Rainfall Erosivity in the Republic of Korea

by

Qi Hu, Clark J. Gantzer, Pil-Kyun Jung, and Byong-Lyol Lee

Qi Hu is assistant professor at the School of Natural Resource Sciences, University of Nebraska-Lincoln. Clark J. Gantzer is associate professor in the Department of Soil and Atmospheric Sciences, University of Missouri-Columbia. Pil-Kyun Jung is senior scientist of Soil Science, Rural Development Administration, Suwon, Republic of Korea. Byong-Lyol Lee is senior scientist of Agricultural Climatology, Korea Meteorological Administration, Seoul, Republic of Korea.

Rainfall erosivity (the *R*-factor) is an important factor used in calculation of soil erosion by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and the Revised USLE, or RUSLE (Renard 1997). Wischmeier et al. (1958) showed that the *R*-factor explains about 80% of the variation in soil loss. Its annual and monthly values serve as a main guide for designing soil conservation practices in many countries (Renard et al. 1997; Babu et al.1978; Bollinne et al. 1980; Mikhailova et al. 1997). In this paper, we describe the rainfall erosivity in South Korea.

South Korea has an area of 98,480 km^2 mostly in mountainous terrain. About 20% of the land is suitable for agriculture. Rice *(Oryza sativa)* is the major crop, and is planted on about 90% of the cultivated land annually. The remaining agricultural land is in upland fields and used for production of corn *(Zea mays L)*, soybean *(Glycine max)*, and major vegetables (Figure 1). Cultivation of these upland fields has been intense and is driven by a very high demand for vegetables. The cultivation has caused excessive erosion and ruined productive soils. Erosion from upland areas also damages valley fields by sediment deposition. Soil conservation has become an urgent need.

Jung (1984) calculated the *R*-factor for Korea. However, the short data record used in Jung's study (8-10 years) causes uncertainty in its accuracy and, hence, its usefulness. This problem is highlighted when the variability of regional rainfall is considered. Precipitation often has inter-annual as well as interdecadal time scale variations (Mann and Park 1997; Hu et al. 1998). Thus, *R*-factors calculated using records shorter than the recommended 22-years may misrepresent the regional rainfall erosion effect. We extend Jung's (1984) study to calculate *R*-factors using 22 year (1974-1995) rainfall data in South Korea. We will present the seasonal and annual variation of the *R*-factors, an isoerodent map, and spatial variation of rainfall erosivity in South Korea.

photograph by Clark Gantzer

Figure 1. Alpine uplands in South Korea. The foreground is a sloped field planted with cabbage [*Brassica campestris* L (Pekinensis group)]. Some of the background open fields were planted with red pepper (Family *Solanaceae*), another major vegetable grown in the upland areas.

Data and methodology

Hourly precipitation data from 59 weather stations in South Korea (Figure 2) were obtained from the Korean Meteorological Administration. Data also includes a daily maximum 10 minute rainfall and the time when it occurred. The rainfall data were subject to quality control checks.

The *R*-factor is a long term average of annual product of the cumulative total rainfall energy of storms *(E)* and maximum 30 minute rainfall intensity (I_{30}) in each of the storms, or EI_{30} (Renard et al. 1997). In calculating the *R*-factor, we separated the rain events into two groups: the severe storms and weak events.

For severe storms, the I_{30} was calculated from a fitted 30 minute intense rainfall based on the observed daily maximum 10 minute rainfall. To do this, we identified the 60 minute period in which the daily maximum 10 minute rainfall occurred. We then fit the 60 minute rainfall to a distribution with a peak intensity at the observed maximum 10 minute rainfall time, t_{max10}, and twice the rainfall amount in the two 10 minute intervals adjacent to t_{max10} as that in the other three 10 minute intervals within the 60 minute period. For weak storms, the I_{30} was calculated using a statistical relation with hourly rainfall intensity obtained using 7-year 5-minute rainfall data collected from 51 stations in Korea (Jung 1986): $EI_{30} = 1.26\ EI_{60} + 14.3$. The R^2 of the predicted EI_{30} using this relation is 0.92. Possible errors induced to the *R*-factor by these weak events are small because contribution to the erosion from weak events have been shown to be much less than that from severe storms (Ghidey and Alberts 1996). The calculation was applied to the 59 stations to obtain the *R*-factor values.

