RAINFALL EROSIVITY FACTORS (R-FACTORS) FOR SELECTED ISLANDS IN THE FEDERATED STATES OF MICRONESIA

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RAINFALL EROSIVITY FACTORS (R-FACTORS) FOR SELECTED ISLANDS IN THE FEDERTADE STATES OF MICRONESIA (FSM)

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ABSTRACT

Soil erosion is a major source of pollution in the tropical islands of the Federated States of Micronesia (FSM). These islands are small, with limited resources, and are heavily dependent on a high quality marine environment both as a source of food and as an attraction for tourism. To implement soil erosion control practices for these islands requires having quantitative values for the factors that contribute to soil erosion. One of these contributing factors is the rainfall erosivity factor (R). In this study, we developed rainfall erosivity (R) factors for the islands of Pohnpei, Chuuk, and Yap . Using correlation analysis, long-term 30-minute and 60-minute rainfall data were used to develop storm erosion indices (EI_{30}). From these EI_{30} indexes, the monthly, yearly, and average annual R factors were calculated for each island.

INTRODUCTION

Soil erosion is a major source of pollution in tropical islands. These islands are small, with limited resources, and are heavily dependent on a high quality marine environment both as a source of food and as an attraction for tourism, which is a major source of income for the islands. In the Federated States of Micronesia (FSM) soil erosion has already degraded the fishing within the reef and has created major water quality problems. For example, the island of Kosrae has one of the world's highest rates of water born disease. A recent study indicated that high turbidity in streams is a major factor in the cause of the problem (US EPA, 1986).

Soil erosion and its effects had been extensively studied for many years, but most quantitative information gathered has resulted from research in subtropical and temperate areas. Attempts to extrapolate this information for use in the tropics are seldom satisfactory. Recent studies by Khosrowpanah and Dumaliang (1998) indicate that the soil erosion rates predicted for the island of Guam could be as much as 45 % in error when using the extrapolated data compared to soil erosion rates based on actual local climatic conditions. In addition to the obvious lack of knowledge and information concerning the basic parameters governing erosion, the predictive capabilities for soil losses are further limited by the large variability of climate, soils, and topography in tropical regions.

The Universal Soil Loss Equation (USLE) and its updated revision the Revised Universal Soil Loss Equation (RUSLE) are the equations used most commonly to predict soil erosion rates and soil losses in the tropical pacific. The five major factors used in USLE and RUSLE to predict soil erosion rates: 1) climate, largely rainfall, 2) soil, its inherent resistance to slaking, dispersion and its water intake and transmission rates, 3) topography, particularly steepness and length of slope, 4) plant cover, and 5) practice factor. Of these, the plant cover, practice and topographic factors are considered management parameters. In contrast, the climate factors and the soil characteristics are normally beyond manipulation by man. In tropical environments, climate or specifically the volume and intensity of rainfall are the most significant cause of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R or rainfall erosivity factor. It is important to have an average annual R-factor and its monthly variation that represents the local climate if successful erosion control plans are to be implemented.

OBJECTIVE

The objective of this study was to develop average annual rainfall erosivity (R-values) for selected rainfall stations in the FSM by using local rainfall data for each station. The rainfall stations that were considered were those that had long-term rainfall data with 30 or 60 minutes interval.

STUDY AREA

I. Geographical Setting

The Federated States of Micronesia (FSM) is geographically part of Micronesia, along with Guam, the Commonwealth of the Northern Mariana Islands, and the Republic of Palau, the Marshall Islands, Nauru, and Kiribati (Karolle, 1990). As shown in Figure 1, the FSM extended from 1 to 14 degrees north latitude and from 136 to 166 degrees east longitude. The FSM consists of four states (from west to east): Yap, Chuuk, Pohnpei, and Kosrae.

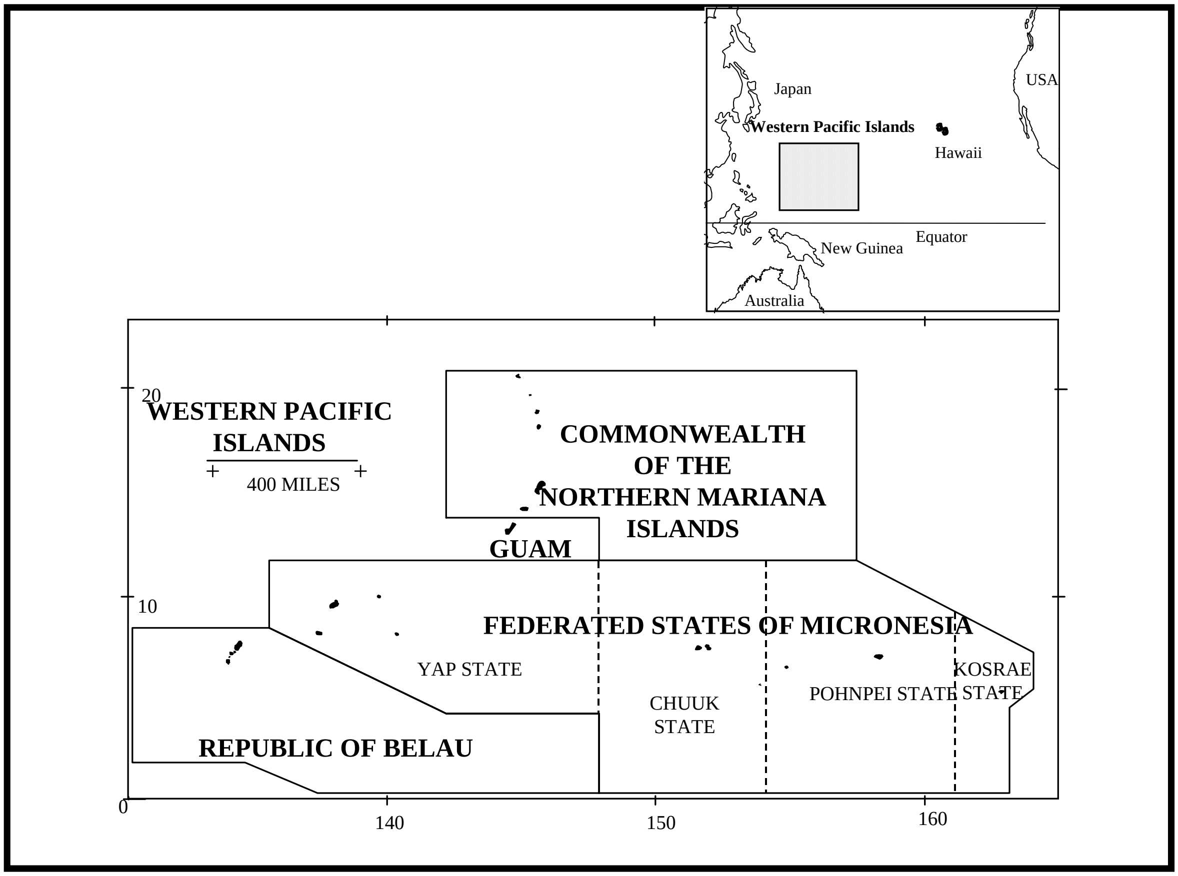

Figure 1. Location of the Federated States of Micronesia

The Yap Islands located between 9°27’ and 9°38’ N. latitude and 138°03’ to 138°12’ E. longitude. The four major islands are Yap, Gagil-Tamil, Maap, and Rumung. As shown in Figure 2, the four islands are separated by narrow channels and are surrounded by a fringing reef. The total land area is 38 square miles (mi^2), with Rumung being the smallest (1.6 mi^2) island and Yap the largest (21.7 mi^2). The town of Colonia on Yap Island is the center of business and government in the State of Yap. Mangrove swamps occupy much of the shoreline of all the islands. The interior sections are hilly, and in some places covered with Savannah-type vegetation. On Yap Island a range of hills trends northwest southwest and averages about 500 feet above sea level.

