International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:5, No:8, 2011

Determination of Critical Source Areas for Sediment Loss: Sarrath River Basin, Tunisia

Manel Mosbahi

***Abstract*—**The risk of water erosion is one of the main environmental concerns in the southern Mediterranean regions. Thus, quantification of soil loss is an important issue for soil and water conservation managers. The objective of this paper is to examine the applicability of the Soil and Water Assessment Tool (SWAT) model in The Sarrath river catchment, North of Tunisia, and to identify the most vulnerable areas in order to help manager implement an effective management program. The spatial analysis of the results shows that 7 % of the catchment experiences very high erosion risk, in need for suitable conservation measures to be adopted on a priority basis. The spatial distribution of erosion risk classes estimated 3% high, 5,4% tolerable, and 84,6% low. Among the 27 delineated sub-catchments only 4 sub-catchments are found to be under high and very high soil loss group, two sub-catchments fell under moderate soil loss group, whereas other sub-catchments are under low soil loss group.

***Keywords*—**Critical source areas, Erosion risk, SWAT model.

I. Introduction

Soil erosion is a serious problem that is strongly increased by human activities such as deforestation, agriculture and urbanization. Mediterranean region is particularly prone to water erosion [1].

In Tunisia, soils are under a serious risk due to long dry periods followed by heavy bursts of intensive rainfall, falling on steep slopes with fragile soils and low vegetation cover. Twenty percent of the total land area is affected by water erosion, yearly, 15000 hectares of farming arable land and 500 million m3 of runoff water are lost [2]. This widespread problem becomes more and more severe and threatens the sustainability of agricultural productivity in the Sarrath river catchment, subject for a future dam. This catchment located in North West of Tunisia (1491 km²) with typical agriculture dry land is characterized with heterogeneous soil erosion patterns.

For assessing soil erosion, Many kind of models are available presently [3] but physically based distributed models would be preferable. The principal advantage of such models is that it can realistically represent the spatial variability of catchment characteristics [4]. Among these models, SWAT has gained international recognition as is evidenced by a large number of applications. Some of the recent applications include simulations of catchment hydrology and water quality [5]–[6], prediction of sediment loads at different catchment scales [7]–[8] and others. The model was also applied on the Medjerda Catchment, located north of Tunisia [9]. In this study the application of SWAT evaluated the potential hydrological and water quality impacts of land management scenarios. It was found that the model represented well the hydrological cycle despite the fact that hill dams were not simulated.

In view of this, the SWAT model was selected to quantify the annual soil erosion and identify the critical sub-catchments responsible of the highest amount of soil loss in the Sarrath catchment to improve the affected areas.

M. Mosbahi is with the Laboratory of Remote Sensing and Information System for spatial reference, from the National School of Engineers of Tunis, BP37, Tunis le belvedere, 1002 TUNISIE (phone: 0021697411333; e-mail: manel241079@yahoo.fr).

II. Materials and Methods

A. Site Description

The Sarrath river catchment is located in the north-west of Tunisia; its river originates in the semi-arid Atlas Mountains of eastern Algeria and drains an area of 1491 km². The elevation range from 573 to 1350 m and the slope steepness range between 3 to 72 % (Fig. 1)

Most of the catchment area is poorly covered with vegetation with the exception of some degraded forests and dense brushes on hilly areas. Major crops grown in the catchment are corn representing 31% of the total area, tree cultivation covering only almost 4% of the whole. The rest of the catchment consists of pasture (9%), uncovered land (8%) and husbandry (4%).

The area under study lies in the sub-humid to Mediterranean humid bio-climatic region. It is characterized with an extreme variability in annual and inter-annual rainfall, in winter; the rain is usually of a frontal type and originates on the Mediterranean. Whereas, summer and fall rain, is generally of a convective type and bursts in to storms on the heights coupled with hot summers and mild winters. In Tunisia, the rainy season extends from September to May with intense precipitations in September, October and February. The mean annual rainfall for the period 1985-2005 is 350 mm with a standard deviation of 134,5 mm and a variation coefficient ranging between 0,32 and 0,47. The major soil types found in the Sarrath river catchment include calcareous brown soils, fluviosols and vertisols.

