RAINFALL DISTRIBUTION IN WEST TIMOR: TEMPORAL AND SPATIAL CHARACTERISTICS, REGIONAL FREQUENCY ANALYSIS AND DROUGHT IDENTIFICATION

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RAINFALL DISTRIBUTION IN WEST TIMOR:

Temporal and Spatial Characteristics, Regional Frequency Analysis and Drought Identification

By

©OBET SABETU

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ABSTRACT

This study of rainfall distribution in West Timor is concerned with the analysis of temporal and spatial rainfall characteristics, regional frequency analysis of annual daily maximum rainfall and pentad (5-days) drought analysis. Several statistical properties such as persistency, trend and seasonality of rainfall series, and also physical factors such as topography and prevailing winds are used to describe the general characteristics of rainfall. The index-rainfall and L-moment approaches are used to provide a regional probabilistic model of annual daily maximum rainfall and, for comparison, the at-site frequency of selected gauges is analyzed. Probability analysis is used to describe pentad drought properties such as onset and end of the rainy season, severity, and vulnerability of drought.

The results of this study show that the rainfall characteristics in West Timor are variable in time and space. The prevailing wind system and topography are the dominant physical factors affecting the spatial and temporal distribution of rainfall in this region. West Timor can be classified into one homogenous rainfall region based on annual daily maximum rainfall analysis, but into two homogenous rainfall regions based on monthly rainfall analysis. The Gumbel distribution is an acceptable model for at-site and regional frequency analysis.

The severity and vulnerability of drought is significant even in the wet season. At site 6 for example, only two months in the wet season are wet enough for rice, and only four months for dry land crops at a reliability level of 75%. The results of this study should provide better guidance to engineers involved in irrigation and agricultural planning in West Timor. In addition, the results obtained provide an up date of an earlier study by Crippen Consultants (1980).

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Abbreviations

#	= number of occurrences
$\bar{x}$	= sample mean
$\bar{R}$	= mean annual rainfall
$\bar{l}^{(i)}_r$	= sample L-moments at site i, where r is 1, 2, 3, 4
ACF	= Auto Correlation Function
CS	= coefficient of skewness
CV	= coefficient of variation
CV of CV	= coefficient of variation of CV
$CV_{\bar{x}}$	= coefficient of variation of the mean of x
CV_E	= existing CV
CV_R	= required CV
D_i	= discordance of measure at site i
k	= lag
K	= Hurst's coefficient
L-moments	= linear combinations of order statistics
Log	= natural logarithm
$\bar{x}_n$	= mean rainfall for month n

N, n	= number of sites, sample length, new number of rainfall stations
NTT-WRDS	= Nusa Tenggara Timur Water Resources Developement Service
PACF	= Partial Auto Correlation Function
PPCC	= Probability Plot Correlation Coefficient
$\bar{t}_r$	= weighted average sample L-moment ratios, where r is 1, 2, 3, 4
R	= range of the cumulative departure from the mean
r_k	= correlation coefficient at lag k
S	= sample standard deviation
SI	= Seasonality Index
$t^{(i)}{}_r$	= sample L-moment ratios at site i, where r is 1, 2, 3, 4
$V_{\bar{x}}$	= variance of the mean of x
V_x	= variance of x
x_i	= observed data at site i
WMO	= World Meteorological Organization

Chapter 1

Introduction

1.1 Background and Objectives

The region under study in this thesis, West Timor, is the western part of Timor Island, Indonesia. West Timor is located in southeastern Indonesia as shown in Figure 1.1. The region lies between $8^0 15'$ and $10^0 24'$ south latitude and $120^0 15'$ and $125^0 25'$ east longitude, and has an area of 15,000 km^2. The population of West Timor is 1.10 million according to the 1990 census, which is equivalent to 77 people per km^2. In this region, most of the inhabitants derive their income from farming. There are two main agricultural products coming from this region: rice and dry land crops. Typical dry land crops include corn, soya beans and sorghum. The potential area of cultivation is 50,000 ha for rice and 1,500,000 ha for dry land crops. On average only 30% of the land is suitable for farming. Since rainfall in this region is extremely variable both in space and time, several areas suffer from severe floods during periods of heavy rainfall, and experience droughts during the dry season and also at certain times during the wet season.

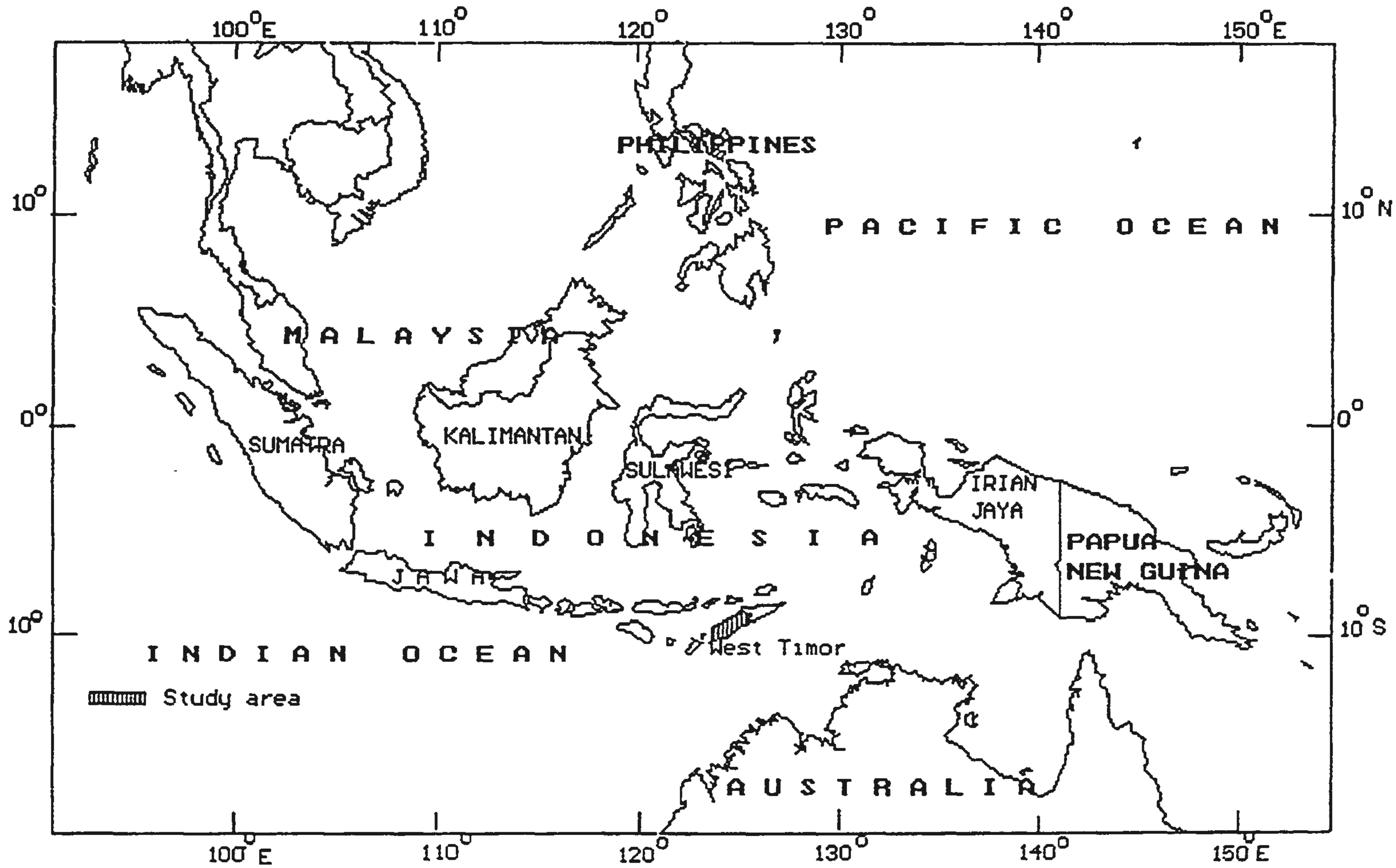


Figure 1.1 Map of Indonesia and the study area

Most rainfall occurs during the wet season, from November to April. Heavy rainfall results in rapid runoff due to the physiography of the island. The slope, soil surface cover and soil do not retain moisture that can be used for crops. During the wet season, periods of more than two or three weeks without rain are frequent. Zero rainfall is common during the dry season, from May to October, for periods of one to four months or more in some areas. This great variability in rainfall affects crop productivity, and poses problems to farmers. Supplemental irrigation and irrigation schedules therefore become necessary to maintain acceptable crop yields. In order to provide reliable information for agricultural and irrigation planning and management, analyses and interpretation of the spatial and temporal rainfall distribution in West Timor are required. Such planning is particularly concerned with three factors: the probable start of the growing season, the rainfall availability for rice and dry land crops, and the frequency and occurrence of excessive rainfall or drought during the growing season. The principal objectives of this thesis are therefore to analyze and better describe these three factors.

To minimize the effects of rainfall variability in West Timor, about one hundred small dams and artificial ponds have been built to store rain water by the Government in certain parts of West Timor for supplemental irrigation water and other needs. Due to financial constraints, non-structural alternatives such as proper planning and management are also needed to maintain good production and reduce losses.

Earlier studies, (e.g Crippen, 1980) were carried out with fewer rainfall data and provide only a preliminary description of rainfall distribution in West Timor. Crippen (1980) divided West Timor into three hydrologic regions based on major drainage basins and rainfall amounts. These regions are: north, southwest and, southeast region as shown in Figure 1.2. These hydrologic regions were initially used as a base in this study to determine the rainfall characteristics of each region. The boundaries of the regions may change because of the availability of more data since the Crippen report.

This study analyzes rainfall distribution in West Timor. Study objectives are threefold:

(1) to investigate the spatial and temporal characteristics of rainfall in West Timor;

(2) to identify a regional frequency distribution for annual daily maximum rainfall for the purpose of extreme rainfall analysis; and

(3) to investigate the drought characteristics of the region, based on pentad data.

This study proposes to make use of the available data, in order to find practical and accessible alternatives for agricultural and irrigation planning and management.

1.2 General I· ˀormation Pertaining to the Region

For the most part, the topography of West Timor is extremely rugged, and 79% of the region has an elevation of more than 100 m. The highest mountain, Mt. Muttis, has an elevation of 2,427 m although the island is less than 80 km wide. The heavy rainfall results in rapid runoff, and the rivers have steep bed slopes which carve deep valleys and deposit extensive alluvial fans along the coastal plains.

Most of the vegetation in West Timor are composed of tropical savanna grassland. On a small part of the region, especially on the mountain ridge, there are little of vegetation.

The climate of the region is classified as tropical monsoon and is dominated by the West-Northwest and East-Southeast monsoons. The wet season is from November to April during the West-Northwest monsoon, and the rest of year is the dry season during the East-Southeast monsoon. The range of mean annual rainfall is high, from 700 mm to 2500 mm, depending chiefly on elevation. On average, monthly rainfall of greater than 100 mm occurs only during a period of four months, December to March, and dry periods are frequent during the wet season, particularly on the plains near the coast. The mean maximum daily temperature is usually between 29°C and 33°C depending on elevation, and the mean minimum daily temperature may range from 21°C to 24°C depending on elevation. The lowest mean daily humidity occurs during the East-Southeast monsoon, and ranges from 40% to 50% depending on elevation.

1.3 Data Sources

The primary sources of rainfall data for this study are the records of the Water Resources Development Service of Nusa Tenggara Timur Province (NTT-WRDS) in Kupang, Timor. There are more than sixty rainfall stations with daily measurements using Indonesian raingauge standard and only six automatic rainfall recorders using US raingauge standard (Crippen, 1980) in West Timor. Most of the rainfall stations were installed after 1975. The locations of the rainfall stations are shown in Figure 1.2 and are listed in Table 1.1.

As shown in Table 1.1, the daily rainfall data cover approximately nine to twenty three years of observations, and only four sites cover more than fifty years of observations. Unfortunately, only one station has hourly rainfall records for a full year.

These rainfall stations are not uniformly distributed throughout the region and they do not have equal recording periods. Data from several of them have many gaps and inconsistencies. For this study, only rainfall records that are at least 10 years in length with no gaps, were considered.

1.4 Outline of the Thesis

This chapter presents the problem of variability of rainfall and their effects on crop yields. The general methodology of characterizing the rainfall are presented in Chapter 2, and Chapter 3 discusses the results of this analysis. Chapter 4 describes the methodology of regional and at-site frequency analysis of the annual daily maximum rainfall, and Chapter 5 discusses the results of this analysis. Pentad drought analysis is presented in Chapter 6. The conclusions and recommendations of this study are presented in Chapter 7. Appendices contain the basic statistical theory and the computer programs developed pertaining to this study.

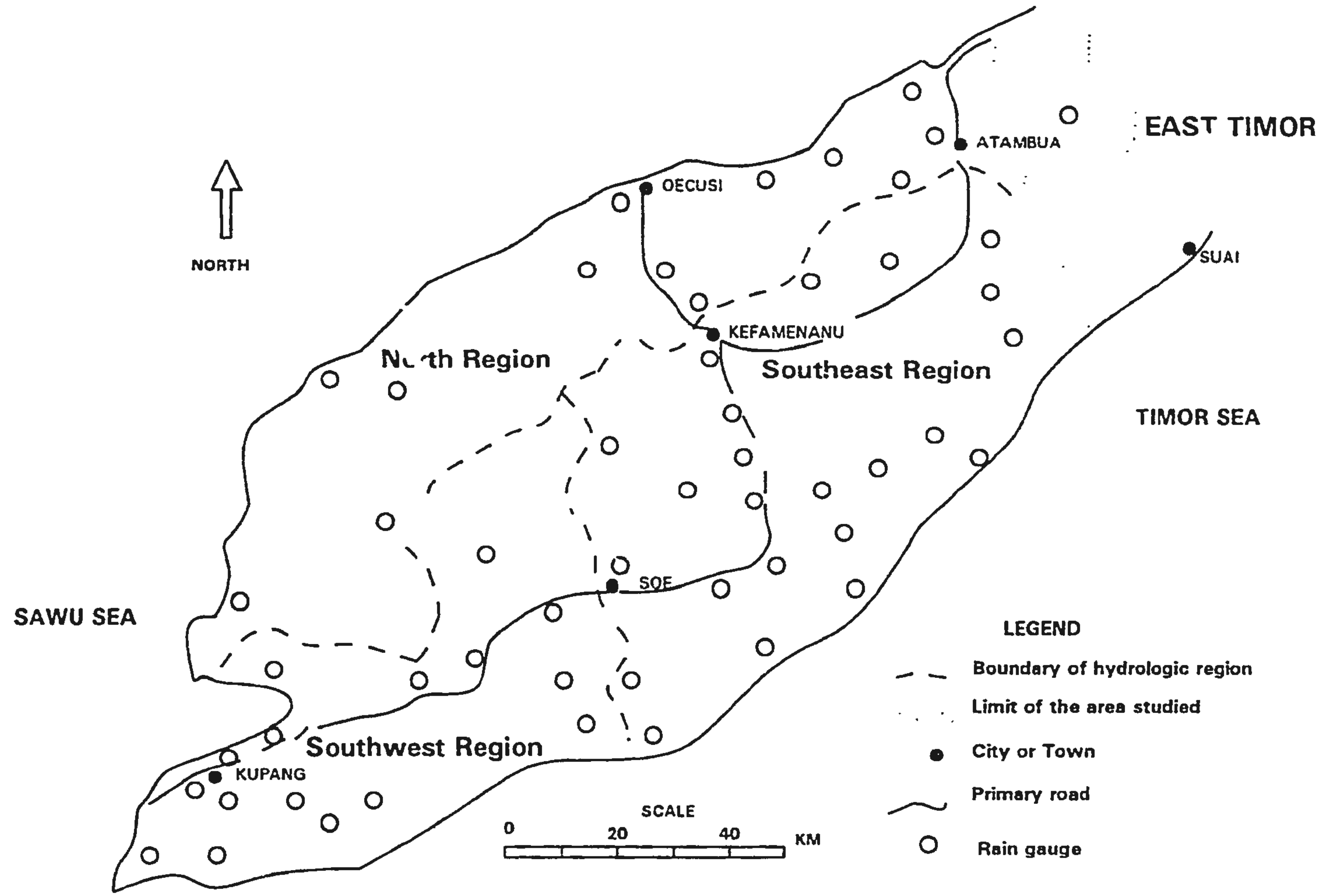


Figure 1.2 Hydrologic regions as defined by Crippen (1980) and the rainfall station network in West Timor

Table 1.1 The availability of daily rainfall record at selected sites in West Timor

Station	Station number	MSL m	Year of record 1920 1930 1940 1950 1960 1970 1980 1990 123456789 123456789 123456789 123456789 123456789 123456789 123456789 12
Batuliti	1	25	xxxxxxxxxxxxxxx
Kupang	2a	70	xxxxxxxxxxxxxxxxxxxxxxx
Penfui	2	115	xxxxxxxxxxxxxxxxxxxxxxxxxxx
Oekabiti	3	50	xxxxxxxxxxxxxxxxxx
Tubutesb	4	320	xxxxxxxxxxxxxxx
Tarus	5	20	xxxxxxxxxxxxxxx
Oesao*	6	40	xxxxxxxxxxxxxxxxxxxxxxxxxx
Pariti	7	15	xxxxxxxxxxxxxxxxxxxx
Camplong	8	200	xxxxxxxxxxxxxxxxxxxxxxxxx
Hueknutu	9	170	xxxxxxxxxxxxxxxxxx
Nauwen	10	10	xxxxxxxxxxxxxxxxxxxx
Lelogama	11	900	xxxxxxxxxxxxxxxxxxxxxx
Oelilak	12	390	xxxxxxxxxxxxxxxxxxx
Naikliu	13	5	xxxxxxxxxxxxxxxxxxxxxxx
Wini	14	9	xxxxxxxxxxx
Fatuoni	15	20	xxxxxxxxxxxxxx
Baurasi	16	600	xxxxxxxxxxxxxxx
Atmbua	30a		xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Fatumnasi	17	1470	xxxxxxxxxxxxxxxx
Soe	17a	1000	xxxxxxxx xxxxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxx xxxx xxxxx
Nifukani	18	670	xxxxxxxxxxxxxxx
Oebelo	19	3	xxxxxxxxxxxxxxx
Nunkolo	20	400	xxxxxxxxxxxxxxx
Besikama	21	10	xxxxxxxxxxxxxxx
Biudfoho	22	415	xxxxxxxxxxxxxxx
Oeoh	23	280	xxxxxxxxxxxxxxx
Noelnoni	24	420	xxxxxxxxxxxxxx
Loli	25	328	xxxxxxxxxxxxxxx
Noelmuti	26	230	xxxxxxxxxxxxxxx
Kefa	27	450	xxxxxxxx xxxxxxxxxxxxxx xxxx xxxxxxxxxx xxxxxx xxxxxxxxxx
Ekoni	28	507	xxxxxxxxxxxxxxx
Sufa	29	800	xxxxxxxxxxxxxxx
Sukabite	30	210	xxxxxxxxxxxxxx

Note: MSL is the elevation above mean sea level in m

* station having hourly rainfall record

Chapter 2

Temporal and Spatial Characterization of Rainfall: Methodology

This chapter deals with the general approaches for depicting the temporal and spatial rainfall characteristics at the ground surface. These approaches can be summarized in five parts:

(1) evaluation of the rainfall station network;

(2) general exploratory rainfall data analysis;

(3) temporal rainfall characterization;

(4) spatial rainfall characterization; and

(5) interaction of rainfall with physical factors.

The results of applying the methodologies discussed in the chapter are presented in Chapter 3.

2.1 Evaluation of the Rainfall Station Network

Theoretical considerations

In many rainfall-runoff models, water balance analyses, and ground water studies, areal estimates of rainfall are important. The accuracy of results of rainfall models depends on the accuracy of areal rainfall estimates, for example. This areal value is obtained from the transformation of at-site rainfall into areal values by using such conventional methods as arithmetic mean, Thiessen's polygon, and the isohyetal technique. These techniques (Sevruk, 1992) are subject to a variety of errors: random error at the gauge including systematic error and random statistical error, and random error of the estimate of areal rainfall due to the natural spatial variability of rainfall and the distance between gauged sites. The latter point will be discussed further, and mostly depends on the network density and the representativeness of the gauged site.

An optimum network of rainfall stations should sample the temporal and spatial rainfall regime of an area to reduce the random error of the areal rainfall to an acceptable level. The number of rainfall stations per unit area (i.e., network density of rainfall station) and its representativeness mostly depend on three factors: the objectives of the investigation, physiography of the area, and weather patterns (e.g., wind regime, monsoons, cyclones, local depression and local winds).

Methods used to estimate the optimum network of rainfall stations

A number of methods of rainfall network design, having various degrees of complexity and validity, are cited in the literature (Husain, T., 1989). For the general approach used in this study, the evaluation of the rainfall station network in West Timor was carried out using the WMO (World Meteorological Organization) Guide (1965), and sampling theory (Moss, 1982). The WMO Guide recommends that the minimum number of rainfall stations for a small mountainous island is one per 25 km^2.

The statistical sampling theory approach in contrast, attempts to quantify the differences that might be expected in a parameter such as the mean, which is estimated repetitively from recurrent samples of data. The equation that is most widely used in statistical sampling theory is:

$$V_{\bar{x}} = \frac{V_x}{N} \tag{2.1}$$

where, $V_{\bar{x}}$ is the variance of the mean of N randomly chosen observations x, and V_x is the variance of x. If $V_{\bar{x}}$ is large, then there is considerable variability in x; if $V_{\bar{x}}$ is approximately equal to zero, then x is almost constant. For a rainfall network, N is the number of rainfall stations, x is the mean monthly or yearly rainfall at a station and $\bar{x}$ is the mean monthly or yearly rainfall in a region, respectively. For convenience, the regional coefficient of variation of the mean x, $CV_{\bar{x}} = V_{\bar{x}}^{0.5}/\bar{x}$, is often used. If $CV_{\bar{x}}$ is close to zero, few rainfall stations are required. Otherwise, extension of the rainfall station network is required. Ganguli et al., (1951) showed that in terms of the existing number of rain gauges N, the new number n, could be determined from the existing coefficient of variation (CV_E), and the required coefficient of variation (CV_R), using:

$$n = N[\frac{CV_E}{CV_R}]^2 \tag{2.2}$$

where, $CV_E = V_{\bar{x}}^{0.5}/\bar{x}$. CV_R depends on the objectives of investigation and the acceptable margin of error. This technique assumes that the values of x which denote the at-site mean values of rainfall, are independent. Although the mean values of rainfall among stations are not truly independent, the results may be sufficiently adequate for general purposes (Moss, 1982).

2.2 General Exploratory Rainfall Data Analysis

The intent of this section is to depict general features of the rainfall data in West Timor prior to more detailed analysis. Based on annual rainfall data series, the standard period of analysis is determined. Statistical summaries and boxplots, which organize the rainfall data into a format which provides a framework for describing, summarizing and comparing the results, were used.

Most samples of rainfall data from West Timor do not have a long record or long concurrent periods of records. As such a standard period of analysis was selected for the comparison of the rainfall characteristics. There are several ways to determine a standard period of analysis for the rainfall record at each station. These include the use of adjusted averages and the use of a common period of record. The adjusted average method (Sutcliffe et al., 1981) compares the ratio of the common period of record for stations having a shorter record with adjacent stations having a long record. The common period uses data series which have an identical period of record. As shown in Figure 1.1, the annual rainfall data in West Timor display many inconsistencies such as different record spans and different durations of station operation. Therefore, the common period method is more convenient to use in this study.

2.3 Temporal Rainfall Characterization

This section discusses several procedures of temporal rainfall characterization and their application to annual, monthly, pentad (5 days), annual daily maximum and hourly rainfall data.

2.3.1 Procedures Used

The temporal rainfall characteristics can be described using the following procedures:

(1) trend analysis to detect the presence of long term trends;

(2) serial correlation analysis to identify persistency in the rainfall data series;

(3) seasonality analysis of monthly rainfall data series; and

(4) comparison of coefficients of variation and hyetographs to describe the variation of rainfall in time.

Trend analysis uses two approaches. The first approach is based on linear regression analysis, and the second approach uses LOWESS (Locally Weighted Scatter Plot Smoothing) plot (Maidment, 1993). LOWESS plotting is a robust procedure for detecting trends in data series. The p-value of the linear regression line is used to detect the significance of a linear trend in the data series.

Short term serial correlation analysis uses the ACF (Auto Correlation Function) and the PACF (Partial Auto Correlation Function). Long-term serial correlation analysis uses the Hurst statistic (Maidment,1993).

The auto correlation function is given by:

$$r_k = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(x_{i+1}-\bar{x})}{\sum_{i=1}^{N}(x_i-\bar{x})^2} \tag{2.3}$$

where r_k is the auto correlation coefficient at lag-k If $r_k = 0$ for all $k \neq 0$, the process is a purely random process.

The partial auto correlation function is given by:

$$\phi_k(k) = \frac{r_k - \sum_{i=1}^{k-1}\phi_j(k-1)r_{k-j}}{1-\sum_{i=1}^{k-1}\phi_j(k-1)r_j}$$

$$\phi_j(k) = \phi_j(k-1) - \phi_k(k)\phi_{k-j}(k-1)$$

$$\phi_1(1) = r_1;\ \phi_1(2) = \frac{r_1(1-r_2)}{(1-r_1^2)};\ \phi_2(2) = \frac{(r_2-r_1^2)}{(1-r_1^2)} \tag{2.4}$$

where $\phi_k(k)$ is the partial auto correlation coefficient at lag-k. The significance of the serial correlations can be tested using Bartlett's test which is given by $|r_k| < 1.96/\sqrt{N}$ at a significance level of 5%. The data were assumed to be approximately normally distributed.

The Hurst K, is used to detect long-term serial correlation or persistence in annual rainfall at selected sites which have greater than 50 years of record. Hurst's K is calculated using:

$$K = \frac{Log(\frac{R}{S})}{Log(\frac{N}{2})} \tag{2.5}$$

where R is the range of the cumulative departures from the mean, S is the standard deviation and N is the sample length. K is theoretically 0.5 for a serially independent series, and it increases with increasing persistency.

The statistical significance of the calculated K value can be tested by comparing with the tabulated values provided in Lin (1993). This test assumes that the data are independent and normally distributed. If the estimated K is greater than the K^* given in Lin's table at a given significance level for a given sample size, it can concluded that this series exhibits long-term persistency. Otherwise, it has no long-term persistence.

Seasonality Index (SI) defined by Wals et al., (1981) is used to identify seasonality in monthly rainfall data. The seasonality index is expressed as:

$$SI = (\frac{1}{\bar{R}})\sum_{i=1}^{12} |\bar{x}_i - (\frac{\bar{R}}{12})| \tag{2.6}$$

where, $\bar{R}$ is the mean or total annual rainfall and $\bar{x}_i$ is the mean or total rainfall for month i. Wals et al., (1981) have proposed a classification of seasonal precipitation regimes, ranging from 'very equable' climates ($SI \leq 0.19$) through 'seasonal' ($0.60 \leq SI < 0.80$) to 'extreme' (almost all rain in 1-2 months only, $SI \geq 1.20$). If each month within the year has an equal amount of rainfall, the SI is zero, and if the rainfall occurs only in a month within the year, the SI is 1.83.

