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Estimation of Rainfall Erosivity Indices for the Kingdom of Saudi Arabia

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Abstract. Rainfall erosivity index of the Universal Soil Loss Equation was obtained, using the daily rainfall records for twenty stations, covering most of the regions in the Kingdom of Saudi Arabia. The kinetic energy and the erosivity index (EI30) were estimated by Wischmeier's Equation. composite curves were drawn as a basis for determining the erosive power of rainfall. A risk of erosion from rainfall exists in some areas of the Kingdom. Also, a contour map of the erosion factor (R), was produced to form as a basis for planning and designing appropriate soil conservation practices throughout.

Introduction

The soil erosion in some areas can be serious and may continue for such a period that the most fertile soil is lost. Generally, in the agricultural countries, the potential productivity is reduced by past erosion and that the land may not fully recover.

The factors controlling the working of soil erosion systems are the erosivity of the eroding agent (e.g. rain), the erodibility of soil, the slope of land and nature of plant cover [1]. The soil loss by rain is closely related to the detaching power of the raindrops striking the soil surface and the transportation power of the resulting runoff from rain.

The rainfall erosivity factor (R), used in the University Soil Loss Equation (USLE) is a measure of the effect of rainfall on erosion. Wischmeier *et al.* [2] showed that the rainfall characteristic most closely related to soil loss is the kinetic energy (K.E.) of the rain. However, the K.E. alone is not enough to describe the erosion potential of the rain because it does not provide enough information on its distribution over time and the surface runoff available to transport the detached soil particles. After testing many other rainfall parameters [3], it was concluded that the second important rainfall characteristic is the 30 minutes maximum rainfall intensity (I30). The rainfall erosion index has been found to give an excellent correlation with soil loss.

To determine the quantitative value of the rainfall erosion factor (R), it is necessary to have long time rainfall recording period.

The rainfall factor for a particular area depends on the geographical location and elevation of the site. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff [1]. It has been proved experimentally that the average soil loss per rain event increases with the intensity of storm. In general, estimating erosivity potential of a rainfall means to measure those rainfall characteristics which correlate well with soil erosion.

However, many equations were developed to estimate the rainfall erosivity factor which describes the potential of rainfall to cause erosion. Original procedures for determining R values taking into consideration the effects of raindrop impact have been discussed by Wischmeier and Smith [4]. Later modifications [5] outlined procedures for adding the effects of snowmelt or irrigation to the R factor.

Studies to improve and develop equations for erosivity index under different conditions were conducted elsewhere [6,7,8,9]. Assessment and estimation of rainfall erosion factor from daily rainfall records have been carried out in various parts of the world [10,11,12,13].

Due to the lack of information about erosion by rain in the Kingdom of Saudi Arabia, this study was undertaken in an attempt to (1) estimate the value of one of the most important factors (erosivity index) influencing the erosion process, which will be helpful in selecting, planning and designing soil conservation practices and (2) produce a contour map of erosivity for the Kingdom which can be used to predict annual erosion losses.

Procedure and Methods

A bulk of rainfall data consisting of rainfall intensity, duration and total amount was obtained from the Ministry of Agriculture and Water 'MAW' (Hydrology Division). All available rainfall records from 31 stations, scattered around the Kingdom, covering a period of 26 years between 1963 – 1988 were reviewed. After scrutinizing and careful study of the rainfall events, it was found that only 12 stations, with sufficient data for 11 years (1970-1980) were suitable for the analysis of the rainfall erosivity criteria. The selected stations represent the major regions of the Kingdom (Fig. 1). However, eight more stations were included to draw the contour map of the erosivity index for the Kingdom. Each station has been named by MAW after a nearby city, village, wadi, or other conspicuous feature. The sites were ranging in