International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:5, No:8, 2011

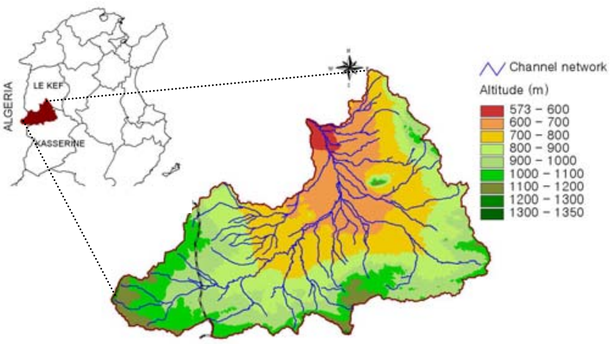

Fig. 1 Study site location and the rain gauge network

B. Model Description

SWAT is a hydrologic/water quality model developed by the United States Department of Agriculture–Agricultural Research Service (USDA–ARS) [10]–[11]. The main objective of SWAT is to predict the impact of agricultural or land management on water, sediment and agricultural chemical yields in ungauged basins. The present study focuses solely on the sediment component of the model.

The model is a continuous-time, spatially distributed simulator of the hydrologic cycle and agricultural pollutant transport at a catchment scale. Major model components are hydrology, weather, erosion and sediment transport, soil temperature, crop growth, nutrients, pesticides, and agricultural management [12].

Soil interflow is calculated by the kinematic storage model, which takes account of soil hydrological conductivity, topographical slope and the temporal and spatial change of soil moisture.

Lateral subsurface flow in the soil profile is calculated simultaneously with percolation. Ground water flow contribution to total stream flow is simulated by routing shallow aquifer storage component to the stream [10].

Surface runoff volume from daily rainfall is predicted with the modified SCS curve number method. The peak runoff rate is calculated according to the rational formula. Thus, runoff is reduced by channel transmission losses that infiltrate to an underlying aquifer.

Evaporation of soil water and transpiration by plants are evaluated as functions of potential evaporation and plant leaf area. The potential evapotranspiration (PET) can be simulated with three methods: Priestley and Taylor [13], Penman–Monteith [14] and Hargreaves and Samani [15], in this study, the Hargreaves equation based on daily temperatures was used.

Soil erosion and sediment caused by rainfall and runoff are estimated with the Modified Universal Soil Loss Equation (MUSLE) [16] for each sub-catchment.

In SWAT, a catchment is divided into multiple sub-catchments which are then divided into units of unique soil/land use characteristics called hydrological response units (HRUs). These HRUs are defined as homogeneous spatial units characterized by similar geomorphologic and hydrological properties [17]. Thus, HRUs are composed of a unique combination of homogeneous soil properties, land use and topography.

C. Data Collection

Spatial data used in the study were derived using the SWAT ArcView Interface which provides a graphical support to the desegregation scheme and allows the construction of the model input from digital maps. The basic data sets required to develop the model input are: topography, land use, soil and climatic data.

A digital elevation model (DEM) with a scale of 1:50 000 was generated using contours lines created for the purpose of this study from national topographic maps. The cell resolution with an interval of 50 m was used to generate the derived physical characteristics of the catchment.

The soil and land use layers were obtained from the Soil and Water Conservation Agency. They were produced from Landsat Thematic Mapper images and from soil maps. Soil properties were obtained from Soil Database created by the Soil and Agriculture Land Authority;

The meteorological data during 1985-2005 which include, maximum and minimum temperature, were collected for two weather stations in and near the Sarrath catchment, from the National Meteorological Institute.

Daily precipitations are gathered for twelve (12) rain gauges stations over the same period from the National Water Authority. A GIS ArcView was used for generating the catchment and sub-catchments boundaries, drainage networks, slope, soil and land occupations layers from topography maps and Landsat images at a scale of 1:50 000.

The catchment area is portioned into 27 sub-catchments and into 273 discrete computational units called Hydrologic Response Units (HRUs) which are a particular combination of topography, soil and land cover.

III. Analysis and Discussion

A. Soil Loss

Wischmeier and Smith [18] defined the soil loss tolerance of 12 $ton.ha^{-1}.y^{-1}$ as the maximum level of soil erosion that will permit a level of crop productivity to be economically sustainable. Experiments throughout the Tunisian semiarid area have determined the average tolerable soil loss to about 2.5, 5, and 10 ton ha^{-1} y^{-1} for a thin, average, and thicker soil, respectively [19]. With a very slow rate of soil formation in some parts of the Mediterranean region, any soil loss of more than 1 $ton.ha^{-1}.y^{-1}$ can be considered as irreversible within a time span of 50-100 years [20].

Based on these experiments, the Sarrath catchment was classified into four erosion severity classes (Table I). Accordingly, most of the area of the catchment (84,6 %) fell under low erosion risk where soil loss is lower than 5 $ton.ha^{-1}$

.y^{-1} followed by 5,4 % of the area under a tolerable erosion risk, 3 % with high erosion risk and 7 % suffers from very high erosion. Soil loss decreases from downstream to upstream, the highest erosion values are found in the valley area used mainly for agriculture.