Hyetographs are used to describe the rainfall variation on a water year basis. Comparison of coefficients of variation (CVs) are also used to describe the variation of rainfall in time.

2.3.2 Application of the Procedures to Rainfall Data

Rainfall is highly variable over a variety of time scales; therefore, annual, monthly, pentad, annual daily maximum, and hourly rainfalls, are analyzed.

Annual Rainfall Series

The temporal properties of an annual rainfall series can be summarized by measures of persistency, year to year variability and trend. The persistency can be described using Hurst's K for long term persistency and using the ACF and PACF for short term persistency. The year to year variability can be evaluated using its coefficient of variation (CV), and the trend can be described by means of a linear regression analysis or a LOWESS plot.

Monthly Rainfall Series

The persistency of the monthly rainfall can also be characterized using serial correlation analysis. The auto correlation function (ACF) can be used to describe the periodicity of the monthly rainfall data series. The month to month and year to year variability of rainfall by month can be described using the coefficients of variation (CVs), and also using the seasonality index (SI).

A plot of the mean monthly rainfall based on a water year (November to October) is a useful tool to detect the monthly rainfall fluctuation. The reference lines which represent the minimum monthly rain water requirement for rice (200 mm) and dry land crops (100 mm), provide a general guideline for determining the number of wet months for agricultural purposes. Oldeman (1982, pp. 215) used 200 and 100 mm of monthly rainfall as a criterion of the minimum rain water requirement for rainfed rice and dry land crops, respectively, to regionalize agroclimatology of South East Asia.

Pentad Rainfall Series

Pentad rainfall persistency can be described using the auto correlation (ACF) and partial auto correlation (PACF) coefficients as previously mentioned. A pentad in this study is approximately one-sixth of a month. Therefore, 35 mm and 17.5 mm of rainfall are assumea as a criterion of the minimum pentad rain water for rice and dry land crops, respectively. The amount and occurrence of the pentad rainfall can be visually described using hyetographs, and the reference lines of pentad rain water requirement for rice (35 mm) and dry land crops (17.5 mm) can be drawn to detect dry spell occurrences during the wet season which would damage the crops during the growing stages. The choice of pentad rainfall analysis reflects the need to consider shorter periods for drought sensitive crops which can withstand longer dry periods as discussed in chapter 6.

Annual Daily Maximum Rainfall Series

The persistency of annual daily maximum rainfall can be described using the auto correlation and partial auto correlation coefficients. The trend can be described by means of a linear regression analysis or a LOWESS plot. These procedures are conducted in conjunction with the regional frequency analysis of annual daily maximum rainfall in Chapter 4.

Hourly Rainfall Series

Hourly rainfall distribution can be described in terms of rainfall intensities and storm occurrences. Rainfall intensities can be expressed as an average value, which is obtained by dividing rainfall depth by rainfall duration. Storm occurrences can be determined by the relationship between number of storm occurrences and their respective durations. However, due to the limited amount of hourly data, only a hyetograph representation was used to describe the amount and occurrence of hourly rainfall.

2.4 Spatial Rainfall Characterization

The spatial variability of rainfall can be described by:

(1) using regional coefficient of variation (CV), and coefficient of skewness (CS) to depict the homogeneity of rainfall through out the region;

(2) using hyetograph of the mean monthly rainfall at selected sites to compare the rainfall amplitudes of the region;

(3) using contour maps of rainfall amounts at a given duration to display spatial rainfall distribution; and

(4) using contour maps of the number of months receiving a certain amount of

monthly rainfall for crops such as rice and dry land crops.

The coefficient of variation of coefficient of variation (CV of CV), can be a useful index to depict the homogeneity of regional data. A CV of CV of less than 0.40, for example, and an identical coefficient of skewness of regional data would mean that the regional data are possibly homogenous (Cunnane, 1989). In this study, contour maps were drawn using rainfall data having a common period of greater than 10 years of record (1976-1990).

2.5 Interaction of Rainfall with Physical Factors

Physical factors such as latitude and longitude, wind regime, topography, windward and leeward exposure, coast, rainfall mechanism (cyclone, convective) and local wind, affect the spatial distribution of rainfall. Linear regression analysis was used to assess the relationship between mean annual rainfall and elevation. Since the monsoons are the principal source of precipitation, the prevailing winds during the monsoons are also taken into account in describing the spatial rainfall distribution in West Timor.

Chapter 3

Temporal and Spatial Characterization of Rainfall: Results and Discussion

This chapter discusses the results of the temporal and spatial characterization of rainfall using the methodologies described in Chapter 2. The results are grouped as follows:

(1) evaluation of the rainfall station network;

(2) general exploratory rainfall data analysis;

(3) temporal rainfall characterization;

(4) spatial rainfall characterization; and

(5) interaction of rainfall with physical factors.

Figure 3.1 shows the selected rainfall stations in West Timor used in this analysis.

3.1 Evaluation of the Rainfall Station Network

As shown in Figure 1.2 in Chapter 1 and in Figure 3.1, raingauges are not uniformly distributed in the region. Table 3.1 shows that the network density of daily rainfall stations is about 240 km^2 per gauge. Only 6 gauges record hourly rainfall.

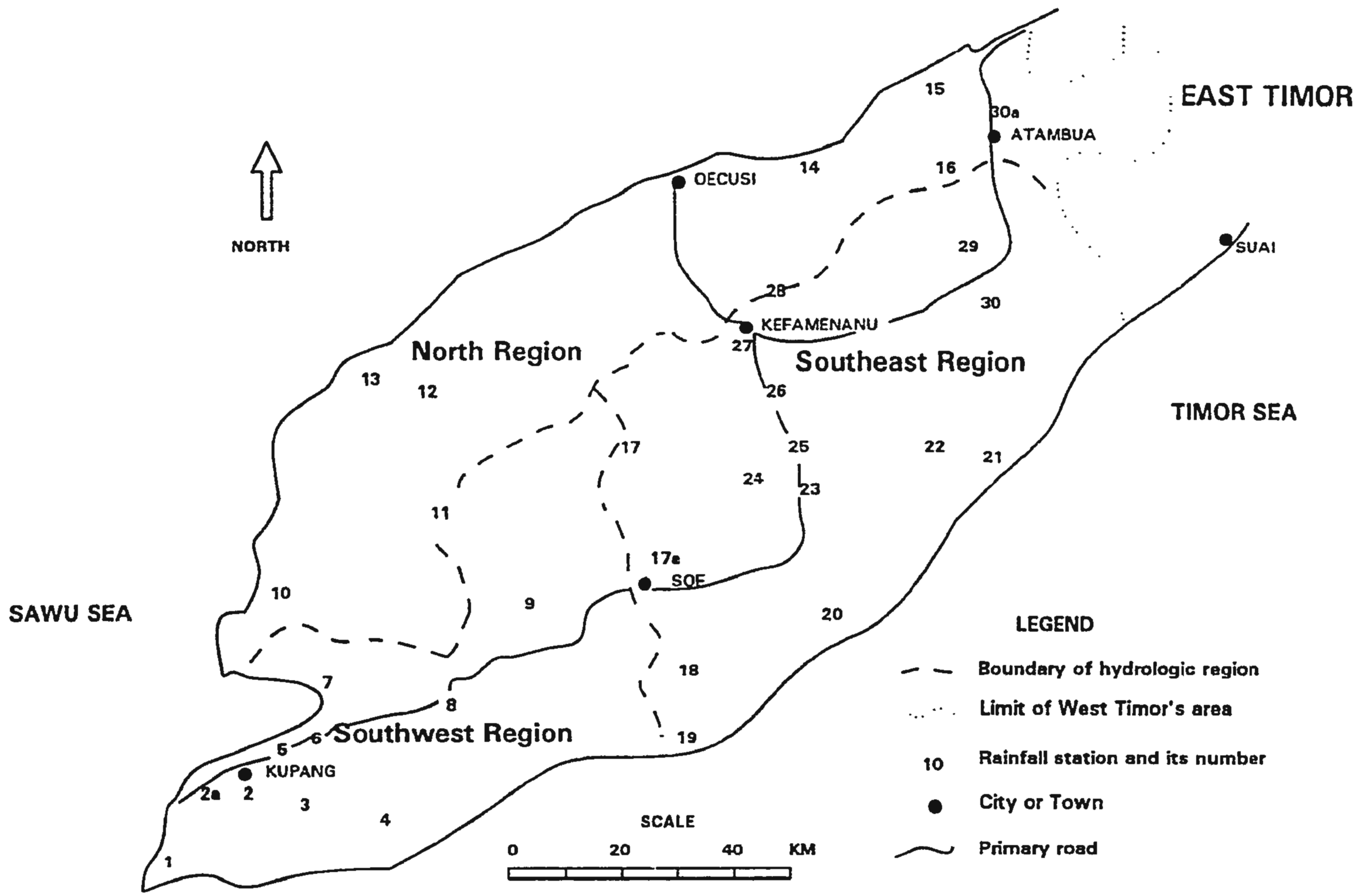


Figure 3.1 Locations of selected rainfall stations in West Timor

Table 3.1 The number of rainfall stations in West Timor

Duration	Number of stations	Area (km^2)	Network density (km^2/gauge)
Daily	60	14,400	240
Hourly	6		

Table 3.2 summarizes the results of using statistical sampling theory for annual and daily durations. The regional standard deviations of the mean values ($V_{\bar{x}}^{0.5}$) of the 60 stations are 51.6 mm and 7.5 mm for annual and daily maximum rainfall, respectively. The regional means of the at-site values ($\bar{x}$) are 1429 mm and 105 mm for annual and daily maximum rainfall, respectively. The regional coefficient of variation of the mean at-site values ($CV_{\bar{x}}$) is 0.04 for annual rainfall and is 0.07 for daily maximum rainfall. The regional variance of the mean at-site values ($V_{\bar{x}} = V_x/N$), is 2667 for annual rainfall and 56 for daily maximum rainfall.

Table 3.2 The summary of rainfall station variability in West Timor for annual and daily rainfall series

Duration	Number of stations	$V_{\bar{x}}^{0.5}$	$\bar{x}$ mm	$CV_{\bar{x}}$	V_x/N
Annual	60	51.6	1429	0.04	2667
Daily maximum	30	7.5	105	0.07	56

The rainfall station network in West Timor is very sparse relative to that suggested in the WMO Guide (1965) and in Ganguli's (1951) approach. Based on Ganguli's approach for example, if we assume that a $CV_{\bar{x}}$ of 0.02 is acceptable for the mean annual rainfall, the required number of rainfall stations is doubled, to 120, and based on the WMO Guide (1965) the required number of stations is increased more than eight times, to 516. The cost incurred to install the additional stations would be substantial. However, as shown in Table 3.3 the CV of CV of regional annual rainfall data in West Timor was less than 0.40 implying a possibly homogeneous region (Cunnane, 1989). This means that if the particular concern is annual rainfall, the existing network could be considered adequate. But if one considers monthly rainfall series, the existing monthly variability is large (see Table 3.5.), and the rainfall station network requires extension before it can be considered adequate. This analysis shows that temporal and spatial variability of rainfall affects the number of rainfall stations required, but for most purposes the present network is inadequate.

3.2 General Exploratory Rainfall Data Analysis

The exploratory analysis focussed on the evaluation of a standard period to be used for further analysis, the particular summary statistics (e.g mean, coefficient of variation, coefficient of skewness and kurtosis) to represent the general magnitude of rainfall amount, and the graphical display of rainfall data using boxplots for comparing data from selected sites. Only annual rainfall data were considered for the general description of rainfall data in West Timor.

As Table 3.3 shows, the average record length of annual rainfall data is 20 years. Most of the rainfall stations were installed after 1975. As Table 1.1 shows, most of the rainfall stations are recorded for the period of 1976 to 1991. Based on this standard period, 30 rainfall stations were selected for further analysis (Figure 3.1).

A statistical summary of annual rainfall is given in Table 3.3. The mean annual rainfall ranges from 862 mm at site 14 (Wini) on the northern coast to 2670.7 mm at site 11 (Lelogama) which is situated at the high mountain ridge in the direction of the windward side of the wet monsoon. The coefficient of variation of the mean annual rainfall ranges from 0.19 at site 2 in the coastal area to 0.35 at site 17 in the high mountain ridge. In the high mountain ridges, the mean and the variance of annual rainfall are usually higher than in the lowland and coastal areas.

The boxplots illustrate the variability of annual rainfall (Figure 3.2). The higher rainfall amounts and variability are at sites 11 and 17 located in the high mountain ridge. The mean of the mean annual rainfall of West Timor is about 1500 mm for thirty four rainfall stations as shown in Table 3.3.

Table 3.3 Statistical summary of annual rainfall at selected sites in West Timor

Site	Station no.	Elevation MSL(m)	Years	Mean mm	CV*	CS*	Kurtosis
Batuliti	1	25	14	1261.6	0.226	-0.039	1.767
Baun	1a	370	15	1448.1	0.332	1.817	6.662
Kupang	2a	15	71	1400.9	0.266	0.397	2.383
Penfui	2	115	23	1495.5	0.271	0.015	2.289
Tubutesb	4	320	12	1475.2	0.209	0.137	2.373
Oesao	6	40	18	1435.3	0.203	-0.103	1.519
Pariti	7	15	15	1568.7	0.181	1.063	3.701
Camplong	8	200	16	1438.4	0.228	0.056	2.549
Hucknutu	9	1[illegible]0	15	1685.3	0.213	0.597	2.223
Boentuka	9a	160	10	992.5	0.189	0.385	1.683
Nauwen	10	10	12	1748.8	0.213	-0.414	2.323
Lelogama	11	900	16	2670.7	0.224	0.332	2.670
Naikliu	13	5	14	1661.0	0.237	0.467	2.667
Oesilo	31	460	19	1572.8	0.161	1.062	3.533
Oecusi	32	2	19	1118.4	0.326	0.267	2.453
Wini	14	3	10	860.0	0.630	0.877	2.567
Fatuoni	15	20	13	1173.2	0.244	0.063	2.073
Baurasi	16	600	15	1812.4	0.200	0.595	2.361
Atambua	30a	325	58	1472.5	0.274	0.811	3.157
Lahurus	33	514	13	1809.2	0.227	0.049	2.076
Balibo	34	566	19	1379.4	0.298	0.820	2.764
Fatumnasi	17	1470	12	2422.0	0.299	1.290	3.738
Soe	17a	850	51	1419.0	0.261	0.664	3.318
Oebelo	19	3	15	861.9	0.266	0.184	2.274
Nifukani	18	670	15	1545.7	0.241	0.065	2.795
Nunkolo	20	400	13	1936.7	0.220	-0.454	2.988
Besikama	21	9	26	1400.9	0.253	0.702	3.318
Oenlasi	21b	811	10	1413.3	0.197	0.627	2.537
Biudfho	21a	415	11	1669.6	0.305	1.552	5.044
Sukabite	30	210	14	1057.4	0.204	0.092	2.934
Maubesi	30b	350	12	960.8	0.258	-0.390	1.538
Noemuti	26	230	15	1211.5	0.255	0.173	2.083
Noelnoni	24	420	15	1422.9	0.196	0.672	2.537
Nikiniki	21c	800	36	1198.3	0.290	0.177	3.002
Range			61	1808.8	0.171	2.271	5.143
Maximum			71	2670.7	0.332	1.817	6.662
Minimum			10	861.9	0.161	-0.454	1.519
Mean			20	1489.7	0.241	0.403	2.774
CV			0.7	0.3	0.176	2.352	0.360

* CV is coefficient of variation
CS is coefficient of skewness

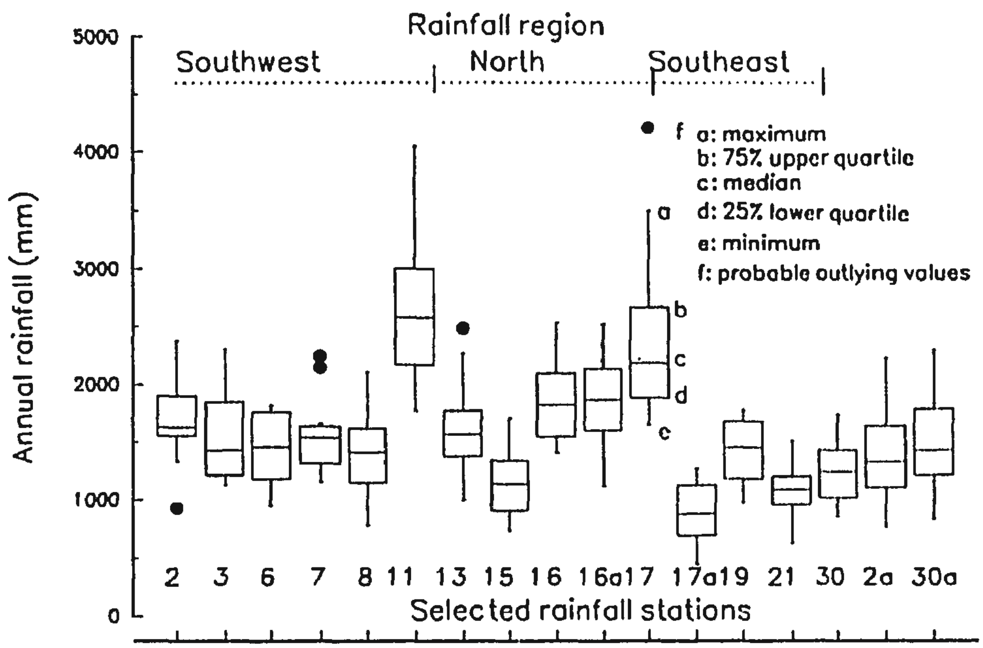


Figure 3.2 Boxplots of annual rainfall at selected stations in West Timor (for locations of the rainfall stations see Figure 3.1)

3.3 Temporal Rainfall Characterization

This section is mainly concerned with the characteristics of annual, monthly, pentad, annual daily maximum and hourly rainfall series.

Annual Rainfall Series

Sites 2a and 30a were selected for the annual analysis because they have the longest continuous records covering two different periods: 71 and 58 years of records, respectively. For these two sites, the ACF, PACF and Hurst's K, were computed. Based on Bartlett's tests, both annual series show no significant serial correlations at the 5% significance level (Figure 3.3 and Figure 3.4), indicating that the annual rainfall series is independent in time. This means that the occurrence of annual rainfall in this year does not depend on the annual rainfall of the previous or another year. The Hurst's K, is 0.73 for site 2a and 0.71 for site 30a (Table 3.4). At significance level of 5%, the tabulated K^* (Lin, 1993) values are 0.733 and 0.724 for site 2a and 30a, respectively. These results indicate that neither annual series shows long-term persistence.

LOWESS plot and linear regression were used to check the long-term trend of the annual rainfall for sites 2a and 30a. Although there are slight slopes to the linear regression lines, these slopes are not significantly different from zero (Figure 3.5 and Table 3.4), and the LOWESS plots also show no significant upward or downward trends (Figure 3.5).

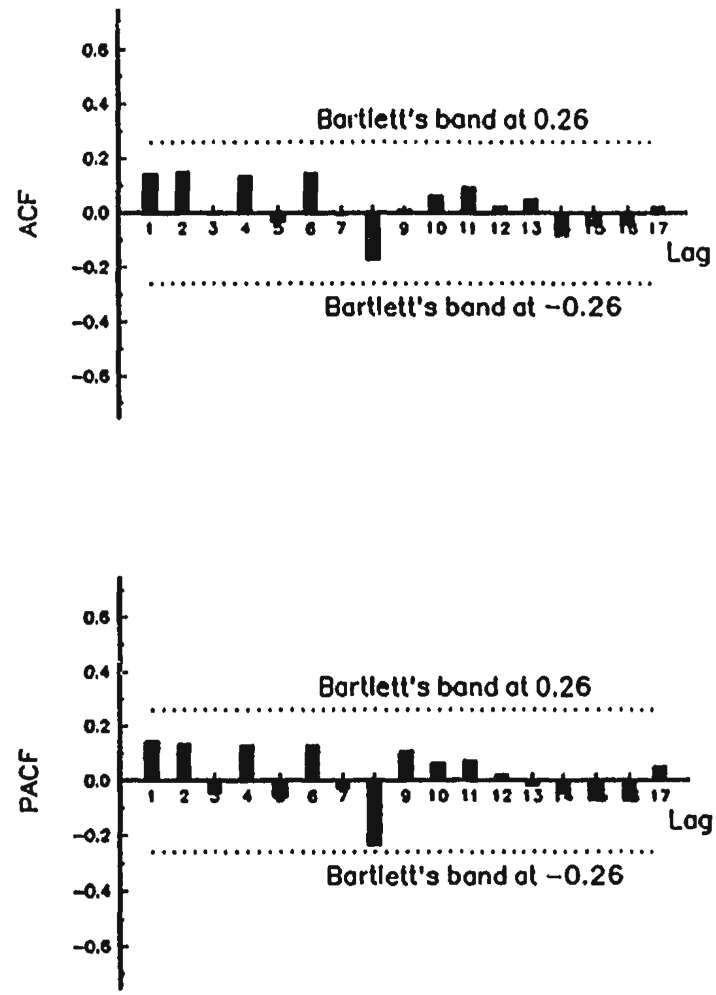


Figure 3.3 ACF and PACF of annual rainfall at site 2a in West Timor (1884-1941)

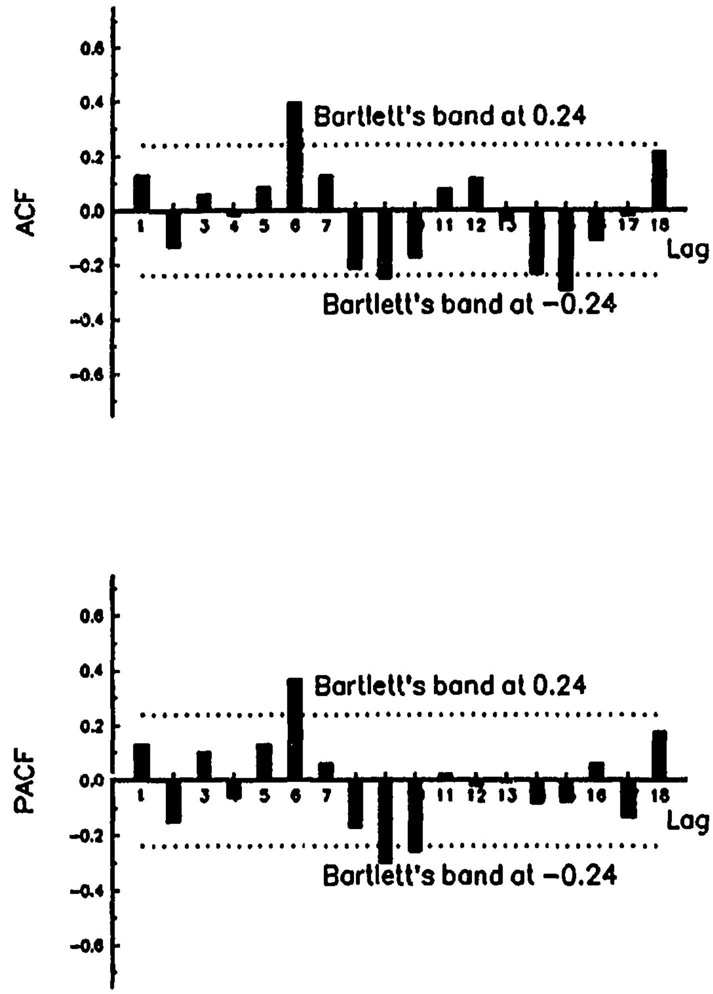
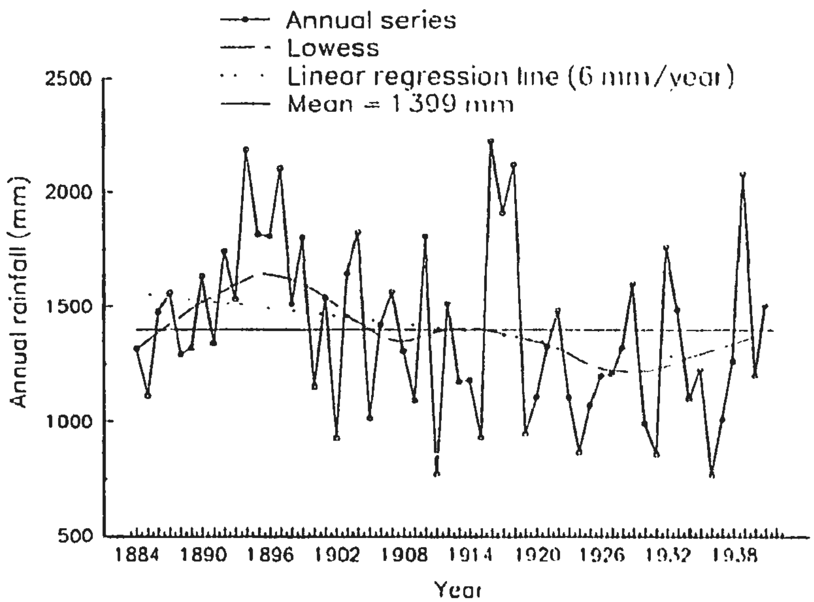
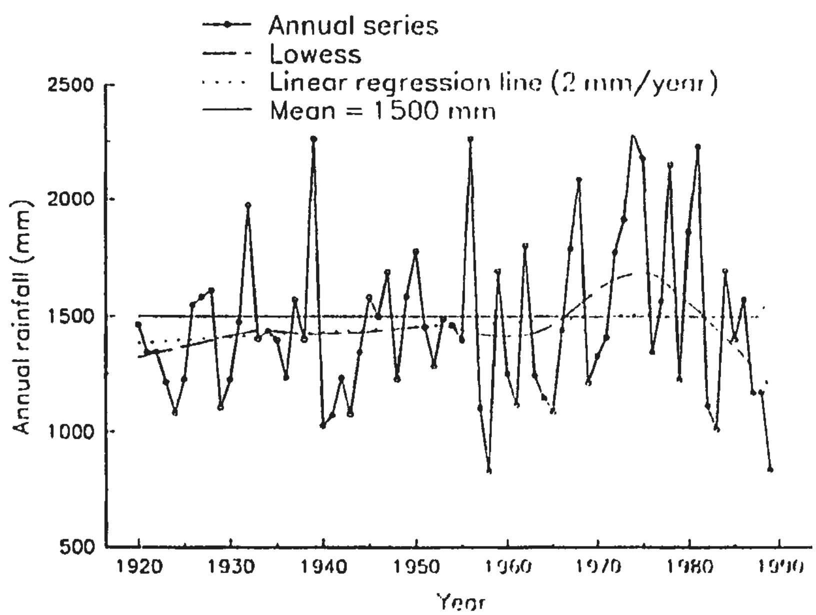


Figure 3.4 ACF and PACF of annual rainfall at site 30a in West Timor (1925-1989)



a) Site 2a, Kupang



b) Site 30a, Atambua

Figure 3.5 The trend test of annual rainfall at site 2a and 30a in West Timor

Table 3.4 Linear regression results and Hurst's K of the annual rainfall series at selected sites in West Timor

N	Site	Slope	Intercept mm	R^2	p-value	K	K^*
58	2a (Kupang)	-5.70	12305.79	0.07	0.21	0.73	0.733
71	30a (Atambua)	2.24	-2915.65	0.02	0.28	0.71	0.724

Note: N is the length of record (years)
K^* is the Hurst's K at significance level of 5%

Monthly Rainfall Series

The analysis of monthly rainfall was carried out at 12 sites listed in Table 3.5. These sites have continuous records which are greater than 10 years. The ACF, PACF, seasonality index (SI), coefficient of variation and hyetograph were used to describe monthly rainfall properties. Figure 3.6 shows the ACF and PACF for the monthly rainfall series at site 6 as an example. The ACF indicates a seasonality of 6 months. This seasonality is due to the wet monsoon and dry monsoon, respectively. Based on Bartlett's test at $\alpha = 5\%$, the series shows significant serial correlation because of the seasonality. This implies that for example, the occurrence of monthly rainfall of this month is dependent on the monthly rainfall of previous months.

