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APPLICATION OF RAINFALL INTENSITY – KINETIC ENERGY RELATIONSHIP FOR SOIL LOSS PREDICTION

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ABSTRACT

In order to explore the consequences of rainfall intensity – kinetic energy relationships for soil loss, climatologically data for monthly and yearly rainfall depth over period of 30-yrs for Mosul city which is located at northern Iraq, were analyzed for the rainfall erosivity index (EI_{30}). The modified Fourneir erosivity (MFI) model was used as an indicator for the combination effect of kinetic energy(E) and maximum rainfall intensity at 30 minute (I_{30}) on the soil loss. The results showed that EI_{30} index was varied within a year and between years of the rainfall records and was ranged from 25.1 to 411.9 metric unit with average 140.3metric unit .The monthly distribution of EI_{30} showed that the rainfall erosivity was very sever in four months (50% of rainy months) through any year of recorder data and December to March was found to be the most erosive months in the studied region. Regression analysis for EI_{30} with mean annual rainfall depth showed that the natural log law is the best suitable mathematical function judged their relation and 83.3**%** of the changes in EI_{30} were due to variation in the rainfall depth. .
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INTRODUCTION

Rainfall erosivity is a measure of climatic influence on water erosion. When other variables such as topography and vegetation cover are held constant, the rate of erosion is directly related to the level of rainfall erosivity . A number of rainfall erosivity indices have been proposed so that the amount of soil eroded is linearly proportional to rainfall erosivity index. The most commonly used rainfall erosivity index is EI_{30} ,where E, is the total kinetic energy per unit area for a storm (MJ/ha.)and I_{30} is its peak intensity (mm/hr). Bofen (2003) found that the combination of kinetic energy and peak intensity is almost closely related to the observed amount of soil loss.

There are two forms of kinetic energy considered in rainfall data analysis. First is kinetic energy per unit area per unit time (KER, $J.\ m^{-2}\ h^{-1}$) and the second is kinetic energy per unit area per unit depth (KE, $J.\ m^{-2}\ mm^{-1}$). Wischmeier and Mannering (1978) found that the rain kinetic energy (E) could be predicted by:

$$E = 916 + (331)\log_{10} I$$, in ft-tons/acre per inch of rain ……………(1)

where I is the average rain intensity. E is given in ft-tons per acre per inch of rain, if intensities in inches per hour are used (for up to 3 in/hr). The rain energy is therefore only dependent on rain intensities alone. The maximum calculated kinetic energy using this equation is 1074 ft-tons/acre/inch. and is applied to rain intensities of 3.0 inch/hr, and greater. This equation has been used to calculate the rainfall erosivity factor(R) of the USLE and the maps in RUSLE (Uson *et al* 2002).
However, he recommend the following equation;

E = 1099 [1-0.72 exp(-1.27 I)], also in ft-tons/acre / inch of rain…………….(2)

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Moreover, it has been postulated that the square of rainfall intensity (I^2) provides a measure of the rainfall kinetic energy. It was found that KE has a log-based relationship with rainfall intensity. Empirical relationships widely used in soil erosion studies have generally adopted a $\log_{10}$ basis. A direct relationship between the two KE variants and I^2 appears to be absent Brodie *et al.*(2007) .Mathematically, Garollina *et al.* (2007) indicated that it is possible to express EI_{30} (storm kinetic energy*maximum 30-minut intensity)in terms of the rainfall amount;

$$EI_{30} = a\, Vr^{b} \quad \ldots\ldots\ldots\ \ldots\ldots \quad \ldots\ \ldots (3)$$

Where ; EI_{30} = is in N h^{-1} Vr is in mm

The coefficients a and b are empirical parameters depended on the rainfall pattern. Hussein and Othman (1988) used the rainfall amount to find a tentative estimate for a and b. The value of (b) in the power equation was near 3/2 . The data were refitted to equal 3 with exponible(b) fixed at 3/2.