At the sub-catchment level, the highest soil loss is 23,5 ton ha^{-1}.y^{-1} (S27), and the lowest is 0,03 ton.ha^{-1}.y^{-1} (S26). Land use/cover and slope gradient appeared to be the major leading factors for soil loss in this catchment.

TABLE I
ANNUAL SOIL LOSS AND EROSION RISK CLASSES

Soil loss (ton.h^{-1}.y^{-1})	Sub-catchment number	Area		Erosion risk
		(Km²)	(%)	
0-5	1, 3, 6 and from 9 to 26	1262	84,6	Low
5-10	7, 8	80,4	5,4	Tolerable
10-20	4, 5	44,8	3	High
>20	2, 27	103,8	7	Very high

B. Critical Source Area for Soil Loss

Many studies have shown that for the majority of catchments, a few critical areas are responsible for a disproportionate amount of sediment yields [21]–[22]–[23]. Thus, it is necessary and strategic to prioritize sub-catchments for treatment with appropriate soil and water conservation measures.

Fig. 2 demonstrates the spatial distribution of simulated sediment yield over the Sarrath catchment during the period of 1985- 2005.

Among the 27 sub-catchments only 4 sub-catchments numbered (2, 4, 5 and 27) fell under high and very high soil loss group of soil erosion classes, with a simulated average amount of soil loss higher than the acceptable soil loss tolerance (5 to 10 ton.ha^{-1}.y^{-1}). Whereas most of the catchment area fell under low soil erosion classes with the sub-catchments S24 and S26 contributing the minimum to soil loss rate. Only 10 % of the total catchment area contributed with the maximum amount of sediment loss over the simulation period which will help in identifying the areas in urgent needs for suitable conservation measures.

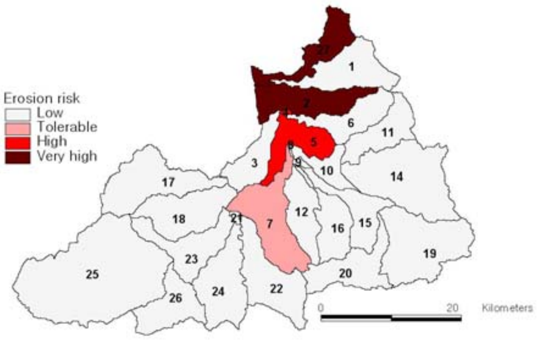

Fig. 2 Spatial distribution of sediment yield predicted by SWAT in the Sarrath catchment

Comparison of sediment yield between sub-catchments indicates that most erosive areas are cultivated lands and bare soils with steep slope as it is presented in Table II. The topography, rainfall, and land cover types are different in the sub-catchments, and the processes and outcomes of runoff and sediment were consequently different. In fact, more rainfall does not usually mean more runoff. For instance, relatively higher precipitation in S24 produced lower runoff, and lower precipitation in S5 produced higher runoff (Table II). This can be explained by the change in land cover type, S24 is characterized with better forest cover and less cultivated land while S5 is predominately covered with corn and bare soils the rest of the year. The second reason is the landscape steepness as it facilitates high runoff allowing less residence time for rainwater to infiltrate and consequently resulting in high erosion rates for S5 and S7. The sub-catchment S26, with high slope, responded differently as the land cover is mostly forest.

TABLE II
COMPARISON OF MORE INFLUENCE EROSION FACTORS OF SUB-CATCHMENTS

Sub-catchment number	Area (Km²)	Slope (%)	Rainfall (mm)	Predominate land cover	Runoff (10^6 m^3)	Soil loss (t.h^{-1}.y^{-1})
2	59,1	4,4	328,9	corn	211,3	21,1
4	0,9	0,8	328,9	bare soil	201,7	17,2
5	43,9	4,5	230,3	corn	198,5	15,3
7	80,4	4,7	497,6	corn	161,4	6,6
24	71,2	1,2	349,8	forest	6,1	0,06
26	50,8	6,7	349,8	forest	10,7	0,03
27	44,7	4,9	360,4	corn	50,75	23,45

Studies related to erosion simulation models indicated that erosion response is much more sensitive to rainfall amount and intensity than the other environmental variables [24]. In view of this, annual variability of precipitation is very important and must be treated with more attention to evaluate the annual risk of erosion.