The seasonality indices of selected sites are presented in Table 3.5. The SI ranges between 0.54 at site 21 in the southeast region and 1.06 at site 13 in the north region implying that the number of months having rainfall within a year in the southeast region is greater than those in the north and southwest region.

Table 3.5 shows the CV of monthly mean rainfall series (CV_{mm}) to describe the variation of the monthly mean rainfall series within a year (from November to October),

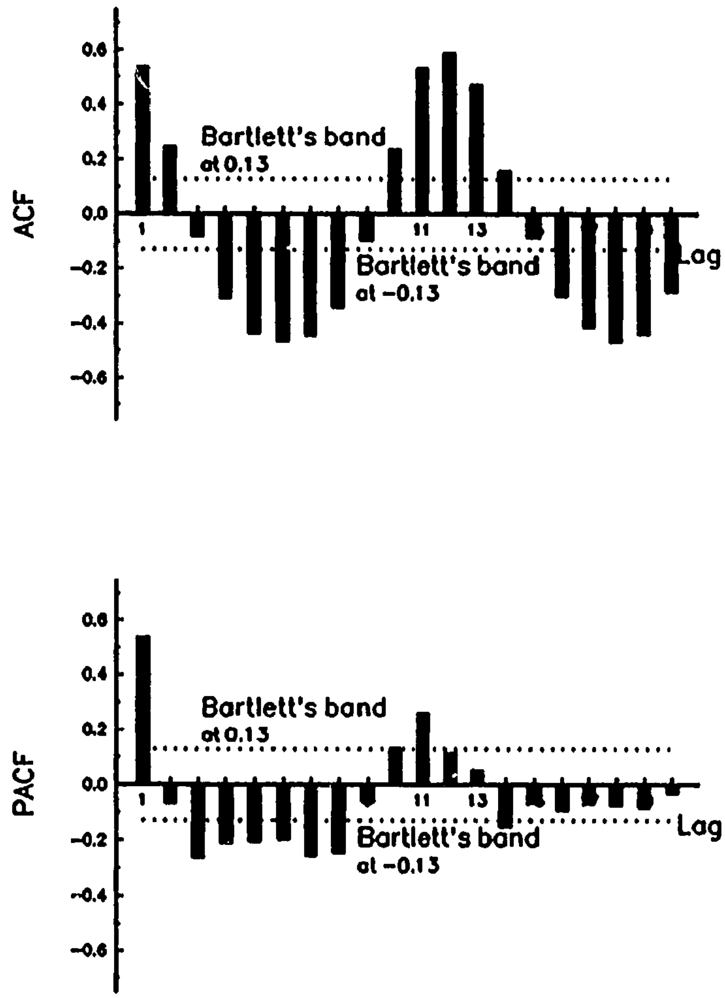


Figure 3.6 ACF and PACF of monthly rainfall at site 6 in West Timor (1974-1991)

the CV of year to year (CV_{yy}) of monthly rainfall series (i.e., January rainfall series), and the mean monthly rainfall at wet months (November-April) and dry months (May-October) for selected rainfall stations in West Timor. The monthly rainfall varies greatly from month to month as indicated by the high values of the CV_{mm} of the monthly mean rainfall. The CV_{mm} ranges from 0.58 to 1.19.

Table 3.5. Monthly rainfall variability and seasonality index at selected sites in West Timor

Region*/ station number	Elevation m	Mean (mm)		CV_{mm}	CV_{yy}		SI
		Wet months	Dry months		Wet months	Dry months	
Southwest*							
2	115	54-402	< 54	1.19	0.83-0.43	1.10-2.50	1.00
6	40	84-378	< 84	1.08	1.23-0.49	0.97-4.76	0.89
9	170	116-364	< 54	0.90	0.97-0.41	1.66-2.39	0.83
North*							
13	5	105-453	< 36	1.19	1.29-0.49	1.40-2.55	1.06
15	20	75-313	< 26	1.17	1.00-0.47	1.47-2.55	0.94
16a	514	111-399	< 68	0.99	1.06-0.37	1.11-2.08	0.84
11	900	211-650	< 71	0.95	0.63-0.39	0.89-1.56	0.78
Southeast*							
17	1470	148-505	23-161	0.75	0.79-0.36	0.49-1.59	0.61
19	3	89-174	< 58	0.77	1.00-0.49	0.72-2.96	0.65
21	10	59-178	17-187	0.58	1.05-0.28	0.46-2.96	0.54
27	450	60-221	< 62	0.89	0.86-0.39	0.63-1.97	0.77
23	280	79-289	< 63	0.79	1.05-0.49	0.74-2.62	0.79

* Crippen's hydrologic region

The monthly rainfall also varies greatly from year to year as indicated by the high values of the CV_{yy} which ranges from 0.28 in the wettest month of February to greater than 3.00 in the dry months (August, September or October). Table 3.5 also shows that for example, at site 2 in the southwest region receives monthly rainfall between 54 mm and 402 mm in the wet months (November-April), and receives monthly rainfall of less than 54 mm in the dry months (May- October). On average, the north and southwest regions are almost dry in the dry monsoon whereas several sites in the southeast region still receive rainfall from the prevailing east-southeast winds in the dry monsoon.

As shown in Figure 3.7, hyetograph of mean monthly rainfall at selected sites is presented. Three sites were considered to describe the variations of the mean monthly rainfall at each hydrologic region (Crippen, 1980) in West Timor. In Figure 3.7, the critical line of rain water requirement for rice and dry land crops are also plotted to determine the number of wet months available for these crops. This figure shows that sites in the southeast region have lower mean monthly rainfall than those sites in the north and southwest regions. However, sites in the southeast region have a greater number of wet months for dry land crops, and a lower seasonality index (Table 3.5) than those sites in the north and southwest regions. This implies that the southeast region receives rainfall even during the dry monsoon.

The values of the seasonality index in Table 3.5, and the plots of mean monthly rainfall in Figure 3.7 indicate that the north and southwest may be considered as one rainfall region, rather than two regions as suggested by Crippen (1980).

Pentad Rainfall Series

Site 6 was selected for the pentad analysis as an example because it has a continuous record of seventeen years. The ACF, PACF and hyetograph were used to describe the pentad rainfall properties. Figure 3.8 shows the ACF and PACF for the pentad rainfall series at site 6 in West Timor. Based on Bartlett's test at $\alpha = 5\%$, the

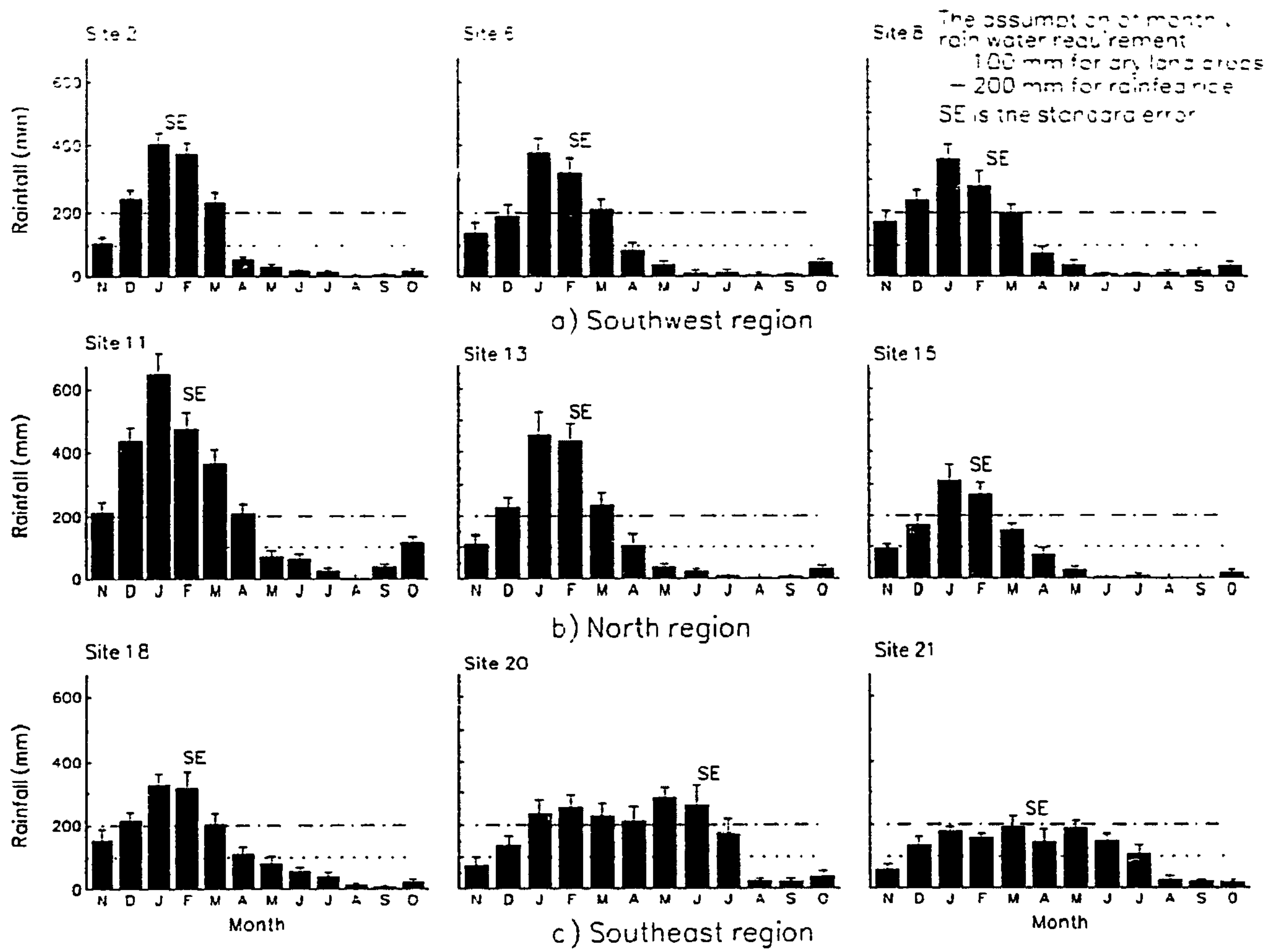


Figure 3.7 Mean monthly rainfall at selected sites in West Timor (1976-1990)

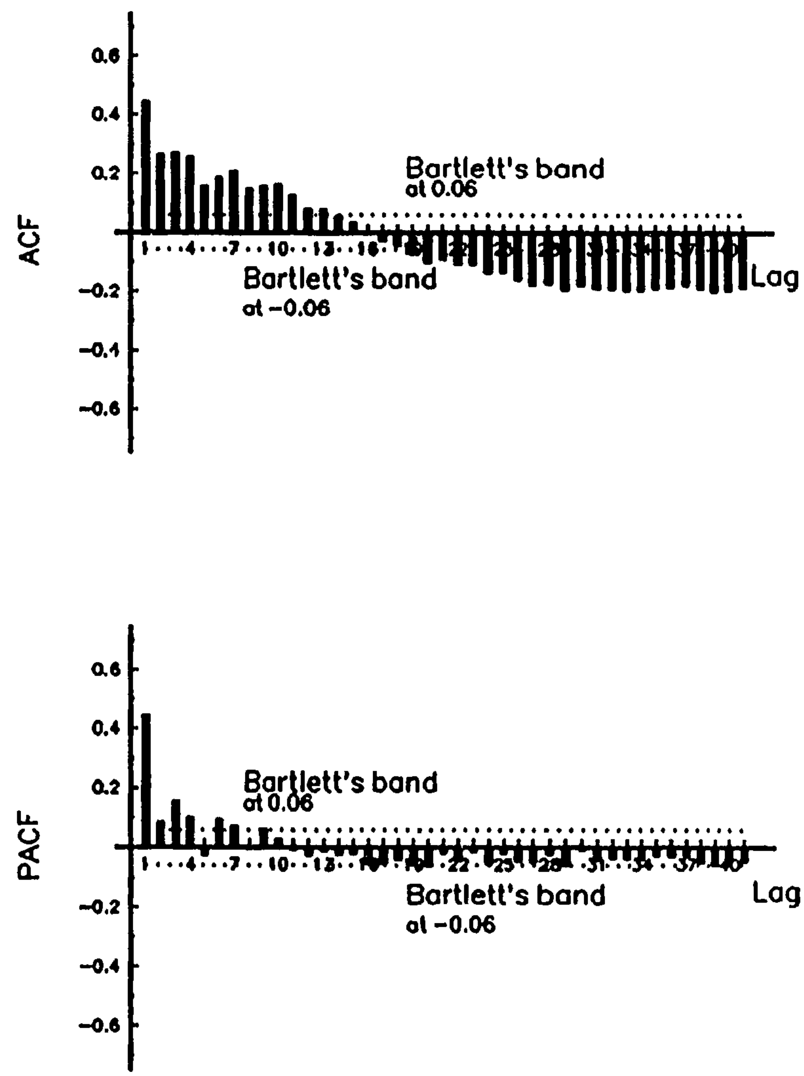


Figure 3.8 ACF and PACF of pentad rainfall at site 6 in West Timor (1974-1991)

series shows significant correlations up to lag 4. This indicates that the occurrence of pentad rainfall in a given pentad is dependent on the pentad rainfall up to four previous pentads.

Figure 3.9 shows the hyetograph of pentad rainfall on a calendar basis at site 6, as well as the pentad rain water requirements for dry land crops (17.5 mm) and rice (35 mm). The hyetograph of pentad rainfall from November 1987 to October 1988 is also plotted as an example to show the frequent occurrence of dry periods in the wet season. These dry periods can damage crops during the growing stages. In the 1977/1978 calendar year for example, the maximum drought magnitude in the wet season was 2 consecutive pentads for dry land crops and 5 for rice. This result shows the important of drought analysis based on pentad series as a source of information for planning supplementary irrigation.

Annual daily maximum rainfall series

Site 2 was selected for the annual daily maximum analysis as an example because it has twenty three years of observations. The ACF, PACF, linear regression and LOWESS plot were used to describe annual daily maximum rainfall properties. Figure 3.10 shows the ACF and PACF for the annual daily maximum rainfall series at site 2 in West Timor. Based on Bartlett's test at $\alpha = 5\%$, the series shows no significant serial correlation. The annual daily maximum rainfall series is thus independent in time.

LOWESS plot and linear regression analysis were used to check the long-term trend of the annual daily maximum rainfall for site 2. Linear regression analysis shows

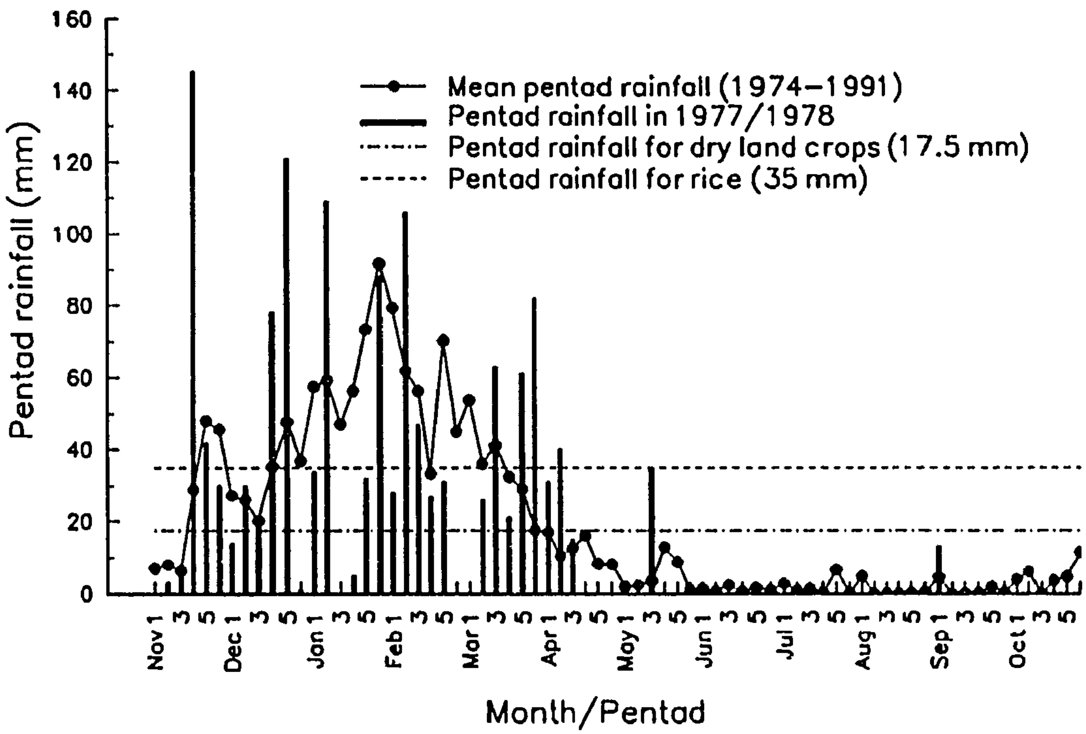
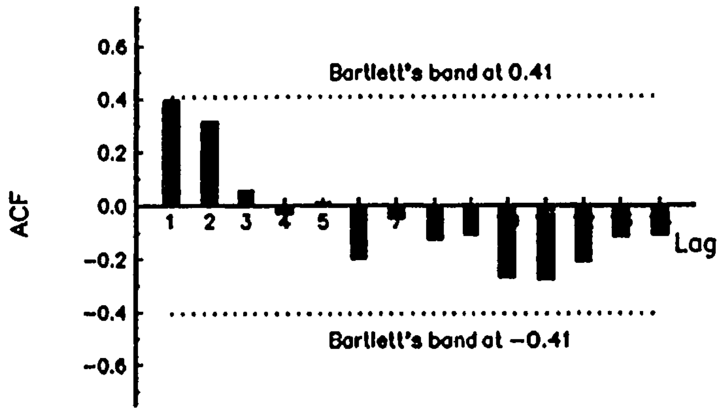


Figure 3.9 Hyetograph of pentad rainfall at site 6 in West Timor (1974-1991)



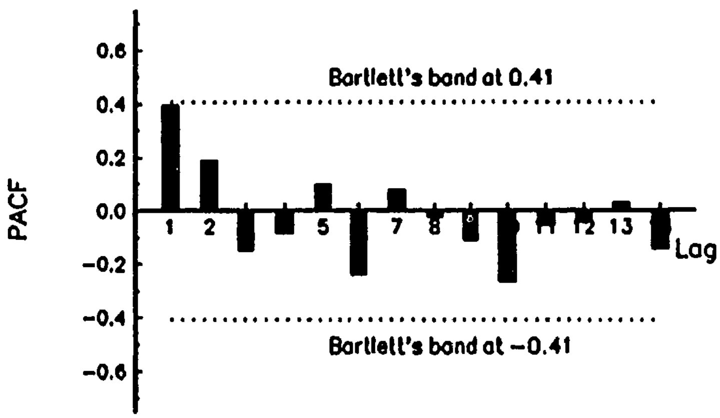


Figure 3.10 ACF and PACF of annual daily maximum rainfall at site 2 in West Timor (1966-1988)

that the slope of the regression line is not significantly different from zero (Table 3.6 and Figure 3.11), and the LOWESS plot also shows no consistent upward or downward trend.

Table 3.6 Linear regression result for detecting trend in the annual daily maximum rainfall series at site 2 in West Timor

N	Site	Slope	Intercept mm	R^2	p-value
23	2 (Penfui)	2.22	-4266.68	0.07	0.21

Note: N is the length of record (years)

The occurrence of annual daily maximum rainfall is assumed to be random in time and space since the annual daily maximum rainfall may not occur on the same day at each site due to the localised nature of the rainstorms. This implies that the cross correlations between stations of annual daily maximum rainfall will be negligible.

Hourly rainfall Series

The only station with one year (1976-1977) of complete hourly rainfall record in West Timor is site 6. This hourly record was therefore taken as representative of the region. Hyetograph was used to describe hourly rainfall properties. Figure 3.12 shows the hyetograph of hourly rainfall at site 6 in West Timor. The total number of hours with rain of greater than 1 mm at site 6 in a year (November 1976-October 1977) was 438 hours (Figure 3.12.a) out of a total of 8760 hours in a year, and the maximum hourly rainfall in the year was 47.5 mm. Figure 3.12 (b) shows an example of the occurrence of intense and prolonged hourly rainfall for the period from January 4th to January 6th of 1977. This figure indicates that hourly rainfall occurred continuously for almost two days. This condition commonly occurs in January and February.

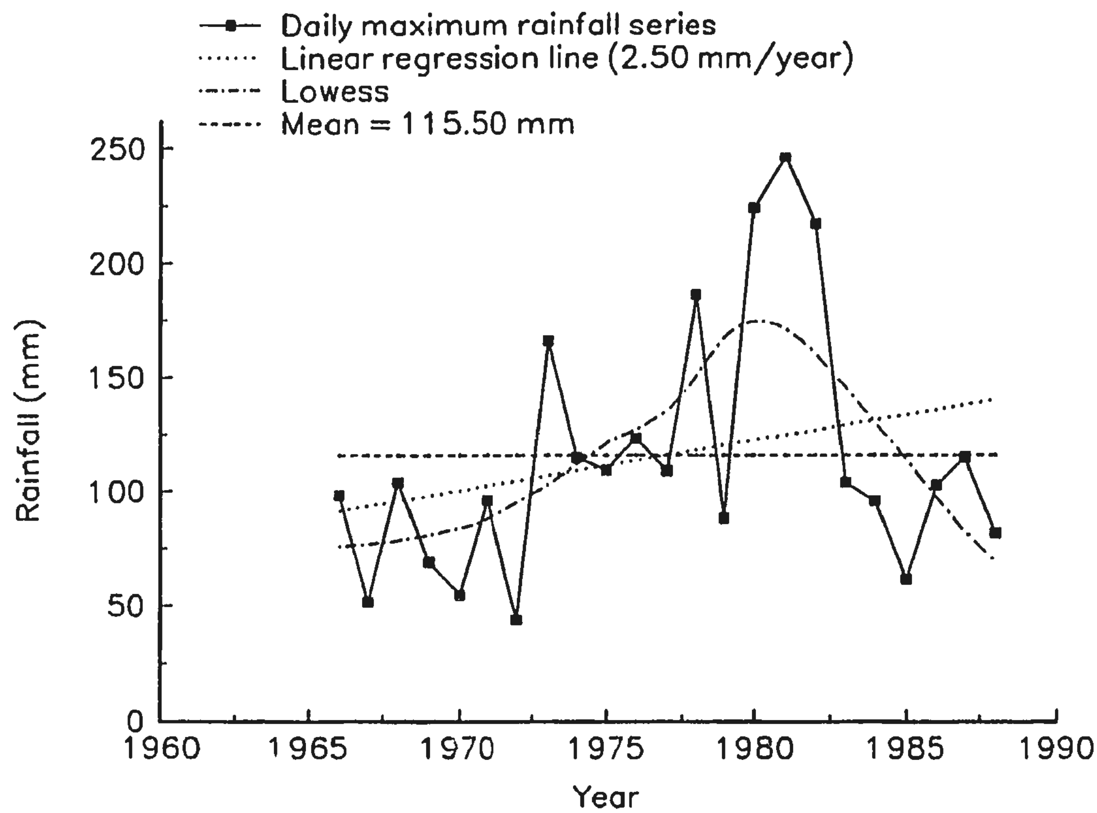
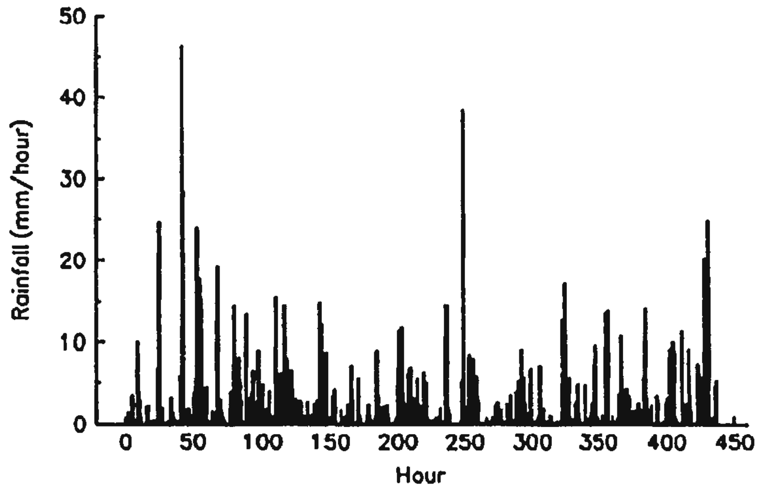
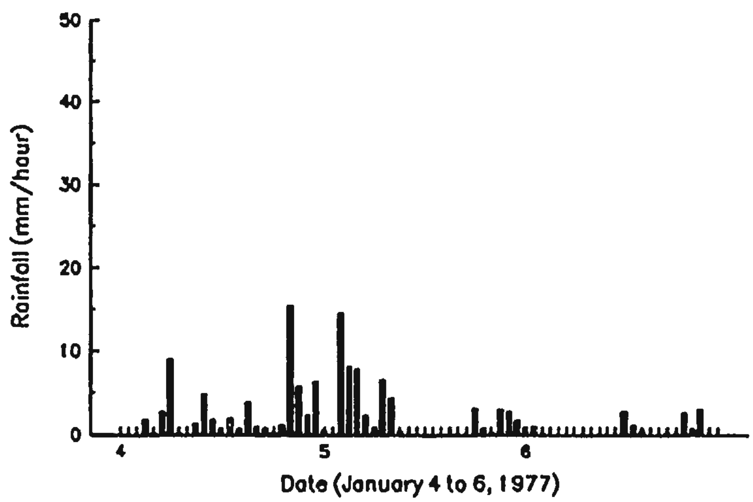


Figure 3.11 The trend test of annual daily maximum rainfall at site 2 in West Timor (1966-1988)



a) Hour with rain (November 1976 – October 1977)



b) Hourly rainfall (January 4 to 6, 1977)

Figure 3.12 Hyetograph of hourly rainfall at site 6 in West Timor (November 1976 - October 1977)

3.4 Spatial Rainfall Characterization

The results were summarized using isoline maps for the mean annual rainfall, the mean annual daily maximum rainfall, and for the number of months receiving 100 mm and 200 mm of rainfall. The contour lines of isoline map were drawn using simple linear interpolation method (Sevruk, 1992). In addition, the CV of CV of the annual rainfall was used as a measure of the spatial homogeneity of rainfall in the region.

