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Distribution of Monthly Rainfall in Northeast Thailand

Huynh Ngoc PHIEN,* Anat ARBHABHIRAMA** and Apichai SUNCHINDAH**

Abstract

The distribution in space and in time of monthly rainfall in Northeast Thailand is investigated in this paper, using daily data at 56 stations, each having at least 20 years of continuous record. It was found that monthly rainfall sequences at all stations in this region have six significant harmonics corresponding to six periods: 12, 6, 4, 3, 2.4 and 2 months. At a station, the rainfall sequence in a month can be considered to be independent and can be fitted by the leakage law. Moreover, during the months of April through September, monthly rainfall in the region has a general pattern of increasing values towards the eastern and northeastern sections, while during the months of October to January, it has a general pattern of decreasing values towards these sections. Finally, an assessment of water availability for irrigation is made using the distribution of monthly rainfall and the potential evapotranspiration.

Introduction

Monthly distributions of rainfall in space and time can provide guidelines for crop scheduling, better cropping patterns and the planning and design of water resources development projects. The present study aims at two main objectives: (i) Fitting the distribution in time of the monthly rainfall sequences at various stations in Northeast Thailand, hereafter referred to as the Northeast; (ii) Assessment of water availability for irrigation purposes, based on the most appropriate distribution found in (i) and the evapotranspiration data. In addition, several important characteristics of rainfall sequences in the region such as the periodicity and the degree of irregularity are also presented.

* Division of Computer Applications, Asian Institute of Technology, Bangkok, Thailand
** Division of Water Resources Engineering, Asian Institute of Technology, Bangkok, Thailand

I Study Area and Data Assembly

The Northeast has an area of about 167,300 km^2 and a population of approximately 15 million. It consists of 16 provinces listed in alphabetical order as follows: Buriram, Chaiyaphum, Kalasin, Khon Kaen, Loei, Maha Sarakham, Nakhon Phanom, Nakhon Ratchasima, Nong Khai, Roi Et, Sakhon Nakhon, Si Sa Ket, Surin, Ubon Ratchathani, Udon Thani and Yasothon. (Fig. 1)

The daily rainfall data from 56 rainfall stations in the Northeast were employed in the analysis. These stations were selected using the following two criteria:

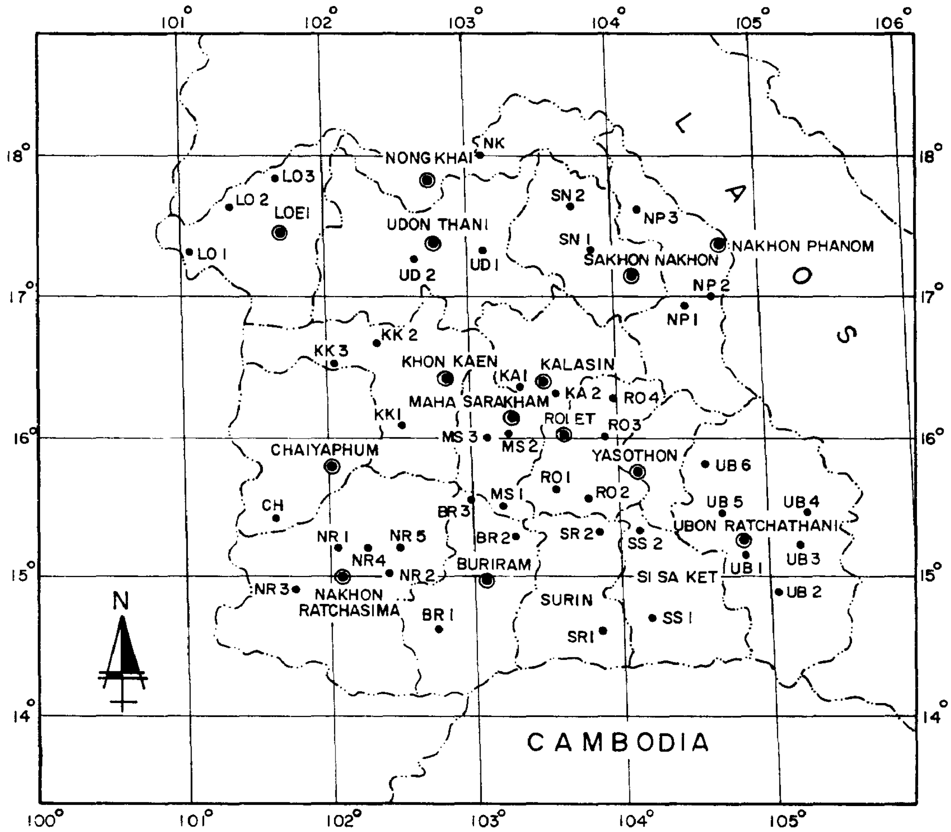

Fig. 1 Map of the Northeast with the Locations of Selected Rainfall Stations

(i) Continuous daily data for at least 20 years should be available for each station.

(ii) Stations should be evenly distributed over the region.

As a result of these criteria, at least two stations from each province were used in this study, except for the province of Yasothon where only one station satisfies the stated criteria. The stations located at the provincial capitals are designated by their respective names while the remaining ones are denoted by abbreviations as shown in Fig. 1.

The data were processed according to *water year*, which begins on the 1st of April and ends on the 31st of March of the following year.

The amount of rainfall in a month at a station was obtained by summing up all the daily amounts in that month and the collection of these monthly values over the period of the record formed the monthly rainfall sequence at that station.