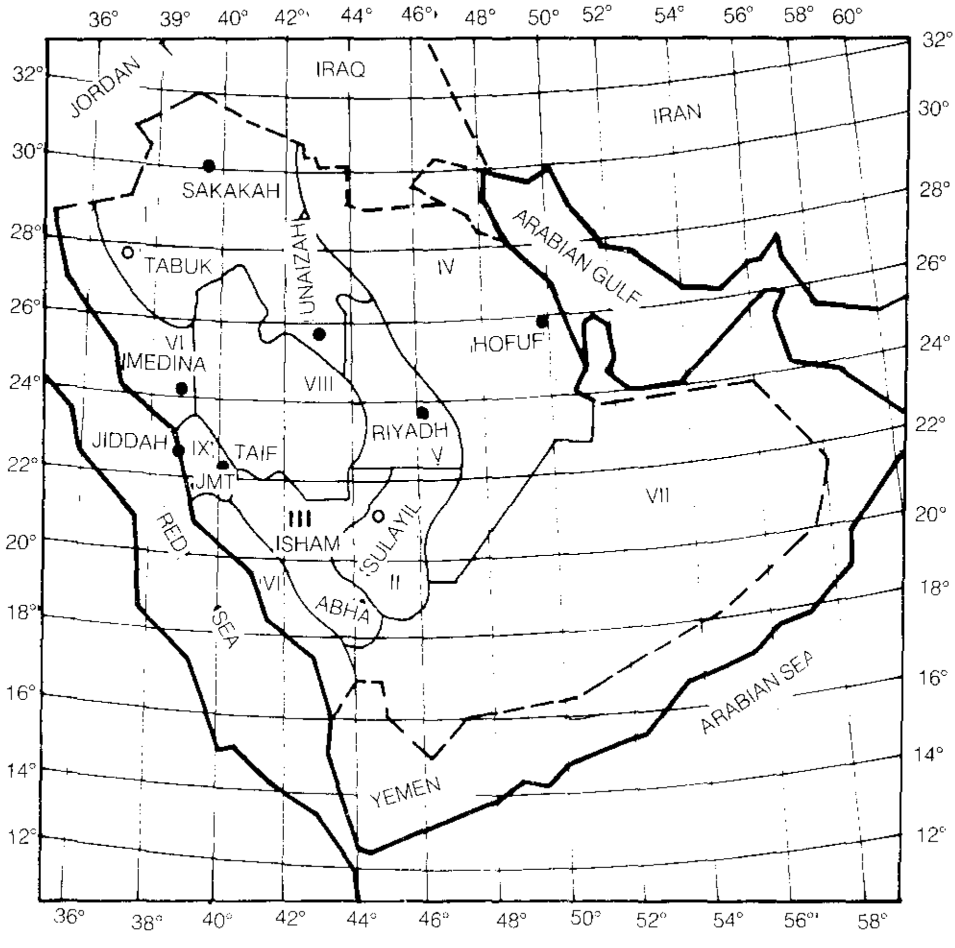

Fig. 1. General map of the Kingdom of Saudi Arabia showing different regions.

elevation from 4.7 m to 2600 m above mean sea level (M.S.L.). List of station names, identification numbers, and their alphabetical prefix letters are presented in Tables 1 and 2.

The data selected for use were taken from a continuous rainfall gauge chart picking the maximum incremental rainfall which fell during the periods of ten, twenty, and thrity minutes; and one, two, three, six, and twelve hours. Total rainfall, along with duration, were also determined for each storm.

Table 1. The location and elevation of the various stations (No. = 12) used in the study

Area and stations name	Basin	Sub-basin	Latitude	Longitude	Elevation EL(M)	No. of rainy days (Av.) N	Annual rainfall (Av.) P(mm)
A: I,TB001 Tabuk	Sirhan-11	Qa-Sharaw-ah	28 22 0	36 35 0	773	4	27.9
A: II.N001 Najran	Asir Najran-4	Najran	17 33 0	44 14 0	1250	7	73.3
A: III.B002 Bishah	Asir Dawasir 3A	Bishah	19 6 0	42 9 0	2600	37	463.7
A: III,B004 Bishah	Asir Dawasir 3A	Bishah	20 1 0	43 36 0	1020	10	122.6
A: IV,EP002 Eastern Province	North Towayq-8B	Durayda	26 30 0	50 0 0	4.7	4	81.3
A: V,R001 Riyadh	Birk Nizah Sahaba-7B	Hanifa	24 34 0	46 43 0	564	6	76.5
A: V,R005	Hutah Sudair	Dahna	25 32 0	45 37 0	665	8	111.1
A: VI,J001 Jeddah	Red Sea Coast 1A	Qarma	19 32 0	411 3 0	53	11	79.9
A: VI,SA001 Malaki	Red Sea Coast 1A	Jizan	17 3 0	42 57 0	190	24	358.6
A: VI,SA003 Kwash	Red Sea Coast 1A	Hali	19 0 0	41 53 0	350	16	308
A:JMT,TA002	Taif Fadat Mislah2	Waij	21 18 0	40 30 0	1500	10	157.2
A: VIII,M204 Al-Madinah	Red Sea Coast 1A	Hamd	24 51 0	40 10 0	850	7	44

Table 2. Informations related to the extra 8 - stations used in producing the rainfall erosivity contour map

