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Analysis of relations between water erosion features and effective parameters on their intensity and spatial patterns (Case study: Baleghli chay watershed, Ardebil, Iran)

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Abstract

Soil erosion results from an interaction of several parameters, which vary in space and time. Awareness of environmental changes and their impact on the intensity and spatial pattern of water erosion can effectively help in recognition of erosional reactions versus the affecting factors. The aim of this paper is to describe the development of a methodology based on present knowledge and available data, for evaluation of water erosion behavior and risk as well as an estimation of soil erosion. Accordingly, based on the conducted research on different types of water erosion in some areas of Baleghli Chay Watershed, between two hydrometric gauging stations were studied, with an exclusion of erosion due to mass movements. Four major types of water erosion namely: sheet, rill, channel and streambank which play a considerable role in sediment yields of the area, were separately studied. In order to determine the inter-effects of erosive factors, the study was conducted using multivariate statistical tests. For each erosion type, an individual model was then presented. The results indicated complex and different interactions between the likelihood of water erosion and environmental changes in the study area. Sheet and rill erosions act differently from channel erosion while streambank erosion is completely different from others. Therefore, a study of individual types of water erosion can help in recognition of accelerating factors that effectively influence water erosion, and consequently to come up with appropriate models.

Keywords: Water erosion, Erosion model, Watershed, Baleghli Chay, Ardebil, Iran

1. Introduction

Soil is a natural resource that is not renewable within periods of a small time scale. Erosion is a major soil degrading factor, which causes irreversible damaging effects. Within a sustainable natural resources policy, reduction of soil erosion must undoubtedly be a priority in any land planning project. Erosion causes damage not only to cultivated soils, but it also affects water quality. It as well as responsible for sediment transport, causing many off-site problems such as floods and destruction of landscape (Bissonnais *et al.*, 2001). Awareness of erosion extent and intensity for determining principal strategies and optimum soil conservation, as well as control of erosion and sediment yield are matters of concern for researchers, so that they can predict the spatial pattern and erosion hazard rates (Morgan, 1996).

As erosion results from the interaction of several parameters, which vary in space and time, no simple model can take into account all the relevant factors, particularly in the areas where human influences are predominant. It must be considered that in a specific area, it is

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impossible to introduce a single factor as the main factor responsible for water erosion. The existing condition of erosion in an area is the result of mutual effects of all factors causing soil erosion. Each factor can either intensify or prevent the activity of other factors. Main affecting factors on water erosion are: climate, soil & rock erodibility, topography (mostly slope), land cover, and land utilization (Refahi 2006).

Soil erosion is likely to be more affected by changes in rainfall and vegetation cover than by runoff (Nearing *et al*., 2005). Rain is the main factor for water erosion, its erosive effect being related to its depth and intensity (Morgan, 1996); hence, an attempt has been made to combine both parameters to characterize erosivity for each season (Bissonnais *et al*., 2001). In addition, the spatial distribution of rainfall erosivity is strongly related to mean annual precipitation (Silva, 2004). Rainfall intensity will cause severe erosion in case of a relatively long duration. On the other hand, most erosive rainfalls are of high intensity and adequate duration (Refahi, 2006). Stoching and Elwell (1976) presented a generalized map of erosion risk in Zimbabwe based on mean annual erosivity values (Morgan 1996).

Air temperature is also a factor that contributes to soil erosion. High temperatures cause a reduction of soil moisture and cohesiveness of the aggregates that result in ease of particles detachment and transportation (Refahi, 2006).

Soil erosion occurs when the effective rainfall starts generating surface runoff, leading to detachment of soil particles and moving them downslope. A soil ceases to absorb water when rainfall intensity exceeds surface infiltration capacity, or when the rain falls onto a surface, saturated due to either antecedent wet conditions or an underlying water table (Bissonnais *et al*., 2001). Auzet *et al*. (1995) showed a close correlation between runoff contributing area and conditions of the surface in a catchment.

Resistance to erosive forces is primarily determined by soil properties, which are therefore critical in determining spatial and temporal patterns of sediment transport on hillslopes, thereby affecting not only hillslope evolution, but also sediment delivery patterns in drainage basins at all scales (Troeh *et al*., 1991; Schwab *et al*., 1993; Bryan, 2000 and Grimm and Montanarella, 2001).

There is a close linkage between topographically induced surface hydrological conditions, as well as dominant runoff and erosion processes. In addition, erosion may be highly variable due to climatic and pedological conditions (Huang *et al*., 2001).

All kinds of cover that protect soil against the erosive elements such as: raindrop impacts, runoff and wind are referred to as land cover. Types of land cover include vegetation, litter, stone and gravel covers. Generally any kind of land use that decreases the amount of land cover on a slope may cause severe erosion and sediment production (Refahi, 2006).