II Distribution of Monthly Rainfall Sequences

Periodicity

Due to the periodic motion of the earth around the sun and about its own axis, rainfall, like any other hydrologic event, is believed to have periodic components. There have been several methods for determining the periodicity of a hydrologic sequence such as spectral analysis or harmonic analysis (see, for example, Chow and Karetiotis, 1970; Quimpo and Cheng, 1974), however, the most widely accepted scheme is that of Yevjevich (1972). In this context, the monthly rainfall sequence at a station is considered to be a periodic-stochastic process, with periodicities caused by astronomical cycles and stochasticities being the result of the chance processes in the terrestial environment (Yevjevich, 1976). To determine these periodicities, the method of Yevjevich (1972) was used. Details concerning this method can be found in Tao *et al.* (1976) and in Tao and Delleur (1976). A brief description is given below. The periodic parts of the monthly means and standard deviations are written, using the Fourier series approach, in the following general form:

$$\nu_j = \upsilon + \sum_{k=1}^{m}\left(A_k \cos\frac{\Pi kj}{6} + B_k \sin\frac{\Pi kj}{6}\right) \quad (1)$$

where

ν_j = the periodic part, $j = 1, \ldots, 12$,

υ = the mean of twelve sample statistics υ_j; υ_j being the mean or standard deviation of month j;

A_k, B_k = the Fourier coefficients which can be estimated by the least-squares method, and

m = the number of significant harmonics.

For the k-th harmonic, the ratio

$$(1/2)(A_k^2 + B_k^2)/\text{Variance}\ (\upsilon_j) \quad (2)$$

represents the part of the variance of υ_j explained by this harmonic. The number of significant harmonics is then easily determined using the empirical method of Yevjevich (1972). It was found that monthly rainfall sequences at all stations in the region have six significant harmonics. This means that monthly rainfall can be considered to have a periodic part that consists mainly of six components corresponding to the following six periods: 12, 6, 4, 3, 2.4 and 2 months. Moreover, the variances of the monthly means and monthly standard deviations are explained up to more than 90% by these six harmonics as shown in Table 1 for stations at the provincial capitals. Due to the high proportions of the variances being explained by the periodic parts in the monthly means and standard deviations, the removal of these six periodic components from a rainfall sequence yields a stochastic process stationary in the mean and variance, which is commonly referred to as a weakly stationary process.

Table 1 Percent of Variance Explained by the First Six Harmonics

Station	Mean	Standard Deviation
Buriram	9.925	0.917
Chaiyaphum	0.940	0.938
Kalasin	0.924	0.920
Khon Kaen	0.927	0.937
Loei	0.924	9.921
Maha Sarakham	0.935	0.921
Nakhon Phanom	0.924	0.979
Nakhon Ratchasima	0.931	0.920
Nong Khai	0.919	0.929
Roi Et	0.922	0.919
Sakhon Nakhon	0.917	0.941
Ubon Ratchathani	0.922	0.942
Udon Thani	0.917	0.927
Yasothon	0.927	0.939

Persistence

To examine the influence of rainfall in

a month on the rainfall in the following month at the same station, the serial correlation coefficient was computed. By inspecting the values obtained, it was found that they are very small, and for most cases, they turn out to be non-significantly different from zero by the test of Anderson (1942). Under such a situation, the rainfall sequence at a station for each month can be treated separately.

Distribution in Time

Most of the monthly rainfall sequences in the region were found to have high positive skewness coefficients. It is well-known that for positively skewed sequences, lognormal and gamma distributions often yield the best fits. However, the monthly rainfall sequences in the region, especially those in the dry season, consist of several zero values, which make these two distributions unsuitable (see Mekong Secretariat, 1974). Instead, the leakage law (in French: loi des fuites) was employed. This distribution is defined as follows:

$$P(R=0)=\exp(-a) \tag{3}$$

$$P(x<R<x+dx) = (ab/x)^{1/2} \exp(-a-bx) I_1[2(abx)^{1/2}]dx, \quad x>0 \tag{4}$$

where a and b are the two parameters,

I_1 is the modified Bessel function of order 1,

exp is the exponential function, and

R denotes the amount of rainfall.

The mean and variance of the leakage law are given by

$$\mu=a/b \quad \text{and} \quad \sigma^2=2a/b^2 \tag{5}$$

from which the moment estimates of the parameters a and b are obtained as

$$a=2(\bar{R}/S)^2 \tag{6}$$

$$b=2\bar{R}/S^2 \tag{7}$$

where $\bar{R}$ and S are the estimates of μ and σ, respectively.

The likelihood equations and their solutions were given by Buishand (1977). It can be seen from these equations that estimation of the parameters by the maximum likelihood method is complicated and time-consuming. Therefore, only the method of moments (Eqs. 6 and 7) was used. Typical results of fitting monthly rainfall sequences at several stations by the leakage law are given in Table 2, together with the results corresponding to lognormal and gamma distributions, where applicable. The computed values of the Smirnov-Kolmogorov test are always less than the critical values at both the significance levels of 0.01 and 0.05, thus proving the acceptability of the fittings. Since the smaller the value of the test indicates the better the goodness of fit, the above computed values show that there is no absolute superiority of one distribution over the other two, whenever all of them are applicable, because the values of the test corresponding to one distribution is smallest in some cases and largest in other cases. However, the leakage law is relatively superior to the other two distributions because it has the smallest values for the test in most of the cases. The leakage law has a clear advantage

Table 2 Typical Results from Fitting Monthly Rainfall Sequences (For Transitional Months)