Area and station name	Basin	Sub-basin	Latitude	Longitude	Elevation (Meter) EL.	No. of rainy days (Av.) N	Annual rainfall (Av.) mm P	Erosion index JM,mm,a^-1 hr^-1 yr^-1 R
A:I, SK001 Sakakah	Nafud N.E. Frontier-1	Nafud	29 58 0	40 12 0	574	5	47.8	178.3
A:I, SK002 Sakakah	Sirhan-11	Sirhan	31 20 0	37 21 0	549	5	49.7	140.5
A: V, R003 Riyadh	South Tuwayq-5	Hamr	22 17 0	46 44 0	539	3	60.6	596.3
A: VI, M207 Al-Madinah	Red Sea coast-1D	Hamd	25 43 0	39 14 0	710	9	40	283.8
A: VI, M001 Al-Madinah	Red Sea Coast-1D	Hamd	24 30 0	39 35 0	590	8	36	210.3
A: VIII, M205 Al-Madinah	Taif Fadat Mislah-2	Khafqan	23 8 0	40 34 0	860	8	49.6	558.3
A: VIII, M002 Al-Madinah	Red Sea Coast-1D	Hamd	24 51 0	40 30 0	840	14	42	157.4
A: VIII, M206 Al-Madinah	Red Sea Coast-1D	Hamd	25 7 0	40 20 0	1080	9	40.1	280.9

The method used to calculate the rainfall erosion index (R), was based on direct measurements of rainfall erosivity potential from rainfall records. All available rainfall intensity data for different locations in the Kingdom were used as outlined by Wischmeir [4]. According to this method, individual events are defined as rainfalls with 6 hours intervals or those separated with less than 1.27 mm rainfall in a period of 6 hours. In this study, rains of values less than 1.27 mm were neglected from calculations as insignificant.

Estimating the rainfall erosivity factor (R)

The following equaiton by Wischmeier and Smith [7] was used in this study:

$$KE = 13.32 + 9.78 \log I \quad \text{..........................} \quad (1)$$

where I is the rainfall intensity (mm hr^{-1}) and KE is the kinetic energy (J m^{-2} mm^{-1}).

This equation enables to compute the erosivity index without carrying out any analysis of the raindrop size and its distribution. The rainfall events were analyzed and each storm was divided into different segments of uniform intensity (mm/hr). The unit kinetic energy corresponding to each of these intensities was calculated by using equation 1. The amount of rainfall in each segment of intensity was multiplied by appropriate unit kinetic energy value and the energy was totalled for the whole storm. To obtain the erosivity index (EI30), the total value of kinetic energy of the rain was multiplied by the maximum 30- minutes rainfall intensity (I30). The inclusion of I30 in the index is an attempt to correct for overestimating the importance of light intensity rain [14]. The maximum 30-minutes intensity was computed by locating the greatest amount of rain received in any 30-minutes interval. It was then doubled to obtain the intensity per hour.

The values of erosivity indices (EI30), computed for individual storms were totalled to get monthly and annual values in mj $mm^{-1}ha^{-1}hr$. To obtain the rainfall factor (R), the computed EI30 values of the eleven recording years were summed and divided by the number of years. In other words, the R- factor is a longtime average of the yearly erosivity index for a specific location.

Results and Discuussions

The values of the rainfall factor (R) for the twelve sites, as computed by Wischmeier and Smith's Method [4] are shown in Table 3. These values vary considerably from one location to another. The annual values of R ranged from 160.1 to 2647.1

Table 3. Rainfall erosivity indices for the 12 - stations

Area	Yearly "R" MJ MM HA -1^5 Hr^-1 yr^-1	Monthly "R" MJ MM HA^-1 HR^-1											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
A: I TB 001	160.1	3.2	7	11.5	18.5	–	–	–	–	–	3	21	95.9
A: II N 001	569.9	6	13.9	75.9	238.2	11.5		52.9	21.8	32.4	103.6	13.7	–
A: III B 002	2647.1	270.9	229.2	471.3	659.2	367.5	6.5	65.1	132.5	0.5	46.1	192	206.5
A: III B 004	2187.4	0.8	9.2	125.5	1317.4	40.7	–	–	136	–	–	22.6	535.2
A: IV EP 002	656.2	49.3	39.3	39.6	64.4	497.8	–	–	–	–	–	–	5.1
A: V R 001	220.2	24.6	11.9	45.7	114.9	18.3			–		–	–	4.8
A: V R 005	396.1	34.7	13.1	92.5	25.7	72.4	–	13.4			27.2	86.6	30.5
A: VI J 001	1941.9	108.3	10.6	10.6	31.2	3.3	297.9	934.2	63.9	4.6	128.3	76.8	272.2
A: VI SA 001	4081.5	182.2	168.6	130.5	153.1	302	20	415.6	1186.9	392.1	603.1	331.9	195.6
A: VI SA 003	2384.1	65.1	56	114.9	40.6	267.5	235.6	190.4	470.5	561.6	250.5	36.8	94.7
A:JMT TA 002	1103.4	36.1	25.8	364.4	76.3	186.7	120.2	–	28.8	35.6	165	20.4	44.3
A: VIII M 204	561.8	29.7	33	34.6	40.8	87.7	–	230.7	0.5	–	73.9	18.4	12.5

