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Rainfed Irrigation and Drought Conditions in Northeast Thailand

Huynh Ngoc PHIEN* and Apichai SUNCHINDAH**

Abstract

A model is developed in this paper for the computation of effective rainfall on a daily basis and for defining a drought day with regard to paddy irrigation. Assessments of the adequacy of rain water for irrigation, the drought conditions, and the supplementary water requirements are then made.

Introduction

Rainfall is the main source of irrigation water in Northeast Thailand (henceforth referred to as the Northeast) where the inhabitants derive their income mainly from paddy farming. In order to improve their economic conditions, the efficient use of available water is essential.

As seen from a previous study [Phien *et al.* 1980], rainfall in the Northeast varies greatly from month to month. It is almost nil in December and January, and increases considerably afterwards until a maximum is reached in August or September. Rainfall in this region also varies with location. The northeastern and eastern sections of the region are the wettest and driest parts during the wettest and driest periods, respectively.

The uneven distribution of rainfall in space and time poses great problems to crop cultivation in the Northeast. There are shortages of irrigation water in many months of the year while severe floods occur during periods of heavy rainfall in other months. Under such a situation, assessments of rainfed irrigation and drought conditions in the region are needed in order to provide basic information for any attempt to bring about effective usage of available rain water. In this study, these assessments are made with regard to paddy cultivation since rice is the most important agricultural product of the region.

Model Development

Not all the rain that falls at a particular location can be considered to be effective from the standpoint of crop use. Rainfall amounts in excess of the water storage capacity of the paddy field will overflow while that from isolated light showers will be evaporated before penetrating into the ground for the plant roots to absorb. Therefore, the concept of effective rainfall should be introduced. In this study, ef-

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

fective rainfall is considered to be that part of rainfall which is useful directly and/or indirectly to crop development in the area where it falls. Thus, the amount of rainfall which can be regarded as effective depends on several factors such as intensity of rainfall, water storage capacity of the field, drainage characteristics of the soil, etc. Since there is no widely accepted method for effective rainfall computation at present, a model which accounts for the soil moisture conditions is developed in this study. The components of the model are defined as follows.

Basic Effective Rainfall

Since isolated light showers evaporate without penetrating the soil, they should not be considered effective, and the concept of basic effective rainfall (BER) is introduced. It is defined as follows:

$$BER_n = \begin{cases} \text{*rainfall in day } n \text{ if it is} \geq 5 \text{ mm;} \\ \text{*rainfall in day } n \text{ if it is} < 5 \text{ mm} \\ \quad \text{but rainfall in day } n\text{-}1 \text{ is} \geq 5 \text{ mm;} \\ \text{*0, otherwise.} \end{cases} \qquad (1)$$

The value of 5 mm adopted here is based upon past experiences and it is the same as that assumed by the Mekong Secretariat [1974].

Evapotranspiration

There have been many formulas for the estimation of the potential evaporation. The Penman [1948] formula, believed to produce the most accurate results, requires substantial amounts of meteorological data such as solar radiation, temperature, vapor pressure and wind velocity, and consequently, it cannot be applied since these data are not all available for the Northeast. Therefore, after a careful consultation with those involved in several irrigation projects in the region, the values given to the daily potential evapotranspiration (ET) by the Mekong Secretariat [1974] are deemed suitable for use:

$$ET_n = \begin{cases} 6 \text{ mm/day if } BER_n > 0 \\ 3 \text{ mm/day if } BER_n = 0 \end{cases} \qquad (2)$$

This assignment simplifies the computation of potential evapotranspiration. Nevertheless, it clearly reflects the fact that there is more evapotranspiration when rain water is available and less otherwise.

Deep Percolation

Although sandy soils are commonly found in the Northeast, deep percolation in the rainy season can still be neglected because a rather permeable horizontal layer in the soil is created as a result of agricultural practices. In the dry season, deep percolation is obviously negligible.

Water Depth

The water depth (WD) in the paddy field is treated here in an algebraic manner. It is positive above the ground surface and negative below. It has an upper bound which depends upon the height of the bunds. It has been observed that in the Northeast, each bund usually has a notch which allows water to flow from one paddy field to another. The height of these notches is quite low (about 60 mm), thereby limiting the amount of water that can be stored in the paddy fields. For rainfed irrigation, the upper limit of water depth (UP) should be 135 mm as adopted in a publication by the Mekong Secretariat [1975]. This value is used also in the present study. The water depth may have a negative value; this occurs when it does not rain after water depth reaches zero value while evapotranspiration still continues. The lower limit of the negative value depends upon the water holding capacity (WHC) of the soil. For the Northeast, the effective root zone is about 250 mm and the bulk percentage of the soil is about 20%. Therefore the water holding capacity is approximately equal to 50 mm. According to the sign convention adopted here, WHC = −50 mm.