Station(+)	Leakage Law			Gamma Distribution	Lognormal Distribution
	a	b	Statistic(*)	Statistic(*)	Statistic(*)
			April		
(1)	4.735	0.061	0.111	0.121	0.147
(2)	8.455	0.104	0.076	—	—
(3)	4.289	0.076	0.059	—	—
(4)	5.077	0.082	0.120	—	—
(5)	6.628	0.056	0.058	0.070	0.097
(6)	2.800	0.041	0.041	0.080	0.097
(7)	3.952	0.040	0.111	0.124	0.123
(8)	6.854	0.093	0.117	0.127	0.157
(9)	8.214	0.090	0.122	0.128	0.152
(10)	5.445	0.068	0.108	0.113	0.138
(11)	6.411	0.086	0.117	0.132	0.161
(12)	4.086	0.054	0.063	0.059	0.111
			October		
(1)	4.380	0.026	0.072	0.092	0.127
(2)	3.558	0.003	0.095	0.111	0.163
(3)	4.028	0.062	0.072	0.088	0.148
(4)	3.580	0.045	0.100	0.130	0.177
(5)	3.923	0.025	0.079	0.086	0.123
(6)	3.832	0.055	0.066	0.083	0.145
(7)	1.842	0.034	0.172	—	—
(8)	7.743	0.048	0.181	0.182	0.210
(9)	2.636	0.046	0.075	—	—
(10)	3.751	0.043	0.102	0.139	0.198
(11)	2.359	0.036	0.132	0.107	0.108
(12)	3.767	0.041	0.061	0.064	0.096

Notes:

(*) Smirnov-Kolmogorov test: Critical value at 5% significance level: 0.27

(−) Not applicable

(+) Stations at provincial capitals

(1) Buriram　(2) Chaiyaphum
(3) Kalasin　(4) Khon Kaen
(5) Loei　(6) Maha Sarakham
(7) Nakhon Phanom　(8) Nakhon Ratchasima
(9) Nong Khai　(10) Roi Et
(11) Sakhon Nakhon　(12) Ubon Ratchathani

over the lognormal and gamma distributions when the sequence under consideration contains zero values.

To show the seasonality of rainfall in the Northeast, the monthly means at some representative stations were plotted in Fig. 2. These graphs clearly indicate that monthly rainfalls in the region fluctuate greatly from month to month. In general, monthly rainfall at a station increases from April until a maximum value is reached in August or September. After that it decreases very rapidly and reaches a minimum value in December or January. The monthly rainfall then starts to increase again and the cycle is repeated.

It should be noted that the months of August and September correspond to the time when depressions and storms from the Vietnamese coast penetrate the region, often bringing along heavy rainfalls and causing severe flooding in many areas. On the other hand, rainfalls at most stations in the region during December and January are almost nil, resulting in long periods of severe drought.

Besides fluctuating considerably from month to month in the year, rainfall in a given month also fluctuates greatly from year to year. This is indicated by the high values of the *variation coefficient*, i.e. the ratio of the standard deviation to the mean, as shown in Table 3. Under such a situation, the common practice of assessing the availability of rain water based on the long-term mean of monthly rainfalls is not reliable. Instead it should

