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Comparison of Rainfall Erosivity Indices in Runoff-Sediment Plots in Northern Iran

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Abstract: The objective of this study is to determine the appropriate rainfall erosivity index for Northern Iran and apply it to weather stations without rainfall intensity to generate a rainfall erosivity map. This study was conducted in twelve plots at two synoptic stations and the intensity of rainfall as well as sediment yield associated with storm events was recorded. Then, the erosivity indexes AI_m, EI_{20}, EI_{30}, EI_{40}, EI_{50}, EI_{60}, EI_{90}, KE>1, KE>2.5, KE>5, KE>10, KE>25, $P_{max.10}$, $P_{max.20}$, $P_{max.30}$ and P/S_t were computed in these stations and ten synoptic stations. In other stations without rainfall intensity, the parameters and indexes based on rainfall amount including $P_{mean.annual}$, $P_{mean.month}$, $P_{max.annual}$, $P_{max.month}$, $P_{max.day}$, δ_{annual}, δ_{month}, FI, FI_{mod} and C_i, were calculated. Our finding shows that EI_{30} and sediment had the most significant correlation in experimental plots. Therefore, EI_{30} is the appropriate erosivity index for the study area. Among available parameters/indexes only FI_{mod} displayed a significant correlation with EI_{30} ($r=0.762$, $P<0.001$) in ten synoptic stations. Therefore, a regression model was developed for estimating EI_{30} in 45 stations. The map of EI_{30} was provided by Inverse Distance Weighting interpolation method, indicated a decreasing trend from west to east. This trend corresponds with a pattern of climatic change from sub-humid to semi-arid conditions.

Key words: Rainfall · Erosivity index · Readily available parameters · Experimental plots · IDW

INTRODUCTION

Soil erosion has long been recognized as one of the most threatening environmental processes that results from faulty land use and climatic factors [1]. The major climatic variable affecting water erosion is rainfall. Various properties of a raindrop including its velocity, size, kinetic energy and intensity are combined to form different erosivity indexes [2]. One of the common rainfall erosivity indexes, EI_{30}, is a function of the total kinetic energy of a storm event (E) and the maximum intensity measured during a 30-minute period (I_{30}). Another index proposed for Africa by Hudson [3], KE>25 mm h^{-1} uses rainfalls with intensity levels higher than 25 mm h^{-1}. In Nigeria, Lal [4] suggested Ai_m as the product of rainfall amount (A) at the maximum intensity of 7.5 mm h^{-1}.

An increased amount and intensity of rainfall causes an increase soil splash and sediment yield [5-7]. Therefore, the relationship between sediment yield and rainfall erosivity could be used for determining an appropriate rainfall erosivity index for every area. Because suitable rainfall erosivity depends on the geographic situation, climate and scale of region, one erosivity index is particularly appropriate for a given study area. In other words, we can not generalize results from one study area to another. In the Mediterranean climate, Uson and Ramus [8], found that the appropriate erosivity index consists of kinetic energy and maximum intensity at 5-minute intervals. In contrast, Ruppenthal *et al.* [9] findings in a tropical watershed and Kariaga [10] study in Kenya showed that EI_{30} was most correlated with the sediment yield of experimental plots.

Estimation of erosivity on the basis of rainfall intensity requires pluviographic data measured at short intervals over a long period of time. However, access to short intervals of rainfall intensity is limited in many parts

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of the world, especially in Iran [11]. Conversely, data on annual, seasonal and monthly rainfall levels are usually available for longer periods. In turn, the combination of these readily available parameters could be used for estimating rainfall erosivity indexes. A number of studies have presented relationships between indexes based on intensity and the amount of rainfall. These relationships could be used to apply erosivity indexes based on intensity to more places. In a related study, Hoyos *et al.* [12] used seasonal rainfall for estimating seasonal EI_{30} by regression models, one for the wet seasons and another one for the dry seasons in a tropical watershed. Also the models using $rain_{10}$- day_{10} to estimate the monthly EI_{30} were investigated in another research [13]. Also, providing a map of the appropriate erosivity index for an area could be useful in the control of soil erosion.

Therefore, there are several findings on the estimation the EI_{30} from rainfall parameters which can be applied to stations without rainfall intensity. However, there are few studies on a range wide of erosivity indexes on the basis of intensity. The objective of this study is to determine an appropriate rainfall erosivity index for the climatic conditions of Northern Iran, based on the relationship between the erosivity indexes and sediment yield in erosion plots. Attempts to estimate and then generalize the best erosivity index from readily available parameters/indexes were made. Finally, a map of appropriate erosivity index was generated by the Inverse Distance Weighting interpolation method to investigate its spatial variations.

