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Contribution of MODIS image to hydrologic and erosion modeling

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Abstract

Erosion is the most dangerous phenomenon of environmental and economic threat to arable land. By FAO. 35 % of Tunisian land are threatened by water erosion and varies regionally. Quantification and estimation of soil loss by water erosion is now essential to install the best management practices. In our study, we used a continuous physical based simulation version of a hydrological and water erosion model ANSWERS-2000. The aim of this study is to investigate the introduction of land use parameters extracted by MODIS image. This study is focused on El Azire watershed, is characterized by a moderate Mediterranean climate and a high spatial heterogeneity of soil and land use proprieties. Describing, monitoring, and predicting land-use and land-cover change in the watershed is a difficult process. However, the usefulness of MODIS image with their daily temporal resolution and spatial resolutions of 250 m and 500 m can make utilization of continuous physical-based models easier for great scale watersheds. A sensitivity analysis was conducted on each application such that the variability in erosion map output and can be assessed and incorporated into the interpretation of results with an acceptable level of confidence.

1. INTRODUCTION

Water soil Erosion is the most environmental and economic dangerous phenomenon threat to arable land and which affect the sustainable agriculture development of developing countries especially. According to Ministry of Agriculture and Water Resources a major part of arable land in Tunisia was affected by water erosion especially in the west center. This phenomenon is the result of two important reasons. First is a high vulnerability of sedimentary nature and origin of soil added to very high soil erosion and outcrops of sedimentary rocks (Sfar Felfoul et al., 1999, Roose et al., 1993, Bouchnak et al., 2009 Boughattas et al., 2003). Second, is the rainfall regime characterized by stormy events after a long period of drought. Hydrologic and water erosion models come to improve the estimation of water soil erosion is important (Wischmeier and al 1978). This is important to develop optimal water and soil management plans for watersheds.

ANSWERS-2000 (The Areal Non-point Sources Watershed Environment Response Simulation) (Beasley et al., 1980, Beasley and Huggins, 1981, Dillaha et al., 2004, Bouraoui et al., 1996 and Byne., 2000) is one of the most physically-based, continuous and distributed parameters model soil erosion and hydrology of small watershed. The version used includes critical shear detachment components for flow detachment with updates on the rainfall detachment component and a channel erosion component established by Byne (2000). This continuous model that were designed to simulate the effects of Best Management Practices (BMPs) on runoff and sediment loss. In addition, this continuous version can simulate a long-term average annual runoff and sediment yield from watersheds (Connolly and al, 1997a, 1997b). This model is tested and calibrated in two watershed situated in centre west of Tunisia (Boughattas and al, 2003).

The aim of this study is to investigate the replacement of the crop and rotation parameters types in the ANSWERS-2000 model with remote sensing data extracted from MODIS Images in order to explore the spatial and temporal evolution of canopy covers and their parameters. This paper discusses briefly only the most relevant crop and rotation parameters of the ANSWERS-2000 model and then explores in more depth the processes of using these parameters to improve modeling runoff and water erosion. In addition, it discusses briefly only the most relevant Land use parametres and equations that it used by ANSWERS-2000 model.

The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor was installed on the TERRA satellite in 1999. It aims to study the earth's surface and detect environmental changes including erosion, desertification, deforestation, etc. The MODIS instrument provides high radiometric sensitivity of 12 bits in 36 spectral bands covering the part of the spectrum from 0.4 µm to 14.4 µm. It records data in three spatial resolutions for bands 1 and 2 the resolution is 250 m, for bands 3 to 7 the resolution is 500 m while for the rest (29 bands) the resolution is 1 km. This sensor makes it possible to visualize the entire earth's surface in one or two days with a swath of 2330 km. daily, 8 days, 16 days, monthly, quarterly or annually.