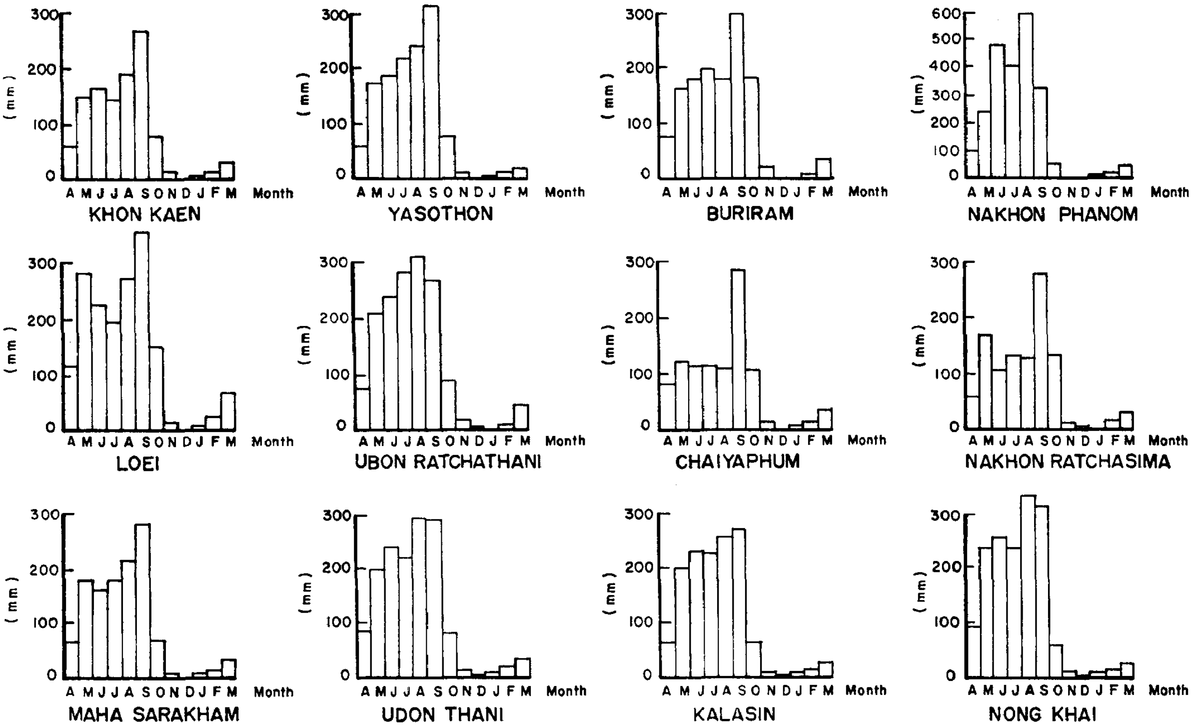

Fig. 2 Mean Monthly Rainfall at Some Representative Stations

Table 3 Variation Coefficients of Monthly Rainfall

Station	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Buriram	0.65	0.51	0.57	0.44	0.39	0.68	1.72	5.02	3.94	2.87	1.80	0.86
Chaiyaphum	0.49	0.42	0.40	0.48	0.75	1.80	2.49	1.89	2.19	1.89	1.54	0.77
Kalasin	0.68	0.51	0.40	0.40	0.46	0.70	2.44	3.26	3.03	2.81	1.21	1.13
Khon Kaen	0.63	0.58	0.60	0.40	0.40	0.75	1.85	2.15	2.31	2.21	1.85	1.16
Loei	0.55	0.46	0.44	0.60	0.40	0.71	1.29	3.09	2.22	1.72	1.10	0.67
Maha Sarakham	0.85	0.53	0.69	0.39	0.32	0.72	1.78	2.42	2.50	3.16	1.55	0.83
Nakhon Phanom	0.71	0.33	0.45	0.26	0.39	1.04	1.84	4.77	3.36	2.36	1.25	0.76
Nakhon Ratchasima	0.74	0.43	0.72	0.52	0.45	0.55	1.90	2.73	2.60	2.62	1.23	1.20
Nong Khai	0.48	0.38	0.35	0.38	0.49	0.81	1.75	2.70	2.52	2.22	1.62	0.88
Roi Et	0.61	0.55	0.36	0.40	0.36	0.71	1.69	3.88	3.51	2.71	1.61	0.50
Sakhon Nakhon	0.56	0.40	0.42	0.44	0.38	0.92	2.13	2.65	2.48	1.98	1.75	0.84
Ubon Ratchathani	0.70	0.64	0.35	0.37	0.34	0.73	1.20	1.94	3.18	2.21	1.75	1.25
Udon Thani	0.66	0.45	0.46	0.29	0.42	0.72	2.05	3.46	3.69	2.78	1.53	0.87
Yasothon	0.86	0.58	0.47	0.36	0.46	0.76	1.87	3.63	2.81	3.99	1.74	1.45

be based upon the distribution of the rainfall sequence. This will be considered later in this paper.

Distribution in Space

Isohyet maps, one for each month, were prepared in order to find how rainfall is distributed over different parts of the Northeast. Shown in Figs. 3 to 6 are four of them; the first corresponds to April, a transitional month between dry season and wet season, the second to August, a month in the rainy season, the third to October, a transitional month