MATERIALS AND METHODS

Study Area: The study area is located in the Khazar watershed that covers 44,090 km^2 in Northern Iran (Fig. 1) and includes the two provinces, Mazandaran and Golestan, between 50° 42 56° 35'E and 38° 19 35° 76'N. The dominant climates of the Mazandaran and Golestan are sub-humid and semi-arid, respectively. The average elevation is 1300 m above sea level. The mean annual precipitation and temperature are 578 mm and 17°C, respectively. For all 55 stations in the study area, data on rainfall amounts, which had a minimum record length of 25 years, were collected from the Iran Meteorological Office. Of these 55 stations, only 10 stations recorded rainfall intensity data. These rainfall intensity data for 20-, 30-, 40-, 50-, 60- and 90-intervals for a 25-year period were obtained from the Water Resources Management Company.

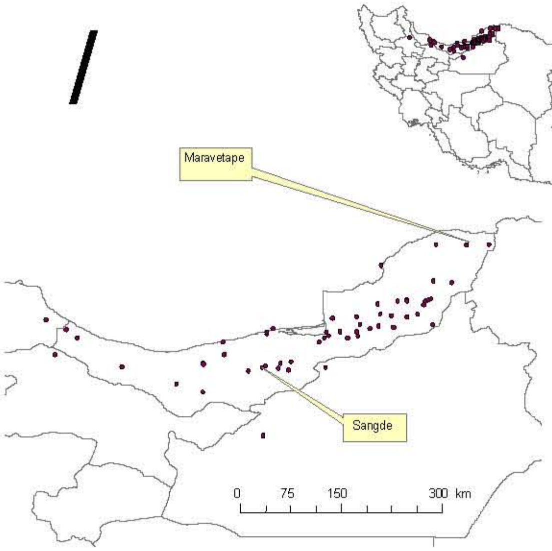

Fig. 1: Location map of the gauge stations and two stations with experimental plots in the study area.

Experimental Plots: The experiment was started in Sangde and Maravetape in Golestan and Mazandaran provinces, respectively. Sangde is located between 53° 14'E and 35° 04'N and Maravetape is found between 55° 47'E and 37°53'N. In both the Sangde and Maravetape stations, research was conducted between 1998 and 2002 in twelve 22×1.8 m^2 plots of silty loam soil. The intensity of storm events and daily, monthly and annual amounts of rainfall were recorded at the Sangde and Maravetape stations. The collected sediment from each plot was measured after every storm event.

Erosivity Indexes Based on Rainfall Intensity: The erosivity indexes based on rainfall intensity were computed for two experimental plots and ten synoptic stations. The kinetic energy was computed for these stations by Brown and Foster [14] is:

$$E=\Sigma\ 0.29\ [1-0.72\exp(-0.05i_r)]\Delta Vr \qquad (1)$$

Where E is rainfall energy per unit depth of rainfall (MJ ha^{-1} mm^{-1}), i_r is rainfall intensity during the time interval mm h^{-1} and is rainfall depth for r intervals. Then combining from equation (1) and maximum intensity for intervals of 20, 30, 40, 50, 60 and 90 minutes produced EI_{20}, EI_{30}, EI_{40}, EI_{50}, EI_{60} and EI_{90}, respectively. Another index, AI_m, is the product of the total amount of rainfall (A) in mm at a maximum intensity of 7.5-minutes (I_m) in mmh^{-1}. Three indexes, $P_{max\,10}$, $P_{max\,20}$ and $P_{max\,30}$, represent the amount of rainfall (mm) per maximum intensity at 10-, 20- and 30-minute intervals. KE>1, KE>2.5, KE>5, KE>10 and KE>25 were computed from the kinetic energy of rainfall intensities over 1, 2.5, 5, 10 and 25 mmh^{-1}, respectively. Finally, the Onchev index, (P/S_t), was calculated from the ratio of the amount of rainfall over 9.5 mm with intensity equal to or greater than 1.8 mmh^{-1}, P, per the time interval during which precipitation occurred, S_t [15].

