ZIBELINE INTERNATIONAL
PUBLISHING

ISSN: 2521-0882 (Print)

ISSN: 2521-0483 (Online)

CODEN: EESND2

Environment & Ecosystem Science (EES)

DOI: <http://doi.org/10.26480/ees.01.2020.15.22>

CrossMark

RESEARCH ARTICLE

ASSESSMENT OF SOIL EROSION BY RUSLE MODEL IN THE MELLEGUE WATERSHED, NORTHEAST OF ALGERIA

Kamel Khanchoul^{a*}, Kaouther Selmi^b, Kaddour Benmarce^c

^a Department of Geology, Laboratory of Soils and Sustainable Development, Badji Mokhtar University-Annaba, P.O.Box 12, Annaba, Algeria

^b Department of Geology, Laboratory of Soils and Sustainable Development, Badji Mokhtar University-Annaba, P.O.Box 12, Annaba, Algeria

^c Department of Earth Sciences, University of Ferhat Abbas, Setif 1, Campus El Bez, Setif, Algeria

* Corresponding author Email: kamel.khanchoul@univ-annaba.dz; kam.khanchoul@gmail.com

This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 12 January 2020

Accepted 15 February 2020

Available online 28 February 2020

ABSTRACT

In Algeria, soil erosion has experienced a spectacular extension, it is therefore imperative to assess the effects of this phenomenon. The purpose of this study is to assess soil loss rate using a GIS/USLE approach at the Mellegue watershed, northeast of Algeria. Geographic Information System techniques have been adopted to process data obtained at the study watershed, of reasonable spatial mapping, for the application of the RUSLE model. The model is a multiplication of the five erosion factors, namely rainfall erosivity, soil erodibility, slope and length of slope, plant cover and anti-erosion practices. Each of these factors has been expressed as a thematic map. The resulting soil loss map, with mean erosion rate of 20.40 T/ha/year, shows very low erosion (≤ 7 T/ha/year) which covers 64.60% of the total area of the basin, and very high erosion (> 60 T/ha/year) which does not exceed 4.80% of the basin area. The results indicate that Chabro and downstream Mellegue sub-watersheds face the greatest risk of soil erosion compared to Meskiana sub-basin, with contributions of 14.20 % and 12.90 % of their basin areas respectively. This is mainly due to natural factors and anthropogenic activities without appropriate conservation practices of agricultural land.

KEYWORDS

Land degradation, RUSLE, GIS, mapping, prediction.

1. INTRODUCTION

Man since his existence has focused on using nature and its richness to meet his needs that increase more and more without having the least concern for the risks to the environment. Water and soil are two vital components of human existence. Soil is the most crucial but highly vulnerable natural resource in the world (Lal, 2001; Yesuph and Dagnew, 2019). Soil erosion is a multifaceted and predominant global land degradation process which leads to decline in ecosystem services and functions (Angassa, 2014; Haregeweyn et al., 2015). It is reported that more than 2/3rd of farmland in Africa is caused by soil erosion (Tully et al., 2015). Soil erosion not only descent soil quality and productivity due to its on-site impacts but also has other negative impacts such as deposition of sediments and associated diversion of streams courses and reservoir siltation (Haregeweyn et al., 2017). Human activities, including urbanization and land use occupation, associated with agricultural practices (e.g. grazing) and deforestation, are significant aggravating factors of erosion (Bouderbala et al., 2018). These factors for soil erosion and sediment production vary from place to place; their actions are generated by a number of environmental (e.g. landforms, soil characteristics, rainfall intensity, vegetation cover, lithology) and socio-economic attributes (Yesuph and Dagnew, 2019).

Erosion-caused land degradation is most popular problems in Algeria, where huge amount of fertile soil is being lost annually (Gessesse et al., 2016; Gliz et al., 2015; Khanchoul and Boubehziz, 2019; Koussa and Bouziane, 2019). This phenomenon reduces the productive capacity of the land and exacerbates poverty and food insecurity (Gessesse et al., 2016).

About 20 million hectares of lands are affected by erosion, particularly in mountainous areas, where people are highly concentrated (Benselama et al., 2018; Mazour and Roose, 2002).

The Revised Universal Soil Loss Equation (RUSLE) with its integration to geographic information system (GIS) is among widely applied empirical models for assessment of the annual loss of soil due to water erosion (Ali and Hagos, 2016). In Algeria, there is a number of research studies pertaining to the peril of soil erosion at various spatial and temporal scales that have used the RUSLE models (Bouguerra et al., 2017; Gliz et al., 2015; Hallouz et al., 2018; Koussa and Bouziane, 2019). All these have highlighted that factors of erosion, which cause land degradation, are by far the major problem, which deprive soil's fertility, water holding capacity and its biodiversity (Morsli et al., 2004).