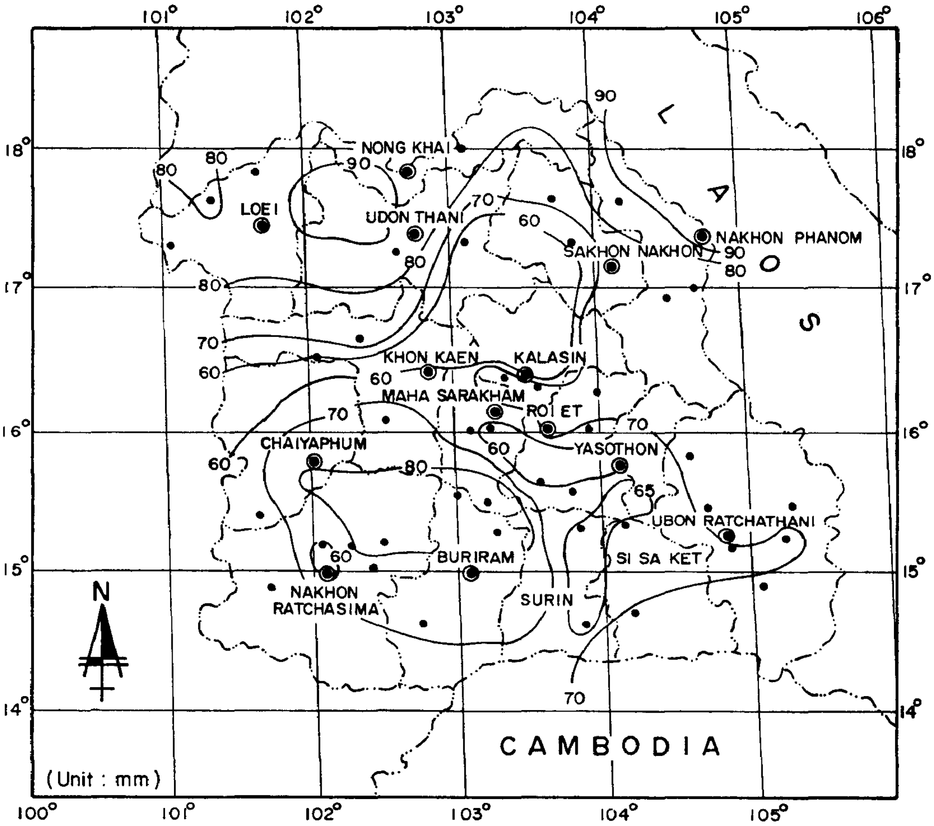

Fig. 3 Isohyets for Mean Monthly Rainfall, April

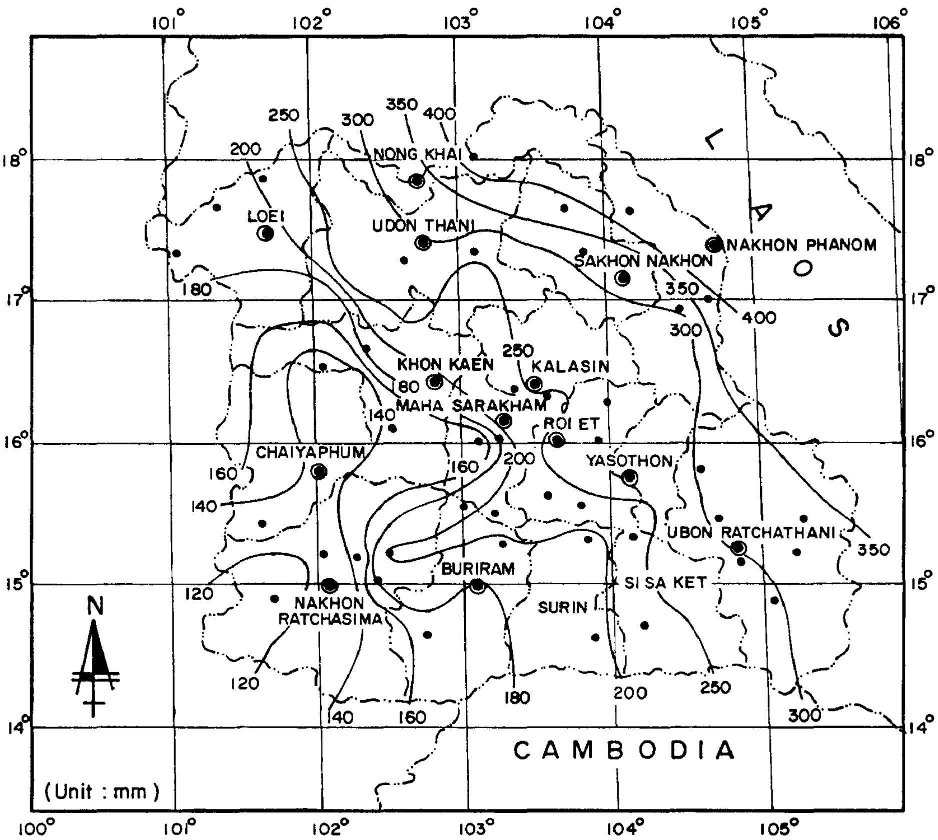

Fig. 4 Isohyets for Mean Monthly Rainfall, August

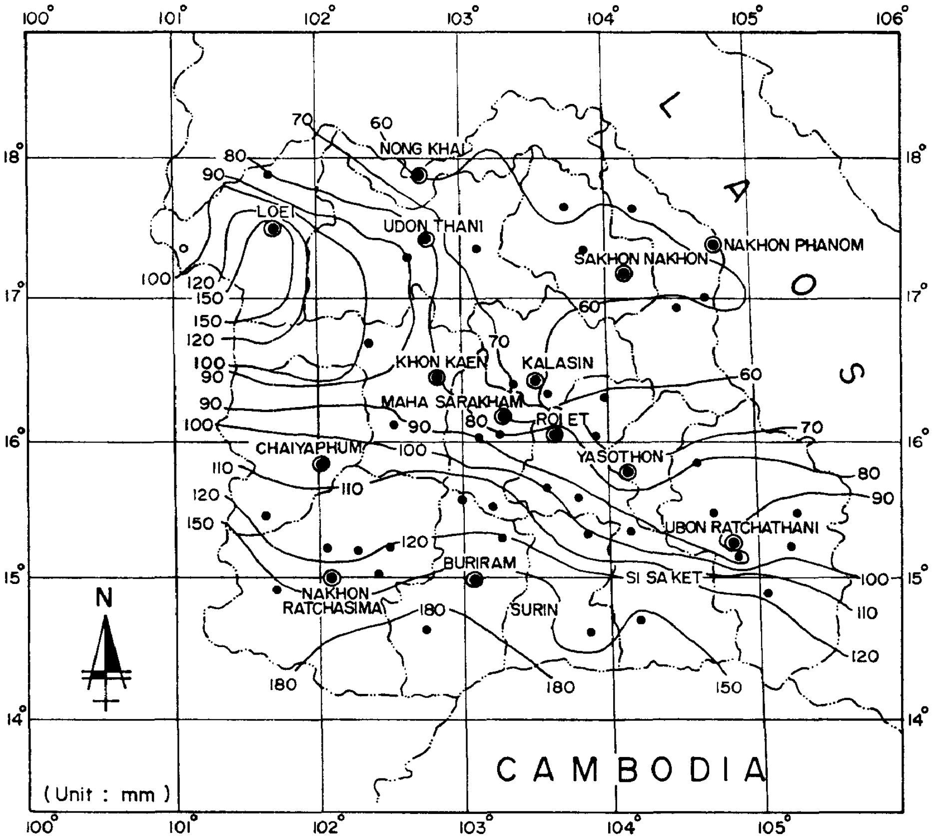

Fig. 5 Isohyets for Mean Monthly Rainfall, October

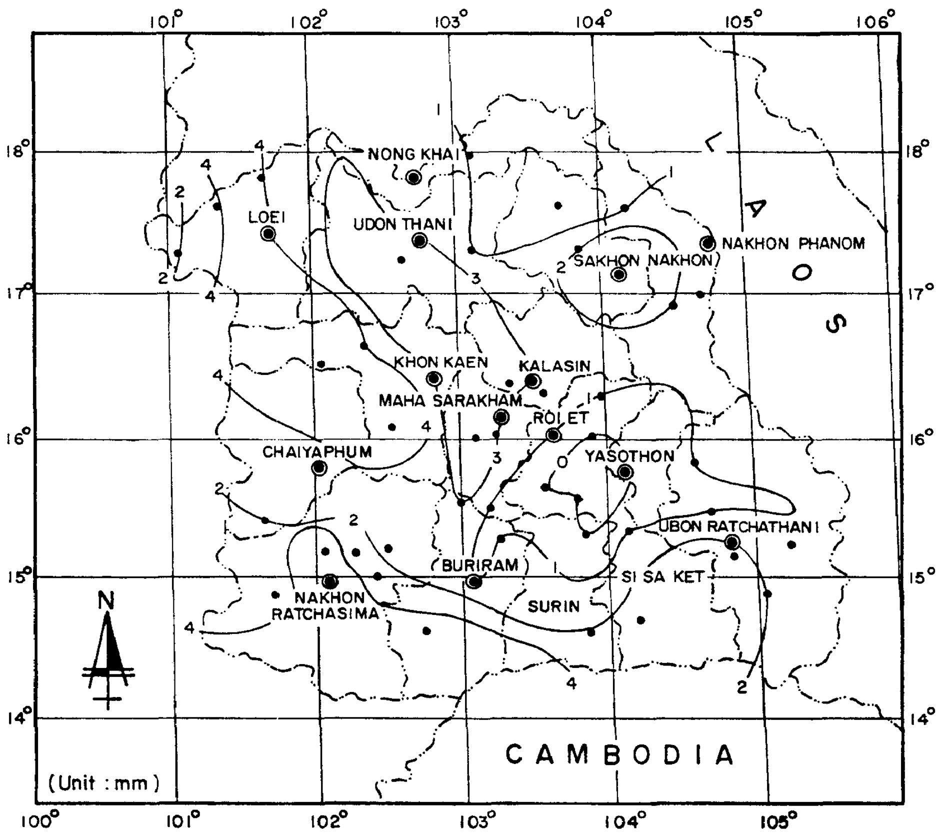

Fig. 6 Isohyets for Mean Monthly Rainfall, December

between wet season and dry season, and the fourth to December, a month in the dry season. From examining all the twelve maps, the following observations were made. During the months of the rainy season, i.e. April through September, the isohyets have a general pattern of increasing values towards the eastern and northeastern sections of the region. From July through September, these two sections have monthly rainfalls exceeding 300 mm. In the months of October to January, when the whole region becomes progressively drier, the isohyets have a general pattern of decreasing values towards the eastern and northeastern sections. Consequently, these sections are the driest parts of the region during this period. The isohyets for February and March do not show any clear tendencies.

Degree of Irregularity

As mentioned earlier, rainfall in the Northeast fluctuates greatly from month to month in the year. In order to express quantatively the variation of rainfall within the year, the concept of the degree of irregularity introduced by Shver (1975) was used. For each month of the year, the ratio $r_j = Pm(i, j)/Py(i)$ is represented by a vector of magnitude r_j making with the horizontal line an angle a_j which is defined by the following equation

