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Validity of Some International Rainfall Erosivity Models for Mosul Climatic Condition in Northern Iraq

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Abstract. The main purpose of this study was to estimate the rainfall erosivity index (R) of USLE for eight models to get on the most appropriate erosivity index that can be used for the climatic conditions of Mosul city / northern Iraq . The validity of the models has been evaluated using the monthly rainfall depth for the period of (1983 – 2012) .

Results showed that there is a wide variation in R value among the models. It ranged from (59.5) to (624.8) MJ.mm .$ha^{-1}.hr^{-1}$ .The reason for that may be to the variation in the basic formula of each model in estimating the errosivity index . . Statistical analysis using MAD, MSD and SE indicate that the Arnoldus model produced better predictions of erosivity at a given output time scale and generated better results than the other models. So it can be justified to use this model in future studies if required for describing the rainfall erosivity under the regional climate of the Mosul watershed.

Keywords: USLE , erosivity indexs , water erosion.

Introduction

Water erosion is one of the most important worldwide environmental concerns. One of the most important active agents of soil erosion is rain due to its potential for producing soil disaggregation and subsequent removal. The effects of rainfall impact and surface runoff on soil erosion are generally estimated using the universal soil loss equation (USLE) ;

A = R x K x L x S x C x P ………………… (1)

Where:

A is the mean annual soil loss (t / ha / yr.), R is the annual rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (t ha yr ha^{-1} MJ^{-1} mm^{-1}), L is the slope length factor, S is the slope steepness factor, C is the cover and management factor, and P is the supporting practices factor(Saygin et. al., 2017).

Amongst these factors, the erosivity factor (R) is recognized as one of the most effective measures for describing the rainfall erosivity power on a regional scale in both the original USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal Soil Loss Equation) (Renard et al., 1997). Most studies in this field indicate that the increase in the value of the erosivity index leads to an increase in the amount of energy available to cause the process of erosion, which leads to an increase in the amount of soil losses (Ferrari et. al., 2005 ; Anache et.al., 2017).

Several researchers have used both monthly and annual rainfall depth to estimate the rainfall erosivity factor (R) in most regions of the world. However, the models used in these studies estimate the mean annual rainfall erosivity over several years rather than the rainfall erosivity in a particular year (Joon and Haeng 2011 ; De vante et. al., 2018).

As a result, various simplified models have been proposed by researchers to evaluate R-factor using readily available rainfall data. So, the aim of this study is to estimating the erosivity index (R) by various wide world models and to establish an approximate model for subsequent usage in the estimation of soil loss under climatic condition of Mosul watershed / northern Iraq.

Materials and Methods

The study was carried out on the climatic condition of Mosul city / northern Iraq which fall within Latitudes 36˚ 19´ and Longitudes 43˚ 09´ The average annual rainfall is within the range of semi –arid climatic zone (< 500 mm.) January and February are the most erosive months in the rainy seasons. The rainfall pattern in the area is unimodal and usually has one peak within the year. Minimum , Maximum , mean and standard deviation of the rainfall depth for Mosul city within the studied period are present in Table (1).

Table 1. Some rainfall characteristic of rainfall for Mosul city during (1983 – 2012).

Period	Rainfall amount (mm)			
	Min.	Max.	Mean	St. deviation
1983 - 2012	97.1	703.1	336.9	40.9

Rainfall data within the period 1983 –2012 for Mosul city was used and the corresponding rainfall erosivity indices for those years were computed by the eight models (four models used rainfall depth and four models used Fournier index – FI) as shown in Table (2).

Table 2. Summarizes the international models used for erosivity index.

Model Formula	Model Name	Model Symbole.
$R= [0.302(F)^{1.93}]$	Arnoldus (1977)	M1
$R=\sum Pi^2 / P$	Arnoldus (1980)	M2
$R=[38.46+0.348 p]$	Lo et. al. (1985)	M3
$R=[0.0739 (F)^{1.847}]$	Renard and Freimaund (1994) –F	M4
$R= [0.0483 (P)^{1.61}]$	Renard and Freimaund (1994) –P	M5
$R =[3.82 (F)^{1.41}]$	Yu and Rosewelt (1996)	M6
$R =[4.0412P – 965.53]$	Ferrari et. al.(2005)- Linear	M7
$R=[0.092 (F)^{1.4969}]$	Ferrari et. al.(2005)- Exponential	M8

Where:
R = Rainfall erosivity index
Pi = monthly rainfall depth(mm)
P = annual rainfall depth (mm)
F = Fournier Index

the monthly and mean annual rainfall depth of the study area is found directly from Mosul metrological station, but the Fournier index (F) is calculated by using the following equation (Eq. 2).

