strong relationship between rainfall and surface runoff with R^2 of 0.93. Kayet *et al*. (2018) evaluated the soil losses by the RUSLE model and the SCS-CN method on the hillslope mining areas and he reported that also, there was a significantly strong linear relationship between the soil loss and runoff rates for the different watershed with a correlation coefficient of determination R^2 of 0.81. Gao *et al*. (2012) coupled two models, the first is that of the SCS-CN for the estimation of the surface erosive runoff and the modified RUSLE model to predict runoff events and soil loss resulting from the restoration of undergrowth plots in the Loess plateau in China. The results showed that a better performance of the modified RUSLE model is due to the impact of runoff taken in consideration directly in the modified RUSLE model through the rainfall-runoff erosivity index, and also has the precision deduced from the prediction of the runoff of events achieved by the modified SCS-CN model, gar preventing the ability of the EI_{30} index to predict the erosion of events. In this context, the

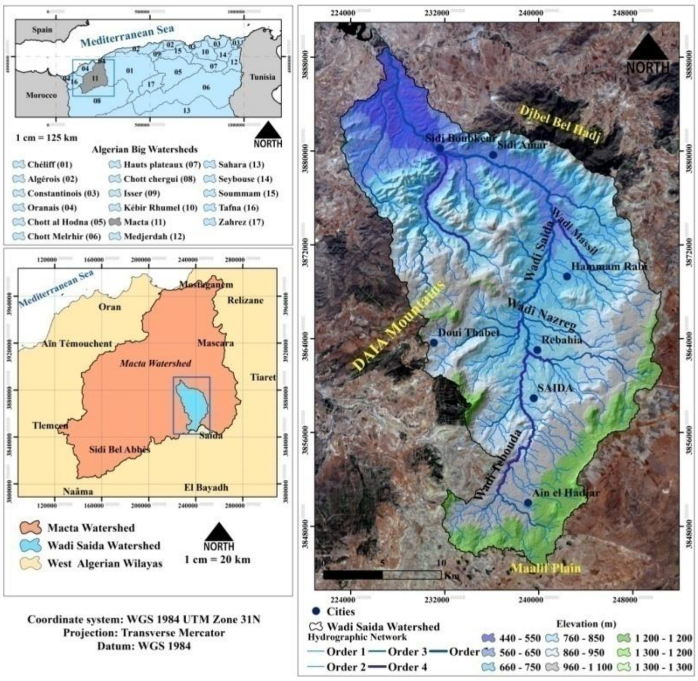


Fig. 1 Study area location

objective of this study is to estimate the potential erosive annual average of the Wadi Saida watershed through the RUSLE and RUSLE-runoff models which is based on estimating surface erosive runoff using the SCS-CN method and evaluating the existing relationship between them.

2. Study area

The Wadi Saida watershed is part of the large basin of Macta indexed according to the National Agency of Hydraulic Resources (NAHR) under code 11-11 with a surface area of 624 km^2. The study zone is located between X = 223 110, X = 250 600 and Y = 3 889 100, Y = 3 844 370 under WGS 84-UTM coordinate system. Located precisely at the southeast of the Macta Basin. It is bounded to the north by the Daia mountains, to the west by mount of Sidi Ahmed Zeggaï and the south by the high plateaus and the Sidi Abdelkader mountain and at the east by the Saida mountains with among others the Djbel Tiffrit at an altitude of 1200 m (Kessar *et al*. 2020) (Fig. 1). The climate of the study area is semi-arid, characterized by two mean seasons in the year. A cold season with an average temperature of 10°C and hot one with an average temperature of 23.8°C. During the winter season, temperatures drop below 0°C, resulting in frost and ice. The study area has quite cold winters and fairly hot summers. According to Yles (2014), the average annual potential evaporation is 835 mm. Rainfall in the Wadi Saida watershed is subject to the influence of two regimes periodically. The first, controlled by the dominant Mediterranean influence with marine entrances causing intense rainfall and the second, characterized by stormy events in the summer. Analysis of the precipitation series of available stations revealed that in the period, from 1976 to 2014, the maximum annual average rainfall value was 516.12 mm and the

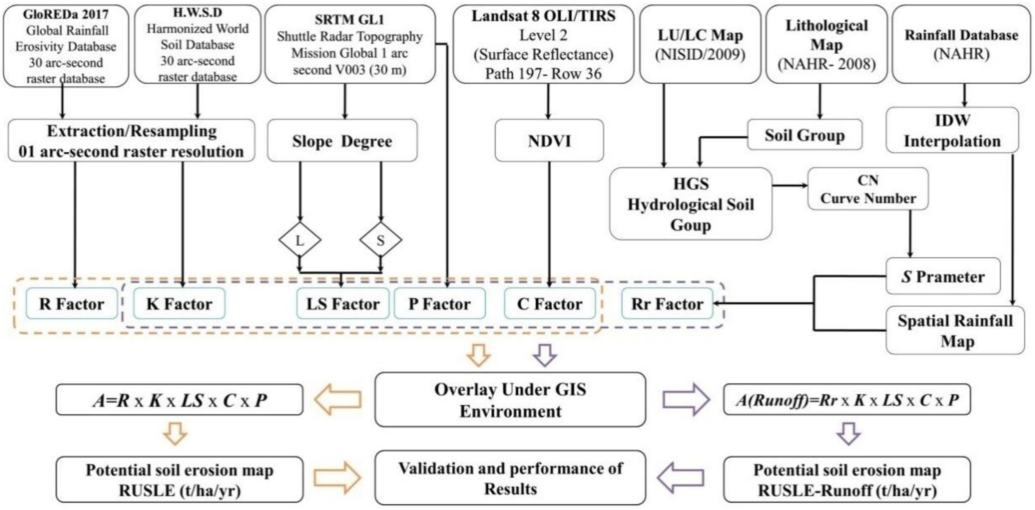


Fig. 2 Flowchart method

lowest record was observed in the PK 50 station at 145.1 mm in 1999. The Wadi Saida valley is characterized by lands of continental origin (fluvial and wind turbines) of often undifferentiated tertiary age: Mio-Pliocene and Quaternary (Kessar *et al*. 2020). The erosion has always been quantified as much as sediment yields on this basin without spatial monitoring of the phenomenon. Accelerated soil erosion is related to excessive runoff caused meanly by anthropogenic practices that destabilize and weaken the soil. The Wadi Saida watershed is subject to acts of overgrazing, deforestation for the satisfaction of domestic needs and the increase of agricultural land, unsuitable cultivation practices, among others, have resulted in an increase in the quantity of material lost from the soil and which ends up in waterways, dam reservoirs, lakes and sedimentation areas.

