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MODELLING OF SOIL EROSION PROCESSES AND RUNOFF FOR SUSTAINABLE WATERSHED MANAGEMENT: CASE STUDY OUED EL ABID WATERSHED, MOROCCO

ABSTRACT

The study was carried out in the watershed of Oued El Abid that is located upstream of the Bin El Ouidane Dam in Morocco. Looking for a sustainable watershed management practices, we estimated soil losses from the river basin and the sediment yield deposited in the dam of Bin El Ouidane, using the Intensity of Erosion and Outflow - IntErO model, based on the Erosion Potential Method - EPM. The watershed of the lake receiving the waters and sediments from the two mean water courses Oued El Abid and Assif Ahansal, therefore before to proceed the calculation, the watershed was divided in two sub basins; the soil erosion and sediment yield were calculated for each sub basin. The result of calculation for the studied Oued El Abid river basin showed that the production of erosion material in the river basin is 3.960.115 m^3yr^{-1}. Coefficient of the deposit retention, calculated using the IntErO model, was 0.3 and as a consequence, real soil losses were calculated on 1.188.657 m^3yr^{-1}; specific real soil losses per km^2 402 $m^3km^2yr^{-1}$. Our findings, based on Gavrilovic classification, pointed out that the studied area is with a medium potential of soil erosion risk, due to the steep land slope and low vegetation cover in the watershed. The model outcome is validated using the Bathymetry measurements in the Dam of Bin El Ouidane.

Keywords: Soil erosion, IntErO Model, Land Use, Runoff, Soil erosion, Soil conservation

INTRODUCTION

Soil erosion is one of the most important causes of land degradation and one of the key global environmental hazards; especially for developing countries

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(Eswaran *et al*, 2001), affecting all natural and human-managed ecosystems (Kalibová *et al*., 2016; Gholami *et al*., 2013). Soil erosion by water affects 1,094 million hectares of arable land worldwide (Noor *et al*, 2013).

According to the various available reports 33% of the continental land is degraded, mainly by the use of agrochemicals, deforestation and water erosion. Among them, water erosion is considered the principal and most widespread agent of soil degradation, causing the reduction of productive capacity and the environmental devastation (Kinnell, 2016). In the Mediterranean neighbourhood of the studied basin, in Europe, data on trends in soil erosion are lacking and erosion estimates are based on modelling studies. In the 1990s, water erosion affected 105 million hectares of soil or 16% of Europe's total land area. In 2006, it was estimated that the surface area affected by water erosion 37 in the EU-27 was 130 million hectares (Spalevic, 2011). In 2014-15, approximately 11.4 % of the EU territory was affected by moderate to high level water erosion rate (more than 5 tonnes per hectare per year). The reduction of this rate against 1990s by 4.6 % is mainly due to the application of water erosion control practices which have been applied during the last decade in the EU.

For the appropriate sustainable watershed management, land use and landscape planning, which will more effectively meet national or local needs and assists in assessing the consequences of the alternatives the important issue is to quantify the sediments and to estimate sediment yield at the river basin scale (Chalise *et al*., 2019; Spalevic, 2019; Curovic *et al*, 2019; Parsipour *et al*, 2019, Fikfak *et al*, 2017; Popovic *et al*, 2018). Sediment sampling in the rivers need a lot of time and costly laboratorial works. Therefore, developing models with ability of estimating total amount of sediment is an inevitable need (Das and Agrawal, 1990; Khaledi Darvishan *et al*, 2010). Modelling of the erosion process is of a vital importance and various research teams developed models to predict soil loss - sediment yield, peak discharge – runoff. That can be used for the analysis of long as well as short periods of time (Spalevic, 2017a; 2017b; Barovic *et al*., 2015, Khaledi Darvishan *et al*., 2014; Sadeghi *et al*., 2013).

In the recent time we recorded the shortfall of rain and the problems of the storage capacity of the river dams in Morocco. In Bin El Ouidane Dam, in the Middle Atlas, the reservoir reached an unpreceded level of storage, almost 16% of its total capacity, just as the empty concrete pipes that snake in the plains to irrigate more than 100,000 hectares of beet, cereals and fruit trees; the point where the agriculture irrigation was no longer possible. The consequences can be disastrous while the country depends on agriculture, this sector, which draws 88% of the country's water consumption, supports 40% of the population and accounts for 15% of GDP.