Isoerodent map

An isoerodent map for South Korea was constructed (Figure 2) using the calculated *R*-factor of individual stations and an objective analysis method (Barnes 1967).

Both the USLE and the RUSLE were developed for general conditions of the

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Figure 1

United States. Although these conditions may differ in other countries and regions, Yu and Rosewell (1996a; 1996b), Oduro-Afriyie (1997) and Mikhailova et al. (1997), showed that the assumptions are satisfactory under most of the agricultural environment worldwide, particularly soil and climate conditions. Application of the USLE/RUSLE is often constrained by slopes exceeding the assumed 10% maximum slope (Wischmeier and Smith 1978; Renard et al. 1997). Because of mountainous landscape and limited flat lands in Korea, much of the agricultural lands occur in hilly areas with slopes greater than 10% (Jung 1984). Jung (1984) compared lysimeter measurements of soil loss from fallow plots of different slope in Suwon, Korea, with the calculated USLE soil loss. He found that the calculated soil loss for plots of 20% slope were consistent with the *lysimeter data* with differences smaller than 0.5 t ac^{-1}. These results support the applicability of the calculated *R*-factor for Korea's soil conservation needs.

Figure 2 shows the *R*-factor ranges from 150 erosivity units [1 unit = 100 ft tonf in (ac hr yr)$^{-1}$, and is, in standard units, 17 MJ mm (ha h yr)$^{-1}$] for the east coast to 495 erosivity units for the south. The greatest values occur in the southern lowland area and the single highest value is in Namhae, Korea. High *R*-factor values also occur in the southwestern and western parts of the peninsula. The northeastern section and the east coasts of the country have low erosivity. This distribution of the erosivity matches well with the distribution of the country's topography and annual rainfall distribution.

As indicated in Figure 2, the Taebaek Mountains lie parallel to the east coast of the Korean peninsula. Stretching out from the Taebaek Mountains, the Sobak Mountains and associated mountain ranges in the southern part of the peninsula form the major barriers that affect the air flows and hence, rainfall distribution.

The primary rainfall in South Korea occurs during the monsoon season (June to early September). The prevailing wind during the monsoon is southerlies and southwesterlies. The orographic effect of these mountains forces the moist on-shore flows to rise and produce intense rainfall. On the lee side of the Sobak Mountains is a "rain shadow" area with the annual rainfall being only 60% of the rainfall in the western and southern windward mountain slopes. The intense monsoon rainfall in the south and the west sides of these mountain ranges exerts a great force for soil loss in those areas. This is shown by the spatial distribution of the *R*-factor in Figure 2.

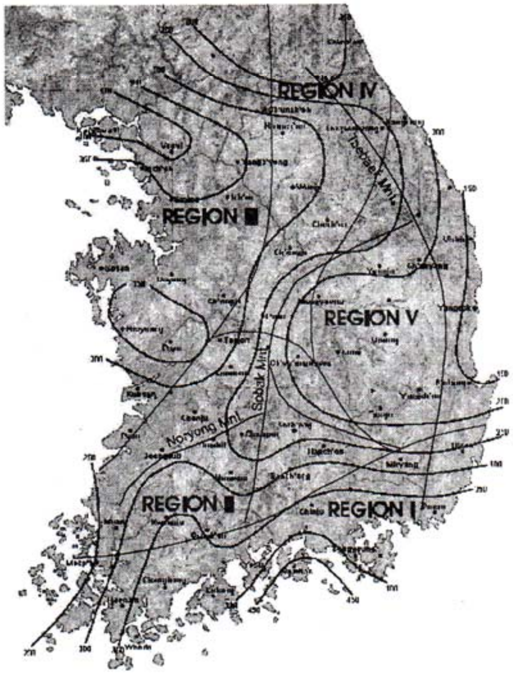


Figure 2. Isoerodent map for South Korea (solid lines). Locations of individual weather stations whose data were used in the calculation are marked by filled circles. The dashed lines in the figure mark the major mountain ranges in South Korea peninsula. The dotted lines define the geographical locations of the five regions with nearly the same *S(t)* variations.

