Quantification of Water Erosion Using the Rusle Model and the S.I.G Geographic Information System Case Study of the Oued Taria Sub-Catchment; Algeria

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Abstract

Water erosion is the first cause of soil degradation, it represents a multidimensional natural risk and an environmental challenge for the ecosystem.

The aim of our study is to determine and map the areas at risk of soil erosion using a GIS/USLE approach at the scale of the Oued Taria catchment (western Algeria).

The latter is a multiplication of five erosion factors, namely rainfall erosion, soil erodibility, slope inclination and length, plant cover and anti-erosion practices. Each of these factors was expressed in the form of a thematic map.

Combining the different maps of these parameters highlighted the erosive impact of each factor, making it possible to define with greater precision the most sensitive areas at risk of erosion.

The results are presented in the form of a map identifying and locating the areas at greatest risk of erosion. It emerges that the phenomenon of erosion affects the whole of the Oued Taria catchment area and varies from 0 to over 100 t/ha/year.

The result is a document that can be used as a decision-making tool for the management and protection of natural resources.

Keywords: USLE, GIS, Water erosion, Oued Taria catchment, Algeria.

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1. Introduction

Soil erosionis a natural process that is undoubtedly largely responsible for today's geomorphology (Dumas 2004). (Morgan 1986) mentions that soil erosion is a two-phase process: the detachment or removal of individual soil particles and the transport of these particles by erosive agents (water, wind).

Water erosion is one of the main factors in land degradation and environmental problems. It is a widespread phenomenon in countries around the Mediterranean (Yjjouet al. 2014).

As a result, Algeria is one of the countries most threatened by erosion (Demmak 1982), which has already affected around 45% of fertile land (Morsli 1996).Nearly 6 million hectares are subject to active erosion (Arabi 2006), and annual water losses due to silting in dams are estimated at around 20 million m3 (Remini 2000).

The Universal Soil Loss Equation (USLE) of (Wischmeier and Smith 1978) remains by far the most widely used mathematical model for predicting water erosion.The integration of the thematic maps of the factors in this model into the GIS made it possible to identify the impact of each factor, to classify erosion areas by relative importance, and to quantify soil losses.

The aim of this study is to produce a set of thematic maps presenting the results of the analysis of the various factors involved in the erosion phenomenon, as well as maps of potential erosion and vulnerability to the risk of erosion in the Oued Taria catchment, in the wilaya of Mascara in western Algeria.

Presentation of the study area

The Oued Taria sub-catchment is the subject of our study and covers an area of 1465 km², bounded by the Beni-Chougranne mountains to the north, the Saida mountains to the south, the Aoufplateaux to the east and the Ain Fekan mountains to the west. The Oued Taria watercourse extends over a length of 85.3 km to supply the Ouizert dam.

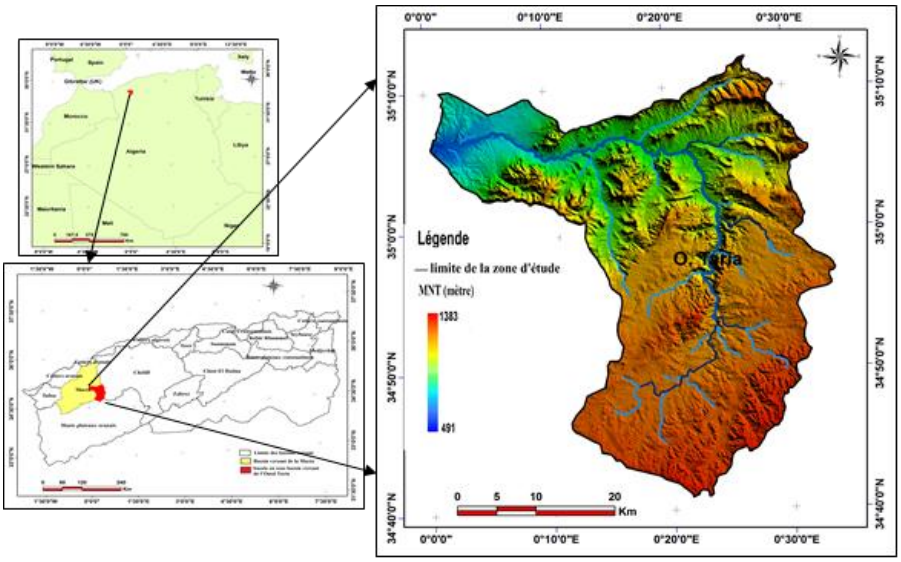


Fig1. Location map of the Oued Taria sub-catchment area

Materials and methods:

The integration of the thematic maps of the various factors of the universal soil loss equation USEL in the geographic information system with their databases has enabled the complexity and interdependence of the factors in the analysis of erosion risks to be clarified quickly and effectively.

