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ORIGINAL ARTICLE

Comparison of the erosion prediction models from USLE, MUSLE and RUSLE in a Mediterranean watershed, case of Wadi Gazouana (N-W of Algeria)

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Abstract
Water erosion is one of the most serious problems of soil degradation in the world, the north of Africa region is particularly exposed to this phenomenon. In fact, the phenomenon gets worse with the climate changes and the adverse anthropogenic environmental interventions. In recent decades, the estimation of soil erosion using empirical models has been a promising research topic. Nevertheless, their application over a large and ungauged areas remains a real challenge due to the availability and quality of the required data. Using the GIS environment, this study aims to estimate and compare the water erosion rates by the three models of Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE) and Revised Universal Soil Loss Equation (RUSLE) in Wadi Gazouana North-West of Algeria. The estimated specific erosion in the entire wadi Ghazouana watershed surface is 9.65, (t/ha/year), 9.90 (t/ha/year) and 11.33 (t/ha/year) by USLE, RUSLE and MUSLE models, respectively. We can also conclude that USLE, RUSLE and MUSLE soil erosion models produced relatively similar results, however, the MUSLE model showed a higher spatial dispersion of the erosion risk compared to the others. The rain factor in this model was more effective; which explain its higher erosion rate.

Keywords Remote sensing · Soil erosion · GIS · USLE/RUSLE/MUSLE · Algeria

List of symbols

- A The computed average soil loss (t/ha/year)
- Q Volume of runoff in (m^3)
- q_p Peak flow rate in (m^3/s)
- R Rainfall erosivity in (MJ/ha mm/h)
- Pi The monthly precipitation (mm)
- P The annual precipitation (mm)
- S Surface (km^2)

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Introduction

Soil erosion is a serious threat to the environment in different region of the world, it causes onsite problems such as the deterioration of soil physical, chemical and biological properties (Lal et al. 2000). Soil erosion is a diffuse process that varies spatially and temporally over a landscape. This phenomenon is caused by detachment and entrainment of soil particles by runoff from land surface.

The influences of climate change on soil erosion rates have been noticed since the 1940s (Bryan and Albritton 1943; Leopold 1951; Ruhe and Scholtes 1956). They include direct impacts which are mainly caused by changes in quantity of precipitation and runoff (Chiew et al. 1995; Bangash et al. 2013), rainfall intensity (Zhang 2012; Tang et al. 2015a) and rainfall spatio-temporal distributional patterns (Maeda et al. 2010).

Algeria, following the like of other Mediterranean countries, is classified among the countries most subject to the scourge of land degradation. In effect, several physical factors, climatic, environmental and anthropogenic are responsible to considerably reduce the area of agricultural land and therefore their productivity. In view of the food challenges facing the country, the management of the resources for sustainable agricultural development is primordial and unavoidable.

Soil erosion by water is a major soil degradation problem in semi-arid Mediterranean landscapes. Its negative impacts are tremendous, including reduction of soil productivity; about six million hectares are experiencing a strong to very strong degradation (Demmak 1982). The water erosion presents also a real threat to all dams in Algeria, the annual loss of the Algerian dams capacity is estimated at about 20 million m^3 (Remini 2000). Moreover, we can cite other impacts like: pollution of watercourses, deficits in water availability, serious damages to properties by soil-laden runoff which increasing the refund demands and desertification of natural environments. Water erosion is a natural phenomenon controlled by climatic characteristics, topography, soil properties, vegetation, and land management.

In Algeria, several natural and anthropogenic factors favoring the onset and the development of the processes of erosion: a fragile ecosystem following the aggressiveness of climate and the irregularity of precipitation, a hilly topography and fragile mountainous and of geological substrates. The human impact manifest in the destruction of a natural plant cover, already low, by overgrazing.

This degradation of land is a scourge which is widespread. At the national level, an average annual specific erosion ranging between 2000 and 4000 (t/km/year) (Demmak 1982). The specific erosion changes from one area to another, the western region is the most affected, i.e., 47% of the whole area, similarly, (26%) and (27%) for the eastern and the central regions, respectively (Planning Ministry of the Environment and Spatial 2000).

Evaluating the factors controlling erosion and their characteristics, as well as the detection of eroded areas, are complex tasks that can be solved with the integration of several data sources (spatial data, measurements and field surveys, and satellite images) in geospatial processing systems such as geographic information systems.

In the scientific literature, different approaches are proposed to estimate, quantify and predict soil erosion and sediment transport. These approaches are based on field observations, many modeling concepts, and sometimes both.

Recently, many models are proposed and developed based on the physical aspects of the erosion process, we quote : the model Areal Non-point Source Watershed Environment (ANSWERS) of (Beasley et al. 1980), Annualized Agricultural Non-Point Source Pollutant Loading (AnnANPSPL), the Erosion-Productivity Impact Calculator (EPIC) model of Williams et al. (1985), the Chemicals Runoff and Erosion from Agricultural (CREAMS) model of (Knisel 1980), the Simulator for Water Resources in Rural Basins (SWRRB) model of (Williams et al. 1985), the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model of (Davis et al. 1990), the Water Erosion Prediction Project (WEPP) model of (Nearing et al. 1989), and the Soil Erosion Model for Mediterranean Areas (SEMMED) model of (Davis et al. 1990).

The empirical models are hydrological models funded from applied mathematical laws and validated with laboratory or field experiments. The simplest and wide used model, which links soil loss to either precipitation or runoff is the Universal Soil Loss Equation (USLE) conducted by (Wischmeier and Smith 1965, 1978). The modified version of USLE, proposed by (Williams 1975), estimates the sediment transport of each storm taking into account the runoff volume instead of the erosivity of the rain.

With further research, experiments, data and available resources, researchers continue to improve the USLE and to developed new soil loss equations, which led to the development of the new universal soil loss equation (RUSLE: Revised Universal Soil Loss Equation), which follows the terms of the USLE by correcting some inaccuracies (Renard et al. 1997) and by providing some improvements in the determination of factors.

It remains the mathematical models, most commonly used to predict losses due to surface erosion. It predicts the annual average rate of long-term erosion based on the factors responsible for the phenomenon: rainfall, soil type, topography, the system of culture and conservation tillage.

The USLE equation was initially proposed for selected cropping systems, but it is also applicable to non-agricultural conditions. Recently, it has been used successfully at regional, national and watershed level (Bera 2017; Elaloui et al. 2017).

However, the extension of the use of USLE/RUSLE to study erosion on larger scales than that of the parcel necessitated the use of geographic information systems and remote sensing. They have led to great progress in the search for soil erosion and soil and water conservation, since the late 1980s. Thus, remote sensing and GIS have become of enormous use in assembling, process, analyze and overlay spatial information that describes the watershed environment, since all factors can be mapped. This, made it possible to determine the values of each factor of erosion per determined spatial unit, which is the pixel (Kinnell 2001).

These techniques also allowed the evaluation of the soil erosion and its spatial distribution at a reasonable cost, reduced time and better accuracy over large areas.

The main purpose of this study aims at comparing the predictions of soil erosion rates between of the universal soil loss equation (USLE) as well as its modified version (MUSLE) and its revised (RUSLE) models integrated under a Geographic Information System (GIS), in the Mediterranean watershed Wadi Ghazouana (north-west, Algeria). Wadi Ghazouana presents a typical case of the watersheds of this region with the advantage of the data availability required by predictions models.

Materials and methods

The study area

The Wadi Ghazouana watershed drains an area of 284.68 km^2 with a perimeter of 103.51 km, it is limited to the North by the Mediterranean Sea; at the South and South East by the Tafna basin. The watershed is geographically located between 34°18′ and 34°29′ north latitude and between 2°50′ and 3°8′ east longitude (Fig. 1).

The Wadi Ghazouana watershed is located on the eastern fringe of the chain mountainous Traras and opens on the Mediterranean Sea, it is characterized by a rugged terrain with steep slopes and the altitudes culminate in the south more than 1100 m at Djebel Fllaoucene.

The slopes in the Wadi Ghazouana watershed are relatively strong, they reach 10–12%. The zone of slight slopes (I < 2%) is represented by the lower zone of the watershed at the mouth of the Oued.

At the level of the North-East, the plateau of Sidi Amar overhangs the city. It is in form triangular whose base reaches 1500 m. The plateau is flat with slopes at the summit less than 1.5%. But the flanks are steep slopes, varying between 10 and 12% (Table 1).

Methodology and used data

Details of various parameters used in the soil erosion modeling are given in the Table 2.

Table 1 Morphometric characteristics of the Wadi El-Ham watershed

Parameters	Unit	Value
Aria A	ha	28468.62
Perimeter P	km	103.51
Index of compactness IC	–	1.72
Maximum altitude H_{max}	m	1120
Minimum altitude H_{min}	m	0
Mean basin elevation H_{mean}	m	437.30
Altitude to 95%	m	210
Altitude to 50%	m	430
Altitude to 5%	m	870
Length of the rectangle L	km	45.50
Width of the rectangle *l*	km	6.26