Satellite images and parameters derived from combinations of their bands such as Normalized Difference Vegetation Index (NDVI) (Momeni and Saradjian, 2007, and Jong *et al*., 1999) as well as GIS techniques have been extensively employed in researches concerning soil erosion around the world (King *et al*., 2005, Bou Kheir *et al*., 2006 and Miller *et al*., 2007).

The main aim of this paper is to present the results of the research performed on factors affecting intensity and spatial pattern of different types of soil erosion by water, to develop the main parameters that in various kinds have been applied in national and international models as well as in methods of soil erosion estimates. It seems that the results of this study can be used to evaluate the erosion hazards in regional and national scales.

2. Study area

The study area is located in the southern ridge of the Sabalan Mountains in Ardebil Province between latitudes 37˚51′- 38˚16′ N and longitudes 47˚48′- 48˚ 12′ E in northwest of Iran (Fig. 1). It covers approximately 870 km^2 and the Baleghli Chay River, which flows towards the Caspian Sea through Ghare Su and Aras Rivers, drains it. As the area is in the middle latitudes, climatic conditions are semi-arid to Mediterranean. The mean annual precipitation is 350-976 mm, increasing with elevation. In higher altitudes the precipitation changes into show falls, and occasionally results in the natural glaciers. The altitude varies between 1430 m a.s.l. at the catchment outlet to 4811 m a.s.l. at the drainage divide. The mean annual temperature for a 25 year period was varied from -8.7˚C in Sabalan Mountain to 9.1˚C in the outlet of the catchment. The geology of the region is rather complex. The formations of the study area range from the Eocene units: rhyolite tuffs, tuffaceous sandstone and limestone (E^{rt2}) to Holocene young alluvium (Q^{al}). Major soils in the area are Typic Xerorthents, Lithic Xerorthents and Lithic Cryorthents so that their properties can be detected by the climatic characteristics of the area as well as by their location on the hillslopes. The productivity of the soils in the higher elevations is severely hindered due to stoniness, stone outcrops as well as due to cold weather.

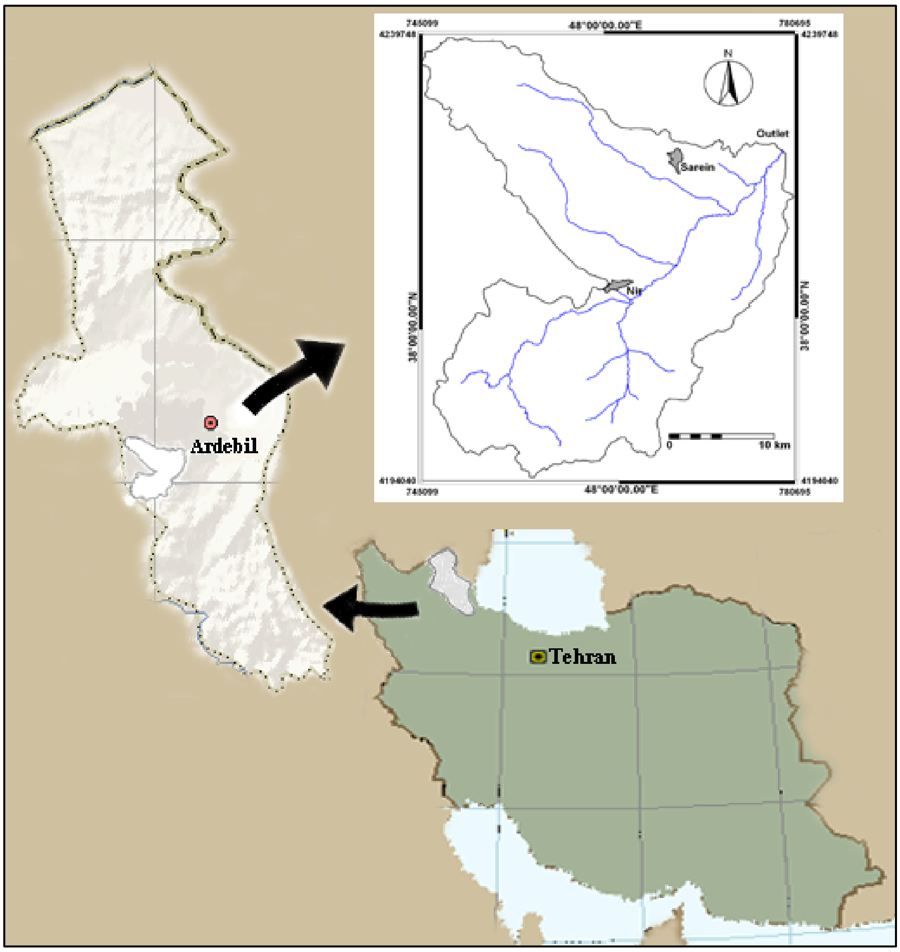

Fig. 1. Location of the watershed of Baleghli Chay in Ardebil province, Iran

3. Materials and methods

The effective factors on water erosion were initially determined. About 30 supposition parameters were studied and their digital maps prepared using Geographic Information System (GIS) techniques (Fig. 2 showing samples of these maps). The geomorphologic map of the area was then prepared using geological and slope maps along with types of water erosion features (section 3.2). The maps of the erosion features and the maps of different parameters were intercrossed to determine the most effective factors, using the GIS based softwares ILWIS3.2, ArcGIS and Idrisi32. Finally, the relationship between types of water erosion patterns and the effective factors were studied through such statistical analyses as two and multivariate analyses. Statistical analyses were performed using ILWIS3.2 and Excel. The multivariate regression analyses were performed using SPSS10 and stepwise method. For each erosion type, the confidence level of 90 % was selected.