Isolines of the mean annual rainfall are presented in Figure 3.13. The isoline map of annual daily maximum rainfall is presented in Figure 3.14 ; this map is also used in the regional frequency analysis in Chapter 5. The isolines of mean annual rainfall show that the highest mean annual rainfall of 2750 mm occurs in the high mountain ridge area in the central part of West Timor (see also Table 1.1 and Appendix C). In general the mean annual rainfall amount reflects the topography of West Timor, in that rainfall increases with increasing elevation, and however, in the upland areas, for example at sites 23 to 30 and at site 9, site to site variability of annual rainfall is large due to the location of these sites on the leeward side during both the wet and dry seasons.

To represent monthly spatial variability of rainfall, isolines of number of months receiving rainfall of greater than 100 mm for rice and 200 mm for dry land crops were drawn. Figure 3.15 and Figure 3.16 show the isolines of the number of months receiving rainfall greater than 100 and 200 mm. The mountainous central area, the northeastern part and the southeast coastal area all have more than 8 months of rainfall greater than 100 mm (Figure 3.15). This indicates that in the dry season (May-October) these three areas still receive rainfall. In the wet season (November-April) the southeast region receives less rain than the northern part due to the location of this area on the leeward side during the prevailing west-northwest winds in the wet season. Assuming the required wet period for rice and dry land crops is four months on average, these areas could be cultivated for two dry land crops per year, while other areas can support only one dry land crop per year.

In Figure 3.16 the isolines of the number of months receiving rainfall of greater than 200 mm for rice are presented. The northwest part, the northeast part, and southeast coastal part of West Timor have 4 wet months of having greater than 200 mm rainfall per month. These parts may be suitable for one rainfed rice crop per year.

Because of the occurrence of 2 to 3 weeks without rain in the wet season in West Timor is common, supplementary irrigation requirements can not be determined from an monthly rainfall analysis alone. Drought characteristics based on rainfall deficiency for shorter durations such as weekly or pentad are important and will be discussed in Chapter 6.

From Table 3.3, the coefficient of variation of the coefficient of variation (CV of CV) of annual rainfall is 0.18. If the general criterion of 0.40 for the CV of CV is adopted, the annual rainfall data in the West Timor can be assumed to be homogeneous. The use of the coefficient of skewness CS, to identify spatial homogeneity of annual rainfall is not appropriate since the skewness coefficient of this region is highly variable, ranging from 0.04 to 1.82.

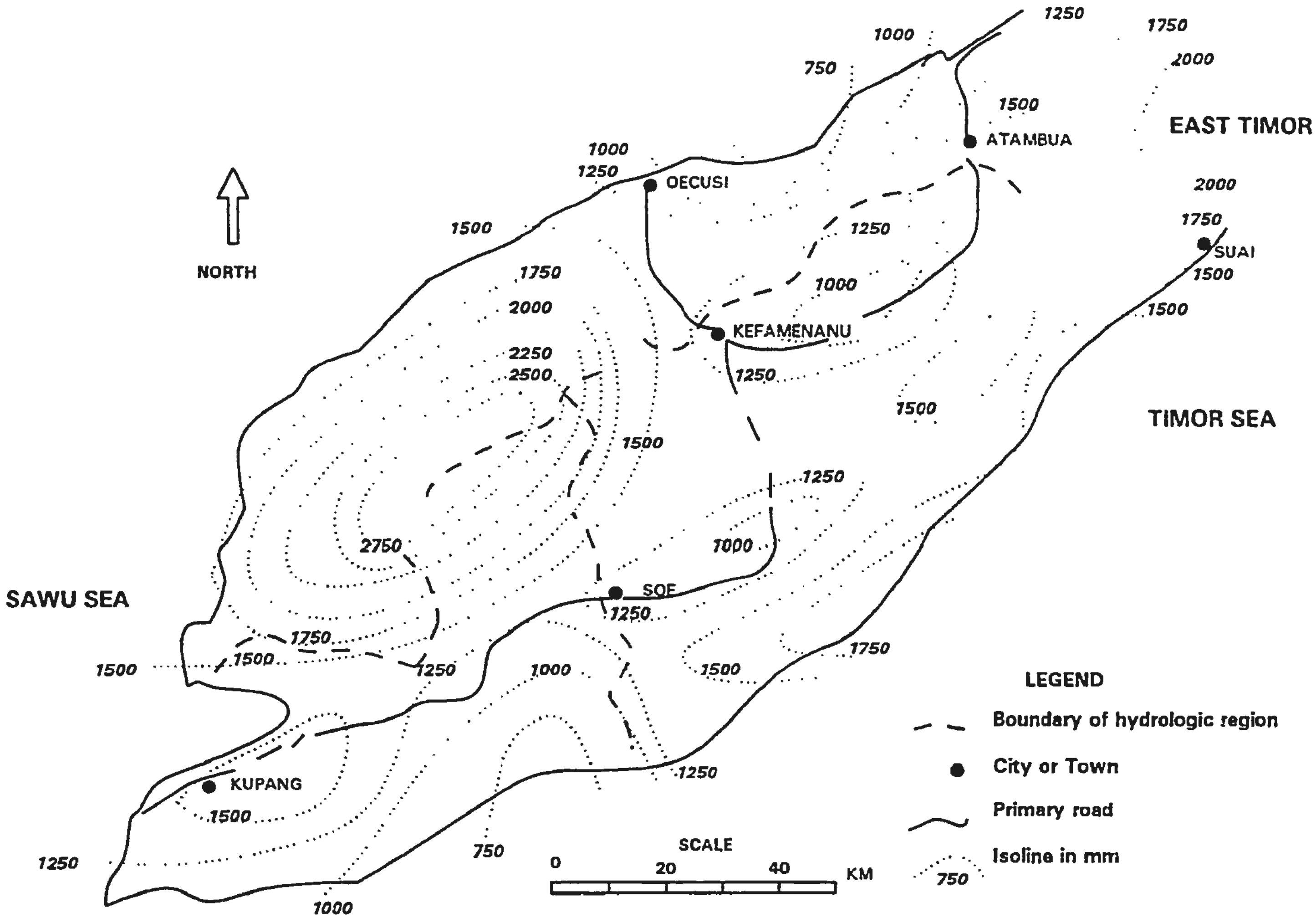


Figure 3.13 Isoline map of the mean annual rainfall in West Timor (1976-1990)

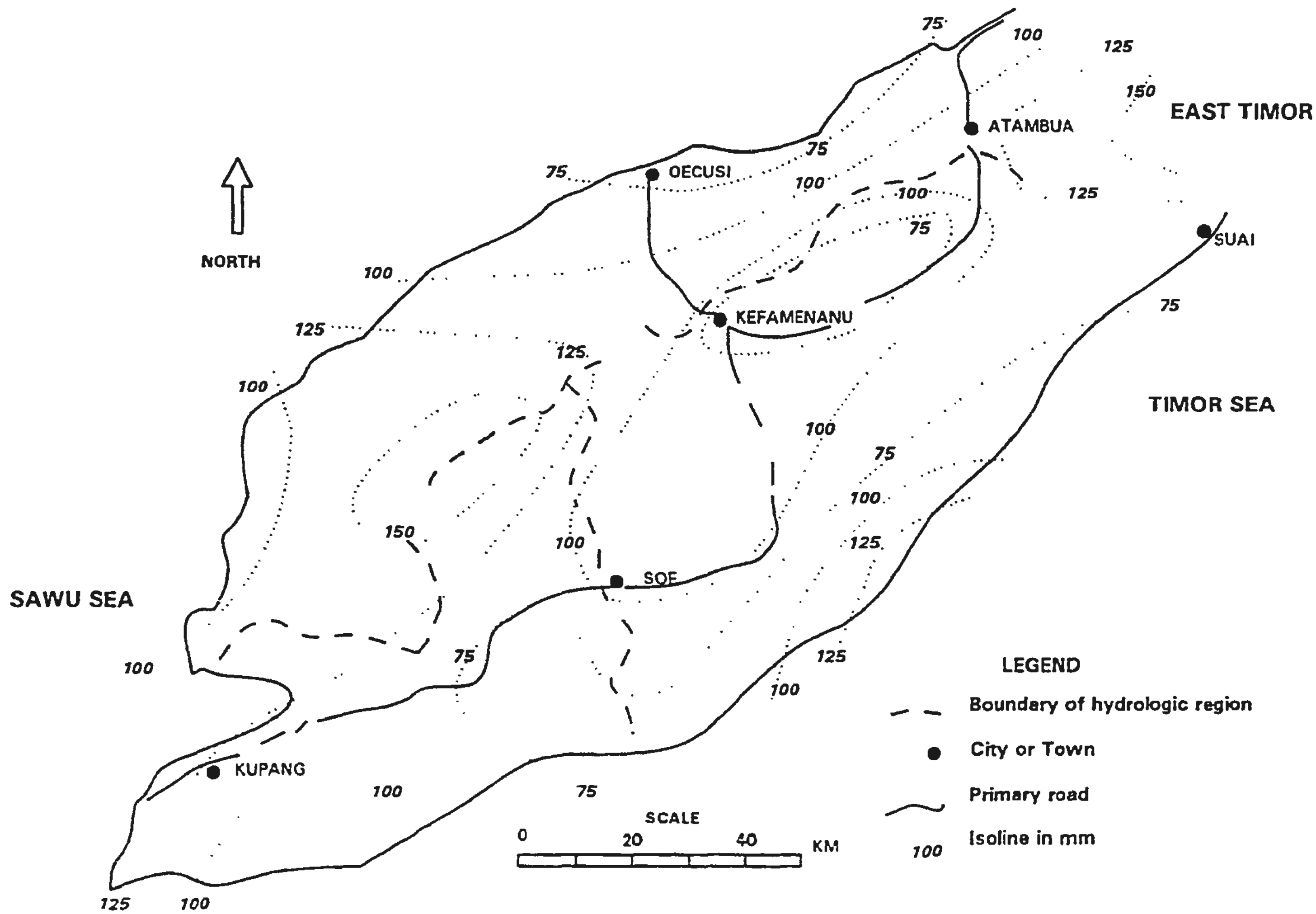


Figure 3.14 Isolines of the mean annual daily maximum rainfall in West Timor (1976-1990)

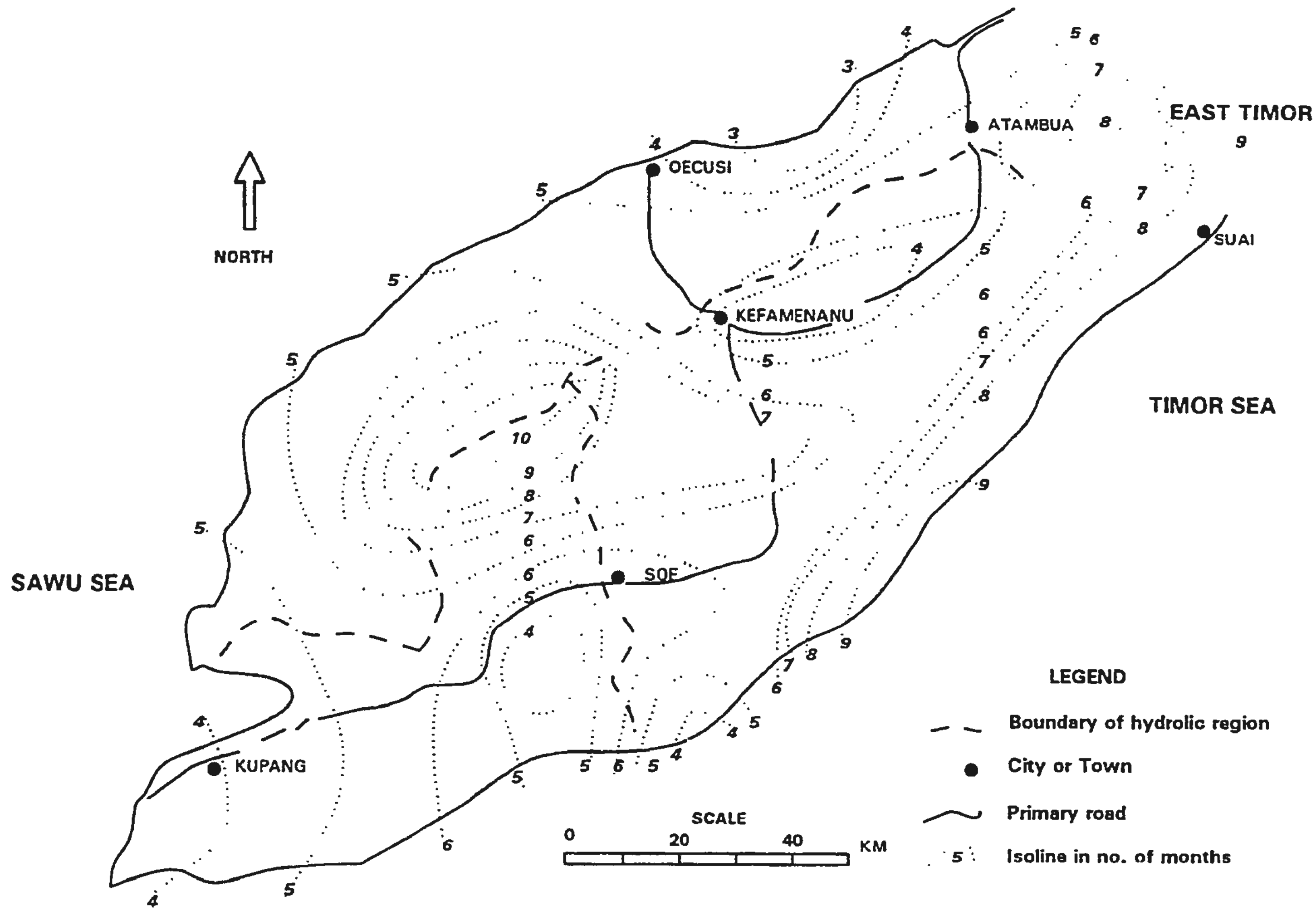


Figure 3.15 Isolines of number of months receiving greater than 100 mm rainfall per month for dry land crops in West Timor (1976-1990)

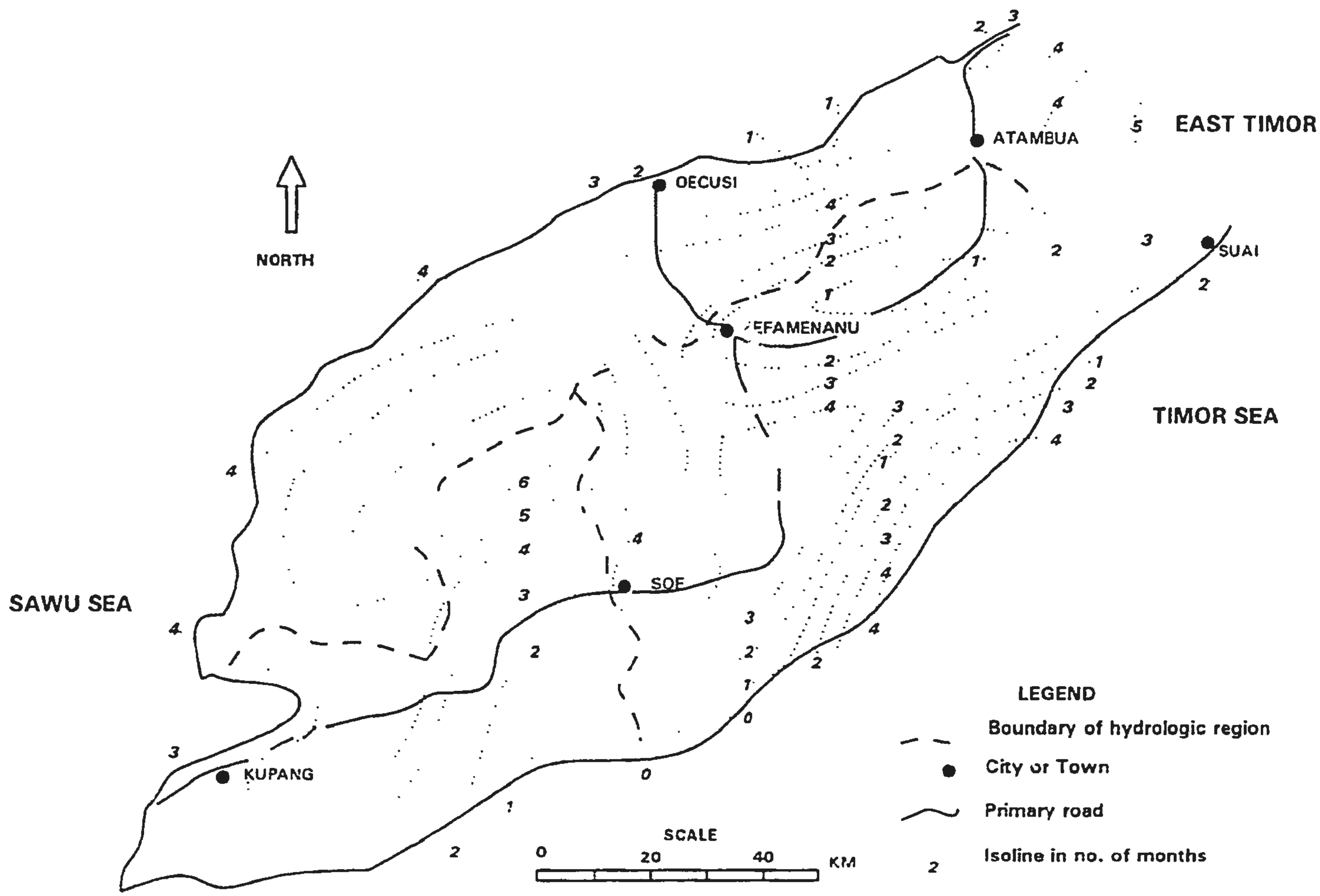


Figure 3.16 Isolines of number of months receiving greater than 200 mm rainfall per month for rainfed rice in West Timor (1976-1990)

3.5 Interaction of Rainfall with Physical Factors

The physical factors such as the prevailing wind system and topography, which affect spatial rainfall distribution, are described here. Spatial rainfall distribution is largely controlled by topography and the monsoons which are associated with the prevailing winds (Figure 3.17 and Figure 3.18).

Maximum rainfall occurs during the wet monsoon (November-April) when the winds of the west-northwest monsoon carrying plenty moist air from surrounding oceans occur, and a very dry period follows during the winds of the east-southeast monsoon (May-October) carrying little moist air from the surrounding oceans (Crippen, 1980; Shaw, 1988). During the wet monsoon, the western part of the region receives more rainfall. During the dry monsoon the southeastern part still receives some rain.

Figure 3.19 shows the linear regression of the mean annual rainfall versus elevation. The relationship is somewhat significant for the north and southeast regions as described by small p-values of the regression lines.

Table 3.7 shows the estimated linear regression parameters for each region and for West Timor as a whole. The regression line of the southwest region is almost horizontal and the p-value is greater than the significance level of 5%. This indicates that the elevations have no significant effects in the spatial rainfall distribution of this region. The reason is that the surrounding area has a low topography with a maximum elevation of only about 500 m. The R-squared and p-value of the regression line for the entire region are 0.38 and 0.0003 respectively.

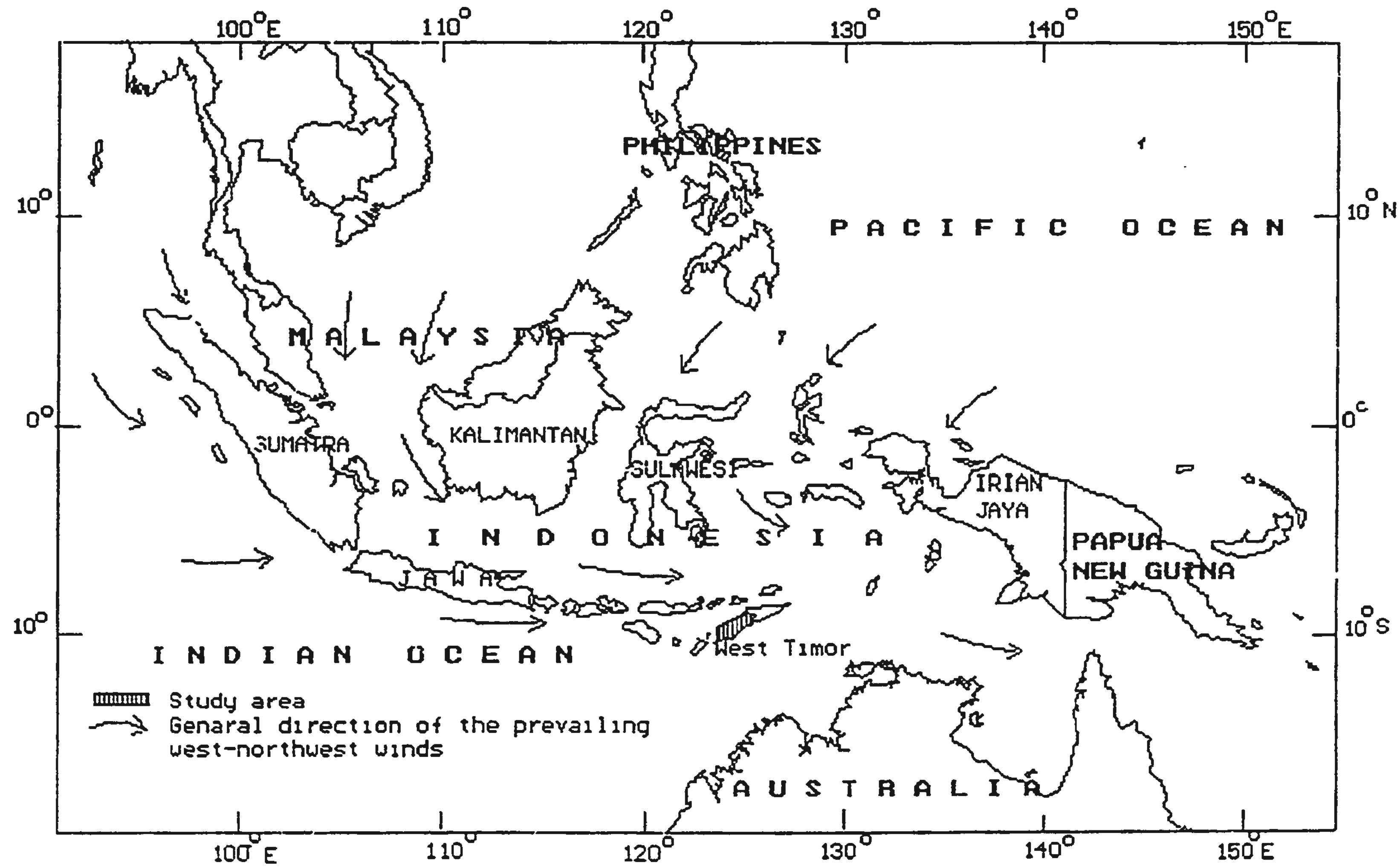


Figure 3.17 Prevailing west-northwest winds in the wet monsoon (November to April) in Indonesia

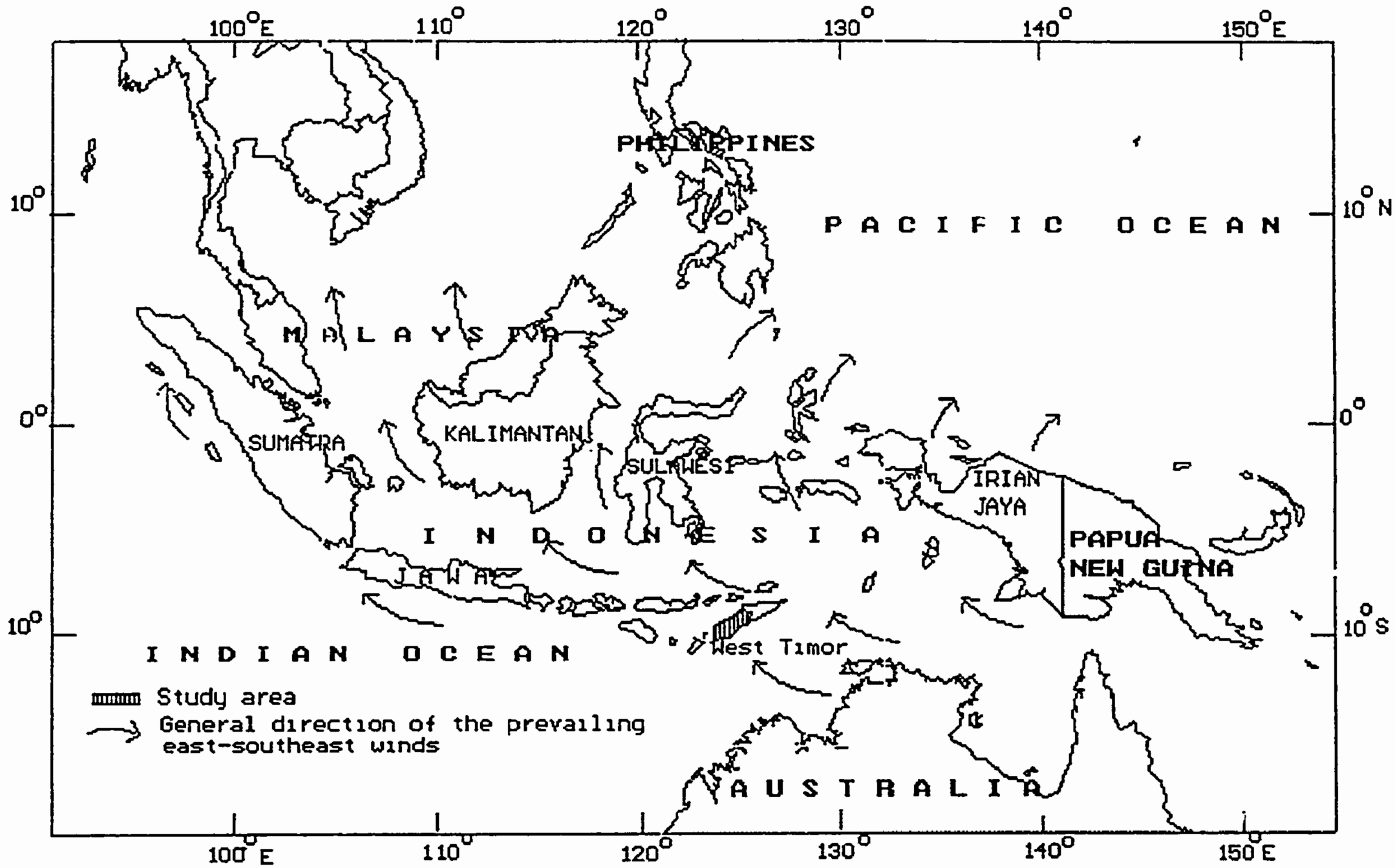


Figure 3.18 Prevailing east-southeast winds in the dry monsoon (May to October) in Indonesia

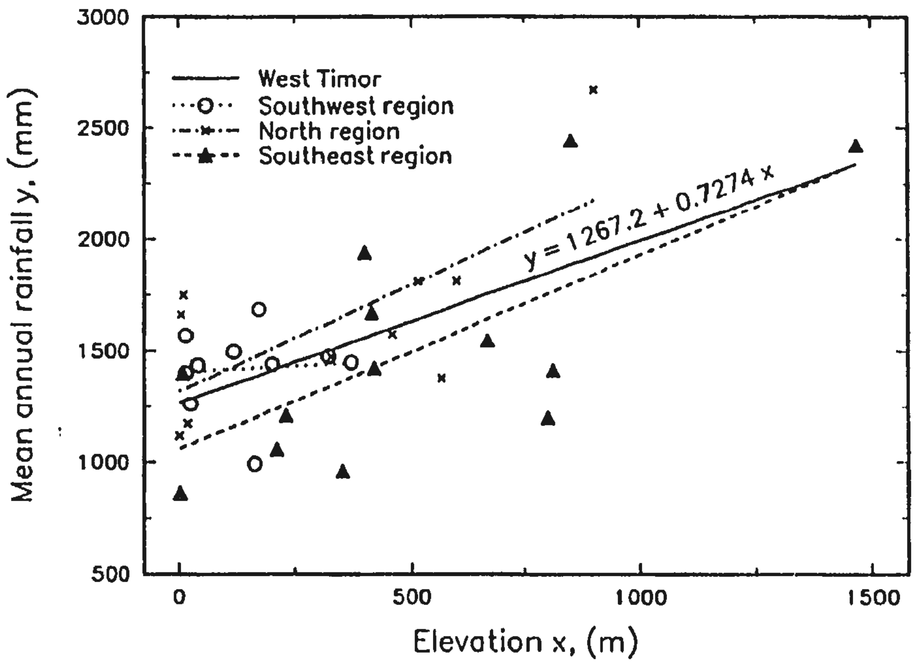


Figure 3.19 Linear regressions of elevation versus the mean annual rainfall in West Timor (1976-1990)

Table 3.7 Linear regression results of elevation versus the mean annual rainfall in West Timor (1976-1990).