Among the period of simulation (1985-2005), two extreme years were chosen, a dry year (1993) with 192 mm of rainfall and a wet year (2003) with 598mm of rainfall in order to focus

TABLE III
CRITICAL SUB- CATCHMENTS FOR THE DRY YEAR 1993

Sub-catchment number	Area		Rainfall (mm)	Runoff (10^6 m^3)	Soil loss (ton.h^{-1}.y^{-1})
	(Km²)	(%)			
2	59,1	4	159	56,3	11,48
27	44,7	3	176	58,8	12,73

TABLE IV
CRITICAL SUB- CATCHMENTS FOR THE WET YEAR 2003

Sub-catchment number	Area		Rainfall (mm)	Runoff (10^6 m^3)	Soil loss (ton.ha^{-1}.y^{-1})
	(Km²)	(%)			
2	59,1	4	696	275,6	64,31
4	0,9	0,1	616	222,6	52,12
5	43,9	2,9	365	214,8	47,40
7	44,7	3	915	116,8	22,59
9	2,8	0,2	365	61,8	10,63
21	2	0,1	918	78,2	14,38
27	44,7	3	695	298,2	71,41

on the simulate annual runoff and the average amount of sediment for critical sub-catchments (Table III and IV).

The spatial distribution of erosion for the dry and the wet years is presented in Fig. 3 and Fig. 4. In fact, areas with sediment yield higher than 10 $ton.h^{-1}.y^{-1}$ represented 7% for 1993 affecting only two sub-catchments (S2, S27) and 13.3% for 2003 with much higher sediment yields reaching 6 to 7 times as much for the same area (S2, S27).

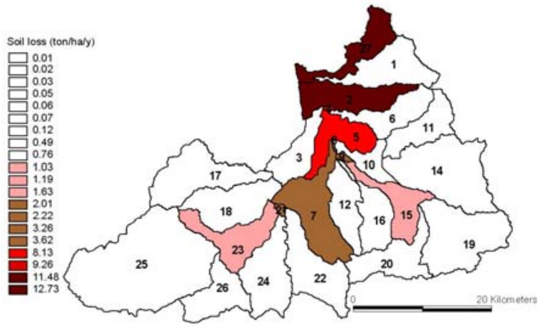

Fig. 3 Spatial distribution of sediment yield for 1993

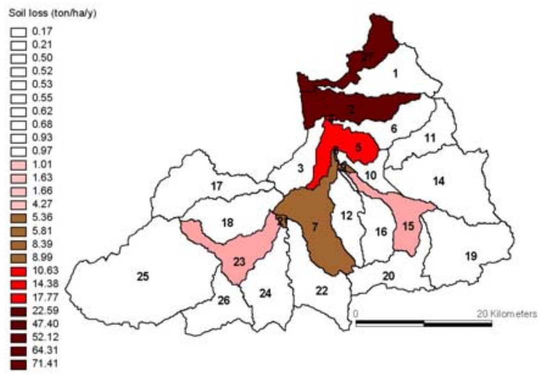

Fig. 4 Spatial distribution of sediment for 2003

IV. Conclusion

The identification of the most erosion prone areas will help the local government who is interested and involved in soil and water conservation activities in the Sarrath river catchment to successfully plan and implement appropriate soil and water conservation measures. Even though the estimated soil erosion rates may not be precise due to lack of field monitoring and measurements, the presented results are quite useful given the fact that it allows to spatially identify the vulnerable areas in a context of unavailable data. Further, it did demonstrate the need for future field surveys.

The prioritization of sub-catchments for conservation measures is important given the resource constraints to treat the catchment entirely and thus it provides efficient use in case of limited resources. The spatial differences in erosion rates within the catchment are mainly caused by differences in land cover type and topography. Thus, area with forest cover provided better protection to soil erosion and areas with high slopes and low forest cover. Rainfall variability has also an important effect, the study showed that the amount of soil loss increased extremely from the dry year to the wet year and the number of sensitive sub-catchments increased accordingly.

The study also revealed that all the sub-catchments do not contribute with the same amount of sediment yield at the outlet; the SWAT model helped in identifying that only 10% of the critical sub-catchments are in need for conservation planning.

Acknowledgment

The authors wish to express their gratitude to the Soil and Water Land Agriculture Authority for supplying land use database.