The impact of monsoon climate on soil loss is further demonstrated by the seasonal variation of the *R*-factor (see Table 1). *R*-factors for the summer monsoon are several times larger than values for spring and autumn for the same stations. Winter is normally dry and has little rainfall erosivity.

Annual variation of erosion potential

Annual variation of soil erosivity by rainfall contains important information, in addition to the total annual erosivity (Figure 2), for design of soil conservation practices. Knowledge of this variation for a particular location, for example, can be useful in the selection of vegetable types by the upland field vegetable producers, with different leafing schedules to provide cover to soil surface and reduce rainfall impact.

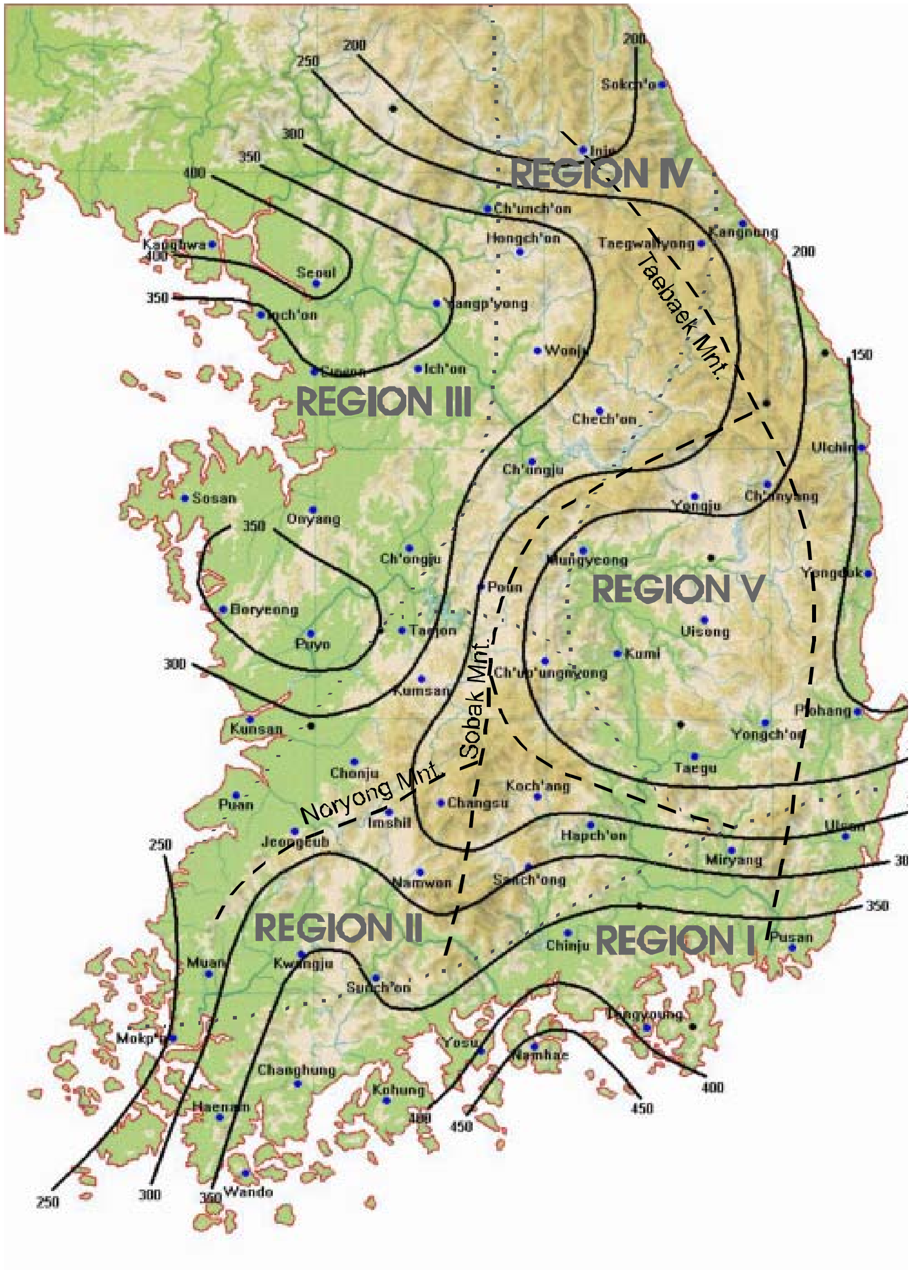
We analyzed the annual variation of erosivity by examining the accumulation of EI_{30} over a year. A general function describing this type of variation has the form of