Effective Rainfall

The effective rainfall is computed using the following procedure. First, the water depth in day n, WD_n, is tentatively computed from the continuity equation:

$$WD_n = WD_{n-1} + BER_n - ET_n \quad (3)$$

—If $WD_n > UP$, set $WD_n = UP$, and the effective rainfall in day n, ER_n, is determined by the following equation:

$$ER_n = UP + ET_n - WD_{n-1} \quad (4)$$

—If $WD_n < WHC$, set $WD_n = WHC$, and the effective rainfall is then set equal to zero:

$$ER_n = 0 \quad (5)$$

—If $WHC \leq WD_n \leq UP$, the tentatively computed value of water depth becomes that of the actual water depth in day n, and the effective rainfall is equal to the basic effective rainfall:

$$ER_n = BER_n \quad (6)$$

Thus, the effective rainfall in a day is that part of the basic effective rainfall which can be stored in the paddy field and it is obtained by balancing the different components in the storage equation.

It should be noted that deep percolation is not included in Eq. 3, since it is neglected as previously mentioned. In the case where the tentative water depth in day n exceeds the upper limit (UP = 135 mm), a portion of the basic effective rainfall will overflow.

Drought Day

A drought day is defined here as a day in which the water depth is less than or equal to zero.

In this study, daily rainfall data at 56 stations in the Northeast [Phien *et al.* 1980: Fig. 1] were employed. The model was run on a day-after-day manner so that the carry-over effect could be accounted for. The severity of the drought conditions in each month could then be evaluated by means of the number of drought days and the maximum period of consecutive drought days in that month.

It should be noted that although the model was developed on a daily basis some rough approximations were made and thus the results is good mainly for planning purposes for which a monthly basis is often adopted. Therefore, all the results obtained in this study are presented in this time frame.

Distribution of Monthly Effective Rainfall

Having defined the effective rainfall in a day by the model, one can obtain the effective rainfall in a month by summing up

Table 1 Skewness Coefficients of Monthly Effective Rainfall

Station	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Buriram	0.44	0.51	1.01	0.42	0.60	0.51	0.71	1.76	4.69	2.34	2.04	0.58
Chaiyaphum	0.46	0.42	0.71	0.74	0.63	1.17	0.62	2.55	3.72	2.10	2.33	0.74
Kalasin	1.20	1.32	2.44	0.62	1.32	0.76	0.79	2.89	3.42	3.04	2.98	1.21
Khon Kaen	0.42	0.76	1.28	0.40	0.59	0.60	0.53	2.17	2.21	2.10	2.20	2.69
Loei	0.77	0.49	0.61	1.71	1.26	1.02	0.52	1.37	3.22	1.74	1.30	0.62
Maha Sarakham	1.51	0.74	1.60	0.42	0.59	0.62	0.78	2.47	4.80	2.99	2.31	0.51
Nakhon Phanom	2.02	1.24	0.62	0.73	0.91	0.65	2.48	2.60	4.80	3.55	1.12	0.61
Nakhon Ratchasima	0.68	0.66	0.61	0.66	0.44	0.85	0.55	1.70	2.39	2.35	1.32	0.87
Nong Khai	0.57	0.67	0.78	0.58	0.61	0.87	0.78	2.26	3.70	3.12	2.05	2.47
Roi Et	0.35	1.17	0.72	0.41	0.40	0.72	0.81	2.17	4.80	4.21	1.98	1.91
Ubon Ratchathani	1.13	1.85	0.69	0.45	0.46	0.70	1.17	1.42	3.58	4.80	2.26	1.16
Udon Thani	0.56	0.47	1.88	0.61	0.47	1.27	0.61	3.16	3.36	4.42	2.86	1.07

Table 2 Fitting Monthly Effective Rainfall at Chaiyaphum (1952–1977) by Gamma Distribution and Leakage Law