mj mm ha^{-1} hr^{-1} yr^{-1} and fall in the category of low to high values according to Foster's classification [15]. Most of the researchers consider the rainfall factor (R) upto 300 as associated with low erosivity, 300-2000 as medium and 2000-5000 mj mm ha^{-1} hr^{-1} yr^{-1} as high. One station in Jizan (SA 001) showed a very high value of R (4081.5). This is the only value estimated on the basis of 7-years recorded data. However, this value was not considered in producing the map of erosivity for the Kingdom.

The variation in R value is expected due to various interdependent factors such as rainfall amount, duration, intensity and geographical location. The values of R are generally higher in the South Western regions including the coastal regions. Hence these areas are potentially more exposed to erosion than other areas in the Kingdom.

Some investigators have suggested that the maximum allowable value for I30 should be 63.5 mm/hr [14] because it leads to excessively high estimates of R in tropical areas. In this study, the threshold quoted above was not observed because the nature of rainfall is not similar to that in tropical areas. In general, the rainfall rate in the arid climate such as that in the Kingdom, rarely exceeds 50% of that experienced regularly in tropical areas.

Curves (Composite curves) based on cumulative percentage of monthly rainfall factors (11 years average) were plotted versus months of the year to show the variation of erosivity during the year for all the locations (Fig. 2). These curves provide a basic information which can be used in planning and design of soil conservation works. it is obvious from these curves that the distribution of erosivity in the regions consists of three categories:

Category A Fairly uniform such as that for

i.	Area VI, (SA 003)	ii.	Area VI, (SA 001)
iii.	Area JMT, (TA 002)	iv.	Area II, (N 001)

Category B Mainly summer such as that for

i.	Area VI, (J 001)	ii.	Area VIII, (M 204)

Category C Mainly winter such as that for

i.	Area I, (TB 001)	ii.	Area III, (B 002)
iii.	Area III, (B 004)	iv.	Area IV, (EP 002)
v.	Area V, (R 001)	vi.	Area V, (R005)

