EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(5), 42–53
https://doi.org/10.12912/27197050/151631
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Received: 2022.06.22
Accepted: 2022.07.16
Published: 2022.08.01

Quantification and Evaluation of Water Erosion by RUSLE/GIS Approach in the Ykem Watershed (Western Morocco)

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ABSTRACT

The Water erosion of soils considered the main cause of soil degradation in Morocco. Soil erosion not only reduces agricultural productivity but also reduces water availability, and negatively contributes to the quality of drinking water sources. Consequently, the assessment of soil erosion risk has become the objective of several researches at the Moroccan level. It is in this context the purpose of this study is to assess the soil erosion risk using a Revised Universal Soil Loss Equation (RUSLE) / Geographic Information System (GIS) approach at the scale of the watershed of the Oued Ykem (western Morocco). (GIS) techniques were adopted to process the data obtained at the watershed scale, of reasonable spatial resolution (30 m) for the application of the RUSLE model. The latter is a multiplication of the five factors of erosion: the rainfall erosivity (*R*), the soil erodibility (*K*), the slope length and steepness (*LS*), the cover and management and the support practice (*P*). Each of these factors has been expressed as a thematic map. The Oued Ykem watershed is an elongated coastal basin with an area of 516 km^2. It is part of the Atlantic coastal basins of western Morocco. It is located southwest of the city of Rabat. Oued Ykem is characterized by a semi-arid climate with oceanic influence. Rare and irregular rains, mostly stormy in nature, combined with deforestation, cause erosion and irregular flow. Its flow-rate increases during the winter. Extreme flows-rate can be recorded after exceptional and very intense showers upstream of the basin. The resulting soil loss map, with an average erosion rate varying from 0 to 54 t/ha/year, showed low erosion. Areas with a strong erosion rate exceeding 30 t/ ha/ year cover about 3.8 % of the basin area. The analysis of the erosion risk map, in comparison with the maps of the different factors in the equation, showed a clear and important influence of the vegetation cover on the soil erosion (C factor is from 0.03 to 0.9), followed by the topographic factor, especially the slope (LS factor varies from 0 to 56.71).

Keywords: Ykem watershed, Atlantic coastal basins, water erosion, RUSLE model, geographic information system.

INTRODUCTION

Land degradation through water erosion is a major phenomenon that reduces the production potential of soil or the quality of natural resources. This phenomenon can be caused by a natural process such as the steep slope and aggressiveness of the rains, and other directly or indirectly anthropogenic factors such as climate change, rapid population growth, deforestation, human activities and poor use of agricultural land (Gelagay and Minale, 2016). Water erosion can cause on-site and off-site consequences, the first being particularly linked to deterioration and reduction in fertility of agricultural land, due to the loss of nutrients and organic matter. Off-site problems are often more serious and more severe, including siltation of dams, sedimentation of reservoirs, transport of pollutants, change in morphology, and increased flooding risk (Raissouni, 2012).

Soil erosion has become a relevant issue globally. In Morocco, in particular, soil erosion has experienced spectacular expansion in recent decades and is causing increasingly worrying on-site and off-site effects, following natural conditions and human impact, especially in the north. But also, in other areas of the country including the Atlantic coastal plains with a lower risk but locally very marked. In Morocco, 40% of the land is affected by water erosion (Chevalier et al., 1994). Acording to the physical characteristics of the Moroccan environment, several natural and anthropogenic factors contribute to the development of erosion processes such as: a fragile ecosystem due to climate change and irregular rainfall, a hilly and mountainous topography and fragile geological substrates. As a result, the consequences of soil degradation in the Moroccan context can result in reduced soil productivity, forest degradation, siltation of dams and reduction in the storage capacity of Moroccan dams with 75 million m^3/year (HCEFLCD, 2007). In Morocco, the intensity of water erosion varies from area to area. The area most affected by water erosion is the northern part of the country, in fact several local studies have been applied to assess and quantify the risk of erosion, particularly in the Rif, Pre-Rif and in the Middle and High Atlas. In some parts of the Rif in northern Morocco, erosion rates sometimes reach 30 to 60 t/ ha/year (Lahlaoi et al., 2015; Ait Fora, 1995) and reach 2000 t/km^2/year for the central and western Rif (Mhirit and Benchekroun, 2006). In the Middle and High Atlas, the annual averages would oscillate between 500 and 1000 t/km^2/year and from 1000 to 2000 t/km^2/year in the Pre-Rif and the Mediterranean areas. The quantification and mapping of the risks of soil loss can be done through two types of direct and indirect measurement. Measuring erosion by direct methods is a complex and demanding process for assessing soil loss (Duarte et al., 2021). The indirect method is essentially based on equations and mathematical prediction models largely reinvented following the evolution of technology over the past half century. Several models have been adopted, including some empirical which call for several parameters such as: precipitation, lithology, topography and plant cover. The most widely used and well-known empirical model is the Universal Soil Loss Equation (USLE) and its modified versions. Another physical-based model can provide a spatial estimate of sedimentation at the level of a watershed (Gumière, 2009). A series of physical-based models have been developed such as: The Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) (Beasley, Huggins and Monke, 1980), Watershed Erosion Prediction Project (WEPP) (Nearing et al., 1989), The kinematic runoff and erosion model (KINEROS) (Smith and Goodrich, 1986), Soils Water Assessment Tools (SWAT) (Arnold et al., 1998), The Limburg Soil Erosion Model (LISEM) (Roo, Wesseling and Ritsema, 1996), (Distributed Hydrological Modelling of Agro-Systems (MHYDAS) (Moussa et al., 2002), Plot Soil Erosion Model 2D (PSEM_2D) (Nord and Esteves, 2005), etc. The empirical USLE model is a prediction model based on the universal equation of (Wischmeier and Smith, 1978). This model was invented for the first time in the United States for the fight against soil loss in small agricultural plots. Subsequently the USLE model found wide use worldwide for estimating erosion in large watersheds on a regional and global scale. USLE predicts long-term average and annual erosion rate on a field slope as a function of rainfall regime, soil type, topography, cropping system and management practices (Kouli et al., 2009).

Several versions of this model have been modified, of which we can distinguish: the original USLE, the (RUSLE), the Revised Universal Soil Loss Equation Version 2 (RUSLE2) (Scheffe, 2008), and the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation-3D (RUSLE-3D) (Mitasova et al., 1996) and Revised Universal Soil Loss Equation incorporating the information diffusion model (RUSLE-IDM); (Xu and Meng, 2013). The RUSLE model (Renard et al., 1997) proposes the same formula as the USLE (Wischmeier and Smith, 1978) but several improvements are made for the determination of the different erosive factors. This included, a different approach to the soil erodibility K and for the topographic factor LS, and a new value for the factor C and conservation practices P. The RUSLE method is considered simple and incorporates readily available and accessible data. Applications of GIS are often combined with soil erosion models as an effective approach to estimate the extent and distribution of erosion (Jahun et al., 2015). The coupling of the RUSLE model with GIS makes it possible to manipulate and analyze a large amount of data. Indeed, the application of this model requires the calculation of the various factors involved in the erosive processes and their spatialization in the form of thematic maps. The integration of these data into the GIS allows them to be superimposed and the rate of erosion to be evaluated by applying the formula of the equation of (Wischmeier and Smith, 1978):

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

where: A – the average annual soil losses [t/(ha·year)];
R – the rainfall-runoff erosivity factor [MJ·mm/(ha·year·h)];
K – the soil erodibility factor [t·h/(MJ·mm)];
LS – the topographic factor;
C – the land cover and management factor;
P – the cultural and anti-erosion practices factor.