3. Material and methods

To predict soil erosion, the RUSLE model is used globally as a universal method. Mapping and integrating different parameters in a GIS environment will provide a better visualization and also an effective interpretation of the phenomenon at the spatial scale. Surface erosive runoff is the mechanism carrying particles detached from soils via the kinetic energy of the water flowing after an intense rainfall event. The RUSLE-runoff model is an attempt on our part to incorporate this important factor into the revised universal soil loss equation. Suggesting that the amount of water runoff is the determining parameter that can effectively help us estimate the rate of soil loss, this work will attempt to compare the results obtained according to the overall methodology presented under the following organization chart (Fig. 2).

3.1 Revised universal soil loss equation (RUSLE)

In this study, the RUSLE empirical model was applied, which it is the most used model in the study of soil loss by erosion. This model was developed by Wischmeier and Smith (1958, 1978) and then revised by Renard (1997). The methodology’s organizational chart consists of the creation of five layers that represent the factors of the RUSLE model, written as follows

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

where *A* is the annual soil loss rate (t/ha/year), *R* is the rainfall erosivity factor (MJ mm/ha/h/yr), *K* soils erodibility (t h/MJ/mm), *LS* topographic factor, *C* cover and management factor, and *P* is the anti-erosive practices factor.

3.1.1 Rainfall erosivity factor (R)

Rainfall is a major factor in the erosion. Erosion occurs when rainwater does not seep into the soil (Le Bissonnais *et al*. 2002). The rainfall erosivity factor was developed by Williams and Berndt (1977). Given the unavailability of the rainfall data required to calculate the *R* factor. We used the global rainfall erosivity map to extract the *R* map of Saida watershed. The global rainfall erosivity map was created using 3625 stations covering 63 countries around the world (Panagos *et al*. 2017). For Algeria, data from 120 stations covering 27-year period (1977-2004) was used. Rainfall erosivity (EI_{30}) was calculated on the basis of the following equations

$$EI_{30} = \left(\sum_{r=1}^{k} e_r v_r\right) I_{30} \tag{2}$$

where e_r represent the rainfall energy unit (MJ/ha/mm) and v_r is the rainfall volume (mm) through a rainfall event divided in k fractions. I_{30} is the maximum of 30-minutes rainfall intensity (mm/h). The rainfall energy unit e_r is calculated for each time period as follows (Brown and Foster 1987)

$$e_r = 0.29\left[1 - 0.72e^{(-0.05i_r)}\right] \tag{3}$$

where i_r represent the rainfall intensity during the time period (mm/h).

$$R = \frac{\sum_{j=1}^{n} \sum_{k=1}^{m_j} (EI_{30})_k}{n} \tag{4}$$

which *n* is the recorded years number, m_j represent the erosive events number in a given year *j*. *k* is the single event index of a corresponding erosivity EI_{30}. The spatial model of the global rainfall erosivity is derived using Gaussian Process Regression (GPR) (Williams and Rasmussen 2006, Stein 2012). GPR is a non-linear regression function; where inputs are projected using basis functions in higher-dimensional space. From a projection of the original input space, the GPR uses the kernel expansion $\emptyset$ to transform into a feature space according to the following expression (Panagos *et al*. 2017).

$$f(x) = \emptyset(x)^T \tag{5}$$

3.1.2 Slope length and steepness factor (LS)

The topographical factor (*LS*) is an important parameter. It represents the combination between two parameters; the first is slope (*S*) and the second is slope length (*L*). Remote sensing data such as the Digital Elevation Model (DEM) are easily accessible for slope characteristic analysis, which mainly affects the soil loss in the area and can be used effectively to enable rapid and detailed risk assessment (Patil *et al*. 2015, Gelagay and Minale 2016). We used the SRTM GL1 (Shuttle Radar Topography Global Mission 1arc second V003) (NASA 2015) downloaded from NASA’s website (http://earthexplorer.usgs.gov) to generate the slope map. According to Wischmeier and Smith (1978), the *LS* factor is calculated as follows

$$LS = \left(\frac{L}{22.13}\right)^{m} \times (0.065 + 0.045 \times S + 0.0065 \times S^{2}) \tag{6}$$

where *L* is the slope length in *m*, *S* is the steepness of the slope in percent, *m* is a parameter such that $m = 0.5$ if the slope is > 5%, $m = 0.4$ if the slope is 3.5-4.5%, $m = 0.3$ if the slope is 1-3% and $m = 0.2$ if the slope is < 1%. This equation was designed for areas that represent regular slopes, which is not the case for our study area; for the irregular slope, McCool *et al.* (1987) proposed the following formula

$$\text{If } \tan\theta < 0.09\% \quad S = 10.8 \sin\theta + 0.03 \tag{7}$$

$$\text{If } \tan\theta > 0.09\% \quad S = 16.8 \sin\theta - 0.50 \tag{8}$$

For the slope length (*L*), Desmet and Govers (1996) proposed an alternative formula

$$L = \frac{((A + D^{2})^{m+1} - A^{m+1})}{D^{m+2} \times x^{m} \times (22.13)^{m}} \tag{9}$$

$$m = \frac{F}{F + 1} \tag{10}$$

$$F = \frac{Sin\theta}{0.0896 \times (3 \times Sin\theta^{0.8} + 0.56)} \tag{11}$$

where θ is the pixel slope in radian (multiplied by 0.01745 for the conversion from the degree), *A* is the flow accumulation at a given pixel, *D* is the size of the pixel (30 m in our case), *m* is the exponent of the slope length and *x* is the pixel shape coefficient = 1.