Month	Gamma Distribution			Leakage Law		
	α	β	Δ*	ρ	θ	Δ*
Apr.	—	—	—	0.099	7.631	0.083
May	—	—	—	0.071	10.355	0.122
Jun.	6.479	19.748	0.174	0.101	12.959	0.100
Jul.	4.778	25.857	0.156	0.077	9.556	0.087
Aug.	3.815	30.950	0.142	0.064	7.631	0.087
Sept.	16.743	10.174	0.196	0.197	33.487	0.174
Oct.	—	—	—	0.050	3.741	0.071
Nov.	—	—	—	0.042	0.475	0.051
Dec.	—	—	—	0.076	0.144	0.033
Jan.	—	—	—	0.126	0.375	0.072
Feb.	—	—	—	0.053	0.656	0.048
Mar.	—	—	—	0.072	2.896	0.145

Notes: (—): Not available
(*): Critical value of Kolmogorov-Smirnov test at significance level of 5 percent is 0.264.

all daily effective rainfalls in that month. By a careful examination of the computed values of the serial correlation coefficient of any two consecutive monthly effective rainfall sequences at a station, it was found that they are insignificantly different from zero, as indicated by, for example, the test of Anderson [1942]. The insignificance of the serial correlation does not necessary mean the independence of two consecutive sequences, but in practice, under such a situation, the effective rainfall sequence at a station for each month can be treated separately, like in the previous paper [Phien *et al.* 1980].

Monthly effective rainfall sequences at

various stations in the Northeast were found to have high skewness coefficients. Typical values are shown in Table 1. Thus fitting these sequences by the gamma distribution and the leakage law [Buishand 1977] should be most appropriate. Shown in Table 2 are the results of fitting monthly effective rainfall at Chaiyaphum by these two probabilistic laws. It should be noted that fitting by the gamma distribution is satisfactory only for sequences without zero values, while fitting by the leakage law is acceptable for sequences with or without zero values.