The evaluation of the risk of water erosion by GIS adopting the RUSLE model has been used in several studies on erosion in the different geological domains of Morocco (Hara et al., 2020; Bou-Imajjane et al., 2020; Aroussi et al., 2011), regional (Medhioub et al., 2018; Khemiri and Jebari, 2021; Boussadia-Omari et al., 2021; Bouhadeb et al., 2018) and international (Efthimiou, et al., 2020; Azaiez, 2021; Senanayake et al., 2020).

The objective of this study is to analyze the morphometric parameters of the Ykem watershed, and to estimate the soil loss and its spatial distribution using the RUSLE / GIS approach using rainfall data, soil, digital terrain model and land use map.

MATERIAL AND METHODS

Study area

Oued Ykem, including Cherrat, Nfefikh and Mellah Oueds are part of the Atlantic coastal basins of western Morocco (Fig. 1). They are located between Rabat and Casablanca and administrated by the "Hydraulic Basin Agency of Bouregreg and Chaouia" (ABHBC, 2012).

Oued Ykem is situated in the Skhirate-Temara province, and covers an area of 516 km^2, representing 9.5% of the total area of the coastal basins. It is located between the meridians 7°01'W and 6°47'W and the parallels 33°31'N and 33°59'N. It is bounded to the North by Ain Al Ouda village, to the west by the city of Skhirate, to the northeast by the city of Temara. The region's climate is a humid to sub-humid Atlantic climate, characterized by an average annual precipitation of 350 to 450 mm. The minimum annual temperature is 12.63 °C and the maximum temperature is 22.64 °C with an average temperature of 17.46 °C.

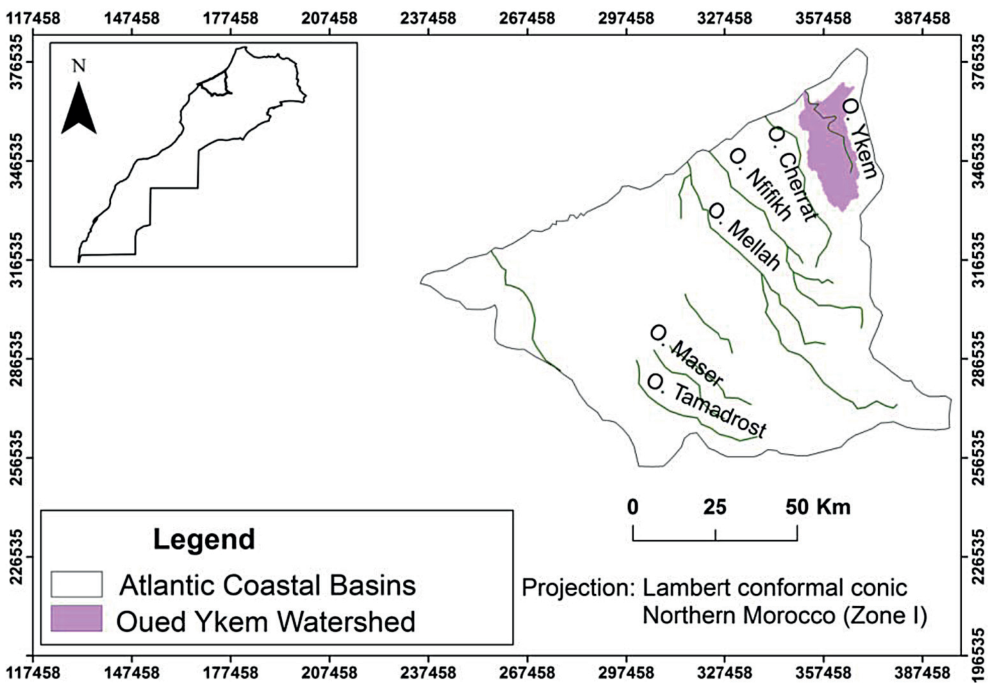

Figure 1. Geographical location map of the Oued Ykem watershed

Datasets used

The RUSLE model is selected among the most applicable models thanks to its very simple structure and the economical input of data in relation to the available data and the scale of the investigation (Issa et al., 2016). The equation has been integrated under a GIS to allow comprehensive modeling and mapping of the erosion phenomenon. The realization of this modeling requires the collection of several data as defined in data as defined in Table 1: the DTM, rainfall data, soil data, and land use.

RUSLE parameters computation

The erosivity (R)

The erosivity factor can be defined as the capacity and intensity of rainfall to cause soil erosion (Shrestha et al., 2020; Le Roux, 2007). It reflects and quantifies the effect of the precipitation impact and runoff on soil loss (Gelagay and Minale, 2016).

R-factor modeling requires continuous and precise precipitation data such as kinetic energy of rainfall and maximum rainfall intensity for 30 minutes (Wischmeier and Smith, 1978).

According to the lack of these data in several countries around the world, (Arnoldus, 1980) had developed a formula that only involves monthly and annual rainfall data (Equation 2).

$$R = \text{Log}\, R = \\ = 1.74.\,\text{Log} \sum (Pi2/P) + 1.29 \quad (2)$$

where: Pi is the monthly precipitation in mm and P is the annual precipitation in mm.

Rainfall data for the study area spanning 33 years (1984 to 2017) were collected by the ABHBC Agency. These data are monthly and annual distributed over 5 stations that surround Oued Ykem watershed. These values were analyzed and interpolated using the Kriging tool (Geostatistical wizard) from Arc GIS software.

Topographic factor (LS)

The topography of the land plays a decisive role in the phenomenon of erosion. The LS factor combines the length (L) and inclination of the slope (S). It reflects the direct influence of these two parameters on the detachment and transport of soils and sediments under the effect of runoff and / or precipitation [56]. As the steepness (S) and length of the slope (L) are greater, the risk of erosion increases. The calculation of the LS factor is based on Equation 2 (Wischmeier and Smith, 1978):

$$LS = (L \div 22.13)^{\text{m}} \times \\ \times (0.0065 + 0.045 \times S + 0.0065 \times S^2) \quad (3)$$

where: L is the slope length in (m), S is the angle of slope expressed in percent, m is a constant dependent on the value of the slope: 0.5 if the slope angle is greater than 5%, 0.4 on slopes of 3% to 5%, 0.3 on slopes of 1 to 3%, and 0.2 on slopes less than 1%.

