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Predicting Rainfall Erosivity in Honduras

E. A. Mikhailova,* R. B. Bryant, S. J. Schwager, and S. D. Smith

ABSTRACT

Iso-erodent maps can be used in soil conservation planning to identify regions with high rainfall erosive potential. This study was conducted to determine the significance of elevation in predicting the rainfall erosivity index (*R*) in addition to the average annual precipitation and to develop an iso-erodent map for Honduras. With previously calculated *R*-factor values for eight climatic stations in Honduras, a regression relationship was established for estimating the rainfall erosivity index as a function of average annual precipitation and elevation with R^2 of 0.972. This regression model was used to estimate the rainfall erosivity index for each of the 344 Honduran climatic stations without calculated rainfall erosivity indices. Due to the limited number of data points and their geographic clustering, the best estimates of mean rainfall erosivity indices were for stations with average annual precipitation in the range from 831 to 1313 mm and elevation between 360 and 1080 m. A provisional iso-erodent map of Honduras at a scale 1:1 000 000 was compiled in Arc/Info format, using a basemap obtained from the digital chart of the world. Iso-lines for the 95% prediction intervals for new rainfall erosivity indices are displayed on the map to show the accuracy of the new estimates. Elevation was found to be highly significant in predicting the rainfall erosivity in addition to the average annual precipitation. Data from Costa Rica, Sri Lanka, and the southeastern USA supported this finding.

Climatic erosivity is defined (Lal, 1990) as the aggressiveness of the climate (rain, wind, snow) in causing erosion. The rainfall erosivity factor (*R*), or *R*-factor, in the USLE and RUSLE models (Wischmeier and Smith, 1965, 1978; Renard et al., 1996) is an index of rainfall erosivity. The methods used to calculate the *R*-factor are described by Wischmeier and Smith (1978) and in the RUSLE user guide (Renard et al., 1996).

The rainfall erosivity factor was the focus of this study because it can provide useful information independent of the USLE–RUSLE model. Iso-erodent maps produced on the basis of this factor can be used to identify regions with high potential rainfall erosivity. The *R*-factor values can be readily calculated for locations where hourly rainfall intensities are known (Wischmeier and Smith, 1978). However, calculation of the *R*-factor values for new locations is laborious and requires long-term rainfall intensity data. Such information for Honduras was limited. Alternatively, rainfall erosivity has been estimated from average annual precipitation data (Renard and Freimund, 1994). Bollinne et al. (1980) developed a provisional iso-erodent map for Belgium; precipitation was utilized to estimate *R* by simple linear regression using three observations ($R^2 = 0.98$). An iso-erodent map of India (Babu et al., 1978) was based on average annual and seasonal precipitation for 44 climatic stations ($R^2 = 0.69$). Studies in Costa Rica and Sri Lanka (Vahrson, 1990; Joshua, 1977) suggested an inverse relationship between rainfall erosivity and elevation, but these studies did not incorporate elevation as a secondary regression variable.

Honduras lies within the tropics between 12°58′N and 16°02′N and extends from 83°10′W to 89°22′W. The total area of the country is 112 088 km^2 and it is the second largest country in Central America (Portillo, 1984). Most of the country is mountainous and therefore it is important to examine the significance of elevation in estimating the potential of rainfall erosivity (Perfil Ambiental de Honduras, 1989).

The objectives of this study were to collect from numerous sources the basic climatic data for weather stations in Honduras, to use this information to derive a statistical model to estimate *R*-factor values, and to produce an iso-erodent map for the country.

MATERIALS AND METHODS

Previously existing calculated erosivity indices for eight climatic stations in the El Cajón watershed and the mean annual precipitation and elevation of these stations are presented in Table 1. The eight stations with calculated *R*-factor values are located in the El Cajón watershed area, which represents ≈8% of the national territory of Honduras (Zavgorodnaya de Costales, 1990). Since the iso-erodent map of Honduras is based on only these eight calculated *R*-factor values, it should be viewed as a preliminary study. Each erosivity index presented in Table 1 is an average value during a 15- to 16-yr period. The rainfall energy per unit depth of rainfall (e_r), a component used in calculating the *R*-factor value, was estimated using the relationship (Foster et al., 1981)

$$\begin{aligned} e_r &= 0.119 + 0.0873\log_{10}(i_r) \qquad i_r \le 76\ \text{mm h}^{-1} \\ e_r &= 0.283 \qquad i_r > 76\ \text{mm h}^{-1} \end{aligned} \qquad [1]$$

where e_r = kinetic energy (MJ ha^{-1} mm^{-1} of rainfall); i_r = intensity of rainfall (mm h^{-1}).