$$S(t) = \frac{A}{(1 + \alpha e^{-\kappa t})} \qquad (1)$$

where S is the accumulated EI_{30} over time t (in month).

The empirical parameters A, α, and κ in (1) describe characteristics of the variation of erosion in terms of annual amount, length of time period of major erosion in a year, and the intensity of the erosivity in that period, respectively. After evaluating these parameters for the 59 stations and comparing their values, we identified five regions with nearly the

Figure 2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250
200
Sokch'o
300
350
400
Inje
REGION IV
Ch'unch'on
Hongch'on
Taegwallyong
Kangnung
Kanghwa
400
Seoul
200
350
Inch'on
Yangp'yong
Taebaek Mnt.
Wonju
150
Ich'on
REGION III
Chech'on
Ulchin
Ch'ungju
Yongju
Ch'unyang
Sosan
350
Onyang
Ch'ongju
Mungyeong
Poun
REGION V
Yongdok
Boryeong
Taejon
Uisong
Puyo
Sobak Mnt.
Kumi
300
Ch'up'ungnyong
Kumsan
Pohang
Kunsan
Yongch'on
Taegu
Chonju
Noryong Mnt.
Koch'ang
Puan
Changsu
Imshil
Ulsan
Jeongeub
Hapch'on
250
Miryang
30
Namwon
Sanch'ong
350
REGION II
Chinju
REGION I
Pusan
Muan
Kwangju
Sunch'on
Tongyoung
Mokp'o
Yosu
Namhae
Changhung
400
Kohung
450
Haenam
400
450
250
300
350
Wando

Table 1. Seasonal R-factor values for individual stations in Korea.

Station Name	Spring	Summer	Fall	Winter
Sokch'o	17.303	130.726	77.321	0
Taegwallyong	16.991	194.270	68.894	0
Ch'unch'on	17.361	227.588	47.670	0
Kangnung	13.774	144.168	73.380	0
Seoul	25.394	294.290	62.600	0.052
Inch'on	19.355	208.018	61.012	0
Wonju	18.283	252.549	42.962	0
Suwon	17.312	272.264	50.148	0
Sosan	27.059	218.431	51.760	0.020
Ulchin	11.158	83.444	42.918	0.011
Ch'ongju	17.608	223.539	32.046	0.001
Taejon	20.181	268.539	34.917	0
Ch'up'ungnyong	12.765	162.384	17.915	0.044
P'ohang	11.591	114.190	28.961	0.635
Kumsan	19.033	205.600	33.309	0
Taegu	14.333	138.724	24.500	0.551
Chonju	19.891	222.272	35.165	0.004
Ulsan	30.127	176.741	55.181	2.122
Kwangju	31.653	273.074	34.437	0.893
Pusan	67.340	230.782	83.218	3.118
Tongyoung	64.518	189.428	42.231	3.164
Muan	20.823	231.458	10.560	0
Mokp'o	19.971	160.043	51.679	0.214
Yosu	50.177	237.028	57.364	2.341
Wando	43.257	257.749	56.620	0.293
Chinju	51.980	230.265	51.397	0.666
Kanghwa	23.048	324.413	63.157	0
Yangp'yong	25.337	268.550	52.365	0
Ich'on	20.670	239.445	48.866	0
Inje	16.629	144.859	32.789	0.038
Hongch'on	17.226	237.305	52.088	0
Chech'on	19.481	241.816	32.287	0.041
Ch'ungju	18.217	213.001	38.002	0
Poun	19.328	198.127	23.659	0
Onyang	18.734	236.536	36.133	0.019
Boryeong	22.211	288.356	37.782	0
Puyo	23.530	291.987	35.257	0
Kumsan	18.045	208.519	35.565	0.004
Puan	20.139	207.466	38.640	0.031
Imshil	20.752	194.298	34.756	0.002
Jeongeub	21.973	213.808	39.474	0.006
Namwon	24.277	218.612	39.577	0
Changsu	20.191	223.780	35.862	0
Sunch'on	34.726	250.360	37.598	0.141
Changhung	47.723	257.483	64.495	0
Haenam	34.618	220.000	57.298	0.104
Kohung	61.934	232.830	62.395	0.725
Ch'unyang	17.215	187.654	27.403	0
Yongju	22.316	196.972	26.123	0.075
Mungyeong	21.061	154.126	20.362	0.263
Yongdok	11.163	101.329	29.300	0.130
Uisong	11.477	120.622	23.039	0.348
Kumi	9.893	121.780	28.352	0
Yongch'on	14.808	127.058	26.730	0
Koch'ang	16.132	182.525	30.176	0.373
Hapch'on	20.106	213.350	35.547	0.375
Miryang	27.464	183.844	32.357	0.867
Sanch'ong	24.138	264.451	56.108	0.273
Namhae	82.578	308.265	83.088	0.627