$$a_j = 360n_j/365 \quad (8)$$

where n_j is the number of days from the beginning of the year to the middle of month j, $Pm(i, j)$ is the rainfall in month j of year i and $Py(i)$ is the annual rainfall in year i.

Vectors for all months of the year were plotted on a polar diagram representing a bundle of vectors issuing at different angles from a single point. The magnitude D of the vectorial sum of all twelve vectors is called the *degree of precipitation irregularity* which was previously referred to as the *degree of precipitation seasonality* by Shver (1973). If all the months of the year have nearly the same amount of rainfall, D is very close to zero. The higher the value of D, the greater is the fluctuation in rainfall among the different months of the year. Shown in Fig. 7 are the zones in the Northeast having the same mean value of D over the period of the record. It can be seen that the monthly rainfalls in the Northeast have high degrees of irregularity, ranging from 45% to 70% and they tend to fluctuate more greatly towards the eastern and northeastern sections of the region.

Amount of Monthly Rainfall

Ten intervals (0–10 mm, 10–25 mm, 25–50 mm, 50–75 mm, 75–100 mm, 100–200 mm, 200–300 mm, 300–400 mm, 400–500 mm and >500 mm) were selected to distribute the monthly rainfalls in the Northeast. Typical results are summarized in Table 4. It can be seen clearly that the monthly rainfalls in the region mostly fall into the first interval 0–10 mm, indicating that most of the time, the amount of monthly rainfall is quite small. For intervals with larger amounts, the

