DESERT

DESERT
Online at http://jdesert.ut.ac.ir

DESERT 16 (2011) 5-12

Runoff and sediment yield modeling using WEPP in a semi-arid environment (Case study: Orazan Watershed)

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Received: 18 February 2007; Received in revised form: 12 November 2007; Accepted: 9 February 2008

Abstract

Water erosion is a major environmental problem in many parts of the world. Majority of semi-arid countries are concerned because of their specific climate and soils sensitivity, but also because of the recent intensification of human activities and agricultural practices. Accurate estimation of water erosion for various land-use and climate scenarios is so an important key to define sustainable management policies. In the last decades, several studies have been carried out to build models suitable for quantifying sedimentation. Among these models, the Water Erosion Prediction Project (WEPP), is a physically based, distributed-parameter model that has been developed and mainly validated in America. Only few studies have investigated its applicability to environmental conditions that differs from those where the model was developed. The aim of this work is to test the efficiency of WEPP model to predict runoff and sediment yield at catchment scale in a semi-arid area. Continuous simulations have been conducted between 1996 and 2005 in Orazan Watershed. Comparison between predictions and measurements indicates that WEPP under-estimates sediment volumes of 23% and over-estimates runoff volumes of 27%. Results shows that sediment yield and Runoff outputs are relatively well predicted but lack of input data to run WEPP model is an important challenge in Iran conditions.

Keywords: Water erosion prediction project (WEPP); Erosion; Runoff; Orazan Watershed ;Iran

1. Introduction

Accurate estimation of soil erosion due to water is very important for assessment of potential soil loss and the evaluation of the loss of water storage capacity in reservoirs due to sediment deposition (Amore *et al*., 2004).Soil erosion has been a major problem for many Iranian soils. Changes in land use due to development strategies exposing erosion-sensitive geological formations and poor vegetation cover in the Alborz Mountains are the main factors in making millions tons of sediment available annually for erosion and transport. Surface erosion and sediment yield are important factors that should be taken into account in planning renewable natural resource projects.

Soil erosion can be reduced by adapting best management practices (BMP). To do this, proper soil loss estimation from various land management scenarios is necessary. In recent decades, many programs and formulas have been developed in order to reduce soil loss from basins and, as a result, optimizing policies for best management of water resources, particularly reservoirs. Consequently, models have been built (empirical, conceptual, or physically based) in order to represent and to quantify the processes of detachment, transport, and deposition of eroded soil, with the aim of implementing assessment tools for educational, planning, and legislative purposes (Renschler and Harbor,2002). Since the phenomena are complex and depend on many parameters, calibration of models is difficult, especially

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because field data are usually not enough and relate to small spatial and temporal contexts.

Empirical models have been and are still used, due to their simple structure and ease of application, but as all these models are based on empirical coefficients which must be precisely evaluated from field observations for each specific situation (crop type, protection, climate …), they can not describe the erosion process as a set of physical phenomena. Several experimental models were used for predicting the erosion severity and sediment yield in a sub-catchment area for which hydrometric data is not available. The commonest models now being used are USLE (Universal Soil Loss Equation) (Mati *et al*., 2000 and Erskine *et al*., 2002), MUSLE (Modified Universal Soil Loss Equation), RUSLE(Revised Universal Soil Loss Equation) (Millward and Mersey, 1999 and Millward and Mersey, 2001; Raghunath, 2002), PSIAC (Pacific Southwest Interagency Committee)(Nelson and Rasele, 1989, Heydarian, 1996 and Clark, 2001), and EPM (Erosion Potential Method) (Refahi and Nematti, 1995 and Tangestani, 2001).