3.1.3 Slope erodibility factor (K)

Factor *K* refers to the soil erodibility, in other words, the soil resistance against the force of raindrops, runoff or both (Djoukbala *et al.* 2018). For this factor, we need four essential parameters: the fractions of silt, sand, clay and the organic matter as a percentage, the first three parameters represent the soil texture and the fourth represents the biological activity in the soil. We used the new version 1.2 of the Word Harmonized Soil Database (HWSD) to determine the soil parameters required to determine the *K* factor in our study area. She was created and performed by the Food and Agriculture Organization (FAO) of the United Nations in collaboration with IIASA (The International Institute for Applied Systems Analysis), ISRIC-World Soil Information, Institute of Soil Science, ISSCAS (Chinese Academy of Sciences) and the European Commission’s Joint Research Centre (JRC). We used the following formulas proposed by Neitsch *et al.* (2011)

$$K = K_{w} = f_{c.sand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \tag{12}$$

where f_{csand} is a factor, that lowers the *K* display in soils with high coarse-sand content and higher for low-sand soils; f_{cl-si} gives low soil erodibility factors for soils with high clay/silt ratios; f_{orgc} decreases *K* values in soils with higher organic matter content; f_{hisand} lowers *K* values for soils with extremely high sand content.

$$f_{csand} = \left(0.2 + 0.3 \times exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \tag{13}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right) \tag{14}$$

$$f_{csand} = \left(1 - \frac{0.25 \times ogrC}{orgC + exp[3.72 - 2.95 \times orgC]}\right) \tag{15}$$

$$\mathrm{f_{hisand}} = \left(1 - \frac{0.7\ \times \left(1 - \frac{\mathrm{m_s}}{100}\right)}{\left(1 - \frac{\mathrm{m_s}}{100}\right) + \exp\left[-5.51 + 22.9\ \times \left(1 - \frac{\mathrm{m_s}}{100}\right)\right]}\right) \tag{16}$$

3.1.4 Vegetation cover and management factor (C)

Considered as the second most important factor after the topography (Koirala *et al*. 2019), the cover-management factor is used to showing the effect of vegetation cover, ground vegetation and management practices on erosion rates. Indeed, a dense plant cover is all the more effective in reducing erosion by dissipating the energy of raindrops, slowing the water flow on the soil surface and maintaining good surface porosity by avoiding surface inlays (Roose 1996, Sabir and Roose 2004, Ouallali *et al*. 2016). The development of remote sensing techniques and the analysis of satellite imagery have helped to determine of this parameter specifically for the large areas studied. Among these techniques, the determination of factor *C* using the Normalized Difference Vegetation Index (NDVI). Van der Knijff *et al*. (2000) generated an exponentially decaying relationship between NDVI and *C* factor after observing that the variation was not linear but she reduces exponentially with NDVI (Ghosal and Bhattacharya 2020) (Eq. (17))

$$C = exp\left[\frac{-\alpha NDVI}{\beta - NDVI}\right] \tag{17}$$

where *C* is the crop management factor; NDVI = (R5 − R4)/(R5 + R4); α and β are constants (α = 2 and β = 1) (Van der Knijff *et al*. 2000). The individual values of *C* vary between 0 for a completely non-erodible condition, to a value somewhat greater than 1.0 (Renard *et al*. 2011), the NDVI result in this study of Landsat 8, the Operational Land Imager (OLI)/Thermal Infrared Sensor image (TIRS) (surface reflectance) (LC08197036201908230IT1).

3.1.5 Support practice factor (P)

By definition, the *P* factor is the ratio between the soil loss under a specific support practice like contour farming, tillage and fertility treatments and also according to the soil loss under cultivated land on an ascending or descending slope. The *P* factor reflects the effects of implementations that will reduce the rate and amount of runoff, which means reducing the rate of erosion (Ghosal and Bhattacharya 2020). In the absence of erosion control practice, *P* = 1.0 over contouring and cutting into contour strips and vary with the slope steepness and to calculate the *P* factor we used the equation developed by Wener (1981), the formula produces a linear relation between slope (*S*) of the area and the amount of conservation practice (*P*). This equation was used in many previous researches like Lufafa *et al*. (2003), they used this equation in a study on Lake Victoria basin in Kenya and Fu *et al*. (2005), and they used this formula in Yanhe watershed in

China.

$$P = 0.2 + 0.03 \times S \tag{18}$$

where P is amount of conservation practice and S is the percentage of slope

3.2 RUSLE-Runoff model

This model consists assesses the rate of erosion by substituting the R-factor usually used in the RUSLE model with the proposed R-factor based on the calculation of surface erosive runoff. The following hydrologically describes the rate of water runoff on a watershed and from a hydrological perspective; it is a determining parameter of water erosion. In terms of our research, erosive runoff is calculated from the SCS-CN method based on the water balance. The others factors used are the same as the Eq. (19). The proposed model is written as follows

$$A = R_r \times K \times LS \times C \times P \tag{19}$$

3.2.1 Surface erosive runoff factor (R_r)

SCS-CN method: Surface runoff is the term used to refer to the flow of excess water through the surface of the earth. The runoff curve number (CN) is an empirical parameter used in hydrology for figuring runoff (Kayet *et al.* 2018). The Soil Conservation Service Curve Number (SCS-CN) method (SCS 1956) is based on the principle of water balance Eq. (20) and two fundamental assumptions (Mishra and Singh, 2007, Gao *et al.* 2012). The first hypothesis suggests that the proportion of direct runoff to maximum potential runoff is equivalent to the proportion of infiltration to maximum potential retention. The second one states that the initial abstraction is proportional to the maximum potential retention (Gao *et al.* 2012)

$$P = I_a + F + R_r \text{ (Water balance equation)} \tag{20}$$

$$\frac{R_r}{P - I_a} = \frac{F}{S} \tag{21}$$

where P is the annual total precipitation in mm, I_a the initial abstraction refer to all losses before runoff beginning in mm, F the cumulative retention in mm, R_r the direct runoff (mm) which is considered us the surface erosive runoff, S the maximum potential retention or infiltration (mm), and λ the initial abstraction coefficient (0.2) which is dependent on region geology and climatic factors.

$$I_a = \lambda\, S \text{ (Initial abstraction and potential maximum retention hypothesis)} \tag{22}$$

From the previous Eqs. (21) and (22), the SCS-CN formula can be calculated as following

$$\frac{R_r}{P - I_a} = \frac{P - I_a - R_r}{S} \tag{23}$$

$$R_r = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{where } P > I_a \tag{24}$$

I_a was found to be approximated by the following empirical equation.