Digital mapping techniques, from satellite image processing to Geographic Information Systems (GIS) based on Wischmeier's universal soil loss equation, are increasingly being used. They are used to quantify annual soil loss and to identify and map soil areas requiring intervention to reduce solid inputs to reservoirs.

The average annual soil loss per hectare is determined on the basis of six factors, namely rainfall erosivity, soil erodibility, length and percentage of slope, land occupation and use, and conservation practices. Integrating the thematic layers of the factors in this model into the geographic information system (GIS) makes it possible to identify the impact of each factor on soil losses, to classify erosion zones by relative importance, and to quantify soil losses (Sadiki et al. 2004).

Mapping erosion patterns is commonly used as a basis for determining soil conservation measures (Vogt 1991).

Choice of model:Because soil erosion is particularly difficult to measure directly in real time, especially at scale, it is necessary to use models that can predict or model the causal parameters and consequently the losses that exist in areas where no measurement is feasible or has not been carried out.

Our choice for this study was therefore the revised Wischmeier equation is combined with GIS techniques to analyse the gross soil loss rate and to assess the spatial distribution of soil loss rates over different land uses (Yjjou et al. 2014).

Furthermore, the GIS/USLE approach is highly recommended as a fast and low-cost modelling tool to estimate sheet erosion in catchments where data are publicly available.

With this coupling between models and these modern techniques, we are gradually discovering the value of spatializing soil loss calculation methods, of mapping to represent results over large areas and of creating intervention scenarios

(Bonn F. 1998).

The universal soil loss equation: (USLE model)

A = R .K .LS .C .Poù

A: is the annual rate of soil loss in t/ha/year,

R:is the rain erosivity factor; it corresponds to the annual average of the sums of the products of the kinetic energy of the rain by its intensity in 30 consecutive minutes; it is expressed in MJ . mm / ha .H .yr,

K: is soil erodibility; it depends on the granularity, quantity of organic matter, permeability and structure of the soil; it is expressed in t .ha . H / ha .MJ . mm, LS:is a dimensionless factor representing slope (S in %) and slope length (L in m),

C:is a dimensionless factor representing the effect of vegetation cover,

P:is a dimensionless factor that takes into account anti-erosion cultivation techniques such as contour ploughing.

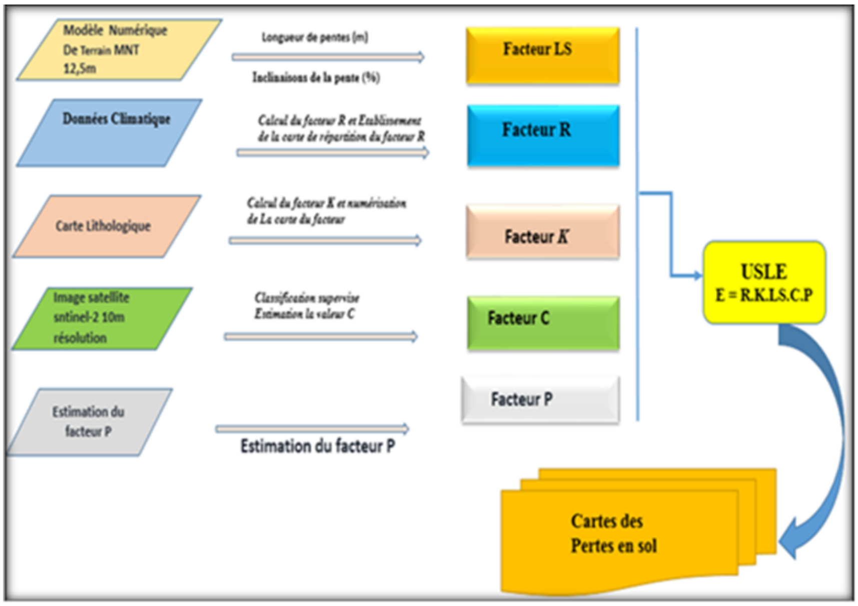


Fig.2 Methodological flow chart for the integration of the universal soil loss equation

Results And Discussion

Topographical factor (LS)

The LS factor is a topographical index that represents the morphology of the terrain. It is calculated from the Digital Terrain Model (DTM) by superimposing maps of slope lengths and gradients. The slope has a major influence on the process of water erosion, aggravating the effect of rainwater run-off.