Equation [1] was calibrated for the climatic conditions of the USA. The validity of using the rainfall erosivity index (*R*), which is based on Eq. [1] as a predictor of rainfall erosive power in Honduras, has not been verified by field studies. The expense of setting up and maintaining field equipment is one major reason why this has not been done in the framework of this study. The rainfall energy for the *R*-factor estimates (Zavgorodnaya de Costales, 1990) used in this study were calculated from Eq. [1], which is not the most current method for estimating rainfall energy. Equation [1] has recently been replaced by another relation (Brown and Foster, 1987):

$$e_r = 0.29[1 - 0.72\exp(-0.05 i_r)] \qquad [2]$$

where e_r = kinetic energy (MJ ha^{-1} mm^{-1} of rainfall); i_r = intensity of rainfall (mm h^{-1}).

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Abbreviations: USLE, universal soil loss equation; RUSLE, revised universal soil loss equation; GIS, geographic information systems.

Table 1. Calculated rainfall erosivity index *R* for eight climatic stations in the El Cajón watershed area (Zavgorodnaya de Costales, 1990; Bonilla, 1991).

Station	Latitude north	Longitude west	Mean annual rainfall	Elevation	*R*-factor SI units
	° ′ ″	° ′ ″	mm	m	MJ mm ha^{-1} h^{-1} yr^{-1}
1. Playitas	14 25 25	87 42 06	890	595	4035†
2. La Ermita	14 28 00	87 04 05	928	760	3934‡
3. Victoria	14 56 07	87 23 22	1313	360	7297†
4. Santa Clara	14 26 38	87 17 00	1272	740	6114†
5. Agua Caliente	14 40 39	87 17 25	1261	560	6995‡
6. Flores	14 17 30	87 34 06	831	620	2980†
7. El Coyolar	14 19 00	87 30 39	862	800	3385‡
8. Siguatepeque	14 34 53	87 50 25	1154	1080	4248‡

† Average of 15 yr.
‡ Average of 16 yr.

Equation [2] is a better estimator of rainfall energy than Eq. [1] because it is based on more data than the relationship in Eq. [1] (Brown and Foster, 1987). Even though Eq. [1] was used in Honduras to estimate rainfall energy, comparison of the two relations (Eq. [1] and [2]) in the USA resulted in a difference of <1% in the EI (storm erosivity index) of sample storms (Renard et al., 1996). It was impossible to recalculate the rainfall energy per unit depth of rainfall using Eq. [2] for the eight stations used in this study, because the daily rainfall records were not available. However, such recalculation could increase the accuracy of this study.

A modification of the general procedure for developing a rainfall erosivity map as discussed by Renard and Freimund (1994) was used in this study; it is outlined in the following steps: (i) Calculated *R*-factor values for climatic stations were obtained wherever possible from existing studies; (ii) A linear regression relationship was developed between the calculated *R*-factor values and the average annual precipitation and elevation values for these climatic stations; (iii) A validation analysis was conducted to examine the significance of elevation as a second predictor variable using larger data sets from different geographic regions; (iv) The developed relationship was used to estimate *R*-factor values for 344 climatic stations without calculated *R*-factor values; (v) Estimated and calculated *R*-factor values were plotted on a map, and iso-lines (iso-erodents) were drawn connecting points with equal *R*-factor values. Space between iso-erodents was coded according to the range of the predicted *R*-factor values. The *R*-factor values for sites between iso-erodents may be predicted by linear interpolation.

The climatic data used in this study were obtained from various sources: articles, theses, and climatic reports as well as Honduran institutions, such as Empresa Nacional de Energía Eléctrica (ENEE), Departamento de Servicios Hidrológicos y Climatológicos de Honduras (DSHC), Servicio Meteorologico Nacional de Honduras (SMN), Servicio Nacional de Acueductos y Alcantarillas (SANAA), and many other agencies and institutions [see Mikhailova (1995a,b) for a complete compilation of climatic data and a reference list of data sources]. Frequently, values of geographic coordinates and elevation for the same climatic station have varied from one source to another. The most recent available climatic data and geographic coordinates have been selected for this study. All statistical calculations in this study were performed using the Minitab statistical software program (Minitab, Inc., State College, PA; Ryan and Joiner, 1994). Note for further investigations that use of different computer regression packages may lead to slightly different numerical results, because of the numerical accuracy of the calculations (Neter et al., 1990, p. 262).