The aim of the present study is to establishing a statistical analysis and modeling of rainfall intensity(I) and kinetic energy (E) relationship for rainfalls data collected from 30-yrs in Mosul city / northern Iraq by using the Modified Fourneir Index. Furthermore, this paper provides a theoretical analysis of the potential inter-relationships between Intensity and kinetic energy of rainfall, as a preface of a wider regional investigation. Estimation of rainfall erosivity is of great importance for soil erosion assessment and has important implication for soil conservation and planning for agricultural land uses.

MATERIALS AND METHODS

As the origin of rainfall erosivity is linked to climatic dynamics ,there is need to apply climatical methodology to study the erosivity factor of rainfall. Rainfall records for rainy months from 1 october 1972 to 31 May 2002 were used to compute the rainfall erosivity index for Mosul city (located at Longitude 43^0 08^- E and Latitude 36^0 20^- N) at northern Iraq. Climatologically , the area is fell within semi - arid zone because the mean annual rainfall depth ranged between 250 – 500 mm. The rainfall depth during this period varied within years as well as among years and was below the 30-yr average(374.5mm). The erosivity index (EI_{30}) for each month and year was calculated by using the modified Fourneir index (Arnoldes 1977) as in the following ;

$$EI_{30} = a \left[\frac{\sum^{n} Pi^{2}}{P} \right]^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where:

EI_{30} = Average rainfall erosivity index in metric unit { 100 t.m.Cm.ha^{-1} hr^{-1}).

Pi = Rainfall depth of rainy months (mm).
P = Annual rainfall depth (mm) .
n = The number of rainy months.
a and b is a coefficients equal to 0.0302 and 1.93 respectively

The coefficient of determination(R^2) for this model is 0.83 which is acceptable for the first approximation of EI_{30} index in Iraq (Hussein 1986).The calculated erosion potential for an individual storm designated EI_{30}. The total annual R is therefore the sum of the individual EI_{30} values for each rain as follows;

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right] \quad \text{..........................(5)}$$

Where;

I = rainfall intensity
J = the counter for each year used to produce the average .
k = the counter for the number of storms in a year,
m = the number of storms n each year, and
n = the number of years used to obtain the average R.

Relationships between rainfall erosivity index and mean annual rainfall depth were obtained using linear and power relationships. The equation obtained from the exponential model produced smaller standard error of estimates than the logarithmic model.(Richardo *et al*.2005).In addition the distribution of mean annual EI_{30} through the rainy months was also obtained by the following relationships;

$$(PE)i = \left[\frac{Pi^2}{\sum Pi^2}\right] \quad \text{--(6)}$$

Where :
(PE)i = The erosivity index of the specific month(i).
Pi = Average monthly rainfall (mm).
$\sum Pi^2$ = Average annual rainfall (mm).

The results were analyzed statistically to determine the best regression equation that could be adequately described the temporal and seasonal distributions of rainfall erosivity (EI_{30}) with mean annual rainfall depth and / or monthly rainfall depth using Microsoft Excel and Minitab package programming systems.

RESULTS AND DISCUSSION

Table(I)summarizes all the actual erosive events (EI_{30}) values which were calculated from 30yr (1972-2002) of rainfall records for Mosul city by using the Modified Fourneir Index (MFI)model. The erosivity index (EI_{30}) revealed somewhat wide variation in their values . It ranged form 37.4 metric unit at season 1972-1973 to 411.9 metric unit at season 1990-1991 with average of 140.3 metric unit. This variation in EI_{30} values means that there is a fluctuation in the amount of annual rainfall depth during the studied period. The data in table 1 also indicate that EI30 values were not actual lead by the higher mean annual rainfall depth. In other words, the increase in annual rainfall depth is not necessarily accompanied by the increasing in EI_{30} values. The minimum and maximum values (25.1 and 441.9 metric unit) of EI_{30} were obtained from somewhat lower and moderately annual rainfall depth of 176.7 and 335.3mm respectively. In this respect, Hudson (1981**)** reported that there was not obviously association between the EI_{30} index and mean annual rainfall depth. This result indicated that MFI model was statistically unable to account for year-to-year variability in the rainfall data and the linear relationship between them is very weak .An analysis with the relationships between EI_{30} and CV % also suggested that total variability in the data set could be better represented to have dependable EI_{30} .The result showed that the MFI model was valuable in determining the potential of the rain for causing soil erosion by providing information on long –term total variability in the rainfall amount record. For this reason the mean annual rainfall erosivity EI_{30} can be considered as a adequately