LS = [0.065 + 0.0456 (slope) + 0.006541 (slope)2](slope length ÷ constant)m

Where :

Slope = inclination of slope (%)

Length of slope = length of slope in m (ft)

Constant = 22.1 in metric units (72.5 in imperial units)

m = see table below

incline	< 1	1 ≤ incline< 3	3 ≤ incline< 5	≥ 5

m	0,2	0,3	0,4	0,5

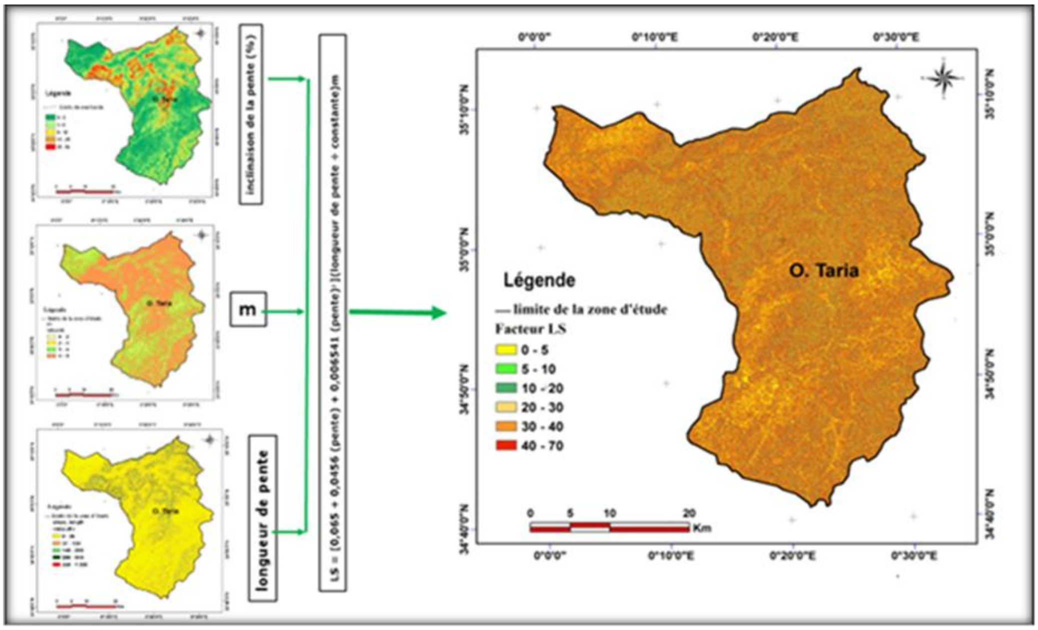


Fig.3 Topographical factor map (LS)

The values obtained for the LS factor were then grouped into six classes of values, and were thus defined for the mapping of this factor on the scale of the Wadi Taria basin. The length and inclination of the slope have a major influence on the erosion process in the catchment.

The distribution map of the topographical factor LS (Fig.3), shows that values varying between 0 and 5 are considered low occupy a small area of 27945.64 located in the north-west and south-west of the basin, corresponding to plain areas.

The majority of the basin has values between 20 and 70%, which are mainly located towards the north-east and south-east of the basin, which means that the very steep terrain with a high LS factor in the study area is subject to a high risk of erosion.

Rainfall erosivity R

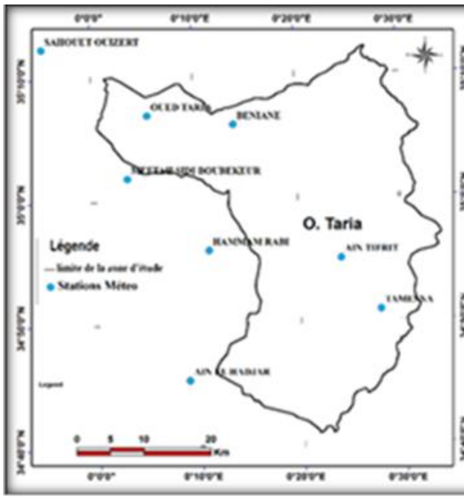
To estimate the R factor, we used the formula of (Rango and Arnoldus 1987).