This alert called for more interest to dam siltation problem caused by soil erosion and sediment yield, including the reservoir sedimentation in the Oued el Abid Watershed (Sabri *et al*. 2017).

We used the computer-graphic “River Basin” model of Spalevic (Spalevic, 1999) and the IntErO model (Spalevic, 2011) for prediction of soil erosion intensity and sediment yield in the Bin El Ouidane Dam. This models calculate inputs using analytics of the Erosion Potential Method (EPM), originally developed by Gavrilovic (1972). This approach has been tasted earlier in many catchments area in Bosnia & Herzegovina, Bulgaria, Croatia, Czech Republic, Italy, Iran, Montenegro, Macedonia, Serbia and Slovenia and Morocco (Behzadfar, *et al*., 2014; Kostadinov *et al*., 2006; Gholami *et al*, 2016; Khaledi Darvishan *et al*, 2016, 2017; Vujacic *et al*, 2017). In Morocco have been successfully used in the Region of Western Rif of Morocco (Ouallali *et al*. 2016).

This study aims to identify the erosion processes in relation to the recent state of the sediment yield in the dam of Bin El Ouidane downstream the watershed of Oued el Abid in Morroco. This included the previous research results on the same watershed and precedent bathymetry measurements in the same dam, using different way of modelling sediment yield by the IntErO model that could be used for the efficient management and protection in the basins with similar climate and physical-geographical conditions.

MATERIALS AND METHODS

Study Area. Morocco, where the study area of Oued El Abid watershed is located, is in Northern Africa, bordering the North Atlantic Ocean and the Mediterranean Sea, between Algeria and Western Sahara. Position of this area is strategic with the location along Strait of Gibraltar; and it is the only African country to have both Atlantic and Mediterranean coastlines.

Terrain is placed between the mountainous northern coast (Rif Mountains) and interior (Atlas Mountains) bordered by large plateaus with intermontane valleys, and fertile coastal plains. Mean elevation of this area is 909 m, the lowest point, Sebkha Tah is -59 m and highest point is Jebel Toubkal, 4,165 m. Agricultural land covers 67.5%, arable land, 17.5%, with permanent crops of 2.9% and permanent pasture of 47.1%. Forests cover 11.5% (other: 21%).

Northern mountains are geologically unstable and subject to earthquakes; periodic droughts; windstorms; flash floods; landslides. This region characterise soil erosion resulting from farming of marginal areas, overgrazing, destruction of vegetation; but also some water and soil pollution due to dumping of industrial wastes into the ocean and inland water sources, and onto the land.

Oued El Abid watershed The study was conducted upstream the Bin El Ouidane dam and is with a total surface of 3119 km^2, in the high Atlas chain in the region of Beni Mellal Khenifra, Morroco. The drainage area of Oued El Abid is presented on the Figure 2. The Bin El Ouidane Dam accumulates the water comes from two rivers and the water is used for irrigation and hydraulic power production.

Figure 1. Details from the Studied area (Photo: Velibor Spalevic, 11/2017)