Because of qualitative nature of some variables such as: surface runoff direction -that is a function of slope aspect, land use, geologic formation type and slope aspects, in early analysis, they were studied visually and nonparametrically through use of graphs for all water erosion types. Nevertheless, in multivariate tests, the above-mentioned variables were compared with the others when changed into quantitative variables through use of multiple regression method.

3.1. Factors affecting water erosion

Through literature review of factors effective in water erosion, the following respectively explained parameters were selected for the study area:

3.1.1. Indices of climate

To obtain the best relationship and for optimum selection of effective parameters in erosion intensity, in the study area, 14 parameters or indices of erosivity as related to climate were selected. The work was based on the results of Morgan (1996), Bissonnais *et al.* (2001), Silva (2004), Refahi (2006), Nearing *et al.* (2005) and Wischmeier and Smith (1978) studies. The parameters are:

- Mean annual precipitation (mm),
- Mean annual precipitation with 2 and 10 year return periods (mm),
- Maximum 24-hour precipitation with 2 and 10 year return periods (mm),
- Depth of 6-hour precipitation with 2 year return period (mm),
- Maximum rainfall intensity of 30 and 60 minutes ($cmhr^{-1}$),
- Rainfall erosivity factor (R) as follows:

$$R = \frac{E130}{100}, E130 = 210.2 + 89\log 130 \qquad (1)$$

where R= factor for annual rainfall erosivity (kg m^{-2} $year^{-1}$), I30= maximum rainfall intensity of 30 minute duration ($cmhr^{-1}$) and EI30= kinetic energy of rain related to I30 ($Jm^{-2}cm^{-1}$).

In addition other erosivity indices of:

- $Pmean/P_a$ (mean of highest monthly precipitation divided to mean annual precipitation),
- P^2mean/P_a (square of mean of highest monthly precipitation divided by mean annual precipitation in mm),
- P^2max/P_a (square of mean of maximum of highest monthly precipitation divided by mean annual precipitation in mm),
- P^2/P_a (square of maximum of highest monthly precipitation divided by mean annual precipitation in mm).

as well as T parameter as the air temperature index of EPM model (Tangestani, 2006) were used with:

$$T = (\frac{t}{10} + 0.1)^{0.5} \qquad (2)$$

where T=factor for annual temperature and t=mean annual temperature (˚C).

3.1.2. Indices of runoff

In order to determine runoff indices of the study area and based on the results of Pacific Southwest Inter-Agency Committee (PSIAC) water management (1968), Bissonnais *et al.* (2001) and Auzet *et al.* (1995) researches, two parameters, mean annual runoff depth (mm) and specific peak discharge ($m^3s^{-1}km^{-2}$), were selected.

3.1.3. Indices of soil and geologic formation

For soil erodibility, the K factor of RUSLE model was employed (Wischmeier *et al.*, 1971) that is expressed as follows:

$$K = \frac{2.1\times10^{-4}(12-OM)M^{1.14} + 3.25(S-2) + 2.5(P-3)}{7.59\times100} \qquad (3)$$

where K=K factor, M=(percentage of very fine sand plus silt) - (100- percentage of clay), OM= percentage of organic matter, P= permeability class, and S= structure class.

Also for geological formation susceptibility, were used the ratings as based on Feiznia Method (Feiznia, 1996; Feiznia and Zare, 2004).

3.1.4. Digital topographic parameters

The following digitalized topographic parameters with cited characteristics, a combination of parameters used in USLE (Wischmeier and Smith, 1978) and Fournier (1972) Models are selected for test in this research.

- The slope with classes; 0-3, 3-5, 5-8, 8-12, 12-25, 25-45 and >45 %,
- The ground slope factor calculated as:

$$S' = 0.065 + 0.045S + 0.0065S^2 \qquad (4)$$

where S′=Slope factor and S=ground slope gradient.

- The slope length factor as a function of equivalent of terrain unit diameter, calculated as:

$$L = (\frac{\lambda}{22.1})^m \qquad (5)$$

where L=length factor, λ=equivalent diameter of terrain unit and m=a coefficient related to slope gradient.

- The combination of slope gradient and length factor (LS)
- Slope aspect (in eight classes plus flat class), and
- Elevation (a.s.l.) in meters.