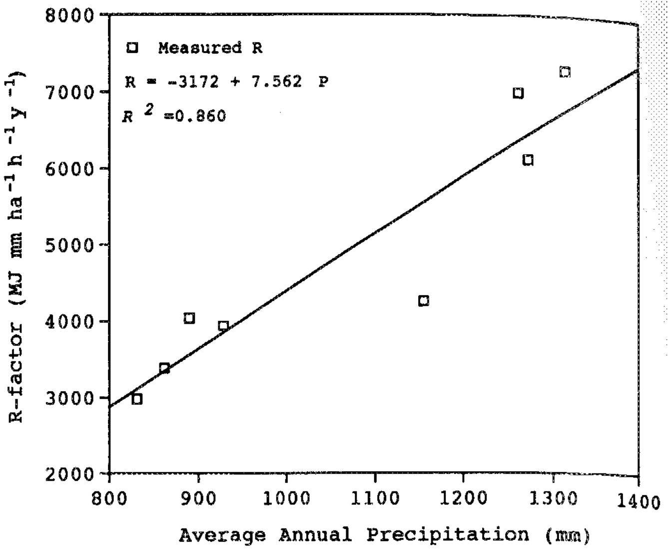

Fig. 1. The relationship between calculated *R*-factor (*R* = rainfall erosivity index) and average annual precipitation (*P*) at eight climatic stations in Honduras.

The regression approach for estimating *R*-factor values was used in conjunction with GIS to compile the iso-erodent map of Honduras. The USLE and the RUSLE have been interfaced with GIS in earlier studies (Spanner et al., 1982; Blaszczynski, 1992). There is unknown error introduced by the interpolation in the GIS routines used to generate the various data layers and by the overlaying of data layers with different spatial resolutions.

The basemap of Honduras used in this study is a 1:1 000 000-scale vector basemap obtained from the digital chart of the world, a comprehensive GIS database for use with Arc/Info and ArcView software (Environmental Systems Research Institute, Redlands, CA; Environmental Systems Research Institute, 1993).

RESULTS AND DISCUSSION

Predicting Rainfall Erosivity from Average Annual Precipitation and Elevation

Inspection and statistical analysis of the data in Table 1 showed a positive linear relationship between rainfall erosivity index and average annual precipitation and a negative linear relationship between rainfall erosivity and elevation (Fig. 1 and 2, respectively).

A linear regression relationship was established estimating the rainfall erosivity index (*R*) from the average annual precipitation and elevation:

$$R_i = -699.3 + 7.0001\,P_i - 2.7190\,E_i \qquad [3]$$

where i denotes location $i = 1, 2, 3 \ldots n$, at which R_i = point estimate of *R*-factor value; P_i = average annual precipitation in mm; E_i = elevation in meters.

The coefficient of multiple determination (R^2) for this regression equation is 0.972 ($P = 0.000$). Elevation was statistically significant, with a partial t-value of -4.46 ($P = 0.007$). This data set did not have any multicollinearity problems (Neter et al., 1990, p. 295), as indicated by the tolerance value of 0.959. Statistical diagnostics

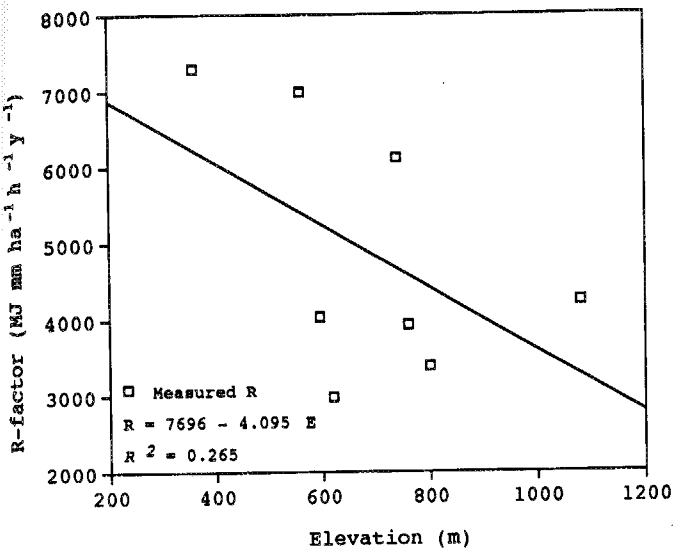

Fig. 2. The relationship between calculated *R*-factor (*R* = rainfall erosivity index) and elevation (*E*) at eight climatic stations in Honduras.

did not reveal any deviations from the assumptions of the multiple regression model.