In recent years, different studies have been done to evaluate soil erosion using models. In northwestern part of Algeria, some researchers have noted that sediment transport has increased over the last 40 years due to climate change and its consequences as a change in hydrological regime (Achite and Ouillon, 2016). As have given an average annual soil loss rate in the Sahouat basin that ranges from 0 to 255 t ha⁻¹ year⁻¹ and have produced a map showing a risk of soil erosion in the Fergoug watershed varying between 0 and 618 T ha⁻¹ yr⁻¹; considering thus both basins are highly susceptible to erosion (Toubal et al., 2018; Bouderbala et al., 2018). Currently, the highest soil erosion rate is being observed in the western part of the country. However, few studies have been undertaken on soil erosion assessment in the northeast of Algeria. Some researcher make investigation on spatial variability of soil erosion in Bouhamdane,

Quick Response Code

Access this article online

Website:
www.educationsustainability.com

DOI:
[10.26480/ees.01.2020.15.22](https://doi.org/10.26480/ees.01.2020.15.22)

Bounamoussa, Soummam watersheds respectively using RUSLE models have stated that the main causes of medium to highly soil erosion in these basins, because of land cover degradation, steep slope cultivation and agricultural intensification, have high relation with human activities (Bouzeria et al., 2017; Bouguerra et al., 2017; Sahli et al., 2019). The results can certainly aid in implementation of soil management and conservation practices to reduce the soil erosion in the later basins.

The aims of the present study are: 1) to estimate annual soil erosion and to identify the factors responsible for the soil degradation in order to better understand the phenomenon of erosion; 2) to highlight the areas subject to the risk of water erosion in the Mellegue watershed; 3) to prevent the Ouldjet Mellegue dam from future sedimentation. Furthermore, this study may enable better land management by farmers and decision-makers in semi-arid areas in Algeria where sediment datasets are unavailable. Integration of mapping procedure using the RUSLE approach into a geographic information system (GIS) technique is the method that is usually followed to produce a soil erosion intensity map for different sub-watersheds particularly exposed to erosion processes under semi-arid climatic conditions.

2. MATERIAL AND METHODS

2.1 Study area

The present Mellegue watershed belongs to the Medjerda Basin (7 847 km²), located in the northeast of Algeria (Figure 1). It drains an area of 4570 km² at the gauging station of Ouenza (basin outlet), controlled by the National Agency of Hydraulic Resources (ANRH). At the study basin outlet, the Ouldjet Mellegue dam is located, at 13 km upstream from the city of Ouenza. The Mellegue River gets its name from the confluence of the two main rivers: Meskiana and Chabro.

The study area is characterized mainly by calcareous crusts and weathered limestone, which occupy 48% of its area in the western part. Cretaceous marl and marly limestone formations and quaternary deposits represent the most erodible lithological formations that cover 27% of the basin area. The rest of the landscape is formed on predominantly resistant rocks including Oligocene sandstone, Aptian limestone and dolomite, and are mainly located in the southeastern part of the Mellegue basin (Selmi and Khanchoul, 2016).

Figure 1: Map location of the Mellegue watershed

Land use has revealed that more than 30% of the basin area is agricultural land, occupied by cereals. Steppes and grasslands cover 26% of this zone. Forest cover is often deteriorated by the human activities, leading to rare and open dense forests of Alep trees because of the frequent fires in summer and intensive overgrazing (Selmi and Khanchoul, 2016). Open forest and shrubs cover 22% of the Mellegue watershed. For the most part, the basin is composed of poorly developed soils (alluvium, loam) located in the southeastern and southwestern part of the Mellegue basin. The northern and southeastern parts are essentially occupied by marl-clayey soils.

The Mellegue watershed has a semi-arid Mediterranean climate, marked by seasonal contrasts in which most of the rain falls in a period of few days during the wet season, concentrated mainly in fall and spring seasons. The

mean annual precipitation is about 270 mm (period 1970-2016), with an abundant rainfall occurring from March to May (mean values ranging from 29 to 38 mm). The precipitation data show that there are rainfall events greater than 40 mm·day⁻¹ recorded mainly in September, October, April and May, and the highest rainfall intensity is recorded in May (62 mm·day⁻¹). The mean annual temperature is about 18°C.

2.2 RUSLE parameter presentation

In countries like Algeria, where soil erosion is severe, it is imperative to apply basic soil erosion models that require less data and therefore can be used with available resources. Several models of soil erosion exist with different degrees of complexity. Although a wide variety of models are available for estimating erosion risk, most require so much source data that their application at the regional scale becomes a problem.

In this study, we are applying the Revised Universal Soil Loss Equation (RUSLE) model which is a revised version of the USLE model to the Mellegue watershed (Renard et al., 1991; Wischmeier and Smith, 1978). Its use is widespread in the scientific community in semi-arid zones in the Maghreb (Algeria, Tunisia and Morocco) and Mediterranean countries particularly in Turkey and Portugal (Bayramin et al., 2008; Ferreira et al., 2015).