$$I_a = 0.2S \tag{25}$$

$$R_r = \frac{(P - 0.2S)^2}{(P - 0.8S)} \tag{26}$$

S depends on the geology of the study area, land use and the nature of the plant cover, as well as previous moisture conditions. The formula proposed by the SCS makes it possible to calculate the value of S using the runoff parameter CN (curve number).

$$S = \frac{25400}{CN} - 254 \tag{27}$$

where CN is a non-dimensional value that varies between 0 and 100 and determined from the standard SCS-CN table (Cronshey 1986). Based on land use, Hydrological Soil Groups (HSG), and Antecedent Moisture Condition (AMC) (Blissag 2020). In our case, AMCII antecedent moisture condition are chosen as reference. As a result of urbanization, the soil profile may be significantly altered and the group classification may no longer apply. Under these circumstances, use the following to determine the HSG based on the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls 1983). Four groups (A, B, C and D) of HSG are derived from soil texture classes according to their minimum infiltration rate (Table 1). In our case we have used the lithologic map of the study area to extract the soil type. As a reference, more detailed descriptions of CN represent the average prior runoff conditions for urban, cultivated agricultural, agricultural and other arid and semi-arid rangelands (Cronshey 1986).

Combining and integrating data into GIS environment allows generating Hydrologic Group Soil (HGS) map by merging two maps data, that of the land use and the litohologic map (Figs. 9 and 10). Finally, the following layers: HSG and the CN table tributary to each soil hydrological group are used to generate the spatial model of the CN in a grid map.

3.3 Performance evaluation of RUSLE/RUSLE-Runoff models

For testing the performance of the results obtained from the proposed model (RUSLE-runoff), a statistical approach is adopted which aims to verify the error between the results of the classic erosion model (RUSLE) and the modified model (RUSLE-runoff) applied to the Wadi Saida watershed. At the spatial level, a sampling in the form of a dot grid is used to extract the values of soil losses pixel by pixel. The database is exported to Excel to complete the statistical analysis. The RMSE, Eq. (28) is used as the main test to validate the results, it represents the absolute fit of the model, and that means how close the observed values are to the predicted values of the model; other tests like mean absolute percentage error (MAPE) Eq. (29), mean squared error (MSE) Eq. (30) which is related directly to RMSE and the mean absolute error (MAE) Eq. (31) are also applied to increase the occurrence of the check process.

Table 1 HSG based on Cronshey (1986) classification

HSG	Soil texture
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clayey loam, silty clay loam, sandy clay, loamy clay or clay

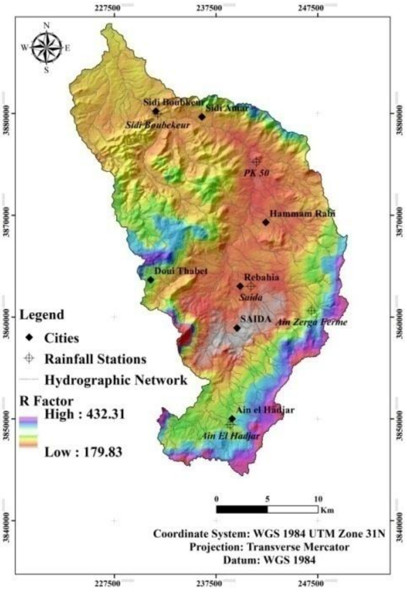


Fig. 3 Erosivity factor (*R*) map

In hydrological modelling, Moriasi *et al*. (2015) indicated that the coefficient of determination (R^2) and the coefficient of variation (r) are used widely for the evaluation of the performance of the relationships between the observed and estimated values of models. The gradient must be close and must exceed 0.6 on annual measurements for it to be acceptable (Krause *et al*. 2005). Considered as a very good agreement, the R^2 must be superior to 0.8, while $R^2 \leq 0.4$ indicates that the relationship is unsatisfactory. It is also known and accepted that the lower values of RMSE represent the better satisfaction of the used model. Signh *et al*. (2004) reported that the closer the values of RMSE and MAE are to zero, the better the fit between the observation and estimation models

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(A_{RUSLE} - A_{RUSLE-Runoff})^2}{n}} \tag{28}$$

where A_{RUSLE} = the soil loss value calculated from RUSLE model and $A_{RUSLE-Runoff} =$ is soil loss calculated from RUSLE-Runoff model, n is the number of grid point extracted from the raster file of spatial distribution of each model.

$$MAPE_{Average} = \left|\frac{\sum_{i=1}^{n}(A_{RUSLE} - A_{RUSLE-Runoff})}{\sum_{i=1}^{n} A_{RUSLE}}\right| \times 100 \tag{29}$$

$$MSE = \frac{\sum_{i=1}^{n}(A_{RUSLE} - A_{RUSLE-Runoff})^2}{n} \tag{30}$$

$$MAE = \frac{\sum_{i=1}^{n}\left|(A_{RUSLE} - A_{RUSLE-Runoff})\right|}{n} \tag{31}$$

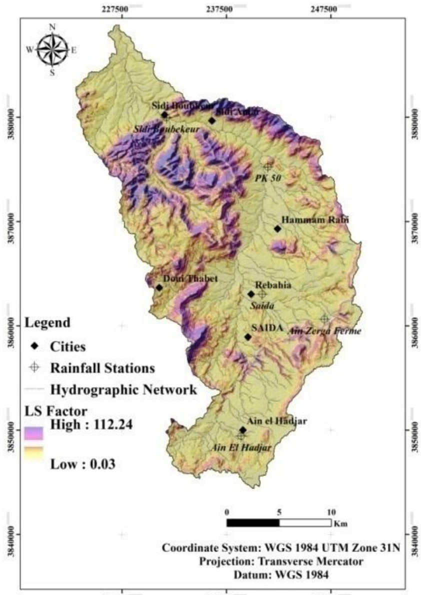


Fig. 4 Slope length and steepness factor (*LS*) map

The coefficient of determination (R^2) between the soil loss values from RUSLE model and predicted values from the proposed model RUSLE-runoff is used the validation. The coefficient of determination (R^2) is calculated using the following equation.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (A_{RUSLE} - A_{RUSLE-Runoff})^2}{\sum_{i=1}^{n} \left(A_{RUSLE} - \left(\frac{1}{n} \sum_{i=1}^{n} A_{RUSLE} \right) \right)} \tag{32}$$

4. Results and discussion

4.1 Rainfall erosivity factor (R)

The erosivity factor map extracted from the global rainfall erosivity map (Panagos *et al*. 2017) shows that the value of the *R* factor in the Saida watershed varies from 179 to 432 (MJ mm/ha/h/year). The highest values are observed in the peripheral areas of the watershed and more precisely the southern part of Ain el Hadjer, north of Doui Thabet and towards the region of EL Hssasna with values ranging from 350 to a maximum of 432 (MJ mm/ha/h/year). These regions are higher compared to the Wadi Saida valley whose values are minimal with less than 200 (MJ mm/ha/h/year) (Fig. 3).