To the authors' knowledge, elevation has not been used previously for predicting the rainfall erosivity index. Studies in Costa Rica and Sri Lanka (Vahrson, 1990; Joshua, 1977) suggested an inverse relationship between rainfall erosivity and elevation. To examine the significance of elevation in estimating the rainfall erosivity index for other geographic areas, published data sets for Costa Rica (Vahrson, 1990; Instituto Meteorologico Nacional de Costa Rica, 1988), Sri Lanka (Joshua, 1977; Domroes and Ranatunge, 1993), and selected states from the southeastern USA (United States Department of Agriculture, 1992) were analyzed statistically.

Table 2 presents the summary of predictive equations for the *R*-factor values for Honduras, Costa Rica, Sri Lanka, and the southeastern USA. In all four cases, there is an inverse relationship between rainfall erosivity index (*R*) and elevation, and the coefficient of multiple determination of each multiple regression model increased significantly when elevation was incorporated as a second predictor variable, after average annual precipitation.

A possible explanation for the inverse relationship between *R*-factor and elevation is as follows. The *R*-factor is calculated from the kinetic energy of individual rainstorms. The kinetic energy of an individual storm is dependent on rainfall intensity, which is influenced by the median raindrop size and the terminal velocity of the free-falling raindrops. The median raindrop size generally increases with greater rain intensity (Wischmeier and Smith, 1958) and the terminal velocities of free-falling water-drops increase with larger drop size (Gunn and Kinzer, 1949). According to Beard (1985), the altitude factor for adjusting raindrop velocities from sea level depends primarily on air density and drop size. Air density decreases by ≈7% for every 1000 m (3280 ft) of elevation, so the kinetic energy of falling raindrops should be greater at 1000 m elevation than at sea level (McIsaac, 1990). Conversely, at greater heights there are more small drops and very few large drops, because of the absence of pronounced accretion (Caton, 1966). Also, there is less raindrop coalescence at higher elevations because of decreased distance between the clouds and the ground. Therefore at higher elevations, the low concentration of large drops formed by accretion and coalescence causes a decrease in raindrop mass, which could overcome the influence of decreased air density on velocity and consequently could result in a net decrease in the kinetic energy. This suggested hypothesis has not been investigated by field studies.

Developing the Iso-Erodent Map

Climatic stations of Honduras were plotted on the basemap of Honduras (Fig. 3, Data Layer 1) according

Table 2. Summary of predictive equations for Honduras, Costa Rica, Sri Lanka, and Southeastern USA.

Equation†	*n*	df‡	MSE	R^2§	*P* value
			Honduras		
$R = -3172.0 + 7.5620\,P$	8	6	460 371	0.860	0.001
$R = 7696.0 - 4.0950\,E$	8	6	2 411 857	0.265	0.192
$R = -699.3 + 7.0001\,P - 2.7190\,E$	8	5	110 808	0.972	0.000
			Costa Rica		
$R = 2110.1 + 1.4743\,P$	111	109	6 841 829	0.330	0.000
$R = 8449.9 - 1.8263\,E$	111	109	7 729 583	0.243	0.000
$R = 3786.6 + 1.5679\,P - 1.9809\,E$	111	108	3 979 794	0.614	0.000
			Sri Lanka		
$R = -727.0 + 3.7711\,P$	8	6	2 081 153	0.857	0.001
$R = 6063.0 - 3.9850\,E$	8	6	13 602 653	0.067	0.535
$R = -344.1 + 3.8473\,P - 4.8460\,E$	8	5	764 276	0.956	0.000
			Southeastern USA		
$R = -9100.0 + 11.8500\,P$	24	22	3 346 952	0.497	0.000
$R = 6891.0 - 2.8793\,E$	24	22	4 457 593	0.330	0.003
$R = -5704.0 + 9.7580\,P - 1.9475\,E$	24	21	2 562 077	0.632	0.000

† *R* = *R*-factor estimate in SI units (*R* = rainfall erosivity index): MJ mm ha^{-1} h^{-1} yr^{-1}; *P* = average annual precipitation in mm; *E* = elevation in m.
‡ Degrees of freedom (df) associated with Mean Square Error (MSE).
§ Coefficient of (multiple) determination.

