www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2021, No. 48 (I–III): 205–214; https://doi.org/10.24425/jwld.2021.136163

Available (PDF): https://www.itp.edu.pl/JWLD; http://journals.pan.pl/jwld

Received 12.03.2020
Reviewed 07.05.2020
Accepted 10.06.2020

Using RUSLE and GIS for the soil loss assessment in arid regions: The case of the Ain Sefra catchment in the Ksour Mountains, Algeria

Ahmed MELALIH [1), 3)] ✉, **Mohamed MAZOUR** [2), 3)]

1) Abou Bakr Belkaïd University, Faculty of Natural and Life Sciences and theUniverse, BP 230, New campus, Tlemcen, 13000 Algeria
2) University Center of Ain Temouchent Belhadj Bouchaib, Institute of Science and Technology, Ain Temouchent, Algeria
3) University Center of Ain Temouchent Belhadj Bouchaib, Laboratory of Applied Hydrology and Environment (LHYDENV), Ain Temouchent, Algeria

For citation: Melalih A., Mazour M. 2021. Using RUSLE and GIS for the soil loss assessment in arid regions: The case of the Ain Sefra catchment in the Ksour Mountains, Algeria. Journal of Water and Land Development. No. 48 (I–III) p. 205–214. DOI: 10.24425/jwld.2021.136163.

Abstract

The loss of soil quality due to erosion is a global problem, particularly affecting natural resources and agricultural production in Algeria. In this study, the Revised Universal Soil Loss Equation (RUSLE) is applied to estimate the risk of water erosion in the Ain Sefra arid watershed (Algeria). The coupling of this equation with Geographic Information Systems (GIS) allows to assess and map the soil loss rates. The land erosion is influenced by many control variables, such as the topographic factor of the terrain and the length of slope (*LS* factor), rainfall erosivity (*R* factor), sensitivity of soil to erosion (*K* factor), presence of vegetation (*C* factor) and the anti-erosion cultivation techniques (*P* factor). To calculate the average annual soil loss, these five factors were considered and multiplied in the RUSLE Equation. The result shows that the average rate of soil loss is estimated at about 5.2 $t\cdot ha^{-1}\cdot y^{-1}$ over the whole watershed. This study is the first of its kind in the region and aims to assess the soil loss caused by water erosion processes in this arid zone. Consequently, it is essential to take real intervention measures in these upstream areas in order to combat this scourge, based on priorities ensuring the sustainable management of natural resources in the study area.

Key words: *Ain Sefra watershed, Algeria, arid region, GIS, RUSLE, soil erosion*

INTRODUCTION

Soil erosion is the detachment, transport and deposition of soil particles by usually combined action of rain and runoff. This process of soil degradation by runoff water, especially in areas without permanent vegetation, is probably the most important scourge, for it is irreversible and generally on a large scale [HONORATO *et al.* 2001]. The world is currently facing a real environmental problem that threatens the biodiversity and productivity of the majority of natural and agricultural ecosystems, which also threatens the lives of most small-scale farmers [GESSESSE *et al.* 2015].

Soil degradation, which often has a more dramatic character, is the result of many factors, including climatic, lithological, natural, topographical, vegetative cover and environmental ones. We confirm that the climatic factor is the most important and it has become increasingly aggressive leading rapidly to soil degradation if the soil is insufficiently protected by dense vegetation. This process occurs when rainfall erosion coincides with inappropriate anthropogenic practices, such as slope tillage, land clearing, deforestation, expansion of urban areas and road construction for the benefit of agricultural land, as well as overgrazing and lack of control, which aggravate the problem [WOLDEMARIAM *et al.* 2018].

Worldwide, average soil erosion rates are estimated to be between 12 and 15 $t\cdot ha^{-1}\cdot y^{-1}$ [PHAM *et al.* 2018]. In drylands, they are aggravated due to severe quantitative and qualitative degradation caused by water erosion. The latter is a natural phenomenon that evolves with the anthropic evolution and the severity of the climate [DJOUKBALA *et* *al.* 2018]. Each year, the land area loses about 0.90 to 0.95 mm of soil [FAO 2015].

In the case of Algeria, the land affected by erosion is estimated at about 20 mln ha. It includes in particular mountainous areas with 90% of dams and the population of about 20 mln people [MAZOUR, ROOSE 2002].

Many tools have been developed by researchers to quantify soil loss, including the Universal Soil Loss Equation (USLE) [WISCHMEIER, SMITH 1978], Revised Universal Soil Loss Equation (RUSLE) [RENARD *et al.* 1997], Water Erosion Prediction Project (WEPP) [NEARING *et al.* 1989], Soil and Water Assessment Tool (SWAT) [ARNOLD *et al.* 1998], etc. Recent studies have shown that the combination of the RULSE, Remote Sensing (RS) and Geographic Information Systems (GIS) have provided reliable support and tools for natural resource monitoring and disaster risk reduction.

The research requires a great deal of spatial data which the GIS is likely to process in a simple and efficient manner. For this reason, many researchers use the GIS as the main approach to estimate soil erosion at all spatial scales [BELASRI *et al.* 2016]. The aim of this study is to provide a spatial analysis of soil erosion using the RUSLE and GIS in the arid catchment area of the Wadi Ain Sefra in the Ksour Mountains, Algeria. The analysis is widely used by scientists in semi-arid and arid regions around the world, particularly in Algeria [BENKADJA *et al.* 2015; BENCHETTOUH *et al.* 2017; DJOUKBALA *et al.* 2018; HASBAIA *et al.* 2017; KOUSSA, BOUZIANE. 2019; TOUBAL *et al.* 2018].

The results have shown a high annual degradation rate and led to the deployment of soil-based tools to ascertain the exact amount of the annual soil loss or degradation, and guide the precise identification of highly degraded areas that require to be prioritized in terms of interventions in the study area.

MATERIALS AND METHODS

STUDY AREA

The basin of the Ain Sefra wadi has an area of 1903.49 km^2. It is located in the south-west of Algeria, in the Ksour Mountains, between 0°26'59" and 1°3'51" W longitude and between 32°28'13" and 33°1'45" N latitude (Fig. 1).

The climate in the study area is of the Mediterranean type, with the arid southern part benefiting from an average annual rainfall of 217 mm, while the average annual temperature recorded at the meteorological station of Ain Sefra is 18.58°C. This watershed, marked by diversified topographical conditions, belongs to the high plateau of north-west Algeria. The relief extends from 1036 to 2141 m a.s.l. (Tab. 1).

The Ksour Massif, part of the Saharan Atlas, is a fairly high mountainous region with peaks exceeding 2000 m in altitude, such as the Jebel Aïssa (2236 m), the Mir-Jebel (2145 m) and the Jebel Mekter (2029 m).