$F =\Sigma Pi / P$ -------------------------------(2)

Where , P and Pi are the same as mentioned above.

The calculated values of erosivity index (Rc) were then compared with the predicted value (Rp) for each model. The differences between the calculated and predicted (Rp) values of each model were evaluated in terms of the mean absolute deviation (MAD) and mean square of deviation (MSD) computed as mentioned by Armstrong,(1985) and Haan (1997):

$MAD= \Sigma \mid Zt - Z\hat{}t \mid / n$ ------------------(3)
$MSD=\sum (Zt - Z\hat{}t)^2 / n$ -----------------(4)

Where :
Zt = Observed value of R
Z^t = Average of observed R
N = Number of observed R (size of sample)

Linear regression equations were developed between the erosion index and total annual rainfall depth in order to develop an accurate model for estimating the rainfall erosivity. In addition, the standard error (SE) of the observed annual rainfall erosivity and annual rainfall depth was also computed (Eq. 4) for each model in accordance with:

$\sigma_x = \sigma / n^{1/2}$ ------------------(5)

σ is the standard deviation of the population, and n is the size (number of observations) of the sample.

Results and discussion

Table (3) shows the calculated erosivity index (R) for the selected models during the time period (1983 - 2012) for the Mosul watershed . In general , this table shows that there is a wide variation in the R-values from one model to another, even under the same annual rainfall conditions. The maximum average rainfall erosivity over all eight models is equal to 612.8 MJ mm $ha^{-1} h^{-1} yr^{-1}$,was obtained by M4- model ,while the minimum average rainfall erosivity of 59.5 MJ mm $ha^{-1} h^{-1} yr^{-1}$ was obtained by the M8-model. In general , this variation in calculated R may be due to the nature of the basic formula of the model used in calculating this factor. Some models are depend directly on the amount of rainfall in their calculations of (R) , while the other models depend in their calculations of (R) through the calculating the Fournier Index (FI).

Also, it was observed that the erosivity index (R) for all models over the studied period starts to increase with increasing in annual rainfall depth with the coefficient of correlation equal to 0.83. The monthly and annual peaks (critical periods of erosivity index) may be attributed to increase rainfall amount due to climate change which in turn resulted to increased aggressiveness of rains to cause erosion in the study area. This result is accomplished with the result of regression analysis which show that ,that there is a strong positive correlation exists between the annual rainfall amount and the annual rainfall erosivity factor. In this study the linear relationship between these two variables using only total rainfall amount as input (as shown in Table 4) was somewhat significant for all models used , with coefficient of determination (R^2) is between 56.3 - 98.8. This result was consistent with that of Aslan (1997), which demonstrated that there may be a clear correlation between the rainfall depth and the erosivity index

Table 3. The calculated erosivity index (R) during the perod (1983 – 2012) by the selected models.