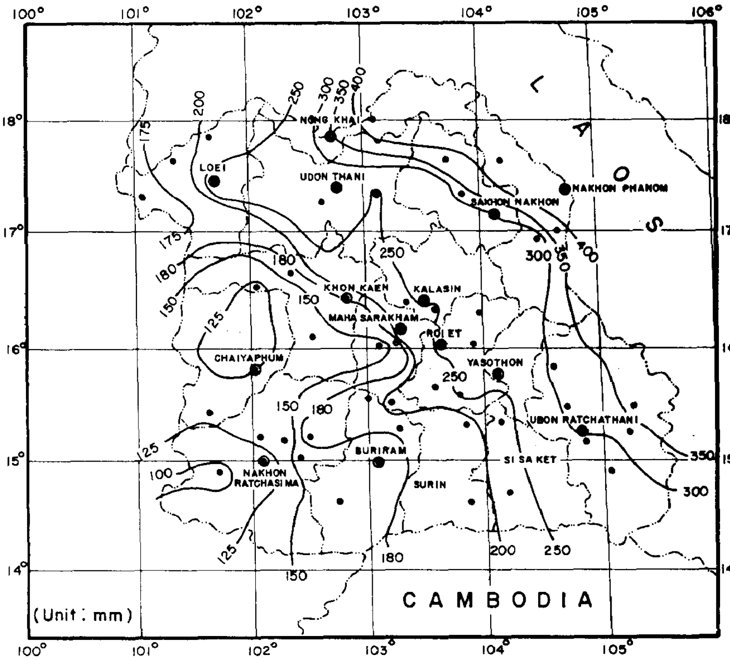

Fig. 1 Isohyets for the Mean of Monthly Effective Rainfall, August

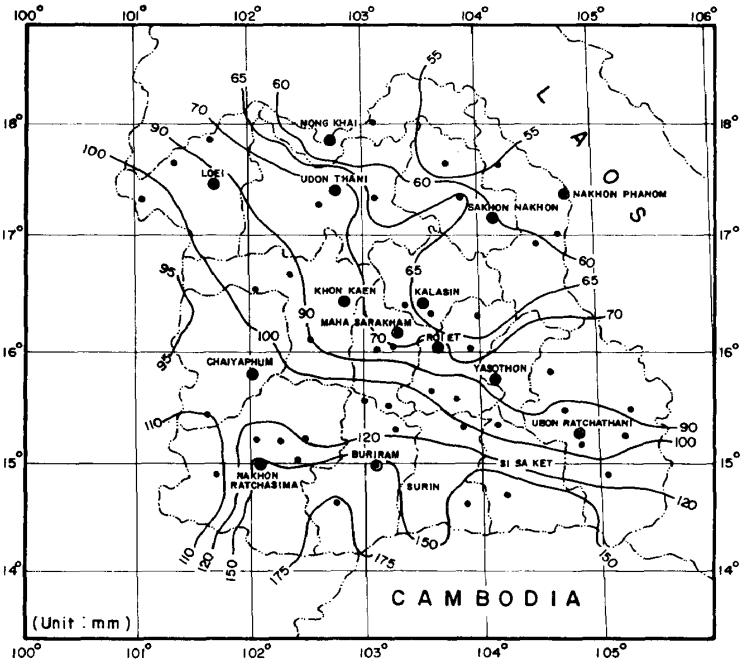

Fig. 2 Isohyets for the Mean of Monthly Effective Rainfall, October

Monthly effective rainfalls in the region have high values for the variation coefficient (the ratio of the standard deviation to the mean) for different months of the year. This means that for a particular month, effective rainfall amounts in different years fluctuate greatly.

In order to provide an overall view of the distribution of effective rainfall over the region, isohyetal maps for the twelve months of the year were prepared, using the means of monthly effective rainfalls at the aforementioned 56 stations. By inspecting these maps, the following conclusions can be drawn:

(1) In the rainy season from April through September, the isohyets have a general pattern of increasing values towards the eastern and northeastern sections of the region. A typical isohyetal map is shown in Fig. 1 for the month of August. The highest amount of effective

rainfall in the region usually occurs in August or September, during which depressions and typhoons from the Vietnamese Coast often reach the Northeast. For the months July through September, the effective rainfalls in the eastern and northeastern sections amount, on the average, to more than 250 mm.

(2) On the contrary, in the months from October through January of the dry season, the isohyets have, roughly speaking, a general pattern of decreasing values towards the aforementioned sections (see Fig. 2 for the month of October). These sections have the least amounts of effective rainfall in the region during the months of October through December.

In summary, monthly effective rainfall in the Northeast has properties quite similar to those of the monthly rainfall in that region (see Phien *et al.* [1980]). This is expected, since the same value of daily potential evapotranspiration is assigned to the whole region. Only some slight change may result from the imposed upper limit of the water depth in the paddy field, as well as from neglecting isolated light showers in the effective rainfall competation.

Drought Conditions

In order to evaluate the drought conditions in the Northeast, the number of drought days and consecutive drought days in each month were computed. Maps of the isolines for drought days and consecutive drought days were prepared. Examing these maps (see AIT [1978]) led to the following conclusions:

(1) In the months of July through October, there are several parts of the extreme northeastern and eastern sections of the region where there is no drought day at all (see Fig. 3 for the month of August). This finding is in agreement with the fact that these areas have very high effective rainfalls during this period of the year.

(2) In December, however, the extreme northeastern section undergoes 30 or 31 drought days (Fig. 4). This situation is due to the fact that the rainfall is nearly nil (hence effective rainfall is zero) in this part during this month. As seen also from Fig. 4, there are more than 20 drought days in December for other parts of the region.

(3) In January, the whole region is subjected to severe drought conditions with 30 or 31 drought days.

(4) Among the three remaining months of the dry season, namely, November, February and March, November has the least number of drought days. In November, the extreme Northeastern section has the highest number of drought days but that amounts to 13 days only. The average number of drought days in February is 28 for almost throughout the Northeast, and there are at least 29 drought days all over the region in March.

(5) In any month of the year, the length of the longest period of continuous drought days is not so much different from the number of drought days in that month. This implies that when there is a lack of water ponded in the paddy fields, it normally lasts for several days

rather than just for a few isolated days. Under such a situation, care should be devoted to the selection of planting dates in order to limit the effect of severe drought conditions on various stages of the plant development. However, such a situation also makes it easier for the provision of supplementary water.

It should be noted that with regard to longest periods of drought, September and October have the smallest values. During these two months, the northeastern and eastern sections of the Northeast do not have any drought period which lasts for more than one day.

Another interesting result is that although the amounts of rainfall and effective rainfall in October are less than those in August for almost all over the Northeast (see Figs. 1 and 2, and Phien *et al.* [1980: Figs. 4 and 5]), the region is in a better situation in October than in August with regard to the two drought indicators, namely, the number of drought days and the length of the longest drought period. This may be due to carry-over effect taken into account by the present model.