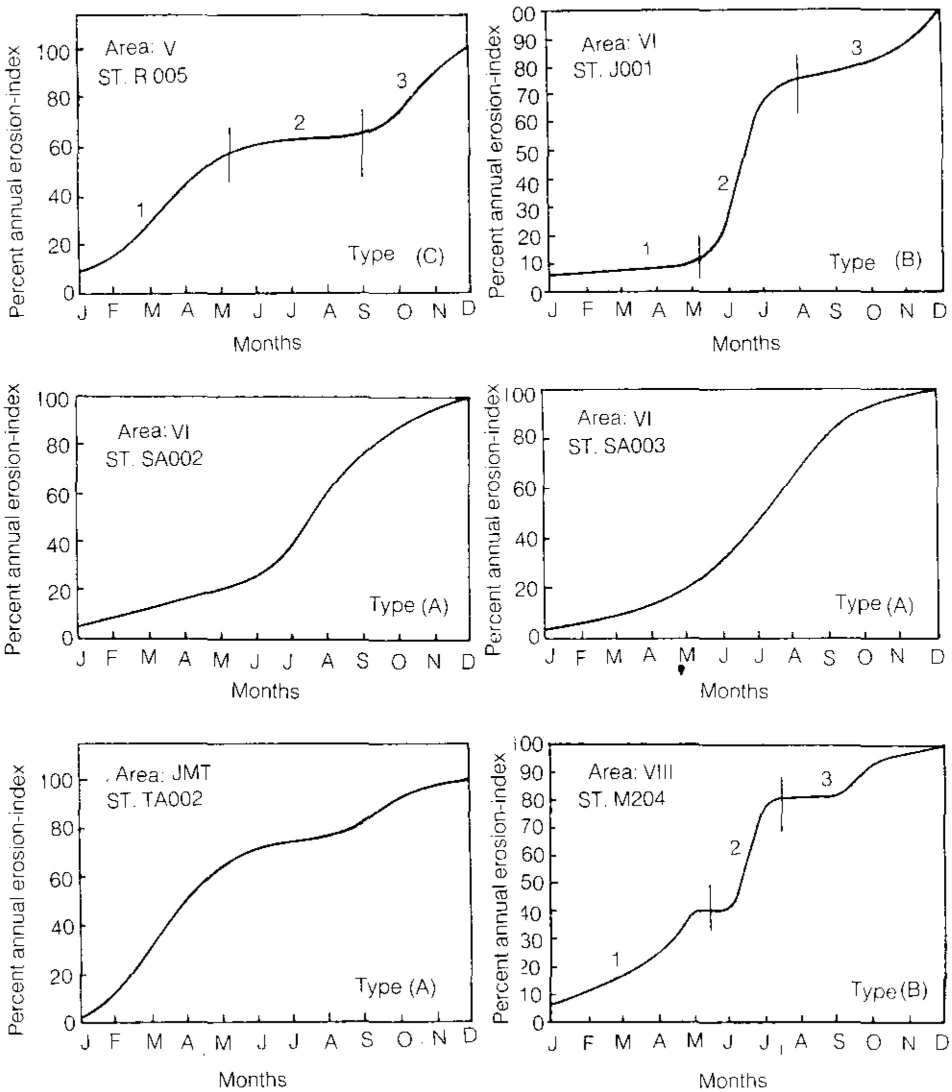

Fig. 2. Rainfall erosion-index distribution curves for various regions in the Kingdom.

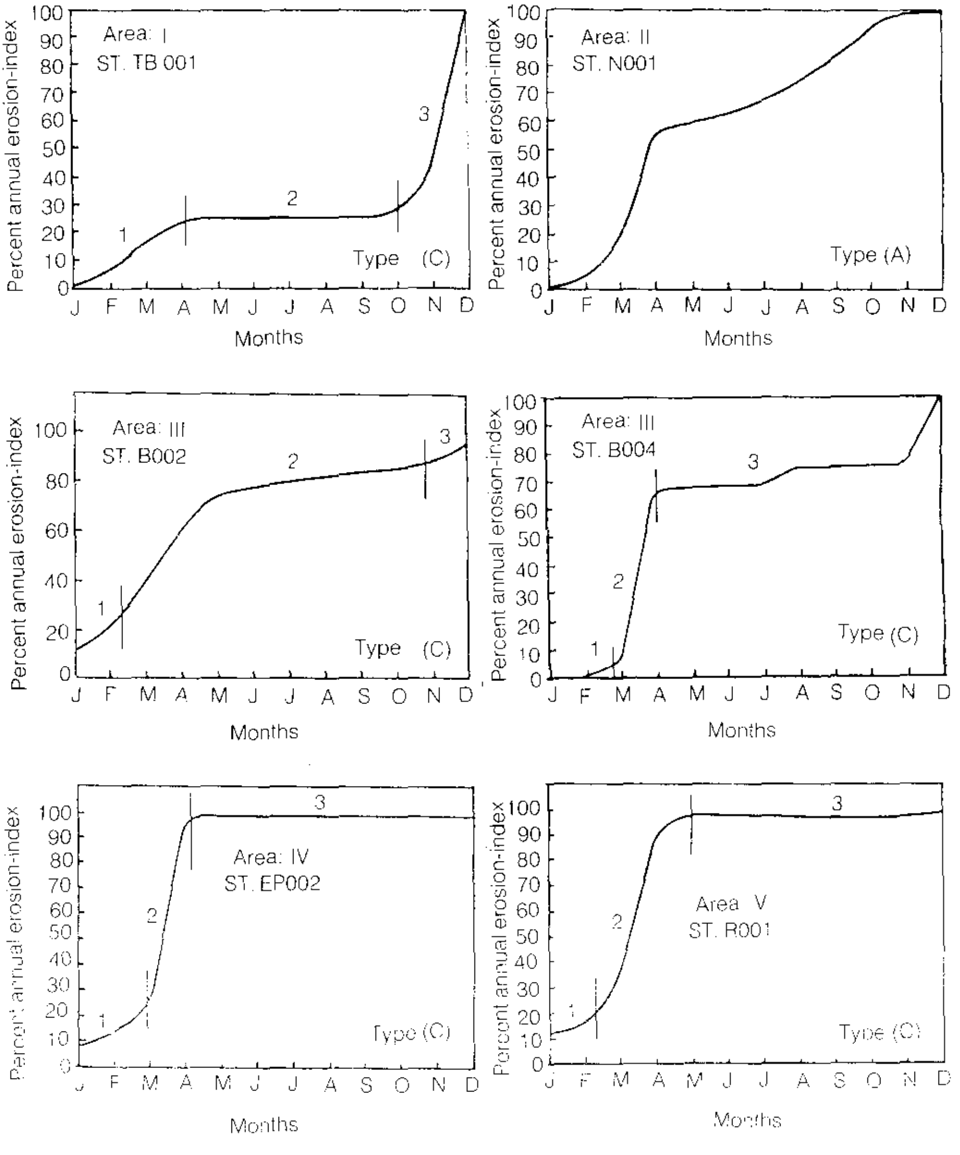

Fig. 2. Continued

Generally, the curves in categories B and C consist of three stages, viz:

Stage 1 with moderate erosivity
Stage 2 with no/low erosivity
Stage 3 with high erosivity

These stages vary from one location to another and according to the rainy season in the area. The steep slope observed in several curves suggests that the erosive power of the rainfall in the corresponding area is very high during a certain period of time. Areas such as J001 and M204 are likely to have greater erosion during the months of June – July, and EP002, N001, B004 and R001 in the months of March – April, while at location B001, the risk of erosion is high in the month of November. Genrally, the degree of erosion occurring under any condition depends on the effect of the rain and the nature of the soil. Hence some storms can cause more erosion damage than others with the same intensity at different locations.

The erosivity index based on any intensity function has a greater reliability in application than an index based on any other rainfall characteristic. However, the estimation of the rainfall index (R) based on the rainfall intensity records is a laborious procedure. Therefore, in this study, an attempt was made to correlate the amount of the yearly average rainfall to the yearly rainfall index. The average of 15 years rainfall was plotted versus the R – values as shown in Fig 3. A linear regression relationship was established and the two variables were found to be fairly correlated ($r = 0.80$). The relationship has the following form:

$$R = 286.15 + 7.08\,P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where P is the yearly average of the rainfall (mm). This relationship is applicable with a 95% confidence as shown in Fig. 3. Since the annual rainfall is relatively easier to obtain for any station, it is more convenient to estimate R from the above equation.

From Fig. 3, it is clear that the deviation of stations J001, B004 and SA001 from the straight line relationship is quite high. This means that the value of R in these areas is comparatively less dependent on the amount of rainfall. The stations R001, R005 and B002 also deviate considerably and suggest that the R – value in these areas is more dependent on I30 rather than the total amount of rainfall.

Since erosivity is related to rainfall, which indicates that the erosivity index (R) might be related to the average number of rainy days (N) in a year, Fig. 4 was plotted to show the relationship between "R" and "N" at 95% confidence. The following equation was obtained:

$$R = 224.7 + 98.7\,N \quad \ldots [\, r = 0.81 \,] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

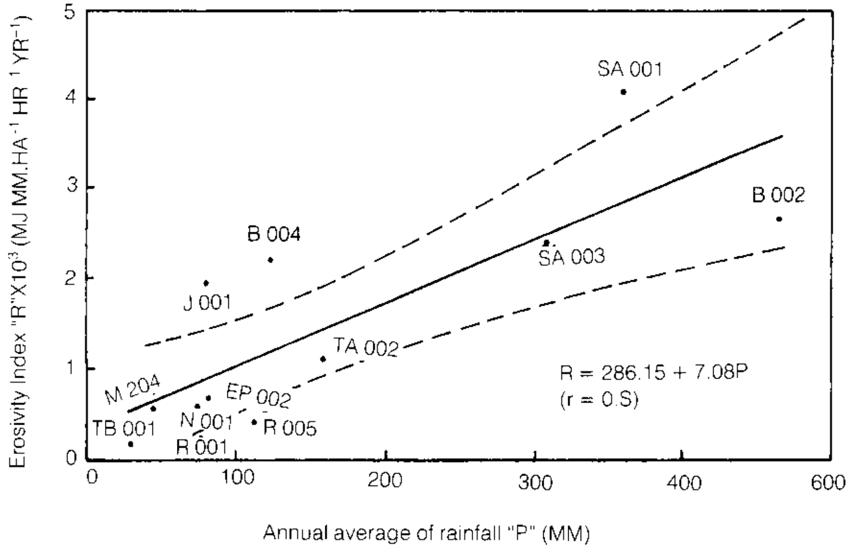

Fig. 3. Relationship between annual erosivity index and annual rainfall for main regions in the Kingdom.