Physically based models simulate the individual components of the entire erosion process by solving the corresponding equations; and so they have a wider range of applicability. Also, such models can assess both the spatial and temporal variability of the natural erosion processes. The Water Erosion Prediction Project (WEPP) is a computer-implemented, physically-based, distributed-parameter model that predicts soil loss and deposition using a spatially and temporally distributed approach (Foster and Lane, 1987; Nearing *et al*., 1989; Laflen *et al*., 1991, 1997). This model is very sensitive to a large number of variables, i.e. parameters concerning vegetation, management, soil, topography, climate, channel and impoundment properties. It is a process-based continuous simulation model and is gaining popularity worldwide for the use of state-of-the art technology.

Applications of Geographic Information Systems (GIS) and remote sensing techniques in erosion and sediment yield assessment have been developed recently (Hill, 1993, Mezosi and Mucsi, 1993, Floras and Sgouras, 1999, Shrimali *et al*., 2001, Mohammed Rinos *et al*., 2001, Tangestani, 2001, Rafaelli *et al*., 2001, Sahin and Kurum, 2002, Lin *et al*., 2002, Bissonnais *et al*., 2002, Yuliang and Yun, 2002 and Martinez-Casanovas, 2003, Lier, 2003). When accessible spatial data are geo-referenced and can be put in the form of maps, GIS allow simpler and faster data and parameter management and can make soil erosion studies easier, especially when repeated applications of similar and complex procedures are required.

The purpose of this study was to provide approximation of the capability of the WEPP model for simulating soil loss in Iran conditions. This research was done by comparing model prediction of soil loss to data measured from a sub-catchment in the Alborz Mountains in Iran.

2. Materials and methods

2.1. Study area

The Orazan Watershed (36º 05' 59"-36º 10' 34" N, 50º 50' 34"-50º 54' 16" E) is a part of the great basin of the Taleghan-Roud River, and covers an area of about 27.o6 km^2, in the northwest of Tehran province. The relief of the area decreases from high mountains (~3280 m) to hills (~1870 m). The landscape is usually composed of S-shaped profiles and the mean slop value is 35% (minimum slop 0.0%, maximum 54% and 90% of slop values are more than 15%). The mean annual temperature is about 3.06^{oc}. Majority of region is semi-arid; with an annual rainfall ranging from more than 600 mm in the higher elevations to about 250-450 mm in lower elevations. Two events per year have average runoff of greater than 10 mm.

According to the FAO classification, the main soil types are: Calcaric Regosols (54%), Eutric Leptosols (42%), Haplic Cambisols (3%) and Calcaric Fluvisols (1%). Table 1 shows all soil classes of study area (Maleki, 2004),(Table 1).

Table 1. Soil classification of study area

Soil unit	area ha	American classification			FAO cl.	Iranian cl.
		class	sub-class	family		
1	701/01	*Entisol*	*Lithic xerorthents*	*Loamy skeletal, mixed(non calcareous)frigid*	*Eutiric Leptosols*	*Litho soils*
2	852/94	*Entisol*	*Typic xerorthent*	*Fine loam,mixed(calcareous), mesic*	*Calcaric Regosols*	*Rego soils*
3	481/41	*Entisol*	*Lithic exerorthent*	*Coarse loamy, mixed(calcareous), frigid*	*Eutiric Leptosols*	*Litho soils*
4	33/73	*Entisol*	*Typic xerofluvents*	*Coarse loamy, mixed(calcareous),mesic*	*Calcaric Fluvisols*	*Alluvial soils*
5	623/52	*Entisol*	*Typic exerorthent*	*Coarse loam over framental,mixed(calcareous), mesic*	*Calcaric Regosols*	*Rego soils*
6	91/82	*Inceptis ol*	*Calcixerollic xerochrepts*	*Fine, mixed, mesic*	*Haplic Cambisols*	*Calsic brown soils*

About 83% of study area is occupied by rangelands covered by Astragalus sp, Agropyron sp, Gundelia sp and Thymus sp. A small portion of the study area is occupied by garden and dry farming, mostly around the Orazan village. Figure 1 shows the location of the study area.