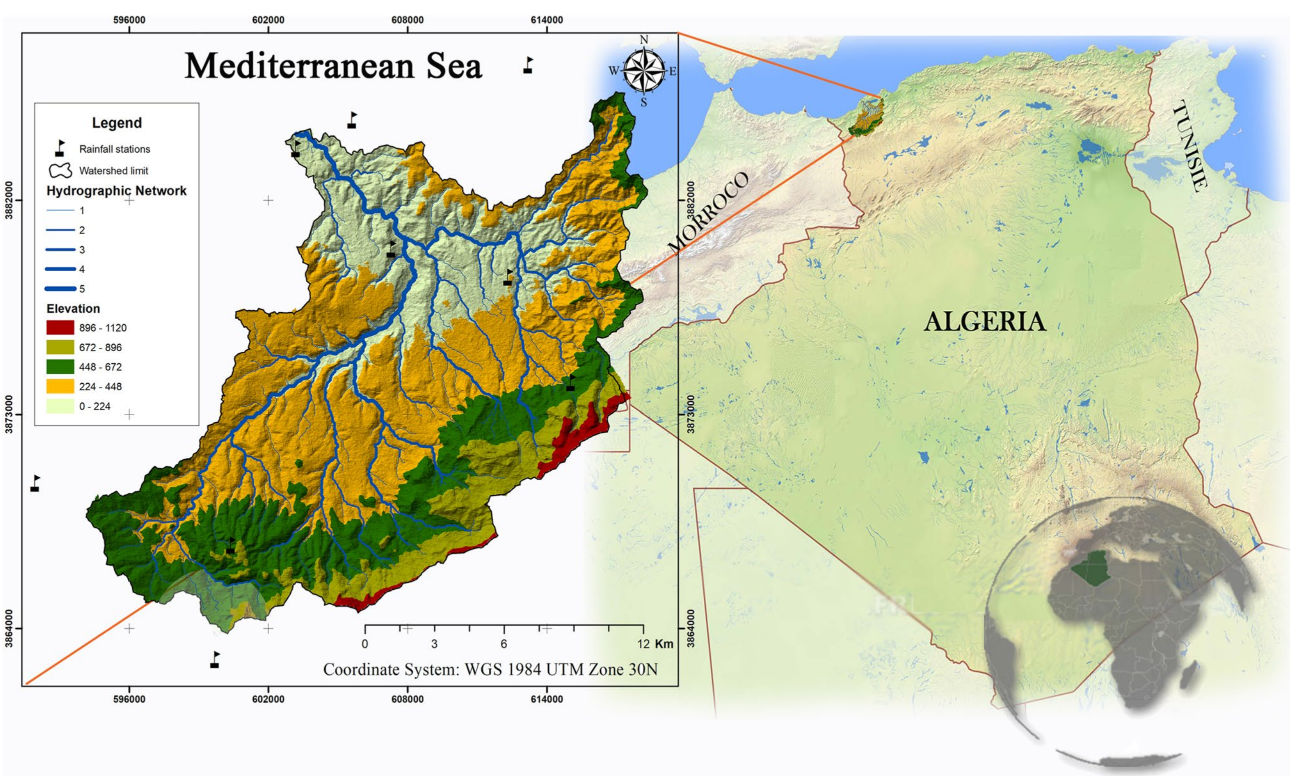

Fig. 1 Location of the study area

Table 2 Description of the data used

Models	Parameter	Materials	Resolution	Year	Source
USLE MUSLE RUSLE	Satellite image	Landsat 8	30 m	2018	United States Geological Survey (http://earthexplorer.usgs.gov/)
	Rainfall data	Monthly/ annual rainfall data	30 m	1985–2015	Agence Nationale des Ressources Hydrauliques (ANRH)
	Soil properties	H.W.S.D	–	–	Harmonized world soil database (HWSD) version 1.2 (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/)
	Topographic data	A.S.F	12.5 m	2011	Alaska Satellite Facility: https://vertex.daac.asf.alaska.edu

The USLE model

The empirical formula of Wischmeier and Smith (1965, 1978) is proposed to estimate the rate of soil loss in many area scales. It is often combined with GIS techniques, and widely used around the world to quantify soil losses. Depending on rainfall patterns, land use, topography, soil erodibility and anti-erosion practices, this model is written:

$$A_{USLE} = R \times K \ \times LS \times C \times P\ , \tag{1}$$

where A is the computed average soil loss (t/ha/year); R is rainfall-runoff erosivity factor (MJ mm/ha/h/y); K is the soil erodability factor (t ha h/ha/MJ/mm); LS is the slope length (L) and slope gradient (S) factor (dimensionless); C is the cropping management factor and P is the supporting conservation practice factor (dimensionless, ranging between 0 and 1).

The MUSLE model

The (MUSLE) model (Williams 1975), is a modified version of the USLE model (Wischmeier and Smith 1965). This model replaced the rainfall factor (R) with instantaneous peak flows and total runoff factor to predict soil erosion. The average soil loss for a flood is a multiplicative function of the volume of the flood (V in m^3), the peak discharge of the flood (Qp in m^3/s), the erodibility of the soil (K), the index slope (S), the slope length (L), the vegetation cover (C) and the cultural practices (P). This formula is written in the following form:

$$A_{MUSLE} = 11.8(Q \times q_p)^{0.56} \times K \ \times LS \times C \times P. \tag{2}$$

The RUSLE model

The RUSLE model estimates the average annual loss of soil. It is a revised version of the universal soil loss equation (USLE) (Wischmeier and Smith 1965, 1978). According to Roose and Noni (2004), erosion is a multiplicative function of rainfall-runoff erosivity (R) multiplied by the resistance of the environment, which includes the soil erodibility factor (K), the topography factor (LS), the anti-erosion practices (P) and the vegetation cover factor (C). This model is written similarly to the USLE as:

$$A_{RUSLE} = R \times K \ \times LS \times C \times P. \tag{3}$$

The Universal Soil Loss Equation is an empirical basic equation. Revised Universal Soil Loss Equation (RUSLE) model is only ones of many modification of USLE, especially for more complex situations of rill and interrill erosion in conservation planning and land uses. Both erosion-prone models calculate detachment capacity and soil loss.

The RUSLE has been applied to many different watersheds about the world (Jiang et al. 2015; Tang et al. 2015b; Fernández and Vega 2016; Markose and Jayappa 2016; Tetford et al. 2017; da Cunha et al. 2017; Toubal et al. 2018; Wijesundara et al. 2018; Djoukbala et al. 2018).

Factors of the models

R-factor

This factor represents the energy with which rain droplets impact the soil at certain intensity by breaking up surface aggregates into particles of transportable size. Many indices have been designed in erosion risk prediction models to estimate the rainfall-runoff effect, the best known of which is the R factor.

The R factor is the erosion index of rainfall and includes the influence of the kinetic energy of rain on erosion, the disaggregation of soil particles and the compaction of their surface, as well as their maximum intensity, determining the appearance of surface runoff infiltration capacity.

Rainfall erosivity factor (R) according to MUSLE

The rainfall erosivity factor was developed by Williams and Berndt (1977). It's estimated from t the runoff volume and the peak flow. Peak flow is calculated using a rational equation, which assumes that precipitation, has a uniform intensity over the entire watershed area.

$$R = 11.8 \times (Q \times q_p)^{0.56}. \tag{4}$$

With Q is volume of runoff in (m^3); q_p is peak flow rate in ($m^3\ s^{-1}$).

In our case study, the measured runoff volume and the peak flow are recorded at the BESBES gauging station situated at the outlet of Wadi Ghazouana watershed.

Rainfall erosivity factor (R) according to RUSLE and USLE

In the original form of USLE, according to the formula of Wischmeier and Smith (1965), the estimation of the factor R requires the knowledge of the kinetic energies (Ec) and the average intensity over 30 min (I30) of the raindrops of each precipitation episode. In our study area, the only available precipitation data are the monthly and the annual averages values.

In the Algerian context, the only available data of precipitation are usually measured at the monthly and the annually scale. An alternative formulas, which only involve monthly and annual precipitation to determine the R factor, are proposed by Arnoldus (Cormary and Masson 1964). Which is presented in the form:

$$\log R = 1.74 \log \sum_{i=1}^{12} \frac{P_i^2}{P} + 1.29, \tag{5}$$

where R: rainfall erosivity in (MJ/ha mm/h); Pi is the monthly precipitation (mm) and P is the annual precipitation (mm).

In our study watershed, the used data of rainfall are recorded from 10 rainfall stations situated inside and around the watershed of Wadi Ghazouana, for a measurement period variable from 25 to 32 years. The R-values were inserted over the entire watershed territory utilizing the geostatistical model of Kriging.

K-factor

The K factor refers to the erodibility of the soil, that is to say the resistance of the soil against the aggressiveness of raindrops, runoff or both. This factor is related to the integrated effect of precipitation, runoff and seepage and relies on the influence of soil properties on soil loss.

This factor is determined according to four necessary parameters: the texture parameter (% silt, sand, clay) and the percentage of organic matter.

Due to the lack of accurate soil map of our study region, we have used the Global Harmonized Soil Database Version 1.2 to determine the required soil parameters over the entire Ghazouana watershed. This database is the result of a collaboration between FAO and IIASA, ISRIC-World Soil Information, the Institute of Soil Sciences, Chinese Academy of Sciences (ISSCAS), and the Joint Research Center (JRC).

The harmonized database of soil data of the world is a database with a frame of 30-s arc and more than 15,000 characteristic soil-mapping units. The resulting database consists of 21,600 rows and 43,200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows data linkage with the card frame to display or query the structure in terms of soil units and description of selected soil parameters (salinity, organic carbon, storage capacity of water, soil profundity, pH, cation exchange capacity of the soil, clay fraction, sum of exchangeable nutrients, lime and gypsum content, percentage of sodium exchange, textural class and granulometry) (FAO and ISRIC 2012).

In this study, the value of the Soil erodibility was calculated using the following formulas proposed by (Neitsch et al. 2011).

$$K_{USEL} = K_w = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand}, \tag{6}$$

where (f_{csand}) is a factor, that brings down the K display 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}) diminishes K values in soils with higher organic matter content; (f_{hisand}) lowers K values for soils with extremely high sand content.

$$f_{csand} = \left(0.2 + 0.3 \cdot exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right), \tag{7}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right), \tag{8}$$

$$f_{orgc} = \left(1 - \frac{0.25 \cdot orgC}{orgC + exp\left[3.72 - 2.95 \cdot orgC\right]}\right), \tag{9}$$

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right), \tag{10}$$

where *ms* is the percent (%) sand content (0.05–2.00 mm diameter particles); *msilt* is the percent (%) of silt content (0.002–0.05 mm diameter particles); *mc* is the percent (%) of clay content (< 0.002 mm diameter particles); *orgC* is the percent organic of carbon content of the layer (%) (Table 3).