The slopes and the accumulation of flows in the studied area were extracted from the DTM with a resolution of 30 m.

Calculation of the LS factor was performed on ArcGIS, based on Equation 4 (Bizuwerk, Taddese and Getahun, 2008):

$$S = (FA \times CS \div 22.13)^{\text{m}} \times \\ \times (0.0065 + 0.045 \times S + 0.0065 \times S^2) \quad (4)$$

where: FA is the flow accumulation and CS is the cell size (for this study 30 m).

Soil erodibility (K)

Soil erodibility refers to the resistance capacity of soil particles and surface material to

Table 1. Description of datasets used for the RUSLE modeling

Data type	Source	Resolution	Coordinate system	Description
GDEM-ASTER (DEM)	Earth Explorer: https://earthexplorer.usgs.gov/	30 m	UTM, WGS 84, ZONE 29	Satellite image (Aster GDEM), Date October 17, 2011.
Landsat	Earth Explorer: https://earthexplorer.usgs.gov/	30 m	UTM, WGS 84, ZONE 29	Two landsat 8 OLI/TIRS, Path 202, Row 37; Date August 20, 2017, and July 14, 2021.
Soil data	HWSD/Version 1.2, FAO: FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009		UTM, WGS 84	Harmonized Soil Map of the World based on the soil textures.
Data climate	Hydraulic Basin Agency of Bouregreg and Chaouia			Precipitation data from 5 stations over 33 years (1984 to 2017).

erosion. It depends on the organic matter, the texture, the permeability and the structure of the soil profile. It generally depends on the nature of the soil, the inclination of the slope and the density of the vegetation cover.

For the present study, we used the HWSD database (FAO, 2009). It is composed of a raster image file coupled with an attribute database containing several characteristics of soil types (Moore and Wilson, 1992) (FAO, 2009). The modeling *K* factor through HWSD involves importing raster layers using Arc GIS software. In order to estimate the *K* factor values we used the equations 4 to 8, proposed by (Williams and Singh, 1995):

$$K_{usle} = f_{csand} \times f_{cl-si} \times f_{org} \times f_{hisand} \quad (5)$$

where: K_{usle} is the erodibility factor;
f_{csand} is a factor, that lowers the *K* indicator in soils with high coarse-sand content and higher for soils with little sand;
f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios;
f_{orgc} reduces *K* values in soils with high organic carbon content;
f_{hisand} lowers *K* values for soils with extremely high sand content:

$$f_{csand} = (0.2 + 0.3 \times \times exp^{0.256 \times ms\left(1-\frac{msilt}{100}\right)}) \quad (6)$$

$$f_{cl-si} = \left(\frac{msilt}{mc + msilt}\right)^{0.3} \quad (7)$$

$$f_{orgc} = (1 - 0.25 \times orgc + +exp^{3.72-2.95 \times orgc}) \quad (8)$$

$$f_{hisand} = (1 - \frac{\left(0.7 \times 1 - \frac{ms}{100}\right)}{1 - \frac{ms}{100}} + +\exp^{-5.5+22.9\times\left(1-\frac{ms}{100}\right)} \quad (9)$$

where: *ms* is the percentage of sand;
msilt is the percentage of silt;
mc is the percentage of clay;
orgc is the percentage of organic matter.

Cover and management (C)

Vegetation plays a decisive role in protecting the soil against erosion. Vegetation cover is considered the second factor (after topography) to control the risk of soil water erosion (Thiaw, 2017). The vegetation rate is often estimated by the C factor which represents the cover and the degree of crop production. Several studies have determined C factor from Normalized Difference Vegetation Index (NDVI). According to (Kouli, Soupios and Vallianatos, 2009), the NDVI is the most widely used index in the field of remote sensing for the assessment of vegetation cover development. In our study, the calculation of the NDVI and the C factor were based on the interpretation of Landsat OLI/TIRS satellite images. These images were taken in 08/20/2017.

NDVI was calculated as euqation 10:

$$\text{NDVI} = ((\text{NIR} - \text{R}) \div (\text{NIR} + \text{R})) \quad (10)$$

where: NIR is near-infrared band;
R is band of Red.

C factor was generated based on NDVI using the equation 10 (Chadli, 2016) (Thiaw, 2017):

$$\text{C} = \exp^{-(2\times\text{NDVI})\div(1-\text{NDVI}))} \quad (11)$$

Support practice factor (P)

The support practice factor generally from 0 to 1, depending on the practice adopted and the slope. Due to the lack of anti-erosion practices observed during the field visits, this factor was considered to be equal to 1.

RESULTS AND DISCUSSION

Erosivity (R)

The map of the rainfall erosivity R factor (Fig. 2A), with varying values between 68.08 $MJ\cdot mm\cdot ha^{-1}\cdot h^{-1}\cdot yr^{-1}$ at the station of Chaikh Rguig and 83.3 $MJ\cdot mm\cdot ha^{-1}\cdot h^{-1}\cdot yr^{-1}$ in Ain Ouda, showed an increase from North-West to South-East, indicating the effect of continentality on precipitation. These results showed a small decreasing spatial variation from north to south, going from the outlet to the upstream of the watershed.

Topographic factor (LS)

Taking as input the Flow accumulation and the slope classes in percentage, the LS factor results show a variation from 0 to 56. These results show that the majority of the study area has an LS factor less than 3.

The map (Fig. 2B) generally reflects the topography of the terrain. Values between 2 and 25 are distributed throughout the basin covering most of it. The remaining part of the basin area is greater than 20, scattered throughout the area, generally coinciding with areas with high slopes and at the level of lower part of the watershed due to high-flow accumulation, which has LS values of 12 to 56.

Soil erodibility (K)

The spatial distribution of the two different classes of the K factor in the Ykem watershed shows values of the erodibility index between 0 and 0.160 t·h·MJ^{-1}·mm^{-1}, also distributed over two homogeneous units of the study area. The watershed generally has a low erodibility (0.125 0.160 t·h·MJ^{-1}·mm^{-1}), covering the entire area of the basin, with a low erodibility for Planosols (0–0.125 t·h·MJ^{-1}·mm^{-1}) around 30% and that medium (0.125–0.160 t·h·MJ^{-1}·mm^{-1}) for Luvisols with 70% of the watershed surface (Fig. 3A).

Cover and management factor (C)

Table 2 and the map of the C factor (Fig. 3B) show the values ranged from 0 to 0.9 corresponding to the different types of land use in the basin of Oued Ykem. Indeed, the results of C factor of the present study show six land use classes that vary from 0 to 0.9, the strong values of this factor from 0.7 to 0.9 correspond to bare soils, these values cover an area of 76.95 km^2, and this represents 14.92% of the basin area. The low values correspond to highly protected areas where the vegetation is very dense (forest class); the values vary from 0.03 to 0.3 for an area of 50.9 km^2 and this represent 9.9% of the surface.