Table (1) ; Yearly and monthly rainfall depth (mm) and EI_{30} for Mosul city during 1972-2002 .

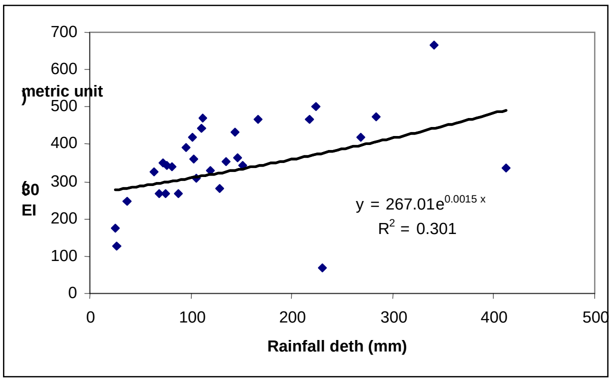
Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	∑ Pi	EI_{30}
1972-1973	0.5	42.2	28.2	32.7	53.5	22.6	16.5	50.8	246.5	37.4
1973-1974	0.0	23.1	28.4	111.4	95.1	172.7	39.9	3.6	474.2	283.3
1974-1975	0.0	43.0	72.8	51.2	101.3	14.3	63.8	14.7	361.1	103.6
1975-1976	0.5	39.2	94..1	65.3	77.6	91.4	66.7	EI30	471.1	111.7
1976-1977	19.4	3.0	30.6	94.3	32.3	30.0	56.2	0.8	266.6	75.1
1977-1978	7.4	19.5	99.9	77.4	80.0	35.1	5.9	4.2	329.4	119.6
1978-1979	0.8	23.0	56.5	78.8	45.7	49.4	10.1	1.8	266.1	68.3
1979-1980	19.2	49.4	79.9	21.3	165.5	81.9	83.1	0.7	501.0	223.4
1980-1981	3.1	75.1	112.2	59.4	52.1	97.1	27.1	5.8	431.9	143.2
1981-1982	26.6	56.6	47.3	97.0	41.9	9.8	85.9	24.4	389.5	95.7
1982-1983	15.0	90.3	46.0	40.5	49.2	40.0	18.9	27.7	327.6	63.6
1983-1984	1.0	54.8	18.2	17.8	15.9	105.3	18.9	35.4	267.3	87.2
1984-1985	18.4	174.4	36.0	52.5	50.9	78.6	52.9	1.5	465.2	217.1
1985-1986	3.0	23.9	38.1	31.5	121.6	37.6	44.1	9.4	309.2	106.1
1986-1987	26.0	59.4	43.3	18.3	126.2	71.6	8.4	1.3	354.5	134.3
1987-1988	84.7	12.0	120.8	198.3	104.3	98.2	45.2	2.5	666.0	340.8
1988-1989	3.6	18.8	95.3	14.9	45.5	97.7	1.3	3.4	280.5	128.6
1989-1990	7.3	133.5	25.8	52.4	77.5	38.6	29.7	0.3	365.1	146.5
1990-1991	4.0	6.2	47.9	28.5	32.0	205.6	9.0	2.1	335.3	411.9
1991-1992	0.2	44.6	82.6	97.8	132.8	24.6	27.2	55.4	465.2	166.8
1992-1993	0.0	109.2	123.9	49.8	85.9	18.8	171.4	144.1	703.1	230.8
1993-1994	17.1	66.7	73.1	76.5	47.3	93.8	63.7	2.9	441.1	11 1.0
1994-1995	18.2	68,6	68.6	37.2	65.7	104.7	39.0	16.5	418.5	102.1
1995-1996	0.7	30.2	10.1	166.9	34.9	121.6	38.7	16.5	419.6	268.3
1996-1997	6.1	8.7	132.9	45.6	75.9	48.7	12.9	11.5	342.3	151.4