Table 3 Estimation of K factor in Wadi Ghazouana watershed

Soil sample	ms (Sand) Top soil %	msilt (Silt) Top soil %	mc (Clay) Topsoil %	orgC Oraganic carbon %	F_{csand}	F_{cl-si}	F_{orgc}	F_{hisand}	K_{USLE}	K
XK	48.7	29.9	21.6	0.64	0.200	0.849	0.977	0.999	0.1658	0.0218
X	72.8	10.5	16.8	0.36	0.200	0.751	0.994	0.918	0.1370	0.0180
LC	64.3	12.2	23.5	0.63	0.200	0.725	0.978	0.983	0.1392	0.0183
ZG	47.8	8.5	43.8	0.38	0.200	0.580	0.993	0.999	0.1151	0.0151
BK	81.6	6.8	11.7	0.44	0.200	0.741	0.991	0.718	0.1054	0.0138

Xk calcic xerosols, *X* XEROSOLS, *Lc* chromic luvisols, *Zg* gleyic solonchaks, *Bk* calcic cambisols

LS-factor

The topographical factor is one of the main factors of water erosion. The degree of slope Play an important role in the process of detachment, transport and deposition of soil particles.

The LS factor refers to the topography of the region, which manifests itself in two sub-factors: The length of the slope (L) and the degree of slope (S), however, it is advisable to use both variables as an only topographic value (LS to evaluate overall the influence of the slope on the speed of erosion).

The sub-factors were determined in a particular way using the digital terrain model DTM obtained from the DEM ALOS PALSAR (Alaska Satellite Facility) under GIS tool in the WGS_1984 coordinate system.

In our study, we used three calculation formulas according to the models:

Factor (LS) according to USLE

$$LS = \left(flow\ accumulation \times \frac{resolution}{22.1}\right)^m \times \left(65.41 sin^2\theta + 4.56 \sin\theta + 0.065\right), \quad (11)$$

$$m = 0.6 \times \left[1 - e^{(-35.835 \times S)}\right], \quad (12)$$

$$\theta = tan^{-1}\left(\frac{S}{100}\right), \quad (13)$$

where S is the field slope (%) and θ is the field slope steepness in degrees.

Factor (LS) according to MUSLE

$$LS = 1.4 \times \left(\frac{A_s}{22.1}\right)^{0,4} \times \frac{\sin(\theta \times 0.01745)^{1,4}}{0.09}. \quad (14)$$

With θ: the angle of the slope in degrees, A_s: The particular surface composition under a GIS in the following method (Moore and Burch 1986):

$A_s = flow\ accumulation \times resolution.$

The surface card (A_s) is determined by multiplying the map of the runoff accumulation (Flow accumulation) by the pixel size (resolution).

Factor (LS) according to RUSLE

$$LS = \left(flow\ accumulation \times \frac{resolution}{22.1}\right)^m \times \left(0.065 + 0.045 \times S + 0.0065 \times S^2\right). \quad (15)$$

With 'S' the angle of the slope in (%) and 'm' is a parameter related to the slope classes (Wischmeier and Smith 1978) (Table 4).

C-factor

The vegetation plays an important slowdown role of the water erosion process, indeed the vegetation cover factor is the second most important factor controlling the risk of soil erosion (Kalman 1967).

Many studies have been proposed to estimate the Cover Management factor (C-factor) using the Normalized Difference Vegetation Index (NDVI) for assessing soil loss (Lin et al. 2002; Wang et al. 2002). These approaches use a regression model to perform a correlation analysis between field-measured C-factor values or obtained from guide boards and NDVI values derived from remote images. The unknown values of the C-factors of the land cover classes can be estimated using the equation obtained from a linear regression analysis.

Table 4 Value of 'm' relative to each class of slope (Wischmeier and Smith 1978)

Slope (%)	M
> 5	0.5
3–5	0.4
1–3	0.3
< 1	0.2

The Normalized Difference Vegetation Index (NDVI) values range from − 1 to + 1, the negative values are attributed for surfaces without plant cover, such as snow, water, or clouds, for which red reflectance is greater than near-infrared (Souidi et al. 2014). For bare soils, the reflectance being of about the same order of size in the red and the near infrared, the (NDVI) has value close to zero. The vegetal formations as for them have a positive values of (NDVI), generally between 0.1 and 0.7. The highest values correspond to the densest cutlery.

In this study, the (NDVI) data (period 2018) are generated from a Satellite Landsat 8 photo with a spatial resolution of 30 m (Fig. 2), was used to estimate the C-factor and explain the effect of different vegetation cover on the Loss of soil, the (NDVI) was calculated from a combination of red and infrared bands.

In order to estimate the values of the C-factor, some authors (Toumi et al. 2013) have used the regression between two extreme values of (NDVI), the obtained regression line is written as

$$c = 0.9167 - NDVI \times 1.1667. \quad (16)$$

P factor

The P factor represents the effect of the conservation practices on the water erosion processes. It varies according to the conservation technics practiced in the watershed from 0 in the zones well protected to 1 without any conservation practices.

In our study area, no significant anti-erosif technic is practiced; the value of 1 was assigned to the P factor in the entire watershed area.

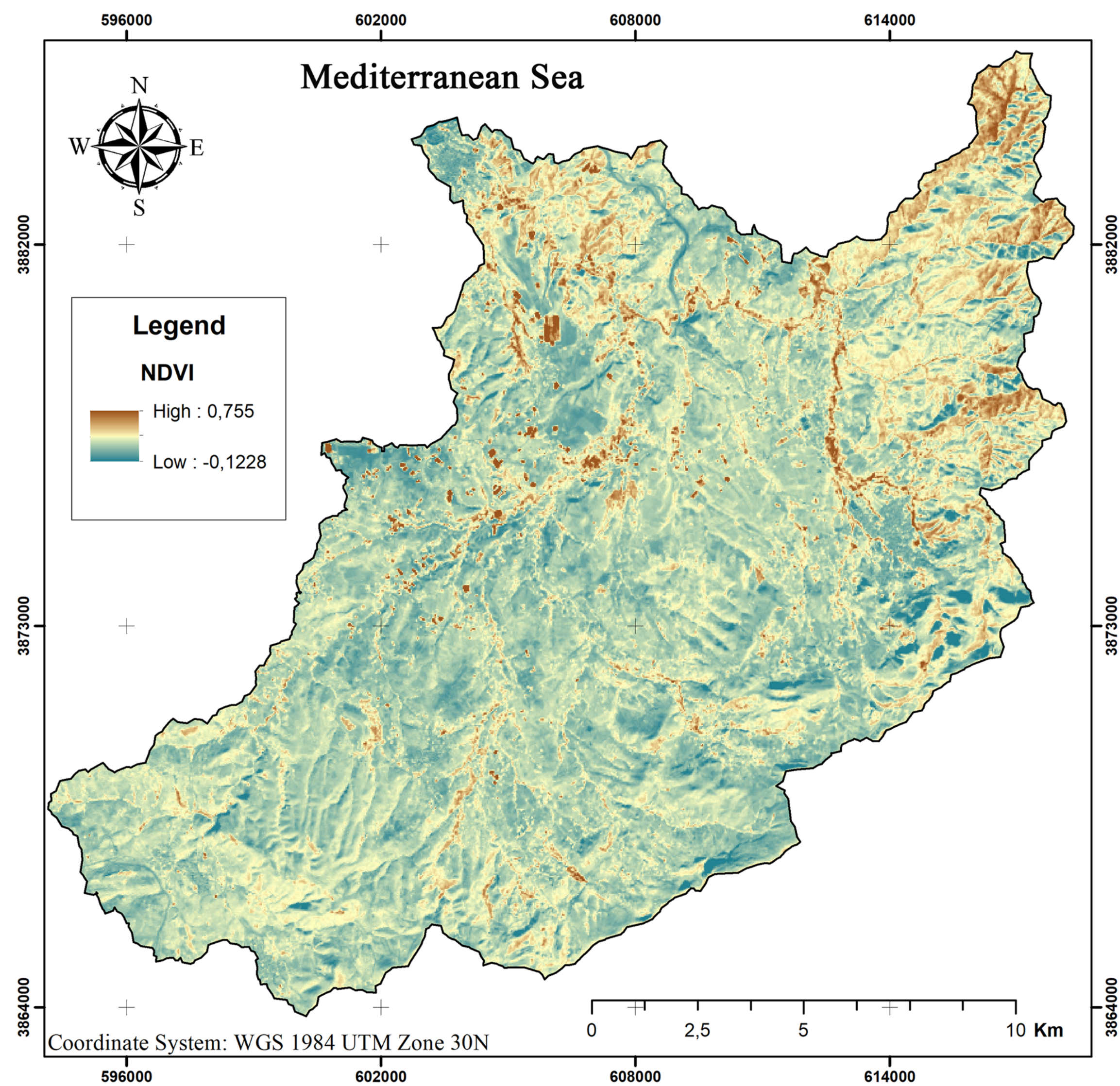

Fig. 2 Spatial distribution of NDVI index values in the Wadi Ghazouana

Figure 3 gives a general idea of the functioning of the model that presents a summary of the used methodology of a soil erosion map are illustrated.

Results and discussion

Erosivity factor (R)

The erosivity map generated from the rainfall data of the 12 used stations, shows that the value of the R factor in the Ghazouana watershed varies from 89 to 130 (MJ mm/ha/h/year). The high values are recorded at the northwest of the basin, while the lowest values are recorded in the Southeast.

La carte d'érosivité réalisé à partir des données pluviométrique des stations pluviométriques, montre que la valeur du facteur R dans le bassin versant de Ghazaouet varie de 89 à 130 (MJ mm/ha/h/year). Les valeurs élevées sont enregistrées du Nord-Ouest du bassin, alors que les valeurs les plus faibles sont enregistrées à Sud-Est (Fig. 4).

The R-factor is distributed over the watershed area in many classes, 24% of the basin area is caracterized by a high erosivity with R-values from 109.38 to 129.96 (MJ mm/ha/h/year). The class of low erosivity with R-factor from 89.59 to 95.92 (MJ mm/ha/h/year) affects 33% of the surface. The rest of the watershed area, about 44% has a moderate erosivity with R-factor ranging from 95.92 to 109.38 (MJ mm/ha/h/year) (Table 5).

K-factor

The soil erodibility factor K in the Wadi Ghazaouna watershed varies from 0.013 to 0.022 (MJ mm/ha/h/an). A composite K factor map was generated to show the spatial distribution of erodibility across five soil groups (Fig. 5). About 85% of the basin area has an erodibility factor of less than 0.015, the rest of the surface, almost 15% of the, presents a high erodibility factor K, ranging from 0.015 to 0.021 (Table 6).