4.2 Slope length and steepness factor (LS)

The topographical factor directly affects the values of the *LS* factor. The more the topography of the area has steep slopes the more the *LS* values increase and vice versa, in the Wadi Saida

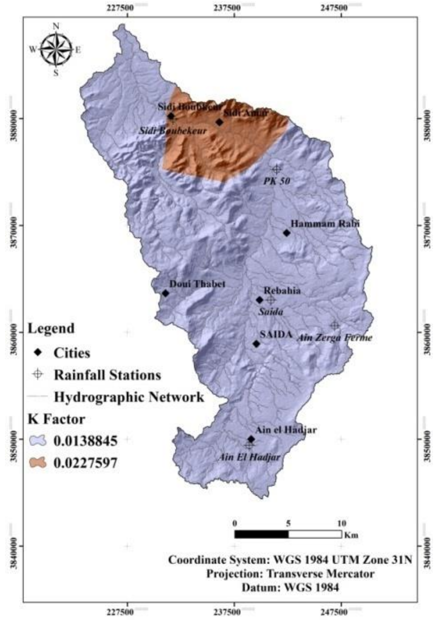
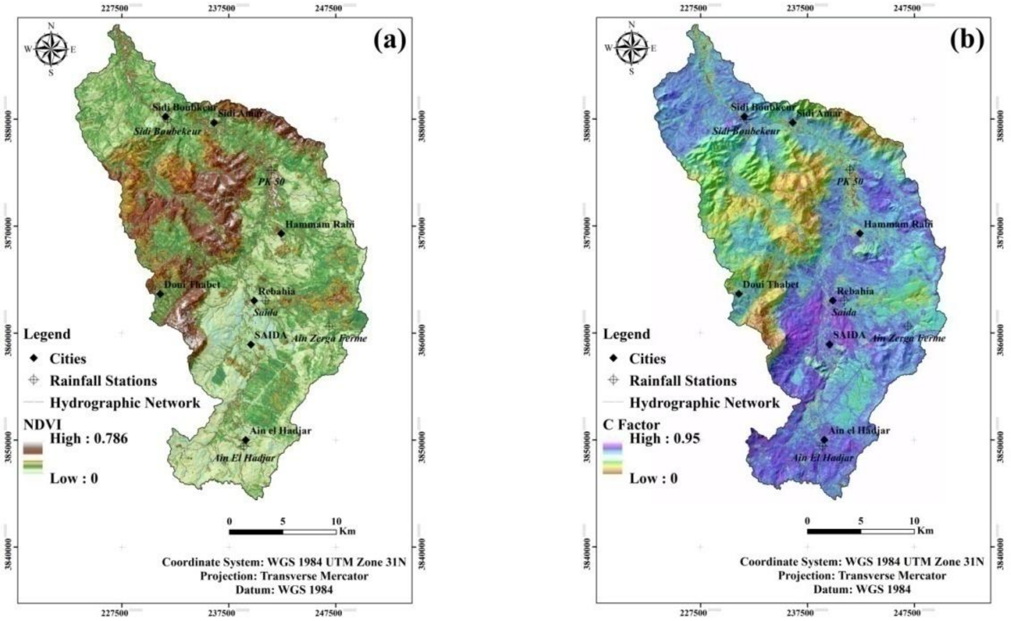


Fig. 5 Soil erodibility factor (*K*) map



(a) NDVI (b) *C*-factor

Fig. 6 NDVI map and vegetation cover and management factor *C* map

watershed the *LS* values vary between 0.03 and 112. High records are observed on steeply sloping areas, including the eastern part of the Daia mountains and the western part of Djbel Bel Hadj as well as the south-eastern part of Doui Thabet. The narrower the slope is over the Boundaries of the

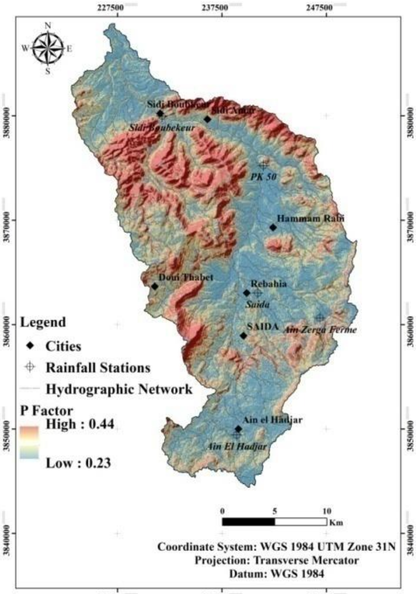


Fig. 7 Support practice factor (P) map

Saida valley and the southern part of the watershed in the border areas of the steppe region (Fig. 4).

4.3 Soil erodibility factor (K)

The erodibility factor (K) is extracted for the Wadi Saida watershed from the Harmonized World Soil Database (HWSD) and two groups of soil types are identified: The first is Cretaceous limestone and marl indexed under the code Bk2-2a and the second the Calcaric Fluvisoils indexed under the code Jc14-2a. Factor K values are respectively ($K = 0.0138$ and 0.0227) (Fig. 5).

4.4 Vegetation cover and management factor (C)

Based on the Eq. (17), the processing of remote sensing data (Landsat 8 OLI/TIRS- Level 2 Surface Reflectance) led us to calculate the normalized difference vegetation index (Fig. 6(a)) that allowed us to map the spatial distribution of C factor. The latter oscillates in the Wadi Saida watershed between 0 and 0.95 which implies a variability of plant cover. High values of the factor C indicate the occurrence of vegetation cover associated with poor practices. While, a low C-factor values of implying good management and anti-erosive practice in the watershed which visible on the surfaces with high NDVI values representing forest cover area (Fig. 6(b)).