The aim of this study is to investigate the introduction of land use parameters extracted by MODIS image. This study is focused on El Azire watershed, is characterized by a moderate Mediterranean climate and a high spatial heterogeneity of soil and land use proprieties. Describing, monitoring, and predicting land-use and land-cover change in the watershed is a difficult process. However, the usefulness of MODIS image with their daily temporal resolution and spatial resolutions of 250 m and 500 m can make utilization of continuous physical-based models easier for great scale watersheds.

2. MATERIAL AND METHODS

2.1. Study area

The study area is the watershed of Oued El Azire, a left bank tributary of Oued Nebhana located in center west of Tunisia and lies between 36°00'27.03'' to 35°53'05.37'' North latitude and 9°40'03.24'' to 9°41'05.58'' East longitude (Fig. 1). It has a total drainage area of 26.56 km2 with a minimum elevation of 256 m and maximum of 779 m above sea level. The relatively high gradients of the overall slope index (18.2 m/Km) can explain the short response times and formation of badlands caused by sheet erosion (Fig. 1).

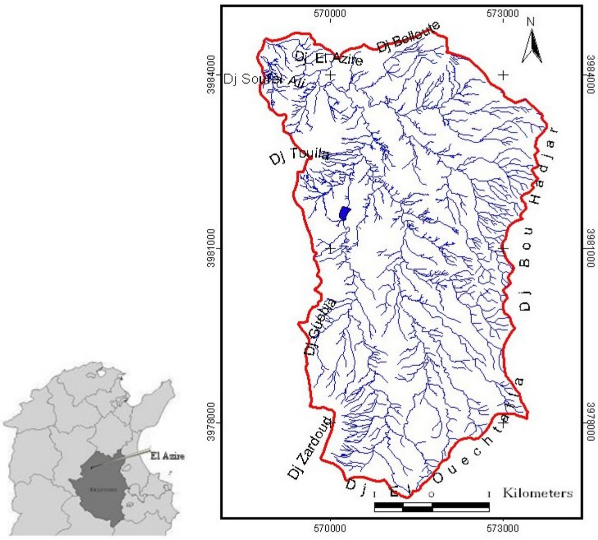


Fig. 1. Location of El Azire watershed and ramification of the channel network.

2.2. ANSWERS-2000 Model

The modeling approach of the ANSWERS-2000 model is showing in flowchart of Fig. 2. In this section we detailed a crop and rotation components simulation with ANSWERS-2000. Crop, and surface parameters introduced by Bouraoui et al. (1997) were listed Below:

- PIT: interception storage for cover for surface type I (mm);
- PER: fraction of element area covered by foliage for surface type I;
- ROUGH: surface depth-storage parameter for surface I;
- HU: maximum height differential on soil surface (mm);
- DIRM: maximum physical retention depth for cropping practice I;
- AC(I): canopy area (%);
- AO(I): area outside canopy (%);
- BC(I): bare area under canopy (%);
- BO(I): bare area outside canopy (%);

The canopy area factors (AC, AO, BC, BO) are used to adjust infiltration in the model. The canopy area factor in the erosion module is also calculated from the area under the canopy. This factor is assumed to be 0 at the beginning of a rotation, and to increase until a maximum value of AC is reached. The interrill cover factors, and live and dead root

