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ESTIMATION OF SEDIMENT YIELD USING THE INTERO MODEL IN THE S1-5 WATERSHED OF THE SHIRINDAREH RIVER BASIN, IRAN

SUMMARY

Soil erosion is natural processes that take place when the power of wind and water on the soil surface go beyond the cohesive forces that bind the soil particles together. Vegetation cover protects the soil from the effects of these erosive forces. Land management activities such as ploughing, heavy grazing may disturb this protective layer, exposing the soil to the erosion processes. In this research, we studied erosion processes caused by water, estimating sediment yield in the S1-5 Watershed of the Shirindareh River Basin of the north eastern mountainous parts of Iran. We started from the fact that the erodibility depends on climate conditions, rocks permeability, soil type, land use, location and degree of exposure to erosive influences. The IntErO model for calculation of soil erosion intensity and runoff was used. During the filed visit it was recorded that the dominant erosion form in this area is surface erosion and has taken place in all the soils on the slopes. Variables which define the physical-geographical characteristics of the river basin are included in the IntErO simulation model. The results shown that the net soil loss was calculated on 13228 m^3 per year, specific 230 m^3km^{-2} per year. The results of this study provided standard data for soil conservation illustrating the possibility of modelling of sediment yield with such approach.

Keywords: Erosion, sediment yield, watershed, IntErO model

INTRODUCTION

Soil erosion is a type of non-point source pollution that can cause river silting and water pollution, and affects normal flood discharge as well as service life and efficiency of hydropower projects (Wilson *et al*, 2008). Many factors influence soil erosion, including natural conditions and human activities (Hessel and Jetten, 2007; Vrieling *et al*, 2009). Natural factors include geomorphology, soil type, climate, and vegetation. Human activity factors mainly include

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construction, land development and land use. Land use change is one of the largest single threats causing increased sediment yield and soil erosion (Marques *et al*, 2007; Bakker *et al*, 2008; García-Ruiz, 2010; Feng *et al*, 2010; Shen *et al*, 2013; Djekovic *et al*, 2013). During the past several decades, research related to this issue has received increasing attention by researchers globally (Hao *et al*, 2004; Ward *et al*, 2009; Nunes *et al*, 2011; Blavet *et al*, 2009; Cai *et al*, 2012; Ouyang *et al*, 2012; Wu *et al*, 2012).

The estimation of the erosion in a watershed is essential to encompass a lot of environmental problems and to evaluate the amount of sediment moved, transported and deposited in and out of the basin. Direct measurements of erosion in a watershed are possible with multi-years measurement of solid transport in the closing-section (Tazioli, 2009).

Some authors (Tazioli *et al*., 2015; and Tazioli, 2009) indicate that sediment load measurements are useful to calibrate erosion predicting models, necessary to estimate the erosion in a watershed on multi-annual basis.

Modelling is a good and proven tool useful to evaluate the amount of discharge and erosion in a watershed when hydrometric and discharge data are not available. For these reasons, mathematical erosion models were developed to forecast the erosion severity and the sediment yield.

Among several models, Erosion Potential Method – EPM, originally developed for Yugoslavia by Gavrilovic (1972), was repeatedly applied in Iran (Draganic *et al*, 2015; Leandro Naves Silva *et al*, 2015; Behzadfar *et al*, 2015, 2014a, 2014b; Moradi *et al*., 2015; Amini *et al*, 2014; Zia Abadi and Ahmadi, 2011; Sadeghi, 2005, 1993; Khaleghi, 2005; Maleki, 2003; Nadjafi, 2003) the watersheds of Apennine and in the Balkan Peninsula (Blinkov and Kostadinov, 2010; Kostadinov *et al*., 2014, 2006; Lenaerts, 2014; Milevski *et al*., 2008; Ristic *et al*., 2012; Sekularac, 2013; Spalevic *et al*. 2014a, 2014b, 2013a, 2013b, 2013c, 2012a, 2012b; Stefanovic, 2004; Tazioli, 2009, Zorn and Komac, 2008), but also in the other regions in the world, for example in arid and semi-arid areas of the south-western USA (Gavrilovic, 1988), Saudi Arabia (Al-Turki *et al*, 2015; Aburas Al-Ghamdi, 2010)... The method is based on the factors affecting erosion in a catchment; its parameters dependent on the temperature, the mean annual rainfall, the soil use, the geological properties and some other features of the catchment.

The IntErO (Spalevic, 2011), developed to predict the soil erosion intensity and the extreme runoff in a watershed, is a computer-graphic method based on the Erosion Potential Method - EPM, which is embedded in its algorithm.

The IntErO model was earlier applied on 48 catchments of Shinindareh watershed in Iran; and one of the studied regions was S1-5 watershed of the Shirindareh River Basin. It was concluded that is a useful tool for researcher's calculations of sediment yield at the level of the watersheds that drains, in this case, to the Caspian Sea, the Coastal area of North Iran.

The main outcomes of this research is new specific information about the state of the runoff and sediment yield in formats that may be used in its efficient management and protection, illustrating the possibility of modelling of sediment yield with such approach.