Population growth in the commune of Ain Sefra (253,530 inhabitants in 2015) is responsible for additional needs for food and agricultural land, which has led to the deforestation. The population growth rate was 4.18% between 2008 and 2014 [DPSB 2016].

Agriculture and pastoralism are indeed the two activities that have always been the economic vocation of this commune. The useful agricultural area is 2,957 ha, 85.99%

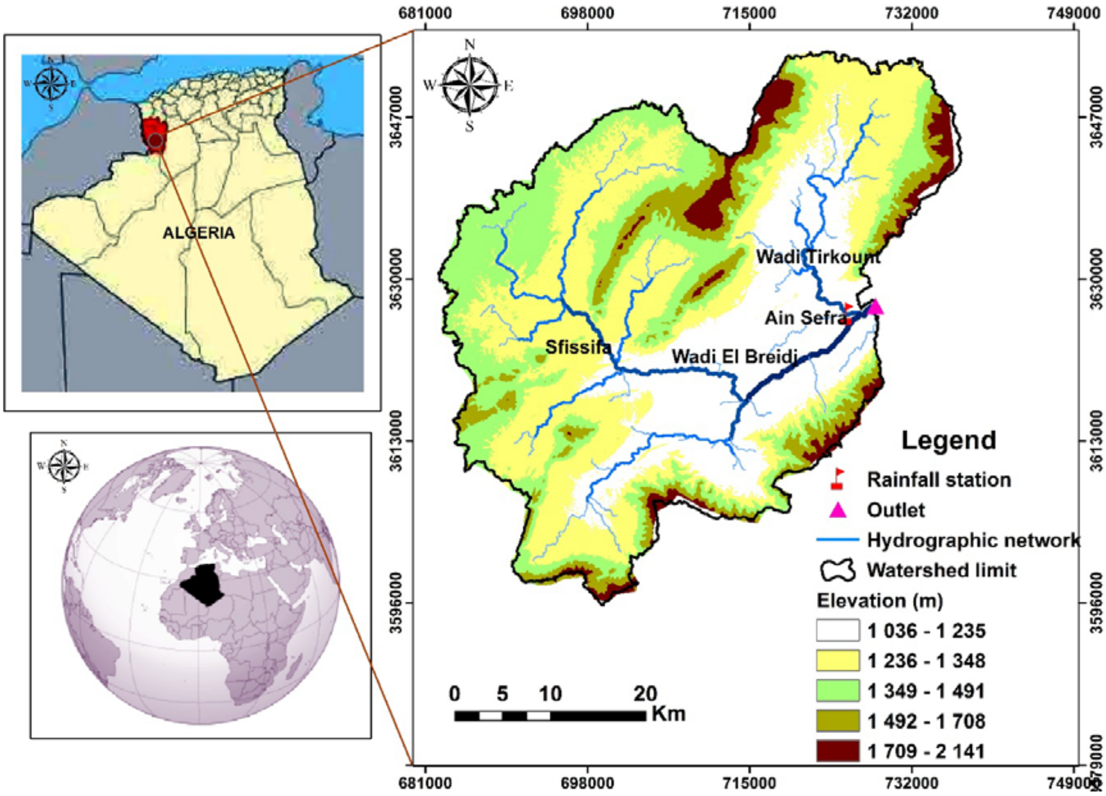

Fig. 1. Location of the study area; source: own elaboration

Table 1. Morphometric data for the Wadi Ain Sefra catchment

Parameter	Unit	Value
Area	km^2	1 903.49
Perimeter	km	275.81
Compactness index	–	1.63
Minimum altitude	m	1036
Maximum altitude	m	2141
Length of the rectangle	km	106.89
Width of the rectangle	km	17.80
Length of the main river	km	89.8
Drainage density	$km \cdot km^{-2}$	3.2

Source: own elaboration.

of which is irrigated. In contrast to this type of land, the area of grazing land and rangelands accounts for almost all of the total area; it is 50 294 ha or 94.42% [DPSB 2016]. These figures clearly show that pastoralism is the main vocation in the commune. It should enable to restore and preserve the balance of the natural environment, improvement of the fodder supply, fight against desertification and water erosion, as well as the creation of jobs through serious and effective development programs that will guarantee sustainable development in these arid regions.

Due to its position at the heart of a fragile ecosystem, the soil has a sandy, silty and sandy-clay texture and has a very low organic matter content, the region of Ain Sefra is characterized by a steppe environment strongly subjected to three scourges: degradation and regression of the plant cover due to the disappearance of *Lygeum spartum* L. and gray-leaved sagebrush (*Artemisia herba-alba* Asso) and a clear regression of Alfa (*Stipa tenacissima* L.) (19 680 ha in 1976 and only 10 732 ha in 2014) which testify to an alarming degradation of the plant cover and the need for emergency interventions [DPSB 2016]. Together with the risk of silting, overloading of rangelands and the anthropic action characterized by clearing and illegal ploughing and abusive exploitation of the plant cover threaten both urban areas and road infrastructure, as well as farms and pose the risks of flooding and water erosion. This often affects the whole of the study area.

RUSLE MODEL

For this study, soil losses were estimated based on the Revised Universal Soil Loss Equation (RUSLE) developed by RENARD *et al.* [1997], which is a revised version of the USLE model [WISCHMEIER, SMITH 1978], the most popular model in the world in this field which is based on the following equation (Eq. 1):

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

Where: A = the estimated annual soil loss ($t \cdot ha^{-1} \cdot y^{-1}$), R = the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$), K = the soil erodibility factor ($t \cdot ha^{-1} \cdot h^{-1} \cdot MJ^{-1} \cdot ha^{-1} \cdot mm^{-1}$), L = the length of the slope and S is the degree of slope (dimensionless), C = the vegetation cover control factor (dimensionless) and P = related to the supporting practices and amenities (dimensionless).

The information on these five main factors controlling the soil erosion was obtained from different primary and secondary data sources (Fig. 2). The description of the data used is presented in Table 2.