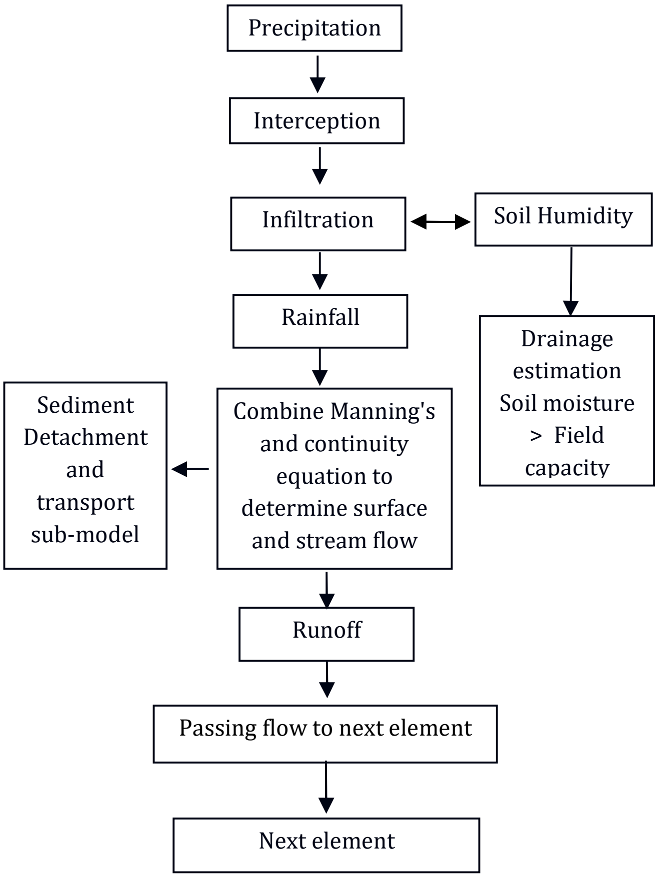


Fig. 2. Flowchart of ANSWERS-2000 sub-models components.

adjustments are used in the erosion subroutines and do not affect infiltration.
- INRCOVI(I) and INRCOVF(I): Interrill cover at the beginning and at the end of the rotation (% of area covered) ;
- LIVEROOT(I): live root mass in the soil at the end of the rotation (kg / m^2 in the upper 15 cm of the soil surface, used in the erosion module, and not the infiltration module);
- DEADROOTI(I) and DEADROOTF(I): dead root mass in the soil at the beginning and at the end of the rotation (kg/m^2 in the upper 15 cm of the soil surface, used in the erosion module);
The dead root factor CANNOT increase during the rotation period, as this will create erroneous results.
- LAI: Leaf area Index (ratio of plant leaf area to surface area m^2/m^2) data for the crop. The program requires input for the growth stage divided into tenths (therefore there are
eleven entries when you include the entry for growth stage.
- DATPLA: planting date (day #)
- DATHAR: harvest date (day #)
- DMY = dry matter ratio
- YP = yield potential (kg/ha)
- ROTMAX = maximum rooting depth for crop i (mm)
- RLAIMX = maximum LAI (m^2/m^2)

2.3. MODIS Image

According to the characteristics and the needs for crop and rotation extraction based on MODIS image, we choose the data products cited and characterized in Table 1 in 3 years 2001, 2002 and 2003. Data preprocessing include geographical correction, projection transformation and image cutting. In this paper, we choose to convert all image data and shapefile data to 250 meters resolution image data (Table 1).

Table 1. MODIS product with palte-forme MODIS TERRA (web site of LP DAAC)

Denomin-ation	MODIS Product	Spatial resolution	Temporal resolution
MOD11A1	Daily temperature	1 Km	Daily temperature
MOD12Q1	Land cover	500 m	Annually
MOD12Q1	Land cover dynamics	500 m	Annually
MOD13Q1			
MOD15A2	Leaf Area Index/FPAR	1 Km	8 days

2.4. Leaf Area Index : LAI

Leaf Area Index or LAI of each crop type is the ratio of leaf area to ground area. LAI is a dimensionless value that range between 0 for bare soil and 1 for dense forests.
In the ANSWERS-2000 model, vegetation growth cycle is divided into 10 stages. For each stage one LAI value must be introduced as input data. Overall, 11 values are introduced for each cropland. These values are used to calculate plant transpiration E_{S0} :

$$E_{S0} = E_0 \, e^{(-0.4 \, LAI)}$$

E_0 : Potential Evapotranspiration (cm)

In this study we will use the MODIS land product distributed from LPDAAC (Land

Processes Distributed Active Archive). The band 2 of MOD15A2 is the level 5 MODIS/Terra global leaf area index is composited every 8 days at 1-kilometer resolution and projected in a sinusoidal grid.