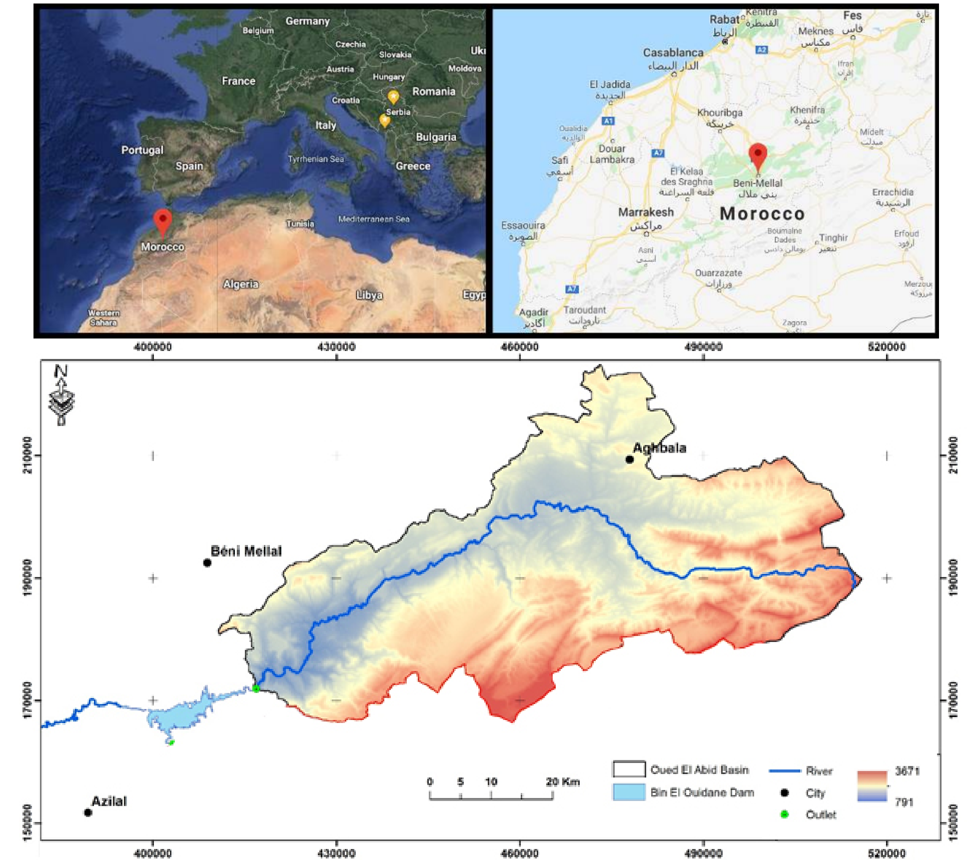

Figure 2. Study area of the Oued El Abid Watershed, Morocco

Soil Erosion IntErO model

Soil erosion models have been developed worldwide. Some of these are chemical runoff and erosion from agricultural management systems – CREAMS (Knisel, 1980), areal nonpoint source watershed environment response simulation – ANSWERS (Beasley *et al* 1980), agricultural nonpoint source pollution model – AGNPS (Young *et al*, 1987), water erosion prediction project – WEPP (Nearing *et al*, 1989), Universal Soil Loss Equation - USLE, Modified Universal Soil Loss Equation - MUSLE and Revised Universal Soil Loss Equation – RUSLE (Wischmeier and Smith, 1978: Williams, 1975; Renard, 1991) and MUSLT (Nicks *et al*, 1994; Sadeghi *et al*, 2013).

Sediment delivery ratio (SDR), transport limiting sediment delivery (TLSD), unit stream power erosion and deposition model (USPED), and sediment distributed delivery (SEDD) have been used to model the sediment removal, transportation, and delivery. Employing soil erosion models to estimate the soil erosion severity at a place is gaining popularity nowadays as field-based erosion studies are tedious, costly, and take a considerable amount of time.

Instead, soil erosion models can assess the soil loss within a short time, provided data are available handy (Chalise *et al*, 2019).

The Erosion Potential Method - EPM (Gavrilovic, 1972) describe the annual sediment yield and transport, the forms and intensity of erosion, from the physical-geographic and hydrological characteristics of the river basin. It is most often used in Europe, North Africa and the Middle East. In recent times the EPM is repeatedly applied in several watersheds in the Mediterranean area, especially in the South East Europe - Balkan region (Blinkov and Kostadinov, 2010; Kostadinov *et al*., 2006, 2014; Milevski *et al*., 2008; Spalevic *et al*. 2013, Spalevic *et al*. 2014; Spalevic *et al*. 2015; Spalevic *et al*. 2016; Stefanovic, 2004; Tazioli, 2009; Tavares *et al*., 2019), and also in arid and semi-arid areas of the south-western USA (Gavrilovic Z., 1988), Saudi Arabia (Aburas Al-Ghamdi, 2010). The method was based on the factors affecting erosion in a watershed; its parameters were dependent on the temperature, the mean annual rainfall, the soil use, the geological properties and some other factors in the watershed scale (Gholami *et al*, 2016; Khaledi Darvishan *et al*., 2016, 2017). The synergic influences of climate and human abandonment could have triggered erosion processes.