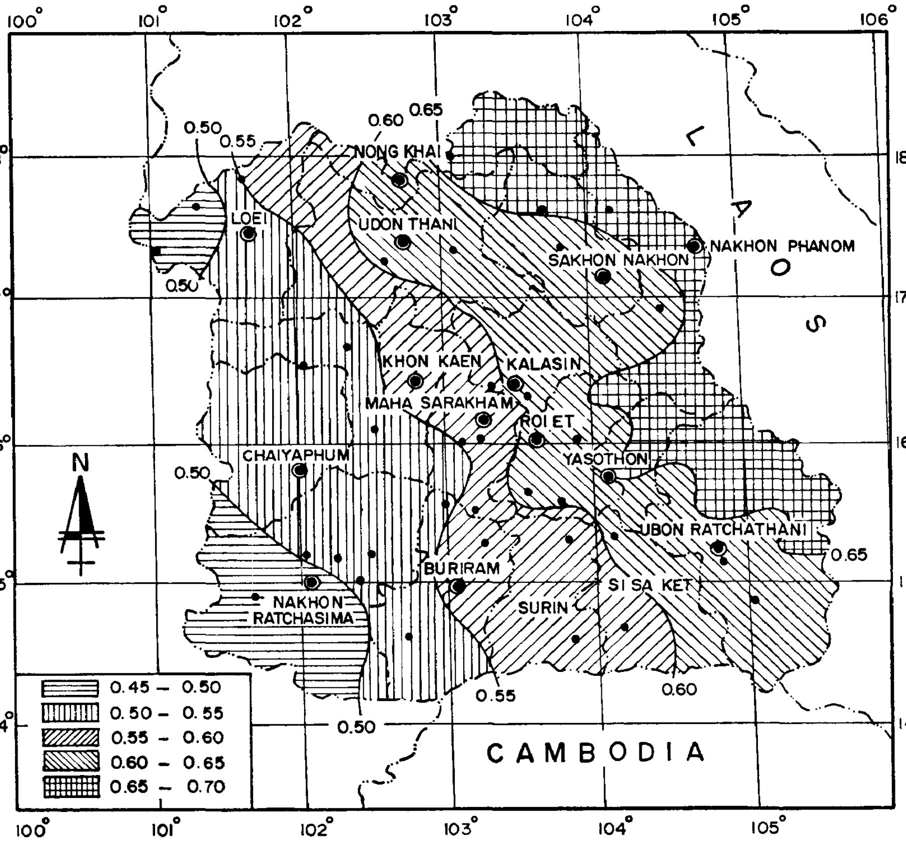

Fig. 7 Degree of Rainfall Irregularity

Table 4 Frequency Distribution of Monthly Rainfall

Station	0–10 mm	10–25 mm	25–50 mm	50–75 mm	75–100 mm	100–200 mm	200–300 mm	300–400 mm	400–500 mm	>500 mm
Buriram	0.31	0.06	0.07	0.05	0.07	0.22	0.15	0.05	0.02	0.00
Chaiyaphum	0.29	0.06	0.09	0.08	0.09	0.28	0.08	0.02	0.00	0.01
Kalasin	0.32	0.06	0.08	0.07	0.04	0.19	0.12	0.08	0.02	0.02
Khon Kaen	0.29	0.08	0.08	0.08	0.07	0.25	0.11	0.02	0.02	0.00
Loei	0.23	0.04	0.07	0.07	0.08	0.20	0.15	0.09	0.03	0.03
Maha Sarakham	0.31	0.06	0.09	0.09	0.08	0.17	0.13	0.07	0.01	0.00
Nakhon Phanom	0.29	0.08	0.08	0.07	0.05	0.19	0.08	0.11	0.03	0.02
Nakhon Ratchasima	0.29	0.06	0.08	0.11	0.08	0.24	0.09	0.03	0.01	0.01
Nong Khai	0.29	0.08	0.08	0.04	0.04	0.16	0.17	0.09	0.02	0.03
Roi Et	0.32	0.05	0.07	0.06	0.04	0.21	0.14	0.06	0.03	0.00
Sakhon Nakhon	0.30	0.06	0.10	0.05	0.06	0.19	0.15	0.07	0.02	0.01
Ubon Ratchathani	0.30	0.07	0.07	0.04	0.05	0.19	0.15	0.08	0.04	0.01
Udon Thani	0.29	0.07	0.07	0.06	0.05	0.18	0.20	0.05	0.03	0.01
Yasothon	0.35	0.06	0.07	0.03	0.08	0.19	0.12	0.08	0.02	0.01

Table 5 Potential Evapotranspiration (mm)

Station	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.
Buriram	209	207	181	180.5	176	162.5	171
Chaiyaphum	206	204	178.5	177	169	150	165
Kalasin	207	203	175	177	166	155	167
Khon Kaen(*)	217	213	182	180	171	159	173
Loei(*)	198	197	171	171	162	151	157
Maha Sarakham	210	208	181	180	172	158	169
Nakhon Phanom(*)	179	176	143	147	142	140	157
Nakhon Ratchasima(*)	205	204	182	180	174	160	167
Nong Khai	194	191	165	168	158	149	161
Roi Et(*)	210	208	180	180	171	156	167
Sakhon Nakhon(*)	196	189	161	170	157	152	165
Si Sa Ket	211	206	177	179	172	159	172
Surin(*)	213	210	180	181	178	165	175
Ubon Ratchathani(*)	209	203	174	177	166	153	170
Udon Thani(*)	204	202	177	180	167	153	165
Yasothon	209	205	177	178	168	154	168

Note: Data for stations marked with (*) were obtained from Mekong Secreteriat (1975). For other stations, etimated values were obtained by taking the average of values at neighboring provinces.

probability of occurrence becomes less. This is in agreement with the fact that monthly rainfall in the region follows positively skewed distributions such as the leakage law.

For irrigation purposes, the two intervals 100–200 mm and 200–300 mm are of important interest (See Table 5). In the interval 100–200 mm, the lowest probability is 9%, the highest is 28% and the average is 20% for the stations listed in Table 4. In the interval 200–300 mm, the lowest probability is 8%, the highest is 20% and the average is 13%. For the last two intervals, monthly rainfalls have very low probabilities of occurrence. This result shows that the rainfall at these stations can hardly amount to more than 400 mm per month.

III Assessment of Water Availability for Irrigation

Using the fact that monthly rainfalls in the Northeast can be fitted very well by the leakage law, an assessment of the availability of water for irrigation purposes in a month can be made by comparing the amount of rainfall corresponding to a specified probability with the potential evapotranspiration in that month. Potential evapotranspiration data employed in this analysis are the monthly mean values and these are shown in Table 5.

For a given month, the amount of rainfall, R, corresponding to a probability p can be determined as follows:

$$p = \text{Probability}\ (X \leq R) = \exp(-a) + \int_0^R \exp(-a-bx)(ab/x)^{1/2} \cdot I_1[2(abx)^{1/2}]dx \quad (9)$$

where X is a random variable representing the rainfall in that month, I_1 is the modified Bessel function of order 1 and a and b are the two parameters of the leakage law. From eq. 9,

$$\text{if } p \leq \exp(-a), \quad R=0 \tag{10}$$

and if $p > \exp(-a)$, R can be obtained by interpolation. Generally speaking, the potential evapotranspiration indicates the water requirement for irrigation purposes. The ratio, r, of rainfall to the potential evapotranspiration therefore represents the portion of water requirement met by rainfall.