Different sources of information are used to provide the requested parameters to complete this study. The use of a Geographic Information System (GIS) is appropriate and provides a map of risk over the area. The GIS we propose is based on topographic data issued from a Digital Elevation Model (DEM) which provides topographic factors (LS) and the conservation practice factor (P). Rainfall data enabled to calculate erosivity factor (R), the soil erodibility (K) is extracted from a database of world soil properties, and satellite image data is used to calculate the cover management factor (C). In a second step, the sensitivity to erosion inferred from the model is compared to Google Earth data for validation. The results can be used to determine criteria for priorities of intervention by sub-basins in order to avoid more removal of topsoil and siltation of the new reservoir at the basin outlet.

The parameters of RUSLE model have been estimated based on the monthly rainfall amounts, DEM, soil type, and land cover. The overall methodology used in the present study is schematically represented in Figure 2.

Figure 2: Flow chart methodology for soil loss assessment

RUSLE is considered the method, most widely to predict long-term rates of soil erosion from inter-rill and rill processes of lands subject to different management practices. The present study is started with delineation of the Mellegue watershed from topo-sheets of 1:50,000 scale and Digital Elevation Model, with a spatial resolution of 30 m STRM, using ArcGIS 10.4 software. The underlying assumption in RUSLE is that the detachment and deposition are controlled by sediment content of the flow (Ganasri and Ramesh, 2016). When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation must also occur during the falling stage of the hydrograph as the stream flow rate decreases. In RUSLE, the rainfall or runoff factor of the unique USLE is replaced by the rainfall erosivity factor (Narayan et al., 2018).

In this study, RUSLE is used for calculating the enduring average annual soil erosion on a surface slope emerged on runoff model, soil category, crop process, slope-length and supervision practices (Narayan et al., 2018). It enumerates the average annual soil erosion in tonnes/ha/year expected on field slopes using the following equation (1):

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

where, A is the estimated average annual soil erosion (tonnes/ha⁻¹/year⁻¹), R is the rainfall or runoff erosivity factor rainfall erosivity factor ((MJ mm ha⁻¹h⁻¹ year⁻¹) or runoff (mm), K is the soil erodibility factor (t MJ⁻¹ h⁻¹ mm⁻¹), L is slope length factor, S is slope steepness factor (dimensionless), C is the cover management factor and P is the supporting practices. All these parameters are mapped in GIS raster format; so, the estimates average annual soil erosion is obtained at the pixel grid level (30*30 m grid cell size).

2.3 RUSLE parameter estimation

2.3.1 Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) describes the erosivity of rainfall at a particular location based on the rainfall amount and intensity and reflects the effect of rainfall intensity on soil erosion (Koirala et al., 2019). The rainfall erosivity used in the RUSLE quantifies the impact of precipitation and also reflects the quantity and runoff rate associated with rain events. Its unit is expressed in MJ mm ha⁻¹ h⁻¹ year⁻¹.

In this study, the rainfall map produced by the authors is used to generate a rainfall erosivity factor. The rainfall map represents mean annual precipitation over the study area, produced from the ground meteorological stations. The equation integrated to generate the R-factor is given by the simplified equation (2) used by different researchers in Morocco and Tunisia, according to the specific erosive phenomena of the North African region (Sadiki et al., 2004):

$$R = 143 \log (P \times (p'24)^2 \times 10^{-6}) + 89.7 \quad (2)$$

Where R is the rainfall erosivity factor; P is the mean annual precipitation (mm); p'24 is the median maximum rainfall in 24 hours of the considered years (mm). With P = 350 mm/an, and p'24 = 32 mm; the value of R factor is equal to 26 MJ.mm.ha⁻¹.h⁻¹.an⁻¹ for the whole basin.

The spatial distribution of average annual precipitation (P) in the study area is estimated using the kriging method of interpolation (Figure 3). In the process of interpolation, 42 year-rainfall for 13 rain gaging stations are considered. It is observed that the highest rainfalls have occurred in Tebessa and Mdaourouch regions and the lowest rainfalls have happened in Bekkaria and Meskiana regions.

Figure 3: Spatial distribution of rainfall in the Mellegue watershed

2.3.2 Soil Erodibility Factor (K)

The soil erodibility factor indicates the susceptibility of soil particles to detachment and transport by rainfall and runoff of a particular soil type. The main soil properties influencing the K factor are soil texture, organic matter, soil structure and permeability of the soil profile. In the present study the erodibility factor is obtained directly from a detailed soil map based on the lithological formations distributed over the watershed surface. The Mellegue river basin consists of 07 different soil types as presented in Figure 4 with varying soil characteristics.

Figure 4: Spatial distribution of soils in the Mellegue watershed

The soil map is reclassified with assigned K-factor value. The K factor is a numerical value varies from 0 to 1 in which soil erodibility values closer to 0 are less prone to soil erosion. The determination of K-factor is based on the method of the indexation coefficients of soil types (runoff curve number) according to USGS, characterizing the aptitude to soil runoff. The K-factor values are presented in the following Table 1.