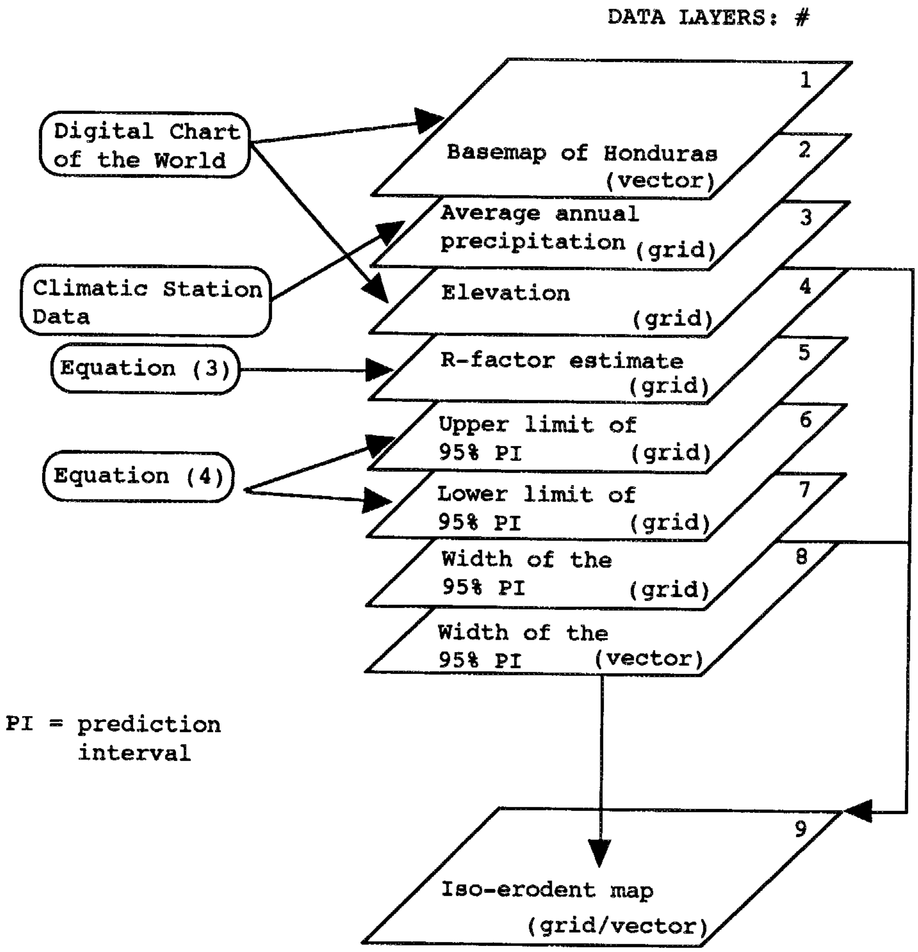

Fig. 3. Schematic representation of the approach used to produce provisional iso-erodent map of Honduras (R = rainfall erosivity index).

to their geographic coordinates. To create the average annual precipitation data layer of Honduras (Fig. 3, Data Layer 2), an inverse distance weighted interpolation routine within the GIS (Arc/Info, Version 6.1.2) was used to interpolate between 352 station points and assign an average annual precipitation value to each 10 by 10 km grid cell on the map. The elevation data layer (Fig. 3, Data Layer 3) was obtained from the digital chart of the world (Environmental Systems Research Institute, 1993). A data layer of the estimated R-factor value for each grid cell (Fig. 3, Data Layer 4) was generated using Eq. [3] with inputs from the average annual precipitation data layer and the elevation data layer.

A 95% prediction interval for the R-factor value at every location can be found in GIS from the general prediction interval formula (Neter et al., 1990, p. 246). The estimated variance matrix of the regression coefficient estimates is used to obtain the 95% prediction interval at each new location, given by

$$R_i \pm 2.571 \begin{bmatrix} 85\ 5014 - 935.847P_i - 674.647E_i + \\ 0.390148\, P_i^2 + 0.370995\, E_i^2 + \\ 0.153343\, P_iE_i \end{bmatrix}^{1/2} \qquad [4]$$

where i denotes location $i = 1, 2, 3 \ldots n$, at which R_i = point estimate of R-factor value (Eq. [3]); P_i = average annual precipitation in mm; E_i = elevation in meters.