$\text{Log } R = 1.74 \log \Sigma(Pi^2 /p) + 1.29$

R: climatic aggressiveness in Megajoules.mm /hectare. hour

Pi : Monthly precipitation

P: Annual precipitation



Station	Long	Lat	R
AIN EL HADJAR	0,14913	34,757058	54,018406
MEFTAH SIDI BOUBEKEUR	0,055986	35,031	47,277699
HAMMAM RABI	0,18628	34,93192	45,070623
OUED TARIA	0,091058	35,115659	46,741132
AIN TIFRIT	0,401859	34,917816	55,339218
TAMESNA	0,464584	34,847322	50,840754
NESMOTH MF	0,381819	35,251571	72,73579
GHRIS	0,166501	35,246272	49,269086
SAHOUET OUIZERT	-0,079531	35,207846	42,857519
BENIANE	0,23145	35,101077	51,777901

Fig4: Location of weather stations

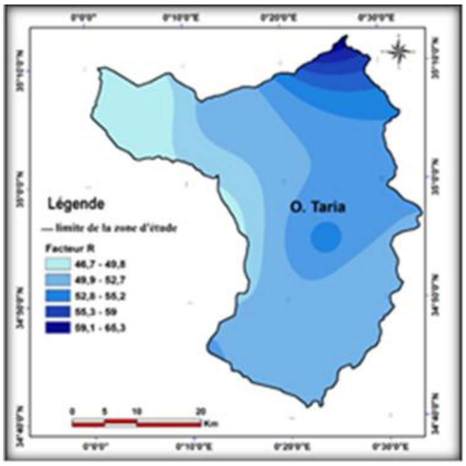


Fig5. Rain erosivity map R

The catchment area is subject to a high level of climatic aggressiveness, corresponding to an R class greater than 65 MJ.mm/ha.h.yr. This result suggests that the catchment is subject to significant erosive power.

Figure 5 shows that the value of the R factor varies from 48.7 (mm/ha.h.yr) to 65.3 (mm/ha.h.yr). High values are recorded in the north-east, while low values are recorded in the south and the lowest are located mainly in the north-west of the Oued Taria catchment area.

- **Soil erodibility K**

Some soils are, by nature, more sensitive to water erosion, or, on the contrary, more resistant than others.

The erodibility index values range from 0.32 to 0.34. Almost the entire surface area of the basin generally shows high erodibility (0.34), followed by low erodibility (0.32), which also extends to soil of continental Pliocene geological age, especially in the north-west of the basin.