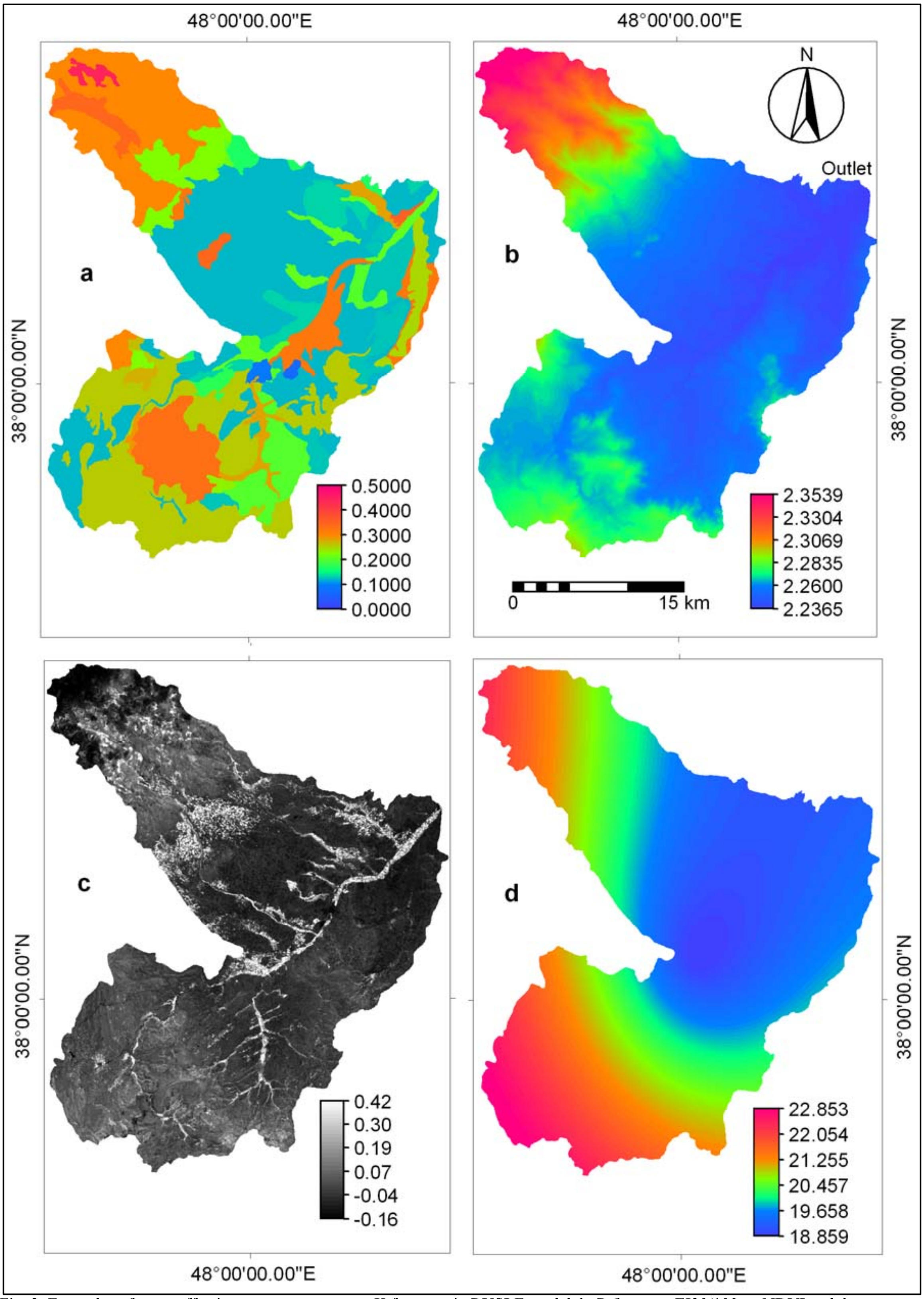

Fig. 2. Examples of some effective parameter maps; a. K factor as in RUSLE model, b. R factor as EI30/100, c. NDVI and d. parameter as P^2max/P_a

3.1.5. Land cover and land use Indices

Based on the research works of Ghoddoussi (2004), Momeni and Saradjian (2007), and Govers *et al*., (2006), the following parameters were selected for examining the effect of land cover and land uses:
- Land cover percentage (percent of canopy + litter + stone + gravel covers),
- Classes of Normalized Difference Vegetation Index (NDVI) expressed as:

$$NDVI = \frac{ETM\,4 - ETM\,3}{ETM\,4 + ETM\,3} \quad (6)$$

where ETM3 and ETM4 are band 3 (infrared) and band 4 (near infrared) of "Landsat 7" satellite images and:
- Land use parameter with four uses including ranges- cultivated areas- gardens and woodlands- cities and rocks.