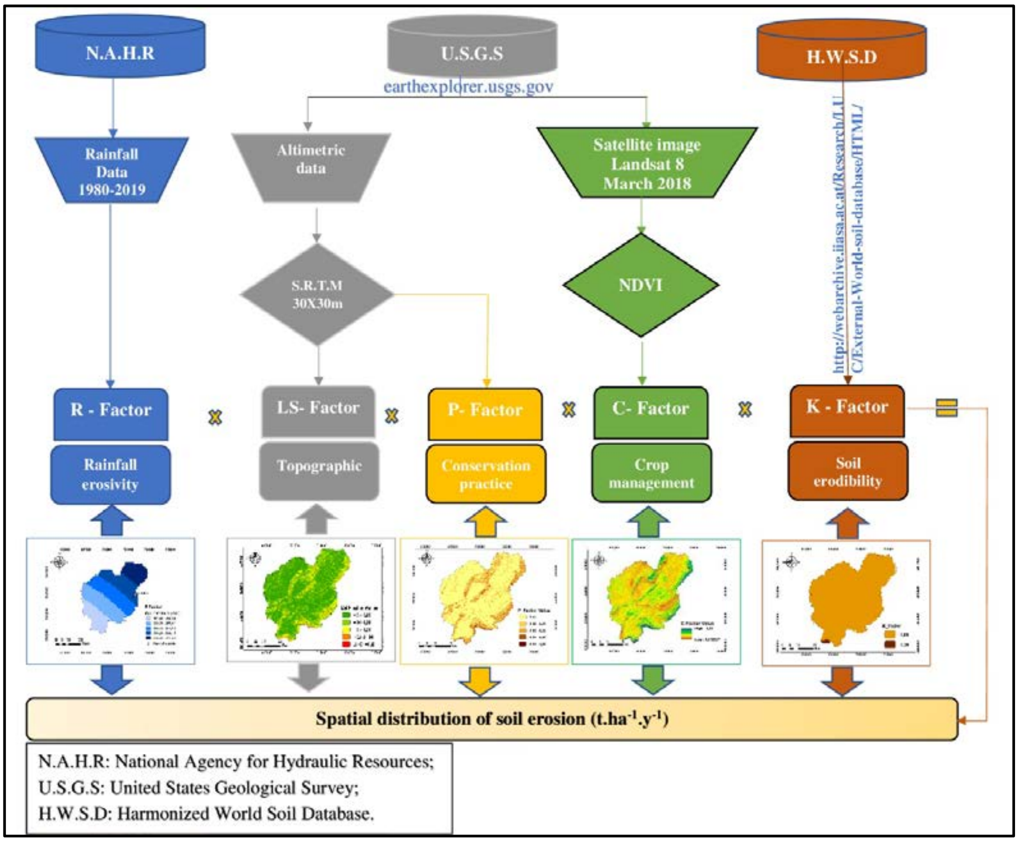

Fig. 2. The flow-chart of the methodology used, based on RUSLE equation and GIS; source: own elaboration

Table 2. Information on the data used in this study

Data type	Data format	Description	Data source
Annual and monthly rainfall	Excel	annual rainfall (1980–2019)	National Agency for Hydraulic Resources (NAHR)
The topographical data (Shuttle Radar Topography Mission SRTM)	Raster	resolution: 30 m	The United States Geological Survey (http://earthexplorer.usgs.gov/)
Landsat 8 satellite image	Raster	capture date: 9 March 2018 resolution: 30 m	The United States Geological Survey (http://earthexplorer.usgs.gov/)
Soil characteristics	Excel and Raster	Harmonized world soil database (HWSD)	Harmonized world soil database version 1.2 (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/)

Source: own elaboration.

Rainfall erosivity factor (*R*)

The process of soil erosion is highly conditioned by the kinetic energy of water drops under the pressure of splashes and runoff (splash effect). According to WISCHMEIER and SMITH [1978], the *R*-factor can be explained by the interaction between the kinetic energy of precipitation and the soil surface.

With the RUSLE model, and according to RENARD *et al*. [1997], the estimation of precipitation erosivity parameters was based on multiplying the total energy of the storm by the intensity of 30 minutes precipitation. In this study, meteorological data used to estimate the rainfall erosivity factor (*R*) were obtained from the National Agency for Hydraulic Resources (Fr. Agence Nationale de Ressources Hydriques – ANHR). Monthly and annual precipitation data were collected from 07 weather stations (Ain Sefra, Naama, Mechria, Bechar, El Bayadh, El Kheiter and Saida) and the National Agency for Hydraulic Resources (ANHR) over a period of 25 to 30 years (Tab. 3). *R* values for the entire watershed were calculated and interpolated using the Ordinary Kriging interpolation within the GIS.

For the present study, due to the lack of available data on precipitation intensity, it is not possible to use the formula given by RENARD *et al*. [1997]. In fact, this situation occurs in most of the Algerian watersheds. Indeed, the most reliable rainfall data are those recorded on a daily, monthly and annual scale; for this reason, an alternative based on monthly and annual rainfall (Eq. 2) was preferred. Numerous researchers have applied and proposed the said formula, such as: KALMAN [1967], RANGO and ARNOLDUS [1977], DJOUKBALA *et al*. [2018] and BENSELAMA *et al*. [2018].

$$\log R = 1.74 \log \sum_{i=1}^{12} \frac{Pi^2}{P} + 1.29 \qquad (2)$$

Where: R = rainfall erosivity factor (MJ·mm·ha^{-1}·h^{-1}·y^{-1}), P = annual rainfall (mm), Pi = monthly rainfall (mm).

Soil erodibility (*K*)

The soil erodibility factor (*K*) depends on soil texture, soil structure, soil permeability and organic matter (OM) richness. It generally depends on the nature of soil, slope inclination and the density of the plant cover [THIAW, HONORE 2017]. For the present study, the *K*-factor is obtained from the Harmonized World Soil Database (HWSD) version 1.2 [FAO/IIASA/ISRIC/ISSCAS/JRC 2012]. This database consists of a raster GIS document that is associated with a database in the Microsoft Access format (Fig. 2). According to FAO/IIASA/ISRIC/ISSCAS/JRC [2012] data, more than 16,000 different soil mapping units are recognized in the HWSD, which consists of 21600 rows and 43,200 columns, or 221 mln grid cells to cover the entire world, which are associated with harmonized attribute sets.

The use of a standardized grid offers the possibility to link the attribute data to the raster layer in order to display or examine the composition in soil units and to determine selected soil parameters, such as those given by BENSELAMA *et al*. [2018]: organic carbon, pH, water storage capacity, soil depth, exchange capacity of soil legends and clay fraction, total exchangeable nutrients, lime and gypsum content, percent of sodium exchange, salinity, texture class and particle size. In our case, the soil erodibility value was calculated according to Equations (3)–(7) recommended by NEITSCH *et al*. [2011].

$$K_{\mathrm{USLE}} = K_w = f_{\mathrm{csand}} \cdot f_{\mathrm{cl-si}} \cdot f_{\mathrm{Corg}} \cdot f_{hi\mathrm{sand}} \qquad (3)$$

Where: f_{csand} = a factor that decreases the *K* value for soils with a high proportion of coarse sand and increases the *K* value in cases where the soil contains little sand; $f_{cl\text{-}si}$ = a low erodibility factor in soils with a high clay-silica

Table 3. Information on rainfall stations located in the study area (period: 1980–2019)

Station	Longitude (E)	Latitude (N)	Altitude (m a.s.l.)	Period	Average annual rainfall (mm)
Ain Sefra	3862472.92	–66366.45	10 580	1981–2019	215.34
Naama	3930900.78	–33804.28	11 660	1995–2019	241.50
Mechria	3965693.96	–31621.04	11 490	1980–2019	275.34
El Kheiter	4048563.64	7643.70	10 000	1981–2019	260.80
El Bayadh	3983133.54	111598.06	13 410	1980–2019	336.19
Saida	4145791.54	16816.15	7 700	1981–2019	430.21
Bechar	3713157.96	–249184.71	7 730	1980–2019	150.17

Source: ANRH [2020].