Region	Slope	Intercept mm	R^2	p-value
West Timor	0.7274	1267.2	0.3763	0.0001
Southwest	0.1068	1404.9	0.0053	0.8411*
North	0.9506	1318.4	0.4797	0.0264
Southeast	0.8709	1058.5	0.4898	0.0077

* The p-value is greater than 0.05 which indicates that the regression line is not significant at α = 5%.

The results show on average that the topography has a significant influence on the mean annual rainfall in West Timor. This indicates that orographic rainfall (Shaw, 1988) may be dominant.

Chapter 4

Regional Frequency Analysis of Rainfall: Methodology

This chapter deals with the regional frequency analysis of annual daily maximum rainfall in West Timor using an index rainfall approach (Schaefer, 1990) based on L-moments (Hosking and Wallis, 1993). The results are then compared with an at-site frequency analysis. The first part of this chapter describes the index rainfall approach and L-moments method, the remaining sections describe the subsequent steps of the analysis, as follows:

(a) screening and homogeneity testing of the rainfall data;

(b) at-site frequency analysis; and

(c) selection of regional frequency distribution.

The results of applying the methodologies discussed in the chapter are presented in Chapter 5.

4.1 Index Rainfall Approach

The index rainfall approach is similar in principle to the index flood approach (Schaefer, 1990). This approach is commonly used since it is easy to apply and has given reasonable results. Regional rainfall probability distribution based on this approach can be defined by:

$$x_R = \frac{x_S}{\bar{x}_S} \tag{4.1}$$

where x_R is a regional dimensionless rainfall variate, $\bar{x}_S$ is the index rainfall, and x_S is the rainfall data at any site. In this study, $\bar{x}_S$ is the mean annual daily maximum rainfall. For estimating the annual daily maximum rainfall at any site x_S, Equation 4.1 can be used where $\bar{x}_S$ is taken from the contour map of the mean annual daily maximum rainfall shown in Figure 3.14. The regional curve x_R, is obtained by regional averaging of the at-site L-moments described below.

4.2 L-Moments Method

L-moments are linear moments of statistical distribution, which do not raise data to power of 2, 3 and 4 as required for variance, skewness and kurtosis respectively as in conventional moments. Since they are linear, they are less biased than conventional moments.

The theory of L-moments parallels the theory of conventional moments (Hosking, 1990). Population L-moments (λ_r, r = 1,2,3,...N) are defined as linear combinations of expected values of order statistics. The first L-moment (λ_1), is the mean of the statistical distribution, and is identical to the conventional first moment. The second L-moment (λ_2) is a linear measure of dispersion which is analogous to the standard deviation. The L-moment coefficient of variation is defined as L-CV ($\tau = \lambda_2/\lambda_1$). Other L-moment ratios are $\tau_r = \lambda_r/\lambda_2$ for r = 3,4,..N. Hosking (1990) showed that $\tau_3 = \lambda_3/\lambda_2$ and $\tau_4 = \lambda_4/\lambda_2$ are measures of a distribution's skewness and kurtosis, respectively. The τ_3 is called the L-skewness and τ_4 is called the L-kurtosis. L-moment ratios are bounded so that their absolute values are less than one ($|\tau_r| < 1$), for r = 3,4,..n.

Unbiased estimators of sample L-moments l_r, from an ordered N-sample or sites $x_1 \leq x_2 \leq x_3 \leq .. \leq x_N$ for r = 1,2,3,4 are:

$$\begin{aligned} l_1 &= b_0 \\ l_2 &= 2b_1 - b_0 \\ l_3 &= 6b_2 - 6b_1 + b_0 \\ l_4 &= 20b_3 - 30b_2 + 12b_1 - b_0 \end{aligned} \tag{4.2}$$

where

$$\begin{aligned} b_0 &= \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \\ b_1 &= \frac{1}{N(N-1)}\sum_{i=2}^{N}(i-1)x_i \\ b_2 &= \frac{1}{N(N-1)(N-2)}\sum_{i=3}^{N}(i-1)(i-2)x_i \\ b_3 &= \frac{1}{N(N-1)(N-2)(N-3)}\sum_{i=4}^{N}(i-1)(i-2)(i-3)x_i \end{aligned} \tag{4.3}$$

The sample L-moment ratios at the site i ($t^{(i)}_r$), for r = 2,3 and 4, are:

$$t^{(i)} = \frac{l_2}{l_1} \;; \quad t_3^{(i)} = \frac{l_3}{l_2} \;; \quad t_4^{(i)} = \frac{l_4}{l_2} \tag{4.4}$$

4.3 Screening and Homogeneity Testing of the Rainfall Data

The annual daily maximum rainfall data were screened for consistency as described in Chapter 2. Further screening is required to ensure that the data satisfied the assumptions of the proposed methodology of the regional frequency analysis. There are four assumptions of the regional frequency analysis (Schaefer, 1990). These are as follows:

(1) there is no serial correlation in the data series;

(2) there is no cross correlation in the regional data;

(3) the data series have no trend; and

(4) the regional data are homogeneous.

The results of annual daily maximum rainfall analysis in Chapter 3 show that the rainfall data have no significant trend, serial or cross correlations. The fourth assumption of homogeneity was tested using a discordancy index and Fourier plots, as described in sections 4.3.1 and 4.3.2 below.

An homogeneous region is a set of sites which have approximately identical frequency distribution. This implies that the region have identical coefficients of variation CV, and coefficient of skewness CS, in the regional data. Other ways to delineate homogeneous regions of rainfall data are using a discordancy measure (D_i) (Hosking and Wallis, 1993) and Andrews' Fourier plots (Andrews, 1972) described below.

4.3.1 Discordancy Measure

Using regional data, this numerical measure is used to assess whether there are sites with unusual data in the region. The procedure is based on the L-moments method described earlier.

The discordancy measure D_i, can be expressed using the following equations

(Hosking and Wallis, 1993):

$$D_i = \frac{1}{3}(u_i-\bar{u})^T S^{-1}(u_i-\bar{u})$$
$$S = \frac{1}{(N-1)}\sum_{i=1}^{N}(u_i-\bar{u})(u_i-\bar{u})^T \quad (4.5)$$
$$\bar{u} = \frac{1}{N}\sum_{i=1}^{N}u_i$$

where $u_i = [t^{(i)}, t_3^{(i)}, t_4^{(i)}]$ is a vector of sample L-moment ratios for station i, $\bar{u}$ is the group average, S is the sample covariance matrix, and D_i is the discordancy measure for station i. The use of the unweighted average in the definition of $\bar{u}$ is preferred to isolate the unusual sites and to eliminate the potential data errors due to different record lengths. Hosking and Wallis proposed a criterion of $D_i < 3$ to identify region having no unusual sites and a possible homogenous region. This criterion assumes that the sample u_i's are independent and are normally distributed.

Procedure

The procedure of estimating the sample L-moments and discordancy measure (D_i) in the regional data can be summarized as follows:

(a) rainfall data of each site are arranged in ascending order and scaled by the index rainfall in this case using mean annual daily maximum rainfall;

(b) the sample L-moments $l_1^{(i)}$, $l_2^{(i)}$, $l_3^{(i)}$ and $_4^{(i)}$, and the sample L-moments ratios $t^{(i)}$, $t_3^{(i)}$ and $t_4^{(i)}$ for each station i, are determined using equations 4.2 to 4.4;

(c) for each site i, u_i is calculated using the sample L-moments ratios, and the regional unweighted average $\bar{u}$ is calculated; and

(d) using the sample u_i's and $\bar{u}$, the sample covariance matrix is calculated, and D_i of each site is determined. If the D_i value for any site, in the region is greater than 3, it is an indication that the site, is discordant from the region, or it may indicate errors in the data. If all sites in the region have D_i values less than 3, then they may indicate that the region is homogeneous.

4.3.2 Andrews' Fourier Plots

Andrews' Fourier plots (Andrews, 1972) is a visual method of cluster analysis. Andrews' Fourier plots of the second, third and fourth sample L-moment ratios at each site provide a visual comparison of the wave trends of each site. If the waves of the data plotted have similar trend, then, the regional data can be considered to represent a cluster or homogeneous region. Otherwise, the regional data are from different clusters or may indicate errors in the data.

The mathematical expression of Andrews' plots is:

$$f(d) = \frac{t^{(i)}}{\sqrt{2}} + t_3^{(i)}\sin(d) + t_4^{(i)}\cos(d) \tag{4.6}$$

where f(d) is the Fourier component, d is degrees from -180^0 to $+180^0$, and $t^{(i)}$, $t_3^{(i)}$ and $t_4^{(i)}$ are sample L-moment ratios at site i.

4.4 At-Site Frequency Analysis

At-site frequency analysis provides the at-site annual daily maximum rainfall frequency magnitudes for comparison with those obtained from the regional frequency analysis. It is also provides the L-moment ratios for the regional analysis.

The probability distribution assumed for the at-site analysis is the Gumbel (EV1) distribution. Gumbel distribution is convenient since it has simple properties and is commonly used for extreme rainfall events. The Box-Cox power transformation (Lye, 1992) is used to transformed observed data to approximately follow the Gumbel variate. The PPCC (Probability Plot Coefficient Correlation) test (Lye, 1992, Maidment, 1993) is used to select the best fitting distribution. Details of this test are provided in section 4.4.1 below. The sample L-moment (l_2) at each site is used to estimate the Gumbel parameters. The L-moments method was used to estimate probability distribution parameters because it is less biased and often provides superior estimates compared to other parameter estimation methods (Vogel et al., 1993).

There are two assumptions of at-site frequency analysis: there are no trend in the data series, and the data series is serially independent. As previously mentioned, there is no significant serial correlation or trend in the annual daily maximum rainfall at the selected stations in West Timor.

4.4.1 PPCC Test for Goodness of Fit

The goodness of fit can be checked visually from a probability plot, and numerically using the PPCC method. The inverse Gumbel cumulative distribution function $x = \varepsilon - \alpha\{Log[-Log(F)]\}$, is a linear equation of the form $y = a + bz$, where y is x, a is ε, b is α, and z is $-\{Log[-Log(F)]\}$. Based on this approach, Gumbel probability distribution can be drawn as a straight line on the Gumbel paper, and the observed data can be plotted on this paper. Visual judgment of how well the observed data fit as straight line can be determined.

The next step is how to find the transformation parameter λ, such that the transformed data fit the Gumbel probability distribution. The PPCC method is used to find the best Box-Cox transformation λ, for the Gumbel distribution in this analysis. The Box-Cox transformation is given by:

$$y_i = \frac{(x_i^{\lambda}-1)}{\lambda} \; ; \qquad for\ \lambda \neq 0,\ x_i > 0$$
$$y_i = Log x_i \; ; \qquad for\ \lambda = 0,\ x_i > 0 \tag{4.7}$$

where x_i is the at-site rainfall data, y_i is the transformed data which may follow certain probability distribution, and λ is a transformation parameter.

The numerical measure of fit using the PPCC method allows a comparison of the results in both graphical (probability plot) and numerical (correlation coefficient) forms (Lye, 1992; Vogel 1986). The PPCC method is based on the degree of correlation between the ordered values of the data and their corresponding reduced variate z_i, where the PPCC r, is given by:

$$r = \frac{\sum_{i=1}^{N} (y_i - m_y)(z_i - m_z)}{[\sum_{i=1}^{N}(y_i-m_y)^2 \sum_{i=1}^{N}(z_i-m_z)^2]^{0.5}} \tag{4.8}$$

where y_i are variate (at-site data), m_y is the mean of the variate, z_i = -Log[-Log(F_i)] is the reduced variate, m_z is the mean of the reduced variate and F_i is the cumulative probability. m_z is zero for normal probability distribution. The values of z_i and m_z are based on the use of certain plotting position. If r is 1, there is a perfect linear relationship, and if r is 0, there is no linear relationship. Therefore, the closer r is to 1, the more linear the relationship. Critical value of the correlation coefficient (r_c) is required to show whether the data can or cannot be considered to be Gumbel probability distribution at a given level of significance α. The r_c are available (Vogel, 1986; Maidment, 1993).

To find the transformation parameter λ, by using PPCC method, an iterative process is used such that λ optimum should be found at maximum PPCC r, for a given level of significance α. In this study, α = 5% is used.

Plotting Position Used

The method of assigning the probabilities F_i to the data is important so that the frequency curve does not extend beyond either 0% or 100%. In this study, Gringorten plotting position (Maidment, 1993) was used. This plotting position is:

$$F_i = \frac{(i-0.44)}{(N-0.12)} \tag{4.9}$$

where, F_i is the cumulative probability or plotting position, N is sample size and i is the rank with i=1 indicating the smallest sample value.

Procedure

The procedure for using the PPCC method for at-site frequency analysis, can be summarized as follows:

(a) observed data x_i, are arranged in ascending order and ranked;

(b) a probability value F_i, is assigned to x_i, where $x_i = F_i$, and F_i are based on the plotting position used;

(c) F_i is converted with reduced variate z_i;

(d) Gumbel paper is developed where the horizontal axis is $z_i = -\{Log[-Log(F_i)]\}$ or the Gumbel scale and the ordinate uses a linear scale;

(e) set initial value of transformation parameter λ, (eg. -2, -2.01, -2.02, ..., or 2), the x_i is converted to y_i, and the PPCC r is calculated;

(f) step (e) is repeated with different λ value until a value of λ is found where the PPCC is maximum (r_{max});

(g) based on the number of observations N, and the permissible significance level, the critical value of PPCC r_c, is determined from the available table (Vogel, 1986);

(h) if r is greater than r_c, the transformed data are considered to be Gumbel distributed;

(i) if after transformation, the PPCC r is less than r_c, either another suitable probability distribution is needed or there is something unusual in the observed data; and

(j) the transformed data y_i having r_{max}, are plotted on the Gumbel paper, and visual judgement can be determined to check whether the transformed data form a straight line.

Using sample L-moments (l_2), the Gumbel parameters are determined. For comparison with the regional frequency analysis, the transformed data are scaled by its mean value.

4.5 Selection of Regional Frequency Distribution

This section deals with the procedure of selecting the regional probability distribution for West Timor using the L-moment ratio diagram (Hosking and Wallis, 1993, Maidment, 1993, pp.18-27). Plotting regional weighted average L-moment ratios (L-skewness $\bar{t}_3$ and L-kurtosis $\bar{t}_4$) on such a diagram allows for choosing among various probability distributions such as Gumbel Generalized Extreme Value (GEV), Generalized Logistic (GLOG), Gamma or Generalized Pareto (GPA).

Procedure

The procedure for estimating the regional frequency distribution is summarized below:

(a) The regional weighted average of sample L-moment ratios of $\bar{t}_3$ and $\bar{t}_4$ is estimated and compared to the theoretical distributions of L-skewness and L-kurtosis using the L-moment ratio diagram. This weighted average allows for greater variability in short records (Vogel et al., 1993). The selection of the best fitting regional distribution can be judged by how well the pairs of $\bar{t}_3$ and $\bar{t}_4$ match the various theoretical distribution curves.

(b) Distribution parameters are then determined using the method of L-moments. Hosking (1990) have derived equations for estimating parameters of various probability distributions such as Gumbel, GEV, GLOG, GPA and Gamma (Appendix A).

The theoretical distributions considered in this study are the Gumbel, GEV, GLOG, Gamma and GPA. These distributions are commonly used in regional frequency analysis of annual daily maximum rainfall (Cong et al., 1993). In the L-moment ratio diagram, the third and fourth L-moment ratios of the two-parameter and the three-parameter theoretical distributions are represented by a single point and a curve, respectively.

The regional weighted average of sample L-moments $\bar{l}_r$ and L-moment ratios $\bar{t}_r$, is estimated using the following equations (Hosking and Wallis, 1993):

$$\bar{l}_r = \frac{\sum_{i=1}^{N} N_i l_r^{(i)}}{\sum_{i=1}^{N} N_i} \quad ; \quad \bar{t}_r = \frac{\sum_{i=1}^{N} N_i t_r^{(i)}}{\sum_{i=1}^{N} N_i} \tag{4.10}$$

where r in this study is 2, 3 and 4, $l_r^{(i)}$ is the L-moment at site i, and $t_r^{(i)}$ is the L-moment ratio at site i.

Chapter 5

Regional Frequency Analysis of Rainfall: Results and Discussion

This chapter discusses the results of regional frequency analysis of annual daily maximum rainfall for West Timor using the methodologies described in Chapter 4. The results of this analysis are grouped as follows:

(a) homogeneity testing of the rainfall data;

(b) at-site frequency analysis;

(c) selection of regional frequency distribution; and

(d) comparison between regional and at-site frequency magnitudes.

Figure 5.1 shows the 30 selected stations of annual daily maximum rainfall in West Timor used in this analysis. These stations have an average record length of thirteen years (Table 5.1).

5.1 Homogeneity Testing of the Rainfall Data

The screening of the annual daily maximum rainfall data was discussed in

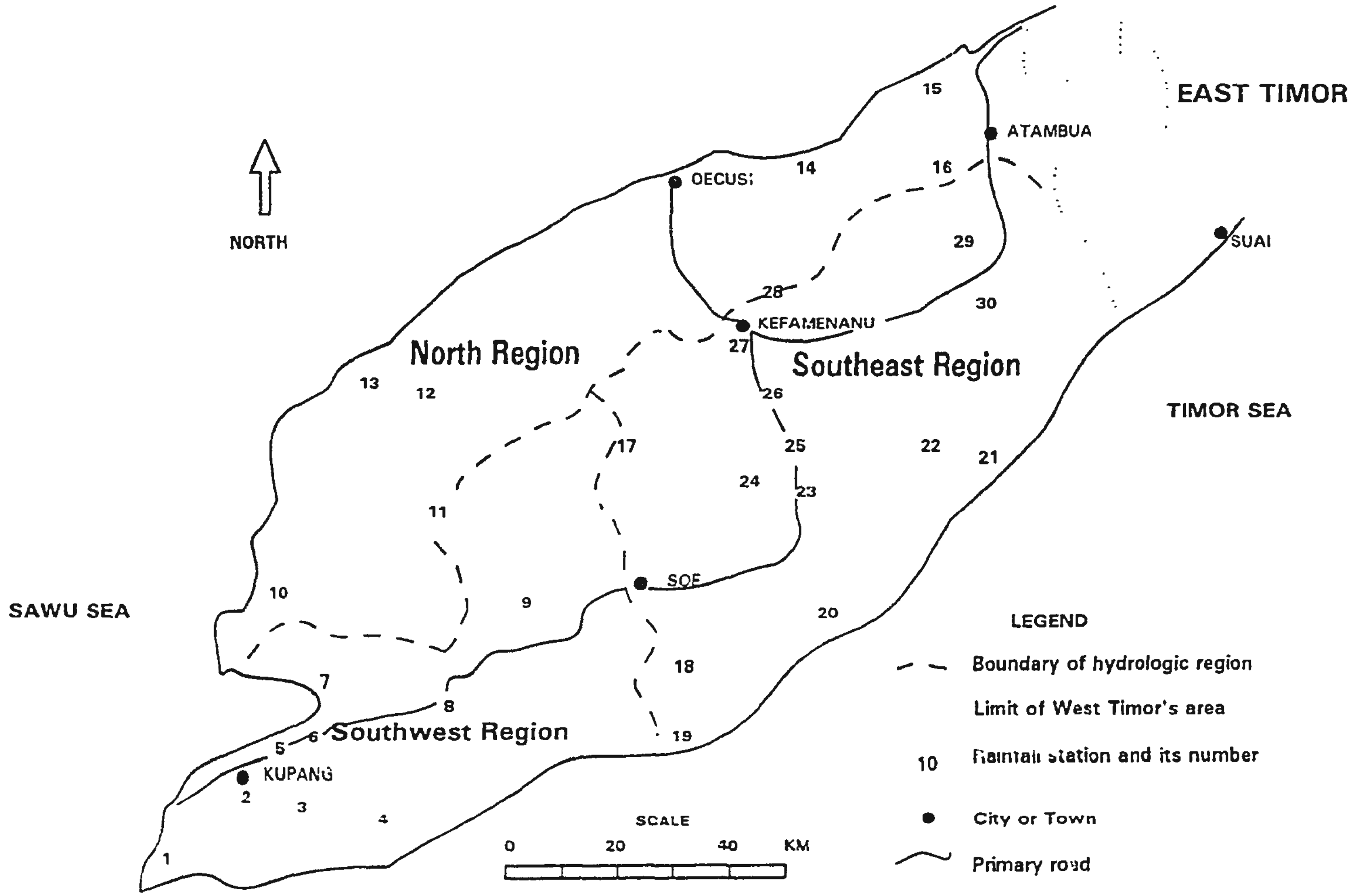


Figure 5.1 Initial hydrologic regions and the selected stations studied of annual daily maximum rainfall in West Timor

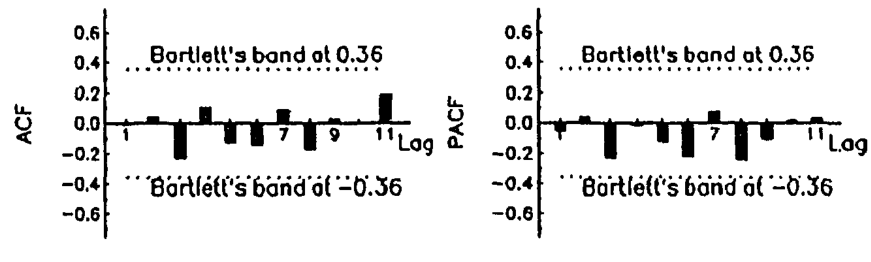
Chapter 3. This section discusses the results of the homogeneity testing of the annual daily maximum rainfall data. The results are summarized in three parts. These are: the results of the discordancy test, Andrews' Fourier plots, and a summary of the analysis.

Discordancy Measure

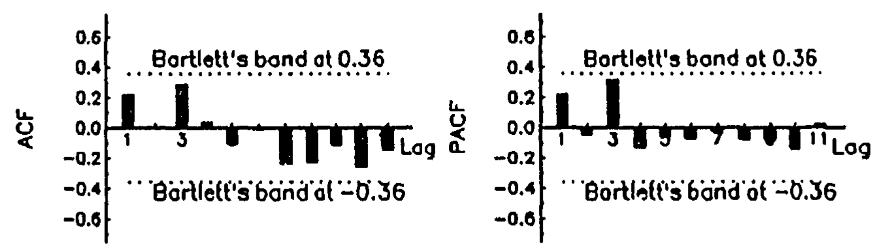
The relevant summary statistics were calculated from the daily maximum rainfall data in West Timor and are presented in Table 5.1. It shows the discordancy measure D_i, L-moment ratios, coefficients of variation and coefficients of skewness of each site's data. The D_i indexes of each site are calculated using the L-moment ratios of all sites in West Timor. In calculating D_i index, the sample vector $u_i = [t^{(i)}\ t_3^{(i)}\ t_4^{(i)}]$'s are assumed to be independent and normally distributed. These assumptions for the sample L-moment ratios t, t_3 and t_4 are confirmed and are presented in Figure 5.2 and Figure 5.3, respectively.

Normality was tested using the PPCC method. The ACF and PACF and Bartlett test at $\alpha = 5\%$ were used to test for serial correlation in the data series. The sample L-moment ratios were ordered based on the station number, and this order was also used in determining the D_i's. The independence test was performed on these sample L-moment ratios.