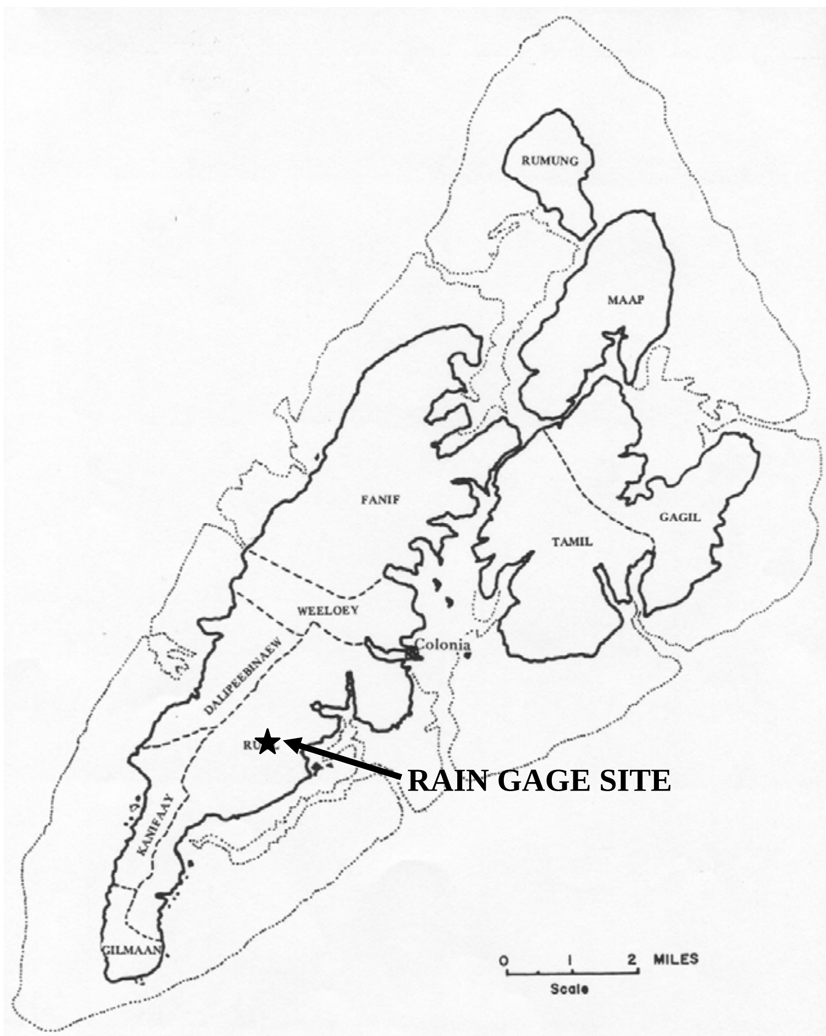

Figure 2. Island of Yap, From Karolle, 1990

The Chuuk State (formerly Truk Islands) consists of 19 high volcanic islands and at least 65 low coral islets (Van der Brug, 1984). Many of the coral islands are a part of the 125-mile-long barrier reef that encloses an 820-mil^2 lagoon in which the volcanic islands and remaining coral islets are scattered. Moen as shown in Figure 3, has a land area of 7.2 mi^2 and is the administrative, commercial, educational, and transportation center of the islands.

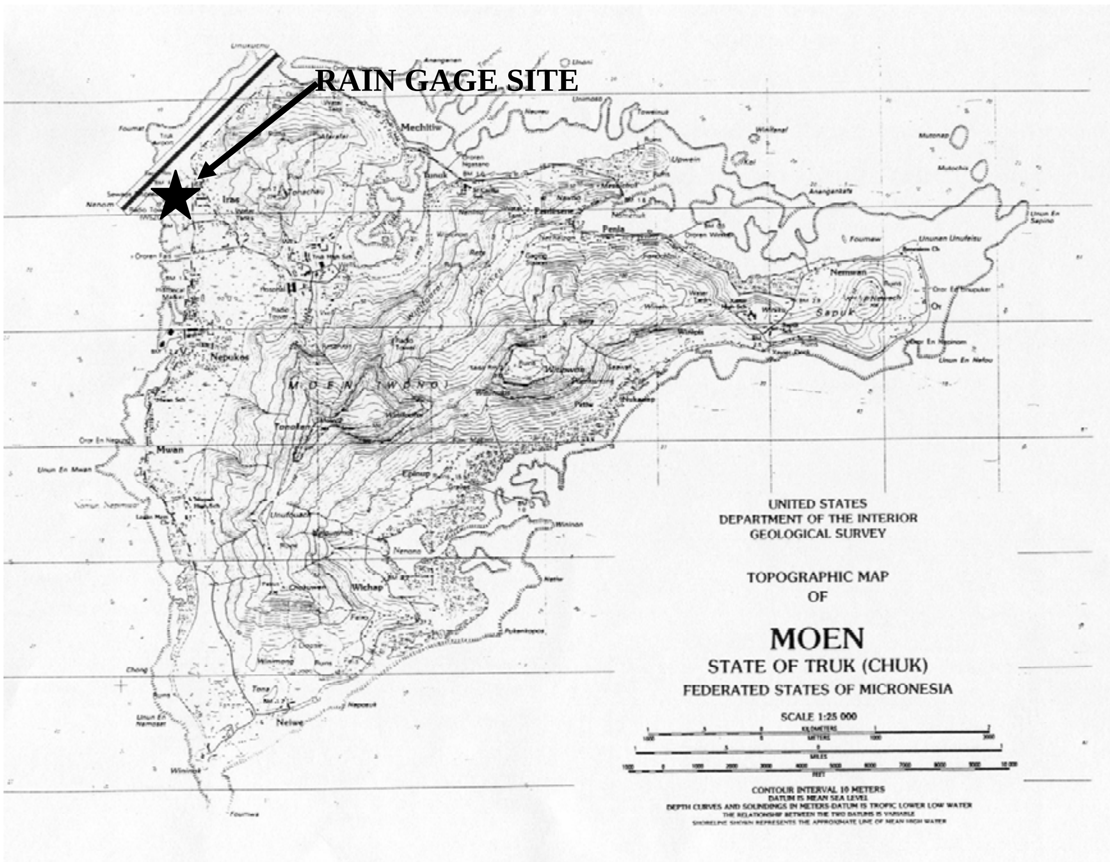

Figure 3. Moen Island, From Karolle, 1990

The Pohnpei State is the third largest island in the Western Pacific, located between latitude 6° 47' and 7°01' North and longitude 158°06' and 158°022' East, and lies approximately 3,100 miles Southwest of Tokyo in Japan. As shown in Figure 4, Pohnpei proper is roughly circular in shape with a land area of about 129 square miles (mi^2). The interior of the island is characterized by high, steep rugged mountains covered with thick, lush venation. The mountainous interior has the highest peaks in the Western Pacific, with the peak rising to over 2,500 feet above sea level. The steep mountainous areas make up about 60 percent of the island. Surrounding the mountains and extending in some areas to the shoreline, are rolling hills, lava flows, and plateaus that make up about 20 percent of the island. The bottomlands and mangrove swamps make up the remaining 20 percent of the island. The town of Kolonia is the only urban area in Pohnpei State. It incorporates the major center of population, government administration and economic development activities. It is fringed by a semi-urban area extending into the municipalities of Sokehs and Nett.