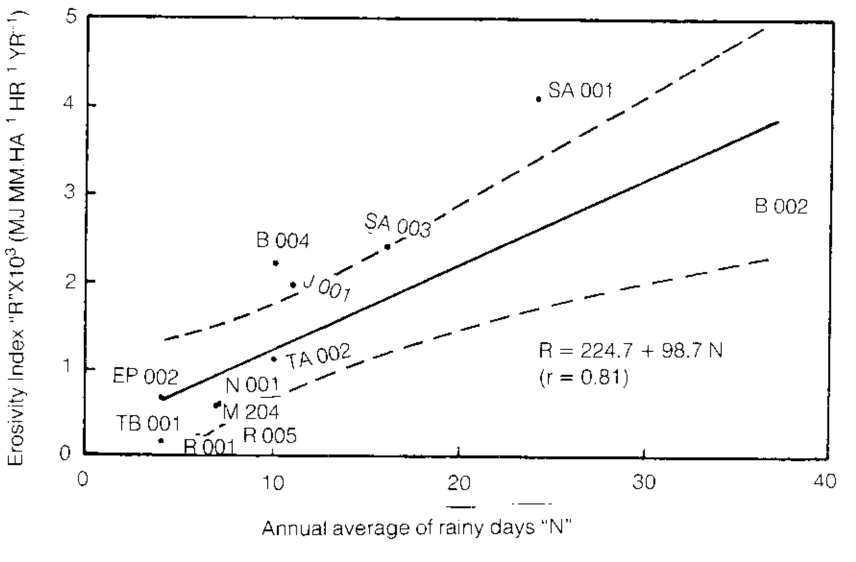

Fig. 4. Relationship between annual erosivity index and number of rainy days in the year.

The high value of R (4081.5 mj mm ha^{-1} hr^{-1} yr^{-1}) at station SA001 was responsible for a decrease in the degree of correlation.

An attempt was also made to correlate elevation to the erosivity index "R". No correlation was found to exist between the two parameters with reasonable accuracy. This finding is in agreement with the conclusion by Cooley, *et al.* [7] who found that the effect of elevation on erosivity index was minor.

R values for the extra 8 stations were calculated and the data collected from the 20 stations were used to produce a contour map of erosivity index for the entire Kingdom, as shown in Fig. 5. The susceptibility of the different regions to erosion, based on R values is also shown in the same figure. The Rub-al-Khali (Empty Quarter) was

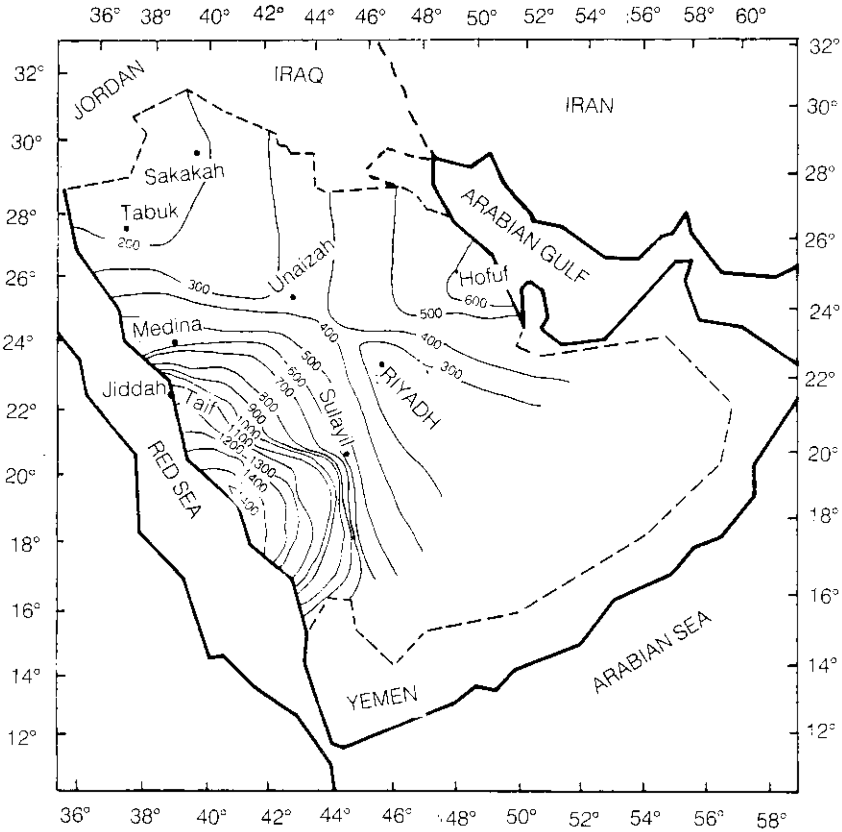

Fig. 5. Contour map of average of the rainfall erosion index.

not considered in producing the map as it receives a very little amount of rainfall. Also, the most effective agent of erosion in this part (mostly desert) is wind and the rainfall is not quite effective. This map will form the basis for predicting annual erosion losses. In future, the map could be modified when more intensive data are available.