Hydrological Years	Erosivity Index (MJ mm ha^{-1} h^{-1} yr^{-1})							
	Arn. 1978 M1	Arn. 1980 M2	LO 1985 M3	RF 1994-F M4	RF 1994-P M5	YU 1996 M6	Fe-lin 2005 M7	Fe-exp 2005 M8
1983-1984	87.2	62.1	131.4	151.5	390.3	341.4	114.6	44.4
1984-1985	217.4	99.6	200.3	363.2	952.4	661.6	914.4	90.2
1985-1986	106.1	68.7	146.0	182.8	493.4	393.3	284.0	51.7
1986-1987	134.3	77.6	161.8	229.1	614.9	466.6	467.0	62.1
1987-1988	340.8	125.8	270.2	558.4	1697.2	917.3	725.9	127.9
1988-1989	128.6	75.9	136.0	219.6	421.8	451.9	168.0	60.0
1989-1990	146.5	81.2	165.5	248.9	644.8	496.8	509.9	66.4
1990-1991	411.9	138.8	155.1	669.3	562.2	1052.0	389.4	148.1
1991-1992	166.8	86.9	200.3	281.8	952.4	545.8	914.4	73.5
1992-1993	334.6	124.6	283.1	548.6	1852.0	905.0	1875.0	126.1
1993-1994	111.0	70.3	191.9	190.8	874.2	406.3	817.0	53.5
1994-1995	102.1	67.3	184.0	176.1	803.3	382.4	725.7	50.2
1995-1996	268.3	111.1	184.4	444.1	806.7	770.8	730.1	106.2
1996-1997	151.4	82.6	157.5	256.8	581.2	508.7	417.7	68.1
1997-1998	73.1	56.6	160.8	127.9	607.1	300.5	455.7	38.7
1998-1999	26.8	33.7	82.86	49.0	118.6	146.4	449.8	17.8
1999-2000	25.0	32.5	99.95	45.9	200.4	139.6	251.4	16.9
2000-2001	76.3	57.9	157.7	133.3	582.8	310.0	420.2	40.0
2001-2002	147.8	81.6	156.7	251.0	574.6	500.0	408.0	66.9
2002-2003	120.9	73.5	103.6	207.1	219.9	432.2	209.0.	57.2
2003-2004	120.8	73.5	177.6	207.0	746.6	432.1	650.5	57.2
2004-2005	123.8	74.4	161.5	211.9	612.9	439.8	464.2	58.34
2005-2006	254.9	108.2	198.4	422.9	934.4	742.6	892.2	102.12
2006-2007	44.5	43.8	142.8	79.71	470.0	210.5	246.8	26.41
2007-2008	20.6	29.4	72.28	38.1	076.5	121.6	572.7	14.54
2008-2009	46.7	44.9	116.4	83.3	293.8	217.6	59.9	27.38
2009-2010	28.4	34.7	110.9	51.8	261.3	152.5	123.5	18.62
2010-2011	53.1	48.0	109.6	94.3	253.7	238.9	138.9	30.28
2011-2012	36.3	39.4	98.73	65.5	194.0	181.9	265.5	22.55
2012-2013	141.2	79.7	158.7	240.3	590.8	483.7	431.9	64.59
Average	134.9	72.8	155.8	227.6	612.8	444.9	509.1	59.5
St. Dev.	100.4	28.9	48.0	162.5	403.4	243.2	367.7	34.8

Table 4. Relationships between erosivity index (R) and annual rainfall depth for the selected models.

R^2	Model Formula	Model Name	Symbol
56.3	R=- 49.25+ 0.545P	Arnoldus (1977)	M1
63.0	R= 16.68+ 0.166 P	Arnoldus (1980)	M2
98.8	R= 38.43+ 0.347 P	Lo et. al. (1985)	M3
57.0	R= - 72.17+ 0.888P	Renard and Freimaund (1994) –F	M4
97.2	R= - 359.0+ 2.879P	Renard and Freimaund (1994) –P	M5
60.5	R= - 17.31+ 0.523P	Yu and Rosewelt (1996)	M6
60.2	R= - 209.3+ 2.073P	Ferrari et. al.(2005)- Linear	M7
59.9	R=E - 6.19+ 0.1949P	Ferrari et. al.(2005)- Exponential	M8

Where :
R = Rainfall erosivity index (MJ mm ha^{-1} h^{-1} yr^{-1}).
P = Mean annual rainfall depth (mm).

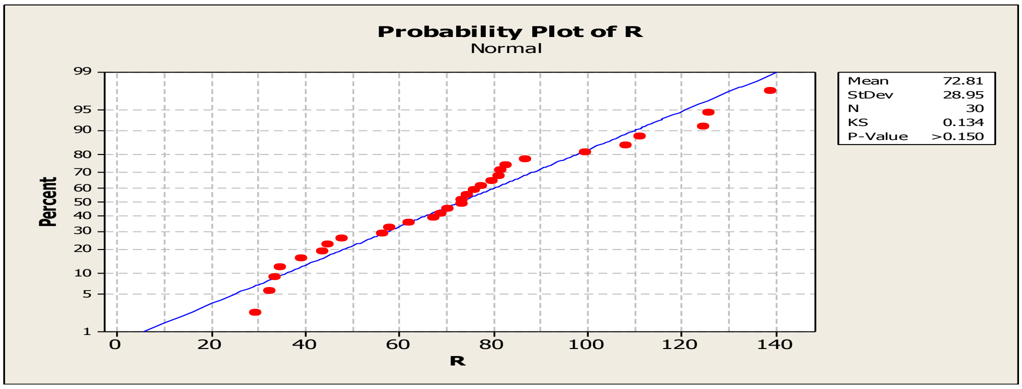
The differentiation and validity among the eight models to choose the right model for the study area ,was carried out using a prediction accuracy measures. Mean Absolut Deviation MAD, Mean square Error MSD and Standard Error (SE) were utilize to reflect the deviation of the calculated R-values (Table 5).