4.5 Support practice factor (P)

Land management and agricultural practices influence soil erosive capacity and in combination with slope. These practices can play a triggering or dampening role in the phenomenon of water erosion. Steeply sloping areas are more exposed to water erosion compared to low-slope areas.

Table 2 Classification of hydrological soil group

HSG	Area (km^2)	Percentage %
A	90.31	14.38
B	130.42	20.76
C	337.97	53.81
D	69.43	11.05

While managing slopes through good conservation practices significantly reduces the aggressiveness of erosion, the values of *P* factor in the Wadi Saida watershed are between 0.23 and 0.44. However, the steeply sloped areas such as the Daia and Djbel Belhadj mountains record high values of *P* compared to the Saida valley and north part of Sidi Boubkeur (Fig. 7).

4.6 Surface erosive runoff factor (R_r)

For the HSG, the studied basin is subject to the four hydrological group with a different percentage (Fig. 8(b)). The Group C occupies almost the entire area with 337.97 km^2 or 53.81% of the total area followed by Group B with 130 km^2 or 20.76%, Groups A and D came last with 90 km^2 and 69.43 km^2 respectively which represent 14.38 and 11% (Table 2). For each land use class, the spatial distribution percentage of HSG and corresponding CN value are presented in Table 2 (Fig. 8(c)).

Land use categories in the study area are classified as shows at Fig. 9. The classes buildings and bare land occupy less than 3% of the watershed, the class of vegetation with 61% and the forest classes (open forest, brush and dense forest) with a total of 36.34% (Table 3), the Wadi Saida watershed shows that a large part of the area is covered either by vegetation (these are usually agricultural areas), or by different types of forests, particularly in foothills and high altitudes zones (Fig. 8(a)).

4.7 Estimate of potential soil erosion

4.7.1 RUSLE model

The use of the GIS environment and remote sensing techniques allowed us to analyze the spatial distribution of water erosion rates in the Wadi Saida watershed through the RUSLE model. The results showed that the area is generally marked by a moderate to high soil losses rate with values ranging from 0 and 30 t/ha/year. The average estimate map of potential erosion by the RUSLE model revealed that the northern part of the watershed is much more affected by soil loss than the southern part. According to the potential soil erosion map (RUSLE model) (Fig. 9); this is probably due to the areas of steep slopes and low vegetation cover and management factor values shown in (Fig. 6(b)). According to the results presented at the Table 4, for the RUSLE model, about 99% of the area of the basin is marked by soil loss values between 0 and 1,000 t/km^2/year, while about 1% of the areas show a loss between 1,000 and 3,000 t/km^2/year representing only 6.32 km^2 of the total area of the basin, the class between 0 and 200 t/km^2/year represents 481 km^2 (77%) of the total study area succeeded by the erosion class between 200 and 500 t/km^2/year which represents less than 99 km^2 (16%). However, the middle erosion class does not exceed 6% between 500 and 1,000 t/km^2/year. This can be explained by the geomorphological variability of

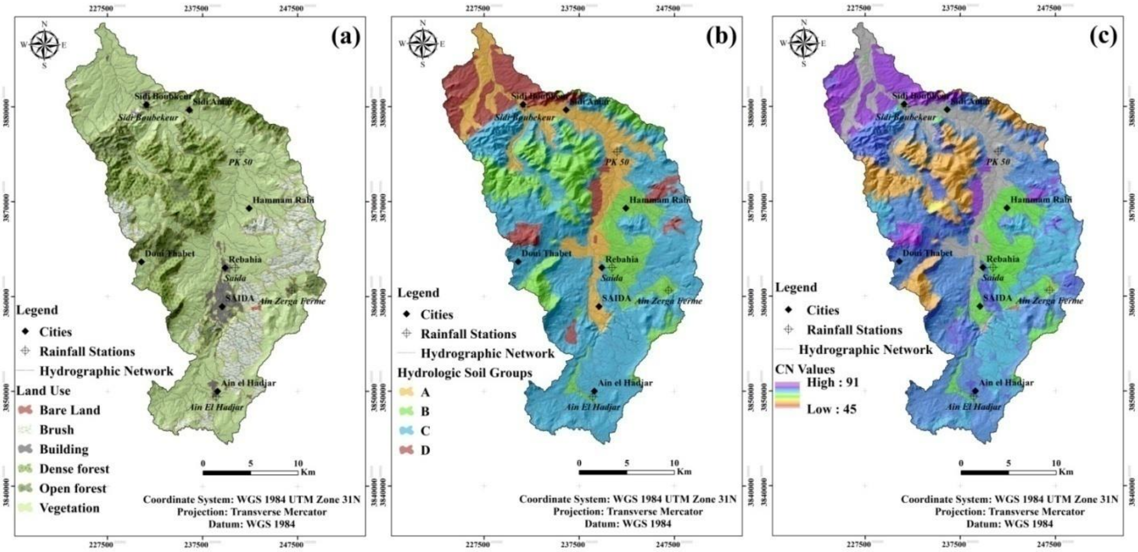
Table 3 Hydrological soil groups characteristics and the curve number values according LU/LC classes

LU/LC classes	LU/LC area (km^2)	Percentage (%)	HSG	CN (AMC II)	Area (km^2)	Percentage (%)
Buildings	16.30	2.59	A	66	7.46	1.188
			B	74	0.37	0.059
			C	80	7.84	1.249
			D	82	0.62	0.099
Bare land	0.41	0.06	A	/	/	/
			B	68	0.04	0.007
			C	91	0.36	0.058
			D	/	/	/
Vegetation	383.13	61.00	A	45	82.24	13.094
			B	66	47.29	7.528
			C	77	198.54	31.608
			D	83	55.06	8.766
Brush	86.39	13.75	A	48	0.14	0.023
			B	66	4.69	0.747
			C	74	74.37	11.839
			D	79	7.19	1.145
Open forest	63.80	10.16	A	51	0.46	0.074
			B	68	1.41	0.224
			C	79	55.37	8.815
			D	84	6.55	1.043
Dense forest	78.11	12.44	A	/	/	/
			B	55	76.62	12.198
			C	70	1.49	0.238
			D	/	/	/

land in the narrow steep slope watershed underlying the Saida valley. Moderate to intense erosion occurs in the foothills of the Daia and Djbel Belhadj mountains. Large amount of soil carried settling on the wadi valley creating flooding on cities due to the nature of the stormy rains that characterize the region at the end of the summer or winter period. Irregular rains cause soil particles detachment by splashing and especially after dry periods, which are widespread in the region (Fig. 9).