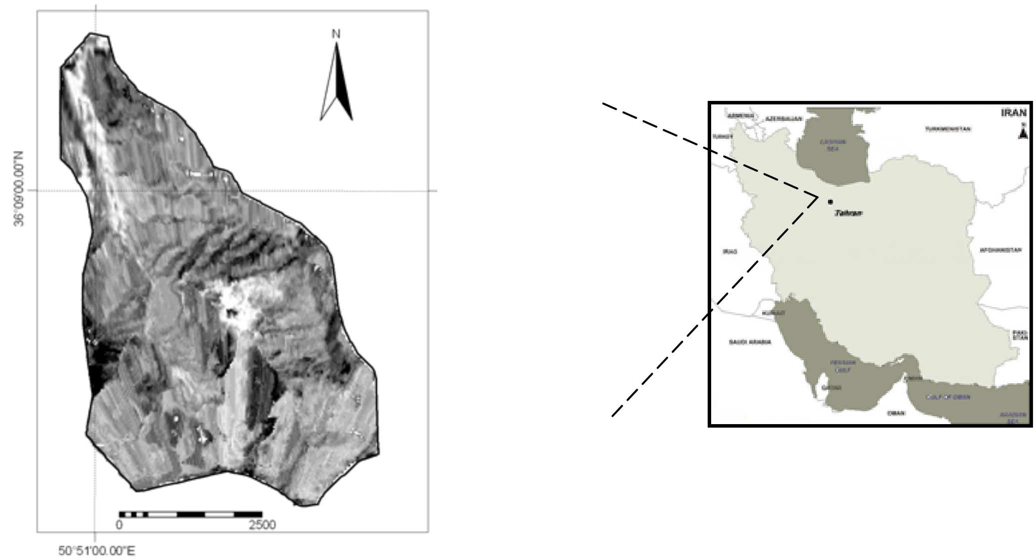

Fig. 1. Topography and location map of the study area

2.2. Model description

Detailed explanation of the WEPP model can be found in Flanagan and Nearing (1995). Nevertheless, a brief overview of WEPP structure and major functions that are particularly important to this study is given below. The WEPP model is a process-based simulation model that predicts spatial and temporal distributions of soil loss and deposition (nearing *et al*., 1989; Laflen *et al*., 1991, 1997). It is built on the basis of infiltration theories, plant science, open-channel and impoundment hydraulics, and erosion mechanics (Flanagan *et al*., 1995). WEPP is a computer-implemented model with a daily, monthly, or annual time step (Flanagan *et al*., 1995). The erosion processes may be simulated at the level of a hill slop profile or at the level of a small watershed. The hill slop version computes erosion along a single slop profile and the major inputs for its running need to be specified in four data files consisting weather, slop, soil and management. The watershed version that is an extension of WEPP hill slop model can be used to assess soil loss on the small watershed. This application is composed of some components considering climate, hydrology and water balance, plant growth with residue decomposition and agricultural practices, soil composition and consolidation. WEPP usually read climate data from CLIGEN input file (Nicks *et al*., 1995). Infiltration is computing through the Green-Ampt Main-Larson equation for unsteady rainfall. The runoff is routed over the land surface through kinematic equations.

Managing large quantities of data for watershed application of WEPP is noticeably simplified using GIS technology. Examples of GIS use (Savabi *et al*., 1995, 1996; Ranieri *et al*., 2002) concern only the evaluation of specific parameters to be used as input data for the model application. In order to allow the transfer of input data from a GIS to WEPP routines, a research group has worked to link WEPP and GIS. In particular, Cochrane and Flanagan (1999) developed an interface between WEPP (the Watershed version), and ArcView GIS for small basins (0.59 to 29 ha), comparing the results obtained from the manual application of WEPP with those obtained using the interface, and studying the effect of the DEM resolution on the results from GISWEPP. There were no significant differences between the manual and the automated applications, and results obtained from different classes of resolution were also not statistically different. Further development in techniques to automate applications of the model has resulted in GeoWEPP, a tool that allows the user to derive topographical input parameters from DEM (Renschler, 2003).