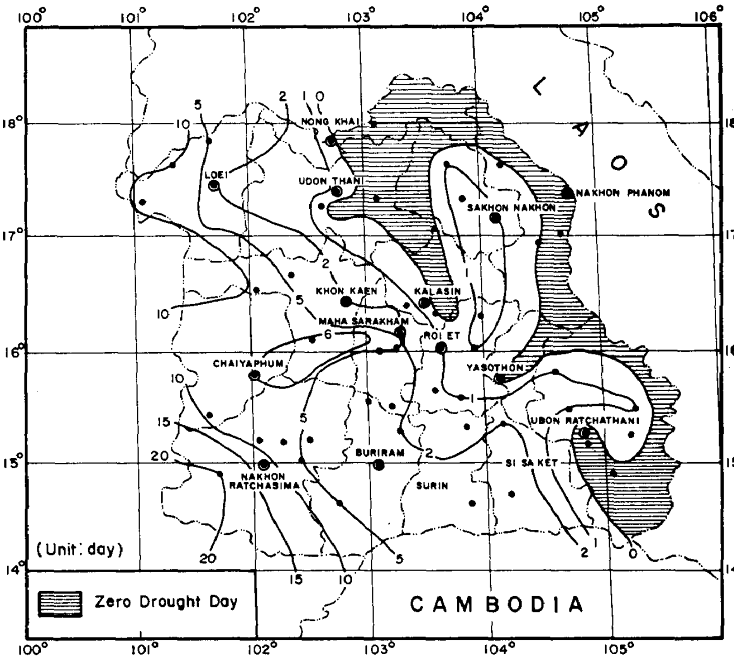

Fig. 3 Isolines of the Monthly Mean of Drought Days, August

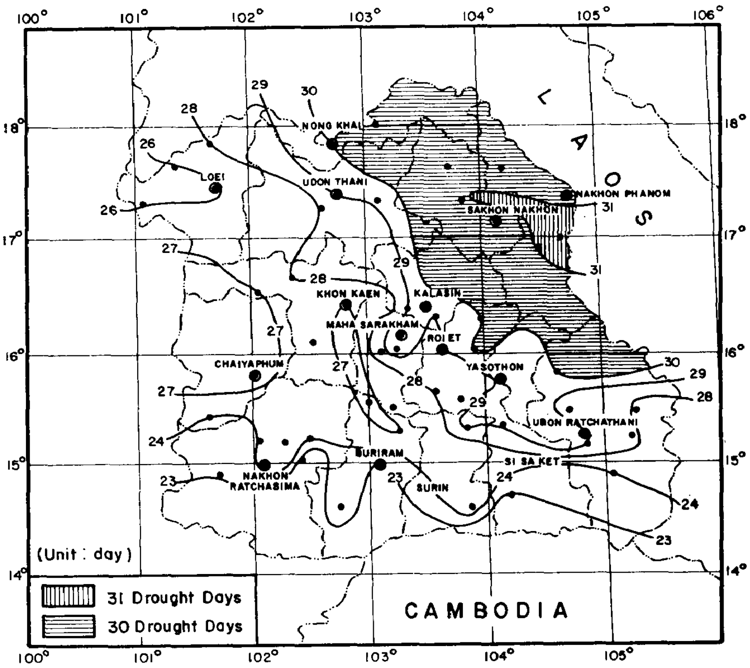

Fig. 4 Isolines of the Monthly Mean of Drought Days, December

Assessment of Rainfed Irrigation

Having defined the effective rainfall, one can evaluate the adequacy of rainfed irrigation. For the Northeast, rainfed irrigation is not possible in the dry season (November through March) because of rainfall scarcity. Therefore, rainfed irrigation is assessed only for the rainy season from April to October. From inspecting the historical record of rainfall in the region, it is reasonable to assume that during the rainy season, the number of days in which rainfall is negligible (or basic effective rainfall, BER, is zero), is 17 days and in the rest of a month (about 13 days), BER$>$0. While available soil moisture could account for the potential evapotranspiration when BER$=$0 (i.e., 3 mm/day), effective rainfall must account for the potential evapotranspiration when BER$>$0. Thus 75 mm ($\simeq$6 mm$\times$13) of effective rainfall is required in each month of the rainy season to ensure continuous development of paddies. This value was also adopted by the Mekong Secretariat [1974]. The results of the assessment are regionalized using the following classification:

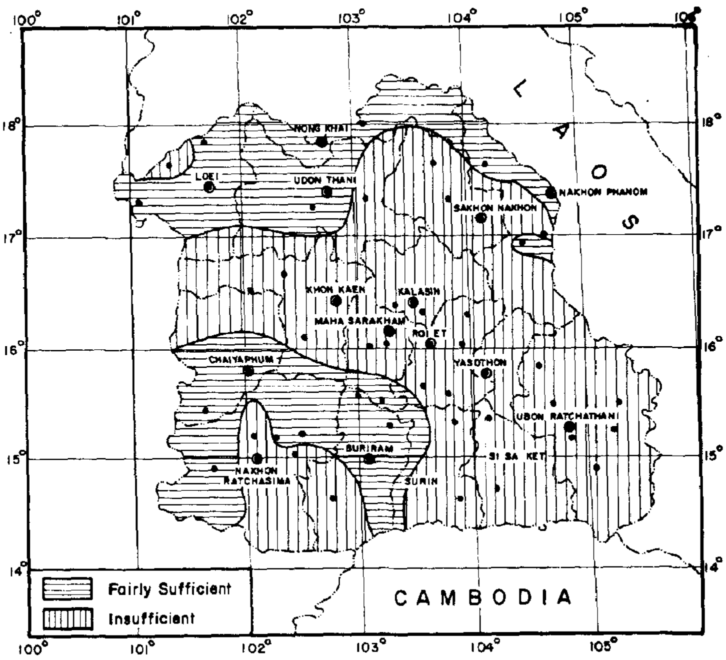

Fig. 5 Assessment of Rainfed Irrigation, April

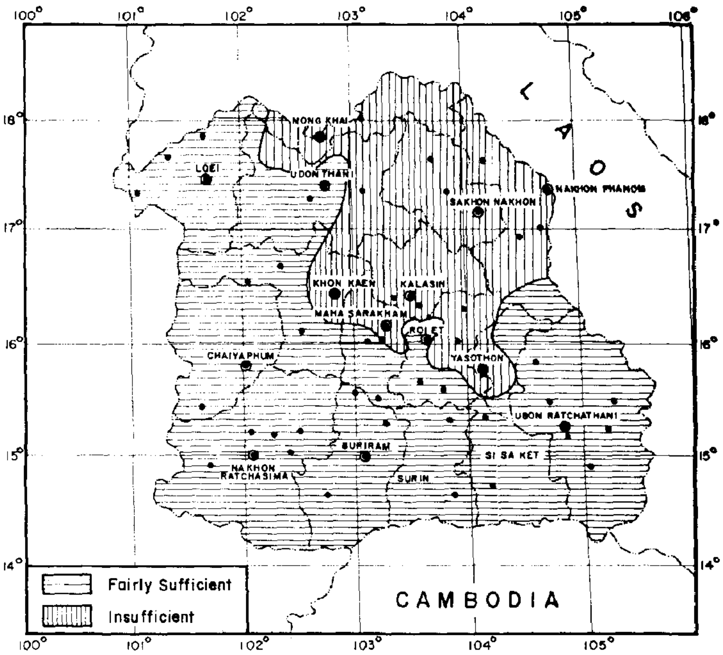

Fig. 6 Assessment of Rainfed Irrigation, October

(1) If $\overline{ER}\leq 75$ mm, and
  (i) if $\overline{ER}+S\leq 75$ mm, rainfall is completely insufficient,
  (ii) if $\overline{ER}+S>75$ mm, rainfall is insufficient.

(2) If $\overline{ER}>75$ mm, and
  (i) if $\overline{ER}-S\leq 75$ mm, rainfall is fairly sufficient,
  (ii) if $\overline{ER}-S>75$ mm, rainfall is sufficient.

In these expressions, $\overline{ER}$ and S stand for the mean and standard deviation of monthly effective rainfall, respectively. The results of this regional assessment can be summarized as follows:

(1) In the two transition months, namely April and October, rainfall is either insufficient or fairly sufficient for rainfed irrigation throughout the region.

In April, the area with insufficient rainfall is larger than that with fairly sufficient rainfall (Fig. 5). However, the reverse is true for the month of October (Fig. 6).

(2) For the months from May through August, only two situations are found: rainfall is either fairly sufficient or sufficient. Except for the month of May, the northeastern and eastern sections of the region have sufficient rainfall for irrigation. The area with fairly sufficient rainfall diminishes from June to September and completely disappears in September, during which there is sufficient rainfall all over the region.