MATERIAL AND METHODS

Study area. We studied soil erosion processes in the S1-5 watershed, a tributary of the Shirindareh River, Sub-basin of the river Atrak (669 kilometres long, drains a basin of 27,300 square kilometres to the Caspian Sea). This area of north eastern parts of Iran are mountainous, with the presence of deep incised valleys (in Limestone Mountains), but also hilly.

Figure 1. Shirindareh region, Iran (*Source: Google maps*)

Shirindareh river basin area has good quality and quantity of surface runoff used for supply of drinking water and water for agriculture and this was the reason and the interest in studding its sub-basins in details, including the S1-5 watershed.

The river basin S1-5 encompasses an area of 57 km^2. The average slope gradient in the river basin, Isr, is calculated on 30.48%, indicating that in the river basin prevail very steep slopes. The elevation of the watershed ranges from 1353 to 2484 m above sea level. The average river basin altitude, Hsr, is calculated on 1694.38 m; the average elevation difference of the river basin, D, is 341 m. The natural length of the main watercourse, Lv, is 15 km. The shortest distance between the fountainhead and the mouth, Lm, is 12.7 km.

Fieldwork & laboratory analysis. During the field work numerous data on intensity and forms of soil erosion, but also on land use were documented. Different forms: the shape of the slope, the depth of the erosion base and the density of erosion rills were determined. We used pedological data from the National Geological Survey Organization (NGS) led by Bolourchi *et al.* (1987), for North Khorasan province.

Soil loss model application. For the estimation of sediment yield, we used the Intensity of Erosion and Outflow - IntErO program package (Spalevic, 2011).

Figure 2. Details from the filed visit V. Spalevic & M. Behzadfar (Feb., 2015): Problems with overgrazing and livestock traces; Sediment transport

RESULTS AND DISCUSSION

Climatic characteristics.

The climate of the studied area characterise cold winters and warm, dry summers. The precipitation pattern varies depending on the physiographic condition. In higher mountains it occurs snow in autumn and winter and rainfall in other seasons. Downstream occurs rainfall except in winter seasons which often falls as snow. This precipitation pattern influences the hydrologic behavior of the river basin which fluctuates seasonally. Flash floods happen during May to October and seasonal flows start from mid-autumn till mid-spring of the next year.

The absolute maximum air temperature is 34.6°C; the negative temperatures can fall to a minimum of -24.4°C. The average annual air temperature, t0, is 9.8°C. The average annual precipitation, Hyear, is 334.4 mm (Source: Data from the North Khorasan Meteorological stations of Iran).

The temperature coefficient of the region, T, is calculated on 1.06; the amount of torrential rain, hb, on 36.12 mm (source: Original).

The geological structure and soil characteristics of the area.

Our analysis, extracting the geological data from the Geological map of Iran (Bolourchi*et al.*, 1987), shown that the structure of the river basin, according to bedrock permeability, is the following: f_0, poor water permeability rocks, 36%; f_{pp}, medium permeable rocks, 44%; f_p, very permeable products from rocks: 20%. The coefficient of the region's permeability, S_1, is calculated on 0.75 (Source: Original). The most common soil type in the studied area is Inceptisols with Calcic horizon.

Vegetation and land use.

The studied area is located in Middle- East of the Kope-Dagh geographical region. According to of the available literature, analysis using the Google maps ad Google Earth, including the records from the field visits, the areas under forests covering 16%; pastures and meadows, 72%; non-arable land, 12 %. The coefficient of the river basin planning, Xa, is calculated on 0.64. The coefficient of the vegetation cover, S2, is calculated on 0.79.

Soil erosion and runoff characteristics.

The state of erosion in the drainage basin, both its distribution and the intensity, were determined by a detailed erosion map, produced according to the method of Gavrilovic (1972). The dominant erosion form in this area is surface erosion and has taken place in all the soils on the slopes. This erosion is the most pronounced on the steep slopes with scarce vegetation cover. Problems with overgrazing and livestock traces are recorded also all over the studied area.

Using the software IntErO we processed 70 variables that finally define the sediment yield of the S1-5 Watershed of the Shirindareh River Basin of Iran. Part of the results is presented at the Table 1.