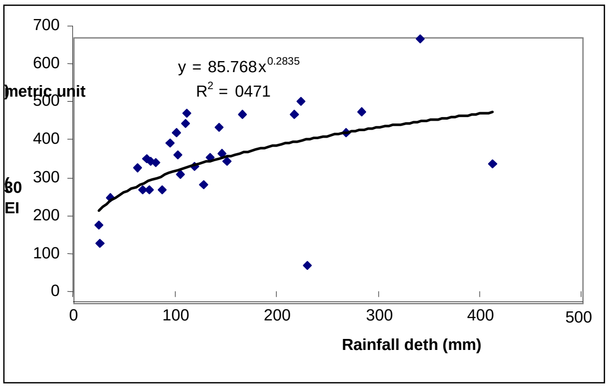
1997-1998	38.9	23.3	83.0	81.1	32.6	48.5	19.5	24.8	351.7	73.1
1998-1999	0.1	0.1	9.7٠	36.8	48.2	19.8	11.7	1.2	127.6	26.8
1999-2000	10.5	08.2	28.0	52.6	23.7	31.1	22.3	0.3	176.7	25.1
2000-2001	12.4	46.7	83.7	25.9	37.9	82.5	36.2	17.6	342.9	76.3
2001-2002	2.60	11.1	48.3	55.4	17.9	126.1	77.4	1.1	339.9	81.6
Average	11.5	40.3	65.1	62.3	65.6	69.9	40.1	15.6	370.4	140.3

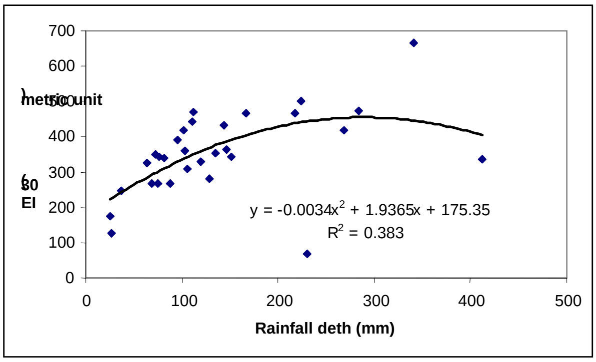
described the seasonal and temporal distribution of rainfall erosivity . It was showed from table (2) that the coefficients of determination (R^2) for the five obtainable models were ranged from (0.301) to (0.833) and the best-fit model of
these relationships which strongly correlated the erosivity index (EI_{30}) values with the event rainfall depth is fitted by an exponential relationships (Model No.4 in table 2) ;

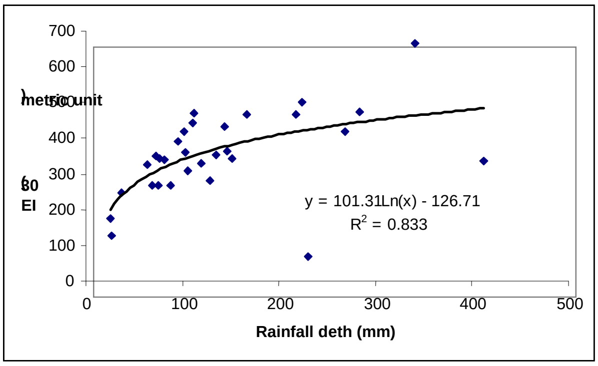
$$Y = 101.3 \ln X - 126.7 + E \quad ....(7)$$

Where:
Y = Predicted EI30 (Metric unit) and E = random, normally distributed error
X = Mean annual rainfall depth (mm).