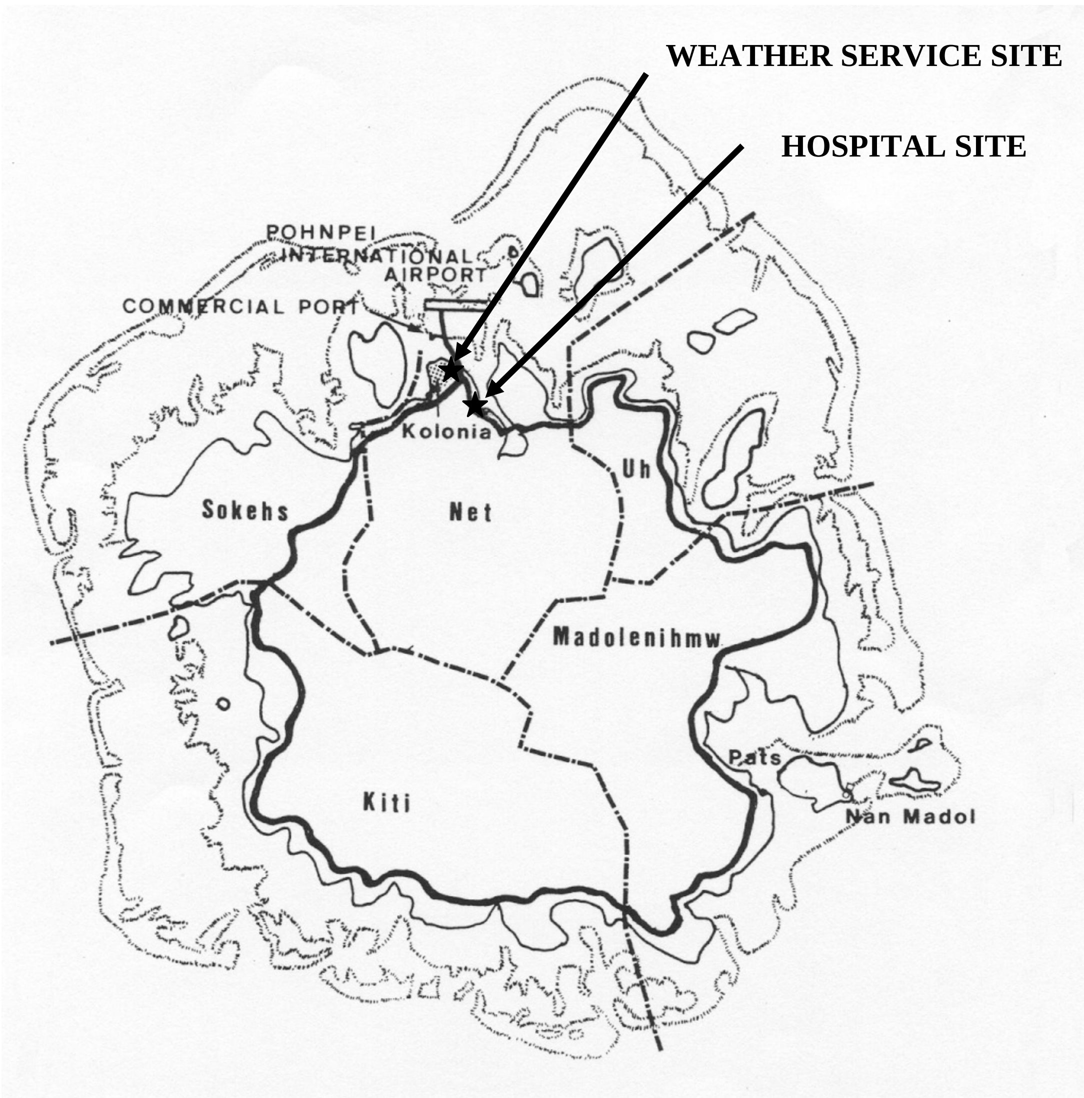

Figure 4. Island of Pohnpei, From Karolle, 1990

II. Climate and Rainfall

The climate of the Federated States of Micronesia is typical of many tropical islands. Temperatures are relatively uniform, averaging in mid 70 to mid 80 degrees Fahrenheit range, humilities average over 80 per cent. Rainfall varies from 120 inches on drier islands to over 400 inches per year in the mountainous interior of Pohnpei. On most islands, there is a pronounced wet season (June to October) and dry season (November to May). The Western region of the FSM is subject to occasional hurricanes and typhoons, which can cause severe land erosion.

The rainfall record for some of these islands goes back in time to the German occupation. For example in Chuuk State, Eten, a small island off the south coast of Dublon island has a rainfall record since 1903 (Van der Brug, 1984). The Japanese collected rainfall data in Dublon Island during 1927-40, in Colonia, Yap (1914-42). After World War II, the US Navy was operating a weather station in most of these islands until 1951. Later on the operation of these weather stations were transferred to the United States National Weather Service Observatory (WSO).

The rainfall stations that were used for R-factor calculation are listed in Table 1. These stations had 15 or 60 minutes rainfall data for more than 10 years period.

Table 1. Federated States of Micronesia, Selected Rainfall Gauge Stations

ID	Station Name	Island	Start	End	Years	Time Interval	Latitude	Longitude	Elevation
4751	Pohnpei WSO	Pohnpei	1984	1993	10	15 minute	6:58:00	158:13:00	120
4745	Pohnpei Hospital	Pohnpei	1980	1997	18	15 minute	6:57:00	158:13:00	30
4111	Chuuk WSO	Chuuk	1984	1993	10	60 minute	7:27:00	151:50:00	5
4951	Yap Island WSO	Yap	1985	1999	15	60 minute	9:29:00	138:05:00	44

BACKGROUND

I. Universal Soil Loss Equation (USLE)

The USLE is the most commonly used estimator of soil loss caused by overland erosion. The equation was based on an extensive set of more than 10,000 plot years of runoff and soil loss data from experimental centers in the eastern U.S.A. It was developed to predict average annual soil loss from sheet and rill erosion, not gully or other forms of erosion. The USLE may properly be used to (Wischmeier 1978):

1. Predict average annual soil movement from a given field slope under specified land use and management conditions.
2. Guide the selection of conservation practices for specific sites.
3. Estimate the reduction in soil loss that would result from a change in cropping or conservation practices.
4. Determine how conservation practices may be applied or altered to allow more intensive cultivation.
5. Estimate soil losses from land use areas other than agricultural purposes.
6. Provide soil loss estimation for determining conservation needs.

The USLE, derived empirically is (Lal, 1994):

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where A is the average annual soil loss (tons/acre-year), R is the rainfall factor (ft-tons-in/acre-hour), K is the soil erodibility factor (tons/acre-year / ft-tons-in/acre-hour), LS is the slope-length (dimensionless) and slope-gradient factor (dimensionless), C is the cropping-management factor (dimensionless), and P is the erosion-control practice factor (dimensionless).

The USLE was designated "universal" because it is free of some of the generalization and geographic and climatic restrictions inherent in earlier models. It has been criticized as not being universal because original parameter values were presented for conditions of the eastern two-thirds of the United States. Regardless of whether the name is fully accurate, the USLE identifies the major factors affecting soil loss (Lal, 1994).

Each of the six factors in the USLE has been formulated by Wischmeier (1978) in such a way that it is linearly related to the soil loss. Each variable can be isolated and quantified into numbers using standard USLE plots or unit plots (Lal, 1994). When the variables of the USLE are multiplied together, the answer is the amount of soil loss.

In 1985, U.S. Department of Agriculture (USDA) and soil erosion researchers agreed that the USLE should be revised to incorporate additional research and technology developed after the 1978. The new revised called RUSLE, which has the basic USLE structure with the exception that the algorithms used to calculate the individual factors have been changed significantly. Perhaps most important has been the computerization of the technology to assist with individual factor determinations (Lal, 1994).

II. Storm EI_{30}

The numerical value used for the R-factor in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff likely to be associated with the rainfall regimes (Lal, 1994). The storm erosion index or Storm EI_{30}, derived by Wischmeier appears to meet these requirements better than any other of the many rainfall parameters. The relationship is expressed by the equation (Lal, 1994),

$$Storm\ EI_{30} = \left\{\sum 1099 \times \left[1 - 0.72 \times Exp\left(-1.27 \times I_r\right)\right] \times R_r\right\} \times I_{30} \quad (2)$$

Where I_r is the rainfall intensity (inch/hour) in a particular time interval of the storm, R_r is the rainfall amount (inch) during the same time interval. These values are input into the equation shown above for each time interval of the storm. The sum of the computed values is called the storm energy or E value. The E value is multiplied by the $I_{30,}$ which is the maximum 30-minute intensity during the storm. The product is called the Storm $EI_{30.}$ It is expressed in hundreds of foot-ton inches per acre-hour (Lal, 1994).

Previous research has indicated that storm soil losses from cultivated fields were directly proportional to a rainstorm parameter identified as the Storm EI_{30}. The sum of the storm EI_{30} values for a given period is a numerical measure of the erosive potential of the rainfall within the period. The average annual total of the storm EI_{30} values in a particular locality was the rainfall erosion index (R-factor) for that locality (Lal, 1994).

Rills and sediment deposits observed after an unusually intense storm have sometimes led to the conclusion that significant erosion was associated with only a few storms, or that it was solely a function of peak intensities. However, more than 30 years of measurements in the U.S. mainland have shown that this was not the case. The data show that a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms, as well as the effects of the occasional severe ones (Lal, 1994). The tropical islands of Micronesia display quite a number of moderate-sized storms along with large rainfall events such as typhoons. These moderate-sized storms include shear lines, thunderstorms, and trade wind showers.

PREVIOUS STUDIES

There have been few studies pertaining to the development of R-factors for the tropical pacific region. One study, conducted by Dr. Keith R. Cooley of U.S. Department of Agriculture - Agriculture Research Service (1990), was to determine the R-factors for 10 Pacific Basin islands. Table 2 provides the results of his study. For his analysis, he used an adjustment factor developed from 30-minute rainfall data from several Hawaii stations to determine the R-factors for the Pacific Basin Islands. Using the adjustment factor, he converted Storm EI_{30} values computed from hourly rainfall to approximate Storm EI_{30} values that would have been obtained if 30-minute data rainfall data had been available. This method was used because he lacked sufficient 30-minute rainfall data for these islands.