2.5. Model performance evaluation and period simulation

Cannolly et al. (1997b) used ANSWERS to simulate runoff at a watershed outlet and concluded that ANSWERS-2000 model could be used for complex watersheds without calibration. Therefore, in order to evaluate the ANSWERS-2000 erosion sub-model on a small watershed with specific lithological formations, and because of the availability of detailed hill reservoir bathymetry data, we choose to apply the model to two periods. The first period goes from 26/10/1993 to 13/06/1995 and the second period starts from 13/06/1995 to 12/06/1996.
The erosion sub-model performance was evaluated using the criteria suggested by the ASCE Task Committee (1993). Relative error between predicted and field measured value is expressed as follow :

$$\text{Relative Error}\,(\%) = \left(\frac{(\text{Predicted} - \text{Measured})}{\text{Measured}}\right) \times 100$$

3. RESULTS AND DISCUSSION

3.1. Land Cover by MODIS Image MOD12Q1

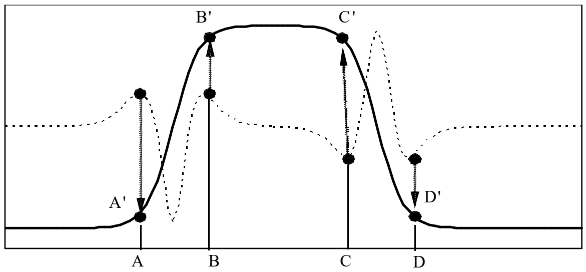
Land cover types used for EL Azire Watershed were extracted from MODIS Terra platform with International Geosphere Biosphere Programme (IGBP). So class of land cover types covered the region during the simulation period (2001, 2002 and 2003) is detailed in Table 2.

3.2. Change of land cover by MODIS image MOD12Q2

MOD12 consists of two suites of data-sets MOD12Q1 (global land cover) and MOD12Q2 (global land cover dynamics) (Tziztiki and al 2012). According to Four phenological transition dates defining a growth cycle (Fig. 3), MOD12Q2 images provides these fours dates of phenological changing for the treated period or each year in Julian day (Table 3).

Table 2. Land Cover classification of El Azire Catchment with MOD12Q1 images (Type IGBP) of MODIS and evolution since 2001 to 2003.

Classes (IGBP)	Code	2001	2002	2003
Open shrublands	7	1750	1835	1635
Woody savannas	8	85	70	76
Grassland	10	143	71	40
Cropland	12	2014	1973	2301
urban and built up	13	13	13	13
Cropland and Natural vegetation	14	63	39	27
Barren and sparsely vegetated	16	97	145	71



A' Onset greenness increase
Vegetation begins active growth and photosynthesis
B' Onset greenness maximum
VI reaches its maximum
C' Onset greenness decrease
First disappearance of green leaves
D' Onset greenness minimum
VI returns to the level at which onset occurred

Fig. 3. Key phenological metrics in an annual trajectory of satellite vegetation index. Four phenological transition(A', B', C' and D') dates defining a growth cycle.

3.3. Evolution of LAI

Change in land cover and especially vegetation cover watershed affect the generation of runoff, detachment and transport of sediments. So make hydrological model dynamic by introducing the variation of land cover during the simulated period and dynamics of the same vegetation cover during the phenological cycle of improve simulation of runoff and soil erosion. Fig. 4. show the evolution of LAI in the watershed. This information is introduced in the ANSWERS-2000 model with alphanumeric form.
The response of runoff and sediment of watershed cropduring the phenologycal cycle response of detachment and the temporal evolution and variation of LAI is among parameters.

Table 3. Julian Calendar of Change of land covers by MODIS image (MOD12Q2) in the treated period, 2001, 2002 and 2003.