3.2. Determination of water erosion features

3.2.1. Preparation of Terrain Mapping Unit (TMU) and erosion features maps

The geomorphologic Terrain Mapping Unit (TMU) is provided to investigate geomorphologic faces and field checks (Ahmadi, 2006). The TMU is provided through overlaying of four maps of: lithology, land type and geo-faces layers (prepared by both aerial photos and satellite images investigations) (Fig. 3) and a layer of slope classes map. Thus, the TMU was obtained with 132 homogenous units (Fig. 4).

In each terrain unit, types of water erosions are separated and the map of water erosion features is prepared (Fig. 5). The map of water erosion features is provided based on Remote Sensing (RS) data, which were available as aerial photos in 1:20,000 scale, satellite images; IRS 2002-2004 ‹TM 1988 and ETM+ 2002. Then the data extracted through image processing were checked through field surveying.

3.3. Investigation of relations between water erosion types and affecting parameters using statistical and GIS techniques

The study of relationship between static and dynamic factors, and climate with different kinds of water erosion as well as density or area of each erosion type (Zhang and Nearing, 2005) was performed through simple and multivariate parametric and nonparametric correlation tests (Sonneveld and Nearing, 2003). This was performed after overlaying and crossing the layers using GIS techniques along with the extraction of output tables as quantitative values. Then using SPSS10 statistical software, the frequency and multivariate analyses of each water erosion density in relation to environmental and climatic factors were compared.

After the determination of such independent variables as: rainfall, slope gradient and length, lithology, soil erodibility, land cover, land use, etc., and dependent variables including density of various water erosion types or in an other words, the area of each kind of erosion frequency to the total area, the process of testing is performed as follows (Ghoddossi, 2004):
1. Frequency analysis; all maps of variables in this stage were crossed with the maps of erosion features. All maps were provided by GIS; ILWIS3.2, ArcGIS9 and Idrisi32, but the frequency and abstract analyses were implemented in ILWIS and Excel.
2. Abstract (one by one) analysis of relationship between independent variables and dependent variable (each type of water erosion) was made by correlation testing (Table 1).
3. Multivariate testing following the selection of factors the correlation coefficient of which in abstract analysis was significant in a high confidence level (Tables 2 and 3).

The environmental factors controlling water erosion dynamics and geomorphic response were analyzed by stepwise multivariate regression (Vanacker *et al*., 2003) using SPSS software. In stepwise method, the confidence level of 90 % was selected for all erosions. Multivariate regression was shown to be the most appropriate method because; (i) analyzing categorical response variables as necessary with the underlying assumptions of the linear regression (the selected variables were shown to possess the acceptable linear relation) and (ii) analysis of the interaction variables are compared with each other.