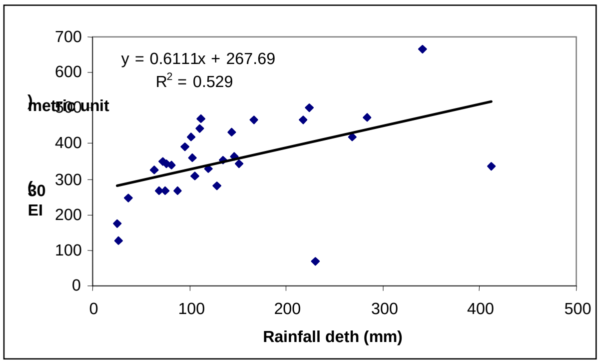


Fig.(1): Linear and curvilinear relationships of EI_{30} to mean annual rainfall depth

The high value of coefficient of determination(R^2) amounted to (0.833) .and the was highly correlated and the model was more accepted to be used. The significant results obtained ,indicate that about 83.3 % of the change in EI_{30} was due to the amount of annual rainfall depth. This mean that the EI_{30} was not only associated with the amount of rainfall depth, but also on the natural distribution of rainfall through the year. In the regressed analysis, all data were used to obtain the relationship and all coefficients of determination were significant at 0.05 level probability.

Although ,the 30-yr of rainfall data were used to calculate the average value of erosivity index (EI_{30}), the estimated value of EI_{30} (140.3 metric unit) for Mosul in our study ,was somewhat higher and overestimated than those predicted by the isoerodent map of Iraq which was presented by Hussein (1986) for rainfall depth

data collected over the period of 1940-1980 which was also constructed using MFI model. This variation in calculated EI_{30} between the two investigations could be attributed to the variation in the period which used in each study .

Table (2): Regression equations and R^2 for EI_{30}* Annual rainfall depth Relationship

Seq.	Models	Intercept (a)	Slope (b)	R^2
1	$Y=267.01e^{0.005X}$	0.000	267.00	0.301
2	$Y= 85.76\ X^{0.206}$	0.000	85.76	0.471
3	Y= 0.6111 X + 267.69	0.6111	267.69	0.529
4	Y= 101.31 Ln X – 126.71	-126.71	101.31	0.833
5	Y=0.0034X2+1.9365X+17.51	17.51	-0.0034	0.529

Al-Jobori (1984) indicated that the semi-average method could be used successfully for describing the trend of annual EI_{30} over any period. This method , in brief, the original data of EI_{30} were divided into two groups of equal period .The values of each group were then summed up and averaged . The average of each group was centered in the period of the time of the group from which it has been calculated and then plotted on the graph.. The slope of the line joining the two parts give the trend. A positive slope implies increasing trend and negative slope for decreasing trend .In the present study ,the actual data were divided into 15yrs-15yrs periods .The first 15yrs period included data of 1972-1987 season and the second 15yrs period include data of 1987-2002 season. Table (3) and figure (2) had shown that there was an increasing in the average EI_{30} from 124.6 to 156.1 metric unit for the 1st group (1972 – 1987) and 2nd group (1987-2002) respectively.

This result means that there was a positive trend equal to + 31.4 metric unit in the values of yearly EI_{30} through the studied period, and this result interpreted the variation between the average value of EI_{30} in this study and the EI_{30} value of isoerodent map of Hussien(1986).