Using the spatial K-factor map, it is possible to manipulate the entire watershed surface, pixel by pixel, we can also generate a resulting maps by applying various operations.

LS-factor

From the three used models USLE, RUSLE, MUSLE, LS vary between 0 and 238.7, 0–216.8 and 0–187.52;

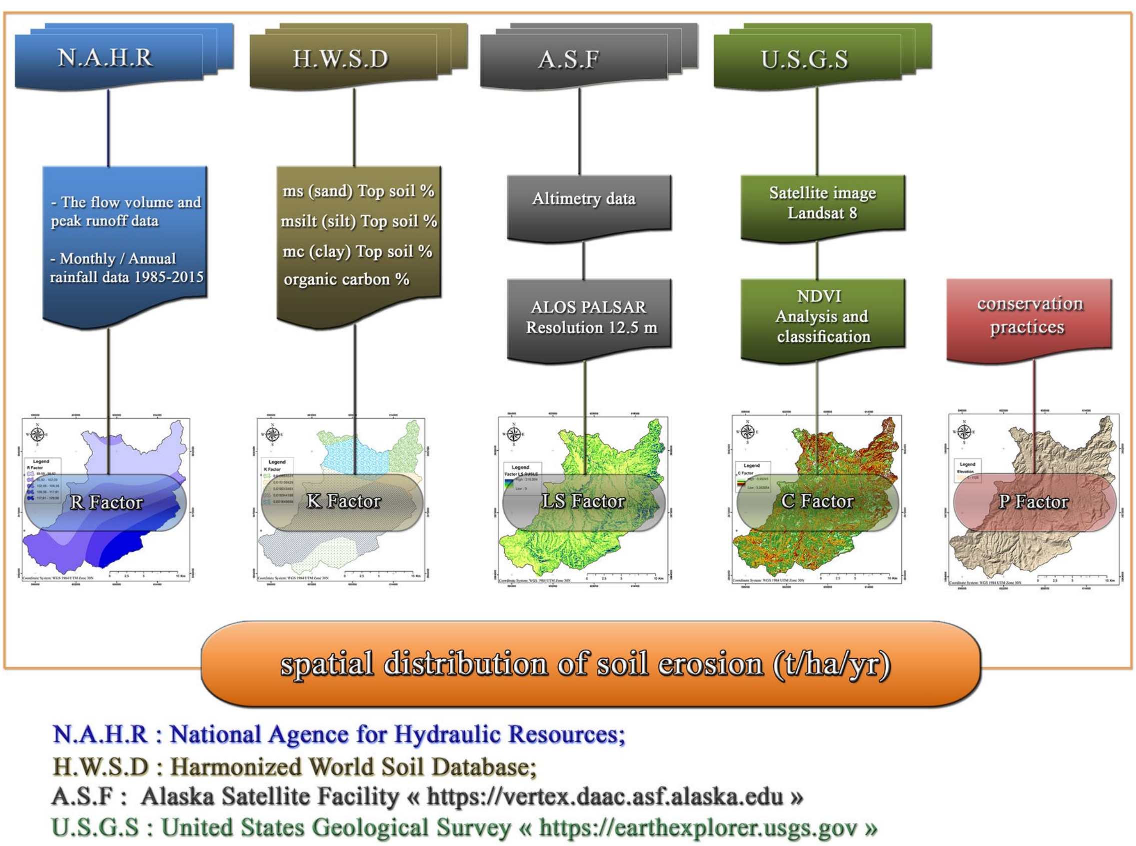

Fig. 3 Diagram of the methodology to map the water erosion risk

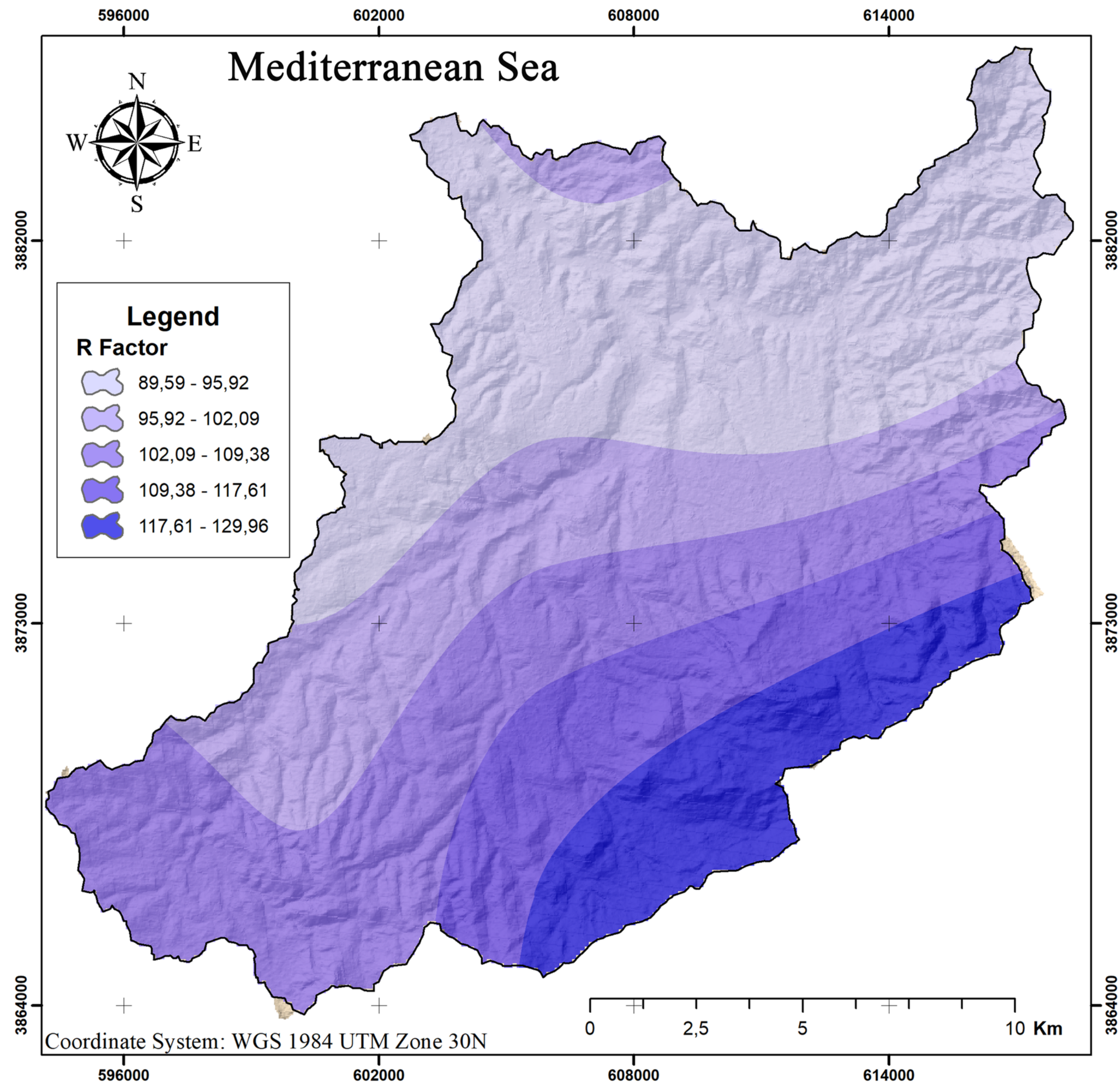

Fig. 4 Map of the rainfall erosivity factor R

Table 5 Distribution of rainfall erosivity classes

Classes R factor	Area (ha)	Area (%)
89.59–95.92	9284.328	32.6
95.92–102.09	5515.239	19.4
102.09–109.38	6854.832	24.1
109.38–117.61	3577.646	12.6
117.61–129.96	3238.477	11.4
Total	28462.82	100

respectively. LS values were grouped into six classes (Table 7). The length and slope of the slope are decisive in the erosion process.

The highest values of LS are located in the upstream part of the Wadi Ghazouana basin and on the hills with very high slopes (Fig. 6a–c). The LS values that considered as low are observed in the plain, this corresponds to low elevation areas, lowland areas and stream bed. Thus, the basin is subject to a high risk of erosion from upstream to downstream. These results are consistent with those obtained by many authors (Abdo and Salloum 2017; da Cunha et al. 2017; Imamoglu and Dengiz 2017; Djoukbala et al. 2018).

Erosion has been shown to increase exponentially depending on the degree of inclination of slope (Pham et al. 2018). Similarly, it has been reported that as the degree of inclination of slope increases, the kinetic energy of the rains remains constant while the transport accelerates downwards due to an increase in the kinetic energy of the runoff (Thomas et al. 2018).