Table 2. Parameter values for the five distributions of annual accumulated EI_{30} in Korea.

Categories (Region I)	South (Region II)	Southwest (Region III)	Northwest (Region IV)	North-central (Region V)	East Coast
α(_1000)	1	50	100	110	10
κ	0.8	1.5	1.7	1.6	1.2

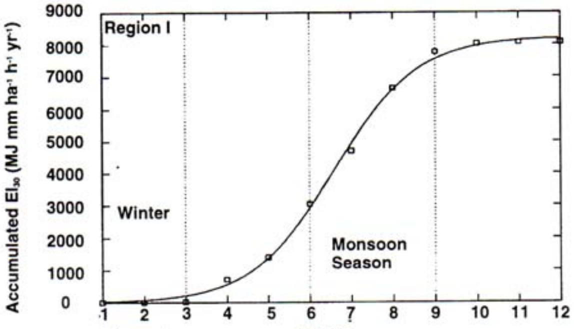

Figure 3a.

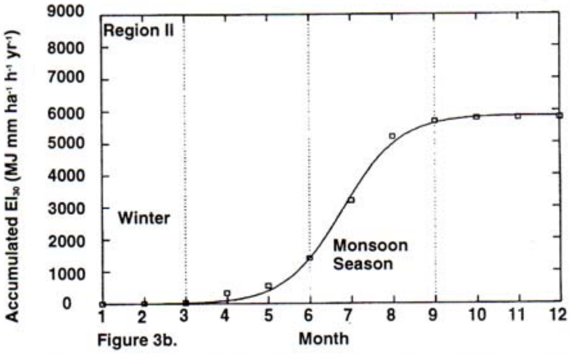

Figure 3b.

Figure 3a-3b. Annual variations of $S(t)$ for the five regions shown in Figure 2.

same values for the parameters as well as $S(t)$ in South Korea. The geographical locations of these five regions are shown in Figure 2 by the dotted lines with the regions printed.

The values of α and κ for Region I through Region V are listed in Table 2. In the following, we discuss the details of the annual variations of accumulated EI_{30} in each of these regions.

Figure 3a shows the $S(t)$ for Namhae, Korea, representing the S for Region I. It shows an increase of S over a broad time period from early spring to late fall. The accumulated value reached about 490 units at the end of the year. The variation is described by small values of κ ($0.5 \le 6 \le 1.0$) and α (α~1.0), and a large value of A in (1). They indicate that erosivity in the southern portion of Korea occurs during the entire year, except for the winter months of December and January. Most erosivity develops in the area from May through September and is severe during the monsoon season. This is consistent with the precipitation distribution for that region where storms result from topographic lift of moist air from the ocean most of the year, with the most intense storms in the summer monsoon season.