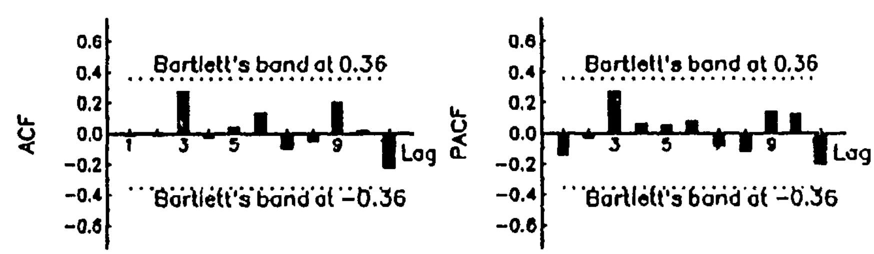
The PPCC and Bartlett's test show that the sample L-moment ratios t, t_3 and t_4 are independent and normally distributed at $\alpha = 5\%$ as shown in Figure 5.2 and Figure 5.3. This implies that sample vector $u_i = [t^{(i)}\ t_3^{(i)}\ t_4^{(i)}]$ is independent and normally distributed. So the use of $D_i > 3$ as a criterion for unusual site in the regional data can



a) Sample L−CV (t)

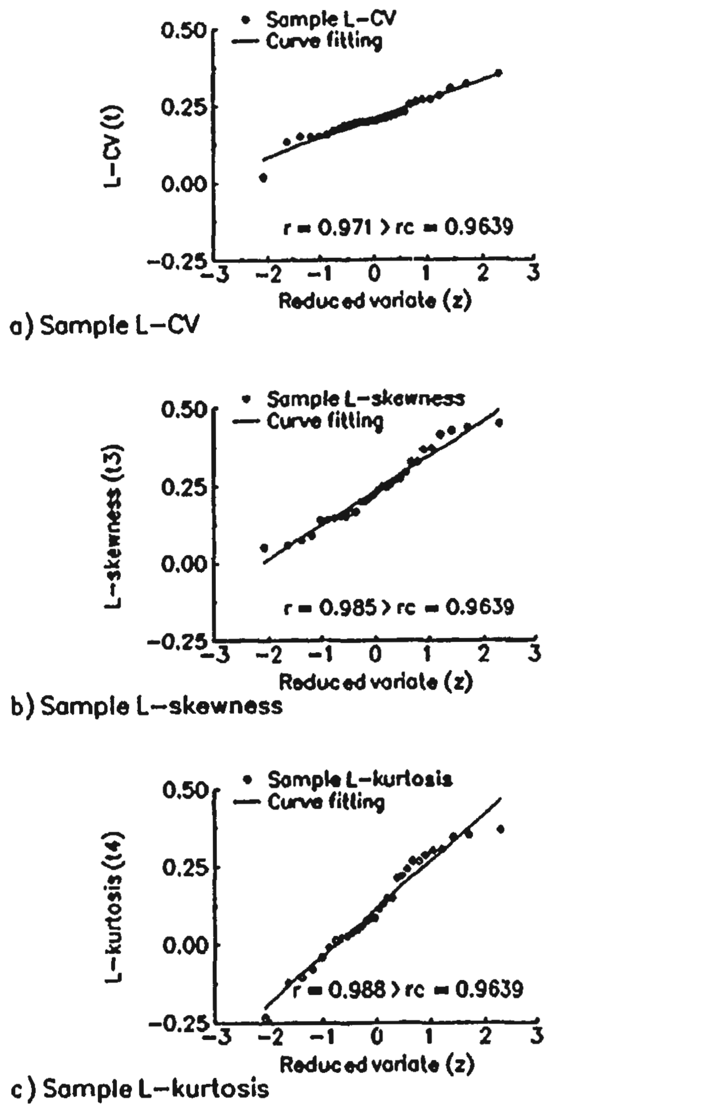


b) Sample L−skewness (t3)



c) Sample L−kurtosis (t4)

Figure 5.2 Independent tests of sample L-CV, L-skewness and L-kurtosis of annual daily maximum rainfall in West Timor



Note: r is the estimated PPCC
rc is the critical correlation at 5% significance level

Figure 5.3 Normality plots of sample L-CV, L-skewness and L-kurtosis of annual daily maximum rainfall in West Timor

Table 5.1 Summary statistics for the West Timor annual daily maximum rainfall data

Site	Site no.	n	Mean mm	CV	CS	t	t_3	t_4	Di
Batuliti	1	11	123.6	0.35	0.93	0.1963	0.2931	0.1301	0.16
Penfui	2	23	115.5	0.48	1.10	0.2599	0.2569	0.2198	0.63
Oekabiti	3	16	107.3	0.35	1.47	0.1837	0.3714	0.2661	0.63
Tubutesb	4	11	112.7	0.40	1.63	0.2129	0.3268	0.3018	0.51
Tarus	5	12	132.2	0.52	0.69	0.3036	0.1680	0.0764	1.35
Oesao	6	15	108.7	0.38	1.64	0.1958	0.4373	0.2860	1.11
Pariti	7	12	132.4	0.30	0.63	0.1736	0.2468	-0.0774	1.31
Camplong	8	16	111.2	0.35	0.79	0.2015	0.2003	0.0473	0.10
Hueknutu	9	12	107.0	0.27	1.35	0.1478	0.2690	0.1488	0.62
Nauwen	10	11	140.8	0.33	0.46	0.1965	0.1516	0.0128	0.27
Lelogama	11	15	150.5	0.54	2.23	0.2662	0.3263	0.3515	1.54
Oelilak	12	11	127.2	0.55	0.18	0.3174	0.0523	-0.2324	2.60
Naikliu	13	11	140.5	0.28	0.22	0.1677	0.0899	-0.1221	1.37
Wini	14	10	66.4	0.47	0.74	0.2684	0.2727	-0.0862	0.92
Fatuoni	15	12	69.3	0.39	1.13	0.2052	0.4163	0.0268	1.81
Baurasi	16	12	115.5	0.36	1.64	0.1878	0.4273	0.2663	1.07
Fatumnasi	17	11	117.4	0.63	1.10	0.3506	0.3660	0.0573	2.46
Nifukani	18	12	64.7	0.27	0.45	0.1488	0.1421	0.2121	0.86
Oebelo	19	12	85.2	0.48	0.66	0.2806	0.2362	-0.0414	0.67
Nunkolo	20	12	136.9	0.38	0.17	0.2277	0.0592	-0.0089	0.87
Besikama	21	12	98.3	0.30	1.41	0.1544	0.1532	0.3661	1.78
Biudkfho	22	12	113.9	0.34	0.69	0.1920	0.1404	0.3435	1.77
Oeoh	23	12	70.7	0.39	0.52	0.2243	0.1665	-0.1036	0.63
Noelnoni	24	12	82.0	0.25	0.63	0.1475	0.1461	0.1482	0.69
Loli	25	11	104.8	0.43	0.86	0.2512	0.2218	0.0855	0.19
Noelmuti	26	12	93.5	0.37	0.66	0.2086	0.1991	0.0381	0.10
Kefa	27	13	57.6	0.35	0.83	0.2001	0.2092	0.1153	0.04
Ekoni	28	12	97.6	0.40	1.92	0.0199	0.4494	0.3058	1.24
Sufa	29	12	92.4	0.22	0.23	0.1310	0.0749	0.0220	1.42
Sukabite	30	11	79.1	0.40	1.54	0.2167	0.2468	0.2419	0.31
Mean		13	105.2	0.4	1.0	0.2	0.2	0.1	1.0
CV			0.24	0.25	0.57	0.31	0.48	1.41	0.70

Note: Di is discordancy measure at site i

t, $t3$ and $t4$ are dimensionless L-moment ratios, where the dimensionless first sample L-moment is one

CV is coefficient of variation

CS is coefficient of skewness

n is length of record (years)

be used.

Table 5.1 shows that all D_i are < 3, indicating that there are no unusual sites in the region. Table 5.1 and Figure 5.6 also show that the mean of the CV is 0.40, and the CV of CV is 0.25. These indicates that the region is possibly homogenous. The use of the CS to identify regional homogeneity of annual daily maximum rainfall in West Timor is not appropriate since the skewness coefficient of this region is highly variable ranging from 0.22 to 1.92.

Andrews' Fourier Plots

Figure 5.4 and Figure 5.5 show Andrews' plots of sample L-moment ratios of annual daily maximum rainfall in West Timor. In Figure 5.4 (a) the thirty stations were plotted together. Most of the plotted functions form a band by remaining close together. Outlying plots from the band are site 12 from north region and site 19 from southeast region. Further investigation was carried out by plotting the Fourier functions based on the 3 hydrologic regions suggested by Crippen (1980). These are shown in Figure 5.4 (b), Figure 5.5 (a) and Figure 5.5 (b) for southwest region, north region and southeast region, respectively. These figures show that some sites do not fit at all. They should be separated. However, those sites that do not fit are not located in adjacent areas. For example, Figure 5.5 (b) shows that sites 11, 15 and 16 form a band having higher amplitude waves on the Andrews' plots, and sites 10, 12, 13 and 14 form another band having low amplitude waves. Site 11 however is located close to the site 12 but is far away from site 15 (Figure 5.1). Therefore, those sites that do not seem to fit can not be

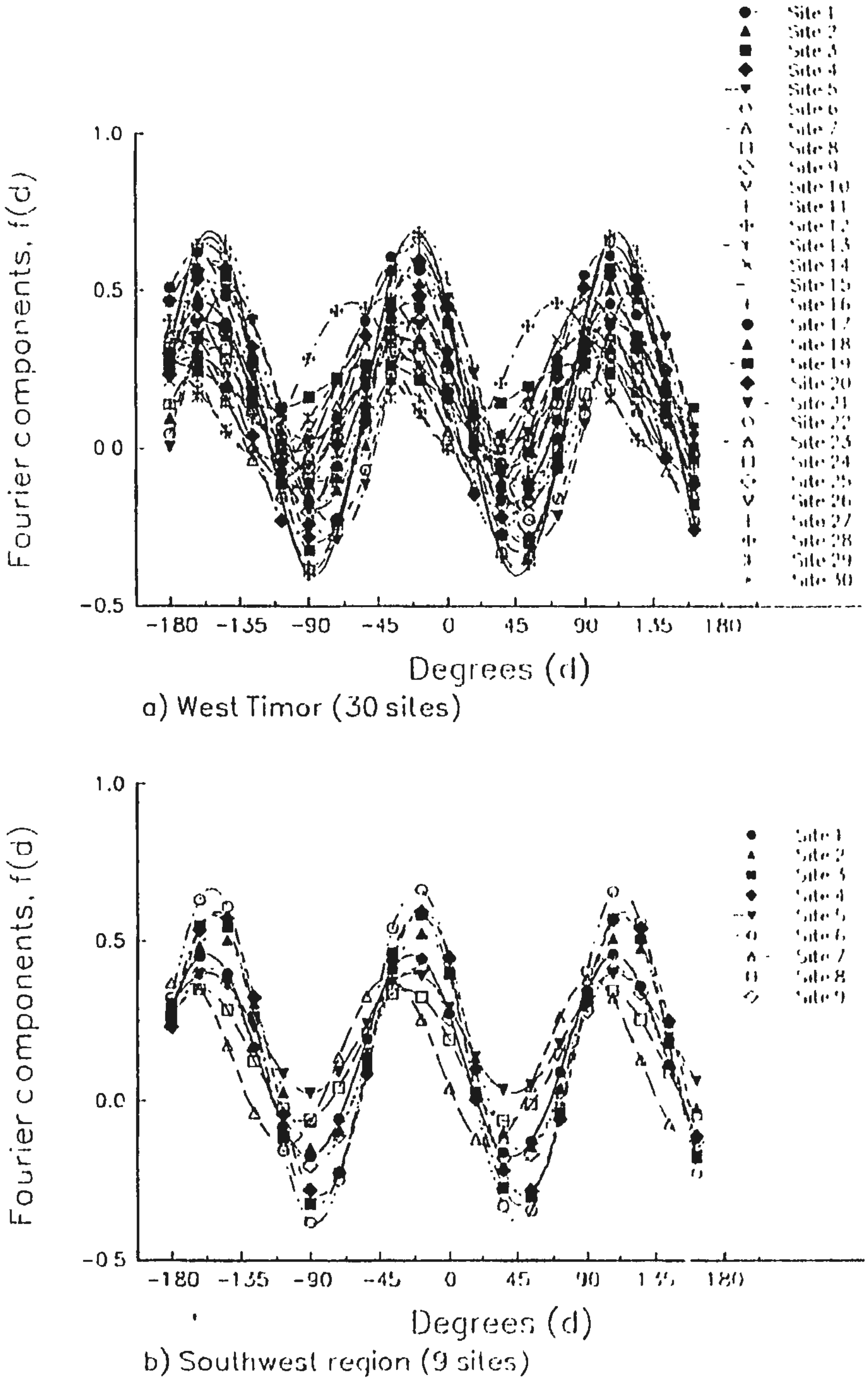
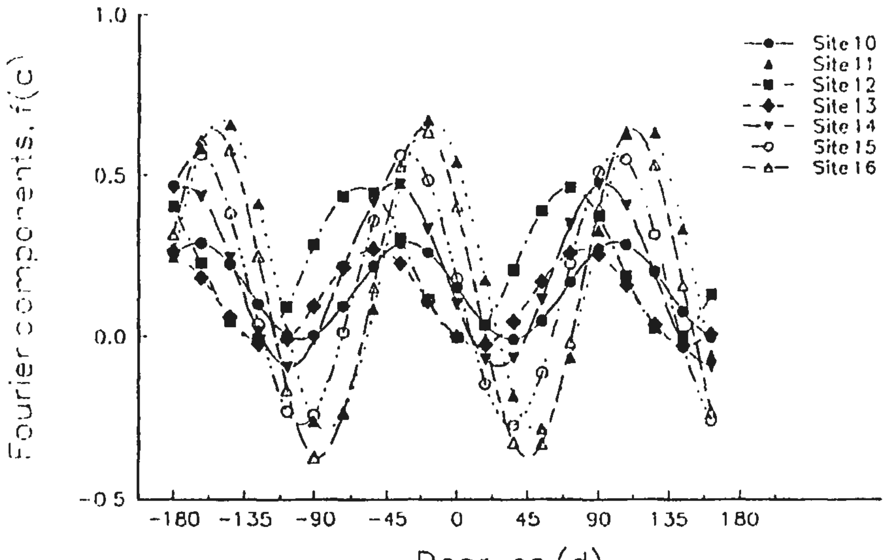
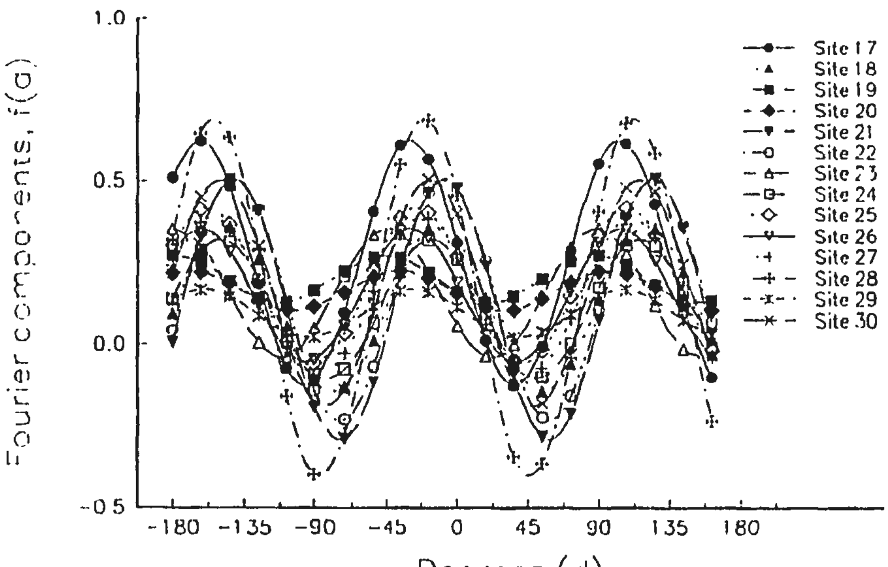


Figure 5.4 Andrews' plots of sample L-moment ratios of annual daily maximum rainfall for West Timor and Southwest region



a) North region (7 sites)



b) Southeast region (14 sites)

Figure 5.5 Andrews' plots of sample L-moment ratios of annual daily maximum rainfall for North and Southeast region in West Timor easily separated into seperate regions.

These figures also show that there are two different sets of waves on the Andrews' plots: high and low amplitude waves. Twelve sites have approximately low amplitude waves whereas the other eighteen sites have high amplitude waves. In Figure 5.6, symbols of L and H represent low and high amplitude waves, respectively, for visual identification of the locations of the sites having these two distinct wave patterns. Figure 5.6 and Figure 5.1 show that these two types of waves on Andrews' plots are located arbitrarily throughout the entire West Timor region. The outlying plots may not be significant, and most of the plots do come close together which represent a cluster of data as defined by Andrews (1972). Therefore, West Timor for the present may be assumed to be a homogeneous region.

Summary

Figure 5.6 shows the visual plots of the CV, D_i and the two types of Andrews' plots (high and low amplitude waves) in West Timor. The trend of each plot for the entire region is different. This indicates that a small value of CV at a given site may or may not have a small value of D_i and a low wave of Andrews' plots.

By considering the CV, D_i values, and the Andrews' plots of annual daily maximum rainfall in West Timor as previously discussed, the entire West Timor may be assumed to be a homogeneous region. This conclusion is different from the results of the monthly data analysis in Chapter 3, which indicates that West Timor should be divided into two rainfall regions, north-southwest and southeast. The reason for the division was that the southeast part receives rain in the dry monsoon for several months, whereas the north-southwest part almost does not. Since the annual daily maximum rainfall always occurs in the wet monsoon with heavy rainfall, however, it is reasonable to accept West Timor as one homogeneous region for annual daily maximum rainfall.

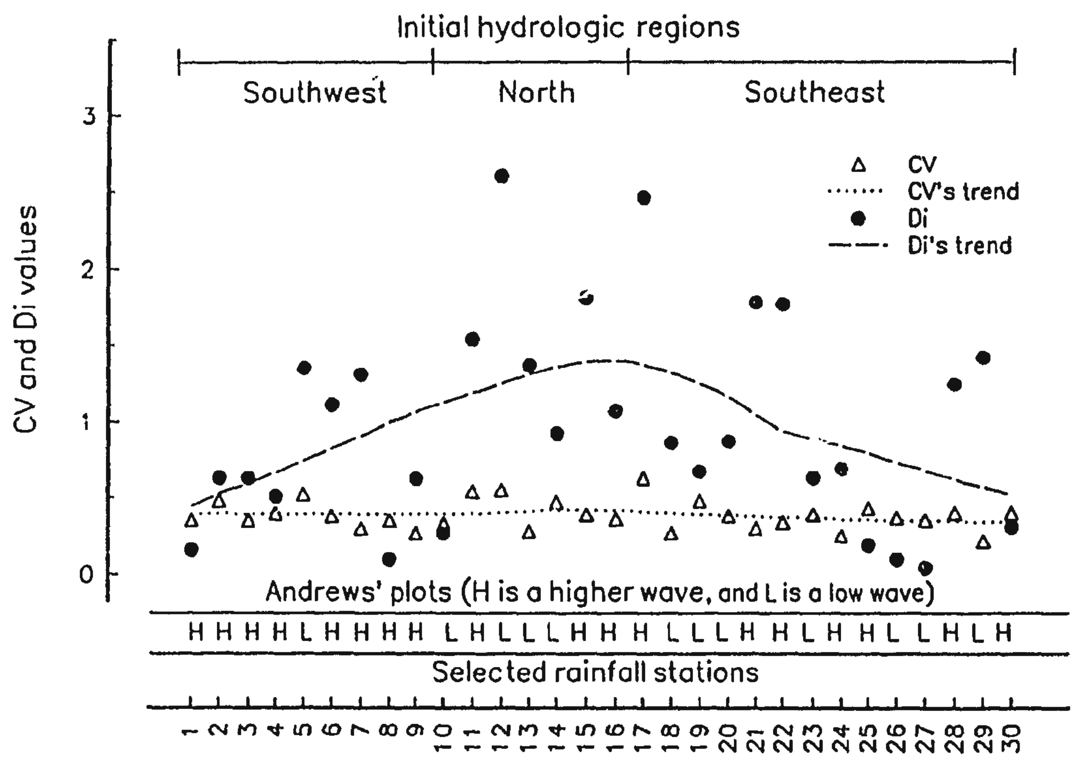


Figure 5.6 Graphical comparison between coefficients of variation and discordancy indexes and Andrews' plots for 30 selected stations of annual daily maximum rainfall in West Timor (for locations of the rainfall stations see Figure 5.1)

5.2 At-site Frequency Analysis

The results of at-site frequency analysis are presented in Table 5.2 and Figure 5.7. Table 5.2 summarizes the results of PPCC test and the estimated parameters of the Gumbel distribution for selected sites. The parameters were calculated using the sample L-moments at each site.

Table 5.2 shows that for each annual daily maximum rainfall series it exists a transformation λ that resulted in estimated PPCC r values which are greater than the critical value r_c. For example, site 2 has a sample size of N=23, λ = 0.58, r = 0.975 and r_c = 0.926. The Gumbel probability distribution with value of λ as tabulated are accepted as models of the annual daily maximum rainfall at each site in West Timor.

Figure 5.7 shows the observed values on Gumbel probability plots for selected stations. Results for other stations were similar.

5.3 Selection of the Regional Frequency Distribution

Table 5.3, Figure 5.8 and Figure 5.9 summarized the results of the regional distribution selection of annual daily maximum rainfall in West Timor.

The L-moment ratios of theoretical distributions (Gumbel, GEV, GLOG, Gamma and GPA), sample L-moment ratios and weighted average sample L-moment ratios of L-skewness and L-kurtosis were plotted on the L-moment ratio diagram as shown in Figure 5.8. This figure shows that the curves of the GPA, Gamma, and GEV distributions are close to the regional weighted average L-skewness & L-kurtosis values. The GPA distribution appears to provide the best fit.

Table 5.2 Identification of the probability distribution of annual daily maximum rainfall using PPCC method at selected site in West Timor

Sta.*	Elevation m	Mean (mm)	λ^*	r^*	r_c^*	Gumbel parameters of transformed data	
						ε^*	α^*
1	25	123.6	0.490	0.979	0.922	17.6066	2.9336
2	115	115.5	0.580	0.975	0.956	21.3551	5.7949
3	150	107.3	0.010	0.981	0.941	4.5509	0.2582
4	320	112.7	0.060	0.990	0.922	5.1738	0.3919
5	20	132.2	1.030	0.992	0.926	100.2200	35.4727
6	40	108.7	0.010	0.971	0.939	4.8501	0.2596
8	200	111.2	1.040	0.984	0.941	107.2800	27.5693
9	170	107.0	0.100	0.981	0.926	6.0295	0.4685
10	10	140.8	1.440	0.984	0.922	692.0710	568.8148
11	900	150.5	0.110	0.981	0.939	6.2566	0.4217
12	390	127.2	1.100	0.914	0.922	135.3070	94.2332
14	3	66.4	0.010	0.970	0.922	4.1210	0.3101
15	20	69.3	0.010	0.922	0.926	4.5964	0.1796
16	600	115.5	0.010	0.982	0.926	4.3995	0.5206
17	1470	117.4	0.036	0.975	0.922	4.4226	0.4805
18	670	64.7	1.330	0.948	0.926	162.4777	55.3039
19	3	85.2	1.070	0.970	0.926	128.4374	42.9001
21	10	98.3	0.350	0.936	0.926	10.6664	1.0976
22	415	113.9	1.150	0.978	0.922	165.3624	64.3393
23	280	70.7	0.480	0.949	0.926	14.0841	1.7600
24	420	82.0	1.180	0.995	0.926	101.3396	49.4795
25	328	104.7	0.790	0.990	0.922	39.7974	14.2107
26	230	93.5	1.440	0.966	0.926	373.9171	211.5030
27	450	57.6	0.810	0.997	0.931	26.9864	7.6463
28	507	97.6	0.010	0.970	0.926	4.4481	0.2631
30	210	79.1	0.016	0.973	0.922	4.5768	0.2134

* Sta. is selected station number
r is PPCC estimated
r_c is critical value of PPCC
ε and α are Gumbel parameters
λ is constant transformation

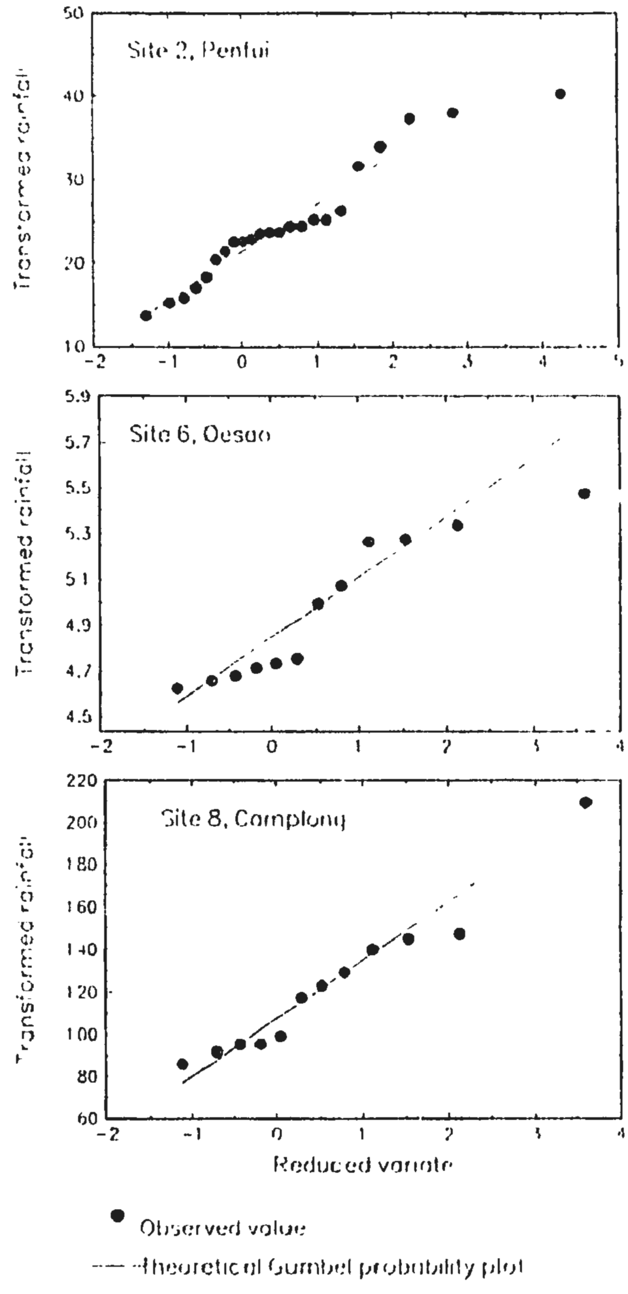


Figure 5.7 Examples of at-site frequency curves of annual daily maximum rainfall at selected sites in West Timor

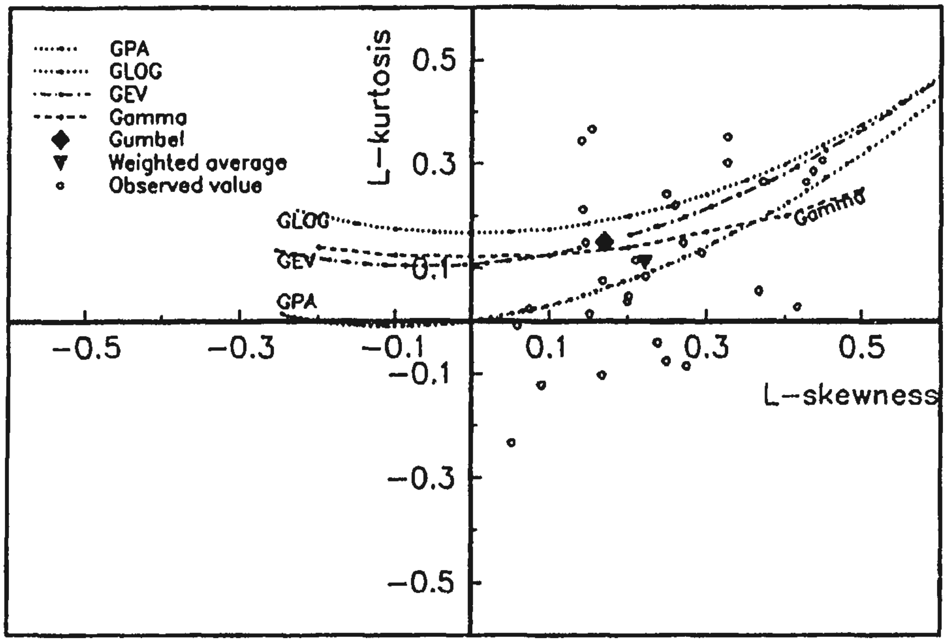


Figure 5.8 L-skewness versus L-kurtosis diagram for selecting regional probability distribution of annual daily maximum rainfall in West Timor

Table 5.3 Regional frequency distributions studied of annual daily maximum rainfall in West Timor

Regional sample L-moments						Model	Model parameter		
$\bar{\lambda}_1$	$\bar{\lambda}_3$	$\bar{\lambda}_4$	$\bar{t}$	$\bar{t}_3$	$\bar{t}_4$		ε	α	κ
1	0.0477	0.0207	0.2093	0.2212	0.1115	GPA GEV Gumbel	 0.8559 0.8257	3.7769 0.3524 0.3020	2.7769 0.2006

The parameters of the GPA distribution are presented in Table 5.3. It shows that the shape parameter, k value is 2.7769. GPA distribution with k > 0.50 has finite endpoints for f(x) > 0 at α/k. This shape is unusual in statistical applications (Hosking and Wallis, 1987), and thus is rejected as a possible regional distribution. Alternative possible distribution is the Gamma followed by the GEV distribution. The use of the GEV distribution however, is more convenient since the Gumbel distribution which is a special case of the GEV distribution, was an acceptable model for at-site frequency distribution as previously mentioned.