References

[1] O. Terranova, L. Antronico, R. Coscarelli, P. Iaquinta, "Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (southern Italy)," *Geomorphol,* vol. 112, pp. 228–245, 2009.
[2] DG/ACTA, *Stratégie nationale pour la conservation des eaux et des sols*, Publication de la Direction de la Conservation des Eaux et des Sols. Ministère de l'Agriculture et des Ressources Hydrauliques. République Tunisienne, 1993.
[3] W. S. Merritt, R. A. Letcher, A. J. Jakeman, "A review of erosion and sediment transport models," *Environ Modell Softw*, vol. 18, pp. 761–799, 2003.
[4] A. Mishra, S. Kar, V.P Singh, "Determination of runoff and sediment yield from a small watershed in sub-humid subtropics using the HSPF model," *Hydrol Process*, vol. 21, pp. 3035–3045, 2007.
[5] K. C. Abbaspour et al, "Modeling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT," *J Hydrol*, vol. 333, pp. 413–430, 2007.
[6] Y. Zhang, J. Xia, T. Liang, Q. Shao, "Impact of water projects on river flow regimes and water quality in Huai River basin," *Water Resour Manage*, vol. 24, pp. 889–908, 2010.
[7] Z. Kliment, J. Kadlec, J. Langhammer J, "Evaluation of suspended load changes using AnnAGNPS and SWAT semi-empirical erosion models," *Catena*, vol. 73, pp. 286–299, 2008.
[8] W. Ouyang, F. Hao, A. K. Skidmore, A. G. Toxopeus, "Soil erosion and sediment yield and their relationships with vegetation cover in upper stream of the Yellow River," *Sci. Total Environ*, vol. 409, pp. 396–403, 2010.
[9] F. Bouraoui, S. Benabdallah, A. Jrad, G. Bidoglio G, "Application of the SWAT model on the Medjerda river basin (Tunisia)," *Phys Chem Earth*, vol. 30, pp. 497–507, 2005.
[10] J. G. Arnold, R. Srinivasan, R. S. Muttiah, J. R. Williams, "Large area hydrologic modeling and assessment. Part I: Model development," *J Am Water Resour Assoc*, vol. 34, no. 1, pp. 73–89, 1998.
[11] R. Srinivasan, S. Huisman, L. Breuer, *European SWAT summer school 2004* (User's manuel). Institute of Landscape Ecology and Resources Management Justus-Liebig-University Giessen, Belgium, 2004.
[12] S. L. Neitsch, J. G. Arnold, J. R. Kiniry, R. Srinivasan, J. R. Williams, *Soil and Water Assessment Tool, Theoretical documentation version 2000*. Grassland, Soil and Water Research Service, Temple, Texas, 2002.
[13] CH. B. Priestley, R. J. Taylor, "On the assessment of surface heat flux and evapotranspiration using large scale parameters," *Mon. Weather Rev.*, vol. 100, no. 2, pp. 81–92, 1972.
[14] J. L. Monteith, *Evaporation and the environment. The state and movement of water in living organisms.* Cambridge University Press, Cambridge, 1965, pp. 205–234.
[15] G. H. Hargreaves, Z. A. Samani ZA, "Reference Crop Evapotranspiration from Temperature," *Appl Eng in Agr*, vol. 1, no. 2, pp. 96-99, 1985.
[16] J. R. Williams, H. D. Berndt, "Sediment yield prediction based on watershed hydrology," *Trans ASAE*, vol. 20, pp. 1100–1104, 1977.
[17] K. Bongartz, "Applying different spatial distribution and modeling concepts in three nested mesoscale catchments of Germany," *Phys Chem Earth,* vol. 28, pp. 1343–1349, 2003.

[18] W. H. Wischmeier, D. D. Smith, *Predicting rainfall erosion losses: a guide to conservation planning*. USDA Agricultural Handbook No. 537, Washington, DC, 1978.

[19] J M. Masson, "L'érosion des sols par l'eau en climat Méditerranéen. Méthodes expérimentales pour l'étude des quantités érodées à l'échelle du champ," *LHBl*, vol. 8, pp. 673–679, 1972.

[20] EEA, *Environment in the European Union at the Turn of the Century*. European Environmental Agency, 1999.

[21] M. P. Tripathi, R. K. Panda, N. S. Raghuwanshi, "Identification and prioritization of critical sub-watersheds for soil conservation management using the SWAT model," *Biosyst Eng*, vol. 85, no. 3, pp. 365–379, 2003.

[22] A. Vrieling, G. Sterk, O. Vigiak, "Spatial evaluation of soil erosion risk in the west Usambara mountains, Tanzania," *Land Degrad Develop*, vol. 17, pp. 301–319, 2006.

[23] W. Bewket, E. Teferi, "Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the Chemoga watershed, Blue Nile Basin, Ethiopia," *Land Degrad Develop*, vol. 20, pp. 609-622, 2009.

[24] M. A. Nearing et al, "Modeling response of soil erosion and runoff to changes in precipitation and cover," *Catena*, vol. 61, pp. 131–154, 2005.