Table 1: The K-factor values based on lithological distribution in the study watershed	
Class	K-factor
Predominantly marly-clayey soils	0.40
Predominantly marly gypsum soils	0.30
Predominantly marly calcareous soils	0.27
Recent soils, alluvium, loam	0.17
Predominantly calcareous soils	0.08
Predominantly conglomeratic soils	0.07
Predominantly sandstone soils	0.05

2.3.3 Topographic factor (LS)

The topographic factor LS has two elements: length of slope (L) and inclination of the slope (S). The DEM has made it possible to interpolate the elevations and produce the slope map and the factor LS map. The LS factor is calculated using the following formula (Mitasova et al., 1996):

$$LS = \left(A \cdot \frac{r}{r_0} \right)^m \cdot \left(\frac{\sin s}{\sin s_0} \right)^n \quad (3)$$

With :

A: drained upstream surface (in number of cells); r: resolution of the DEM (30 m); r₀: reference resolution (22.1 m); s: slope; s₀: reference slope (sin s₀ = 9%). The parameters m and n are between 0.4 and 0.6, respectively, and between 1.0 and 1.4.

The lowest values favor a diffuse erosion process (sheet erosion) while the strongest values favor an erosion process by channls and gullies. According to the field observations at the Mellegue watershed, the chosen values are m = 0.6 and n = 1.3 (Mitasova et al., 1996). The used formula is a derivative formula developed by Wischmeier and Smith (1978) to be able to create the LS map with Arcgis 10.4. The equation used to compute LS-factor is as follows:

$$LS = \left(\text{flowacc}(\text{flowdir}([DEM]) \times \frac{\text{Resolution}}{22.1}) \right)^{0.6} \times \left(\frac{\sin(\text{slope}) \times 0.01745}{0.09} \right)^{1.3} \quad (4)$$

With :

flowacc et flowdir are two functions integrated in Arcgis 10.4. The obtained LS values are grouped into five classes. The length and inclination

of slope have a great influence on the erosive process. The values obtained for the LS factor are been grouped into five classes.

2.3.4 Land use C-Factor

The C factor reflects the effect of land cover on soil erosion process. It is probably the most important factor in RUSLE since it represents conditions that can easily be managed to prevent or reduce soil loss (Bouhadeb et al., 2018). The factor C which depends on the density, height of vegetation and the cropping system is obtained on the basis of the land use map of the study watershed (Figure 5).

Landsat images (30 m resolution) are used to distinguish the vegetation factor from the standardized "NDVI" (Normalized Difference Vegetation Index) indices. The latter corresponds to the vegetative vigor. The ratio between index C and NDVI is given by the following formula (Bouderbala et al., 2018):

$$C = \exp \left[-2 \times \frac{NDVI}{1 - NDVI} \right] \quad (5)$$

Figure 5: Spatial distribution of land use in the Mellegue watershed

By using the Landsat 8 images (Landsat ETM+ and ASTER images) through supervised classification method, raster map of the land use and land cover are converted to vector format file and the resultant C-factor value is allocated to each of the land use classes as proposed (Table 2) (Hurni, 1985). It is convenient to note that the complete satellite image treatment has also been possible using the ENVI 5.1 and Erdas Imagine software which have allowed a classification of vegetation cover and land use, following the operations of radiometric, atmospheric and geometric corrections. The final version of the land use map is rectified after a field work verification.

Table 2: The C-factor values in the Mellegue watershed

Land cover	C-factor
Barren soil	1.00
Grassland, steppes	0.40
Cultures	0.35
Humid zone	0.30
Sparse forest and shrubs	0.25
Dense forest	0.05

2.3.5 Support practice factor (P)

The P-factor expresses the protection of soil par agricultural management practices. The conservation practice factor is calculated based on the slope of the area and equivalent P factor values derived based on each slope classes by reclassifying the slope map in ArcGIS.

This factor takes into account purely anti-erosive practices such as contour plowing or contour ridging. The attribution of an index of anti-erosion practices (P) of the soil expresses the losses in soil of a site that

has basin management facilities, in relation to one that has not experienced any installation of anti-erosion techniques. In other words, the evaluation of P-factor at a watershed is to assess the effectiveness of the existing anti-erosion structures (Nasl'haj, 2009). It varies between 1 on bare ground without any anti-erosion protection at about 0.1, when on a low slope, ridging is practiced.

The high percentage of low slopes in the Mellegue watershed proves the scarcity of anti-erosion practices raised during field visits. However, due to the fact that there are no anti-erosion practices adopted throughout the study area, this factor is considered as a unit value equal to 1.

3. RESULTS

The final soil erosion map displays the average annual soil loss potential of the Mellegue watershed and its sub-watersheds. The GIS analysis has been carried out for RUSLE to estimate annual soil loss on a pixel-by-pixel basis and the spatial distribution of the soil erosion in the study area.

3.1 USLE factor mapping

3.1.1 Factor of rain erosivity « R »

The rainfall erosivity map based on annual data over a 47-year period clearly shows a sub-vertical decline from north to southwest and a parabolic shape from north to southeast (Figure 6). The values of R range from 49.2 to 52.7 MJ.mm.h⁻¹.y⁻¹. The mean annual value of R is equal to 50.71 MJ.mm.h⁻¹.y⁻¹.