Table 2. Cooley R-factors of 10 Pacific Basin Islands

Island	Average Annual Rainfall WSO (inches)	Average Annual R-factor
Pohnpei, FSM	186.60	1987
Koror, Palau	146.62	1541
Chuuk, FSM	136.35	1372
Majuro, RMI	130.86	1283
Pago Pago, Am. Samoa	119.83	1267
Yap, FSM	116.76	1186
Kwajelein, RMI	101.33	985
Guam, USA	101.07	797
Wake, USA	34.56	221
Johnston, USA	24.33	135

The Lo (1985) Study

The study by Lo (1985) involved the use of average annual rainfall in determining an average annual R-factor map for Oahu, Hawaii. A linear regression analysis was performed on the average annual rainfall and R-factor data.

The linear regression of the annual rainfall data obtained a relationship between annual rainfall and average annual R-factor. This relationship was used to develop other average annual R-factors for other rain gauge sites to expand their R-factor database and to produce a spatial distribution of the R-factors.

The Dumaliang (1998) Study

Dumaliang et al (1998) developed the average annual R factors for normal, dry, and wet year for Southern Guam. In their study, 30-minute rainfall data were used to develop the R factors. The Storm Erosion Index or Storm EI_{30} was utilized to develop storm R-factors from the continuous rainfall data from the site. From this analysis of the rainfall data and associated R-factors, a relationship between the monthly rainfall and monthly R-factor was determined. Average annual R-factors were developed from the monthly rainfall and R-factor relationship. To apply the relationship, average monthly rainfall of several rain gauge sites were employed. Similarly, average wet year and dry year R-factors were obtained by separating the historical rainfall record of the rain gauge sites. This approach involved the analysis of drought years known as *El Niño* and *La Niña*. Spatial distribution of rainfall was accounted for by the development of isoerodent contour maps.

Guam U.S. Department of Agriculture - Natural Resource Conservation Service (USDA-NRCS) Procedure

The Guam USDA-NRCS addressed the spatial variability of rainfall by developing a procedure using the existing precipitation maps. The procedure used by the Pacific Basin RUSLE (Revised Universal Soil Loss Equation) R-Factor Team generally encompassed the extrapolation of the measured R factors for each island to construct isoerodent lines and R-factors based on precipitation maps. An established correlation between the measured R-factors and the available precipitation data was used to develop the estimated R factors. A relationship developed by Renard and Friemund (1994) provided a ratio equation using the single known R factor and known precipitation (inches) from the Cooley study and new precipitation at each contour to determine new R factors for any point of interest (Dumaliang, 1997).

The Renard and Friemund correlation equation for determining new R factors was defined by:

$$R_n = R_{known} \times \left(P_n / P_{known}\right) \qquad (3)$$

Where R_n is the estimated new R factor for location, R_{known}, is the known measured R factor from Cooley study, P_n, is the new precipitation values from all available sources, and, P_{known}, is the associated precipitation from Cooley R-factor (Dumaliang, 1997).

As a result of Guam USDA-NRCS study, the R-factors reported by Cooley and average annual rainfall maps were used to develop isoerodent maps.

METHODS AND PROCEDURES

The first step was rainfall data collection. The available rainfall with 15, 30, or 60 minutes interval was gathered from US Weather Service Stations in Pohnpei, Chuuk, and Yap. Kosrae was not included in this study because of the lack of hourly rainfall data.

The second step was to translate all the rainfall data into 30-minutes intervals. When 15-minute data was available (such as the two Pohnpei Stations) we simply summed the first two 15-minute values of the hour to get the first 30-minute value and summed the third and fourth 15-minute values of the hour to get the second thirty-minute value.

For stations where only 60-minute data was available a different technique was applied. A correlation was developed between I_{30} and I_{60} for two gages with long 15-minute rainfall was available (Piti, Guam and Capital Hill, Saipan). This I_{30}-I_{60} relationship was used to generate a record of 30-minute rainfalls from the existing 60-minute rainfall records.

The derived 30-minute rainfall record for each station was split into rainstorms. A new rainstorm was started every time there was a continuous no precipitation period of 6 hours or more (6hr breakpoint). The R-factor for each storm were then calculated and summed to come up with monthly and annual R-factors. The average annual and average monthly rainfall factor were calculated for each station. The last step was to apply a weighting factor in order to account for missing rainfall data.

DATA COLLECTION AND ALALYSIS

I. Rainfall Data

The first phase of this project was dedicated to the collection of rainfall data. To calculate the storm EI_{30} requires having a long-term rainfall data with a recording interval of 30 minutes or less. After reviewing all possible sources, we found that only two stations in FSM met this criterion. The Pohnpei hospital station has been collecting 15-minutes rainfall data since 1980. The Pohnpei (WSO) had a record of 10 years of 15-minutes data. For Chuuk and Yap rainfall data, we did a correlation analysis as explain below. Table 1, shows the length and time interval of the rainfall data for selected stations.

II. Rainfall Intensity Correlation

To calculate the Storm Erosivity EI_{30}, requires having 30-minute rainfall intensity. To convert the hourly rainfall period to 30-minute rainfall we used a method similar to that reported by Cooley (1990), and A. Lo. et al (1983). They determined the storm max I_{30} quantities for 2,000 storms using the 15-minute rainfall record from the Hawaii's Weather Service Station. From the linear regression relationship they found a correlation factor of 1.45 between the maximum 30-minute rainfall intensities and 60-minute rainfall intensities (max I30 = 1.45112x max I60; R2 = 0.9495).

In this study we used correlation analysis to predict 30-minute precipitation values for those stations where only 60-minute rainfall data was available. We used two stations, Capital Hill rain gauge Station in Saipan, CNMI with 15-minute rainfall data for 13 years (1986-99), and Piti Rain gauge Station in Guam with 15-minute continues rainfall data for 20 years (1978-97) to develop the required correlation. The maximum 30-minutes intensity during each 60 minutes of rainfall was plotted against the 60-minutes rainfall for that period. As shown in Figure 5 and 6, the correlation factor of 1.6 was found for both stations.

$$\max I_{30} = 1.6 \times I_{60}; \quad R^2 = 0.9$$

Next all the hourly rainfall data were converted into 30-minute interval data. The first step was to multiply the 60-minute value by the 1.6 thus giving the max I_{30} intensity value in in/hr for that 60-minute period. This value was multiplied by .5 hr to get the depth in that 30-minute period. The value for the second 30-minute period in the hour was computed by subtracting the first 30-minute depth from the total 60-minute rain. This procedure was repeated for each 60-minute rainfall data point.

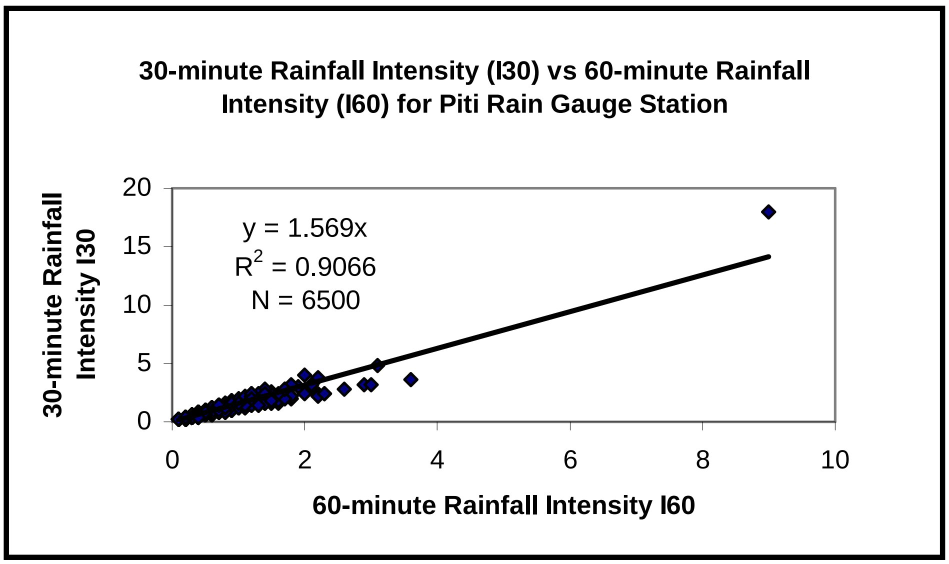

Figure 5. Piti Rain Gauge Station, Guam (1978-1997)