In Region II (Figure 3b, Kwangju), north of Region I, the $S(t)$ shows a rapid increase during summer months. Rainfall erosivity in spring season is much smaller than that in Region I. There is little erosivity during the other two seasons of the year. Region III has a similar annual variation of erosivity as that for Region II except for a more rapid increase of the erosivity in the summer months. An example of this variation is shown in Figure 3c for Suwon. Significant erosivity is concentrated from late June to early September in synchronous with the distinct monsoon rainfall development for that region. Heavy rainstorms from the monsoon system in the summer months create a great potential for soil loss. The relatively short time period and steep climing features of the accumulation curves in these two panels are described by large values of α and κ in Table 2.

Figure 3d shows the annual variation for Chechon, representing the erosivity variation in Region IV in the inland mountainous area of South Korea. The variation exhibits smaller increase of the erosivity in warm season months. Erosivity also plateaus earlier than that in Regions I, II, and III, as a result of a short monsoon season in the mountainous regions of central South Korea. The decrease of rainfall in the central mountainous region occurs when monsoon retreats south while the coastal precipitation events remain active during the retreat process.

Figure 3e describes the $S(t)$ variation along the coastal area east of the Sobak Mountains. While erosivity is present for many months beginning late April through early October, it is quite small due to the nature of stratiform rainfall in this region generated from moist easterly on-shore flows. These on-shore flows are often suppressed, however, by the prevailing westerly and southwesterly winds. The dry air in westerly flows after condensation in the windward side of the major mountains in the west and south of the region produces little threat to soil loss. Figure 3e has a similar width as that in Figure 3a, as a result of the presence of precipitation events in the coastal regions most of the time during a year, even though the intensity is very weak.

Discussion

The isoerodent map for Korea derived from the R-factors of individual stations shows that the erosion potential for the Korean peninsula varies from 150 units at the east coast to about 500 units in the

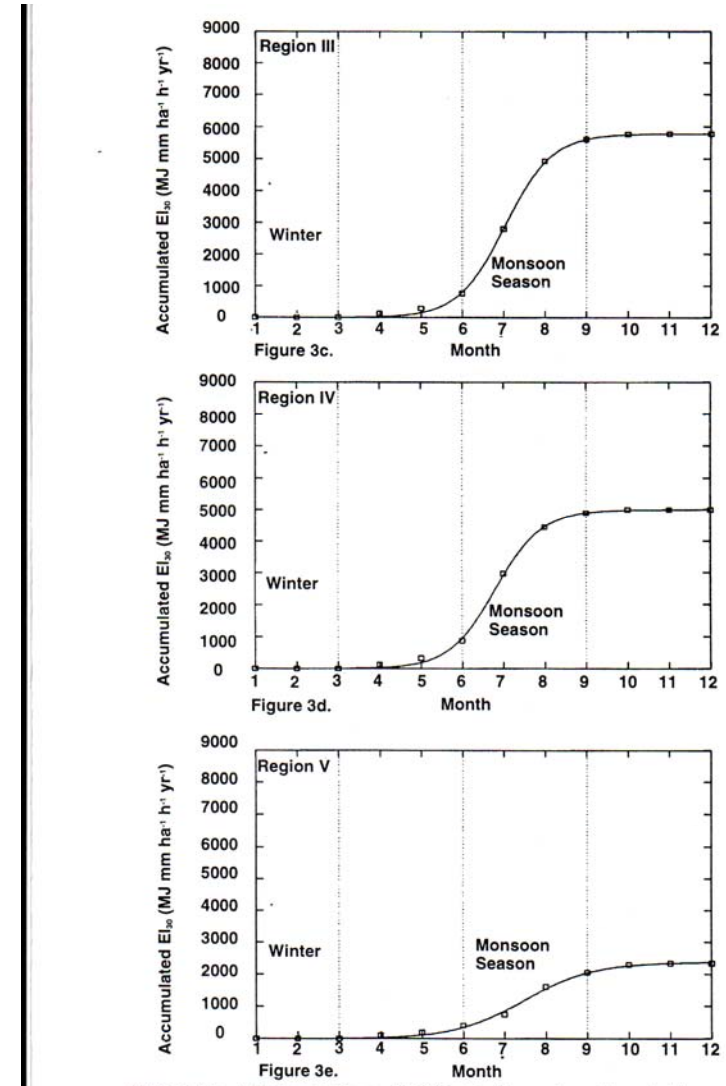

Figure 3c-3e. Annual variations of *S (t)* for the five regions shown in Figure 2.