Parameters and Indexes Based on the Available Types of Precipitation Data: In all 55 stations, the parameters and indexes based on rainfall amounts including daily, monthly and annual rainfall were computed. These parameters are the following: mean annual ($P_{mean.annual}$) and monthly $P_{mean.month}$ rainfall, maximum annual ($P_{max.annual}$), monthly ($P_{max.month}$) and daily ($P_{max.daily}$) rainfall and the standard deviation of annual (δ_{annual}) and monthly (δ_{month}) rainfall. Also, the Fournier Index ($FI=M_x/P$) was calculated, Where FI is the Fournier index, M_x is the mean monthly amount of rainfall in mm and P is the mean annual precipitation in mm [16]. The Arnoldus index or modified Fournier Index ($FI_{mod}=\text{Ó}P_i^2/P$) was computed, in which FI_{mod} is the Arnoldus index, P_i is the mean monthly amount of rainfall in mm and P is the mean annual amount of rainfall in mm [17]. Finally, the Ciccacci index ($C_i=\delta_{month}.P$) [18] was determined, where C_i is the Ciccacci index, δ_{month} is the standard deviation of the monthly amount of rainfall in mm and P is the mean annual amount of rainfall in mm.

RESULTS AND DISCUSSION

Appropriate Rainfall Erosivity Index: The average erosivity indexes based on rainfall intensity at the Sangde and Maravetape stations were determined. The correlation coefficient between erosivity indexes and sediment yield in the 12 experimental plots at the Sangde and Maravetape stations is presented in Table 1. In plots at the Maravetape station, the results revealed significant correlation coefficient between AI_m, $P_{max.30}$ and P_{max10} and sediment yield, 0.605, 0.648 and 0.640, respectively at $P<0.05$ However, the EI_{30} and sediment had a most significant correlation at $P<0.001$ (r=0.727). Therefore, the EI_{30} index at the Maravetape station, which has a semi-arid climate, is the best erosivity index. The 12 plots at the Sangde station displayed a significant correlation coefficient between AI_m, EI_{20}, EI_{40}, EI_{50}, EI_{60}, EI_{90}, $P_{max.30}$, $P_{max.20}$ and sediment (ranging from 0.691 to 0.784) at $P<0.05$. As described in Table 1, at this station, a number of indexes showed significant correlation with sediment. To determine one appropriate erosivity index for generating an erosivity map, the EI_{30} with the highest correlation coefficient (0.784, $P<0.05$) was selected as the best index in the Sangde area. Our findings corroborate previous results. For example, Kariaga [10] in the tropical weather of Nigeria reported that EI_{30} is the best index in comparison with rainfall amount, runoff related to storm events and maximum intensity at 30-minute intervals. Hoyos [12] also confirmed this finding in six plots in a tropical region using the relationship between the erosivity index and sediment yield. In this study, also the EI_{30} index is considered as the appropriate erosivity index based on rainfall intensity.

Appropriate Erosivity Index and Parameters/indexes Based on Rainfall Amount: It is necessary to apply the appropriate erosivity index (EI_{30}) to stations without their own rainfall intensity data. Therefore in this step, the EI_{30} index was estimated from readily available rainfall parameters and indexes based on the amount of rainfall. The descriptive statistics of rainfall parameters, indexes based on rainfall amount and EI_{30} for the ten stations are presented in Table 2. The CV values for all of these factors exhibit very high variation them between ten stations. Only FI (32%), $P_{mean.annual}$ (39%), $P_{max.annual}$ (41%) and FI_{mod} (41%) had spatial variations below 50% at all ten stations.

Table 1: The correlation coefficient between erosivity index and sediment in experimental plots

	Stations			Stations	
Erosivity Index	Sangde	Maravetape	Erosivity Index	Sangde	Maravetape
AI_m	0.691*	0.605*	KE>2.5	0.561	0.252
EI_{20}	0.745*	0.477	KE>5	0.504	0.301
EI_{30}	0.784*	0.727**	KE>10	0.243	0.338
EI_{40}	0.734*	0.471	KE>25	0.057	0.359
EI_{50}	0.737*	0.459	P_{max30}	0.705*	0.648*
EI_{60}	0.714*	0.453	P_{max20}	0.732*	0.499
EI_{90}	0.746*	0.383	P_{max10}`	0.543	0.640*
$KE>1$	0.537	0.197	$\frac{P}{S_t}$	0	0

* and ** mean significant correlation at $P<0.05$ and $P<0.001$, respectively.