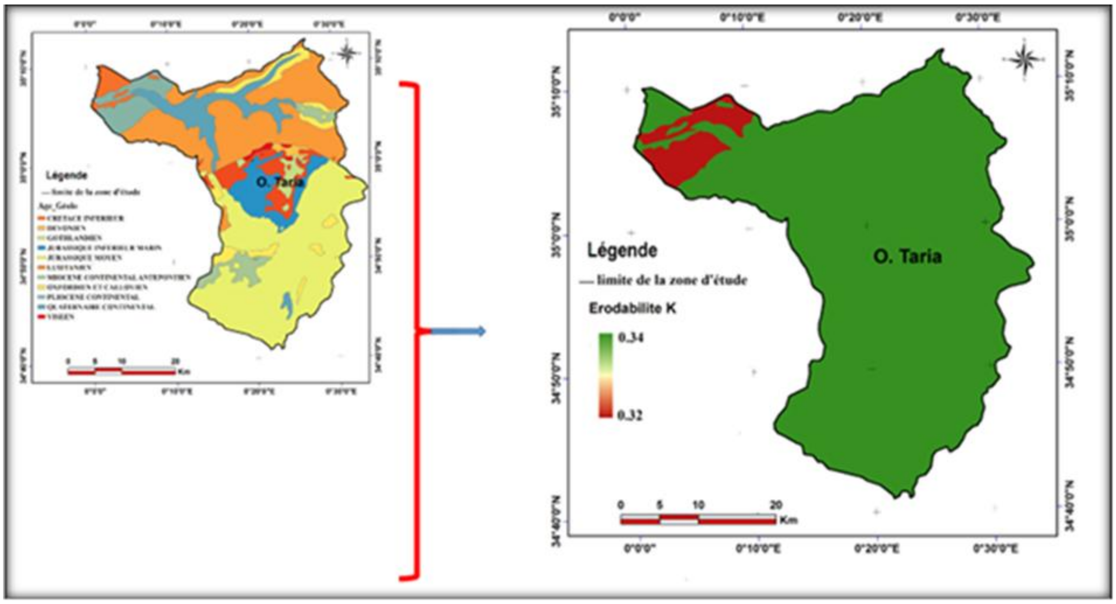


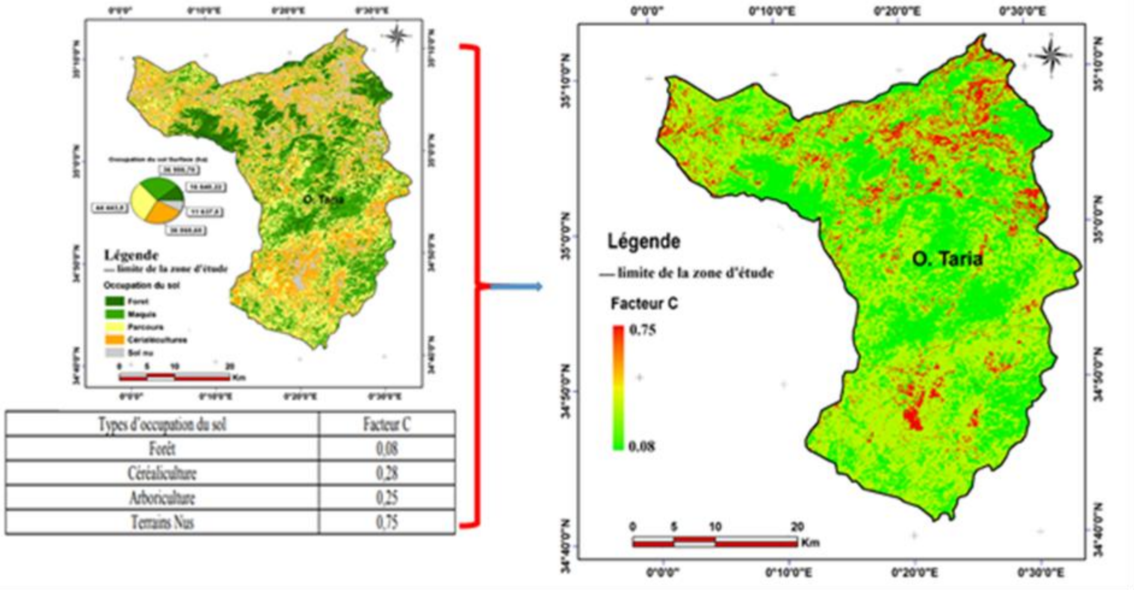
Fig6. Map of soil erodibility K

- **Canopy factor (C)**

The C factor is used to determine the density of vegetation cover, the relative efficiency of the main cropping systems and soil management. In order to be able to assess the different vegetation cover units at the Wadi Taria basin scale, it is necessary to draw up a land cover map based on fieldwork and the use of Sentinel-2 (2019) high-resolution multi-spectral image data. C values vary between 1 for bare fallow land and 0.001 for completely covered land (Wischmeier and Smith 1978).

The value of the C factor in the study area is fairly heterogeneous, ranging from 0.08 to 0.75. On this map, the higher values of the C factor indicate that the area has good vegetation cover, while the lower values indicate bare land.

The map obtained shows that the entire surface area of the basin has a low level of vegetation cover, especially towards the extreme south, whereas areas towards the north, east and centre have good vegetation cover of the forest or scrub type, which greatly limits the erosion process.



Types d'occupation du sol	Facteur C
Forêt	0,08
Céréaliculture	0,28
Arboriculture	0,25
Terrains Nus	0,75

Fig7.map of vegetation cover factor (C)

- Factor (P)

The anti-erosion practices factor (P) reflects practices that reduce the quantity and speed of water runoff, thereby reducing the effects of water erosion. The P factor represents the ratio of land loss on a developed field to that on a neighbouring undeveloped plot of the same size, or the Wischmeier reference plot (Roose 1994).

The most effective soil conservation practices are cultivation on contours, alternating strips or terraces, reforestation on banks, ridging and mounding.

P values are less than or equal to 1.