Figure 6 shows that the high degree of aggressiveness is observed mainly in the north area (Mdaourouch and El Aouinet) and more or less in the southeast at Tebessa area; Meskiana and extreme Bekkaria zones are showing the least affected area by rainstorms. The low to moderate R values (50 to 50.7 MJ.mm.h⁻¹.y⁻¹) occupy 36% of the basin area.

Figure 6: R-factor map in the Mellegue watershed

In general, the variation in rainfall intensity is probably due to variation in altitude and exposure, where the maximum elevations are 1582 m in the western part (Meskiana sub-watershed), 1622 m in the eastern part (Chabro sub-watershed), and 492 m in the north part (downstream Mellegue sub-watershed).

3.1.2 Soil erodibility K-factor

The calculated K-factor in the Mellegue watershed varies from less than 0.08 to 0.40 t.ha.ha⁻¹.ha⁻¹.MJ and has a mean value equal to 0.23 t.ha.ha⁻¹.ha⁻¹.MJ, which is relatively high (Figure 7).

The low values are mainly located in the extreme southern part of the basin where soils are more sandy and calcareous types with an increase in the amount of organic matter, providing high penetration amounts and abridging runoff. Also, the area is more protected by vegetation where grassland, shrubs and sparse forest are the dominated vegetation cover. The high values are located in marl-clayey soils, covering 31% of the basin area. The modest to fairly high K values occupy most of the Meskiana sub-watershed and almost half of the Chabro sub-watershed. These areas (54% of basin area) are dominated by alluvium and silt loam soils. These soils are abstemious to merely separable; penetration is sensible to small creating modest to high runoff.

Figure 7: Soil erodibility K-factor map in the Mellegue watershed

According to the classification established by Bollinne and Rosseau (1978) concerning the resistance of soil to erosion, there is almost 60% of the basin area having low erodibility (with $K < 0.25$). The areas of high erodibility, exceeding a value of $0.30 \text{ t.ha.h.ha}^{-1}.\text{MJ}$, are mostly occupied by steppes, sparse grassland and bare soils.

3.1.3 LS-factor

The LS-factor values vary between 0 and 15, where the class 0 - 0.2 occupies the most dominant basin area with 84%. The mean LS value is estimated to be equal to 0.46. The high LS values are present in only 4% of the basin area (Figure 8). These results are proportional to the basin topography, dominated by relatively flat surfaces where the low slopes are observed in 84% ($\leq 10^\circ$ of slope). The high LS values are attributed to the upstream basin where the relief is high and to areas close to the main river Mellegue watershed. These areas should be the most sensitive to sheetwash, rills and bank erosion processes.

Figure 8: Map of the length/slope (LS) factor in the Mellegue watershed

3.1.4 Crop management factor (C)

According to the results of Panagos et al. (2015), the vegetation cover and management factor (C) are among the main parameters that contribute to soil erosion potential. The C-factor values range between 0.05 and 1, as is shown in Table 2 and Figure 9. The map shows that the lowest values are located along most of the divide borders of the Meskiana and Chabro sub-watersheds, which contain mainly forest and shrubs. Most of the study watershed has values that vary between 0.31 and 1, covering 71% of the basin area, and contains agricultural land, steppes and grassland. The spatial distribution of the C-factor confirms that the study area has been for a long time undergoing human activities land use and climatic changes which have led to the degradation of the forests and the transformation of these areas into cropland, induced grassland and steppes.

Figure 9: Crop management factor (C) in the Mellegue watershed

4. DISCUSSION

4.1 Soil loss estimation

The soil losses result from the combination of factors of the RUSLE model, namely rain erosivity R, soil erodibility K, topographic factor LS, cover management factor C and anti-erosion practices P. After, a modeling of these five factors is realized to produce an erosion map in raster format, taking into account the numerical values of each thematic map and the multiplication of the five factors using GIS program to produce soil loss rates.

Each pixel of the resulting map has a unique value which corresponds to its possible erosive potential. Figure 10 indicates not only the soil loss of each pixel, but also gives a very reliable description of the potential erosion in the study basin. Indeed, the estimates of the soil losses using RUSLE are theoretical and relatively reflect the reality of the basin.

Figure 10: Soil loss rates in the Mellegue watershed

Figure 10 shows that the areas with a high soil erosion are found mainly in the north and southeast of the Mellegue watershed, essentially at Chabro sub-watershed. In order to be able to analyze and assess the soil erosion intensity, soil erosion values are grouped into five classes. The value of $7.00 \text{ T ha}^{-1} \text{ yr}^{-1}$ is used as the average tolerance limit for soil erosion (Sadiki et al., 2004).

Soil losses are spatially connected with the vegetation, slope, gradient and rainfall maps, in a way where erosion is dependent mostly on topography, forest, runoff, and land cover of the study region. The LS factor is an essential factor in erosive potential. Slopes are linked to lithology; steep slopes are often found on hard rocks, while soft rocks give less steep surfaces. Usually, soil losses may therefore be higher on moderate slopes. Mountain soils, often superficial, are mixed with various rock fragments

which will increase their resistance to the beat of raindrops and to the shear of runoff (Roose et al., 1993). In the forest region, the soil is permanently covered (C close to zero) and the rates of water erosion become practically zero.