Expressing the R-factor point estimate and 95% prediction interval in this algebraic form allows the estimation of the R-factor value and corresponding 95% prediction interval for each 10 by 10 km grid cell in the GIS interface. Using Eq. [4], separate data layers were generated containing the upper (Fig. 3, Data Layer 5) and lower (Fig. 3, Data Layer 6) prediction limits for the R-factor estimate for each grid cell. The lower prediction limit values were then subtracted from the upper values to obtain a third data layer containing the 95% prediction interval width for the R-factor estimate for each grid cell (Fig. 3, Data Layer 7). These values were used to produce contour lines representing the width of the 95% prediction interval of the new R-factor estimates (Fig. 3, Data Layer 8). These contour lines were then added to the iso-erodent map of Honduras.

Provisional Iso-Erodent Map of Honduras

The iso-erodent map of Honduras is presented in Fig. 4. The most accurate R-factor estimates are obtained for the stations whose average annual precipitation and elevation values fall in the joint region outlined by the

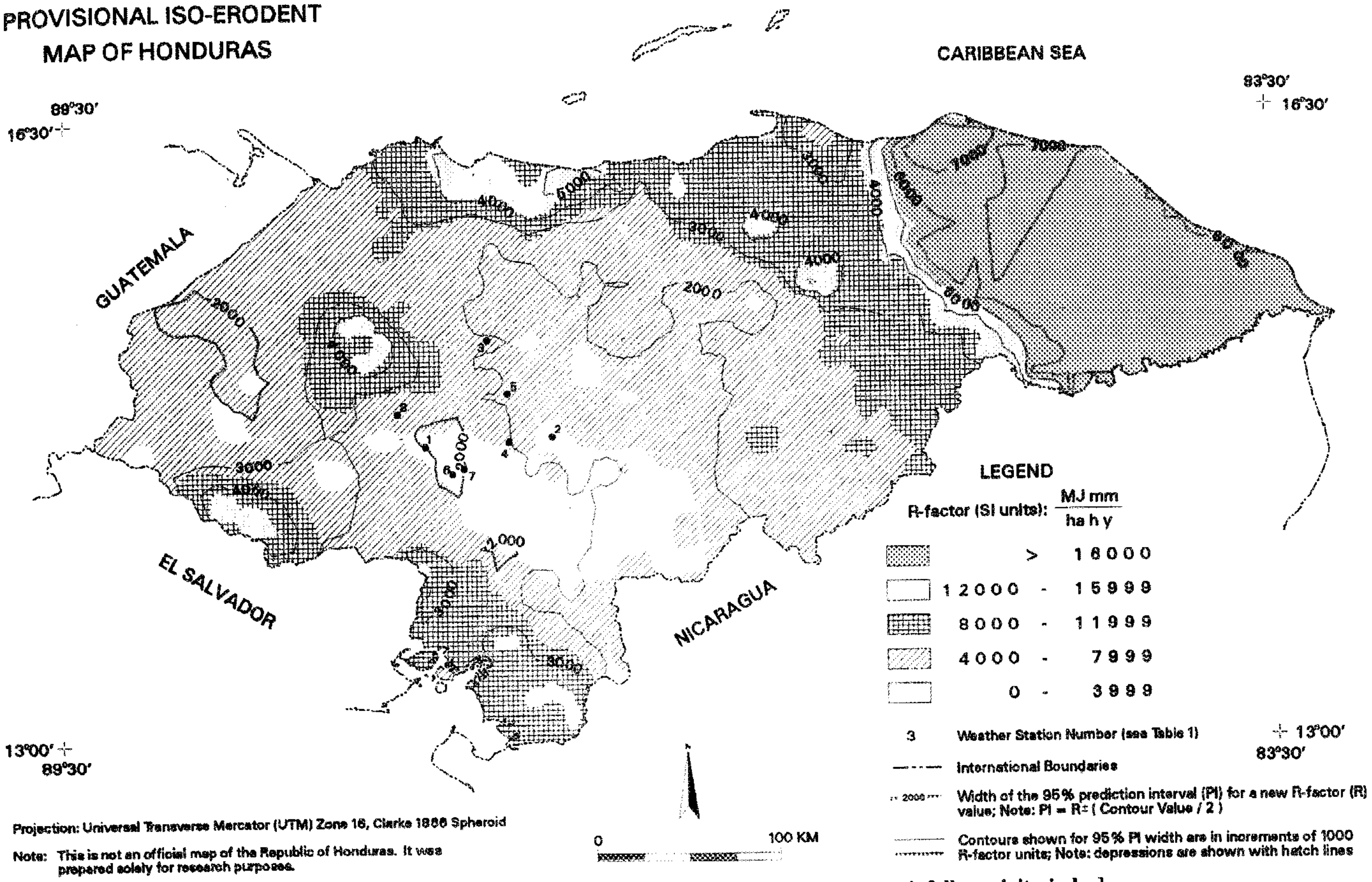

Fig. 4. Provisional iso-erodent map of Honduras [modified from Mikhailova (1995a,b); R = rainfall erosivity index].