(3) The situation where rainfall is completely insufficient is not encountered in the rainy season.

Supplementary Water Requirement for Irrigation

Supplementary water required during the rainy season is estimated by assuming that the total water supply should be 125 mm per month. Having assumed that soil moisture accounts for up to 50 mm, one can determine the supplementary water required by the following equation:

Total water required (125 mm)
=ER+soil moisture(50 mm)
+supplementary water required

or

Supplementary water required
=75−ER (7)

where ER is the monthly effective rainfall, in mm.

In the actual computation, the mean value, $\overline{ER}$, of effective rainfall is used instead of the effective rainfall itself. To be on the safe side, the supplementary water in each month is computed as:

Supplementary water required (mm)
=75−($\overline{ER}$−S)

where S is the standard deviation of effective rainfall as previously employed.

Typical results are shown in Figs. 7–8 for the transition months (April and October), in which the isolines of required supplementary water are sketched. It was found that no supplementary water is needed for the month of September as was observed in the assessment of rainfed irrigation.

In this study, the leakage law was used to fit monthly effective rainfall sequences

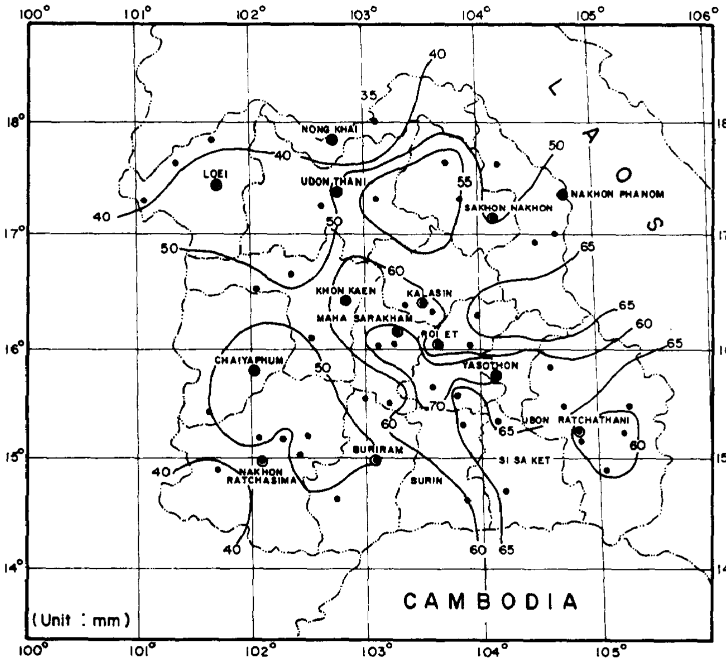

Fig. 7 Isolines for Monthly Supplementary Water Requirement, April

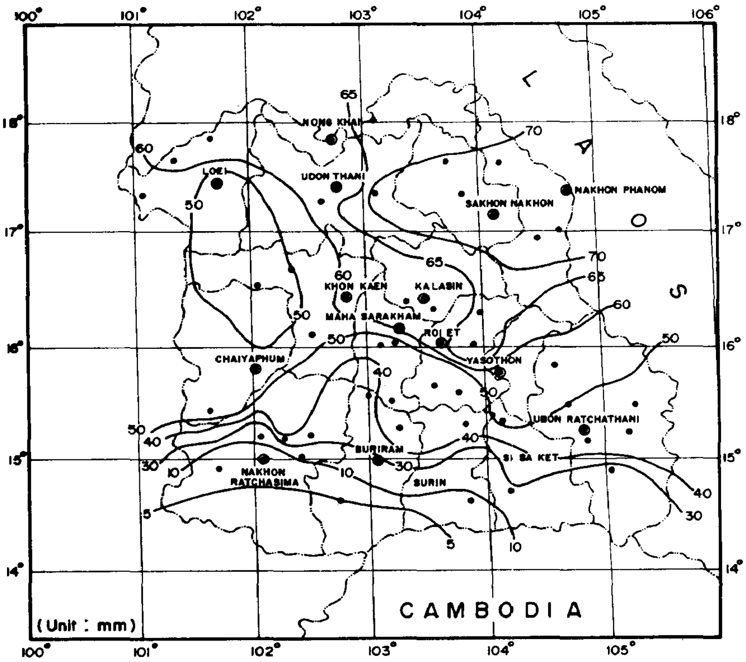

Fig. 8 Isolines for Monthly Supplementary Water Requirement, October

in the Northeast since many of them contain zero values for several months of the year. With this fitting, the risks or probabilities of facing water shortages were also computed. The results at several selected stations which are located at the provincial capitals are shown in Table 3. It can be seen that the risks of facing water shortages are rather small when supplementary water is provided up to the computed values.