Table 2: The Descriptive statistics for rainfall parameters/erosivity indexes and in ten synoptic stations

Rainfall parameters	Mean	C.V. (%)	Rainfall erosivity	Mean	C.V. (%)
δ_{annual}	355.841	65	FI	0.246	32
$P_{max.annual}$	1381.335	41	FI_{mod}	3.462	41
$\overline{P}_{annual}$	886.858	39	C_i	7680.14	83
δ_{nonth}	190.841	64	EI_{30}	466.965	62
$P_{max.month}$	493.590	96			
$P_{max.day}$	149.060	76			

C.V. : Coefficient of variation

Table 3: The correlation coefficient between EI_{30} and parameters/indexes basis on rainfall amount in ten synoptic stations.

	δ_{anual}	$p_{max.annual}$	$\overline{P}_{annual}$	δ_{month}	$p_{max.month}$	$p_{max.day}$	FI	FI_{mod}	C_i
EI_{30}	-0.39	-0.44	0.17	-0.22	-0.27	0.18	0.44	0.76**	0.30

** means significant correlation at $P<0.001$

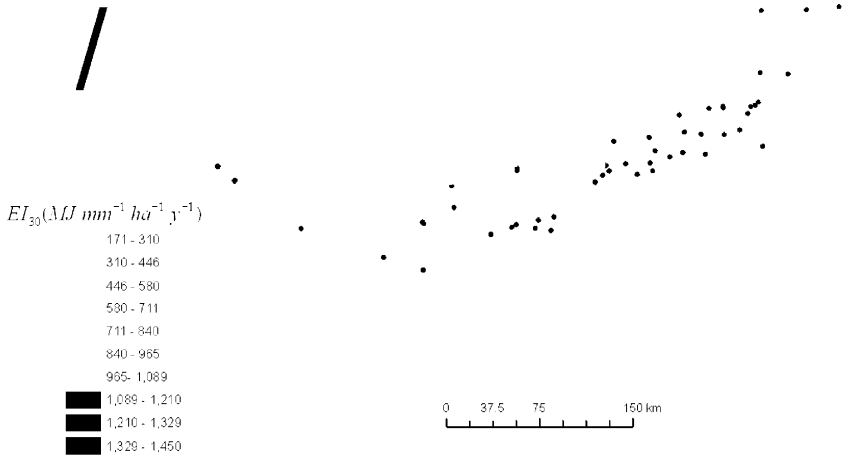

Fig. 2: Spatial variability of EI_{30} as appropriate index and locations of stations

The correlation coefficient between EI_{30} and parameters/indexes based on rainfall amount are presented in Table 3. Only FI_{mod} is significantly correlated (r=0.76, P<0.001) with EI_{30}. Therefore, the regional regression model was obtained for estimating as follows:

$$EI_{30}=-223.20+214.548FI_{mod} \quad (r^2=0.79,\ P<0.001) \quad (2)$$

To apply EI_{30} to the whole study area, the FI_{mod} was computed in the other 45 stations without rainfall intensity data. Then, using relationship between EI_{30} and FI_{mod}, (equation 5), the EI_{30} values were estimated for these 45 stations.

Spatial Variability of Ei_{30}: At the 55 stations, EI_{30} values were interpolated using the Inverse Distance Weighted (IDW) method, a common interpolation technique. The IDW method is based on the assumption that the interpolating surface is most influenced by nearby points and less affected by more distant points. The weight is controlled with power. In this study, the optimal power was one and the number of neighbors included was 16. The spatial distribution pattern of the best index (EI_{30}) provided for this area appears in Fig. 2. From maximum EI_{30} value in the west to the minimum of this index in the east, the EI_{30} value followed a decreasing trend. The EI_{30} index ranged from 171 to 1450 MJ mm ha h^{-1} y^{-1} from sub-humid to semi-arid climates. In a study the annual rainfall erosivity was reported within the range of 250-33481 MJ mm ha^{-1} h^{-1} y^{-1} from the arid/semiarid tropics to the very humid tropics [12]. The largest area in this map (Fig. 2) is covered by the EI_{30} between 840 and 965 MJ mm ha h^{-1} y^{-1}

CONCLUSION

The relationship between rainfall erosivity indexes and sediment yield in plots at two stations demonstrates that among different erosivity indexes, EI_{30} is the most appropriate index in part of Northern Iran. Because of limited access to rainfall intensity at some weather stations, estimating EI_{30} from parameters and indexes based on rainfall amount could be useful. In this study, out of parameters and indexes based on rainfall amount, only the FI_{mod} could be used for estimating EI_{30}. The map of EI_{30} showed a decreasing trend from west (humid climate) to east (semi-arid climate) within the range of 171-1450 MJ mm ha^{-1} h^{-1} y^{-1}. Therefore, the spatial variations of rainfall erosivity depended on the spatial variability of climate. The result of this study could be used in erosion models and conservation efforts in this area of high rates of erosion.