C Factor is closely related to types of land use. It varies from almost zero for well protected soils to 1.5 for surfaces very sensitive to erosion (Angima et al., 2003).

Soil losses

The multiplicative superposition of all of the thematic maps related to erosive factors made it possible to obtain the soil loss map, expressing the potential erosion value in t/ha/year per spatial unit.

Table 2. Distribution of C factor

C-factor	Area (km^2)	Area (%)
0.03–0.3	50.91	9.91
0.3–0.4	116.86	22.75
0.4–0.6	111.88	21.78
0.6–0.7	155.07	30.18
0.7–0.9	76.65	14.92

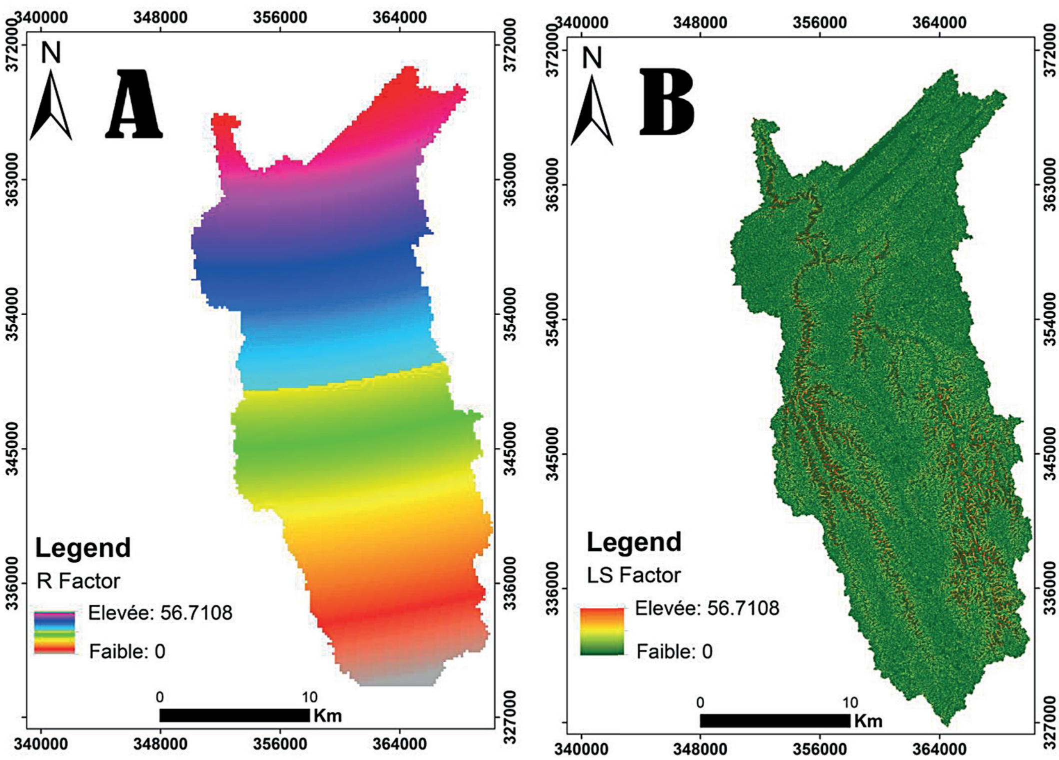

Figure 2. (A) Rainfall erosivity map, (B) Topographic factor (LS)

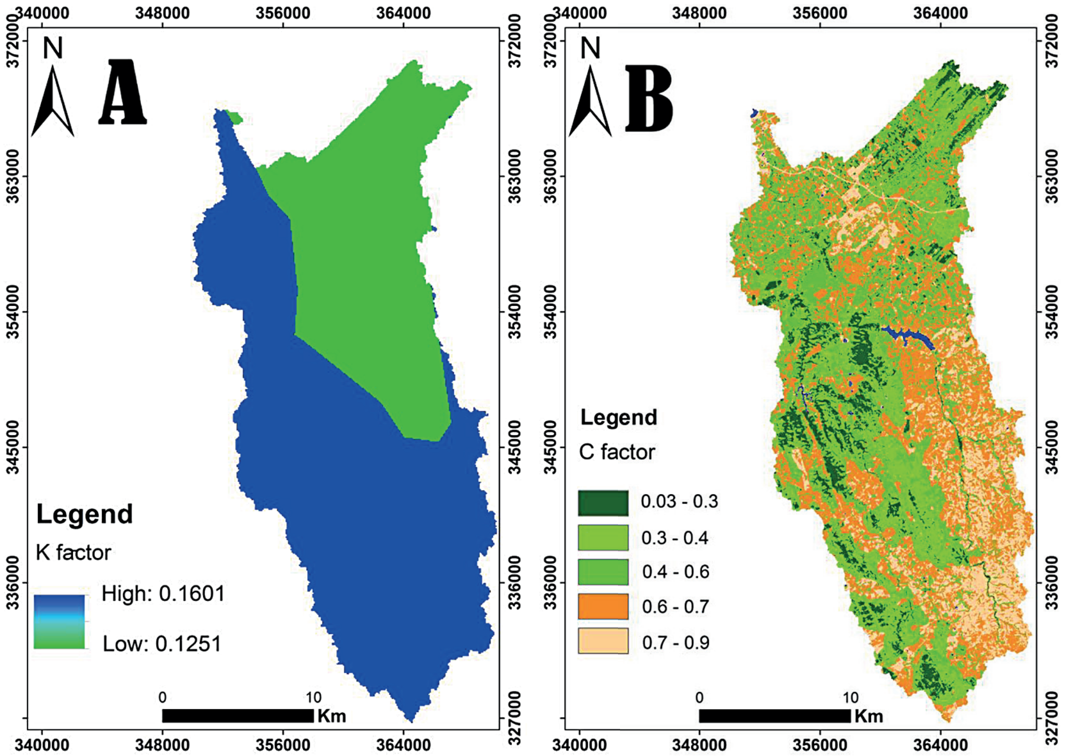

Figure 3. (A) Soil erodibility (K) map, (B) Crop management factor (C) map

The map obtained (Fig. 4) showed erosion rates varying between 0 and more than 50 t/ha/year distributed over the entire study area. For a better readability of this map, we have adopted the classification most used in the various erosion studies adopting the RUSLE application (Markhi et al., 2015; Modeste et al., 2016; Van der Knijff, Jones and Montanarella, 2000; Angima et al., 2003). This shows that soils can tolerate losses of up to 7 t/ha/year, while above 20 t/ha/year the losses become alarming (Table 3).