Table 5.4 shows the estimated parameters of the GEV and Gumbel distributions. The shape parameter k, of the GEV distribution is 0.2006. The test statistic Z, (Maidment, 1993) can be used to detect whether the shape parameter k, of the GEV distribution is significantly different from zero. If k is not significantly different from zero, then the Gumbel distribution can be used. The test statistic Z, is given by:

$$Z = \sqrt{\frac{\bar{n}_l}{0.5633}}\ k \tag{5.1}$$

where $\bar{n}_l$ is the regional average sample lengths. At significance level α = 5%, |Z| should be less than 1.96.

It can be seen from Table 5.3 that the Z value is 0.9637 or less than 1.96. This indicates that the Gumbel distribution is a reasonable model for the regional frequency distribution of annual daily maximum rainfall in West Timor. Figure 5.9 shows the regional curve of annual daily maximum rainfall in West Timor.

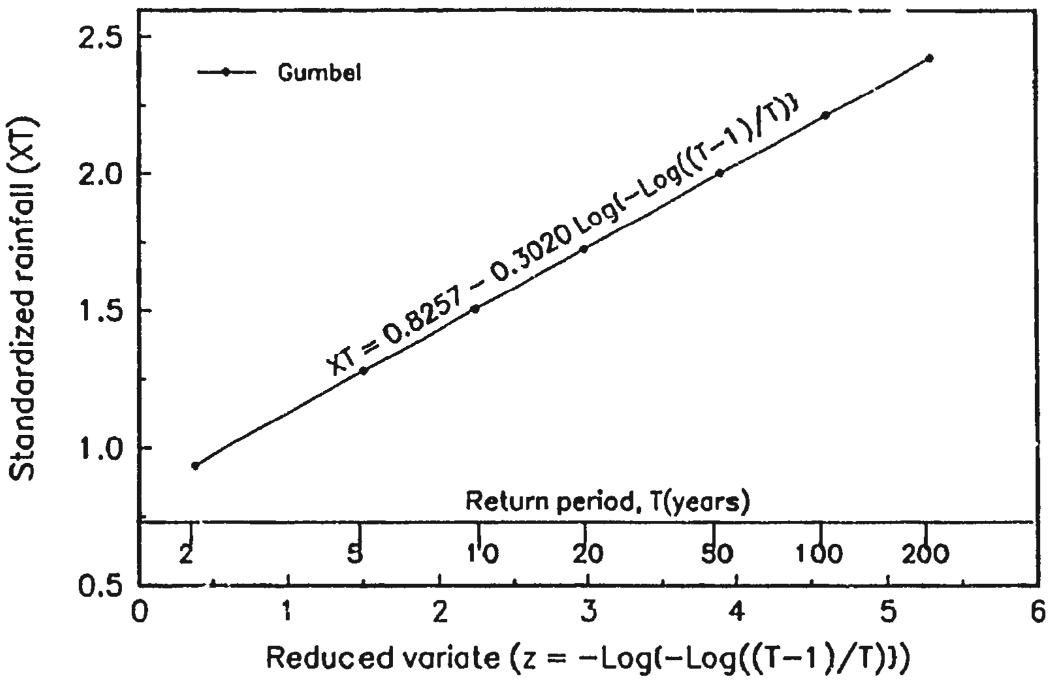


Figure 5.9 Regional frequency curve of annual daily maximum rainfall in West Timor

5.4 Comparison between Regional and At-Site Frequency Magnitudes

This section discusses the comparison of the results between the regional and the at-site quantile estimates at return period T, of 2, 5, 10, 20, 50, 100 years. The results were presented in Table 5.4 and Figure 5.10. The comparison were based on the standardized rainfall, $x/\bar{x}$. The at-site variate were also scaled by their mean values.

Table 5.4 shows the estimated regional and at-site quantiles of selected station. The regional estimates use the at-site mean values to obtained the regional quantiles ie $x_T = \bar{x}\ x_R$, (see Equation 4.1), where x_T is the quantile magnitude at return period T. Figure 5.10 shows the regional curve and selected at-site curves. The regional curve seem to be a compromise among the at-site curves.

These at-site curves were used to predict at-site quantile magnitudes for gauged sites, and the regional curve can be used to predict rainfall quantile magnitudes for ungaged sites where the mean values can be taken from the isoline of annual daily maximum rainfall in West Timor shown in Figure 3.14.

Table 5.4 Index rainfall comparison between regional and at-site frequency analysis at selected sites in West Timor

		Return period, T (years)					
		2	5	10	20	50	100
		Index rainfall comparison					
Regional Curve		0.9364	1.2787	1.5053	1.7227	2.0041	2.2149
At-site curve							
Site	Mean (mm)						
1	123.6	0.9541	1.1239	1.2364	1.3442	1.4838	1.5884
2	115.5	0.9255	1.1844	1.3558	1.5202	1.7330	1.8925
5	132.2	0.7669	1.0393	1.2196	1.3925	1.6164	1.7842
8	111.2	0.9161	1.1599	1.3214	1.4762	1.6767	1.8269
10	140.8	1.0449	1.7930	1.2883	2.7643	3.3784	3.8392
12	127.2	0.9091	1.4808	1.8594	2.2224	2.6924	3.0446
18	64.7	0.9526	1.2793	1.4956	1.7301	1.9717	2.1730
19	85.2	1.3379	1.7892	2.0880	2.3746	2.7455	3.0235
22	113.9	0.9417	1.3052	1.5458	1.7766	2.0754	2.2993
23	70.7	1.0521	1.1946	1.2889	1.3794	1.4965	1.5843
24	82.0	0.7821	1.1492	1.3923	1.6254	1.9272	2.1534
25	104.8	0.9253	1.2564	1.4757	1.6860	1.9582	2.1622
26	93.5	0.9454	1.4475	1.7798	2.0987	2.5114	2.8207
27	57.6	0.9400	1.2135	1.3946	1.5682	1.7391	1.9615

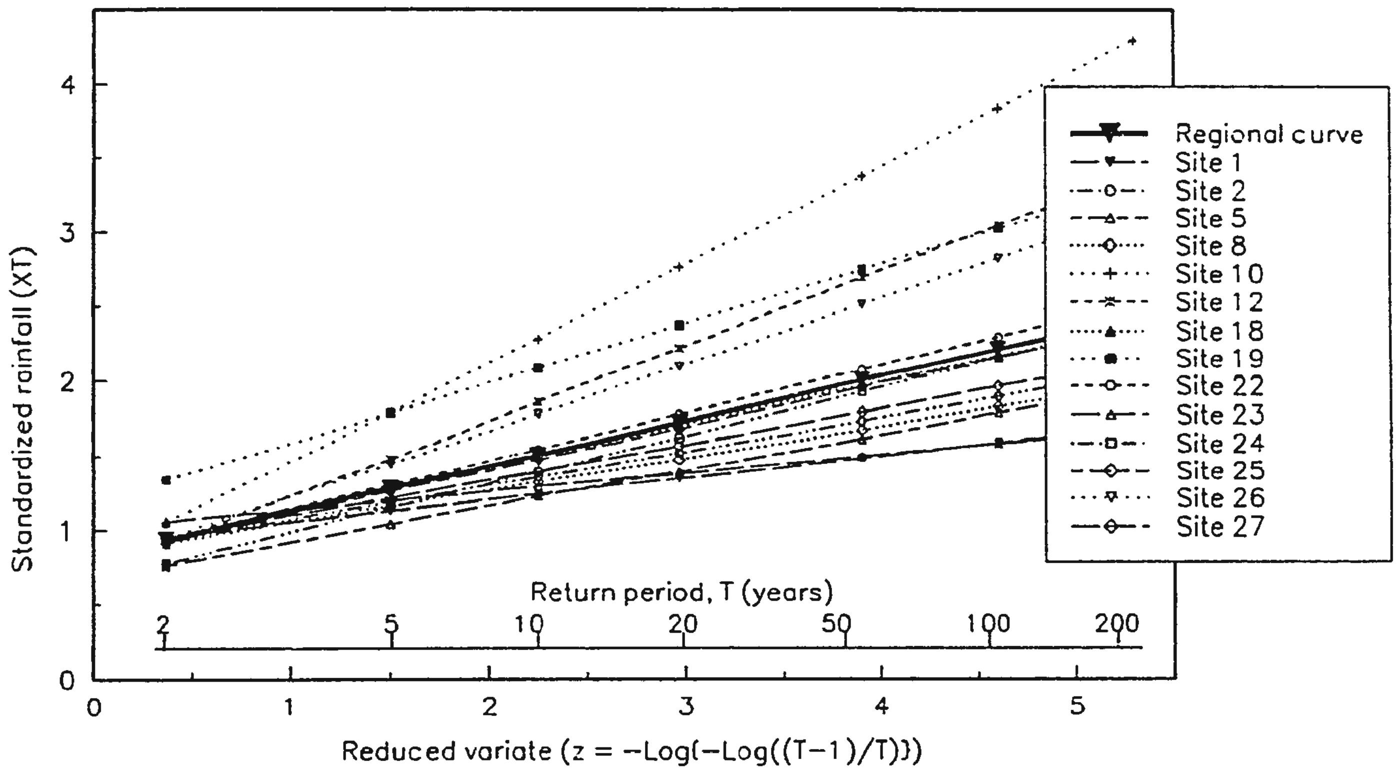


Figure 5.10 Regional curve and selected at-site curves of annual daily maximum rainfall in West Timor on the Gumbel probability plot

Chapter 6

Drought Analysis

This chapter discusses the methodology of drought analysis and the results of applying the methodology using pentad data series from West Timor. The data from site 6 in West Timor which has seventeen years of record was selected for drought analysis because the site has a longest continuous record on a daily basis and is located in an important agricultural area.

6.1 Methodology

This section discusses drought analysis. The steps taken in this analysis are as follows:

(a) assumption of the rain water truncation level; and

(b) identification of drought properties.

These steps are discussed in the following sub-sections.

6.1.1 Assumption of the Rain Water Truncation Level

The rain water truncation level is used to distinguish droughts from other events in the historical record. Hounam et. al, (1975) proposed several truncation levels of rainfall amounts for determining agricultural drought. In this study, pentad rain water truncation levels of 17.5 mm for dry land crops and 35 mm for rice as proposed by Oldeman (1982) are used. Start of the wet season is assumed in November for West Timor. The day having 75 mm and 200 mm forward accumulation (following calendar) of rainfall from the first pentad of November is assumed as the onset time for the growing season for dry land crops and rice, respectively, and the day having 100 mm and 300 mm backward accumulation (reversing the calendar) of rainfall from the end of the dry season (from the sixth pentad of October) is assumed as the end time for the growing season for dry land crops and rice, respectively (Oldeman et al., 1982).

6.1.2 Identification of Drought Properties

Hydrologic drought is defined as a deficiency in water supply on the earth's surface, or the deficiency in precipitation, effective precipitation, runoff or in accumulated water in various storage capacities (Yevjevich, 1967). One aspect of this phenomena, the deficiency of rainfall at ground level, is discussed here using pentad rainfall data.

The identification of drought properties is requireo for irrigation or agricultural applications. The information provides a means for the detection of periods during the growing season that can be hazardous with regard to water availability. Since the distribution of average annual or monthly rainfall does not by itself quantify drought incidence or intensity, the choice of a 5-day spell length (pentad) of rainfall data reflects the need to consider shorter spell length for drought-sensitive crops. The particular concern here are drought indices for dry land crops and rice.

Droughts occur in various time and space scales. Important drought properties of interest in irrigation and agricultural practices include:

(1) drought severity;

(2) drought vulnerability; and

(3) onset and end of the rainy season.

In this study, drought properties are analyzed using probability analysis (Oldeman et al., 1982; Sivakumar, 1992). Drought severity is measured as the total probability of having a consecutive dry period of 1,2 and 3 pentads. These consecutive dry periods were chosen because they reflect a need to consider whether or not such a period coincides with the sensitive growing stage which would damage crop development.

The vulnerability of drought may be expressed as drought persistency in time. The drought vulnerability are described using conditional probabilities of dry spells. First order ($P(D|D)$), and second order ($P(D|DD$ and $P(DD|D)$) dry spells are considered.

The onset of the rainy season may be defined to be the first rain event in which the total accumulated rainfall is greater than a given amount for the start of growing season of certain crops. The end of the rainy season may be defined to be the day in which the total backward summing of rainfall from a known dry day is greater than a given amount to sustain a crop until ripening season.

Each of the above drought properties will be discussed in the following section.

Drought Severity

The analysis of drought severity can be described in terms of the probability of one dry spell (P(D)), the probability of two (P(DD)) and three consecutive dry spells (P(DDD)). For dry land crops, a pentad is dry if the total rainfall in the pentad is less than 17.50 mm. Otherwise, the pentad is wet. For rice, a pentad is dry if the rainfall is less than 35 mm. Otherwise, the pentad is wet. These probabilities can be expressed as follows:

$$P(D) = \#(D)/\{\#(D)+\#(W)\}$$

$$P(DD) = \#(DD)/\{\#(DD)+\#(WD)+\#(DW)+\#(WW)\}$$

$$P(DDD) = \#(DDD)/$$
$$\{\#(DDD)+\#(DDW)+\#(DWD)+(\#(DWW)$$
$$+\#(WDD)+\#(WDW)+\#(WWD)+\#(WWW)\}$$

where P is the probability, D is a dry pentad, DD and DDD are two and three consecutive dry pentads respectively, and # is number of occurrences. For example, P(DD) is the probability of two consecutive pentads which are dry, and #(DD) is the number of two consecutive pentads which are dry. W is a wet pentad, and WW and WWW are two and three consecutive dry pentads, respectively.

Drought Vulnerability

The conditional probabilities of pentad rainfall are used to describe drought vulnerability and the persistency. Two levels of conditional probabilities are used to detect a certain period (two or three pentads) in which certain crops are sensitive to droughts. The conditional probabilities used are the first- and second-order Markov model with two states: dry pentad and wet pentad. These conditional probabilities can be expressed as follows:

First-order transition probabilities:

$$P(D|D) = \#(DD)/\{\#(DD)+\#(WD)\}$$

$$P(W|D) = \#(WD)/\{\#(DD)+\#(WD)\}$$

$$P(DW|W) = \#(DW)/\{\#(DW)+\#(WW)\}$$

$$P(W|W) = \#(WW)/\{\#(DW)+\#(WW)\}$$

Second-order transition probabilities:

$$P(D|DD) = \#(DDD)/\{\#(DDD)+\#(WDD)\}$$

$$P(W|DD) = \#(DDD)/\{\#(DDD)+\#(WDD)\}$$

$$P(D|WD) = \#(DWD)/\{\#(DWD)+\#(WWD)\}$$

$$P(W|WD) = \#(WWD)/\{No(DWD)+\#(WWD)\}$$

$$P(D|DW) = \#(DDW)/\{\#(DDW)+\#(WDW)\}$$

$$P(W|DW) = \#(WDW)/\{\#(DDW)+\#(WDW)\}$$

$$P(D|WW) = \#(DWW)/\{\#(WWW)+\#(DWW)\}$$

$$P(W|WW) = \#(WWW)/\{\#(WWW)+\#(DWW)\}$$

where P is the probability, # is number of occurrences, W is wet pentad, D is dry pentad. For example, P(D|DD) is the probability of having a dry pentad given 2 previous pentads are dry, and #(DDD) is the number of 3 consecutive dry pentads. A QBASIC program was developed to compute the drought severity and vulnerability on an annual and seasonal basis is shown in Appendix C.2 and Appendix C.3.

Onset and End of the Rainy Season

In areas with a distinct dry season, the period from which the rain starts and the wet season ends is an important agroclimatological variable. This study illustrates the way in which a probability distribution for these dates can be determined (Oldeman et al., 1982). Two procedures are examined on a water year basis: probability distribution analysis for the onset of the rainy season, and for the termination of the rainy season. The former uses a forward accumulation procedure (ie pentad rainfall can be summed up from November, December, January, and so on) starting from the first pentad in the first of November to reach 75 and 200 mm accumulated rainfall for dry land crops and rice, respectively. The latter uses a backward accumulation procedure (ie pentad rainfall can be summed up form October, September, August, July and so on) starting from the 72nd pentad at the end of October to reach 100 and 300 mm accumulated rainfall for dry land crops and rice, respectively.

The procedure of the analysis can be simplified as follows:

(a) pentad rainfall data for each year are arranged on a water year basis which is based on the monsoons. Every month has six pentads. The first pentad fall on the first pentad of November, and the final pentad fall on the last pentad of October;

(b) to determine the pentad in which the wet season would start, the accumulated pentad rainfall from the first pentad of each water year are summed up until an amount that is greater than 75 and 200 mm for dry land crops and rice, respectively, is reached. To determine the pentad in which the rainy season would terminate, the backward accumulated rainfall from the end of the water year for each water year (the pentad of the 72nd at the end of October) are summed up backward until an amount that is greater than 100 and 300 mm for dry land crops and rice, respectively, is reached;

(c) for N years of pentad rainfall records, the number of occurrences #, of the onset and end of the rainy season are determined;

(d) the number of occurrence of each pentad (date) are ranked for onset and end of the rainy season;

(e) the ranking number is given a probability level using a simple plotting position: Pi=m/(n+1), where m is a ranked number, n is the number of occurrences of the start or the end rainy season at any pentad (date); and

(f) the relationship between the date (pentad) and the probability of the onset or the end of the rainy season can be estimated and represented graphically.

6.2 Results and Discussions

This section discusses the results of the drought analysis. The results can be summarized in three parts. These are (1) drought severity, (2) drought vulnerability, (3) onset and end of the rainy season.

6.2.1 Drought Severity

The probability of occurrences of one, two or three consecutive dry pentads was used to describe drought severity. As shown in Table 6.1, the value of P(DDD) at site 6, is 0.10 for dry land crops and 0.31 for rice in the wet season. This means that although in the wet season the chance of occurrence of three consecutive dry pentads (10%) may be not significant over the growing stages of dry land crops, it may still be significant for rice (over 30%). Figure 6.1 shows the LOWESS plots of the pentad dry probability of occurrence at site 6 on a calendar basis. It reveals that there is no zero value of P(DDD) in the wet season. In Figure 6.1(a) for example, the fourth pentad of November is certainly not recommended as a sowing date for dry land crops, because there is a greater chance that this pentad (P(D)>0.50), as well as the two following pentads (P(DD)>0.40), will be dry. The sixth pentad of November seems to be a reasonable planting date with a low probability of dry spells (P(D)<0.50, and P(DD)<0.30). As conclusion on average, the severity of pentad drought in the wet season is not significant for dry land crops, but is significant for rice.

Table 6.1 Drought severity at site 6 in West Timor

Crops	Rainfall mm	State probability	Probability		
			Annual	Wet season	Dry season
Dry land crops	< 17.50	P(D)	0.7222	0.4310	0.9303
		P(DD)	0.6097	0.2192	0.8885
		P(DDD)	0.5408	0.1020	0.8554
Rice	< 35.00	P(D)	0.8056	0.6369	0.9742
		P(DD)	0.7027	0.4392	0.9563
		P(DDD)	0.6352	0.3136	0.9300

6.2.2 Drought Vulnerability

Drought vulnerability of pentad rainfall can be expressed by using the transition probabilities between consecutive wet and dry pentads. As shown in Table 6.2 for example, the value of P(D|D) is 0.52 and 0.70 for dry land crops and rice, respectively, in the wet season. This means that there is more than 50% probability of having a dry pentad given that the previous pentad is dry, even in the wet season. The value of P(D|DD) is 0.49 for dry land crops and 0.73 for rice in the wet season. This means that the probability of having a dry pentad given that the previous two pentad are dry is significant even in the wet season. The value of P(DD|D) is 0.24 for dry land crops and 0.73 for rice in the wet season. Again, this means that the probability of having two consecutive dry pentads given that the previous pentad is dry is significant even in the wet season. On average, one can conclude that the vulnerability of pentad drought is significant for rice and dry land crops in the wet season. Therefore, unsuccessful agricultural production in this region is likely. This conclusion is different with the results of drought severity analysis which shows that the severity of drought is only significant for rice.

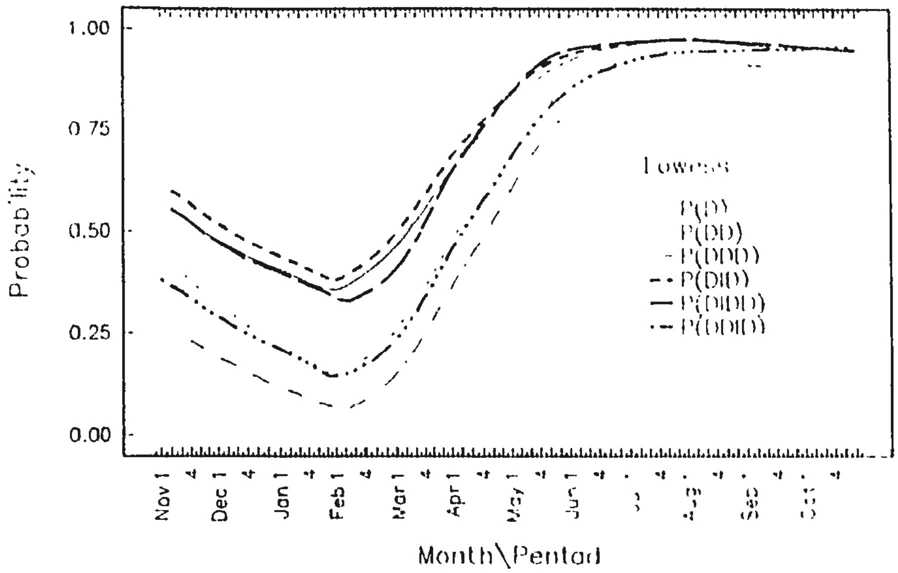
Table 6.2 Drought vulnerability at site 6 in West Timor

Crops	Rainfall mm	State Probability	Probability		
			Annual	Wet season	Dry season
Dry land crops	> 17.50	P(D|D)	0.8452	0.5205	0.9515
		P(D|DD)	0.8908	0.4938	0.9599
		P(DD|D)	0.7488	0.2368	0.9195
Rice	> 35.00	P(D|D)	0.8731	0.7030	0.9777
		P(D|DD)	0.9051	0.7255	0.9813
		P(DD|D)	0.8795	0.7276	1.0000

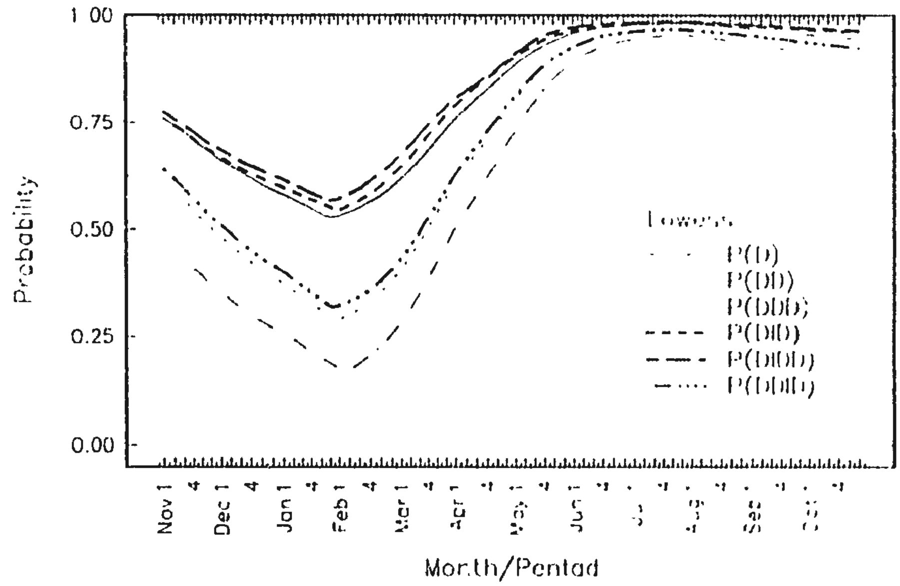
6.2.3 Onset and End of the Rainy Season

The date for the start and end of the rainy season for dry land crops and rice can be determined using probability analysis as discussed earlier. The results have been presented in Figure 6.2 for site 6. Some conclusions can be drawn from this graphical representation using a probability or reliability level of 75% as an example. The end of the rainy season is much more gradual compared to the onset of the rainy season. At the 75% level, it takes 4 pentads to accumulate from 75 to 200 mm, but it takes 7 pentads at the end of the rainy season to drop from the expected 300 mm to 100 mm of rainfall. The end of the rainy season is much more variable than the onset of the rainy season.