2.3. Input data collection for the model

In this study, WEPP watershed model version 2004.7 was used to compute runoff and erosion rate during a continuous period from January 1996 to September 2005. The single storm mode was not applied since it was impossible to run a WEPP calibration for each storm event. On the other hand, the sufficient input data were not available. In order to evaluate the predictive ability of WEPP, parameterization was made as recommended in the WEPP user summary (Flanagan and Livingston, 1995) and no calibration on hydrological or erosion data was conducted.

For the climate input file, daily rainfall amount and intra-event rainfall intensity patterns were tested. Rainfall intensity patterns and daily values of minimum and maximum air temperatures were taken from instruments located near the Orazan Watershed. Solar radiation, dew point temperature, wind velocity and direction available in Galinak (10 km North-West from the Orazan Watershed), were provided by TAMAB research center (water resources research center of Iran). Daily rainfall amounts were obtained by integration of rainfall intensity patterns on each day. Climate input file was built with CLIGEN. When using daily precipitation as input data, the CLIGEN disaggregation method generates storm intensity input assuming a storm with a single intensity peak and described by a double exponential function.

To gathering other information, using GIS issues, erosion faces map, geology map, and slop map were crossed and homogenetic unit map were derived. About forty subdivisions were produced and after assimilating, thirteen units were obtained (Fig. 2). All the studies were accomplished in these homogenetic units. Geometric characteristics of each subdivision were automatically derived from DEM by a procedure developed by Cochrane and Flanagan (1999), and implemented in GeoWEPP. Figure 2b shows DEM of study area. Land use and soil type were affected for each subdivision through GIS overlaying operation according to a majority criteria and so, two digital maps were produced (see Fig. 3a,b). Each map was adjusted using field observations, which showed little variations with respect to the older, cartographic information. Such small variations occurred only within small areas, and on the basis of this information, it was assumed that no significant changes in land use occurred within the time periods considered for model runs.

Plant/management system (i.e. cultural operations and plant growth characteristics), were followed during two successive years for the most representative land-use types (Maleki 2004, Taheri 2005). Because of quite similar behaviors, only three plant/management systems were defined: dry farming by leguminous, rangeland without grazing and horticulture. These three systems were based on WEPP database set but some parameters were adjusted to fit measured plant characteristics as height, cover percentage, or leaf area index (LAI) cover. Two or three field's samples for each soil type were analyzed to evaluate input parameters of texture, action exchange capacity (CEC), and bulk density. Albedo was estimated by Baumer’s formula as suggested in the WEPP user guide. The rill and interrill erodibility and the critical shear for flow hydraulic were calculated according to WEPP user guide; and the effective hydraulic conductivity was internally calculated by WEPP. Finally, morphological subdivisions were superimposed on the soil map and the land use map, so the catchment was ultimately characterized by shape, topography, soil, and land use. Thus some units were obtained; and sediment yield from the basin was computed as the sum of all values estimated on each unit with the WEPP model.

3. Results and Discussion

The results are presented below at annual time step. Annual Measured and predicted runoff and sediment volumes for whole catchment are presented in Table 2. The relative error calculated as the difference of predicted value and measured value divided by measured value, is used to quantify the mismatch between predicted and measured values.

Annual runoff and sediment volumes predicted by WEPP appear to be good whatever the simulations. Whereas it is easier to predict the average than the individual values which contributes to the average, the average values were compared. Results indicate that WEPP under-estimates sediment volumes of 23% and over-estimates runoff volumes of 27% for Orazan. Table 2 illustrates this difference between simulated and predicted values.