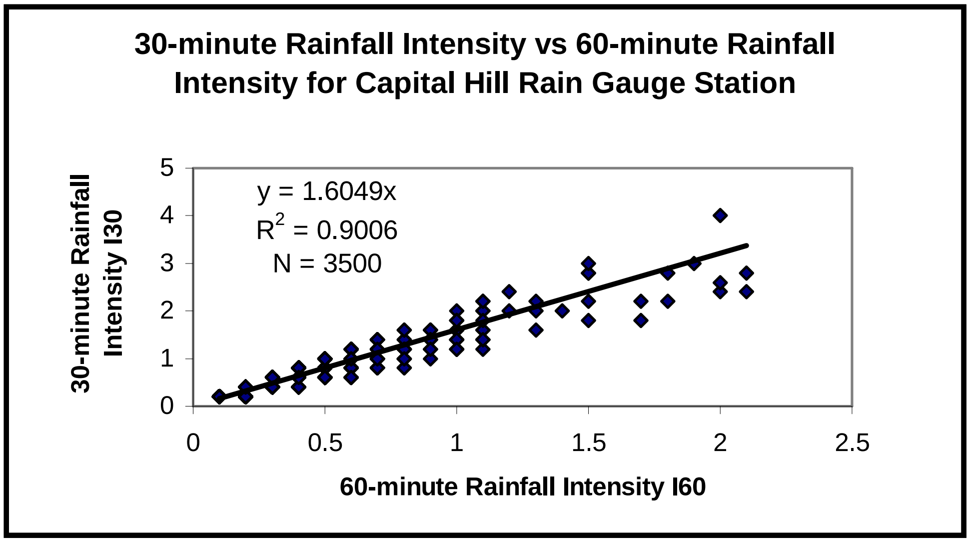

Figure 6. Capital Hill Rain Gauge Station, Saipan, CNMI (1986-99)

III. Storm EI30 Analysis

The derived 30-minute rainfall record for each station was split into separate rainstorms. A new rainstorm was started every time there was a continuous no precipitation period of 6 hours or more (6hr breakpoint). The 6 hours break criteria between storms for the Storm EI_{30} calculation had been used by Wischmeier and Smith (1978) and other researchers, and was adopted for this study.

Equation (2), shown below, was applied to the derived 30-minute rainfall data for each storm to calculate Storm EI_{30} values or R-factors for each storm.

$$Storm\ EI_{30} = \left\{ \sum 1099 \times \left[1 - 0.72 \times Exp\left(-1.27 \times I_r\right)\right] \times R_r \right\} \times I_{30}$$

Table 3 demonstrates a calculation of the Storm EI_{30} values of a rainstorm for Pohnpei Hospital Rain gage Station. The associated continuous rainfall data is provided in Appendix A.

Column (1) was the interval of the storm. As indicated, the storm was divided into 0.5 hour or 30 minute intervals. Column (2) represented the rainfall amount in inches associated in each interval. Column (3) was the associated intensity in inches per hour (Column (2)/Column(1)). Column (4) through (6) represented the calculation of the energy of the storm represented by the following equation.

$$E = 1099 \times \left[1 - 0.72 \times Exp\left(-1.27 \times I_r\right)\right] \quad \text{(ft-tons per acre)} \qquad (4)$$

Where I_r, in column (3), was rainfall intensity (in/hr) of the storm during a particular time interval. The total energy, Total E, in column (7) was then calculated by multiplying the energy of the storm, column (6), with the rainfall amount in column (2). This calculation was represented by the following equation.

$$\left\{\sum 1099 \times \left[1 - 0.72 \times Exp\left(-1.27 \times I_r\right)\right] \times R_r\right\}$$ (ft-tons inches per acre)

The total energy for each interval of the storm were then summed to obtain the total energies for the storm. The maximum 30-minute intensity, column (8), was then determined by choosing the largest value of Intensity shown in Column (3). The Storm EI_{30} (column 9) was obtained by multiplying the total energy of the storm (column 7) and the maximum 30-minute intensity (column 8). The Storm EI_{30} was then divided by 100 to determine the storm R-factor. The division of 100 was done for convenience of expressing the units. The criterion used for Storm EI_{30} calculations are summarized in Appendix C, which also explains why other related criteria were not followed.

The rainfall and associated Storm EI_{30} values were summed for each month to produce monthly rainfall and its respective monthly R-factors. Appendix A and B shows sample of calculation R-factor for Pohnpei hospital station.

Table 3. Sample Calculation of the Storm R-factor of a Rainstorm at Hospital Rain Gauge Station, Pohnpei

Interval (hr) (1)	**Rainfall (in) (2)**	**Intensity (in/hr) (3)**	**(a)=0.72* exp(-1.27I) (4)**	**(b)=1-(a) (5)**	**E 1099*(b) (6)**	**Total E (7)**	**Maximum 30-minute Intensity (8)**	**Storm EI_{30} (9)**
0.5	0.1	0.2	0.558	0.441	485.21	48.52	0.8	11
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
0.5	0	0	0.72	0.28	307.720	0		
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
0.5	0.4	0.8	0.26	0.739	812.52	325.0		
0.5	0.2	0.4	0.433	0.566	622.88	124.57		
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
0.5	0.2	0.4	0.433	0.566	622.88	124.57		
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
0.5	0.3	0.6	0.336	0.663	729.68	218.9		
0.5	0.1	0.2	0.558	0.441	485.21	48.52		
Sum	2							

IV. Accounting for Missing Rainfall Data

As shown in Table 4 through 7, there were many days that no rainfall was recorded at the Pohnpei, Chuuk and Yap stations. To have a good representation of R-factor for Pohnpei, Chuuk, and Yap stations we did a weighted analysis to account for the days that no rainfall was collected. To fill those data voids we did a weighted average for each day of the data set. As an example for Pohnpei WSO Station for month of January of 1985 there was 8 days missing data (23 days of available data). The amount of rain that was reported was 14.83 inches for this month. To estimate the total monthly rain we first divided the amount recorded (14.83 inch) by the number of days that data was available (14.83/23 = 0.64) and then multiplied this value by the total number of days in the month (31x 0.64 = 19.99 inches of rain) this number is reported in Appendix D as weighted rainfall for that month. This process was applied to all other rainfall stations with missing data. Appendix D shows the un-weighted and adjusted weighted monthly rainfall data for all these stations.

The computed monthly R-factors for each site were adjusted using the same weighing techniques as described above. Total computed monthly R-factor was first divided the amount by the number of days that data was available. This value was then multiplied by the actual number of days in the month. This number is reported in Appendix D as weighted R-factor for that month. The summary of the weighted and un-weighted value for average annual rain and R-factor are shown in Table 8 and 9.

Table 4a. Pohnpei Weather Service Observatory: Number of Days with Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1984	0	23	21	17	20	16	16	26	18	27	23	24
1985	26	15	25	21	24	24	19	24	27	23	21	21
1986	24	21	25	18	20	25	24	19	26	24	24	24
1987	22	9	24	22	16	25	25	29	18	22	26	24
1988	24	15	13	24	23	22	22	24	25	26	25	29
1989	20	19	18	26	25	24	26	27	20	22	17	27
1990	20	10	23	17	27	27	28	28	22	22	25	16
1991	21	20	19	23	25	21	26	23	22	17	23	19
1992	17	16	14	17	15	23	27	27	19	23	21	23
1993	22	11	25	20	24	24	27	24	23	27	0	0
Sum	**196**	**159**	**207**	**205**	**219**	**231**	**240**	**251**	**220**	**233**	**205**	**207**
%	**63**	**57**	**67**	**68**	**71**	**77**	**77**	**81**	**73**	**75**	**68**	**67**

Table 4b. Pohnpei Weather Service Observatory: Number of Days without Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1984	31	5	10	13	11	14	15	5	12	4	7	7
1985	5	13	6	9	7	6	12	7	3	8	9	10
1986	7	7	6	12	11	5	7	12	4	7	6	7
1987	9	19	7	8	15	5	6	2	12	9	4	7
1988	7	13	18	6	8	8	9	7	5	5	5	2
1989	11	9	13	4	6	6	5	4	10	9	13	4
1990	11	18	8	13	4	3	3	3	8	9	5	15
1991	10	8	12	7	6	9	5	8	8	14	7	12
1992	14	12	17	13	16	7	4	4	11	8	9	8
1993	9	17	6	10	7	6	4	7	7	4	30	31
Sum	**114**	**121**	**103**	**95**	**91**	**69**	**70**	**59**	**80**	**77**	**95**	**103**
%	**37**	**43**	**33**	**32**	**29**	**23**	**23**	**19**	**27**	**25**	**32**	**33**