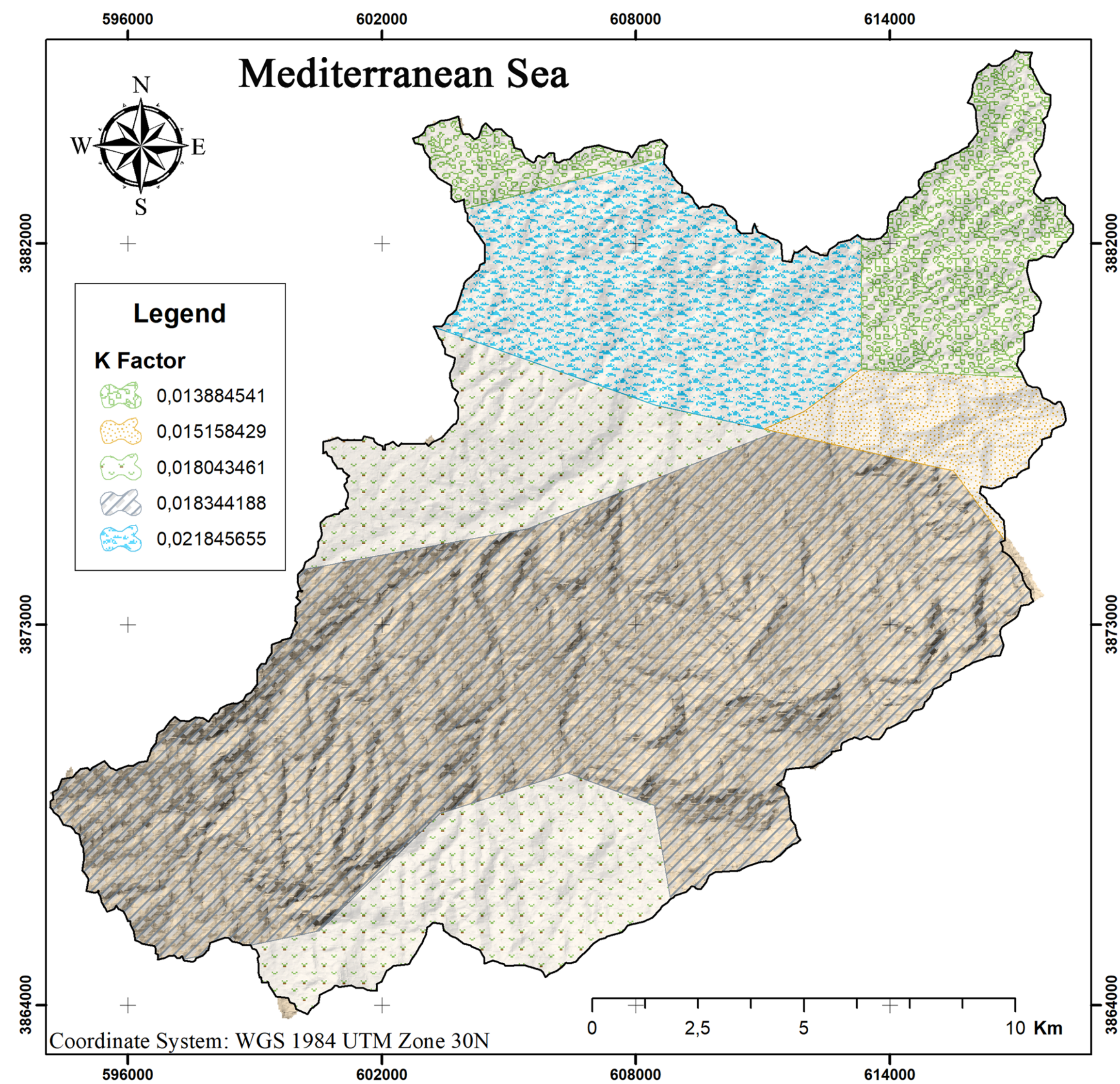

Fig. 5 Spatial distribution of the soil erodibility factor K

Table 6 Distribution of K factor class in the Wadi Ghazouana Watershed

Classes K factor	Area (ha)	Area (%)
0.01388	2862.392	10.05
0.01516	1219.79	4.2
0.01804	5509.52	19.3
0.01834	14738.39	51.8
0.02185	4120.94	14.4
Total	28462.52	100

C-factor

The spatial distribution of vegetation cover management factor C of Wadi Ghazouana watershed is generated from the NDVI map, under ArcGIS software (Fig. 7). The observed C-factor value over the whole study area is very variable, from 0.26 and to 0.95, 89% of the basin area has a very low vegetation cover and only 11% of the area is well protected with $C < 0.7$. Low vegetation cover is found in open forests, the degraded rangelands and cultivated lands

Table 7 Distribution of LS factor class in the Wadi Ghazouana Watershed

USLE			RUSLE			MUSLE		
Classes LS factor	Area (ha)	Area (%)	Classes LS factor	Area (ha)	Area (%)	Classes LS factor	Area (ha)	Area (%)
0–2.8	17826.23	62.6	0–2.55	17901.16	62.9	0–2.5	16833.43	59.2
2.8–8.4	7804.270	27.4	2.55–8.47	7608.68	26.7	2.5–8.4	8897.443	31.3
8.4–18.66	2283.037	8.0	8.47–17.8	2221.66	7.8	8.4–17.5	1798.350	6.3
18.66–36.38	440.1233	1.5	17.8–33.03	561.65	2.0	17.5–35	604.40	2.1
36.38–70.89	97.51	0.3	33.03–66.07	138.32	0.5	35–65	301.20	1.1
70.89–238.8	16.46	0.1	66.07–216.8	17.92	0.1	65–187	14.57	0.1
Total	28462.63	100	Total	28462.63	100	Total	28462.63	100

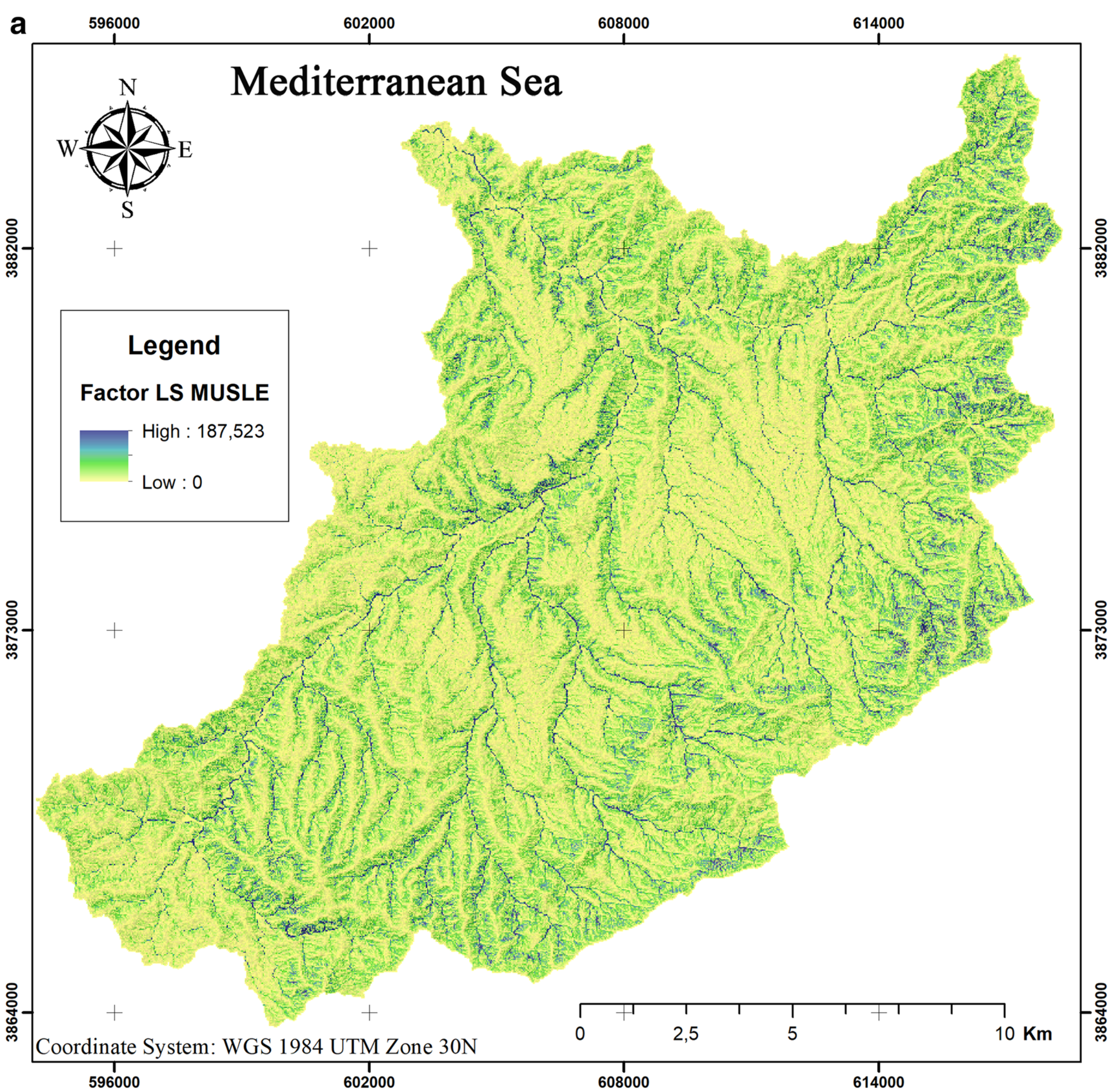

Fig. 6 **a** The LS factor map (MUSLE). **b** The LS factor map (RUSLE). **c** The LS factor map (USLE)

are considered highly susceptible to erosion. Values below 0.5 refer to dense forests, dense matorrals and arboriculture. Values between 0.5 and 0.9 are attributed to areas covered by low density, sparse forests and light matorrals. Values tending towards 1 are related to bare soils and harvested cropland (Table 8).