Land cover	2001				2002				2003			
	1	2	3	4	1	2	3	4	1	2	3	4
Open shrublands	419	438	506	616	827	866	927	920	1148	1194	1264	1264
Woody savannas	409	461	506	626	802	855	872	939	1134	1219	1346	1346
Grassland	416	467	526	638	776	880	957	960	1151	1192	1270	1270
Gropland	418	461	520	660	764	911	1017	1034	1136	1177	1282	1282
Urban and built up	415	430	455	556	1088	-	-	-	1136	1173	1377	1377
Cropland and Natural vegetation	409	448	497	631	792	875	932	942	1145	1200	1261	1261
Barren and sparsely vegetated	415	453	533	665	793	903	1047	1049	1145	1187	1260	1260

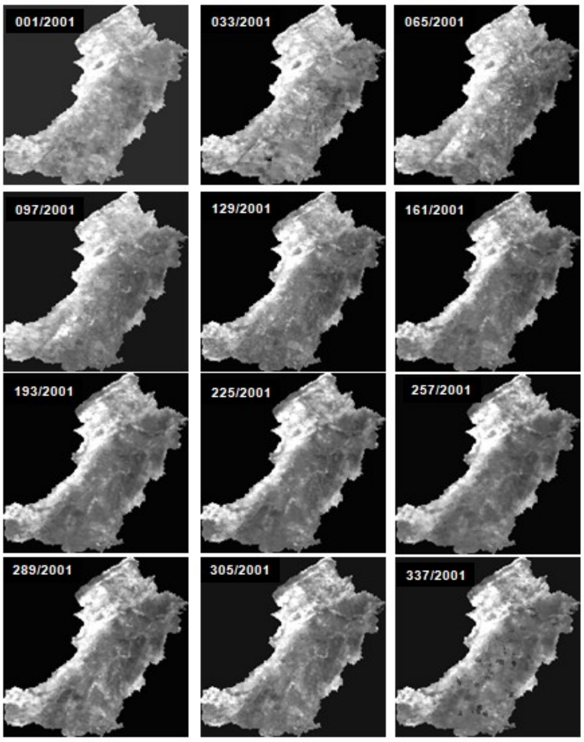


Fig. 4. Evolution of leaf area index (LAI) during 2001 (one rotation)

3.4. Spatial variation of Erosion rate at EL Azire Wartershed

El Azire watershed does not have a sediment monitoring station. Therefore, the erosion rates derived from field measurement which was used to assess the performance of ANSWERS-2000 sediment component were computed using an optimization method.
Distributed models pose further problems in assessing their performance. In practice, the validation and calibration of spatially distributed soil erosion and deposition models are most often performed using hydrographs and sedigraphs measured at catchment outlets. The ANSWERS-2000 continuous simulation and distributed parameter model used in this study allows modellers to visualize the spatial pattern of erosion at an event time step, annual or a mean of period treated, with the use of GIS techniques (Fig. 5 and Fig. 6). However, such maps would be useful in identifying the areas that are producing more sediment and which require top priority for the implementation of appropriate soil conservation. Furthermore, the spatial distribution of the soil loss in El Azire watershed under the current condition (Land use, lithology, Best Management Practices (BMP), climate condition) and in the period mentioned above was analyzed by a continued, distributed and physically-based model. So, a 100 m grid-based average annual soil loss is calculated by ANSWERS-2000 model (Fig. 5 and Fig. 6). These grid values are classified into five classes, null, low, medium, high and very high, which represent the area distribution of soil erosion severity classes.
Fig. 5 show the spatial distribution of erosion rate derived from ANSWERS-2000 Model and using estimated values of land cover parameters and rotations from literature and user's manual of model. Otherwise, Fig. 6 show the spatial distribution of erosion rate derived from ANSWERS-2000 Model but using extracted values of land cover parameters and rotations from MODIS image and use the real time and precision of land cover and rotations.
Table 4 show the difference in the percentage of each erosion rate class between the outputs of ANSWERS-2000 model using, in the first time, estimated values of land cover and rotations parameters and, in the second time, using the real time evolution data from MODIS image.