For the case $p=0.1$, this ratio was found to be smaller in the dry season (November through March) and larger during the wet season (April through October). In April, the value of r is less than 25% for the entire region. In May, most of the region has values for r ranging from 25% to 50%. Even at this probability, rainfall reaches 150% of the evapotranspiration in the months of July and August in the extreme northeastern part of the region. Shown in Fig. 8 are the isolines of r for the month of July, expressed in percentages, together with a division of the region into five zones. Thus the portion of water requirement met by rainfall in different parts of the region can be clearly seen.

The amount of available rainfall over each part of the region was evaluated for different return periods by varying

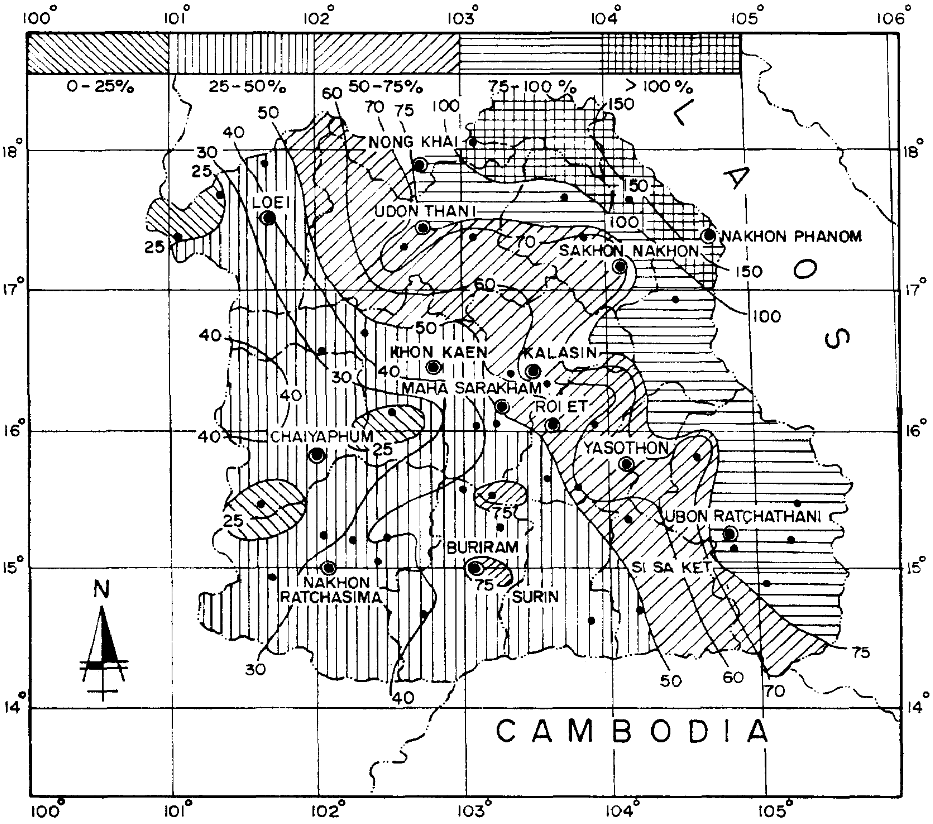

Fig. 8 Isolines of r in percent for $p=0.1$, July

the value of the probability p. The value of r was computed accordingly, and hence an assessment of water availiability for irrigation purposes was achieved. As predicted, even for high values of p, the portion of water requirement met by rainfall was found to be very small during the dry season for the whole region, and hence no rainfed irrigation is expected for any part of the Northeast during this period.

The value of r becomes larger when the region becomes wetter, indicating that rain water can meet a higher portion of irrigation demand. However, during the months of August and September, rainfall is overabundant in the northeastern and eastern sections of the region even for low values of p. During these months, with depressions and storms entering the region, attention should be given to appropriate measures for efficient drainage as well as for flood protection in these sections, rather than just be concerned with having enough water for irrigation.

Summary and Conclusions

In an attempt to provide guidelines for crop scheduling, better cropping patterns and the planning and design of water resources projects in the Northeast, the distribution of monthly rainfall in space and time was investigated in this study. Rainfall data at 56 stations were used in the analysis and from the investigation, the following conclusions can be drawn:

(1) Monthly rainfall sequences in the Northeast can be represented by periodic-stochastic processes in which the periodic parts consist mainly of six constituents corresponding to the following six periods: 12, 6, 4, 3, 2.4 and 2 months.

(2) Rainfall sequences in successive months at a station have very low values for the serial correlation coefficient, indicating that rainfall in a month is independent of rainfall in other months at the same station.

(3) Monthly rainfall sequences in the region are fitted very well by the leakage law. Sequences without zero values are also fitted well by the lognormal and gamma distributions.

(4) Monthly rainfalls in the region vary greatly from month to month, resulting in high values for the degree of irregularity, ranging from 45% to 70%.

(5) Rainfalls in a month fluctuate greatly from year to year.

(6) The maximum monthly rainfall occurs in August or September and the minimum, which is almost nil, occurs in December or January.

(7) The eastern and northeastern sections of the region generally receive the most and the least amounts of rainfall in the rainy and dry seasons, respectively.

(8) The ratio of rainfall at a specified probability level to the potential

evapotranspiration in a month varies from month to month. It has low values in the dry season even at high probability levels and high values in the rainy season even at low probability levels.

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