沙漠研究 **19**-1, 287- 290 (2009)
Journal of Arid Land Studies "Desert Technology IX "
Refereed Paper

Estimation of Soil Loss by Using Combination of Erosion Model and GIS
-Case of Study Watersheds in Tunisia-

Mohamed KEFI[1], Kunihiko YOSHINO[1], Khemaies ZAYANI[2], Hiroko ISODA[3]

Abstract : Soil erosion due to water is a serious environmental problem. Its damage has negative impacts not only on agriculture but also on economy. The purpose of this study is to compare the estimation of soil loss due to soil erosion by water using GIS tools and Universal Soil Loss Equation (USLE) as erosion model in three watersheds in Tunisia which have different location, climate, land use and topography. USLE is a model to predict soil loss from agricultural lands. It is based on rainfall pattern (R factor), soil type (K factor), topography (LS factor), vegetation cover (C factor) and supporting practices (P factor). The result of the research is that high potential soil loss area is an area with severe slope, poor vegetation, sandy soil and no water and soil conservation practices. Therefore, this combination of USLE and GIS can be useful for decision makers to establish appropriate strategies of soil and water conservation.

Keywords : GIS, Soil loss estimation, Tunisia, USLE

1. Introduction

Agriculture has a dominant role in the economy especially for developing countries. Because it has a substantial economic impact, many countries have displayed important efforts to improve and to preserve agriculture by protecting water and soil resources. But these resources are threatened by erosion phenomena. This problem is defined as a process consisting of detachment and transport of soil particles by erosive agents such as flowing water and wind. Due to its damage, soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture and consequently to the economy of developing and developed countries (Pimentel *et al*., 1995).

Because of its serious impact, many researchers have worked in this specific field using computer technology and models to assess and predict the soil loss caused by water erosion. Thus, the emergence of various models which differ by complexity such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) or Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997). Despite the considerable number of erosion model, USLE is widely accepted and is considered as the most used to predict soil loss.

In order to increase the accuracy of erosion assessment and to predict the spatial location and intensity of degradation, many researchers combined USLE model, Remote Sensing technique and Geographic Information System (GIS) (Fistikoglu and Harmancioglu, 2002), (Mati *et al*., 2001). In recent studies, some researchers have applied the remote sensing techniques to evaluate the soil loss by using USLE where the C factor is estimated by Perpendicular Vegetation Index (Yoshino and Ishioka, 2005).

In addition to the researchers' efforts and in order to protect their natural resources, many countries, mainly those threatened by this environmental problem, have adopted different strategies such as Tunisia where about 3 million ha are threatened by erosion with 50% seriously affected. For this reason, Tunisia has adopted two strategies - the first during the period ranging from 1990 to 2001 and the second between 2002 and 2011- whose main objective is to protect and to preserve soil and reduce erosion effects (DG/ACTA, 2002). **Table 1** shows the main realizations of the first strategy and the prevision of the second.

Therefore, this research aims at comparing the estimation of soil loss due to soil erosion by water using GIS tools and USLE as erosion model in three watersheds in Tunisia which differ by climate, land use and topography. Then, we are going to predict the effects of soil and water conservation practices on the reduction of soil loss using a specific scenario.

[1] Graduate School of Systems and Information Engineering, Department of Social Systems and Management, University of Tsukuba, Japan. E-mail : moh_kefi@yahoo.fr
[2] Borj Cedria Higher Institute of Environmental Sciences and Technologies, Tunisia
[3] Alliance for Research on North Africa (ARENA), Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan

Table 1. Realization and prevision of the Tunisian Strategies.