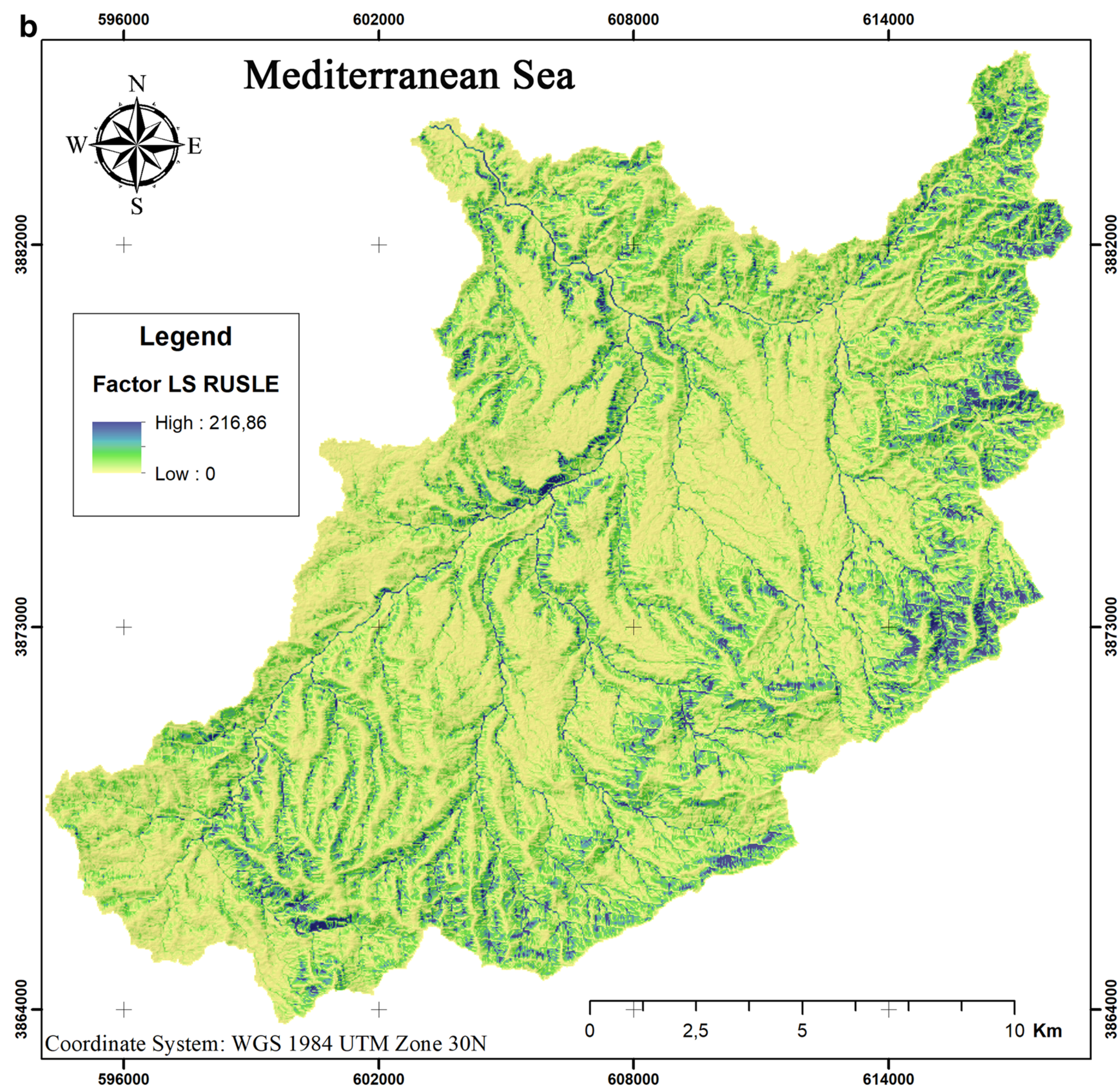

Fig. 6 (continued)

Erosion assessment and quantification

The average annual soil loss in Wadi Ghazouana watershed was calculated with USLE RUSLE and MUSLE models according the Eqs. 1, 2 and 3; respectively. The final maps are obtained by superimposing the grids of five factors in a single result grid under ArcGIS environment with a uniform spatial resolution of 30 m.

Potential soil loss

USLE model

The erosion risk map obtained bu the USLE shows that the average total annual soil loss of Wadi Ghazouana watershed is about 2655.22 (t/year) equivalent to a specific rate of 9.65 (t/ha/year). The examination of the spatial distribution show a large dispersion, over the whole watershed surface, the water erosion vary from 0 to 303 (t/ha/year) (Fig. 8). It is also observed that, the areas with high erosive risk are located on hills and areas characterized by steep slopes and favorable substrates; they represent 47.2% of the surface of Wadi Ghazouana watershed. The rest of the watershed surface, ie 52%, is characterized by a low and medium erosion-sensitivity (Table 9).

RUSLE model

The erosion risk map (Fig. 9) obtained by this revised model (RUSLE) indicates a results close to those obtained by the previous model (USLE), the average total annual soil loss of Wadi Ghazouana watershed is about 2783.52 (t/year)

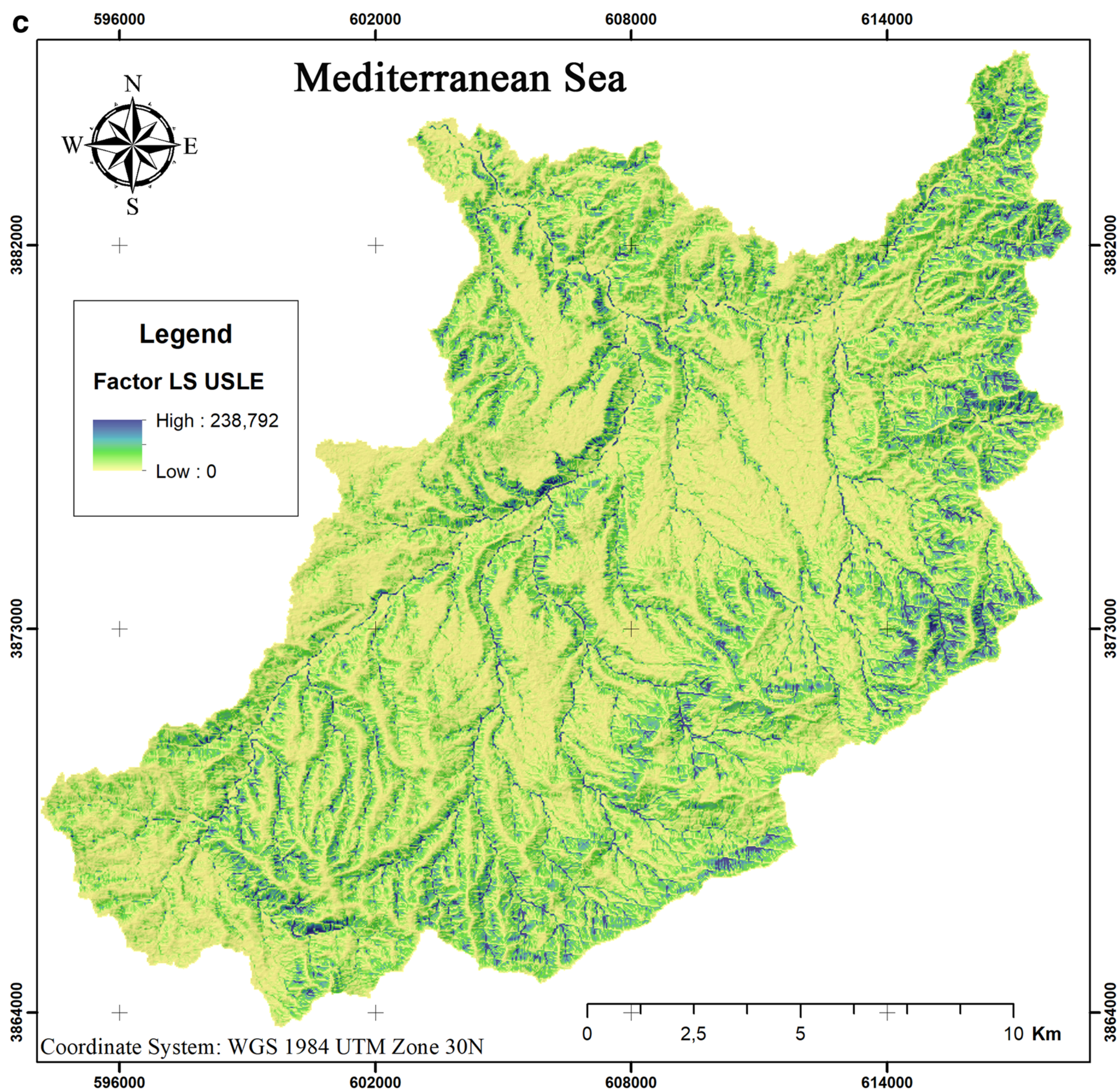

Fig. 6 (continued)

equivalent to a specific rate of 9.90 (t/ha/year). The distribution of erosion risk by class is summarized in the Table 10.

MUSLE model

The erosion risk map (Fig. 10) obtained by this MUSEL model shows slightly different results compared to USLE and RUSLE maps, the average total annual soil loss of Wadi Ghazouana watershed is about 3231.34 (t/year) equivalent to a specific rate of 11.33 (t/ha/year). The calculated soil loss by MUSLE model varies from 0 to 395 (t/ha/year), it is also classified from very low to very high (Table 11).

The high rates of erosion are observed at hills and lands characterized by steep slopes of Wadi Ghazouana watershed. This finding is consistent with those obtained by USLE and RUSLE models. This indicates that erosion is very active downstream of Wadi Ghazouana watershed.

The results of this study in Wadi Ghazouana watershed, together with other previous studies in this area, show that the water erosion rates are much higher than tolerance levels [$A_{(USLE)(MUSLE)(RUSLE)} > 7$ (t/ha/year)]. This explains the severity of soil degradation in Wadi Ghazouana watershed due to the unfavorable land use, lithology and the aggressiveness of climate.

The USLE, RUSLE and MUSLE soil erosion models produced relatively similar results, however, the MUSLE model showed a higher spatial disputation of the erosion risk compared to the others. R factor was more effective in the MUSLE model; which explain the higher erosion rates obtained by this model. The comparison of the obtained results by the three models show a very close value of