circle in Fig. 5. Because regression Eq. [3] is obtained from observations all lying within this circle, extrapolation is required for observations far outside this circle. Therefore, regression Eq. [3] may not be appropriate for estimating R-factor values for stations whose average annual precipitation falls far outside the range of 831 to 1313 mm or whose elevation falls far outside the range of 360 to 1080 m. Most of the stations located in the coastal areas of Honduras are outside of these ranges of average annual precipitation and elevation. Furthermore,

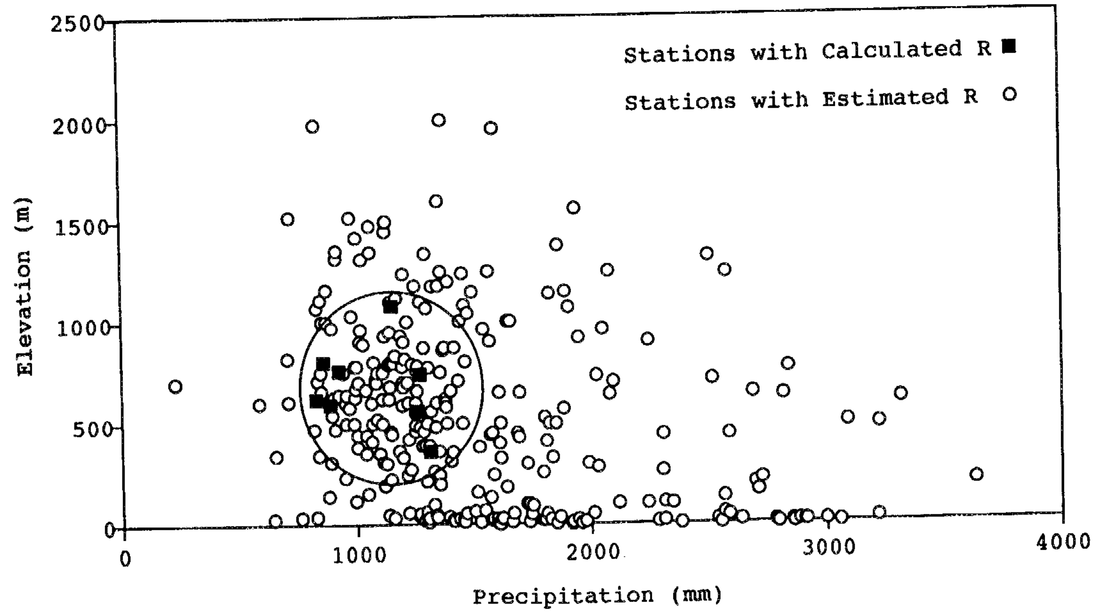

Fig. 5. Plot of elevation against average annual precipitation for stations with calculated and estimated R-factor values (R = rainfall erosivity index).