Table (3): Detailed statistical parameters (Semi-average , St. deviavtion and C.V.) of EI_{30}

Gr.	Yrs record	Semi-total	Semiaverag	St.deviation	C.Variation
1	72-1987	1869	124.64	67.663	54.28%
2	87-2002	2347	156.07	112.230	71.91%

Separation the data of EI_{30} index into two groups of equal periods(15yr),the mean annual EI_{30} shows a decrease(MFI1-15 = 124.6 metric unit) in the 1st group of rainfall record (1972-1987) and increase gradually (MFI2-15= 156.1 metric unit) during the 2nd group(1987-2002) . In detailed ,the calculated mean annual EI_{30} for the total period (1972 – 2002) was slightly above the mean annual of the 1st group (1972-1987) and was below the mean annual of the 2nd group (1987-2002).Because of the data set were widely different in their means , the standard deviation and C.V % were more better to use for comparison between the two groups. The high value

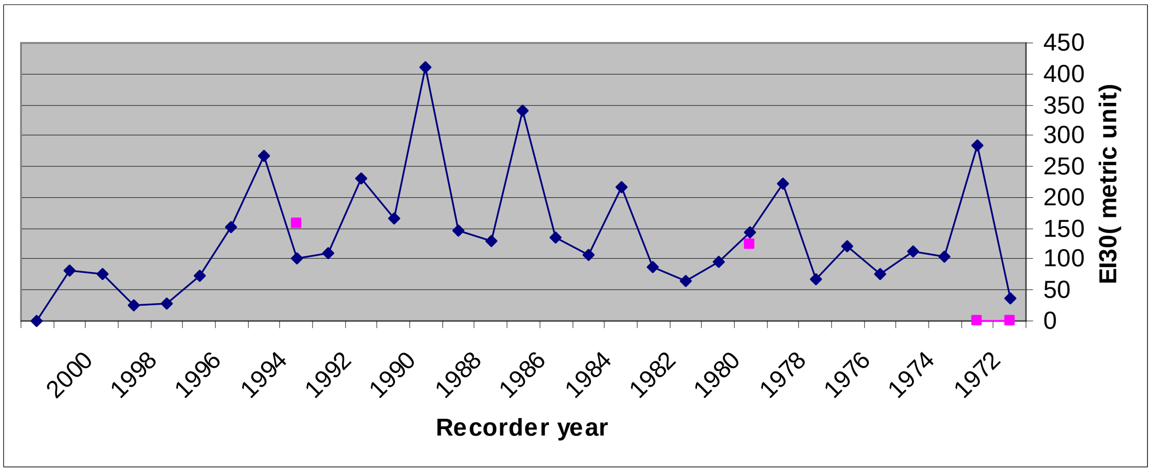


Fig.(2): The trend of actual EI_{30} by Semi-Average Method.

of standard deviation(123.23) for the 2nd group, in comparison with the standard deviation(67.633) of the 1st group, means that the actual data of the EI_{30} have a high variance in their distribution (in comparison with the EI_{30} of the 1st group) through the years of the rainfall records used in this study ,and this result can show clearly from the C.V. % value for the two groups of rainfall recorder (table 3) in which the C.V. % value of the 2nd was less than that of the 1st group. On the other hand ,the distribution of estimated annual EI_{30} (percent of annual erosivity index) by rainy months and 30 – yr average along the rainy seasons are presented in Table (4). It can be seen that approximately(21.9 %) of annual erosion was concentrated during March (21.9 %) , (19.7 %) in February and (18.8 %) in January while it decline to (17.4 %) in December and (11.9 %) in November and decrease to(6.4 %) and (2.8) and (1.1 %)in April, May and October respectively . These results give an idea that the rainfall erosivity was very sever in four months (50% of rainy months) through any year of rainfall records and December to March was found to be the most erosive months in the studied region The summation of mean monthly EI_{30} (as shown in Fig 3) was considered as a good indication to smoothing the EI_{30} movement to predict event soil loss for area under study over period 1972-2002.

The Actual Soil Erosion Risk (ASER) produced by the monthly return frequencies of rainfall event for 10yrs(MFI-10 =126.1metric unit) ,20yrs (MFI-20= 153.1)and 30yrs (MFI-30 = 140.3) year as accumulative periods showed a significant improvement and agreement with the line of curvilinear (non-linear) of

EI_{30} * average rainfall depth relationships of the studied area. Therefore, the empirical equation explain the relationship is ;

$Y = - I.582 + 0.281256 X$ ……………………….. (8)

$R^2 = 0.998$)

Where ; Y = acc. EI_{30} in metric unit and X = mean annual rainfall depth in mm.