Erosion Control measures	First Strategy Realizations	Second Strategy Prevision
Watershed management (ha) (contour ridges, Bench terracing,…)	892 573	700 000
Cereal areas protection (ha)	70 494	100 000
Maintenance (ha)	338 496	700 000
Spreading and Refill works (unit)	3 556	4 500
Hills dams (unit)	580	500

(DG/ACTA, 2002)

2. Materials and Methods

2.1. Study area

The survey was conducted in three different watersheds which are located in different prefectures in Tunisia. Batta watershed is situated in Siliana between 36˚2.648' to 36˚5.048' N latitude and 9˚33.519' to 9˚35.007' E longitude. The area of this watershed is about 961 ha which is mainly covered by rangeland and agriculture land suitable for cereal. The annual average rainfall is around 495 mm. The watershed is composed of different soil types as vertisol and rendzina. Boulabouz watershed is located in Zaghouan between 36˚14.404' to 36˚16.9' N latitude and 10˚10.833' to 10˚10.868' E longitude. Its area is about 1435 ha. Around 80% of the basin is covered by rangeland. The annual average rainfall is about 365 mm. The soil is rich of lithosols and regosols. For Koukat watershed, it is situated in Kairouan between 35˚49.218' to 35˚52.676' N latitude and 9˚43.916' to 9˚45.908' E longitude. The total area is about 3210 ha which is totally covered by forest and rangeland. The annual average rainfall is about 348 mm. The soil type is dominated by lithosols, regosols and rendzina.

2.2. Methodology

USLE model is to predict soil loss from agricultural lands due to rill and sheet erosion and it is based on rainfall pattern, soil type, topography, land use and land management practices (Wischmeier and Smith, 1978). It is composed of 5 factors and can be written as

$$\mathbf{A = R \times K \times C \times LS \times P} \qquad \textbf{(1)}$$

A is the annual loss (Ton/ha/year). R represents the rainfall erosivity factor (MJ.mm/ ha.Hr.year). K is the erodibility factor (Ton.ha.hr/ha.MJ.mm). C is the crop management factor. P is the supporting practice factor and LS is the slope length and Slope inclination factor. C,P and LS are dimensionless.

Different data is used to obtain these factors. R factor was derived from rainfall data of General Directorate of Water Resource in Tunisia. Taking account of FAO soil classification and by using soil map of Tunisia and some informations of the study areas, we analyzed the K factor. C factor and P factor are obtained by using Landsat 7 ETM+ data and aerial photos of the study area and supplemented by some observations in the field. Finally, LS factor is analyzed by using a Digital Elevation Model "DEM" with 90 meter resolution developed by NASA. By using all required data and Arcview 3.2, we will be able to obtain all factors' layer at first and then, the amount of soil loss in the three watersheds.

2.2.1. Rainfall Erosivity factor (R factor)

This factor represents the erosive potential of rainfall. To obtain this factor, the following relationship (Arnoldus, 1980), which is based on monthly and the annual rainfall data, is used.

$$R = \sum_{i=1}^{12} \frac{P_i^2}{P} \qquad \textbf{(2)}$$

Where P_i is the monthly rainfall (mm) and P is the annual rainfall (mm).

2.2.2. Soil Erodibility factor (K factor)

K factor represents the susceptibility of soil to erosion. It is calculated using the following relationship (Wischmeier and Smith, 1978), which is a combination of soil's texture, organic matter, structure and permeability.

$$\mathbf{K = 2.8 \times 10^{-7} \times (12 - OM) \times M^{1.14} + 4.3 \times 10^{-3} \times (s - 2) + 3.3 \times 10^{-3} \times (p - 3)} \qquad \textbf{(3)}$$

Where K is the soil erodibility factor. OM is the percent of organic matter content. p is the soil permeability code. s is the soil structure code. M is the particle size parameter and can be written such as

$$M = (\%\ silt + \%\ very\ fine\ sand)\ x\ (100 - \%\ clay) \qquad (4)$$

2.2.3. Crop Management factor (C factor)

C factor is used to reflect the effect of cropping on erosion rate. According to Cormary and Masson (1964), C value is attributed to each land use. Bare soil is 1, olive tree is 0.6, cereal is 0.4, rangeland is 0.15 and forest is 0.01.