Table 4. Determination of *K*-factor values within the Wadi Ain Sefra catchment

Sample	Percentage content in top soil			C_{org} (%)	f_{csand}	f_{cl-si}	f_{Corg}	f_{hisand}	K_{USLE}	K
	m_s	m_{silt}	m_c							
YK – sand	63.5	17.9	18.7	0.26	0.200	0.147	1.000	0.986	0.029	0.029
YK – sand	63.5	17.9	18.7	0.26	0.200	0.147	1.000	0.986	0.029	0.029
Y – loam	49.2	26.0	24.8	0.33	0.200	0.154	0.999	0.999	0.031	0.340
YK – sand	63.5	17.9	18.7	0.26	0.200	0.147	1.000	0.986	0.029	0.029
Y – loam	49.2	26.0	24.8	0.33	0.200	0.154	0.999	0.999	0.031	0.340

Explanations: m_s = the percentage of sand particles content (0.05–2.00 mm diameter), m_{silt} = the percentage of silt content (0.002–0.05 mm diameter), m_c = the percentage of clay content (<0.002 mm diameter); C_{org} = the percentage of the organic carbon content of the stratum.
Source: own study.

ratio; f_{Corg} reduces the *K* values when the organic matter content is high; f_{hisand} reduces the *K* values when the sand content is high.

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

$$f_{cl-si} = \frac{m_{silt}}{m_c + m_{silt}} \quad (5)$$

$$f_{Corg} = 1 - \frac{0.25\mathrm{C_{org}}}{\mathrm{C_{org}} + \exp[3.72 - 2.95\mathrm{C_{org}}]} \quad (6)$$

$$f_{hisand} = 1 - \frac{0.7(1 - \frac{m_S}{100})}{\left(1 - \frac{m_S}{100}\right) + \exp\left[-5.51 + 22.9(1 - \frac{m_S}{100})\right]} \quad (7)$$

Where: m_s = the percentage of sand particles content (0.05–2.00 mm diameter), m_{silt} = the percentage of silt content (0.002–0.05 mm diameter), m_c = the percentage of clay content (<0.002 mm diameter); C_{org} = the percentage of the organic carbon content of the stratum.

The samples YK and Y represent sandy and clayey soil textures respectively of the topsoil collected in the Harmonized World Soil Database (HWSD) on the FAO/IIASA/ISRIC/ISSCAS/JRC [2012] (Tab. 4).

LS factor

The topographic component (*LS*) consists of two elements, namely the length of the slope (*L*) and its degree of inclination (*S*), which have a great impact on water flows and thus on water induced erosion, in general. When the length and slope of the watershed slope are longer and steeper, the flow rate and speed of runoff will increase. In this work, the digital elevation model (DEM) of the area was used, extracted from the ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) which was downloaded from the USGS (United States Geological Survey) platform accessible in 2018 (resolution 30 m) – Figure 2. This required multiple pre-processing from the Spatial Analyst interface of the GIS software. Firstly, the accumulation of flows (flow-acc) was identified, which allowed us to deduce the length of the slope (*L*). In the second step, we estimated the slope, by using the Slope tool from Spatial Analyst Tools, which is used to determine the exponent (*m*) and then the factor (*S*) respectively. The last step is the combination of factors *L* and *S*.

To calculate the topographic factor (*LS*), we have relied on the formula defined by WISCHMEIER and SMITH [1978], which has been applied by several researchers such as: RODRIGUEZ and SUÁREZ [2010], DJOUKBALA *et al.* [2018]; BENSELAMA *et al.* [2018], KOUSSA and BOUZIANE [2019] (Eq. 8).

$$LS = \left(FA\frac{A}{22.1}\right)^m (0.065 + 0.045S + 0.0065S^2) \quad (8)$$

Where: *FA* = flow accumulation; *A* = the size of the DEM data (30 m by 30 m); *S* = the angle of the slope (%); *m* = a parameter related to different classes of slopes.

In our study, *m* = 3 which corresponds to the slope of (1–3%) WISCHMEIER and SMITH [1978].

C factor

STONE and HILBORN [2000] defined the *C*-factor, the vegetation factor, and compared losses on land under a specific cropping and management system with the corresponding losses in a field constantly left fallow. BENCHETTOUH *et al.* [2017] considered the land cover factor (*C*) to be the second major factor determining soil erosion after topography. We consider the land cover factor to be the most important one, since together with other conditions it is the easiest to control and combat erosion. Therefore, parameter *C* is a factor closely related to landscape conservation.

In general, *C*-factor values close to 0 are assigned to areas of a high vegetation cover while those close to 1 correspond to bare land [SEMWAL *et al*. 2017]. In the current study, data related to the normalized difference vegetation index (*NDVI*) (acquisition date: 9 March 2018, acquired from Landsat 8 satellite imagery with a spatial resolution of 30 m) were used to assess the C-factor and thus interpret the impact of different vegetation layers on the soil loss in the study area (Fig. 2). The *NDVI* was determined from a combination of red and infrared GIS bands. The following formula, applied by DJOUKBALA *et al.* [2018] and BENSELAMA *et al.* [2018] was used to calculate parameter *C* from:

$$C = 0.9167 - 1.1667\,NDVI \quad (9)$$

Agricultural practices and soil conservation factor (*P*)

The *P*-factor reflects the cultivation practices used (land management methods, in particular direction of ploughing and orientation of crop on sloping land), as well as soil conservation measures (reforestation and slope fixation). This runoff management system reduces the speed of runoff and promotes soil infiltration by modifying soil properties to reduce the effects of soil erosion.

This *P*-factor varies according to the protection techniques implemented at the watershed level. It ranges from 0 in the most protected areas to 1 in those areas where there are no conservation practices. In this study, the *P*-factor was estimated based on the slope system of the watershed, and we used the value of the supporting practice factor based on the cultivation methods and slope [SHIN 1999].

Table 5. Values of the *P*-factor by crop and slope types

Parameter	*P*-value at slope (%)				
	0–7.0	7.0–11.3	11.3–17.6	17.6–26.8	>26.8
Contouring	0.55	0.60	0.80	0.90	1.00
Strip cropping	0.27	0.30	0.40	0.45	0.50
Terracing	0.10	0.12	0.16	0.18	0.20

Source: SHIN [1999], modified.