By mapping the main factors involved in water erosion of the soil, it has been possible to obtain a map of soil losses at every point in the oued Taria catchment area. A preliminary reading of the erosion map shows a spatial distribution of erosion classes, which clearly highlights the cumulative impact of the various factors responsible for erosion.

the P factor generally varies in our case between 5-10 T/ha/year for areas with a gentle slope, and for steep slopes the coefficient varies between 50 and more than 100 t/ha/year (Fig.8), in most of the basin, there is a concentration of the medium to strong erosion class, other areas are spread throughout the basin and much more in its south-eastern and north-western parts but also in the centre of the basin with a soil loss of between 10 t/ha/year and 50 t/ha.

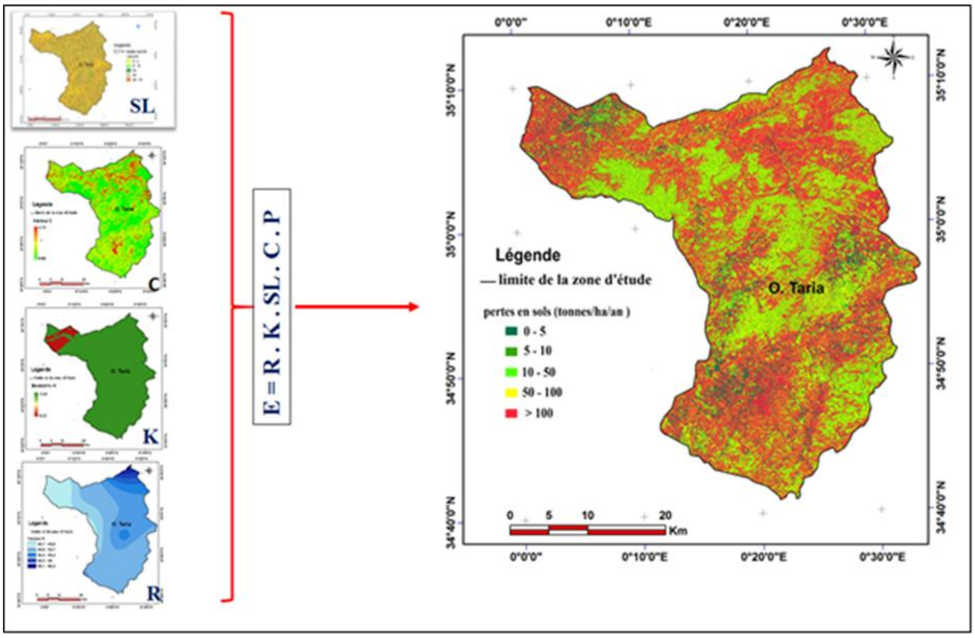


Fig8: Map of soil losses in the Oued Taria catchment area

Soillosses (Tonnes/ha/year)	Surface area (ha)	Percentage (%)
0 - 5	23691,01	16,16
5 - 10	1482,47	1,01
10 - 50	21274,93	14,52
50 - 100	36905,26	25,17
>100	63217,45	43,13

Conclusion

Soil degradation in the basin has visible effects on the environment, with suspended solids being transported mainly during floods (Elahcene et al. 2013) and negative socio-economic consequences.

The maps of potential and current risks obtained during this study constitute an enhancement of natural resources and more particularly soil resources. They have been used to implement a soil conservation plan that prioritises prevention over restoration, which is much more costly and generally less accessible, and sets out the measures to be taken to reduce water erosion to an acceptable level.

The chosen scale of 1:50,000 is sufficient to estimate the potential areas at risk of water erosion with a view to an overall power to protect these areas. The map of potential risks constitutes an information plan that is stable over time, and is of decisive interest for updating the map of current risks. The available data has been statistically analysed for the different categories of land according to their susceptibility to water erosion.The use of satellite images and GIS offers significant advantages over methods based on field experiments for the sustainablemanagement of soil resources.

The USLE soil loss method is an important aid for decision-makers and planners in simulating scenarios of regional change and planning erosion control measures. The approach used has made it possible to characterise the condition of surfaces and the temporal variation in the factors influencing water erosion in the catchment (Toumi et al. 2013).

The results show that the risk of erosion is visible throughout the Wadi Taria basin, with soil losses varying from 0 to over 100 t/ha/year, and over 68.3% of the total surface area of the basin has values greater than 50 t/ha/year.

This serious situation is exacerbated by the erosion factors that combine to accelerate erosion: steep slopes (54%), degradation of the plant cover and highly erodible soils (34%).

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