2.2.4. Topographic factor (LS factor)

Topographic factor is a combination of two factors L and S where **L** is the slope length factor, representing the effect of slope length on erosion and **S** is the slope steepness, representing the effect of slope steepness on erosion.

LS factor can be estimated from the DEM and we have used a technique proposed by (Moore and Burch, 1986) which is based on flow accumulation and slope steepness. The equation is:

$$LS = (Flow\ Accumulation\ \ x\ \ cell\ size/22.13)^{0.4}\ x\ (\sin\ slop/0.0896)^{1.3} \qquad (5)$$

2.2.5. Supporting Practice factor (P factor)

According to Wischmeier and Smith (1978), the supporting practice factor P represents the water and soil conservations practices or measures that control the erosion such as contour ridge and terrace. The value of P factor depends on the soil management measures which are related to the slope of area. In addition P value is attributed as 1 in area without erosion control practice, 0.11 in area with slope (0-5%), 0.12 with a slope (5-10%), 0.14 with a slope (10-20%) and 0.19 with a slope (20-30%).

3. Results and Discussions

The results obtained using USLE model are presented in **Table 2** which shows the mean of soil loss and all factors by watershed. The comparison between the three watersheds shows that Batta watershed has the highest average of soil loss which is due essentially to a higher value of LS factor and R factor. Besides, in this watershed, vegetation cover is scarce which is proved by the high value of C factor. In addition conservation practices are low for this reason P value is almost 1 which indicates no erosion control practice founded. Even for Boulabouz watershed, it has also an average of a quite important soil loss which is caused especially by these factors LS, C and P. However, Koukat watershed has the lowest mean of soil loss because LS factor is low and a large part of the watershed is covered by forest which is a substantive factor in intercepting rainfall hence declining the effect of erosion. Furthermore, P factor value is lower than the other watersheds. It means that soil and water conservation practices are more accomplished there. For K factor, it is almost the same for the three watersheds with a value ranging from 0.06 to 0.08 ton.ha.hr/ha.MJ.mm which is recognized as a high soil erodibility (Foster *et al*., 1981).

According to the result mentioned in Table 2, the highest soil loss amount occurs where the slope and the rainfall are important. That's why, soil loss variation is mainly due to a high value of two factors, R and LS. The higher they are, the more soil loss is detected. But, C and P factors have a positive impact on the preservation of soil as they reduce the effects of soil erosion by water. Therefore, high potential soil loss can occur particularly in areas with steep slope, poor vegetation, sandy soil, which is easy to be detached, and no water and soil conservation practices.

In order to examine the impact of soil and water conservation practices, a specific scenario is proposed to assume the realization of about 5% of the watersheds by some conservation measures such as contour ridges especially in steep areas. Therefore, only P factor will be altered.

Figure 1 shows the result of the assumed scenario. We can notice the decrease of soil loss in the three

Table 2. Estimation of soil loss and factors by watersheds.

	Batta watershed	Boulabouz watershed	Koukat watershed
Soil Loss predicted (T/ha.year)	16.75	5.18	0.39
R factor	90.40	64.00	65.40
LS factor	10.95	7.25	2.31
C factor	0.30	0.20	0.04
K factor	0.06	0.06	0.08
P factor	0.94	0.93	0.81

watersheds. It is quite clear that soil and water conservation practices have a positive impact on reducing erosion effects, the fact that has urged Tunisia to follow this strategy which will be more successful by combining erosion model and GIS to determine the spatial location of high potential soil loss. In addition, erosion effects can be also reduced by increasing and preserving the vegetation coverage specially forest.

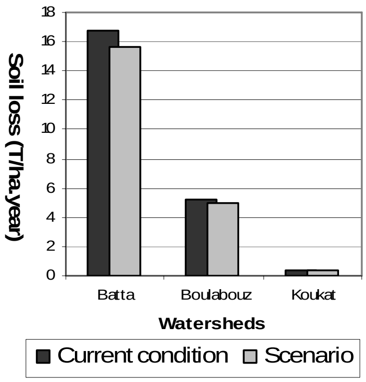

Fig. 1. Effect of conservation measures.