RESULTS AND DISCUSSION

MODEL PARAMETERS

The rainfall erosivity factor (*R*). The spatial distribution of the rainfall regime in the Wadi Ain Sefra catchment ranges from 197.50 to 227.58 MJ·mm·ha^{-1}·h^{-1}·y^{-1} and varies according to the rainfall characteristics (Fig. 3). This distribution highlights high erosivity in the northeast part of the basin, whereas the lowest values are found in the southwest of the study area. Indeed, the catchment area of the Wadi Ain Sefra is marked by a strong aggressive climate impact ranging from south to north.

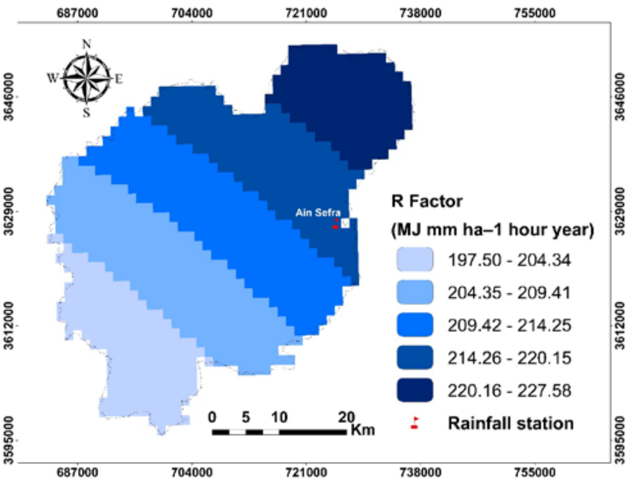

Fig. 3. *R* factor map of the study area; source: own study

The distribution of the *R* factor over the catchment area can be divided into several classes, of which 41% are marked by a high erosivity, with *R* values ranging from 214.26 to 227.58 MJ·mm·ha^{-1}·h^{-1}·y^{-1}. On the other hand, low erosivity is observed with *R* values between 197.50 and 209.41 MJ·mm·ha^{-1}·h^{-1}·y^{-1}, affecting 38% of the surface area of the basin. The moderate erosivity class with *R* factor of 209.42 to 214.25 MJ·mm·ha^{-1}·h^{-1}·y^{-1} can be found in the rest of the catchment area, i.e. about 21% of the surface area.

The soil erodibility factor *(K)*. *K* factor values extracted from the HWSD global database for the Wadi Ain Sefra catchment range from 0.03 to 0.34 t·ha^{-1}·h^{-1}·MJ^{-1}·mm^{-1}; they are low over the entire catchment area and are attributed to the coarse soils that favour water infiltration rather than runoff (Fig. 4).

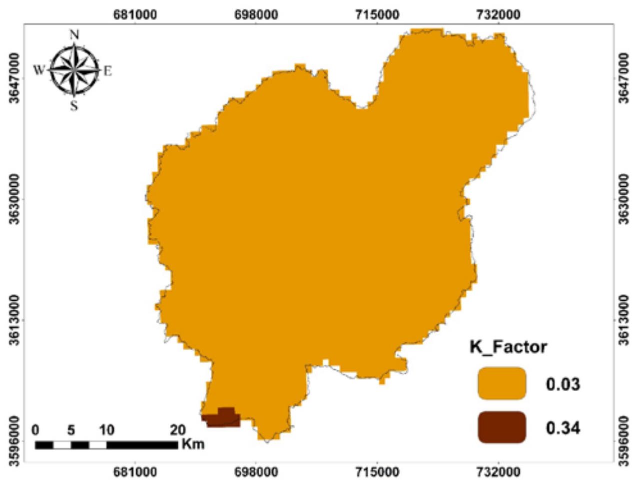

Fig. 4. The soil erodibility factor (*K*-factor) map of the Wadi Ain Seftra catchment; source: own study

LS factor

According to the distribution of the *LS*-factor, its values range from 0.03 to 63.29 (Fig. 5). High values are found in the mountainous areas of the upper valley, where the soil is uneven and threatened by erosion. On the other hand, lower values (*LS* < 5) are recorded in the central and north-western part of the Ain Sefra catchment. *LS* values considered to be low (less than 0.5) are observed in the plain which occupies the largest area of the Wadi Ain Sefra watershed (89%). They correspond to a low altitude of the plain and the stream channel. This is explained by a rather heterogeneous relief that characterizes the study area.

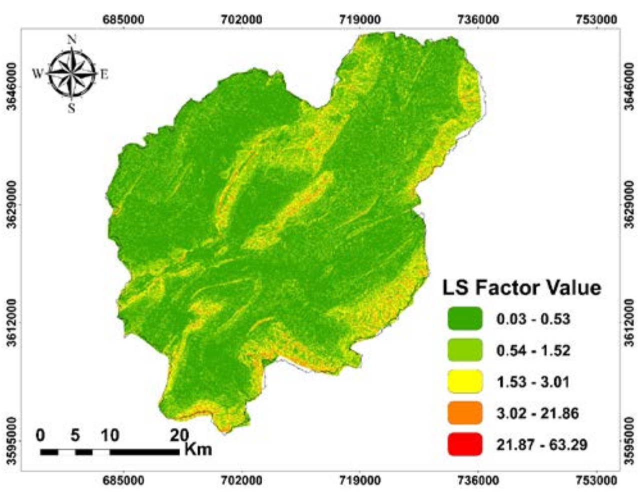

Fig. 5. The *LS* factor map of the Wadi Ain Seftra catchment; source: own study

Vegetation cover factor (*C*)

The values of the normalized difference vegetation indices (*NDVI*) are in the range of –1 to +1. Negative values are found in areas without vegetation cover but with snow, water or clouds, where the reflectance of red is higher than that of near infrared SOUIDI *et al.* [2014]. Since the reflectance is of the same order of magnitude for red and near infrared, the *NDVI* value is practically zero for bare ground. Vegetation formations have a positive *NDVI* value, generally between 0.1 and 0.7. The highest values are attributed to the densest vegetation cover. As shown in Figure 6, *NDVI* values vary between –0.22 and +0.47. Low values can be found in the summits of the Djebels while high values correspond to lands with variable vegetation. Agricultural activity is concentrated at the edges of the wadis in the center and south-east of the watershed.