In this work, we have classified the soil loss map into 4 classes for a better spatial visualization of soil loss (Table 4). However, the discussion of the results will take into account the following thresholds: very low erosion (0–1.5 t/ha/year) which represents 81.23% of the area, low (1.5–6 t/ha/year) which represents 14.94%, average (6–14 t/ha/year) which occupies 3.07%, strong and very strong (14–50 t/ha/year) which occupies 0.74%. The first two classes are distributed throughout the watershed while the last two are mainly located upstream and on hills and slopes characterized by steep slopes and favorable substrate. According to the erosion classification proposed by (Wall et al., 1987) and that proposed by (FAO, 1979), the study area shows that 96.18% of the basin area is at low risk of erosion, while only 3.81% is medium at high risk of erosion. These results show that more than 96.18% of the area has less than 7 t/h/year of soil loss, the tolerable threshold of soil loss for Wischmeier.

The erosion class map shows a sporadic spatial distribution of erosion classes, which clearly showed the cumulative impact of the various factors responsible for erosion. The unequal distribution of soil losses in the different areas of the watershed is due to the great variability presented by the different factors from one sector to another. Figure 5 shows ravines in the Ykem watershed.

Indeed, the erosion map showed that soil losses are often located upstream of the watershed and at the level of notches and valleys. This is perhaps explained by the lack of plant cover upstream, more precisely the southwestern part of the basin, the low altitudes, the importance of rainfall aggressiveness upstream compared to the downstream, and the steep slope around valleys.

Table 3. Classification of soil loss

Classes of soil loss (t/ha/year)	Risk class
0–11	Very weak to weak
11–22	Moderate
22–33	Strong
> 33	Very high

Table 4. Distribution and classification of soil loss

Classes (t/ha/year)	Average annual soil losses (t/ha/year)	Area (km²)	Area (%)	Risk class
0–1.47	0.21	408.49	81.23	Very low
1.47–6	2.76	75.17	14.94	Low
6–14	8.43	15.45	3.07	Moderate
14–53	19.14	3.74	0.74	High to very high

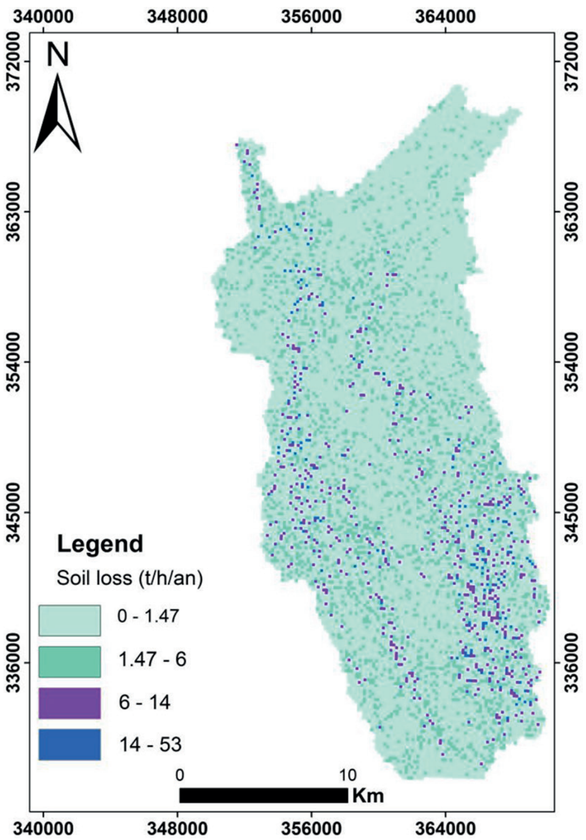

Figure 4. Estimated soil losses map of the Oued Ykem watershed

From a pedological point of view, the watershed shows a wide distribution of hydromorphic soils with a clay texture, which are little affected by water erosion (Ghanem, 1981). Erodible fersiallitic soils are often found in areas where vegetation cover is important. The distribution of these soils in areas with very steep slopes explains the increased soil loss in the notches and valley. In addition to a low erodibility (K between 0.12 and 0.16; Fig. 3A) which contributes to reduce soil loss.

Comparison of the soil loss map with the other factors showed that the erosion phenomenon is strongly influenced by the vegetation cover and the topographic factor. The comparison of these results with other studies carried out in the coastal zone showed similar results which present low risk of erosion. For example, 73.38% of the surface of the Oued el Mellah is at low risk of erosion (Lahlaoi et al., 2015) and 78.83% of the surface area of the Oued Sebou has a low risk of erosion (Chadli, 2016). The modeling of the erosion risk by the SWAT model prepared by (Xu, Xu and Meng, 2013) showed that the maximum rate of soil erosion in the Oued Bouregreg watershed is 70 t/ha/year and that most of parts of the basin show an erosion rate that varies from 7 to 15 t/ha/year.

The modeling of the M'dez watershed (Sefrou region, Morocco) by the RUSLE model (Boufala et al., 2020) showed that 98.66% of the surface is affected by a low to very low risk of erosion with a LS factor that varies from 0 to 33.57, most of which shows a LS that varies between 0 and 4.65. The modeling carried out on other watersheds in other regions of the world, shows very consistent results with our work in terms of the distribution of soil loss and its strong correlation with the morpho-pedological characteristics of the zone, especially the weakness of the soil slopes. In Asia, in a sub-basin located in Kerala in India, water erosion varies from 0 to 17 t/ha/year of which 92% of its area has a very low risk of erosion due to a very dense vegetation cover and a low LS factor often less than 5. Other areas relatively affected by erosion are characterized by a LS factor> 10, erodible land and highly degraded forests (Prasannakumar et al., 2012).

In West Africa, the quantitative mapping of soil erosion in the municipality of Karangassso-Vigué in the West of Burkina Faso, showed that 97.92% of its area is at low risk of erosion, which may be due to a very low LS factor, whereas 92.49% of the surface spanning 0–1.65 of LS factor (Ouedraogo, Kabore and Kabore, 2019).