southern lowlands. The characteristics of the spatial distribution of erosivity are shaped by the primary north-south orientation of the major mountain ranges and related spatial distribution of rainfall. Large erosivity is strongly affected by the intense monsoon rainfall developed in the southerly and southwesterly winds during the annual precipitation cycle in the region. The rain-shadow effect of the major mountains in the peninsula spares the east coast region of South Korea from severe rainfall erosion.

The *R*-factor calculated in this study has a smaller value to that reported by Jung (1984) for the southern coastal region and in an area centered at Seoul, although the spatial distribution of both results are similar. This difference between the two studies is probably a result of the smaller sample size and the shorter period for the previous study (Jung 1984) because the average time period used in the previous calculations was 10 years compared to 22 years of records in this study.

Differences resulting from changes in sampling period and sample size suggest that the variability of erosivity is time sensitive. To explore this idea, we show an example (Figure 4) of the variation of the *R*-factor for 36 seperate 22 year periods from 1941 through 1997 for the McCredie Claypan Research Station at Kingdom City, Missouri. The *R*-factor at a particular year was calculated using 22 years of data ending in that year. The increase of the *R*-factor since 1970 is a consequence of increasing precipitation amount and frequency of intense storms in the area (Hu et al. 1998). The temporal variation of erosivity shown in Figure 4 indicates a need to revise isoerodent maps on a periodic basis to reflect the climate variations. A revised isoerodent map may be more relevant than a constant isoerodent map for conservation planing if an area exhibits periodic or long term trend changes over time. This matter invites further exploration.

Summary

In this study, we calculated the annual variation of accumulated EI_{30} for 59 stations in Korea. Accurate knowledge of the *R*-factor and erosivity distribution within a year is essential to planning and implementing conservation practices in upland fields and alpine areas. Recent research has found that soil erosion on steeply sloping land in alpine areas can be as high as 66 t ha^{-1} during the summer (Rural Development Administration 1995). Using the newly computed *R*-factors and the annual variations of rainfall erosivity, Korean soil conservationists can develop economical land use and treatment combinations for upland agriculture. In particular, with the site specific *R*-factor and annual erosivity variation, they can identify the minimum combination of plant cover required, and necessary additional support practices, if any, to reduce erosion to tolerable levels for specific soils and locations. In the meantime, with the knowledge of the spatial variations of these quantities they can identify the areas of most critical need for development of practical strategies to conserve the limited soil resource.

Our analysis revealed five regions in

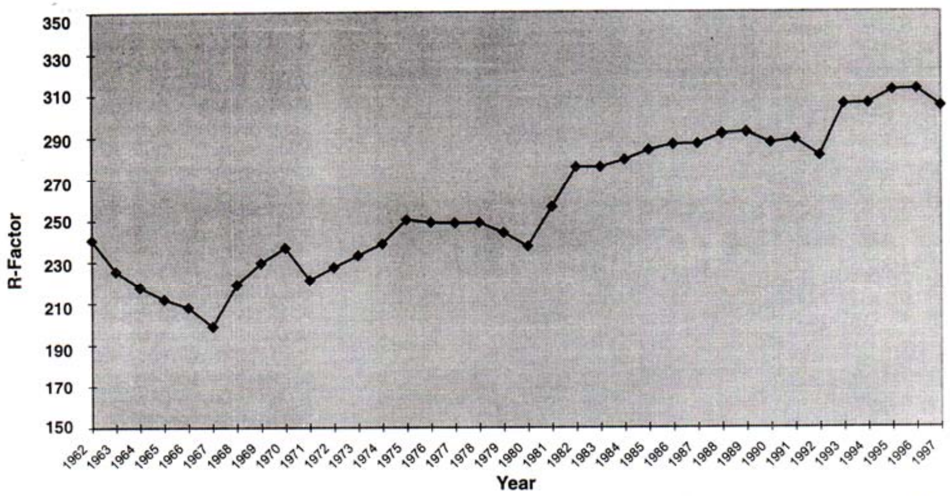

Figure 4. Temporal variations of the *R*-factor calculated for McCredie Erosion Station at Kingdom City, Missouri. The abscissa is time in years and the ordinate is *R*-factor values in erosion unit.