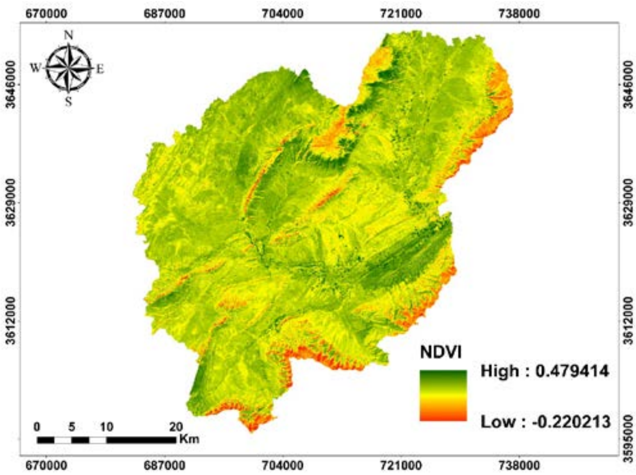

Fig. 6. Normalized difference vegetation index (*NDVI*) values spatially distributed in the Wadi Ain Sefra catchment area; source: own study

The *C*-factor map (Fig. 7) shows the reaction of different land use patterns to the erosion process. It is observed that the value of the *C*-factor over the whole study area in question is highly variable, ranging from 0.15 to 1. Most of the study area (96%) has a very low vegetation cover and only 4% of it is sufficiently well protected, with a $C < 0.6$. There is a low vegetation cover in pastures overgrazed by overstocking, sparse forests threatened by land clearing and cereal fields which are highly sensitive to all forms of erosion (water and wind).

Conservation support practice factor (*P*)

As shown in Figure 8, the value of factor *P* of the revised universal soil loss equation for the Ain Sefra watershed varies from 0.55 to 1.00 depending on the land use and gradients of the land slope. In our situation, the highest values (0.60–1.00) are justified by the absence or inadequacy of support means and practices in 90% of the overall watershed perimeter. On the remaining 10%, low *P* values (<0.60) are distributed in the central and north-western part of the catchment area, in association with a slight relief.

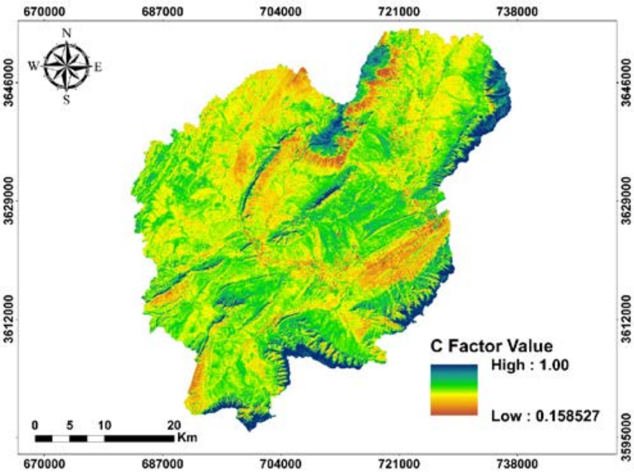

Fig. 7. Vegetation cover factor (*C*-factor) mapping in the Wadi Ain Sefra catchment; source: own study

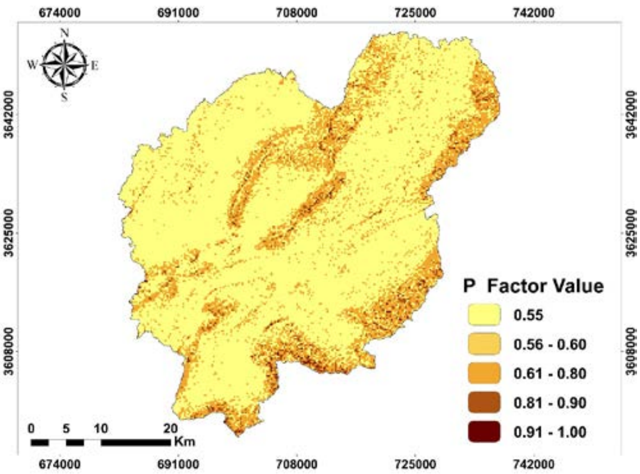

Fig. 8. The conservation support practice factor (*P*-factor) map of the Wadi Ain Sefra watershed; source: own study

POTENTIAL EROSION RISK MAP

The application of the RUSLE soil erosion model coupled with the GIS allowed us to estimate the spatial distribution of soil loss over the Wadi Ain Sefra watershed. Figure 9 presents classes related to soil loss in the study area.

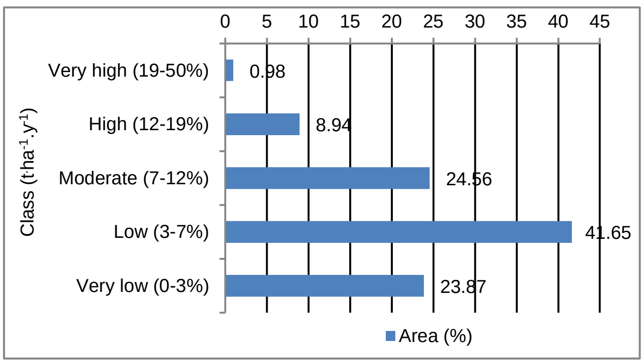

Fig. 9. Soil loss ($t \cdot ha^{-1} \cdot y^{-1}$) rates by classes for the Wadi Ain Sefra catchment; source: own study

The results show that about 23.87% of the study area has a very low potential erosion risk (<3 t·ha^{-1}·y^{-1}), while 41.65% of the study area has a low potential erosion risk (between 3 and 7 t·ha^{-1}·y^{-1}), 24.56% of this area is classified under a potentially moderate risk (between 7 and 12 t·ha^{-1}·y^{-1}), 8.94% under a potentially high risk (between 12 and 19 t·ha^{-1}·y^{-1}), and finally 0.98% is classified under a potentially very high risk (higher than 19 t·ha^{-1}·y^{-1}). The average soil loss in the study area, estimated at 5.2 (t·ha^{-1}·y^{-1}), is concentrated in sectors where the risk of erosion is low.

According to the erosion risk map (Fig. 10), this threat does not manifest itself in a homogeneous form in the Ain Sefra catchment. It is judged as low to moderate on the 171,457.15 ha, which represent 90.08% of the total catchment area. The area is located in a relief with low *LS* and with moderate to high vegetation cover (*C*). For the rest of the catchment area (9.02%), the situation is more worrying and erosion risks are classified from high to very high (Fig. 9). This applies especially to the central and south-eastern part of the Ain Sefra catchment, where high values for rainfall erosivity (R > 209) and soil erosion (K > 0.03), with very hilly relief (LS > 3) are associated with a moderate vegetation cover (C > 0.30) and negative impacts of uncontrolled agricultural practices (P > 0.60).