In North Africa, in western Morocco, studies carried out in the catchment areas of the western Rif present very different results compared to our study. For example, the modeling of the Oued Sania watershed carried out by (Tahiri and Tabyaoui, 2014) showed that the risk of soil loss varies from 0 to 1596.85 t/ha/year with an average value of 47.18 t/ha/year. This basin is characterized by

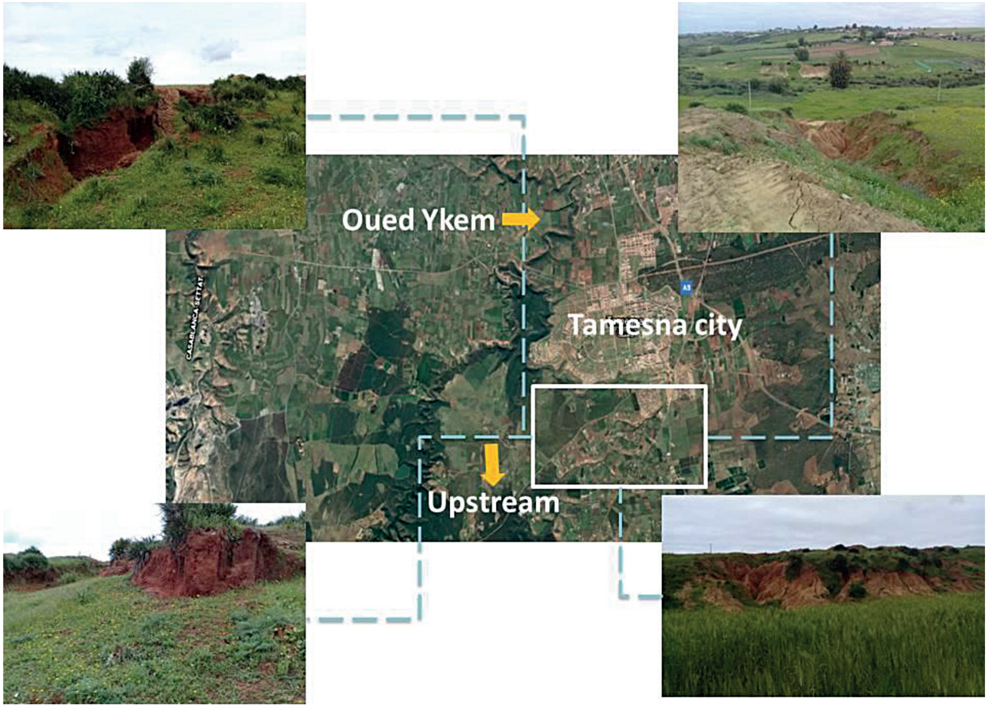

Figure 5. Types of gully in the Oued Ykem watershed

a fairly flattened morphology with LS values generally less than 5 and a very degraded vegetation cover, 62% of the surface of which has little protection against the erosion.

Soil loss in the watershed of the Oued Arbaa Ayacha (Ouallali et al., 2016) showed a variation from 0.11 to 468, of which 80% of its surface has a medium to high risk. This very high risk is mainly located on sites with badlands of a friable nature, not covered by vegetation and which have high altitudes.

The Moulay Bouchta watershed (Zouagui et al., 2018) presents erosion risks ranging from 0 to 81.4 t/ha/year with an average risk of 39.5%. The erosion risk classification showed that 56% of the surface presents strong to very strong erosion. At the level of the Khmiss (North-West Rif) watershed, erosion rates varying between 0 and more than 200 t/ha/year, with a relatively high average of around 36 t/ha/year, of which 38% of its area presents a strong erosion to very high risk between 45 to 200 (t/ha/year). These areas are characterized by a steep slope despite a dense vegetation cover which slows down erosion and a soil less susceptible to erosion (Issa et al., 2014).

Generally, the erosion map showed that more than 95% of the basin area has an erosion rate less than or equal to the maximum tolerance threshold, on deep soil, which generally varies from 1 to 12 t/ha/year depending on climate, rock type and soil thickness (Kalman, 1967). 3% of the basin area represents moderate erosion, while strong and very strong erosion classes represent less than 1%.

The RUSLE method is one of the most suitable erosion models despite these limitations and the need for validation of the output values. The modeling carried out at the level of the M'dez watershed previously mentioned by applying the RUSLE model showed that 98.66% of the watershed is at low risk of erosion and that 1.34 at medium risk. While its validation by applying the SWAT model shows that 84.47% of the basin presents low to very low risk and 15.52% at medium risk of erosion, this proves that validation of our results with other methods of water erosion evaluation is essential for more precision, among these methods we particularly cite: the SWAT [14], the WEPP (Nearing et al., 1989), the CREAMS (Knisel, 1980), Erosion Productivity Impact Calculator (EPIC) (Williams, Renard and Dyke, 1983), etc.

CONCLUSIONS

This study highlights the quantitative and qualitative aspect of soil losses, through the RUSLE model, the parameters of which were mainly estimated by the use of GIS and satellite images. The mapping of water erosion zones in the Oued Ykem watershed through the RUSLE equation made it possible to distinguish three classes of vulnerability to water erosion. The low vulnerability areas which cover 97% of the study area, the medium vulnerability areas are 3.07% and those with high and very high vulnerability represent 0.74%. Statistics show that the study area is not very subject to intensive erosion. In the absence of previous work, this study constitutes a contribution to understand the factors that fuel the erosion of this coastal basin. The use of geomatics is necessary for the evaluation of soil losses, because the spatialization of the parameters makes it possible to widen the study area which can exceed the experimental field and consider regions or watersheds. The spatialization of the soil loss model in a GIS and remote sensing software has given results whose validation remains necessary watersheds. The spatialization of the soil loss model in a GIS and remote sensing software has given results whose validation remains necessary.