Table 5a. Pohnpei Hospital: Number of Days with Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1980	0	0	0	18	1	18	22	22	21	21	17	1
1981	18	15	16	20	4	22	23	18	1	17	24	24
1982	14	15	1	19	24	26	26	1	0	19	15	0
1983	0	8	1	4	13	22	24	1	19	17	21	20
1984	27	20	14	16	12	22	21	15	16	17	24	17
1985	20	15	9	19	20	22	21	22	23	18	21	27
1986	16	20	21	16	21	26	19	23	23	16	21	12
1987	19	12	20	16	10	21	24	21	16	22	18	17
1988	0	6	11	19	21	20	19	21	0	0	0	23
1989	1	15	14	13	26	19	20	22	14	21	14	19
1990	16	11	19	3	20	21	18	24	9	23	15	20
1991	11	11	20	22	15	18	16	7	11	22	18	0
1992	11	5	1	2	4	0	0	0	4	0	0	1
1993	1	5	22	18	7	22	29	5	22	14	0	2
1994	18	11	22	15	9	23	29	18	0	12	15	22
1995	15	10	12	2	23	0	5	0	19	22	17	25
1996	1	17	16	21	26	20	25	19	19	23	18	17
1997	18	22	12	14	19	14	21	21	15	1	8	9
Sum	**206**	**218**	**231**	**257**	**275**	**336**	**362**	**260**	**232**	**285**	**266**	**256**
%	**37**	**43**	**41**	**48**	**49**	**62**	**65**	**47**	**43**	**51**	**49**	**46**

Table 5b. Pohnpei Hospital: Number of Days without Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1980	31	28	31	12	30	12	9	9	9	10	13	30
1981	13	13	15	10	27	8	8	13	29	14	6	7
1982	17	13	30	11	7	4	5	30	30	12	15	31
1983	31	20	30	26	18	8	7	30	11	14	9	11
1984	4	8	17	14	19	8	10	16	14	14	6	14
1985	11	13	22	11	11	8	10	9	7	13	9	4
1986	15	8	10	14	10	4	12	8	7	15	9	19
1987	12	16	11	14	21	9	7	10	14	9	12	14
1988	31	22	20	11	10	10	12	10	30	31	30	8
1989	30	13	17	17	5	11	11	9	16	10	16	12
1990	15	17	12	27	11	9	13	7	21	8	15	11
1991	20	17	11	8	16	12	15	24	19	9	12	31
1992	20	23	30	28	27	30	31	31	26	31	30	30
1993	30	23	9	12	24	8	2	26	8	17	30	29
1994	13	17	9	15	22	7	2	13	30	19	15	9
1995	16	18	19	28	8	30	26	31	11	9	13	6
1996	30	11	15	9	5	10	6	12	11	8	12	14
1997	13	6	19	16	12	16	10	10	15	30	22	22
Sum	**352**	**286**	**327**	**283**	**283**	**204**	**196**	**298**	**308**	**273**	**274**	**302**
%	**63**	**57**	**59**	**52**	**51**	**38**	**35**	**53**	**57**	**49**	**51**	**54**

Table 6a. Chuuk Weather Service Observatory: Number of Days with Daily RainfallData

	January	February	March	April	May	June	July	August	September	October	November	December
1984	0	23	21	17	20	16	16	26	18	27	23	24
1985	26	15	25	21	24	24	19	24	27	23	21	21
1986	24	21	25	18	20	25	24	19	26	24	24	24
1987	22	9	24	22	16	25	25	29	18	22	26	24
1988	24	15	13	24	23	22	22	24	25	26	25	29
1989	20	19	18	26	25	24	26	27	20	22	17	27
1990	20	10	23	17	27	27	28	28	22	22	25	16
1991	21	20	19	23	25	21	26	23	22	17	23	19
1992	17	16	14	17	15	23	27	27	19	23	21	23
1993	22	11	25	20	24	24	27	24	23	27	0	0
Sum	**196**	**159**	**207**	**205**	**219**	**231**	**240**	**251**	**220**	**233**	**205**	**207**
%	**63**	**57**	**67**	**68**	**71**	**77**	**77**	**81**	**73**	**75**	**68**	**67**

Table 6b. Chuuk Weather Service Observatory: Number of Days without Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1984	31	5	10	13	11	14	15	5	12	4	7	7
1985	5	13	6	9	7	6	12	7	3	8	9	10
1986	7	7	6	12	11	5	7	12	4	7	6	7
1987	9	19	7	8	15	5	6	2	12	9	4	7
1988	7	13	18	6	8	8	9	7	5	5	5	2
1989	11	9	13	4	6	6	5	4	10	9	13	4
1990	11	18	8	13	4	3	3	3	8	9	5	15
1991	10	8	12	7	6	9	5	8	8	14	7	12
1992	14	12	17	13	16	7	4	4	11	8	9	8
1993	9	17	6	10	7	6	4	7	7	4	30	31
Sum	**114**	**121**	**103**	**95**	**91**	**69**	**70**	**59**	**80**	**77**	**95**	**103**
%	**37**	**43**	**33**	**32**	**29**	**23**	**23**	**19**	**27**	**25**	**32**	**33**

Table 7a. Yap Weather Service Observatory: Number of Days with Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1985	0	0	0	0	0	0	0	0	0	1	1	0
1986	0	1	1	1	1	1	0	0	1	1	1	1
1987	1	1	1	1	0	0	1	1	1	1	1	1
1988	1	0	1	0	0	0	0	1	1	1	1	1
1989	1	1	1	1	0	1	1	1	1	1	0	0
1990	1	1	0	1	0	1	0	0	0	1	1	0
1991	1	1	1	1	1	1	0	1	0	1	1	0
1992	1	0	0	0	0	0	1	1	0	0	1	1
1993	1	0	1	0	1	0	1	1	0	0	23	20
1994	23	22	21	24	27	26	23	22	26	12	20	22
1995	21	19	16	18	24	27	23	29	26	31	19	26
1996	25	26	23	24	26	26	27	21	21	26	26	27
1997	20	23	20	17	12	26	29	23	25	22	19	26
1998	25	16	10	9	16	26	25	20	22	27	24	25
1999	24	22	27	23	23	25	25	26	24	21	27	28
Sum	**145**	**133**	**123**	**120**	**131**	**160**	**156**	**147**	**148**	**146**	**165**	**178**
%	**31**	**32**	**26**	**27**	**28**	**36**	**34**	**32**	**33**	**31**	**37**	**38**

Table 7b. Yap Weather Service Observatory: Number of Days without Daily Rainfall Data

	January	February	March	April	May	June	July	August	September	October	November	December
1985	31	28	31	30	31	30	31	31	30	30	29	31
1986	31	27	30	29	30	29	31	31	29	30	29	30
1987	30	27	30	29	31	30	30	30	29	30	29	30
1988	30	28	30	30	31	30	31	30	29	30	29	30
1989	30	27	30	29	31	29	30	30	29	30	30	31
1990	30	27	31	29	31	29	31	31	30	30	29	31
1991	30	27	30	29	30	29	31	30	30	30	29	31
1992	30	28	31	30	31	30	30	30	30	31	29	30
1993	30	28	30	30	30	30	30	30	30	31	7	11
1994	8	6	10	6	4	4	8	9	4	19	10	9
1995	10	9	15	12	7	3	8	2	4	0	11	5
1996	6	2	8	6	5	4	4	10	9	5	4	4
1997	11	5	11	13	19	4	2	8	5	9	11	5
1998	6	12	21	21	15	4	6	11	8	4	6	6
1999	7	6	4	7	8	5	6	5	6	10	3	3
Sum	**320**	**287**	**342**	**330**	**334**	**290**	**309**	**318**	**302**	**319**	**285**	**287**
%	**69**	**68**	**74**	**73**	**72**	**64**	**66**	**68**	**67**	**69**	**63**	**62**

Table 8. Average Annual Rainfall for Islands of FSM

Island	Average Annual Rain (inch) Un-weighted	Average Annual Rain (inch) Weighted
Pohnpei Hospital	142.57	255.4
Pohnpei WSO	183.23	224.19
Chuuk WSO	128.47	174.7
Yap WSO	52.06	122.74

Table 9. Average Annual R-Factor for Islands of FSM

Island	Average Annual R-factor Un-weighted	Average Annual R-factor Weighted
Pohnpei Hospital	1302.41	2354.17
Pohnpei WSO	1604.34	1965.2
Chuuk WSO	983.14	1326.59
Yap WSO	400.72	970.55

RESULTS AND DISCUSSIONS

A comparison between the average annual rainfall and average annual R-factor from this study with those that reported by Cooley is shown in Table 10 and 11. According to these tables with the exception of Pohnpei Hospital Station, the average annual R-factor from this study is less than the Cooley's value. Dumaliang et al (1998) shown the same result as reported in Table 10. This discrepancy can be due to 1) Cooley used the Hawaii rainfall data for extrapolation instead of a similar rainfall data such as Guam, and 2) Cooley used the un-weighted rainfall data which has many missing data as reported in Table 8 and 9. To have a better presentation of the R-factor we used weighted rainfall data for our calculation.