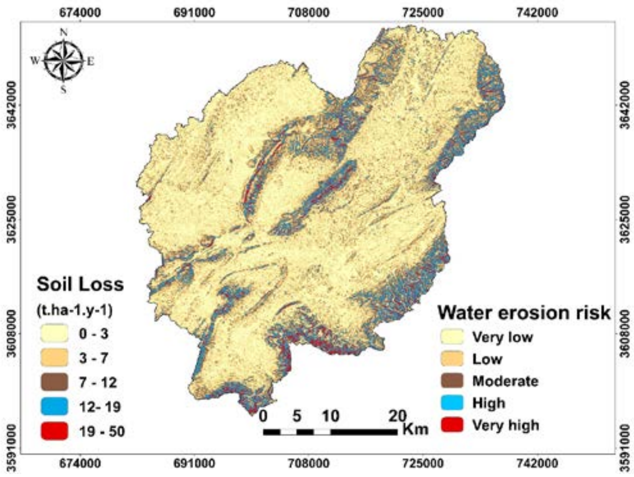

Fig. 10. Soil loss map (t·ha^{-1}·y^{-1}) and erosion risk classes in the Wadi Ain Sefra catchment; source: own study

These results differ from those found in many Algerian catchment areas, such as the Wadi Mina (11.2 t·ha^{-1}·y^{-1}) [BENCHETTOUH *et al.* 2017], as well as in the Wadi Sahouat catchment, whose potential soil losses are estimated between 12 and 16 t·ha^{-1}·y^{-1} [TOUBAL *et al.* 2018], or in the Wadi El Maleh with 9 t·ha^{-1}·y^{-1} [BENSELAMA *et al.* 2018].

They are also compatible with the results from other studies on water induced erosion problems carried out in mountainous areas with similar climatic and environmental characteristics. In Khanechela, the K'sob catchment has an average annual loss of 4.6 t·ha^{-1}·y^{-1} [BENKADJA *et al.* 2015]; they also indicate that the regions of Masàad and Hassi bahbeh are subject to high erosion leading to annual losses between 1.5 and 23 t·ha^{-1}·y^{-1} [KOUSSA, BOUZIANE 2018], whereas in the Wadi El-Ham the loss is 5.7 t·ha^{-1}·y^{-1} [DJOUKBALA *et al.* 2018].

The results show that the soils of the Ain Sefra region are subject to various factors that promote the erosion mechanism, notably the degradation of the vegetation cover through overgrazing and the extension of random cereal crops to the perennial plant profile. These results also make it possible to improve the land management through anti-erosion schemes designed to combat the effects of water erosion. This calls for adequate decision-making to preserve the environment in a sustainable manner and to ensure a balance between agricultural potential and natural water and soil resources.

CONCLUSIONS

This study shows the application of the empirical model to estimate the spatial distribution of soil erosion in the Wadi Ain Sefra catchment. The coupling of the RUSLE model with GIS helps to determine different types of erosion and sectors most affected and to quantify specific soil degradation.

It is also noted that soil losses are strongly related to the degree of rainfall erosivity as well as on the density of the vegetation cover in interaction with several factors. These include mainly the predominance of steeply erodible soils combined with intensive agriculture and grazing, which leads to the disappearance of plant stands in favour of anarchic cereal crops. The situation is aggravated by insufficient or absent means for combating erosion in the region.

According to the results obtained, approximately 23.87% of the study area has a very low potential erosion risk (<3 t·ha^{-1}·y^{-1}), 41.65% has a low potential erosion risk (between 3 and 7 t·ha^{-1}·y^{-1}), and 24.56% of this area fall in the moderate potential risk category (between 7 and 12 t·ha^{-1}·y^{-1}). The potential erosion risk is high (between 12 and 19 t·ha^{-1}·y^{-1}) in 8.94% of the study area, and in only 0.98% of the Wadi Ain Sefra catchment the potential erosion risk is very high (more than 19 t·ha^{-1}·y^{-1}).

The results provide important support to decision-makers and development managers help to simulate land degradation evolution scenarios in the Wadi Ain Sefra catchment. Above all, the results should be used for planning and programming of anti-erosion actions in the entire Ksour Mountains region. It should be pointed out that there is a shortage of studies that would allow us to estimate soil losses due to water erosion in these arid regions.

The RUSLE model has proven its effectiveness as a practical and modular tool in this field. The model enables to analyse the evolution of the general soil erosion and to provide basic data to prevent soil losses in the region. At the same time, it provides decision-makers with useful information for setting up future soil and water conservation programs in the region in particular in the Wadi Ain Sefra catchment.

REFERENCES

ANRH 2020. Bulletins de Séries de données climatiques 1980–2020 [Climate Data Series Bulletins 1980–2020]. Agence Nationale des Ressources Hydrauliques Algérie pp. 30.

ARNOLD J.G., SRINIVASAN R., MUTTIAH R.S., WILLIAMS J.R. 1998. Large area hydrologic modeling and assessment part I: model development. Journal of the American Water Resources Association. Vol. 34(1) p. 73–89. DOI 10.1111/j.1752-1688.1998.tb05961.x.

BELASRI A., LAKHOUILI A. 2016. Estimation of Soil Erosion Risk Using the Universal Soil Loss Equation (USLE) and Geo-Information Technology in Oued El Makhazine Watershed, Morocco. Journal of Geographic Information System. Vol. 8 p. 98–107. DOI 10.4236/jgis.2016.81010.

BENCHETTOUH A., KOURI L., JEBARI S. 2017. Spatial estimation of soil erosion risk using RUSLE/GIS techniques and practices conservation suggested for reducing soil erosion in Wadi Mina watershed (northwest, Algeria). Arabian Journal of Geosciences. Vol. 10(4). DOI 10.1007/s12517-017-2875-6.

BENKADJA R., BOUSSAG F., BENKADJA A. 2015. Identification et évaluation du risque d'érosion sur le bassin versant du K'sob (Est Algérien) [Identification and evaluation of erosion risk in the K'sob watershed (Eastern Algeria)]. Bulletin of Engineering Geology and the Environment. Vol. 74 p. 91–102. DOI 10.1007/s10064-014-0611-y.

BENSELAMA O., MAZOUR M., HASBAIA M., DJOUKBALA O., MOKHTARI S. 2018. Prediction of water erosion sensitive areas in Mediterranean watershed, a case study of Wadi El Maleh in north-west of Algeria. Environmental Monitoring and Assessment. Vol. 190(12), 735. DOI 10.1007/s10661-018-7117-1.

DJOUKBALA O., MAZOUR M., HASBAIA M., BENSELAMA O. 2018. Estimating of water erosion in semiarid regions using RUSLE equation under GIS environment. Environmental Earth Sciences. Vol. 77, 345. DOI 10.1007/s12665-018-7532-1.

DPSB 2016. Monographie de la Wilaya de Naâma [Monograph of the Wilaya of Naâma]. Direction de la programmation et du Suivi Budgétaires de La Wilaya De Naâma pp. 164.