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REFERENCES

1. Gobin, A., R. Jones, M. Kirkby, P. Camping, G. Govers, C. Kosmas and A.R. Gentile, 2004. Indicators for Pan-European Assessment and Monitoring of Soil Erosion by Water. Environmental Science Policy, 7: 25-38.
2. Wischmeier, W.H. and D.D. Smith, 1978. Predicting Rainfall Erosion losses- A Guide to Conservation Planning. Agriculture Handbook, USDA, Washington.
3. Hudson, N.W., 1971. Soil Conservation. Cornell University, Ithaca.
4. Lal, R., 1976. Soil Erosion on Alfisols in Western Nigeria, III: Effects of Rainfall Characteristics. Geoderma, 16: 389-401.
5. Michael, A., J. Schmidt, W. Enk, T.H. Deutschlander and G. Malitz, 2005. Impact of Expected Increase in Precipitation on Soil Loss-Result of Comparative Model Simulations. Catena, 61: 155-164.
6. Salvador Snchis, M.P., D. Torro, L. Borselli and J. Poesen, 2008. Climate Affects on Soil Erodibility. Earth Surface Processes and Landforms, 33: 1082-1097.
7. Capolongo, D., N. Diodato, C.M. Mannaerts, M. Piccarreta and R.O. Strobl, 2008. Analyzing Temporal Changes in Climate Erosivity Using a Simplified Rainfall Erosivity Model in Basilicata (Southern Italy). J. Hydrol., 5: 35-39.
8. Uson, A. and M.C. Ramos, 2001. An Improved Rainfall Erosivity Index Obtained from Experimental Interrill Soil Losses in Soils with a Mediterranean Climate. Catena, 43: 293-305.
9. Ruppenthal, M., D.E. Leihner, T.H. Hilger and J.A.F. Castillo, 1996. Rainfall Erosivity and Erodibility of Inceptisols in the Southwest Colombian Andes. Experimental Agriculture, 32: 91-101.
10. Kariaga, B.M., 2002. Rainfall Erosivity Factor for Uasin Gishu Plateau, Kenya. Discovery and Innovation, 14(1-2): 57-62.
11. Yu, B., G.M. Hashim and Z. Eusof, 2001. Estimating the R-Factor with Limited Rainfall Data: A Case Study from Peninsular Malaysia. Journal of Soil and Water Conservation, 56: 101-105.
12. Hoyos, N., 2005. Spatial Modeling of Soil Erosion Potential in a Tropical Watershed of the Colombian Andes. Catena, 63(1): 85-108.
13. Shamshad, A., M.N. Azhari, M.H. Isa, W.M.A. Wan Hussin and B.P. Parida, 2008. Development of an Appropriate Procedure for Estimation of RUSLE EI_{30} Index and Preparation of Erosivity Maps for Pulau Penang in Peninsular Malaysia. Catena, 72: 423-432.
14. Brown, L.C. and G.R. Foster, 1987. Storm Erosivity Using Idealized Intensity Distributions. Transactions of the American Society of Agricultural Engineers, 30: 379-386.
15. Onchev, N.G. 1985. Universal Index for Calculating Rainfall Erosivity. In Soil Erosion and Conservation, Eds. El-Swaify, S.A. W.C. haver and A. Lo. Soil Conservation Society of America, Ankeny, pp: 384-392.
16. Cohen, M.J. K.D. Shepherd and M.G. Walsh, 2005. Empirical Formulation of the Universal Soil Loss Equation for Erosion Risk Assessment in a Tropical Watershed. Geoderma, 124: 235-252.
17. Arnoldus, H.M.J., 1980. An Approximation to The Rainfall Factor in The Universal Soil Loss Equation. In Assessment of Erosion. Eds. De Boodt, M.and M. Gabriels. Wiley, New York, pp: 127-132.
18. Ciccacci, S., P. Fredi, E. Lupia Palmieri and F. Pugliese, 1986. Indirect Evaluation of Erosion Entity in Drainage Basins through Geomorphic Climatic and Hydrological Parameters. International Geomorphol., 2: 33-48.