Table 10. R-factor for selected stations in FSM.

			AVERAGE ANNUAL RAIN (inches)		AVERAGE ANNUAL R-FACTOR	
ISLAND	**RAINFALL RECORD**	**MISSING RAINFALL DATA %**	**COOLEY 1968-87**	**THIS STUDY (weighted)**	**COOLEY**	**THIS STUDY (weighted)**
Pohnpei WSO	1984-93	21	186.60	224.19	1987	1965
Pohnpei Hospital	1980-97	51	186.60	255.40	1987	2354
Chuuk WSO	1984-93	29	136.35	174	1372	1326
Yap WSO	1985-99	68	116.76	122.76	1186	970
*Guam WSO			101.07	102	797	*600

* From Dumaliang et al (1998)

Table 11. Comparison between Cooley study and this study.

ISLAND	MISSING RAINFALL DATA %	% Difference Rain-Cooley and Rain-Study	% Difference R-Cooley and R-study
Pohnpei WSO	21	20	1.1
Pohnpei Hospital	51	37	18
Chuuk WSO	29	27	3.3
Yap WSO	68	5	18
*Guam WSO		0	12

Monthly variation of the percentage of annual R factor and accumulated R factor for the selected stations are shown in Figure 7 through 14.

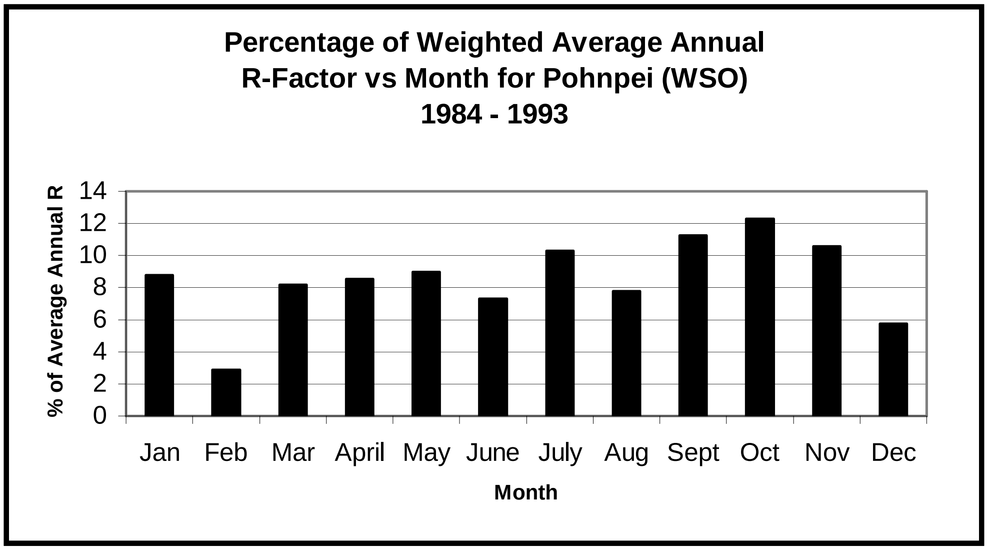

Figure 7. Percentage of weighted average annual R-factor vs. month for Pohnpei WSO

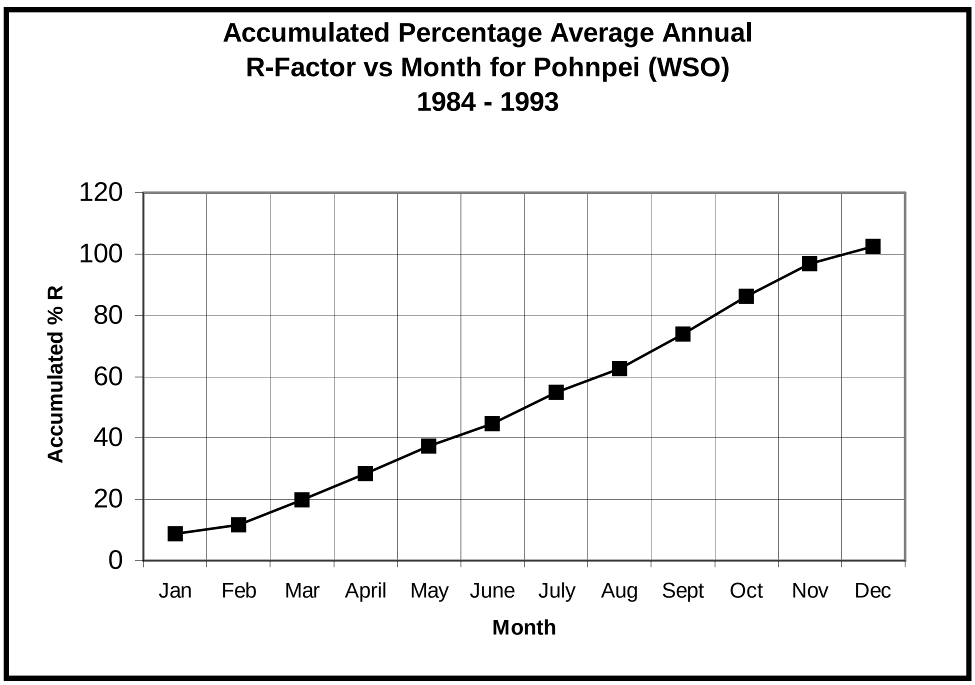

Figure 8. Accumulated percentage average annual R-factor vs. month for Pohnpei WSO

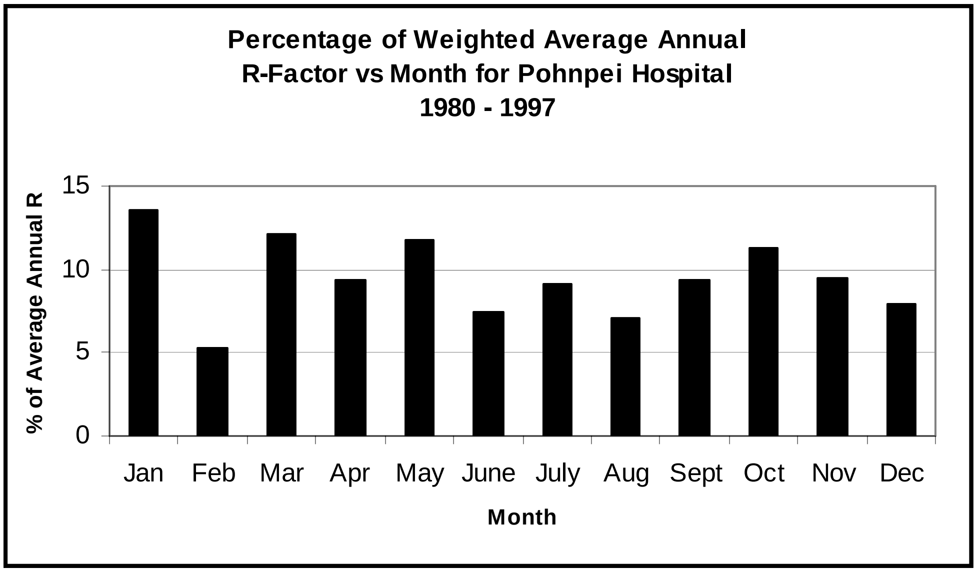

Figure 9. Percentage of weighted average annual R-factor vs. month for Pohnpei Hospital