REFERENCES

1. ABHBC. 2012. Plan directeur d'Aménagement Intégré des Ressources en eau du Bassin du Bouregreg et de la Chaouia. Rapport de Synthese 305-1192–12a. Maroc, 79.
2. Ait Fora, A. 1995. Modélisation spatiale de l'érosion hydrique dans un bassin versant du roc marocain : validation de l'approche géomatique par la sédimentologie, les traceurs radio-actifs et la susceptibilité magnétique des sédiments. Sherbrooke University. Available at: https://savoirs.usherbrooke.ca/handle/11143/15382 (Accessed: 31 October 2021).
3. Angima, S.D. et al. 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. Agriculture, Ecosystems & Environment, 97(1–3), 295–308. DOI: 10.1016/S0167-8809(03)00011-2
4. Arnold, J.G. et al. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development1. JAWRA Journal of the American Water Resources Association, 34(1), 73–89. DOI: 10.1111/j.1752-1688.1998.tb05961.x
5. Arnoldus, H.M.J. 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. An approximation of the rainfall factor in the Universal Soil Loss Equation., 127–132.
6. Aroussi, O.E. et al. 2011. Predicting the potential annual soil loss using the revised universal soil loss equation (RUSLE) in the Oued El Malleh catchment (prerif, morocco)'. Available at: https://www.semanticscholar.org/paper/predicting-the-potential-annual-soil-loss-using-the-Aroussi-Mesrar/50381b48bba6af663ec91fbff868802ab717e7eb (Accessed: 31 Oct. 2021).
7. Azaiez, N. 2021. Improved modelling of soil loss in El Badalah Basin: Comparing the performance of the universal soil loss equation, revised universal soil loss equation and modified universal soil loss equation models by using the magnetic and gravimetric prospection outcomes. Journal of Geoscience and Environment Protection, 9(4), 50–73. DOI: 10.4236/gep.2021.94005
8. Beasley, D., Huggins, L., Monke, E. 1980. 'ANSWERS: a model for watershed planning.', Transactions of the ASAE, 23. DOI: 10.13031/2013.34692
9. Bizuwerk, A., Taddese, G., Getahun, Y. 2008. Application of GIS for Modeling Soil loss rate in Awash River Basin, Ethiopia'. Available at: https://www.academia.edu/8344707/Application_of_GIS_for_Modeling_Soil_loss_rate_in_Awash_River_Basin_Ethiopia (Accessed: 4 June 2020).
10. Boufala, M. et al. 2020. Assessment of the risk of soil erosion using RUSLE method and SWAT model at the M'dez Watershed, Middle Atlas, Morocco. E3S Web of Conferences. Edited by A. Akhssas et al., 150, 03014. DOI: 10.1051/e3sconf/202015003014
11. Bouhadeb, C. et al. 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. DOI: 10.2478/jwld-2018-0003.
12. Bou-Imajjane, L. et al. 2020. Soil erosion assessment in a semi-arid environment: a case study from the Argana Corridor, Morocco', Environmental Earth Sciences, 79. DOI: 10.1007/s12665-020-09127-8
13. Boussadia-Omari, L. et al. 2021. Contribution of phytoecological data to spatialize soil erosion: Application of the RUSLE model in the Algerian atlas. International Soil and Water Conservation Research, 9(4), 502–519. DOI: 10.1016/j.iswcr.2021.05.004
14. Chadli, K. 2016. Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). Modeling Earth Systems and Environment, 2(2), 51. DOI: 10.1007/s40808-016-0105-y
15. Chevalier, J. et al. 1994. Systèmes d'Aide à la Planification Pour la Conservation des Eaux et des Sols (Tunisie). Systèmes d'Information Géographique Utilisant les Données de Télédétection. Actes du colloque scientifique international, Hammamet, Tunisie.
16. Duarte, L., Cunha, M., Teodoro, A.C. 2021. Comparing Hydric Erosion Soil Loss Models in Rainy Mountainous and Dry Flat Regions in Portugal. Land, 10(6), 554. DOI: 10.3390/land10060554
17. Efthimiou, N., Lykoudi, E., Psomiadis, E. 2020. Inherent relationship of the USLE, RUSLE topographic factor algorithms and its impact on soil erosion modelling. Hydrological Sciences Journal, 65(11), 1879–1893. DOI: 10.1080/02626667.2020.1784423
18. FAO. /IIASA/ISRIC/ISS-CAS/JRC. 2009. Harmonized World Soil Database - Version 1.1. FAO,

Rome, Italy and IIASA, Laxenburg, Austria.

19. FAO, UNEP and UNESCO. 1979. A provisional methodology for soil degradation assessment. Available at: https://agris.fao.org/agris-search/search.do?recordID=XF8108785 (Accessed: 4 June 2020).
20. Gelagay, H.S., Minale, A.S. 2016. Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia', International Soil and Water Conservation Research, 4(2), 126–136. DOI: 10.1016/j.iswcr.2016.01.002
21. Ghanem, H. 1981. Classification et répartition des sols dans la région des Zairs, de la basse Chaouia et des Sehouls, Méséta Atlantique Marocaine. Thèse de Doctorat. Université de Gand.
22. Gumière, S.J. 2009. Contribution à la modélisation déterministe spatialisée de l'érosion hydrique des sols à l'échelle des petits bassins versants cultivés. phdthesis. Institut National d'Etudes Supérieures Agronomiques de Montpellier. Available at: https://hal.inrae.fr/tel-02823756 (Accessed: 31 October 2021).
23. Hara, F. et al. 2020. Study of soil erosion risks using RUSLE Model and remote sensing: case of the Bouregreg watershed (Morocco). Proceedings of the International Association of Hydrological Sciences, 383, 159–162. DOI: 10.5194/piahs-383-159-2020
24. HCEFLCD. 2007. Plan d'Action du Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification. Maroc, 37. Available at: https://www.fao.org/faolex/results/details/es/c/LEX-FAOC164708/ (Accessed: 31 October 2021).
25. Issa, L.K. et al. 2014. Mapping and Assessment of Water Erosion in the Khmiss Watershed (North Western Rif, Morocco). Current Advances in Environmental Science, 2(4), 119–130. DOI: 10.14511/caes.2014.020401
26. Issa, L.K. et al. 2016. Cartographie Quantitative du Risque d'Erosion des Sols par Approche SIG/USLE au Niveau du Bassin Versant Kalaya (Maroc Nord Occidental). Journal of Materials and Environmental Science, 7(8), 2778–2795.
27. Jahun, B.G. et al. 2015. Review of Soil Erosion Assessment using RUSLE Model and GIS. Journal of Biology, 13.
28. Kalman, R. 1967. Le facteur climatique de l'érosion dans le bassin du Sebou. Maroc: Rapport du Ministère de l'Agriculture, 40.
29. Khemiri, K., Jebari, S. 2021. Évaluation de l'érosion hydrique dans des bassins versants de la zone semi-aride tunisienne avec les modèles RUSLE et MUSLE couplés à un Système d'information géographique', Cahiers Agricultures, 30, 7. DOI: 10.1051/cagri/2020048
30. Knisel, W.G. 1980. CREAMS: A field Scale model for Chemicals, Runoff and Erosion From Agricultural management Systems. 26. US Department of Agriculture, 690. Available at: https://www.tucson.ars.ag.gov/unit/publications/PDFfiles/312.pdf (Accessed: 31 October 2021).
31. Kouli, M., Soupios, P., Vallianatos, F. 2009. Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environmental Geology, 57(3), 483–497. DOI: 10.1007/s00254-008-1318-9.
32. Lahlaoi, H. et al. 2015. Potential Erosion Risk Calculation Using Remote Sensing and GIS in Oued El Maleh Watershed, Morocco. Journal of Geographic Information System, 7(2), 128–139. DOI: 10.4236/jgis.2015.72012.
33. Le Roux J.J., Jacobus J. 2007. Soil erosion prediction under changing land use on Mauritius. Dissertation. University of Pretoria. Available at: https://repository.up.ac.za/handle/2263/25468 (Accessed: 1 November 2021).
34. Markhi, A. et al. 2015. Quantification et évaluation de l'érosion hydrique en utilisant le modèle RUSLE et déposition intégrés dans un SIG. Application dans le bassin versant N'fis dans le haut atlas de Marrakech (Maroc). European Scientific Journal, ESJ, 11(29), 17.
35. Medhioub, E., Bouaziz, M., Bouaziz, S. 2018. Assessment of soil erosion by water using RUSLE, remote sensing and GIS in Gabes Coast-Southern Tunisia: Study case of Oued El Sourrag Watershed. In: Kallel, A. et al. (Eds.) Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions. Cham: Springer International Publishing. Advances in Science, Technology & Innovation, 1805–1806. DOI: 10.1007/978-3-319-70548-4_523
36. Mhirit, O., Benchekroun, F. 2006. Abhatoo: Les écosystèmes forestiers et périforestiers: situation, enjeux et perspectives pour 2025. Rapport sur le Développement Humain au Maroc. Rabat: Haut Commissariat au Plan, 91. Available at: http://www.rdh50.ma/fr/pdf/contributions/GT8-7.pdf (Accessed: 31 October 2021)
37. Mitasova, H. et al. 1996. Modelling topographic potential for erosion and deposition using GIS. International Journal of Geographical Information Systems, 10(5), 629–641. DOI: 10.1080/02693799608902101
38. Modeste, M. et al. 2016. Cartographie Des Risques De L'erosion Hydrique Par L'equation Universelle Revisee Des Pertes En Sols, La Teledetection Et Les Sig Dans Le Bassin Versant De L'ourika (Haut Atlas, Maroc). European Scientific Journal, ESJ, 12(32), 277. DOI: 10.19044/esj.2016.v12n32p277
39. Moore, I.D., Wilson, J.P. 1992. Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation. Journal of Soil and Water Conservation, 47(5), 423–428.
40. Moussa, R., Voltz, M., Andrieux, P. 2002. Effects of the Spatial Organization of Agricultural Management on the Hydrological Behaviour of a Farmed Catchment During Flood Events, Hydrological