The soil losses at the study watershed vary from 0 to 374.5 T/ha/year with a mean value of 20.4 T/ha/year (Table 3). Depending on the sub-watershed, the mean erosion estimation varies between 12.5 T/ha/year and 21.8 T/ha/year.

Table 3: Soil losses in the sub-watersheds and Mellegue watershed				
Watershed	Mean (T/ha/year)	Coefficient of variation	Minimum	Maximum
Downstream Mellegue	18.80	3.23	1.20	204.70
Meskiana	12.50	2.90	0.00	125.60
Chabro	21.80	3.67	2.00	374.50
Mellegue basin	20.40	2.56	0.00	374.50

According to table 4, we can see that very low erosion potential belongs to soil loss of less or equal to 7 T/ha/year and which represents more than half (64.6%) of the total basin area. This is explained by the low values of LS factor and by the protective effect of the vegetation in the sloping areas. Soil losses greater than 30 T/ha/year occupy only 9.1% of the total area and are located mainly in areas of steep slopes where the soil has fragile skin composed of marly and clayey types. The erosion potential of this area is distinguished by an intensity of high to very high.

Table 4: Classes and intensity of soil losses in the Mellegue watershed			
Soil loss classes (T/ha/year)	Erosion intensity	Basin area (km ²)	Basin area (%)
0 - 7	very low	2955.4	64.60
7 - 15	low	702.00	15.30
15 - 30	moderate	503.70	11.00
30 - 60	high	195.80	4.30
> 60	very high	218.10	4.80

The minimum soil loss is observed at the Meskiana sub-basin. It can partly be explained by the slight slopes of this sub-basin comprising a large alluvial plain (slope < 3°). On the contrary, the maximum soil loss is seen at the Chabro sub-basin (Figure 10). It is high because of the steep slopes and the marly-clayey soils of the hills delimiting the sub-basin. However, the downstream alluvial plain presents a much lower erosion (< 7 T/ha/year). The high coefficient of variation reflects this disparity in the values of soil losses observed in the Chabro sub-basin. The downstream Mellegue sub-basin has an intermediate soil loss value. The variability is less high than that of the Chabro watershed, which reflects a more homogeneous spatial distribution of the erosive phenomenon.

The comparison of the distribution of the erosion potential classes by sub-watersheds using Table 5 shows that the Chabro sub-watershed and downstream Mellegue sub-basin are the ones that contain the most surface at very high to high risk of erosion with 13 to 14% of their basin areas respectively. Meanwhile, the downstream sub-watershed manifests the highest susceptibility to erosion because 36% of its total area represents soil losses greater than 15 T/ha/year. Furthermore, the Meskiana sub-basin seems to be the least sensitive to the erosive process, in which almost 90% of its surface presents a very low to low erosion risk (0 to 15 T/ha/year).

Table 5: Soil erosion results in the Mellegue sub-watersheds							
	Sub-basins	Downstream Mellegue		Meskiana		Chabro	
Erosion potential	Soil loss classes (T/ha/year)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Very low	0 - 7	416.20	35.60	1448.50	78.50	1090.70	69.90
Low	7 - 15	332.60	28.40	202.40	11.00	167.00	10.70

Moderate	15 - 30	255.10	21.80	147.00	8.00	101.60	6.50
High	30 - 60	69.60	6.00	40.90	2.20	85.30	5.50
Very high	> 60	96.50	8.20	6.20	0.30	115.40	7.40

4.2 Soil losses according to land use

GIS and the RUSLE model make it possible to obtain a value for the average erodibility potential for the different land use classes. Analysis of the map of soil losses classified according to land use shows that four of the six land uses are responsible for 97% of soil losses according to the RUSLE model (Table 6).

Table 6: Soil loss according to land use					
Land use	Occupation Km ² %		Mean soil loss (T/ha/year)	Soil loss volume (Kt/year)	Soil loss (%)
Barren soil	537.20	11.80	63.20	3421.50	40.70
Grassland, steppes	1203.30	26.30	20.80	1902.70	22.60
Cultures	1462.80	32.00	6.70	715.00	8.50
Sparse forest, shrubs	1013.50	22.20	27.30	2132.50	25.40
Dense forest	303.90	6.60	7.00	225.40	2.70
Humid zone	49.30	1.10	3.30	11.60	0.10
Watershed	4575	100	21.58	8408.70	100

Crops have a low soil loss of 6.7 T/ha/year; however, they represent 32% of the basin area and the volumes generated are therefore significant (with 8.5% of total soil losses). The grassland and steppes, with a risk of almost 21 T/ha/year, represent 26.3% of the basin and are an important source of sediment (with 22.6% of total soil losses). The sparse forest and shrubs, with soil loss of 27.3 T/ha/year, are areas considered as a source of sheetwash and rill processes. The presence of these vegetal covers are almost exclusively observed on moderate and/or steep slopes, which explains the high value of the erosive risk observed for these land use types. Barren soils, although representing only 12% of the basin area, are the largest producer of fine sediments, with a very high soil loss (63.2 T/ha/year). Its soil loss is estimated at almost 41% of total soil losses, with an erosion potential that belongs to the very high class.