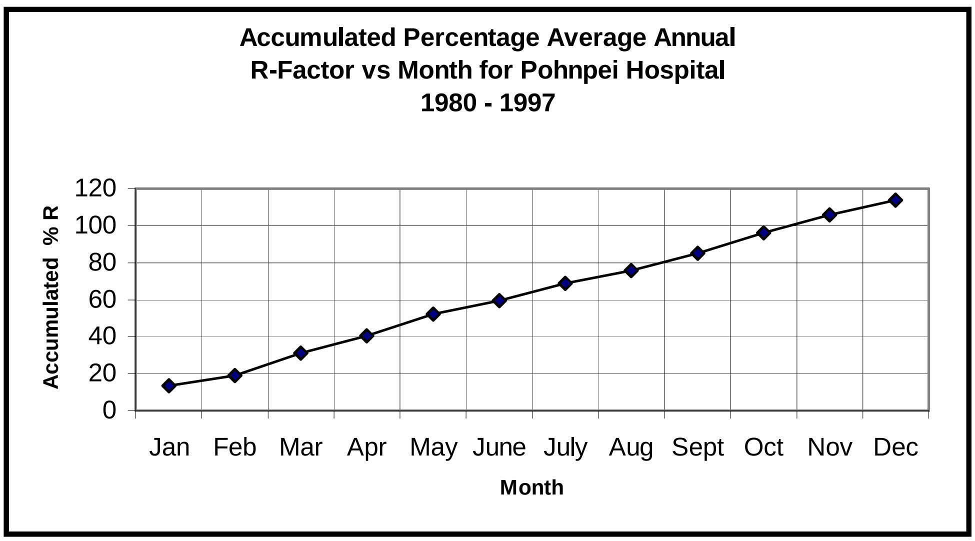

Figure 10. Accumulated percentage average annual R-factor vs. month for Pohnpei Hospital

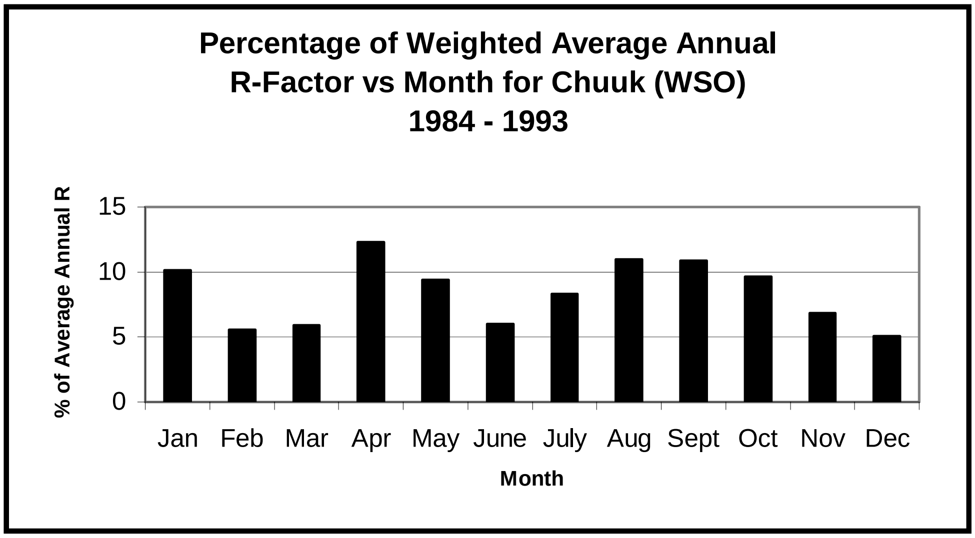

Figure 11. Percentage of weighted average annual R-factor vs. month for Chuuk WSO

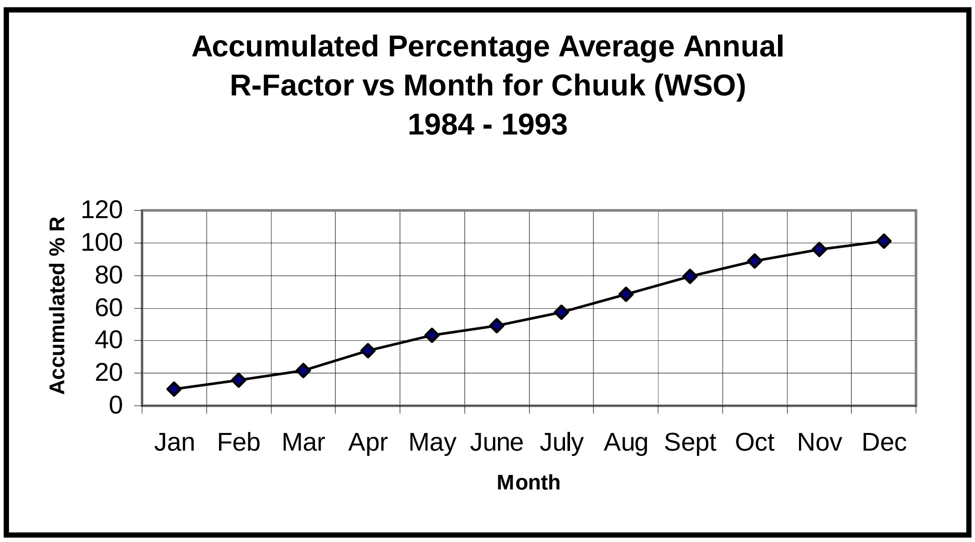

Figure 12. Accumulated percentage average annual R-factor vs. month for Chuuk WSO

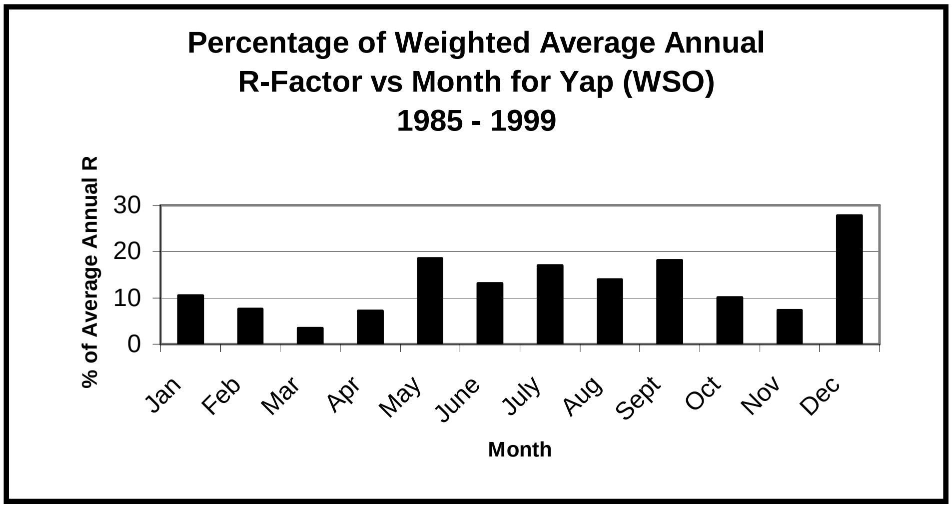

Figure 13. Percentage of weighted average annual R-factor vs. month for Yap WSO

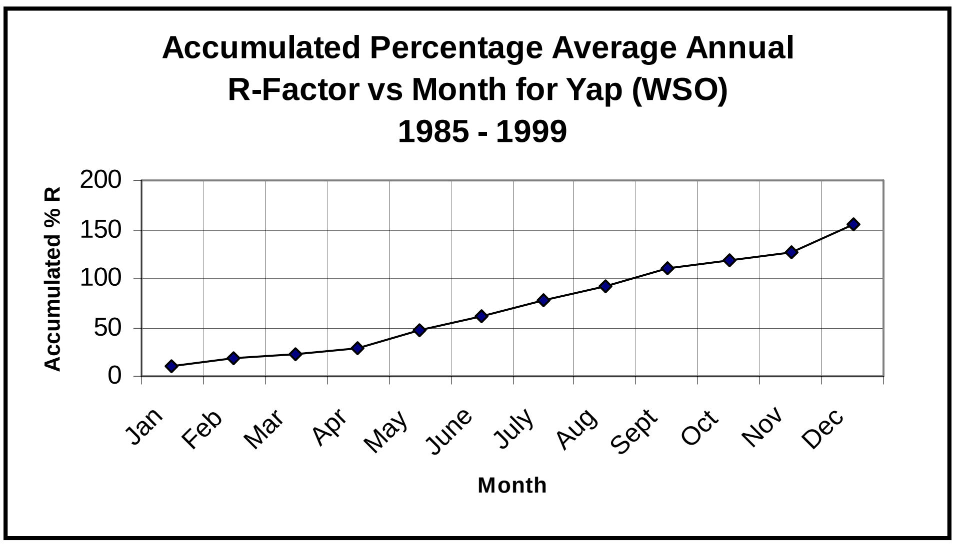

Figure 14. Accumulated percentage average annual R-factor vs. month for Yap WSO

ACKNOWLEDGMENTS

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