Korea with similar variation characteristics of annual accumulation of EI_{30}. The corresponding geographical locations are in the southern (Region I), the southwestern (Region II), the northwestern (Region III), the central and northeastern areas (Region IV), and the east coast (Region V) regions. The distribution functions of the accumulated EI_{30} for each of these regions were characterized. Large differences among these regions occur during summer. These range from 26% on the east coast (Region V) to 100% in the northwest region (Region III) of the total annual values for those regions. This result clearly shows that more intensive cover management and support practices are needed in those areas with high erosivity during monsoon season (Regions I, II, and III). Additionally, this information can serve as a basis for the development and implementation of new erosion models such as the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing 1995). Indeed, Korean researchers are now working on implementing WEPP through the internet for computer assisted soil erosion prediction technology. The *R*-factor, the annual variation of accumulated EI_{30}, and their spatial variations will be useful for this purpose. Currently, these results are being digitized for dissemination to the producers in South Korea through the Internet service at the Korea Rural Development Administration in Suwon, Korea.

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References

Babu, R., K.G. Tejwani, M.C. Agarwal, and L.S. Bhushan. 1978. Distribution of erosion index and iso-erodent map of India. Indian Journal of Soil Conservation 6 (1):1-12.

Bollinne, A., A. Laurant, P. Rosseau, J.M. Pauwels, D. Gabriels, and J. Aelterman. 1980. Provisional rain erosivity map of Belgium. Pp 111-120. In: M. DeBoodt and D. Gabriels (eds.) Assessment of erosion. Chichester: John Wiley & Sons.

Flanagan, D. C., and M. A. Nearing (eds.). 1995. USDA-Water Erosion Prediction Project: Hillslope profile and watershed model documentation. U.S. Department of Agriculture-ARS National Soil Erosion Research Laboratory, West Lafayette, IN. NSERL Report No. 10.

Ghidey, F., and E.E. Alberts. 1996. Comparison of measured and WEPP predisted runoff and soil loss for Midwest Claypan Soil. Transactions of the ASAE 39:1395-1402.

Hu, Q., C.M. Woodruff, and S.E. Mudrick. 1998. Interdecadal variations of annual precipitation in the central United States. American Meteorlogical Society Bull. No. 79:221-229.

Jung, P.K. June 1984. Rainfall factor and its relationship to soil loss. Pp 43-58 in the proceedings of the Sino-Korea Bilateral Symposium on Soil And Water Conservation on Sloped Farm Land. Taipei, Taiwan.

Mann, M.E., and J. Park. 1997. Global-scale modes of surface temperature variability on interannual to century timescales. Journal of Geophysic Research 99:25819-25833.

Mikhailova, E.A., R.B. Bryant, S.J. Schwager, and S.D. Smith. 1997. Predicting rainfall erosion in Honduras. Soil Science Society of America Journal 61:273-279.

Oduro-Afriyie, K. 1996. Rainfall erosion map for Ghana. Geoderma. 74:161-166.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture: Agricultural Research Service, Washington, D.C.

Rural Development Administration. 1996. Annual Research Report. Pp 441-707. Rural Development Administration: Ministry of Agriculture, Forestry, and Fisheries, Republic of Korea, Suwon, Korea.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses. United States Department of Agriculture Handbook No. 537.

Yu, B., and C.J. Rosewell. 1996a. Rainfall erosion estimation using daily rainfall amounts for South Australia. Australian Journal of Soil Research 34:721-733.

Yu, B., and C.J. Rosewell. 1996b. An assessment of a daily rainfall erosion model for New South Wales. Australian Journal of Soil Research 34:139-152.