Conclusions

The risk of erosion from rainfall exists in some areas of the Kingdom, espeically in the coastal and mountain areas in the west and southwest. The erosive power of the rainfall was found to be high during a certain period of time in Jizan, Madinah, Najran and Bishah areas.

A fairly good correlation exists between the erosivity index and yearly rainfall amount on one hand and number of rainy days on the other during the year.

Further studies are needed to assess the erosion process due to rainfall in all parts of the Kingdom and to modify the contour map of erosivity already produced in this study. It is also suggested that studies be undertaken to obtain the other parameters of the Universal Soil Loss Equation for the Kingdom.

References

[1] Morgan, R.P.C. *Soil Erosion*. London and New York: Longman, 1980.
[2] Wischmeier, W.H. "Punched Card Record Runoff and Soil Loss Data." *Agric. Eng.*, 39 (1955), 458-474.
[3] Wischmeier, W.H., Smith, D.D., and Uhland, R.E. "Evaluation of Factors in the Soil-Loss Equation." *Agric. Eng.*, 39 (1958), 458-474.
[4] Wischmeir, W.H. and Smith, D.D. *Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains. Guide for Selection of Practices for Soil and Water Conservation.*" Washington D.C: USDA Agr. Res. Service Handbook No. 282, 1965.
[5] Wischmeier, W.H. and Smith, D.D. *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*. Washington D.C.: USDA Agric. Res. Service Handbook No. 537, 1978.
[6] Brown, L.C. and Foster, G.R. "Storm Erosivity Using Idealized Intensity Distributions." *Trans. of the ASAE* 30 No. 2 (1987), 379-386.
[7] Cooley, K.R., Hanson, C.L. and Johnson, C.W. "Precipitation Erosivity Index Estimates in Cold Climates." *Trans. of the ASAE* 31 No. 5 (1988), 1445-1450.
[8] Edwards, L.M. and Burney, J.R. "Soil Erosion Losses Under Freeze/Thaw and Winter Ground Cover Using a Laboratory Simulator." *Canadian Agric. Eng.* 29 (1987), 109-115.
[9] Haith, D.A. and Merrill, D.E. "Evaluation of a Daily Rainfall Erosivity Model." *Trans. of the ASAE* 30 No. 1 (1987), 90-93.
[10] Bullock, P.R., Dejong, E., and Kiss, J.J. "An Assessment of Rainfall Erosion Potential in Southern Saskatchewan from Daily Rainfall Records." *Cnadian Agric. Eng.* 32 No. 1 (1990), 17-24.
[11] Richardson, C.W., Foster, G.R., and Wright, D.A. 1983. "Estimation of Erosion Index from Daily Rainfall Amount." *Trans. of the ASAE* 26 (1983), 153-160.

[12] Salehi, F., Pesant, A.R. and Lagace, R. "Validation of the Universal Soil Loss Equation for Three Cropping Systems Under Natural Rainfall in Southern Quebec." *Canadian Agric. Eng.* 33 No. 1 (1991), 11-16.
[13] Wigham, J.M. and Stolte, W.J. "Rainfall and Runoff Factor for Erosion Estimates – Prairie Region." *Canadian Agric. Eng.* 28 (1986), 71-75.
[14] Hudson, N. *Soil Conservation.* London: Batsford Academic and Educational Ltd., 1981.
[15] Foster, G.R., McColl, D.K., Renard, K.G. and Moldenhauer, W.C. "Conversion of Universal Soil Loss Equation to S.I. Metric Units." *J. Soil Water Conservation.* 36 (1981), 355-359.

تقدير مؤشرات التعرية المطرية للمملكة العربية السعودية

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ملخص البحث. تم تقدير مؤشرات التعرية المطرية باستخدام البيانات المطرية اليومية من عشرين محطة أرصاد تمثل أقاليم المملكة العربية السعودية كافة، واستخدمت معادلة وشماير في تقدير الطاقة الحركية ومؤشر التعرية (EI_{30})، وقد تم استنتاج علاقات تدل على قدرة المطر على التعرية، وأظهرت النتائج وجود خطورة احتمال التعرية في بعض الأقاليم، وعلى ضوء نتائج هذه الدراسة وضعت خارطة كنتورية لمعامل التعرية المطرية للاستفادة منها في مشروعات وقاية وحفظ التربة من التعرية.