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where ϕ_s is the dimensionless soil loss. It can be concluded that this dispersion is relatively small. Thus, the sum of erosion losses from n storms on an annual basis can be substituted by the sum of expected values which depends on rainfall depth.

6 Summary

The hypothesis that the annual rainfall depth can be used for predicting annual soil erosion losses from upland areas has been tested with field data from 135 experimental plots in Iraq. The 100 m^2 plots were monitored over a period of four years under a broad variety of soil types, vegetation cover and conservation practices. The first three years of data were used in a regression analysis which relates soil losses to rainfall depth and also to runoff depth.

Under similar conditions of rainfall, soil type, vegetation and conservation practices runoff volumes are shown to increase with the slope of the experimental plot. This indicates that infiltration losses increase on flatter surfaces.

The runoff depth and the soil erosion losses were regressed (Eqs. 2, 3 and 4) against surface slope S, rainfall depth r and relative correction factors for the soil type K, vegetation C and conservation practice P. The results shown in Figs. 3 and 4 are excellent. The fourth year of data validates the empirical regression equation and the small dispersion predicted from the theoretical analysis in the companion paper is confirmed with the experiments. It can be concluded that on an annual basis, soil erosion losses can be predicted either as a function of runoff and slope (Eq. (3)) or as a function of rainfall depth and slope (Eq. (4)).

This method for predicting annual soil erosion losses is preferred to the USLE when annual rainfall amounts are known and the rainfall precipitation data are insufficient to calculate the kinetic energy factor of the USLE.

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On predicting upland erosion losses from rainfall depth

Part 2: Field applications in Iraq

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Abstract: Annual erosion losses from 135 experimental plots under a variety of soil types, vegetation cover densities and conservation practices in Iraq have been measured over a period of four years. The first three years of this data set demonstrate that annual erosion losses can be predicted from annual rainfall depths. The results obtained from regression analysis were then validated with the fourth year of soil erosion data. These results corroborate the theoretical findings of the companion paper in that long term erosion losses can be predicted from the total amount of rainfall.

Key words: Upland erosion, annual soil losses

1 Introduction

Since the turn of this century, quantitative information on soil erosion rates has been collected on a large number of instrumented field plots under a variety of climatic, physiographic, land use and soil management situations. Previous studies on small experimental plots located across the United States led conclusively to the well known Universal Soil-Loss Equation (USLE). This prediction model developed by Wischmeier and Smith (1960, 1978) expresses the average annual soil-loss as a function of six factors: (1) a rainfall erosion index, (2) a soil erodibility factor, (3) the land gradient, (4) the length of slope, (5) a cropping management factor, and (6) a conservation practice factor.

In a study to determine the best rainfall erosivity index (Wischmeier and Smith 1960), several expressions representing rainfall depth, intensity, and energy were correlated with soil-loss. The product of kinetic energy of rainfall and the maximum 30-minute rainfall intensity (the R factor) explained a larger percentage of soil-loss variation than any other rainfall-derived parameter.

To support these findings, Dragoun (1962) found very poor correlation between sediment yield and rainfall depth on a single storm basis at two field-size watersheds in Nebraska. In the latest version of the USLE (Wischmeier and Smith 1978), the erosivity index was determined empirically for all significant storms to be the summation on an annual basis of the individual storm product of the kinetic energy of rainfall in hundreds of foot-tons per acre, and the maximum 30-minute rainfall intensity in inches per hour.

The objective of this work is to examine the relationship between soil losses and rainfall depth on an annual basis through a detailed analysis of instrumented field plot data from Iraq. In contrast to the empirically derived USLE which requires detailed knowledge of the kinetic energy of rainfall, it is hypothesized that annual soil erosion losses can be predicted from rainfall depth and without knowledge of the kinetic energy of rainfall.

Field studies related to rainfall, surface runoff and soil erosion losses were conducted at the Zawita Experimental Station within the Dohuk Governate in Iraq. The station is located 480 km north of Baghdad and lies between 42E and 43E longitude and between 36N and 37N latitude.

2 Rainfall

Daily rainfall at 14 stations in the northern part of Iraq has been investigated over a period of 16 to 30 years to determine its temporal and spatial distribution. Three models describing the distribution of rainfall depths were tested against the measurements: (1) the one-parameter exponential distribution, (2) the two-parameter gamma distribution, and (3) the three-parameter mixed-exponential distribution.

The probability density function $f(x)$ of rainfall depth for the exponential, gamma and mixed-exponential models are detailed in Dawod and Julien (1986). The goodness-of-fit based on the Smirnov-Kolmogorov test demonstrated that the exponential distribution can best represent the distribution of rainfall depth in the northern part of Iraq. As an example, the distribution of daily rainfall depth for the months of December and January at Zawita Station is shown in Fig. 1. On a monthly basis, the average rainfall depth per storm at the 14 stations is presented in Table 1. It is observed that rainfall occurs mainly from October until May and that the average rainfall depth per storm at a given station remains fairly constant except for the first and last months of the rainy season. The mean annual rainfall depth per storm is given in the last column of Table 1. When these mean annual values are plotted on a map of Iraq (Fig. 2), a four-fold increase in average rainfall precipitation per storm is noticeable in the northeastern part of the country.