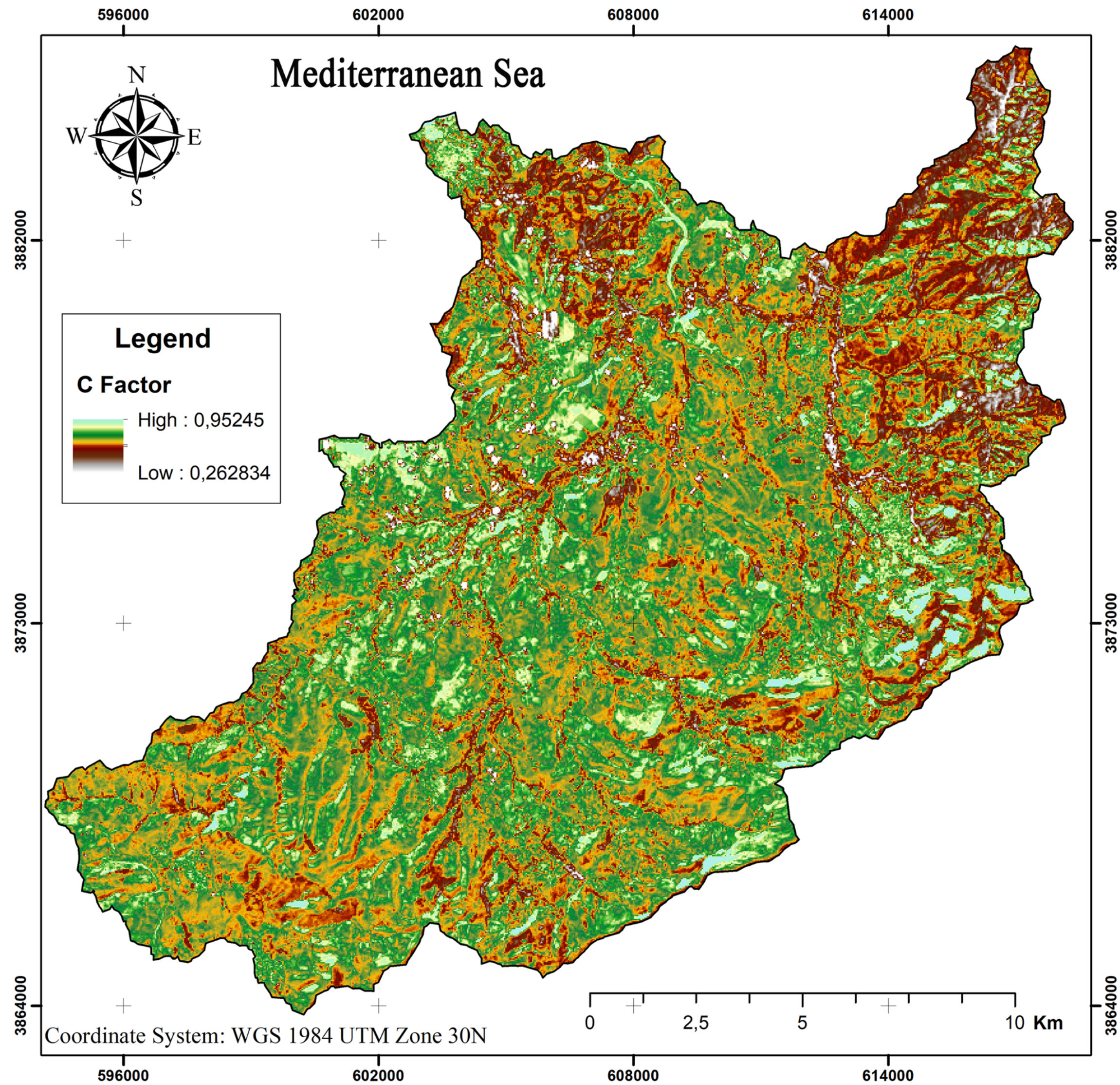

Fig. 7 The C-factor map of Wadi Gazouana watershed

Table 8 Distribution of C factor class in the Wadi Ghazouana Watershed

Classes c factor	Area (ha)	Area (%)
0.26–0.66	285.53	1.0
0.66–0.75	2334.25	8.2
0.75–0.80	6399.03	22.5
0.80–0.84	12303.21	43.2
0.84–0.95	7140.81	25.1
Total	28462.82	100

the averages rates. The coefficient of determination R^2 between the results ranges from 93 to 98%, which confirms the strong correlation between the studied models (Fig. 11).

We can notice that, relatively the RUSLE results are the most compatible to the nature of the data used. However, this may not always be the case, as it depends on the region and state in which the model was developed. The best response of RUSLE model in our region allows us to consider it as the most suitable model for the semi-arid Mediterranean. The observed differences in model results may also be due to the dominant erosion processes at different spatial and temporal scales, models that have been designed for different regions such as RUSLE, and that have been designed for agricultural areas in the United States, differ in mixing erosional processes with dryland ecosystems. The advantages of such model are their simplicity in terms of data requirements and computation (Harmon and Doe 2001). However, the different modeled processes can not be disaggregated or modified, which is problematic if the model has been designed

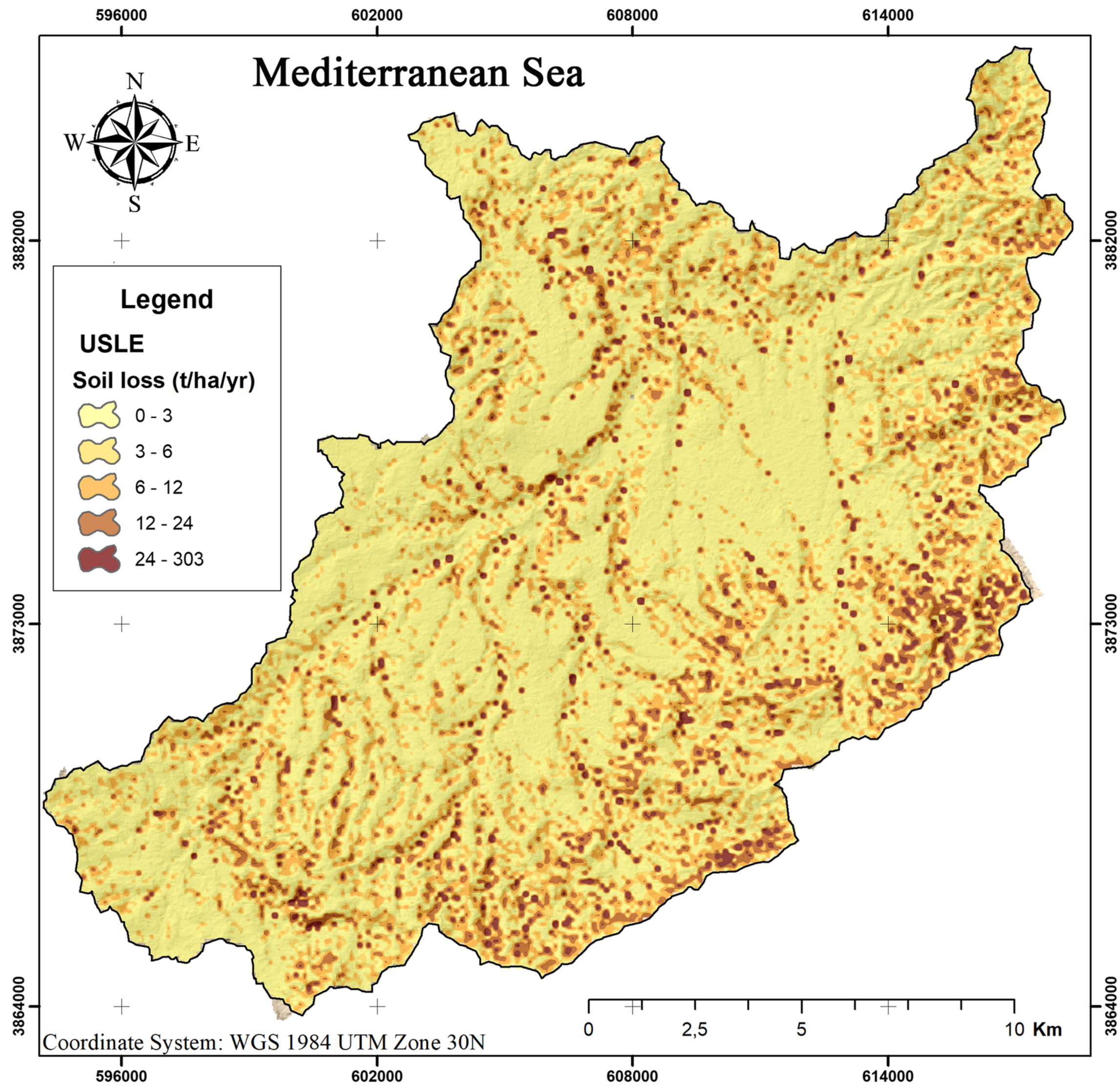

Fig. 8 Soil erosion map in the Wadi Ghazouana (USLE)

Table 9 Percentage of area under different soil erosion classes (USLE)

Soil loss (t/ha/year) USLE	Area (ha)	Area (%)
0–3	15029.01	52.8
3–6	5153.807	18.1
6–12	4960.176	17.4
12–24	2469.052	8.7
24–303	850.7745	3.0
Total	28462.82	100

for a different location or spatial scale. Besides, empirical relationships are often calibrated for a particular set of data that is valid only for the dataset from which they are derived (Ghadiri and Rose 1993; Hudson 1993). The ideal approach is to develop new models or to calibrate existing ones to the regional context, such, (SLEMSA) the Soil Loss Estimation Model for Southern Africa (Elwell 1978) and (EUROSEM) the European Soil Erosion Model (Hudson 1993).

The current results are also compatible with other works on the evaluation of water erosion carried out in other Mediterranean watersheds having climatic and environmental characteristics that are similar. such as in Wadi Mina watershed at 11.2 (t/ha/year) (Benchettouh et al. 2017), in Wadi Boumahdane of 11.18 (t/ha/year) (Bouguerra et al. 2017) and in Wadi Sahouat basin average soil losses between 12 and 16 (t/ha/year) (Toubal et al. 2018).