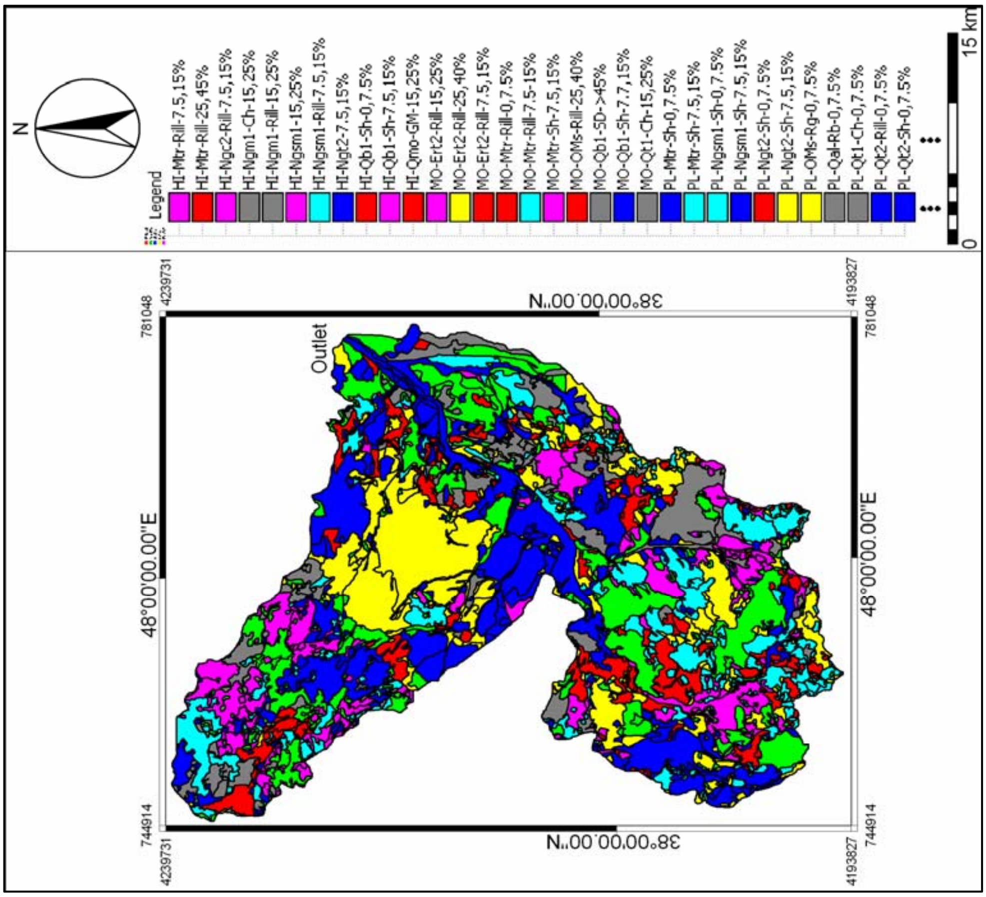

Fig. 4. Terrain Mapping Unit (TMU) of the area; legend from left are land type, geologic formation, geomorphologic face and slope (percent), respectively