4.7.2 RUSLE-Runoff model

The modified RUSLE-Runoff model is based on the proposal to use surface erosive runoff as a replacement factor for the rainfall erosivity factor used in the regular RUSLE model. The results revealed that this factor plays an important role in the phenomenon of soil loss. From the map, we found that the results are almost identical to those of the map produced by the RUSLE model and that the rate of soil loss varies between 0 and 3,000 t/km^2/year in the Wadi Saida basin. The class



(a) LU/LC (b) HSG (c) CN

Fig. 8 Land use/land cover map (modified from NISID (2009), HSG map and the spatial distribution of CN

Table 4 Soil loss classes characteristics for the two models (RUSLE/RUSLE-runoff)

Soil loss class RUSLE model (t/ha/year)	Area (km^2)	Percentage (%)	Soil loss class RUSLE-runoff model (t/ha/year)	Area (km^2)	Percentage (%)
0-2	481.13	77.23	0-2	500.60	80.35
2-5	98.92	15.88	2-5	93.92	15.08
5-10	36.58	5.87	5-10	25.57	4.10
10-30	6.32	1.01	10-30	2.91	0.47

properties of this model show roughly the same trends as the conventional model. The very low class of soil loss by erosion between 0 and 200 t/km^2/year presents 500 km^2 (80%) of the total area of interest zone. The second class of low soil loss represent 93.32 km^2 (15%). 25.57 km^2 which is (4%) from the studied area is exposed to a moderate soil loss between 500 and 1,000 t/Km^2/year. The very high soil losses due to erosion represent only 2.91 km^2 or even 0.5% reaching 1,000 t/km^2/year (Table 4). The southern part of Sidi Boubkeur is much more affected compared to the rest of the basin as well as the southern area of Doui Thabet, and more or less on the high altitude regions of Hammam Rabi, the area of Ain Zerga and the south of Ain el Hadjar. The soil lost and transported by the hydrographic stream accumulates in the main tributary of Wadi Saida to the north; the water laden with soil particles loses kinetic energy as it reaches the valley, where the slope weakens (Fig. 10). The achieved results recently by studies carried out on different watersheds in Algeria by the RUSLE model citing; Mostephaoui *et al*. (2013), Benchettouh *et al*. (2017), Bouhadeb *et al*. (2018), Toubal *et al*. (2018), Djoukbala *et al*. (2018), Neggaz and Kouri (2018), Chikh *et al*. (2019), Sahli *et al*. (2019), Mihi *et al*. (2020) and Khanchoul *et al*. (2020) have revealed that most watersheds are subject to an average or a high erosion pressure, where the rate of soil loss ranges globally between 2 and 10 t/ha/year, and which can go up to 20 t/ha/year, with a spatial average of 7 and 8 t/ha/year. The areas vulnerable to soil loss by water erosion are

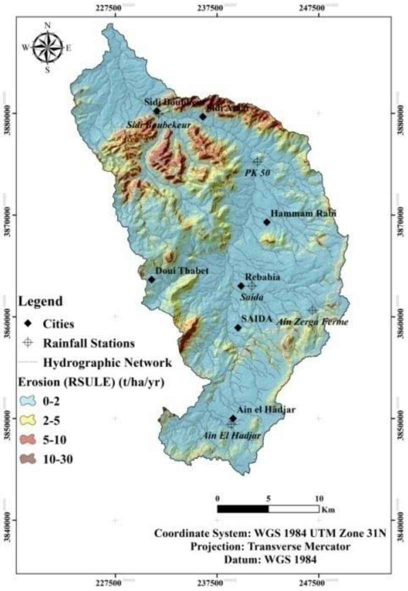


Fig. 9 Potential soil erosion map (RUSLE model)

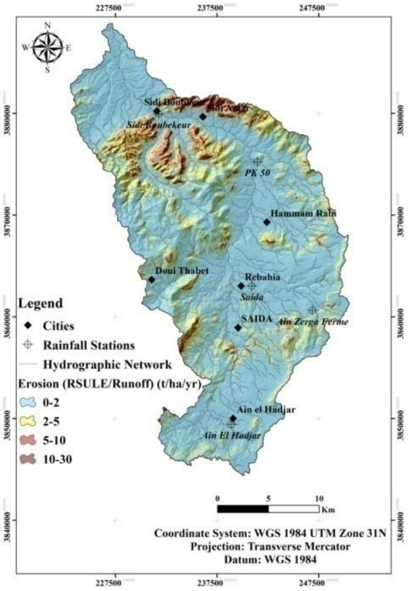
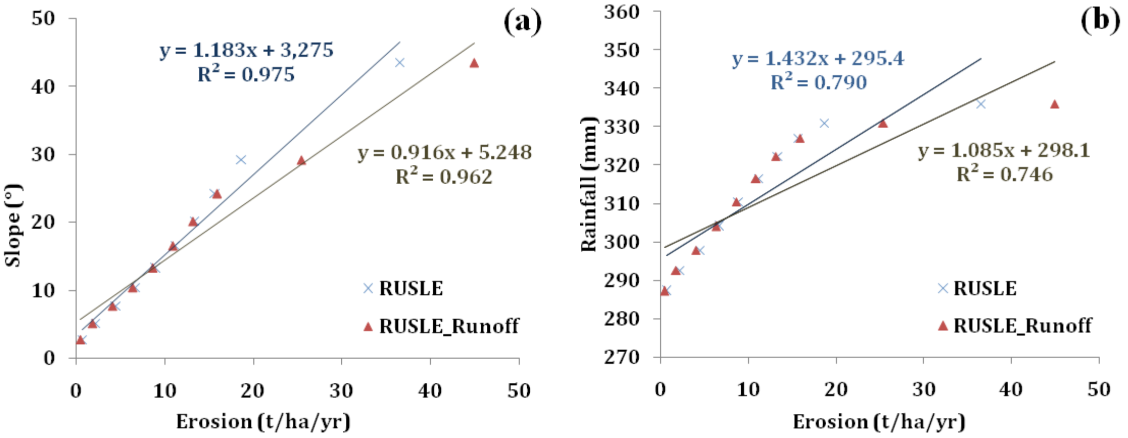


Fig. 10 Potential soil erosion map (RUSLE-runoff model)

those exposed to a strong rainfall accommodated by rather severe slopes, the results of the authors cited above confirm those concluded on Wadi Saida watershed.