Table (4): % erosivity(EI_{30}) distribution for rainy months at the studied area over period 1972-2002.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1972-1973	0.0	18.0	8.1	10.8	28.9	5.2	2.8	26.2
1973-1974	٠.0.	0.98	1.5	22.9	16.7	55.0	2.9	0.1
1974-1975	0.0	7.6	21.7	10.7	41.8	0.8	16.6	0.9
1975-1976	0.0	4.4	25.4	12.3	17.3	24.0	12.8	3.8
1976-1977	2.5	0.1	6.1	58.1	6.8	5.8	20.6	0.0
1977-1978	0.2	1.6	41.4	24.9	26.6	5.1	0.1	0.1
1978-1979	0.0	3.7	21.9	42.6	14.3	16.7	0.8	0.0
1979-1980	0.7	4.8	12.6	0.9	54.1	13.2	13.6	0.0
1980-1981	0.1	16.2	36.3	10.2	7.8	27.2	2.1	0.1
1981-1982	2.8	12.6	8.8	37.1	6.9	0.4	29.1	2.3
1982-1983	1.4	47.1	12.3	9.4	14.1	9.2	2.1	4.4
1983-1984	0.0	18.0	2.0	1.9	1.5	67.1	2.0	7.5
1984-1985	0.7	66.1	2.6	5.8	5.5	13.3	6.0	0.0
1985-1986	0.0	2.6	6.8	4.6	69.5	6.6	9.4	0.5
1986-1987	2.5	12.9	6.8	1.3	57.8	18.4	0.3	0.0
1987-1988	8.6	0.2	17.4	46.9	13.0	11.5	2.4	0.0

1988-1989	0.1	1.6	42.6	1.1	9.7	44.8	0.0	0.1
1989-1990	0.2	60.0	2.2	9.3	20.2	5.0	3.0	0.1
1990-1991	0.1	0.1	4.9	1.7	2.2	90.8	0.1	0.0
1991-1992	0.0	4.9	16.9	23.7	43.6	1.5	1.8	7.6
1992-1993	0.0	13.7	17.5	2.8	8.4	0.4	33.5	23.7
1993-1994	0.9	14.3	17.2	18.9	7.2	28.3	13.1	0.1
1994-1995	1.2	16.7	16.7	4.9	15.3	38.9	5.4	0.9
1995-1996	0.0	1.9	0.2	59.7	2.6	31.7	3.2	0.6
1996-1997	0.2	0.3	62.4	7.4	20.3	8.4	0.6	0.4
1997-1998	7.6	2.7	34.6	32.9	5.3	11.9	1.9	3.1
1998-1999	0.0	.0٠	2.2٠	31.5	54.0	9.1	3.2	.0٠
1999-2000	1.9	1.2	13.6	48.1	9.8	16.8	8.6	0.0
2000-2001	0.8	11.0	35.2	3.3	7.2	34.2	6.7	1.6
2001-2002	0.1	0.4	8.3	11.4	1.1	57.2	21.5	0.0
Average	1.1	11.9	17.4	18.8	19.7	21.9	6.4	2.8

Furthermore, although almost all factors of the Universal Soil Loss Equation
(USLE) were influence by changing in climate, it was evident that the rain erosivity factor (R) was of primary importance and directly involved (Carollina *et al* 2007). The formula for the USLE is :

A = RKLSCP ………………………………….(9)

Where;

A = Mean annual soil loss R =Rainfall erosivity factor
K = Soil erodibility factor L = Slope length factor
S = Slope gradient factor C = Cropping system and soil management factor
P P = Supporting practices factor