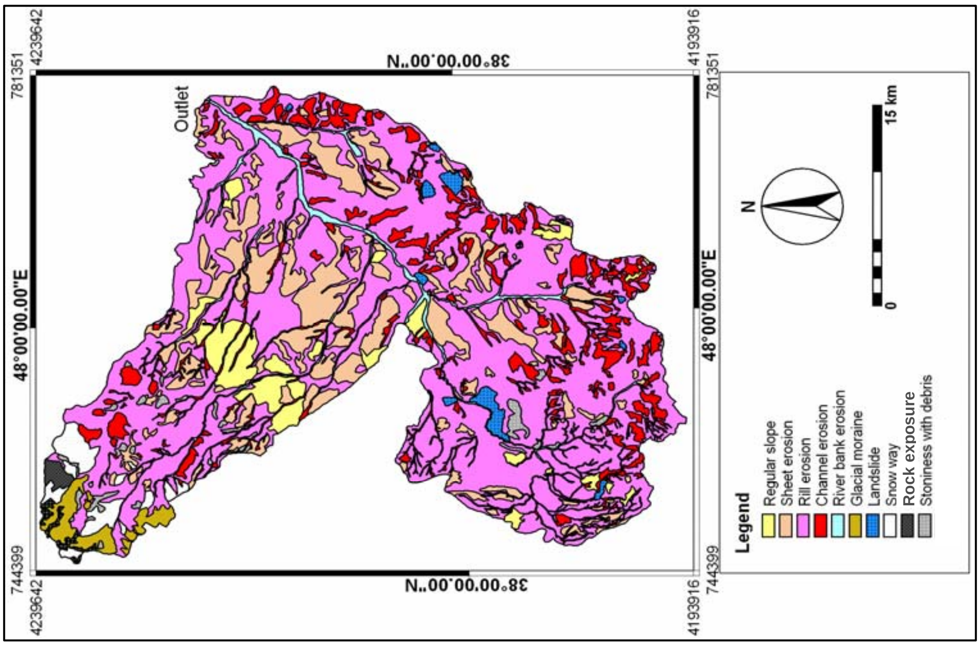

Fig. 3. Geomorphologic features map of the area

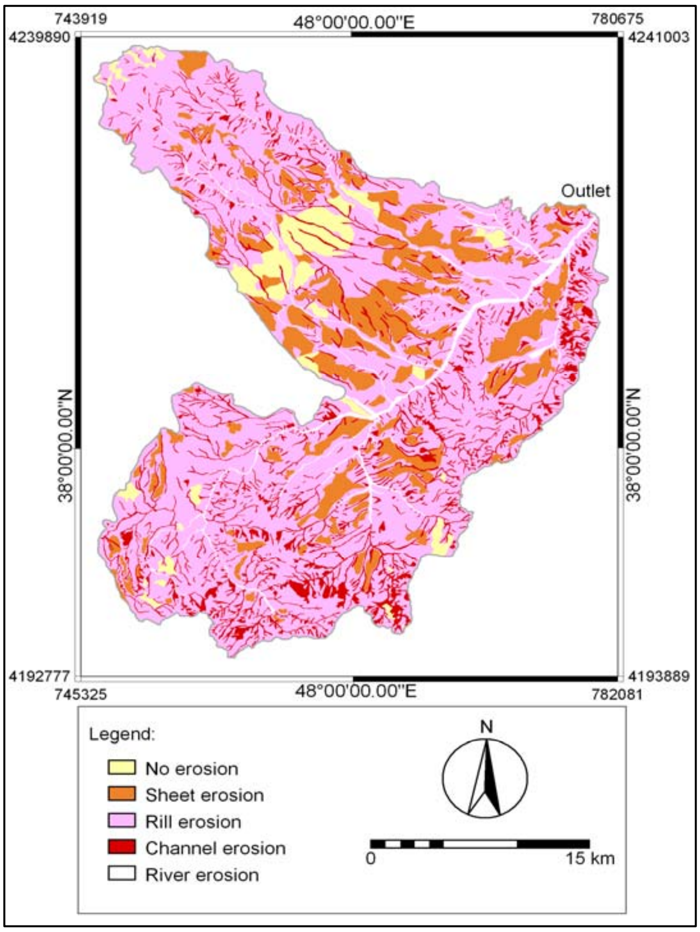

Fig. 5. Water erosion features map of the area

4. Results and discussion

Table 1 shows that in abstract analysis (one by one), the sheet erosion is in high correlation with the parameters; P^2max/P_a, slope, specific peak discharge, mean annual precipitation, maximum rainfall intensity of 30 minutes, maximum 24-hour precipitation and K factor, respectively. Rill erosion indicates the highest correlation with the parameters of rainfall erosivity, runoff depth, L factor, K factor, land cover and susceptibility of geologic formation. Channel erosion is in the highest correlation with the parameters of rainfall intensity, slope, runoff depth and susceptibility of geologic formation. Furthermore, the streambank erosion exhibits the highest correlation, primarily with NDVI index and in the second stage with the parameters; P^2mean/P_a, specific peak discharge, susceptibility of geologic formation and slope.

The variables in Table 1 are the parameters that are analyzed in multivariate analysis until the reaction effects of affecting factors on erosion coincide with each other.

As shown in Table 2, in a confidence level of 90-100%, only those parameters remained whose significance levels were acceptable (column 6). Also Table 2 shows that for each kind of water erosion, any variable with the highest correlation (or the lowest significance) entered into the model prior to the others and the model continued up to where the significance level was in the range of 0-0.1 (disregarding the values for constants). For example, in sheet erosion case, the obtained constant is 211.256 which has the meaningless significant value of 0.005, while for parameters K, P2max/Pa, Slop and I30, the values are 0, 0.023, 0.025 and 0.067 respectively that are in the acceptable range.

Table 1. Summarized results and selected parameters following abstract analyses for various types of water erosions

Best fitted equations	Explanation	Independent variables (X)	Dependent variable (Y)	
Sheet erosion (*sheetero*)	Pa	Mean annual precipitation	$Y= 300.15e^{-0.0066x}$	$R^2 = 0.7292$
	Max24k2	Maximum of 2-year, 24-hour precipitation	$Y = 0.055x^2 - 6.67x + 207.09$	$R^2 = 0.66$
	I30	Maximum rainfall intensity of 30 min	$Y = 164.8x^2 - 596.4x + 541.7$	$R^2 = 0.67$
	P2max/Pa	Square of highest mean monthly to the mean annual precipitation	$Y = -150.24Ln(x) + 469.43$	$R^2 = 0.9028$
	Qp	Specific peak discharge	$Y = 188.57x - 27.372$	$R^2 = 0.7852$
	K	K factor in RUSLE model	$Y = 100.69x - 10.164$	$R^2 = 0.5928$
	Slope	Slope values derived from 13 m resolution DEM	$Y = 25.292e^{-0.038x}$	$R^2 = 0.8586$
	Flowdirect	Flow direction of surface runoff	-	
	Landuse	Type of land use	-	
Rill erosion (*rilleros*)	Pa	Mean annual precipitation	$Y = 0.0798x + 28.116$	$R^2 = 0.9373$
	Max24k2	Maximum of 2-year, 24-hour precipitation	$Y = 1.3762x + 1.3298$	$R^2 = 0.924$
	EI30/100	R factor in RUSLE model	$Y = 327.28x - 675.84$	$R^2 = 0.9156$
	P2max/Pa	Square of highest mean monthly to the mean annual precipitation	$Y = -2.68x^2 + 117.5x - 1212.4$	$R^2 = 0.96$
	Rp	Mean annual runoff depth	$Y = 13.501Ln(x) + 5.0345$	$R^2 = 0.9391$
	K	K factor in RUSLE model	$Y = 117.68x + 40.549$	$R^2 = 0.7962$
	Geosens	Geo formation sensitivity	$Y = -2.3051x + 80.167$	$R^2 = 0.59$
	L	L factor in USLE model replacing the slope length with terrain unit equivalent diameter	$Y = 2.7551x + 34.766$	$R^2 = 0.9349$
	Cover	Land cover (vegetation + litter + stone)	$Y = -0.007x^2 + 0.126x + 81.6$	$R^2 = 0.72$
Channel erosion (*channel*)	Pak2	Mean annual precipitation with return period of 2 years	$Y = -0.0356x + 31.98$	$R^2 = 0.9727$
	Max6k2	Maximum of 2-year, 6 -hour precipitation amount	$Y = -3.2734x + 69.13$	$R^2 = 0.9777$
	I60	Maximum rainfall intensity of 1 hr	$Y = -59.643x + 66.807$	$R^2 = 0.9405$
	P2max/Pa	Square of highest mean monthly to the mean annual precipitation	$Y = 1.6223x - 22.257$	$R^2 = 0.9142$
	Rp	Mean annual runoff depth	$Y = -0.0102x + 15.254$	$R^2 = 0.8041$
	Geosens	Geoformation sensitivity	$Y = 22.326x^{-0.3499}$	$R^2 = 0.5126$
	Slope	Slope values derived from 13 m resolution DEM	$Y = 0.498x + 5.7365$	$R^2 = 0.9678$
	Geo	Type of geologic formation	-	
	Aspect	Slope aspect direction	-	
	Landuse	Type of land use	-	
River bank erosion (*riverero*)	P2mean/Pa	Square of mean monthly to the mean annual precipitation	$Y = 1E+06x^{-5.8481}$	$R^2 = 0.8867$
	Qp	Specific peak discharge	$Y = 351.83x^{3.4459}$	$R^2 = 0.7393$
	Geosens	Geo formation sensitivity	$Y = 0.048x^2 - 1.043x + 6.131$	$R^2 = 0.66$
	Slope	Slope values derived from 13 m resolution DEM	$Y = -1.0148x + 9.9092$	$R^2 = 0.6364$
	NDVI	Normalized difference vegetation index	$Y = 25.238x^2 + 10.02x + 1.84$	$R^2 = 0.99$
	Geo	Type of geologic formation	-	
	Aspect	Slope aspect direction	-	