5. CONCLUSION

The RUSLE model adopted for estimating the soil erosion in the Mellegue watershed has provided satisfactory results and can be used for estimating soil loss in additional similar micro-watersheds. The mean soil loss using RUSLE is found to be equal to 20.4 T/ha/year; which leads to point that the Mellegue basin presents a moderate soil erosion loss. In fact, the erosive risk is tolerable in the Meskiana sub-watershed. In the Chabro sub-basin, the erosion potential is intense but localized in its periphery at hills and piedmonts. On the other hand, it is high and generalized over the northern sub-basin of the study area (downstream sub-basin). With regard to the risk of erosion depending on land use, the majority of soil losses are due to grasslands and steppes, sparse forests and shrubs, barren soils and bedrocks. Although, they are presenting low potential erosion, the cereal crops cannot be neglected because of their concerned large areas, with 32% of the basin area.

The results obtained by the RUSLE model can provide valuable assistance, at very low costs, to decision-makers and land developers in order to simulate evolution scenarios, and subsequently show priority areas that require conservation and erosion control. Also, it should be noted that vegetal cover is a parameter on which land use planning actions must be based to limit sensitivity to land erosion. Sustainable land management practices are urgently needed to reduce the rates of soil erosion located mainly in the north and southeast parts of the Mellegue watershed in order to improve land productivity and farm program practices. Agricultural activities and irrigation practices should continue to be improved by using development of terraces, the practice of crop rotation and the improvement of agroforestry practices. Reforestation with Aleppo pine trees provides protection against scour and minimizes the risk of erosion by reducing the stream flow rate.

This study developed for soil loss mapping provides the primary information that can assist in watershed management for the Direction of Agriculture and the Agency of Dams. It can use such information to decide for soil conservation measures, land degradation and decrease in soil loss and to prevent Ouldjet Mellegue dam from future siltation. Based on these premises, future studies should advance knowledge of the main factors influencing adoption of soil conservation measures. It is also strongly recommended that more developed technical approaches and solutions should be applied to solve similar sedimentation problems in other existing reservoirs.