4. Conclusion

In this study, we have used a simple methodology to show that in a GIS environment the USLE can be applied to determine soil loss on a local scale. Moreover, soil loss can increase under the effect of LS and R factors but it can decrease with the effect of C and P factors.

In addition and in order to prevent and to preserve soil and water resource against water erosion, it is required to follow these recommendations:

- Vegetation coverage such as forest and rangeland should be preserved and increased
- Conservation measures should be established especially in the steep slope lands
- Farmers should be encouraged to adopt the techniques of Agriculture of conservation such as crop rotation, fertilization and no-till farming.
- Planning appropriate measures by the integration of GIS and erosion model

Acknowledgement

The authors gratefully acknowledge the Grant-in-Aid for Scientific Research (A) No. 17255011 with title Investigation research on bio-resources in semi arid and arid area in North Africa for its support. We also thank the CRDA (Regional Office of the Ministry of Agriculture) of Kairouan, Siliana and Zaghouan and the General Directorate of Water Resources in Tunisia for their help and data providing. The authors would also like to thank the two anonymous reviewers for their useful comments and suggestions.

References

Arnoldus H.M (1980): An approximation of the rainfall factor in the Universal Soil Loss Equation. In De Boodt M., Gabriel D. eds, *Assessement of erosion*. John Wiley and Sons, Inc. Chichester, West Sussex,UK. 127 – 132.

Cormary Y., Masson J.(1964): Etude de conservation des eaux et du sol au centre de recherches du génie rural de tunisie. Application à un projet-type de la formule de pertes de sols de Wischmeier. Cahiers ORSTOM. *Série Pédologie,Vol.2,*Num.3,p.3-26.

Fistikoglu O., Harmancioglu N.B. (2002) : Integration of GIS with USLE in Assessment of Soil Erosion. *Water Resources Management*, **16**(6): 447-467.

Foster G.R., McCool D.K., Renard K.G., Moldenhauer W.C. (1981): Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation,* **36**(6): 355-359.

DG/ACTA (Direction Générale de l'aménagement et de la conservation des terres Agricoles) (2002) : *Second strategy of soil and water conservation (2002-2011)*. Ministry of Agriculture of Tunisia.

Mati B.C., Morgan R.P.C., Gichuki F.N., Quiton J.N., Brewer T.R., Liniger H.P. (2000): Assessment of erosion hazard with USLE and GIS : A case of study of the Upper Ewaso Ng'iro North basin of Kenya. *International Journal of Applied Earth Observation and Geoinformation (JAG),* **2**(2): 78-86.

Moore I.D., Burch G. (1986): Physical Basis of the Length-Slope Factor in the Universal Soil Loss Equation. *Soil Sci. Amer. J.,* **50**: 1294 – 1298.

Pimentel D., Harvey C., Resosudarmo P., Sinclair K., Kurz D., McNair M., Crist S., Shpritz L., Fitton L., Saffouri R., Blair R. (1995): Environmental and Economic Costs of Soil Erosion and Conservation Benefits. *Econ61,* **267**: 1117-1123.

Renard K.G., Foster G.R., Weesies G.A., McCool D.K., Yoder D.C.(1997): Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation. *U.S. Department of Agriculture, Agriculture Handbook 703*. 384pp.

Yoshino K., Ishioka Y. (2005): Guidelines for soil conservation towards integrated basin management for sustainable development :A new approach based on the assessment of soil loss risk using remote sensing and GIS. *Paddy Water Environ.,* **3**: 234-247.

Wischmeier W.H., Smith D.D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. *Agriculture Handbook No. 537,* US Dept. of Agric.,Washington, DC.