Table.1. Part of the IntErO report for the S1-5 watershed river basin

Input data			
River basin area	F	57.3	km²
The length of the watershed	O	42.49	km
Natural length of the main watercourse	Lv	15.22	km
The shortest distance between the fountainhead and mouth	Lm	12.75	km
The total length of the main watercourse with tributaries I&II class	ΣL	108.71	km
River basin length measured by a series of parallel lines	Lb	12.75	km
The area of the bigger river basin part	Fv	43.12	km²
The area of the smaller river basin part	Fm	14.18	km²
Altitude of the first contour line	h0	1400	m
Equidistance	Δh	100	m
The lowest river basin elevation	Hmin	1353	m
The highest river basin elevation	Hmax	2484	m
Part of the basin consisted of a very permeable rocks	fp	0.2	
Part of the river basin area consisted of medium permeable rocks	fpp	0.44	
Part of the river basin consisted of poor water permeability rocks	fo	0.36	
Part of the river basin under forests	fš	0.16	
Part of the river basin under meadows, pastures and orchards	ft	0.72	
Part under plough-land and ground without grass vegetation	fg	0.12	
The volume of the torrent rain	hb	36.12	mm
Incidence	Up	100	years
Average annual air temperature	t0	9.8	°C
Average annual precipitation	H year	334.4	mm
Types of soil products and related types	Y	1.1	
River basin planning, coefficient of the river basin planning	Xa	0.64	
Numeral equivalents of clearly exposed erosion process	φ	0.61	
Results:			
Coefficient of the river basin form	A	0.54	
Coefficient of the watershed development	m	0.57	
Average river basin width	B	4.49	km
(A)symmetry of the river basin	a	1.01	
Density of the river network of the basin	G	1.9	km km^{-2}
Coefficient of the river basin tortuousness	K	1.19	
Average river basin altitude	Hsr	1694.8	m
Average elevation difference of the river basin	D	341.38	m
Average river basin decline	Isr	30.48	%
The height of the local erosion base of the river basin	Hleb	1131	m
Coefficient of the erosion energy of the river basin's relief	Er	130.85	
Coefficient of the region's permeability	S1	0.75	
Coefficient of the vegetation cover	S2	0.79	
Analytical presentation of the water retention in inflow	W	0.4708	m
Energetic potential of water flow during torrent rains	2gDF^½	619.51	m km s
Maximal outflow from the river basin	Qmax	94.05	m^3s^{-1}
Temperature coefficient of the region	T	1.04	
Production of erosion material in the river basin	W year	43797	m^3year^{-1}
Coefficient of the deposit retention	Ru	0.302	
Real soil losses	G year	13228	m^3year^{-1}
Real soil losses per km^2	Gyear km^{-2}	230.86	$m^3km^{-2}year$

The coefficient of the river basin form, A, is calculated on 0.54. Coefficient of the watershed development, m, is 0.57 and average river basin width, B, is 4.49 km. (A)symmetry of the river basin, a, is calculated on 1.01 and **that indicates that there is a reduced possibility for large flood waves to appear in the studied river basin**.

Drainage density, G, is calculated as 1.9 km km^{-2} which corresponds to **high density of the hydrographic network**. The height of the local erosion base of the river basin, Hleb, is 1131 m. Coefficient of the erosion energy of the river basin's relief, Er, is calculated on 130.85. According to the erosion type, the dominant process is surface erosion.

For the current state of land use and taking into consideration all the physical-geographical characteristics, calculated peak discharge is 94.05 m^3s^{-1}, for a return period of 100 years.

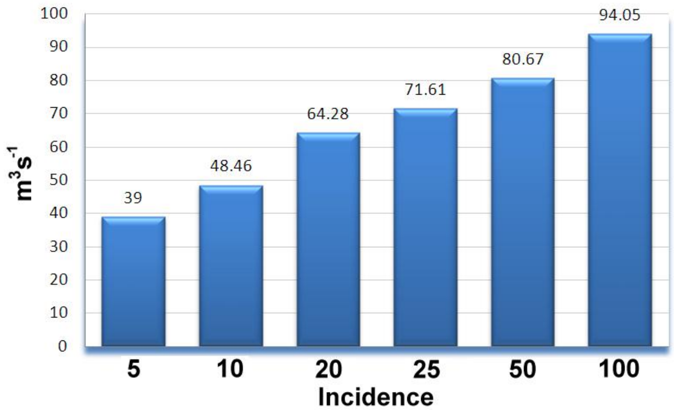

Figure 3. Calculations of the peak discharge
for the incidence of 5, 10, 20, 25, 50 and 100 years

The production of sediments in the basin, W_{year}, is calculated as 43797 m^3 $year^{-1}$; and the Coefficient of the deposit retention, Ru, at 0.302.

Sediment yield at catchment outlet was calculated as 13228 m^3year^{-1}; and specific sediment yield at 230.86 $m^3km^{-2}year^{-1}$.

CONCLUSIONS

According to our findings, it can be concluded that there is a reduced possibility for large flood waves to appear in the studied S1-5 river basin.

Calculated peak discharge is 94.05 m^3s^{-1} for the incidence of 100 years. The calculated net soil loss from the river basin is 13228 m^3 per year, specific 230 m^3km^{-2} per year. According to the erosion type, the dominant process is surface erosion.

This study further confirmed the findings of Behzadfar *et al*, 2015, 2014a, 2014b; Amini *et al*, 2014; Yousefi *et al*, 2014; Moradi *et al*, 2015; Zia Abadi & Ahmadi, 2011; as well as Amiri, 2010; Khaleghi, 2005; Maleki, 2003; Nadjafi, 2003; Sadeghi (1993) in possibility of implementation of the Erosion Potential Method in Iran, what leads to the conclusion that the IntErO model may be a useful tool for researchers in calculation of runoff and sediment yield at the level of the river basins draining to the Caspian Sea and the areas with the similar physical-geographical characteristics like the Shirindareh river basins.

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