4.8 Validation and performance evaluation of results

The correlation between slope class values based on erosion by the two models shows a strong



(a) Slope/erosion (b) Rainfall/erosion

Fig. 11 Relationship between soil loss by erosion and slope degree classes diagram and the relationship between soil loss by erosion and rainfall classes diagram

relationship between slope degree and erosion soil loss rate. Thus, as the degree of slope increases, so does the amount of soil loss is great in the Wadi Saida watershed. The determination coefficient shows a very strong relationship between these two variables for the two models with R^2 = 0.975 for the RUSLE model and R^2 = 0.962 for the RUSLE-Runoff model (Fig. 11(a)). The slope gradient strongly controls the rate of soil loss in the basin. Rainfall is an extremely important parameter in surface flow events in watersheds. It controls the amount of particles detached and transported by surface runoff to the outlet. So therefore, it represents a function dependent on erosion. The correlation between the classes of these two parameters in the Wadi Saida watershed also shows a strong correlation that is demonstrated by the value of the coefficient of determination which is of the order of R^2 = 0.790 for the RUSLE model and R^2 = 0.746 for the RUSLE-runoff model (Fig. 11(b)).

The correlation between soil loss the values according the classic RUSLE model and the modified RUSLE-runoff model shows that the integration of the surface erosive runoff as a factor instead of the rainfall erosivity factor yields very good results: The Pearson *R* coefficient is 0.956 and the R^2 determination coefficient is 0.915 (Fig. 12). The spatial distribution and the analysis of the data extracted from the two maps allow the correct diagnosis of the values obtained, the root mean square error RMSE = 0.437, the mean absolute error MAE = 0.25, the mean squared error MSE = 0.553 and the mean absolute percentage error MAPE = 0.007.

Therefore, the rainfall and slope factors have a direct connection to soil loss in the Wadi Saida watershed. Areas influenced by steep-slope and weak vegetation caver and management actions are the most vulnerable to the erosion. The soil surface strongly exposed to the kinetic energy of runoff. Since the study area is subject to intense and torrential rainfall characterizing semi-arid regions, precipitation has a direct influence on the origin of erosion in combination with other factors such as the vegetation cover which takes the role of protecting the topsoil. The low values of the RMSE indicates that the difference between the values observed by the RUSLE model and estimated by the modified RUSLE-runoff model is minimal, which implies that the use of the surface erosive runoff which takes into account the hydrological state and land use instead of the rainfall erosivity factor is effective on the Wadi Saida basin. The difference between values of the

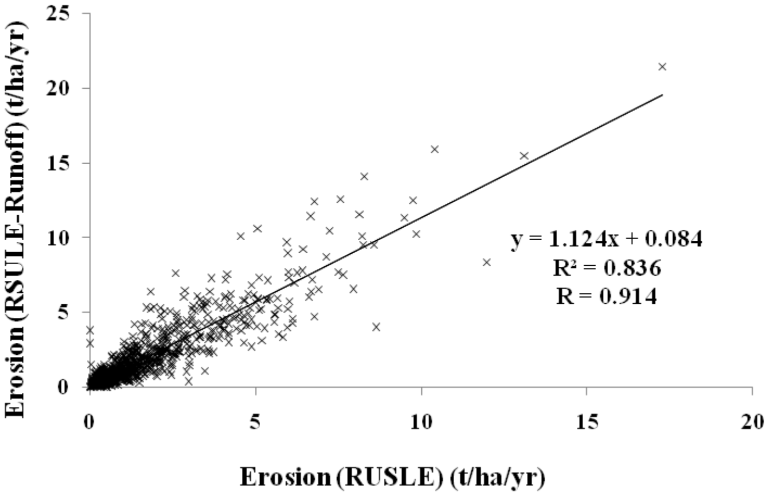


Fig. 12 Relationship between potential soil loss by RUSLE and RUSLE-runoff models

RMSE and the MAE indicates a small variation in the magnitude of the errors interpreted by the good relationship between the two models. A well-correlated linear relationship is noticeable between the two models, with values of $R^2 > 0.8$ indicating a very good performance between the two models in the study area. The erosion on the Wadi Saida basin is subjected to the pressure of the surface runoff generating the intensity of precipitation (high intensity/short duration).

5. Conclusions

The application of remote sensing (RS) techniques and geographic information systems (GIS) in environmental studies has become a trend that yields good results in terms of analysis and effectiveness of results obtained, not to mention the ease of study in large areas such as watersheds. The use of these approaches for the study of soil loss by water erosion in Wadi Saida watershed has made it possible to recognize and compare the application of two models that are based on the combination of several influence factors. Spatial variability offers the privilege of access to difficult areas of study and even offers a generalized global visualization of the phenomenon.

The spatial distribution and analysis of the data extracted from the two maps of the erosion potential by the classical RUSLE model and the modified RUSLE-Runoff model lead us to see that certain factors have a significant influence on the results. The slope gradient and the runoff volume calculated from precipitation (rainfall erosivity) and by erosive surface runoff lead to roughly the same conclusion. Cultivation practices and the state of soil cover play an important role in exacerbating the erosion process.

In conclusion, the analysis of the two models on the Wadi Saida watershed revealed that moderate to high soil loss is observed in the basin with local variation of values. Soil loss rates range from 0 to 1,000 t/km^2/year in most of the watershed and can reach 3,000 t/km^2/year on steeply sloping parts to the north. This side hydrologically represents the outlet of the basin which is much more affected than to the south. The presence of a large part of the forest on the Doui

Thabet side and the Daia mountains means that erosion is low in some areas. The appropriate application of agriculture practices in the valley can protect the soil during stormy rains. The result of this study will enable field engineers and decision makers to manage the necessary field specific procedures to protect areas primarily influenced by soil erosion.

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