The Intensity of Erosion and Outflow - IntErO program package (Spalevic, 2011) with the EPM embedded in the algorithm of this model, was developed to predict the runoff peak discharge and the intensity of soil erosion in a watershed scale. The use of this model has been reported in various countries all around the world including Bosnia & Herzegovina, Bulgaria, Croatia, Czech Republic, Italy, Iran, Montenegro, Macedonia, Serbia, Slovenia, Morocco, Brazil and Nepal. The efficiency of IntErO model to predict peak outflow, soil erosion and sediment yield was also assessed in some cases and the results showed that this model can be use in variety of watershed sizes with various land uses (Spalevic, 2011).

The present study was conducted to use the IntErO for modelling of soil erosion processes and runoff for sustainable watershed management to predict peak outflow, soil erosion and sediment yield for the Oued El Abid Watershed in Morocco.

The IntErO model estimates the total erosion yield on the catchment level and quantifies the hydro-sedimentological parameters using the equations 1-5:

$$W_{yr} = T_i \cdot H_{yr} \cdot \pi \cdot \sqrt[2]{Z^3} \cdot F \qquad \text{Equation 1}$$

$$T_i = \sqrt[2]{\frac{t_0}{10}} + 0.1 \qquad \text{Equation 2}$$

$$Z = Y \cdot X_a \cdot (\varphi + \sqrt[2]{I_{sr}}) \qquad \text{Equation 3}$$

$$G_{yr} = W_{yr} \cdot R_u \qquad \text{Equation 4}$$

$$R_u = \frac{(O \cdot D)^{0.5}}{0.25 \cdot (Lv \cdot 10)} \qquad \text{Equation 5}$$

where: W_{yr} = Annual erosion ($m^3\ km^{-2}\ yr^{-1}$); T_i = Coefficient of temperature (dimensionless); H_{yr} = Mean annual rainfall ($mm\ yr^{-1}$); Z = Coefficient of erosion (dimensionless); F = Basin area (km^2); t_0 = Mean air temperature (°C yr^{-1}); Y = Soil resistance to erosion (dimensionless); X_a = Coefficient of soil use and management (dimensionless); φ = Coefficient of visible erosion features (dimensionless); I_{sr} = Mean slope (%); G_{yr} = Sediment production ($m^3\ km^{-2}\ yr^{-1}$); R_u = Coefficient of retention (dimensionless); O = Basin length (km); D = Difference in basin elevation (m) and; Lv = Length of main stream (km).

The analysis of the Geological and Physical and chemical soil properties were done at laboratory based on soil survey and geological maps (scale 1:500.000). To obtain accurate analytical results, each of the 143 soil samples was reported based on the mean of five subsamples taken within a 1000 m^2 area.

The meteorological data obtained from the measurements of two meteorological stations in the last 50 years (1970-2019), the physical characteristics were extracted from a Digital Elevation Model using Gis tools. The land cover data has obtained after a radiometric- atmospheric treatments and classification of satellite images.

After the field visit, but also using all the available data from the Soil and Geological surveys, receiving the relevant data from the local Hydro meteorological stations, and analysing the satellite images we completed the table with the inputs needed for calculations with the IntErO model. The input data needed for modelling of erosion processes are presented in the Table 1.