FAO 2015. Status of the world's soil resources (SWSR) – Main report. Soil change: Impacts and responses. Chapt. 7. The impact of soil change on ecosystem services. Rome. Food and Agriculture Organization of the Unites Nations. ISBN 978-92-5-109004-6 pp. 222.

FAO/IIASA/ISRIC/ISSCAS/JRC 2012. Harmonized world soil database version 1.2 [online]. Rome Food and Agriculture Organization of the Unites Nations, Laxenburg, International Institute for Applied Systems Analysis. [Access 12.02.2019]. Available at: http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/HWSD_Data.html?sb=4

GESSESSE B., BEWKET W., BRÄUNING A. 2015. Model-based characterization and monitoring of runoff and soil erosion in response to land use/land cover changes in the Modjo watershed, Ethiopia. Land Degradation and Development. Vol. 26 p. 711–724. DOI 10.1002/ldr.2276.

HASBAIA M., DOUGHA M., BENJEDOU F. 2017. Erosion sensitivity mapping using a multi-criteria approach under GIS environment the case of the semiarid Hodna Basin in Central Algeria. International Journal of Water Resources and Arid Environments. Vol. 6(1) p. 13–19.

HONORATO R., BARRALES L., PENA I., BARRERA F. 2001. Evaluacion del modelo USLE en la estimacion de la erosion en seis localidades entre la IV y IX Region de Chile [Evaluation of the USLE model in the estimation of erosion in six locations between the IV and IX Region of Chile]. Ciencia e Investigacion Agraria. Vol. 28(1) p. 7–14.

KALMAN R. 1967. Le facteur climatique de l'érosion dans le bassin de Sebou [The climatic factor of erosion in the Sebou basin. Sebou Project, Report]. Projet Sebou, Rapport. Ronéo pp. 40.

KOUSSA M., BOUZIANE M.T. 2018. Apport du SIG a la cartographie des zones à risque d'érosion hydrique dans la région de Djelfa, Algérie. Lebanese Science Journal. Vol. 19. No. 1 p. 31–46. DOI 10.22453/LSJ-019.1.031-046.

KOUSSA M., BOUZIANE M.T. 2019. Estimation des paramètres de l'érosion hydrique par Approche SIG/USLE : cas du bassin versant de l'Oued Arab (région de Khenchela, Nord-Est de l'Algérie) [Estimation of water erosion parameters by GIS/USLE approach: Case of the Oued Arab watershed (Khenchela region, North-East Algeria)]. Agriculture and Forestry Journal. Vol. 3(1) p. 36–45. DOI 10.5281/zenodo.3239252.

MAZOUR M., ROOSE E. 2002. Influence de la couverture végétale sur le ruissellement et l'érosion des sols sur parcelles d'érosion dans des bassins versants du Nord-Ouest de l'Algérie. En : Techniques traditionnelles de GCES en milieu méditerranéen [Influence of vegetation cover on runoff and soil erosion on erosion plots in watersheds in north-western Algeria. In: Traditional techniques of GCES in the Mediterranean environment]. Eds. E. Roose, M. Sabir, G. De Noni. Bulletin – Réseau Erosion. Vol. 21 p. 320–330.

NEARING M., FOSTER G., LANE L., FINKNER S. 1989. A process-based soil erosion model for USDA-Water Erosion Prediction Project technology. Transactions for the ASAE. Vol. 32(5) p. 1587–1593. DOI 10.13031/2013.31195.

NEITSCH S., ARNOLD J., KINIRY J., WILLIAMS J. 2011. Soil & water assessment tool theoretical documentation version 2009. Texas Water Resources Institute Technical Report. No. 406 pp. 647.

PHAM T.G., DEGENER J., KAPPAS M. 2018. Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. International Soil and Water Conservation Research. Vol. 6(2) p. 99–110. DOI 10.1016/j.iswcr.2018.01.001.

RANGO A., ARNOLDUS H.M.J. 1977. Applications de la télédétection a l'amenagement des bassins versants. En : Aménagement des bassins versants [Applications of remote sensing for watershed management. In: Watershed management] [online]. Cahiers techniques de la FAO. Rome. FAO p. 1–11. [Access 12.02.2019]. Available at: http://www.fao.org/3/AD071F/AD071f00.htm

RENARD K.G., FOSTER G.R., WEESIES G.A., MCCOOL D.K., YODER D.C. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook. No. 703 pp. 385.

RODRIGUEZ J., SUÁREZ M. 2010. Comparison of mathematical algorithms for determining the slope angle in GIS environment. Aqua-LAC. Vol. 2. No. 2 p. 78–82.

SEMWAL P., KHOBRAGADE S.D., NAINWAL H.C. 2017. Modelling of recent erosion rates in a lake catchment in the North-Western Siwalik Himalayas. Environmental Processes. Vol. 4 p. 355–374. DOI 10.1007/s40710-017-0234-y.

SHIN G.J. 1999. The analysis of soil erosion analysis in watershed using GIS. Ph.D. Thesis. Chuncheon. Gang-won National University. South Korea.

SOUIDI Z., HAMIMED A., DONZE F. 2014. Cartographie du risque de dégradation des terres en région semi-aride: Cas des Monts de Beni Chougrane dans le Tell Occidental Algérien [Mapping the risk of land degradation in the semi-arid region: Case of the Beni Chougrane Mountains in the Algerian Western Tell]. Geo-Eco-Trop. No. 38 p. 85–102.

STONE R.P., HILBORN D. 2000. Équation universelle des pertes en Terre (USLE) [Universal Soil Loss Equation (USLE)]. Ontario. Ministère de l'agriculture, de l'alimentation et des affaires rurales. Fiche technique. Commande. No. 00-002 pp. 8.

THIAW I., HONORE D. 2017. Mapping of soil erosion risk in the Diarha watershed using RUSLE, RS and GIS. American Journal of Remote Sensing. Vol. 5. No. 4 p. 30–42. DOI 10.11648/j.ajrs.20170504.11.

TOUBAL A.K., ACHITE M., OUILLON S., DEHNI A. 2018. Soil erodibility mapping using the RUSLE model to prioritize erosion control in the Wadi Sahouat basin, north-west of Algeria. Environmental Monitoring and Assessment. Vol. 190, 210. DOI 10.1007/s10661-018-6580-z.

WOLDEMARIAM G.W., IGUALA A.D., TEKALIGN S., REDDY R.U. 2018. Spatial modeling of soil erosion risk and its implication for conservation planning: The case of the Gobele Watershed, East Hararghe Zone, Ethiopia. Land. Vol. 7(1), 25. DOI 10.3390/land7010025.

WISCHMEIER W.H., SMITH D.D. 1978. Predicting rainfall erosion losses – A guide to conservation planning. Supersedes Agriculture Handbook. No. 282. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agriculture Handbook. No. 537. Washington, DC. USDA pp. 58.