3 Overland runoff

A series of 135 rectangular experimental plots, each covering an area of 100 m^2 (5 m wide and 20 m long) was constructed at five different slopes to measure overland runoff and surface erosion under a set of three different soil conditions, three vegetation types and three conservation practices. Each plot was surrounded with a metal border (30 cm high). Ten holes were drilled into a plate fixed at the lower end of each plot. One of the ten holes was connected to a 4 cm rubber pipe leading to two large barrels used for collecting overland flow and trapping sediments. Surface runoff and erosion losses were measured after each storm and compiled each year for a period of four years from 1976 to 1980. Details on this field investigation are available in Dawod (1981, 1983).

Overland runoff and soil erosion losses from Zawita Experimental Station have been compiled by Dawod (1986) and include fifteen tables similar to Table 2 (presented as an example) with overland flow and soil erosion data for five different slopes (1%, 5%, 10%, 15%, and 20%) and three types of soil texture.

Similar natural precipitation conditions prevailed for each of the 135 plots allowing comparison of the relative erodibility of soil surface to various combinations of slope, soil texture, vegetation cover and conservation practices.

Regression analysis between the measured variables indicates a significant correlation between the surface slope, S, and the annual runoff depth, V_r in mm and the annual rainfall depth r:

Table 1. Monthly and annual variation of rainfall depth per storm (mm) at 14 stations in northern Iraq

	Station	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Annual * Mean
A	Sarsink	18.9	15.6	15.4	17.9	17.2	16.7	14.5	16.1	16.2
B	Amidia	14.1	22.7	20.8	20.4	17.2	16.4	19.2	15.2	19.5
C	Shaqlaw	6.8	13.2	17.9	13.5	22.7	12.7	15.2	12.2	15.9
D	Rawanduz	40.0	23.3	19.6	25.0	23.8	20.0	20.0	19.2	22.0
E	Dokan	5.2	14.3	14.3	14.5	15.9	15.6	14.5	13.5	14.9
F	Mosul	3.0	5.6	6.8	6.1	6.3	6.8	4.9	4.7	6.1
G	Sinjar	4.8	6.7	8.0	8.3	8.1	8.3	7.9	10.5	7.8
H	Kirkuk	3.4	5.1	6.7	7.0	7.1	8.1	6.6	4.3	6.8
I	Khanaqin	4.3	6.4	9.8	7.9	7.1	8.7	6.3	4.0	7.7
J	Sulaimoniya	6.4	11.6	11.4	9.8	14.1	11.8	11.1	11.1	11.6
K	Arbil	17.9	9.1	12.2	12.2	13.2	10.6	16.1	20.4	12.2
L	Salahddin	4.1	17.9	14.5	10.8	10.5	10.6	11.0	13.5	12.6
M	Duhok	19.2	12.2	10.2	15.9	12.7	12.8	11.2	18.2	12.5
N	Zawita	11.5	13.9	13.2	16.9	15.6	13.9	12.7	15.2	14.4

* Average values during the wet season (November through April).

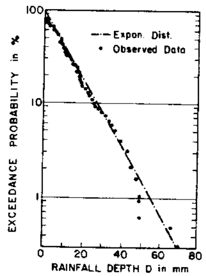

Figure 1

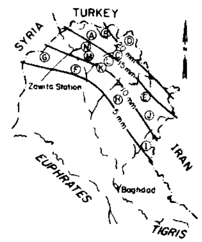

Figure 2

Figure 1. Exceedance probability for rainfall depth at Zawita Station

Figure 2. Average rainfall depth per storm in the northern part of Iraq

Table 2. Annual surface runoff and erosion losses from field plots at Zawita Station for 20% slope gradient and fine soil texture

Conservation practice		NP	NP	NP	CO	CO	CO	WF	WF	WF
Soil texture		NC	MC	FC	NC	MC	FC	NC	MC	FC
Annual	1976-77	127	104	63	98	80	50	120	99	59
Surface	1977-78	111	95	57	90	72	45	109	93	53
Runoff	1978-79	84	73	41	70	66	35	82	69	40
ha.mm/ha	1979-80	135	112	68	102	89	56	133	109	67
Annual	1976-77	192	63	20	130	45	13	149	47	16
Erosion	1977-78	170	60	16	125	43	13	135	49	17
Losses	1978-79	130	47	13	101	32	10	96	36	13
m^3/ha	1979-80	170	62	17	127	44	14	134	47	16

NP = No conservation practice, CO = Contouring, WF = Wattle fences
NC = No vegetation cover, MC = Medium vegetation cover, FC = Full vegetation cover

Table 3. Runoff coefficients for conservation practice P_r, vegetation C_r and soil texture T_r