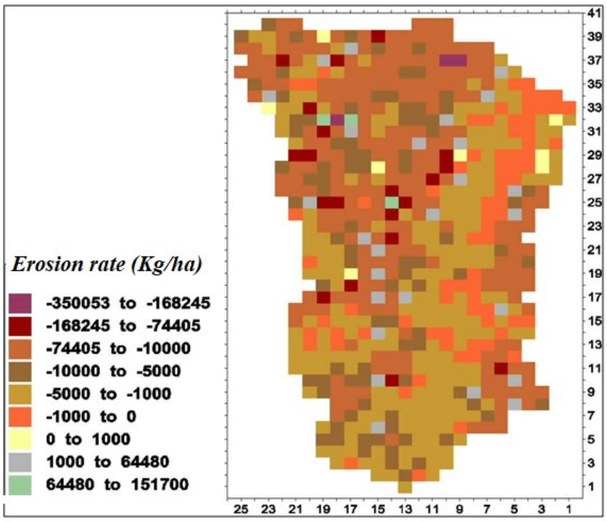


Fig.5. Spatial distribution of erosion rate (average annual soil loss as provided by ANSWERS-2000) at El Azire watershed in the period 2001, 2002 and 2003, Use of prespected or estimated land cover change. (Dimension Grid is 250 m).

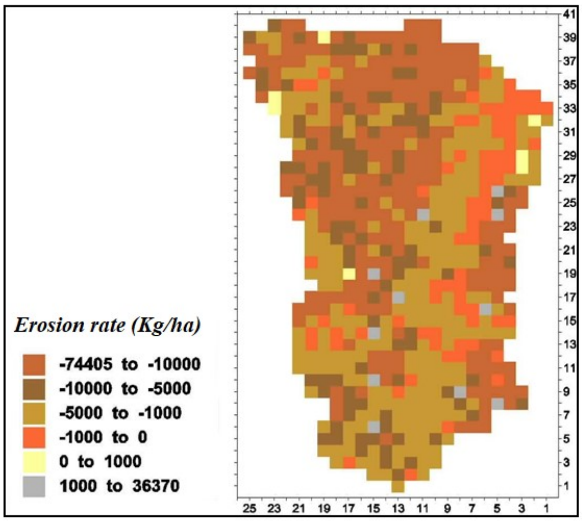


Fig.6. Spatial distribution of erosion rate (average annual soil loss as Provided by ANSWERS-2000) at El Azire watershed in the period 2001, 2002 and 2003, using Use of land cover change by MODIS. (Dimension Grid is 250 m).

Table 4. Comparison between percentages distributed of erosion classes in EL Azire watershed using estimated or MODIS outputs of land cover and rotation parameters with ANSWERS-2000 Model.

Erosion class	Soil loss rate (10^3 kg/ha)	Use of prespected land cover	Use of land cover change by MODIS
		Percentage (%)	
Class 1 : Extremely High	-370 - -90	1.7	0
Classe 2 : Very High	-90 - - 10	25.2	23.6
Classe 3 : High	- 10 - -1	39.3	44.4
Classe 4 : Moderate	-1 - -0.5	8.3	9.3
Classe 5 : Slight	-0.5 - -0	20.3	20.6
Classe 6 : Nul	0 - 1	5.3	2.1

4. CONCLUSION

This study is part of current researches on improving the contribution of modeling for quantification and monitoring of water erosion on large watersheds using essentially geomatics tools to respond to data spatial variability. This study constitutes also a first attempt to develop a valuable classification for land cover change analysis on watershed scale. Therefore, it is highly recommended that further efforts would be continued on extraction land cover change information with different higher spatial resolution sensors.

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