Table 2. Results of correlation analyses based on significance level

Model		Unstandardized Coeff.		Standardized Coeff.		
		B	Std. error	Beta	t	Sig.
1. Sheet erosion:	Constants	211.256	71.734		2.945	0.005
	K	95.794	20.486	.521	4.676	0.000
	P2maxpa	-7.367	3.127	-.262	-2.356	0.023
	Slope	-.480	.206	-.259	-2.327	0.025
	I30	-35.762	19.012	-.210	-1.881	0.067
2. Rill erosion:	Constants	25.990	19.152		1.357	0.183
	Cover	-.659	.143	-.479	-4.596	0.000
	K	82.705	24.652	.355	3.355	0.002
	L	2.265	.917	.256	2.471	0.018
	Pa	0.07.181	.029	.252	2.463	0.018
3.Channel erosion:	Constants	67.097	23.789		2.821	0.007
	Geo	3.678	.859	.473	4.284	0.000
	I60	-57.341	21.545	-.294	-2.661	0.011
	Pak2	-0.03.55	.014	-.280	-2.539	0.015
	Geosens	-.824	.378	-.240	-2.178	0.035
4. River bank erosion:	Constants	-3.621	3.214		-1.127	0.268
	Landuse	3.599	.519	.726	6.933	0.000
	NDVI	13.283	5.158	.270	2.575	0.015
	Slope	-.989	.476	-.218	-2.077	0.046

The equations of related models for each type of water erosion with their inter-correlation values (r) are presented in table 3.

Table3. Estimated models for each type of water erosion and their correlation coefficients (r)

Erosion type	Model	r
1. Sheet erosion:	sheetero = 211.256 + 95.794K - 7.367P2maxpa - 0.48Slop - 35.762I30	0.685
2. Rill erosion:	rilleros = 25.99 - 0.659Cover + 82.705K + 2.265L + 0.07181Pa	0.770
3. Channel erosion:	channel = 67.097 + 3.678Geo - 57.341I60 - 0.0355Pak2 - 0.824Geosens	0.672
4. Riverbank erosion:	riverero = -3.362 + 3.599Landuse + 13.283NDVI - 0.989Slop	0.806

5. Conclusions

In general the obtained results of the conducted research study indicate a complex interaction between the likelihood of water erosion and environmental changes in the study area. Land use, land cover and NDVI indices in the catchment of Baleghli Chay are relatively dynamic at spatial and temporal scales. Other factors such as: parameters of precipitation, K, slope and so on, are the factors witch change either temporally or spatially. Therefore, the investigation of accelerating factors of each water erosion type can effectively help in a distinction of erosion causing factors, modeling and estimation of erosion.

K factor of the USLE plays an important role in intensity of sheet and rill erosions in the study area. Land surface cover is an important controlling factor of rill erosion, while other factors such as precipitation and topography are among secondary priorities (Table 2). There are some parameters such as geologic condition, depth and intensity of rainfall that exert have considerable effects on acceleration of channel erosion. As the type of geologic formation is the most important factor (Table 2). Streambank erosion acts differently as compared with other types of erosion. This is because: (i) it shows the good power and nonlinear relation with its effective parameters as compared with linear relation in the other types of erosion (Table 1). This result conforms to the findings of Hughes and Prosser (2003) in Murray-Darling Basin, Australia and (ii) the mostly accelerating factor is primarily the land use and vegetation index of NDVI and secondarily ground slope (Table 2) that is relatively different from that in other erosion types.

Furthermore, the results of the research show that individual study of each type of water erosion can effectively help in a determination of erosion accelerating factors as well as proper modeling regarding the related factors.

It can finally be concluded that by developing the method presented in this article as well as by an evaluation of the effects of temporal changes on water erosion patterns, it is possible to simulate the affecting factors in the future and to model them in a more practicable way.

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