Table 1. Input data needed for modelling of soil erosion processes and runoff

Inputs	Symbol	Value	Unit
River basin area	F	3119.14	km²
The length of the watershed	O	484.16	km
Natural length of the main watercourse	Lv	175.85	km
The shortest distance between the fountainhead and mouth	Lm	93.79	km
The length of the main watercourse with tributaries	ΣL	58984.36	km
River basin length measured by a series of parallel lines	Lb	130	km
The area of the bigger river basin part	Fv	2272.15	km²
The area of the smaller river basin part	Fm	846.99	km²
Altitude of the first contour line	h0	900	m
The lowest river basin elevation	Hmin	791	m
The highest river basin elevation	Hmax	3699	m
A part of the basin with very permeable product from rocks	fp	0.2	
A part of the river basin area consisted of medium permeable rocks	fpp	0.32	
A part of the basin consisted of poor water permeability rocks	fo	0.48	
A part of the river basin under forests	fš	0.49	
A part of the basin under grass, pastures and orchards	ft	0.32	
A part under bare land, plough-land and ground without grass	fg	0.19	
The volume of the torrent rain	hb	112.8	mm
Average annual air temperature	t0	16.8	°C
Average annual precipitation	Hyr	347.1	mm
Types of soil products and related types	Y	1.4	
coefficient of the river basin planning	Xa	0.91	
Numeral equivalents of visible erosion process	φ	0.5	

RESULTS AND DISCUSSIONS

After preparing the inputs required for IntErO model, the model was ran and all the model outputs were obtained and shown in Table 2.

Table 2. Modeling results for the Oued El Abid Watershed, Morocco

Results	Symbol	Value	Unit
Coefficient of the river basin form	A	0.58	-
Coefficient of the watershed development	m	0.8	-
Average river basin width	B	24.62	km
(A)symmetry of the river basin	a	0.17	-
Density of the river network of the basin	G	18.82	-
Coefficient of the river basin tortuousness	K	1.55	-
Average river basin altitude	Hsr	1975.12	m
Average elevation difference of the river basin	D	1325.12	m
Average river basin decline	Isr	2.17	%
The height of the local erosion base of the river basin	Hleb	2576	m
Coefficient of the erosion energy of the basin's relief	Er	111.22	-
Coefficient of the region's permeability	S1	0.66	-
Coefficient of the vegetation cover	S2	0.74	-
water retention in inflow	W	8763.61	m
Energetic potential of water flow during torrent rains	2gDF^½	2845.94	m km s
Temperature coefficient of the region	T	1.33	
Coefficient of the river basin erosion	Z	0.796	
Production of erosion material in the river basin	Wyr	3960115	m^3 yr-1
Coefficient of the deposit retention	Ru	0.3	
Real soil losses	Gyr	1188657	m^3 yr-1
Real soil losses per km^2	Gyr (km^2)	402.39	$m^3 km^2 yr^{-1}$

With the modelling of the erosion processes at the Oued El Abid Watershed, in Morocco we concluded that there is a possibility for large flood waves to appear in the studied river basin. The value of G coefficient of 18.82 indicates that there is very high density of the hydrographic network in the studied river basin. Calculations showed that in the river basin prevail mild slopes. The strength of the erosion process is high, and according to the erosion type, it is surface erosion.

In 2015 the team led by Sabri el Mouatassime in the watershed of Oued El Abid, using the USLE model came out with a result of sediment yield which shows that an annual amount of soil loss of 5.2 million m^3 reaches the dam of Bin El Ouidane downstream the watershed. Our research showed that annual real soil losses for the Oued El Abid Watershed in Morocco are 1.2 million m^3. The other, unpublished result from the same team of researchers, calculated annual real soil losses for both river basins: Oued El Abid and the Tillouguite basin, that all together counts on 4.1 million m^3. Analysing the bathymetric measurement for the period 1953-2008, sediment yield rate resulted to 5 million m^3 year^{-1}. The tributaries are inflowing from the northeast and southeast and that most but not all sediments are depositing from those two rivers, the result of modelling by using the IntErO is quite satisfactory.

CONCLUSION

Different geographical factors and hydrological processes govern sediment dynamics in the studied river basin, which are highly variable in spatial and temporal scales. The IntErO is an appropriate technique for modelling of soil erosion processes to estimate the soil losses by water erosion in the conditions similar to the study area of Oued El Abid Watershed, Morocco. For the conditions of the studied area, the USLE model is providing slightly higher results (4% higher than the bathymetric measurements). The IntErO modelling provided about 10% less than measurements for this specific case. Both models proof to be useful for modelling of soil erosion processes and runoff for the needs of sustainable watershed management.

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