Processes, 16, 393–412. DOI: 10.1002/hyp.333.

41. Nearing, M. et al. 1989. A Process-Based Soil Erosion Model for USDA-Water Erosion Prediction Project Technology', Transactions of the ASAE, 32. DOI: 10.13031/2013.31195
42. Nord, G., Esteves, M. 2005. PSEM_2D: A physically based model of erosion processes at the plot scale', Water Resources Research, W08407, 41. DOI: 10.1029/2004WR003690.
43. Ouallali, A. et al. 2016. Evaluation et cartographie des taux d'érosion hydrique dans le bassin versant de l'Oued Arbaa Ayacha (Rif occidental, Nord Maroc)', 38, 65–79.
44. Ouedraogo, B., Kabore, O., Kabore, M. 2019. Cartographie quantitative de l'érosion des sols par approche SIG/RUSLE dans la Commune de Karangasso vigué (Burkina Faso). International Journal of Biological and Chemical Sciences, 13(3), 1638. DOI: 10.4314/ijbcs.v13i3.35.
45. Prasannakumar, V. et al. 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geoscience Frontiers, 3(2), 209–215. DOI: 10.1016/j.gsf.2011.11.003.
46. Raissouni, A. 2012. Modélisation et cartographie de la sensibilité et de l'aléa d'érosion des sols à l'échelle régionale par SIG et USLE (Rif Nord occidental, Maroc). Université Abdelmalek Essaadi faculté des sciences et techniques Tanger. Available at: http://thesesenafrique.imist.ma/handle/123456789/1682 (Accessed: 8 January 2022).
47. Renard, K.G. et al. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Washington, DC (USA) ARS. Available at: https://scholar.google.com/scholar_lookup?title=Predicting+soil+erosion+by+water%3A+a+guide+to+conservation+planning+with+the+Revised+Universal+Soil+Loss+Equation+%28RUSLE%29&author=Renard%2C+K.G.&publication_year=1997 (Accessed: 27 February 2022).
48. Roo, A.P.J. de, Wesseling, C.G., Ritsema, C.J. 1996. 'LISEM: a single-event physically based hydrological and soil erosion model for drainage basins; I: theory, input and output', Hydrological Processes, 10(8), 1107–1117.
49. Scheffe, L. 2008. Revised Universal Soil Loss Equation, Version 2 (RUSLE2)'. USDA NAL. Available at: http://fargo.nserl.purdue.edu/rusle2_dataweb/NRCS_Soils_Database.htm (Accessed: 1 November 2021).
50. Senanayake, S. et al. 2020. Assessing Soil Erosion Hazards Using Land-Use Change and Landslide Frequency Ratio Method: A Case Study of Sabaragamuwa Province, Sri Lanka. Remote Sensing, 12(9), 1483. DOI: 10.3390/rs12091483.
51. Shrestha, S. et al. 2020. Evaluation of adaptation options for reducing soil erosion due to climate change in the Swat River Basin of Pakistan. Ecological Engineering, 158, 106017. DOI: 10.1016/j.ecoleng.2020.106017.
52. Smith, R., Goodrich, D. 1986. KINEROS: A kinematic runoff and erosion model documentation and user manual [Preprint]. Available at: https://www.semanticscholar.org/paper/KINEROS%3A-A-kinematic-runoff-and-erosion-model-and-Smith-Goodrich/873ed4e563b14c05ef40fd7f701034d10199f924 (Accessed: 31 October 2021).
53. Tahiri, M., Tabyaoui, H. 2014. Evaluation et Quantification de l'Erosion et la Sédimentation à Partir des Modèles RUSLE, MUSLE et Déposition Intégrés dans un SIG. Application au Sous-Bassin de l'Oued Sania (Bassin de Tahaddart, Rif nord occidental, Maroc), 23.
54. Thiaw, I. 2017. Mapping of Soil Erosion Risk in the Diarha Watershed Using Rusle, RS and GIS', American Journal of Remote Sensing, 5(4), 30. DOI: 10.11648/j.ajrs.20170504.11
55. Van der Knijff, J., Jones, R., Montanarella, L. 2000. Soil erosion risk assessment in Europe. EUR 19044 EN. Luxembourg: Office for Official Publications of the European Communities, 34.
56. Wall, G. et al. 1987. Soil Erosion – Causes and Effects. Soil Erosion, 10.
57. Williams, J.R. 1975. Sediment Routing for Agricultural Watersheds1. JAWRA Journal of the American Water Resources Association, 11(5), 965–974. DOI: 10.1111/j.1752-1688.1975.tb01817.x
58. Williams, J.R., Renard, K.G., Dyke, P.T. 1983. EPIC: A new method for assessing erosion's effect on soil productivity. Journal of Soil and Water Conservation, 38(5), 381–383.
59. Williams, J.R., Singh, V. 1995. The EPIC Model, Computer models of watershed hydrology. Water Resources Publications, Highlands Ranch, Colorado, 909–1000.
60. Wischmeier, W.H., Smith, D.D. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Handbook. Department of Agriculture, Science and Education Administration.
61. Xu, L., Xu, X., Meng, X. 2013. Risk assessment of soil erosion in different rainfall scenarios by RUSLE model coupled with Information Diffusion Model: A case study of Bohai Rim, China', CATENA, 100, 74–82. DOI: 10.1016/j.catena.2012.08.012
62. Zouagui, A. et al. 2018. Modelisation Du Risque D'érosion Hydrique Par L'équation Universelle Des Pertes En Terre Dans Le Rif Occidental: Cas Du Bassin Versant De Moulay Bouchta (Maroc). European Scientific Journal, ESJ, 14(3), 524. DOI: 10.19044/esj.2018.v14n3p524.