A.	Conservation practice	P_r	P_s	P
	No conservation practice	1.00	1.00	1.00
	Contouring	0.78	0.89	0.62
	Wattle fences	0.96	0.82	0.77
B.	Vegetation cover density	C_r	C_s	C
	No cover (bare soils)	1.00	1.00	1.00
	Medium vegetation cover	0.77	0.52	0.36
	Full cover	0.54	0.23	0.10
C.	Soil texture	K_r	K_s	K
	Coarse texture	0.81	0.72	0.53
	Medium texture	1.00	1.00	1.00
	Fine texture	1.23	0.54	0.73

$$V_r = 0.23 S^{0.357} r \; ; \quad (R^2 = 82\%). \tag{1}$$

All other conditions being similar, the increase in runoff with slope is likely caused by the increased effects of surface depression storage and higher infiltration losses at low slopes. The variability of runoff volume under various conditions of conservation practice, vegetation cover density, and soil texture was determined from comparison with a reference value. Bare soils with no conservation practice and medium soil texture were selected as the reference conditions. Relative runoff volumes were defined as the ratio of the runoff volume under any condition of vegetation, soil type and conservation to the runoff volume for bare soils used as reference conditions. After averaging the values of the relative runoff volumes, three sets of correction factors were determined as shown in Table 3 for conservation practice P_r, vegetation C_r and soil texture K_r.

Table 3 indicates that the effects of contouring and wattle fences reduce the runoff from experimental plots slightly in comparison with no conservation practice conditions ($P_r = 1$). The coefficient C_r quantifies the influence of vegetation; runoff and hence C_r are shown to decrease gradually as the vegetation density increases. Soils with a coarse texture and larger grain sizes have larger infiltration rates than fine silt soils, thus the soil texture parameter K_r decreases with increasing texture or size of soil particles.

As derived from these experiments at Zawita station, the runoff depth can be expressed as:

$$V_r = 0.23 P_r C_r K_r S^{0.357} r \tag{2}$$

in which the rainfall depth r and the runoff depth V_r are in mm.

4 Soil erosion losses

Multiple non-linear regression analysis was applied to the first three years of the Zawita Station soil erosion loss data and the fourth year of data was used for validation. Annual erosion losses V_s in m^3/ha were regressed against the surface slope S in m/m and runoff depth V_r in mm in the following power form:

$$V_s = 0.743 S^{0.72} V_r^{1.44} P_s C_s K_s \; ; \quad (R^2 = 0.95). \tag{3}$$

The conservation practice coefficient P_s in Table 3 takes a reference value equal to unity for experimental plots with no conservation practice. The relative influence of wattle fences and contouring is shown to reduce soil erosion losses by as much as 20%. The vegetation factor C_s decreases with vegetation cover density.

The soil losses calculated from Eq. (3) are in excellent agreement with the observed soil losses shown in Fig. 3. Few data points lie outside of a relatively narrow band around the expected value.

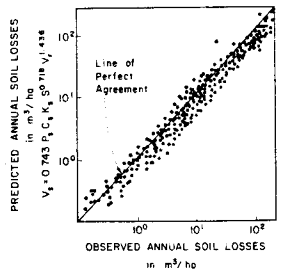

Figure 3

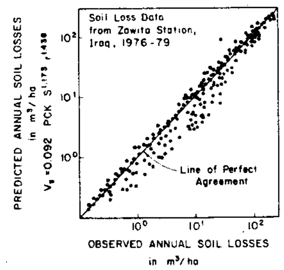

Figure 4

Figure 3. Predicted and observed annual soil losses at Zawita Station 1976-1979 (From Eq. (3))

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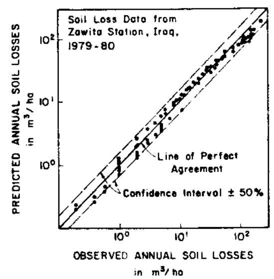

Figure 5. Predicted and observed annual soil losses at Zawita Station 1979-1980 (From Eq. (4))

The soil loss V_s was also regressed against the slope S and annual rainfall depth r after the coefficients for vegatation C, conservation P and soil texture K were combined as shown in Table 3. The soil loss equation reads:

$$V_s = 0.092 PCK S^{1.17} r^{1.44} \, , \tag{4}$$

with V_s = annual soil loss in m^3/ha/year, S = slope in m/m, P = conservation practice parameter, C = vegetation parameter, K = soil texture parameter, r = annual rainfall depth in mm.

The field observations from the Zawita Station under a large variety of vegetation, soil types and conservation practices are compared with erosion losses calculated from Eq. (4) in Fig. 4. The analysis demonstrates the feasibility of modeling soil erosion losses from annual rainfall r and the soil surface parameters P, C, K and S.

5 Validation

The data collected during the fourth year (1979-1980) of investigation at Zawita Station were used for validation of the method. As shown in Fig. 5 the observed values of the annual soil erosion losses are in excellent agreement with the calculations from Eq. (4). As could be assessed from the theoretical investigation in the companion paper, the variability around the mean value can be calculated as follows, with $\gamma = 1.44$, $\alpha = 95\%$ and $n = 46$ on an annual basis,

$$0.90 < \frac{E(\sum^{46}\phi_s)}{\sum^{46} E(\phi_s)} < 1.10 \quad (5)$$

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