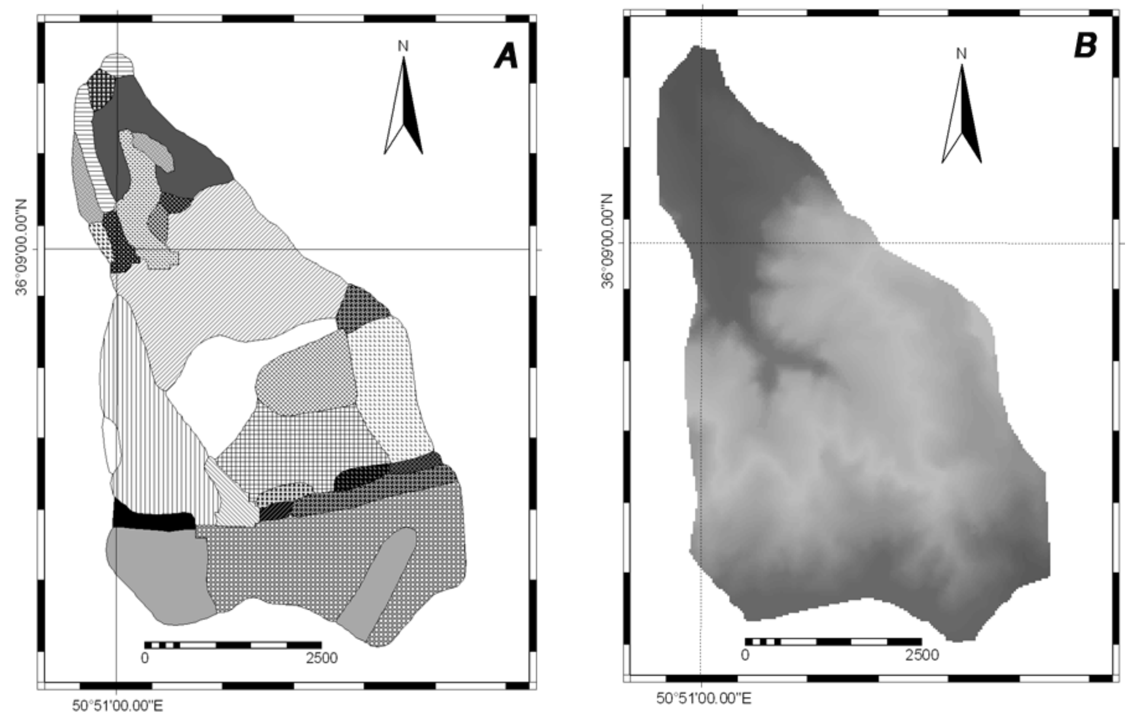

Fig. 2. (A) homogenetic unit map and (B) Digital Elevation Model of study area

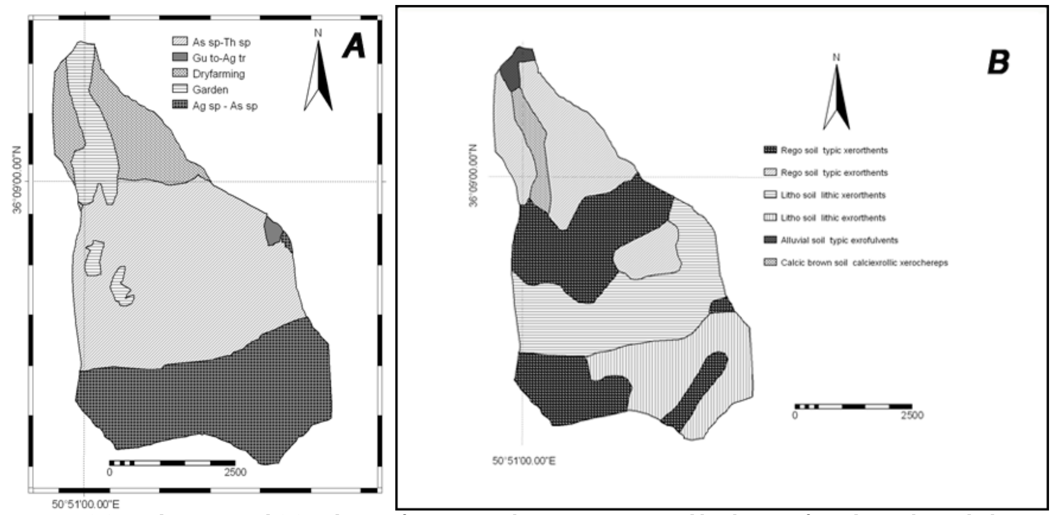

Fig. 3. (A) Landuse map and (B) soil map of Orazan catchment area generated by the use of Landsat Enhanced Thematic Mapper (ETM^+) data. The names of soil units are according to Iranian and American classifications