REFERENCES

- Achite, M., Ouillon, S., 2016. Recent changes in climate, hydrology and sediment load in the Wadi Abd, Algeria (1970–2010). *Hydrology and Earth System Science*, 20(4), 1355-1372.
- Ali, S.A., Hagos, H., 2016. Estimation of soil erosion using USLE and GIS in Awassa Catchment, Rift Valley, Central Ethiopia. *Geoderma Regional*, 7, 159-166.
- Angassa, A., 2014. Effects of grazing intensity and bush encroachment on herbaceous species and rangeland condition in Southern Ethiopia. *Land Degradation and Development*, 25(5), 438-451.
- Bayramin, I., Basaran, M., Erpul, G., Canga, M.R., 2008. Assessing the effects of land use changes on soil sensitivity to erosion in a highland ecosystem of semi-arid Turkey. *Environmental Monitoring and Assessment*, 140, 249-265.
- Benselama, O., Mazour, M., Hasbaia, M., Djoukbal, 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*, 190, 735.
- Bollinne, A., Rosseau, P., 1978. Erodibilité des sols de moyenne et haute Belgique, utilisation d'une méthode de calcul du facteur K de l'équation universelle de perte en terre [The soil erodibility of the medium and high Belgium, using a method of calculating the K factor of the universal soil loss equation]. *Bulletin Société Belge d'Etudes Géographiques*, 14(4), 127-140.
- Bouderbala, D., Souidi, Z., Donze, F., Chikhaoui, M., Nehal, L., 2018. Mapping and monitoring soil erosion in a watershed in western Algeria. *Arabian Journal of Geosciences*, 11, 744.
- Bouguerra, H., Bouanani, A., Khanchoul, K., Derdous, O., Tachi, S.E., 2017. Mapping erosion prone areas in the Bouhamdane watershed (Algeria) using the Revised Universal Soil Loss Equation through GIS. *Journal of Water and Land Development*, 32, 13-23.
- Bouhadeb, C.E., Menani, M.R., Bouguerra, H., Derdous, O., 2018. Assessing soil loss using GIS based RUSLE methodology. Case of the Bou Namoussa watershed – North-East of Algeria. *Journal of Water and Land Development*, 36, 27-35.
- Bouzeria, H., Ghenim, A.N., Khanchoul, K., 2017. Using artificial neural network (ANN) for prediction of sediment loads, application to the Mellah catchment, northeast Algeria. *Journal of Water and Land Development*, 33, 47-55.
- Ferreira, V., Panagopoulos, T., Andrade, R., Guerrero, C., Loures, L., 2015. Spatial variability of soil properties and soil erodibility in the Alqueva reservoir watershed. *Solid Earth*, 6(2), 383-392.
- Ganasri, B.P., Ramesh, H., 2016. Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi basin. *Geoscience Frontiers*, 7, 953-961.
- Gessesse, B., Bewket, W., Bräuning, A., 2016. Determinants of farmers' tree-planting investment decisions as a degraded landscape management strategy in the central highlands of Ethiopia. *Solid Earth*, 7, 639-650.
- Gliz, M., Remini, B., Anteur, D., Makhoulf, M., 2015. Vulnerability of soils in the watershed of Wadi El Hammam to water erosion (Algeria). *Journal of Water and Land Development*, 24, 3-10.
- Hallouz, F., Meddi, M., Mahé, G., Alirahmani, S., Keddar, A., 2018. Modeling of discharge and sediment transport through the SWAT model in the basin of Harraza (Northwest of Algeria). *Water Science*, 32, 79-88.
- Haregeweyn, N., Tsunekawa, A., Nyssen, J., Tsubo, M., Meshesha, D.T., Schutt, B., Adgo, E., Tegegne, F., 2015. Soil erosion and conservation in Ethiopia: a review. *Progress in Physical Geography*, 39(6), 750-774.
- Haregeweyn, N., Tsunekawa, A., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J., Adgo, E., 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: case study of the Upper Blue Nile River. *Science of the Total Environment*, 574, 95-108.
- Hurni, H., 1985. Erosion-productivity conservation systems in Ethiopia. *Proceedings of 4th International Conference on Soil Conservation*, Maracay, Venezuela, 654-674.
- Khanchoul, K., Boubehziz, S., 2019. Spatial variability of soil erodibility at El Hammam catchment, northeast of Algeria. *Environment and Ecosystem Science*, 3(1), 17-25.
- Koirala, P., Thakuri, S., Chauhan, S.J.R., 2019. Estimation of Soil Erosion in Nepal Using a RUSLE Modeling and Geospatial Tool. *Géosciences*, 9, 1-19.
- 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). *Agriculture and Forestry Journal*, 3(1), 36-45.
- Lal, R., 2001. Soil degradation by erosion. *Land Degradation Development*, 12, 519-539.
- 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. *Bulletin - Réseau Erosion*, 21, 320-330.
- Mitasova, H., Hofierka, J., Zlocha, M., Iverson, R., 1996. Modeling topographic potential for erosion and deposition using GIS. *International Journal of Geographic Information Systems*, 10, 629-641.
- Morsli, B., Mazour, M., Mededjel, N., Hamoudi, A., Roose, E., 2004. Influence de l'utilisation des terres sur le risque du ruissellement et d'érosion sur les versants semi-arides du nord-ouest de l'Algérie. *Note de recherche. Sécheresse*, 15 (1), 96-104.
- Narayan, K., Khanindra, P., Abhisek, C., Satiprasad, S., 2018. Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hillslope mining areas. *International Soil and Water Conservation Research*, 6, 31-42.
- Nasl'haj, Y., 2009. Evaluation de l'érosion des sols et proposition d'aménagement du bassin versant à l'amont du barrage Hassan II, Haute Moulouya, Maroc. *Mémoire de troisième cycle*, IAV, Rabat, 77.
- Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science and Policy*, 54, 438-447.
- Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE: revised universal soil loss equation. *Journal of Soil and Water Conservation*, 46 (1), 30-33.
- Roose, E., Arabi, M., Brahamia, K., Chebbani, R., Mazour, M., Morsli, B., 1993. Erosion en nappe et ruissellement en montagne algérienne. *Cahier - ORSTOM. Pédologie*, 28(2), 289-308.
- Sadiki, A., Bouhlassa, S., Auajjar, J., Faleh, A., Macaire J.J., 2004. Utilisation d'un SIG pour l'évaluation et la cartographie des risques d'érosion par l'Equation universelle des pertes en sol dans le Rif oriental (Maroc) : cas du bassin versant de l'Oued Boussouab. *Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Terre*, 26, 69-79.
- Sahli, Y., Mokhtari, E., Merzouk, B., Laignel, B., Vial, C., Madani, K., 2019. Mapping surface water erosion potential in the Soummam watershed in Northeast Algeria with RUSLE model. *Journal of Mountain Science*, 7,

- 1606-1615.
- Selmi, K., Khanchoul, K., 2016. Sediment load estimation in the Mellegue catchment, Algeria. *Journal of Water and Land Development*, 31, 129-137.
- 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*, 4, 190-210.
- Tully, K., Sullivan, C., Weil, R., Sanchez, P., 2015. The state of soil degradation in sub-saharan Africa: baselines, trajectories, and solutions. *Sustainability*, 7(6), 6523-6552.
- Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion. A guide to conservation planning. USDA-ARS. Agriculture Handbook, 537, 58.
- Yesuph, A.Y., Dagne, A.B., 2019. Soil erosion mapping and severity analysis based on RUSLE model and local catchment of the Blue Nile Basin, Ethiopia. *Environmental Systems Research*, 8(17), 1-21.