Summary and Conclusions

In order to assess the rainfed irrigation and drought conditions in Northeast Thailand, a simple model of balancing type was developed in this study for the determination of effective rainfall with regard to irrigation of paddy fields. In the model, (i) the daily effective rainfall is treated as that part of rainfall which can be stored

Table 3 Irrigation Water Requirements and Corresponding Risk of Water Shortage

Station	April		May		June		July		August		September		October	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Buriram	49.5	0.148	3.4	0.152	2.7	0.151	0.0	0.193	0.0	0.193	0.0	0.206	22.9	0.147
Chaiyaphum	37.7	0.153	0.0	0.180	0.0	0.183	8.1	0.154	10.8	0.157	0.0	0.154	52.0	0.143
Kalasin	61.2	0.145	0.0	0.153	33.9	0.141	0.0	0.160	0.0	0.153	0.0	0.156	59.3	0.145
Khon Kaen	56.1	0.148	19.9	0.150	14.1	0.150	0.0	0.159	0.0	0.160	0.0	0.159	61.2	0.142
Loei	28.3	0.151	0.0	0.155	0.0	0.158	5.3	0.150	0.0	0.157	0.0	0.159	38.0	0.144
Maha Sarakham	69.6	0.137	0.0	0.153	34.3	0.145	0.0	0.159	0.0	0.158	0.0	0.160	59.5	0.144
Nakhon Phanom	53.1	0.144	0.0	0.160	0.0	0.157	0.0	0.160	0.0	0.160	0.0	0.159	75.0	0.0
Nakhon Ratchasima	44.4	0.152	6.7	0.153	21.9	0.153	9.5	0.158	22.7	0.152	0.0	0.160	1.4	0.153
Nong Khai	34.3	0.153	0.0	0.160	0.0	0.160	0.0	0.160	0.0	0.160	0.0	0.154	67.5	0.139
Roi Et	48.7	0.149	0.0	0.151	0.0	0.160	0.0	0.159	0.0	0.158	0.0	0.160	57.6	0.143
Sakhon Nakhon	49.4	0.150	0.0	0.159	0.0	0.158	0.0	0.156	0.0	0.151	0.0	0.160	75.0	0.0
Ubon Ratchathani	59.2	0.144	10.5	0.148	0.0	0.160	0.0	0.160	0.0	0.160	0.0	0.160	58.3	0.142
Udon Thani	51.7	0.147	0.0	0.154	0.0	0.156	0.0	0.160	0.0	0.159	0.0	0.159	57.0	0.144
Yosothon	69.5	0.137	5.6	0.151	0.0	0.154	0.0	0.160	0.0	0.160	0.0	0.156	58.5	0.143

Notes: 1. Water Requirement in mm
2. Risk (Probability) of Water Shortage

in the paddy fields as ponded water above the ground surface or as soil moisture below it, (ii) A drought day is a day in which no rain water is ponded in the paddy fields. The model was run on a day-after-day manner using daily rainfall data at 56 stations in the region.

From the analysis, the following conclusions were reached:

(1) Monthly effective rainfall sequences in the Northeast are fitted well by the leakage law.

(2) The eastern and northeastern sections have the highest values for effective rainfall in the rainy season from April through September and have the least amounts of effective rainfall during the months from October to December.

(3) Some areas of the extreme northern and eastern sections have no drought day at all from July to October. However these areas also undergo the most severe drought conditions in the months from October to December.

(4) In January, the whole region is subject to severe drought conditions with 30 or 31 drought days.

(5) In any month of the year, the longest period of continuous drought days is quite close to the number of drought days in that month. Thus when there is a lack of water ponded in the paddy fields, the situation is likely to last for several days.

(6) In April and October, rainfall is either insufficient or fairly sufficient for rainfed irrigation all over the region.

(7) From May to August, rainfall is either fairly sufficient or sufficient. The area with fairly sufficient rainfall diminishes from June to September and completely disappears in September.

(8) Supplementary water required for irrigation is rather high in April and October. No supplementary water is needed for the whole region in September, and also for many places in May, June, July and August.

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