On the WEPP prediction capabilities, our results are in complete accordance with the conclusions of a major evaluation exercise of current erosion models (Maleki, 2004). Calibration is desirable for many models, and necessary for some. As the aim of this study was to test the prediction capabilities of WEPP, no calibration has been undertaken. The errors related to parameterization, processes representation, catchment splitting and so on have not been compensated by the calibration process. That may partially explain the relatively poor performance of the WEPP model to predict soil losses (relative errors sometimes bigger than 80%).

Analysis of model performance at different time scales shows when considering results only over the total period studied or on the annual time step, it may have been tempting to conclude to a very good performance of the model. The results on shorter time periods have shown that it was not the case. The good matching between observed and predicted soil losses values on the annual period was in fact the result of a balancing of errors obtained by chance. The daily predicted values (Taheri,

2005) were not matched to observed data. This study shows that precautions are required before assessing the quality of a model on an integrated value of an output variable.

Overall, the differences between predicted and measured values and relatively poor performance of the model have three reasons: (i) Including sampling, etc…. the errors concerned to WEPP structure including its equations and calibrations, (ii) the errors related to experiments consisting of gathering data, differences between Orazan environment and native conditions of WEPP, etc … (iii) the errors connected to observed values

Table 2. Average of Annual measured and predicted runoff and sediment volumes for whole Orazan catchment

	average measured volume (m^3/YEAR)	average predicted volume (m^3/YEAR)
Sediment	7000	5389.9 (-23%)
runoff	2487685	3159359 (+27%)

5. Conclusion

In this study the prediction capabilities of WEPP was tested on a semi-arid catchment from 1996 to 2005. Results showed that annual sediment yield and Runoff outputs are relatively well predicted. These results are in accordance with some evaluations in this area by other models (Maleki, 2004). Overall, this initial analysis of the WEPP erosion model has shown that it can be an effective tool for studying the hydrologic and erosion processes that drives soil loss in Orazan sub-catchment. The model should be particularly valuable for focusing on the quantitative relations and interactions between soil, weather, topography, slop, channel conditions and management factors that determine runoff, soil loss, and deposition on a site-specific basis. Nevertheless, we must caution that this study should not be seen as a validation of the WEPP model for Iran conditions. More rigorous testing of model assumptions is needed. That will require more complete experimental data sets than the one used in this study.

The results presented in this study represent one of the first attempts at using of the WEPP model and collating the type of measured data needed to parameterize and evaluate the model. The runoff plot study used in this analysis was certainly not ideal for model testing as shown by the lack of some on-site measurements needed to parameterize the model. It did at least start us on the road toward a better understanding of model assumptions and data input needs. As part of an ongoing regional effort, experimental data must be gathered from other historical runoff plot studies in Taleghan watershed. We will continue to evaluate the WEPP model with these data. As the need and opportunity arise, we will also conduct new experiments using the WEPP model to help us focus on improved understanding of processes. In addition, gathering data and producing digitized maps will be continued because it is an essential task to be able to: (i) improving the climate information, (ii) identifying the role of non-permanent channels or gullies in sedimentation (these factors are not considered in WEPP) and (iii) creating a database of management practices, etc to run WEPP and other models easier. Nevertheless, soil erosion modeling by WEPP, still requires complement researches in Iran conditions. To achieve this important purpose, the cooperation of several Iranian institutes is necessary.

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