The values calculated by the empirical soil loss models are subject to discussion, but the method is among the

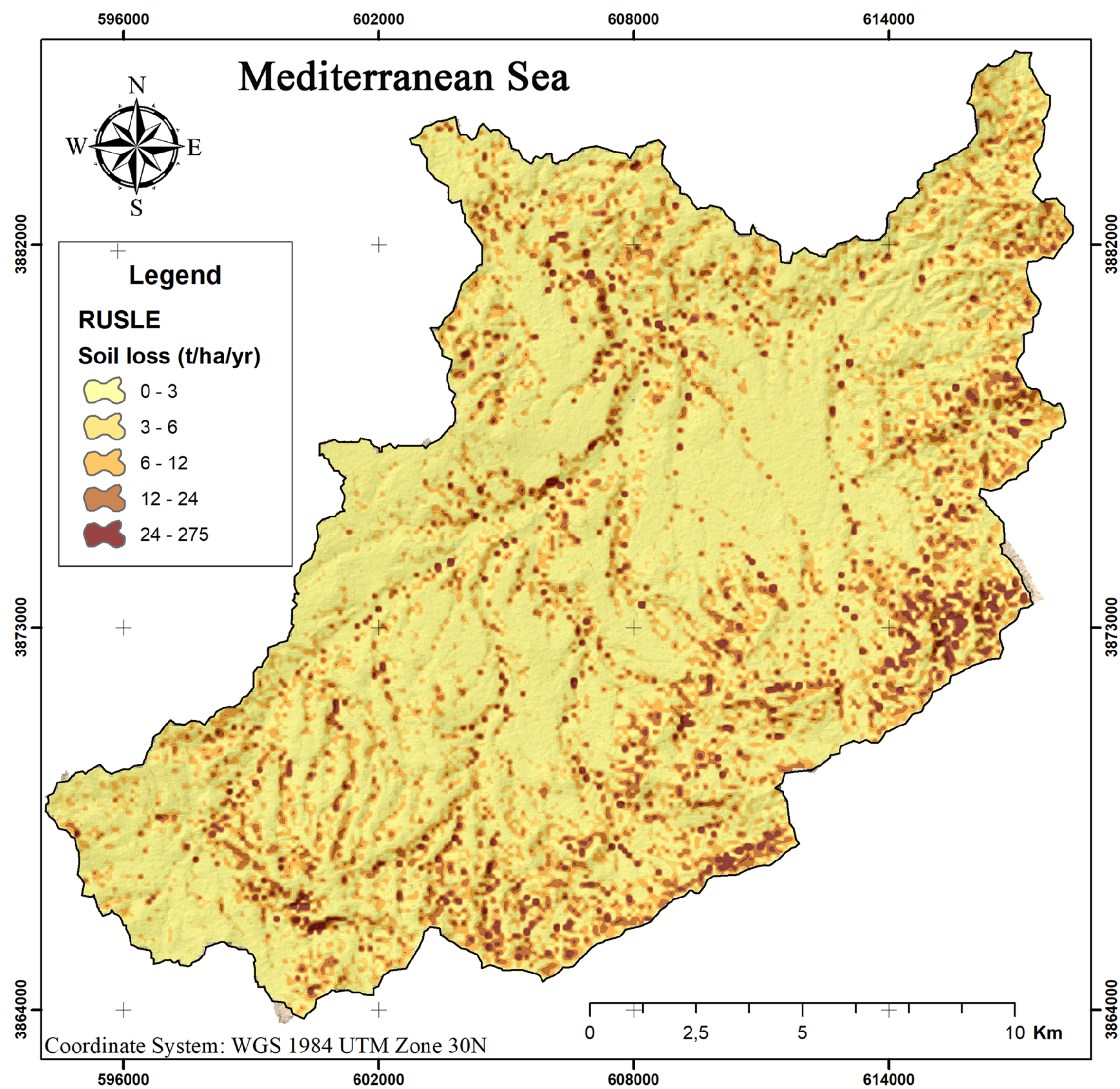

Fig. 9 Soil erosion map in the Wadi Ghazouana (RUSLE)

Table 10 Percentage of area under different soil erosion classes (RUSLE)

Soil loss (t/ha/year) RUSLE	Area (ha)	Area (%)
0–3	16775.61	58.9
3–6	4423.125	15.5
6–12	3937.541	13.8
12–24	2434.64	8.6
24–275	891.9087	3.1
Total	28462.82	100

decision support tools used by planners, as it simulates soil protection and conservation scenarios to plan erosion control interventions, especially on slopes where water erosion is predominant.

Conclusion

The availability and the quality of required data to estimate the water erosion risk is a real challenge in the large and the ungauged basins, empirical models are ideal tools to overcome this handicap, especially, with the quick development of the GIS tools. This study aimed to use and compare the results of the water erosion rates obtained from three models USLE, MUSLE and RUSLE, the spatial distribution of the phenomenon is also verified in the coastal watershed Wadi Ghazouana in the Mediterranean region.

The three models were successfully applied in the study area, the obtained results are relatively close. The estimated specific erosion in the entire Wadi Ghazouana watershed surface is 9.65, (t/ha/year), 9.90 (t/ha/year) and 11.33 (t/ha/year) by USLE, RUSLE and MUSLE models,

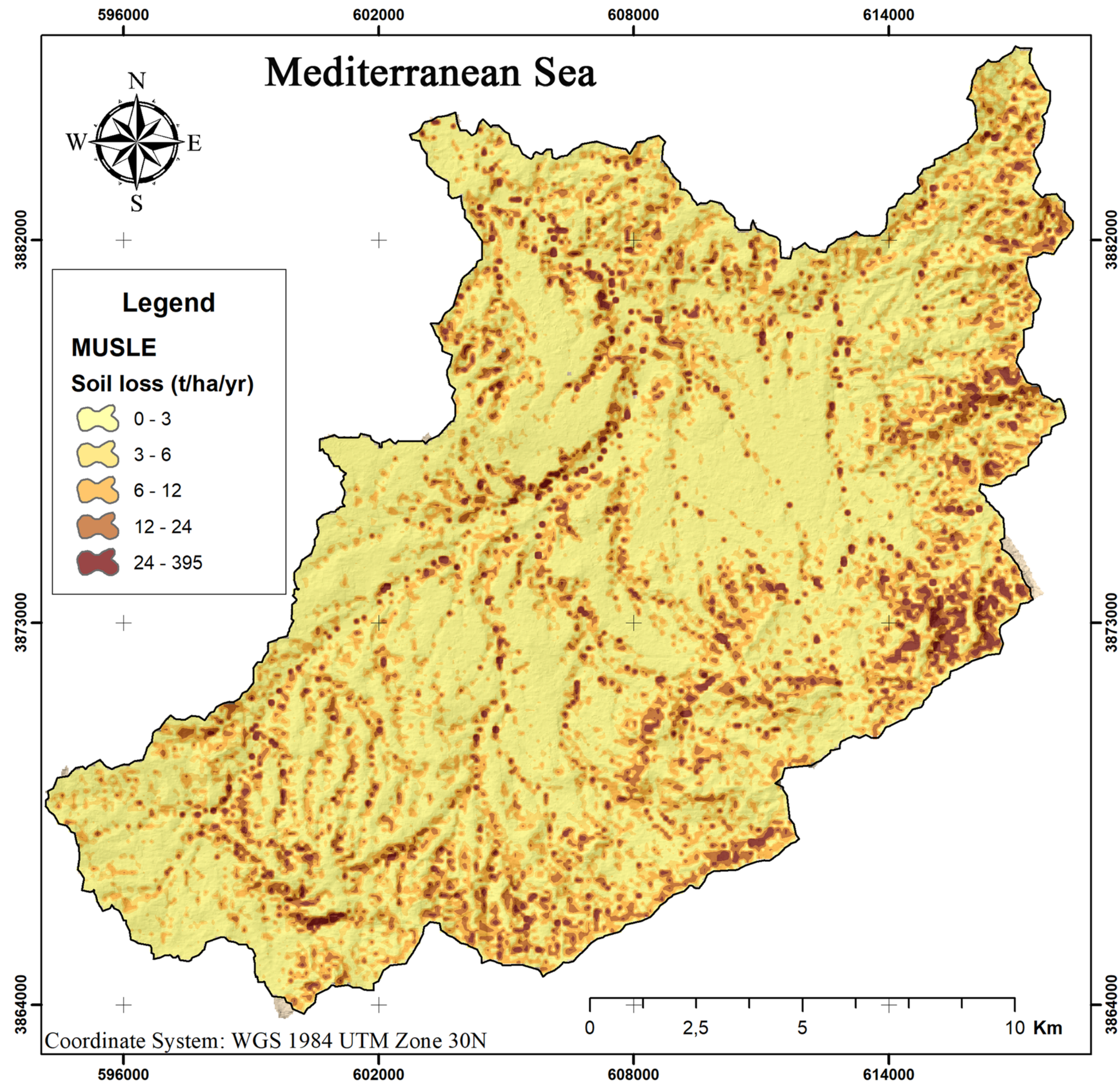

Fig. 10 Soil erosion map in the Wadi Ghazouana (MUSLE)

Table 11 Percentage of area under different soil erosion classes (MUSLE)

Soil loss (t/ha/year) MUSLE	Area (ha)	Area (%)
0–3	16971.2	59.6
3–6	3627.829	12.7
6–12	3840.49	13.5
12–24	2860.651	10.1
24–395	1162.653	4.1
Total	28462.82	100

respectively. The MUSLE model showed a higher spatial distribution of erosion due a better efficiency of rain factor.

The MUSLE model results showed that more than 30% of watershed surface, present a higher erosion rates, greater than 6 (t/ha/year), observed at hills and lands characterized by steep slopes of the watershed. This explains the severity of soil degradation in Wadi Ghazouana watershed due to the unfavorable land use, lithology and the aggressiveness of climate.

The erosion maps, obtained from the three models, can be useful to select the suitable zones for soil conservation planning and revegetation efforts based on assessed erosion rates or composition factors mapped by each input factor independent. The development of GIS tools and remote sensing technics can significantly improve the results of this kind of models.

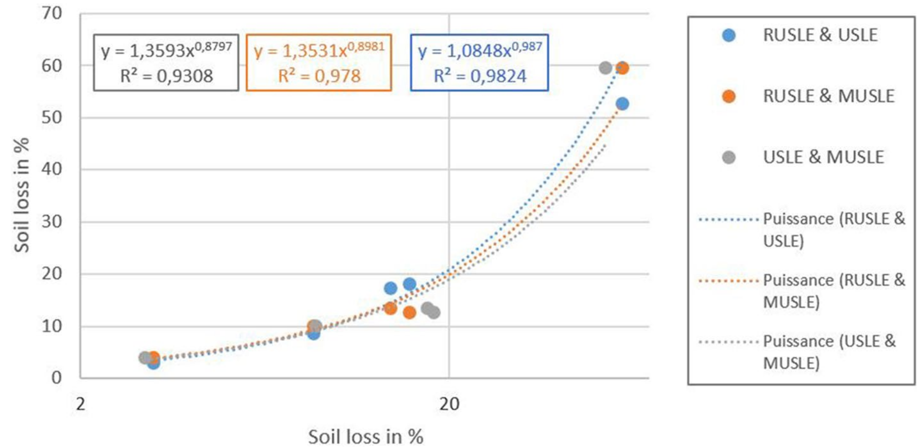

Fig. 11 Variation of the erosion calculated by the three models

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