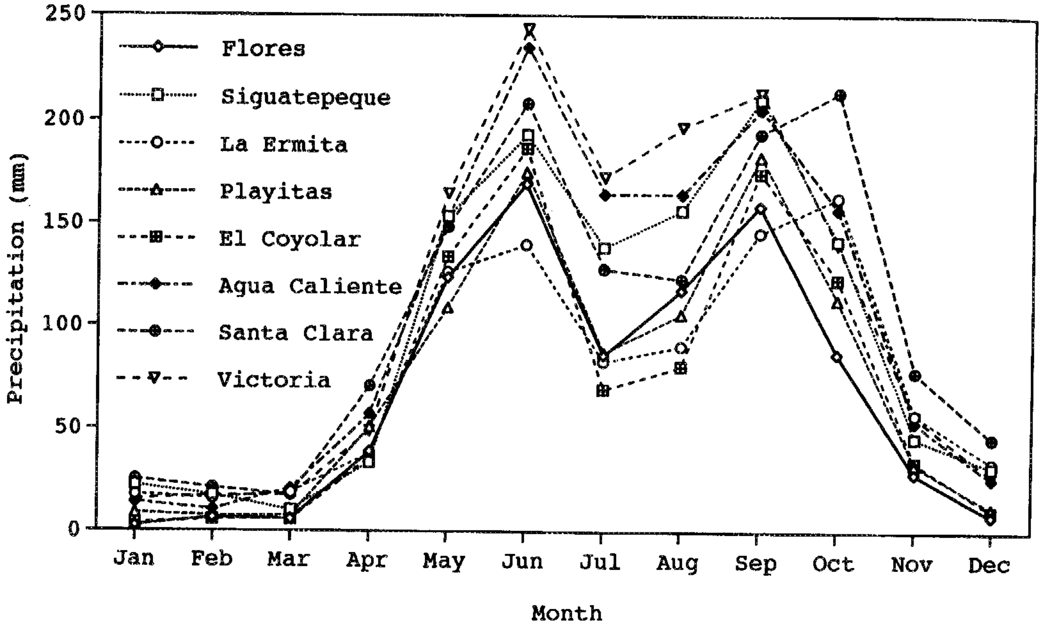

Fig. 6. Average monthly rainfall distribution for eight stations with calculated *R*-factor values (*R* = rainfall erosivity index).

the eight stations with calculated *R*-factor values have similar monthly rainfall distributions (Fig. 6), so using Eq. [3] to estimate *R*-factor values may not be appropriate for those stations with different monthly rainfall distribution.

Different ranges of the estimated *R*-factor value are coded by color (Fig. 4). The new *R*-factor estimate can be obtained from the map with its corresponding 95% prediction interval. For example, the cross-hatched region in southern Honduras represents the range of the estimated *R*-factor value from 8000 to 11 999 MJ mm ha^{-1} h^{-1} yr^{-1}, and the width of the 95% prediction interval, as taken from the contour line for that area, is 3000 MJ mm ha^{-1} h^{-1} yr^{-1}; therefore the 95% prediction interval for the *R*-factor value is between 8000 ± 1500 and 11 999 ± 1500 MJ mm ha^{-1} h^{-1} yr^{-1}. For any location of interest, both a point estimate and a prediction interval for the *R*-factor value can be obtained from the digital provisional map of Honduras (Mikhailova, 1995b).

The lowest range of estimated *R*-factor value, from 0 to 3999 MJ mm ha^{-1} h^{-1} yr^{-1}, is found primarily near the capital of Honduras, Tegucigalpa. Estimated *R*-factor values for this central region of the country generally vary from 0 to 8000 MJ mm ha^{-1} h^{-1} yr^{-1}.

The high range of estimated *R*-factor values, from 8000 to 16 000 MJ mm ha^{-1} h^{-1} yr^{-1}, is found primarily in the coastal regions, as well as in the Lake Yojoa area, which is inland.

The Caribbean lowlands in northeastern Honduras are characterized by the highest range of estimated *R*-factor values, greater than 16 000 MJ mm ha^{-1} h^{-1} yr^{-1}. This region also has the highest average annual precipitation (Perfil Ambiental de Honduras, 1989).

The contour lines representing the width of the 95% prediction interval for the *R*-factor value are shown in Fig. 4 in increments of 1000 *R*-factor units on the provisional iso-erodent map of Honduras. This approach allows for the identification of areas where the multiple regression model (Eq. [3]) used to predict *R*-factor values may not be appropriate. The best estimates of the *R*-factor values, with the narrowest prediction intervals, are found near the eight climatic stations with calculated *R*-factor values. Any station with average annual precipitation outside the range of 831 to 1313 mm or elevation outside the range of 360 to 1080 m has a wide prediction interval. Wide prediction intervals are associated with *R*-factor values for the stations in the Caribbean lowlands.

CONCLUSION

Based on previously calculated *R*-factor values for Honduras, a regression relationship was established for estimating the rainfall erosivity index as a function of average annual precipitation and elevation. Elevation was highly significant in predicting the potential rainfall erosivity in addition to average annual precipitation as indicated by data from Honduras, Costa Rica, Sri Lanka, and southeastern USA.

An iso-erodent map of Honduras was compiled in an Arc/Info format using regression model and a basemap obtained from the digital chart of the world (Environmental Systems Research Institute, 1993). This map is provisional due to the limited number of data points and their geographic clustering.

The limitations of predicting rainfall erosivity in Honduras by the method outlined in this study should not be discouraging for people who must make land use decisions. The iso-erodent map presented in this study is based on the best available information for Honduras. As pointed out by Van Wambeke (1987), information with known limitations can lead to better decisions, if used carefully, than those made without information.

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