In the original formula of the USLE, the R-factor was calculated as a product of total kinetic energy by the maximum rainfall intensity at 30-minut.Since this rainfall parameter are not readily available, the EI_{30} of MFI was taken into account to determine the rainfall erosivity as a function of soil loss. Then the erosivity index EI_{30} by MFI model is similar and equal to the erosivity index (R-factor)in equation 9) ,therefore the equation becomes;

A = f (R) klscp ………………………………….(10)

Where ; R = EI_{30}(metric unit) and klscp =constant

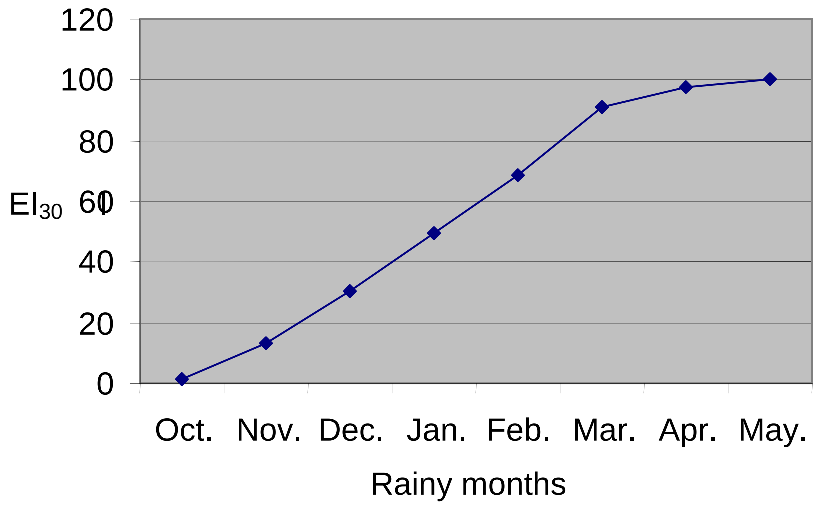


Fig 3: Summation curve of mean monthly EI_{30}

This conceptual mean that when factors other than rainfall are held constant , soil loss directly proportional to rainfall erosivity index (EI_{30}). Therefore, the mean annual EI_{30} are represented the mean annual soil loss which removed from the studied region yearly. From the result obtained in this study ,it may be concluded that in semi – arid condition ,serious rainfall erosion (sheet and rill) often occur ,because the rain although low in quantity ,it could come in very sever storm, and the estimation of rainfall erosivity index for this region is a key point for the selection of soil conservation system (Hussien 1986 and Bayramin *et al* 2006) and the analysis of MFI value with additional data over period 1972-2002 showed that the studied area was under the moderate erosion risk according to the erosivity classes of Soil Conservation Service (SCS) especially in winter and spring season.

استخدام علاقة الشدة المطرية بالطاقة الحركية للتنبؤ بمعدل فقد التربة

خالد فالح حسن
قسم علم التربة والمياه – كلية الزراعة والغابات- جامعة الموصل

الخلاصة

لتحديد العلاقة بين الشدة المطرية - ا لطاقة الحركية بمعدل فقد التربة فقد تم استخدام البيانات المناخية لمدينة الموصل لفترة ٣٠ سنة حيث تم تحليلها واستخراج دليل قابلية المطر على التعرية بطريقة دليل فورنير المعدلة-اشارت النتائج الى ان دليل قابلية المطر على التعرية يختلف من سنة الى ا خرى حيث تراوح بين ٢٥.١ – ٤٤١.٦ وحدة مترية وبمعدل ١٤٠٣ وحدة مترية وان هذا المعدل يتوزع بدرجة عالية على اربعة شهور مطرية ٥٠/ حيث تعتبر الفترة من شهر كانون الاول – اذار من اشد الفترات تاثيرا على فقد التربة وان نتائج تحليل الانحدار اشارت الى ان النموذج الاحصائي اللوغاريتمى يعتبر من افضل النماذج للتعبير عن العلاقة بين دليل قابلية المطر على التعرية ومعدل الامطار السنوية للمنطقة.

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