Based on the lowest value of the three criteria (MAD, MSD and SE) despite the high significance of model for predicting the rainfall erosivity index as mentioned by Wilmot (1992) and Kraus et.al.(2005).So it can be observed from Table 5 that the M2- model achieved higher predictive accuracy than the other models. The statistical indicators of this model have acquired the following values: (MAD = 20. MSD = 610.8). Also , In this study, the standard error (SE) as shown in Table (5) was directly used to estimate the dispersion of prediction errors. it can be observed that M2 is showing lowest percentage of error (SE = 5.29) during the calculation of long-term rainfall erosivity index . So, the R-factor and related statistics MAD , MSD and SE showed that the M2 - model had a good prediction rate and justified to use under climatic condition of the studied watershed.

Table 5. Statistics (MAD , MSD , and SE) used for assessment the models.

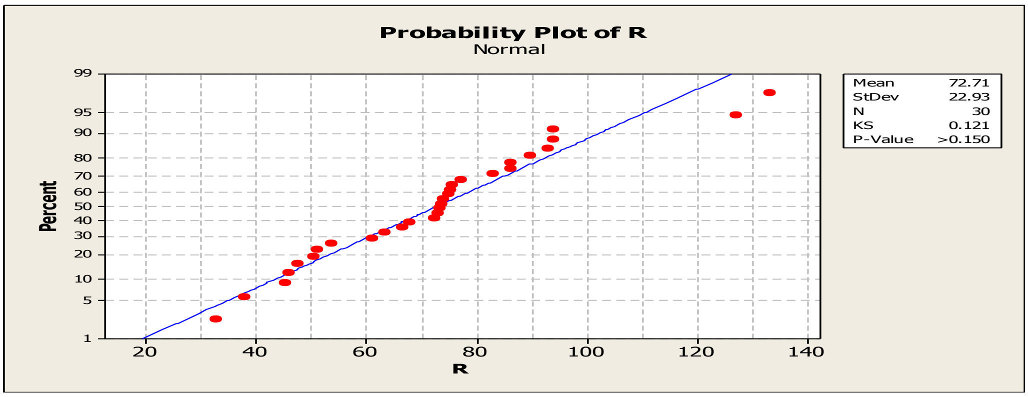
Model Symbol	Name Model	Statistical Paramters		
		MAD	MSD	SE
M1	Arnoldus (1977)	68.0	7746.8	18.3
M2	Arnoldus (1980)	20.3	610.8	5.29
M3	Lo et. al. (1985)	32.9	1765.1	8.78
M4	Renard and Freimaund (1994) –F	110.5	20182.1	29.7
M5	Renard and Freimaund (1994) –P	261.0	127943.0	71.2
M6	Yu and Rosewelt (1996)	168.9	44082.0	44.4
M7	Ferrari et. al.(2005)- Linear	248.0	120205.0	68.3
M8	Ferrari et. al.(2005)- Exponential	24.0	907.6	6.36

These result is accompanied with the result of scatter plot of calculated rainfall erosivity values (Rc) through this model (M2-model) as shown in Fig 1 and 2 , is almost relatively correlated with the predicted rainfall erosivity factor (Rp) and characterized by moderate normal distribution according to Nonparametric Kolmogorov-Smirnov Test (K-S test). This mean that the present model (M2–model) can be still be considered for calculating the long-term rainfall erosivity (R) at study watershed.



Rc

Fig 1 . Normal distribution for calculated R (Rc).according to K – S test



Rp

Fig 2. Normal distribution for predicted R (Rp).according to K – S test

These all results can lead us to conclude that in both calibration and validation of all models used in this study , that M2-model (Arnoldus 1980) can provides a reliable means of predicting the long – annual rainfall erosivity and has a higher accuracy for describing the erosivity index for the regional climate of the studied watershed, so we can recommended to use it in future studies**.**

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