At the 75% probability or reliability level, the season with sufficient rainfall to grow dry land crops is from the first pentad of December until the sixth pentad of March or 4 months. It is clear that this season is too short to grow 2 dry land crops. For sufficient rainfall to grow rice, the season with heavy rainfall is from the fifth pentad of December until the fifth pentad of February or 2 months only. It is clear that this season is too short to grow a single rice crop. Rainfed wet land rice will thus normally require supplemental irrigation. This result is quite different from the results obtained based on monthly data analysis presented in Chapter 3. As can be seen in Figure 3.16 at site 6 for example, an average of 4 wet months is available for rice. Because of the shorter duration considered, pentad drought analysis would give a more detailed characterization of the droughts and would provide better guidance for supplemental irrigation or field operations.



a) Drought severity and vulnerability for dryland crops



b) Drought severity and vulnerability for rice

Figure 6.1 Drought severity and vulnerability at site 6 in West Timor (1974-1991)

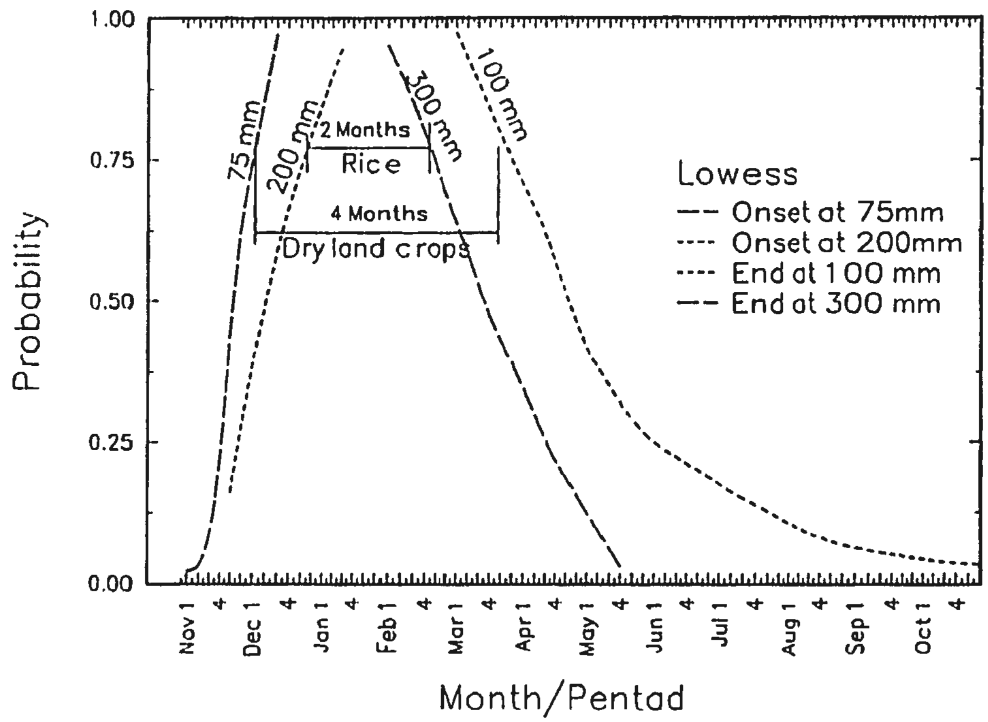


Figure 6.2 Onset and end of the rainy season at site 6 in West Timor (1974-1991)

Chapter 7
Conclusions and Recommendations

7.1 Conclusions

The conclusions from this study can be grouped into three parts: (1) temporal and spatial characterization of rainfall, (2) regional frequency analysis of rainfall, and (3) drought analysis.

Temporal and spatial characterization of rainfall

(1) The temporal and spatial variability of rainfall are controlled by the interaction of the rainfall with topography and the prevailing wind systems.

(2) The rainfall station network is sparse and is not uniformly distributed.

(3) The short term and long term persistencies of annual rainfall at sites with long record are not significant.

(4) Monthly rainfall series has significant persistency and is periodic, as expected from a climate dominated by monsoons.

(5) The northern and southwestern regions of West Timor have practically identical patterns in monthly mean rainfall and in the seasonality index, when compared to the southeastern region.

(6) Annual daily maximum rainfall series can be considered to be independent.

(7) An analysis of a representative hourly series over a one-year period shows that the number of hourly rainfall occurrences in a year is 438 or only 5% of 8760 hours in a year. The maximum hourly rainfall in the year was 47.50 mm.

Regional frequency analysis of rainfall

(8) The coefficient of variation of CV of annual daily maximum rainfall in West Timor is 0.25 and the discordancy measure ranges from 0.04 to 2.60. This implies that the regional data is possibly homogeneous. This conclusion differs from the results of the monthly rainfall data analysis. Monthly analysis shows that the West Timor should be divided into two rainfall regions, because the southeast region still receive rain in the dry monsoon as opposed to the southwest and the north region. For the purposes annual daily maximum rainfall analysis, it is reasonable to considered West Timor as one homogeneous region, since daily maximum rainfall only occur during the wet monsoon.

(9) The annual daily maximum rainfall data at different stations are best fitted by the Gumbel distribution.

(10) The annual daily maximum rainfall on a regional basis in West Timor can be approximated by the Gumbel probability distribution.

(11) The comparison of quantile magnitudes using both regional and at-site curves

based on index rainfall shows that the regional estimation results tend to give estimates that fall in between the at-site estimates as expected by averaging at-site estimates of L-moments.

Drought Analysis

The following conclusions are drawn from a drought analysis at site 6, a site with longest continuous record and it is located in an important agricultural area.

(12) In the wet season, the probability of having severe drought of 3 consecutive dry pentads is not significant for dry land crops, but is significant for rice. In terms of drought vulnerability in the wet season, the probability of having 2 consecutive dry pentads given that the previous pentad is a dry pentad is not significant for dry land crops, but is significant for rice.

(13) There is 75% reliability that the 4 month period from December to March will be sufficiently wet for dry land crops. The period with sufficient rainfall at the 75% reliability level to grow rice is from the end of December to the end of February. Two months is too short to grow a single rice crop. Supplemental irrigation would be required.

(14) Pentad drought analysis gives more information on the drought characteristics than those based on the analysis of monthly data.

7.2 Recommendations

Recommendations from this study are as follows:

(1) The general description of the temporal and spatial rainfall characteristics, the regional frequency analysis, and the drought analysis should be up dated as the amount of rainfall data increases.

(2) Extension of the station network in West Timor should be considered. Although it depends on the purpose of the analysis and therefore requires further study, extension is required for most purposes.

(3) Regional data homogeneity and the best fit of the regional curve by applying the L-moment method should be further investigated. One such method which uses the Monte Carlo method (Hosking and Wallis, 1993) can be tried.

(4) The regional frequency analysis curve of annual daily maximum rainfall should be used for estimating rainfall quantile magnitudes at any site. Regional analysis in this study can be applied to other durations such as daily and hourly rainfall as well.

(5) The pentad drought curve presented in this study should be used as a guidance in planning supplemental irrigation or field operations. Drought analysis procedures used in this study can also be applied to other sites in West Timor to describe the drought characteristics on a spatial basis.

(6) Rain water truncation levels for crops for West Timor should be further investigated and drought studies based on other physical parameters such as rainfall and evapotranspiration or soil water and crop parameters should be undertaken.

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APPENDIX A

L-moments of Distributions Studied

There are three distributions used in regional rainfall analysis in this study. These are Gumbel, Generalized Extreme Value (GEV), and Generalized Pareto (GPAR). Their distribution parameters using sample L-moments are as the following table:

Table A.1 Parameters of distributions studied

Distribution	Inverse cdf	Parameter
Gumbel	$x = \varepsilon - \mathrm{Log}[-\mathrm{Log}\, F]$	$\alpha = \bar{l}_2/\mathrm{Log}\ 2$ $\varepsilon = \bar{l}_1 - 0.5772157\alpha$
GEV	$x = \varepsilon + \alpha/\kappa\{1-[-\mathrm{Log}\, F]^{\kappa}\}$	$\zeta = 2/(3+\bar{t}_3)$ $-\mathrm{Log}\ 2/\mathrm{Log}\ 3$ $\kappa = 7.8590\zeta + 2.9554\zeta^2$ $\alpha = \bar{l}_2\kappa/\{(1-2^{-\kappa})\Gamma(1+\kappa)\}$ $\varepsilon = \bar{l}_1 + \alpha\{\Gamma(1+\kappa)-1\}/\kappa$
GPAR	$x = \varepsilon + \alpha/\kappa\{1-[1-F]^{\kappa}\}$	$\varepsilon = 0$ (known) $\kappa = \bar{l}_1/\bar{l}_2 - 2$ $\alpha = (1+\kappa)\bar{l}_1$

Note: cdf is cumulative density function

ε, α and κ are estimated parameters of distributions studied

$\bar{l}_1$ and $\bar{l}_2$ are weighted averages of sample L-moments

$\bar{t}$, $\bar{t}_3$ and $\bar{t}_4$ are weighted averages of sample L-moment ratios

For GEV distribution, an approximation of the gamma function (Maidment, 1993) for $0 \geq \kappa < 1$ is

$$\Gamma(1+\kappa) = 1 + \sum_{i=1}^{5} a_i \kappa^i$$

where $a_1 = -0.5748646$

$a_2 = 0.9512368$

$a_3 = -0.6998588$

$a_4 = 0.4245549$

$a_5 = -0.1010678$

If $-1 < \kappa < 0$ use $\Gamma(\kappa^*) = \Gamma(1+\kappa^*)/\kappa^*$, where $\kappa^* = (1+\kappa)$.

APENDIX B

Computer Programs Developed and Used in the Thesis

Appendix B.1 QUICKBASIC PROGRAM of L-MOMENTS

This program calculates conventional moments and L-moments and also computes probability distribution parameters (GEV, GPAR, GLOG and Gumbel).

```
CLS
LPRINT "                    WEST TIMOR REGIONAL LMOMENT PARAMETERS"
LPRINT "                        Annual daily maximum rainfall"
LPRINT " i) At site sample l-moments and conventional moments"
LPRINT "------------------------------------------------------------------------------"
LPRINT " Station      m1   l1   l2&m2   l3&m3   l4&m4   t1   t2&cv   t3      t4&ex"
LPRINT "------------------------------------------------------------------------------"
d1$ = " \          \ ###.# # ###.##### ##.##### ##.##### #  #.##### #.##### ##.#####"

INPUT "Number of stations  "; p

DIM l1(100), l2(100), l3(100), l4(100), t1(100), t2(100), t3(100), t4(100)
DIM m1(750), m2(750), cv(750), m3(750), m4(750), ex(750)

FOR m = 1 TO p
INPUT "Please type in station's name eg Kupang "; station$
DIM x(2000)


INPUT "Please type in file's name eg C>\dir\station$.dat"; rain$
OPEN rain$ FOR INPUT AS #1
INPUT #1, name$, n   'n is sample size.

     sum = 0
  FOR i = 1 TO n
     INPUT #1, x(i)
        x(i) = x(i): sum = sum + x(i)
  NEXT i
  m1 = sum / n

  m2 = 0: m3 = 0: m4 = 0
  FOR i = 1 TO n
  m2 = m2 + (x(i) - m1) ^ 2
  m3 = m3 + (x(i) - m1) ^ 3: m4 = m4 + (x(i) - m1) ^ 4
```

```
    NEXT i

    m2 = ((1 / (n - 1)) * m2) ^ .5: cv = m2 / m1
    m3 = ((n) / ((n - 1) * (n - 2))) * (m3 / (m2 ^ 3))
    m4 = ((n ^ 2) / ((n - 1) * (n - 2) * (n - 3))) * (m4 / (m2 ^ 4))
    ex = m4 - 3
    CLOSE #1

      b0 = 0: b1 = 0: b2 = 0: b3 = 0
    FOR i = 1 TO n
      b0 = b0 + x(i) / m1
      IF i > 1 THEN 10
      GOTO 40
10     b1 = b1 + (x(i) / m1) * (i - 1)
      IF i > 2 THEN 20
      GOTO 40
20     b2 = b2 + (x(i) / m1) * (i - 1) * (i - 2)
      IF i > 3 THEN 30
      GOTO 40
30     b3 = b3 + (x(i) / m1) * (i - 1) * (i - 2) * (i - 3)

40  NEXT i

 b0 = b0 / n
 b1 = b1 / (n * (n - 1))
 b2 = b2 / (n * (n - 1) * (n - 2))
 b3 = b3 / (n * (n - 1) * (n - 2) * (n - 3))

'L-moments
 l1(m) = b0: l2(m) = 2 * b1 - b0
 l3(m) = 6 * b2 - 6 * b1 + b0
 l4(m) = 20 * b3 - 30 * b2 + 12 * b1 - b0

 t1(m) = l1(m): t2(m) = l2(m) / l1(m)
 t3(m) = l3(m) / l2(m): t4(m) = l4(m) / l2(m)

'Conventional moments
 m1(m) = m1: m2(m) = m2: cv(m) = cv: m3(m) = m3: m4(m) = m4: ex(m) = ex

LPRINT USING d1$; station$; m1(m); l1(m); l2(m); l3(m); l4(m); t1(m); t2(m); t3(m); t4(m)
LPRINT USING d1$; station$; m1(m); blank; m2(m); m3(m); m4(m); blank; cv(m); blank; ex(m)
LPRINT
NEXT m
'Weighted average
   l1 = 0: l2 = 0: l3 = 0: l4 = 0: t1 = 0: t2 = 0: t3 = 0: t4 = 0: sm = 0
   FOR m = 1 TO p
   l1 = l1 + (l1(m) * m): l2 = l2 + (l2(m) * m)
   l3 = l3 + (l3(m) * m): l4 = l4 + (l4(m) * m)
   t1 = t1 + (t1(m) * m): t2 = t2 + (t2(m) * m)
   t3 = t3 + (t3(m) * m): t4 = t4 + (t4(m) * m)
   sm = sm + m
```

```
   NEXT m
   ml1 = l1 / sm: ml2 = l2 / sm: ml3 = l3 / sm: ml4 = l4 / sm
   mt1 = t1 / sm: mt2 = t2 / sm: mt3 = t3 / sm: mt4 = t4 / sm
'Weighted standard deviation
   v = o: sumv = 0
   FOR m = 1 TO p
   v = v + ((t2(m) - mt2) ^ 2) * m: sumv = sumv + m
   NEXT m
   v = v / sumv
'Average
   la1 = 0: la2 = 0: la3 = 0: la4 = 0: ta1 = 0: ta2 = 0: ta3 = 0: ta4 = 0
   FOR m = 1 TO p
   la1 = la1 + l1(m): la2 = la2 + l2(m): la3 = la3 + l3(m): la4 = la4 + l4(m)
   ta1 = ta1 + t1(m): ta2 = ta2 + t2(m): ta3 = ta3 + t3(m): ta4 = ta4 + t4(m)
   NEXT m
   mla1 = la1 / p: mla2 = la2 / p: mla3 = la3 / p: mla4 = la4 / p
   mta1 = ta1 / p: mta2 = ta2 / p: mta3 = ta3 / p: mta4 = ta4 / p
'Standard deviation
   l12 = 0: l22 = 0: l32 = 0: l42 = 0: t12 = 0: t22 = 0: t32 = 0: t42 = 0
   FOR m = 1 TO p
   l12 = l12 + (l1(m) - mla1) ^ 2: l22 = l22 + (l2(m) - mla2) ^ 2
   l32 = l32 + (l3(m) - mla3) ^ 2: l42 = l42 + (l4(m) - mla4) ^ 2
   t12 = t12 + (t1(m) - mta1) ^ 2: t22 = t22 + (t2(m) - mta2) ^ 2
   t32 = t32 + (t3(m) - mta3) ^ 2: t42 = t42 + (t4(h) - mta4) ^ 2
   NEXT m
m1 = p - 1
sl1 = (l12 / m1) ^ .5: sl2 = (l22 / m1) ^ .5: sl3 = (l32 / m1) ^ .5: sl4 = (l42 / m1) ^ .5
st1 = (t12 / m1) ^ .5: st2 = (t22 / m1) ^ .5: st3 = (t32 / m1) ^ .5: st4 = (t42 / m1) ^ .5

'Conventional moments: mx, sx, cv, cs, k, ex
   mx = 0: sx = 0: cv = 0: cs = 0: kur = 0: ex = 0
   FOR m = 1 TO p
   mx = mx + m1(m): sx = sx + m2(m): cv = cv + cv(m): cs = cs + m3(m)
   kur = kur + m4(m): ex = ex + ex(m)
   NEXT m
   mx = mx / p: sx = sx / p: cv = cv / p: cs = cs / p
   kur = kur / p: ex = ex / p

LPRINT
LPRINT " ii) Mean of L-mom & conv-mom of regional dm rainfal in  West Timor"
LPRINT " mla1&mx mla2&sx  mla3&cs  mla4&kur mta1  mta2&cv  mta3   mta4&ex"
LPRINT "-----------------------------------------------------------------"
d2$ = "  ###.#  ##.###### #.###### #.#####    #  #.###### #.###### #.######"
LPRINT USING d2$; mla1; mla2; mla3; mla4; mta1; mta2; mta3; mta4
LPRINT USING d2$; mx; sx; cs; kur; blank; cv; blank; ex
LPRINT
LPRINT " iii) Weighted of regional dm rainfall in West Timor"
LPRINT " ml1     ml2      ml3      ml4     mt1     mt2     mt3      mt4      V"
LPRINT "--------------------------------------------------------------------"
d3$ = "  # ##.###### #.###### #.######    # #.###### #.###### #.###### #.####"
LPRINT USING d3$; ml1; ml2; ml3; ml4; mt1; mt2; mt3; mt4; v
```

```
LPRINT
LPRINT
LPRINT " iv) Standard deviation  of regional dm rainfall in West Timor"
LPRINT "    sl1    sl2   sl3    sl4       st1    st2    st3    st4  "
LPRINT "-----------------------------------------------------------"
d4$ = " ##.#### #.#### #.#### #.####  ###.#### #.#### #.#### #.####"
LPRINT USING d4$; sl1; sl2; sl3; sl4; st1; st2; st3; st4
LPRINT



'Parameters of regional distribution
  'Gamma factors:
     DIM a(100)
     a(1) = -.57486459#: a(2) = .9512363#: a(3) = -.6998588#
     a(4) = .4245549#: a(5) = -.1010678

  '1. General extreme value, GEV
     zgev = 2 / (3 + mt3) - LOG(2) / LOG(3)
     kgev = 7.859 * zgev + 2.9554 * zgev ^ 2
     IF kgev > 0 THEN
             gmmkgevplus = 0
          FOR L = 1 TO 5
             gmmkgevplus = gmmkgevplus + a(L) * kgev ^ L
          NEXT L
             gmmkgev = 1 + gmmkgevplus
     END IF
     IF kgev < 0 THEN
             gmmkgevmin = 0
          FOR L = 1 TO 5
             gmmkgevmin = gmmkgevmin + a(L) * (1 + kgev) ^ L
          NEXT L
             gmmkgev = (1 + gmmkgevmin) / (1 + kgev)
     END IF

     agev = ml2 * kgev / ((1 - 2 ^ -kgev) * gmmkgev)  ' gamma(1 + kgev)
     egev = ml1 - agev * (gmmkgev - 1) / kgev)        ' (gamma(1 + kgev) - 1) / kgev)

  '2. General pareto,GPAR
     kgpar = (ml1 / ml2) - 2: agpar = (1 + kgpar) * ml1
     egpar = ml1 - (agpar / (1 + kgpar))

  '3. General logistik, GLOG
     kglog = -mt3

     IF kglog > 0 THEN
          gmmkglogp = 0
          FOR L = 1 TO 5
             gmmkglogp = gmmkglogp + a(L) * kglog ^ L

          NEXT L
```

```
            gmmkglog = gmmkglogp + 1

      END IF
      IF kglog < 0 THEN
            gmmkglogmin = 0
            FOR L = 1 TO 5
               gmmkglogmin = gmmkglogmin + a(L) * (1 + kglog) ^ L
            NEXT L
               gmmkglog = (1 + gmmkglogmin) / (1 + kglog)
      END IF
      IF (-kglog) > 0 THEN gmmkglogmum = gmmkglogp + 1
      IF (-kglog) < 0 THEN gmmkglogmum = (gmmkglogmin + 1) / (1 + kglog)

      aglog = ml2 / (gmmkglog * gmmkglogmum)   'gamma(1 + kglog) * gamma(1 - kglog)
      eglog = ml1 + (ml2 - aglog) / kglog

   '4. Gumbel
      agumb = ml2 / (LOG(2)): egumb = ml1 - (.5772157 * agumb)


INPUT "Please type in distribution's name eg Lognormal3"; dstb1$, dstb2$, dstb3$, dstb4$
LPRINT
LPRINT
LPRINT " v) Regional distribution parameters"
LPRINT "-----------------------------------------"
LPRINT "  Distbs.'name     e         a       k"
LPRINT "-----------------------------------------"
d4$ = "    \        \ ####.####   ####.#### ####.####   "
LPRINT USING d4$; dstb1$; egev; agev; kgev
LPRINT USING d4$; dstb2$; egpar; agpar; kgpar
LPRINT USING d4$; dstb3$; eglog; aglog; kglog
LPRINT USING d4$; dstb4$; egumb; agumb; blank
LPRINT p

100   END
```

Appendix B.2 QUICKBASIC PROGRAM of FIRST ORDER MARKOV MODEL

This program calculates transition probability of drought occurrences to describe drought vulnerability at the first order.

```
CLS
'          Information of the station considered
'          ====================================
INPUT "     Please type in the stasion's name and years of record"; stasion$
PRINT
INPUT "     Please type in the length of spell ( days )"; spell$
PRINT
INPUT "     Please type in the  season ( month, annual)"; season$
PRINT

'+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
'          Open and read the file data
'          ==========================
DIM PR(3000)
INPUT "     Please type in FILE NAME of rainfall stasion"; rain5$
PRINT
OPEN rain5$ FOR INPUT AS #1
INPUT "     Please type in name of OUTPUT FILE"; outfile$
PRINT
OPEN outfile$ FOR OUTPUT AS #2

'+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
'          Data analyses
'          =============
INPUT #1, name$, n
      sum = 0
FOR i = 1 TO n

      INPUT #1, x'(i)
      sum = sum + 1
      PR(i) = x'(i)
NEXT i
   DIM R(100, 100)
   INPUT "     Please type number of spells in this season"; nsm
   PRINT
   totyrs = sum / nsm
         dj = 0: wj = 0
   INPUT "     Please type in rainfall amount for determining dry or wet (mm)"; rain
   PRINT
   FOR j = 1 TO totyrs
         Di = 0: wi = 0
   FOR i = 1 TO nsm
```

```
            R(j, i) = PR(i + ((j - 1) * nsm))
            IF R(j, i) >= rain THEN 10
             Di = Di + 1: GOTO 20
10            wi = wi + 1: GOTO 20
20        NEXT i
            wj = wj + wi: dj = dj + Di
        NEXT j
        wwj = 0: wdj = 0: dwj = 0: ddj = 0
    FOR j = 1 TO totyrs
          wwi = 0: wdi = 0: dwi = 0: ddi = 0
          nsm1 = nsm - 1
    FOR i = 1 TO nsm1
          IF R(j, i) < rain THEN 110        '(... |D,i)
          IF R(j, i + 1) < rain THEN 100    '(D,i+1|W,i)
            wwi = wwi + 1: GOTO 130
100          dwi = dwi + 1: GOTO 130
110       IF R(j, i + 1) < rain THEN 120    '(D,i+1|D,i)
           wdi = wdi + 1: GOTO 130
120          ddi = ddi + 1: GOTO 130
130   NEXT i
          wwj = wwj + wwi: wdj = wdj + wdi
          dwj = dwj + dwi: ddj = ddj + ddi
    NEXT j

'++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    '         Result
    '         ======
          pw = wj / (wj + dj): pd = dj / (wj + dj)
          pww = wwj / (wwj + wdj): pwd = wdj / (wwj + wdj)
          pdw = dwj / (dwj + ddj): pdd = ddj / (dwj + ddj)

'++++++++++++++++++++++++++ ; +++++++++++++++++++++++++++++
    '         Print out the result
    '         ====================
    PRINT #2, ""
    PRINT #2, "       Transition matrix and the Conditional Probability"
    PRINT #2, "       ***************************************************"
    PRINT #2, " Stasion's name and years of record are: "; stasion$
    PRINT #2, "                    Length of spell is  "; spell$
    PRINT #2, "                     Seasonal basis is "; season$
    PRINT #2, "                 Rainfall amount is (mm) "; rain
    PRINT #2, ""
    PRINT #2, " No. of Wet =", wj, "PW  =", pw
    PRINT #2, " No. of Dry =", dj, "PD  =", pd
    PRINT #2, " No. of WW  =", wwj, "PWW = ", pww
    PRINT #2, " No. of WD  =", wdj, "PWD =", pwd
    PRINT #2, " No. of DW  =", dwj, "PDW = ", pdw
    PRINT #2, " No. of DD  =", ddj, "PDD = ", pdd
    PRINT

    PRINT "        Transition matrix and the Conditional Probability"
```

```
    PRINT "          *********************************************"
    PRINT "    Stasion's name and years of record are: "; stasion$
    PRINT "                Length of spell is "; spell$
    PRINT "                Seasonal basis is "; season$
    PRINT "              Rainfall amount is (mm)"; rain
    PRINT "    No. of Wet =", wj, "PW  =", pw
    PRINT "    No. of Dry =", dj, "PD  =", pd
    PRINT "    No. of WW  =", wwj, "PWW =", pww
    PRINT "    No. of WD  =", wdj, "PWD =", pwd
    PRINT "    No. of DW  =", dwj, "PDW =", pdw
    PRINT "    No. of DD  =", ddj, "PDD =", pdd

'++++;++++++++++++++++++++++++++++++++++++++++++++++
CLOSE #1
CLOSE #2
INPUT " do you wish to analyse another rainfall station? type y or n"; y$
IF y$ = "y" THEN 5
END
```

Appendix B.3 QUICKBASIC PROGRAM of SECOND ORDER MARKOV MODEL

This program calculates transistion probability of drought occurrences to describe drought vulnerability at the second order.

```
    CLS

'++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    '       Information of the station considered
    '       ==================================
    INPUT "    Please type in name of station and years of record"; stasion$
    PRINT
    INPUT "    Please type in the length of spell"; spell$
    PRINT
    INPUT "    please type in the season or month or annual"; season$

'++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    '       Open and read the file data
    '       ==========================
    DIM PR(3000)
    PRINT
    INPUT "    Please type in FILE NAME of rainfall stasion"; rain5$
    OPEN rain5$ FOR INPUT AS #1
    PRINT
    INPUT "    Please type in name of OUTFILE NAME"; outfile$
    OPEN outfile$ FOR OUTPUT AS #2

'++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    '       Data analysis
    '       =============
    INPUT #1, name$, n
         sum = 0

    FOR i = 1 TO n
         INPUT #1, x'(i)
         sum = sum + 1
         PR(i) = x'(i)
    NEXT i
       PRINT
       INPUT "    Number of spells in this season"; nsm
       totyrs = sum / nsm
            dj = 0: wj = 0
       PRINT
       INPUT "    Rainfall amount for determining dry and wet(mm)"; rain
       PRINT
       DIM R(100, 100)
       FOR j = 1 TO totyrs
```

```
        di = 0: wi = 0
    FOR i = 1 TO nsm
        R(j, i) = PR(i + ((j - 1) * nsm))
        IF R(j, i) >= rain THEN 10
        di = di + 1: GOTO 20
10       wi = wi + 1: GOTO 20
20   NEXT i
        wj = wj + wi: dj = dj + di
    NEXT j

    wwwj = 0: wwdj = 0: wdwj = 0: wddj = 0
    dwwj = 0: ddwj = 0: dwdj = 0: dddj = 0
  FOR j = 1 TO totyrs
     wwwi = 0: wwdi = 0: wdwi = 0: wddi = 0
     dwwi = 0: dwdi = 0: ddwi = 0: dddi = 0
     nsm1 = nsm - 2
    FOR i = 1 TO nsm1
     IF R(j, i) < rain THEN 150              '(.....|.... |D,i)
     IF R(j, i + 1) < rain THEN 110          '(.....|D,i+1|W,i)
     IF R(j, i + 2) < rain THEN 100          '(D,i+2|W,i+1|W,i)
       wwwi = wwwi + 1: GOTO 200
100     dwwi = dwwi + 1: GOTO 200

110    IF R(j, i + 2) < rain THEN 120         '(D,i+2|D,i+1|W,i)
       wdwi = wdwi + 1: GOTO 200
120     ddwi = ddwi + 1: GOTO 200

150    IF R(j, i + 1) < rain THEN 170         '(.....|D,i+1|D,i)
     IF R(j, i + 2) < rain THEN 160          '(D,i+2|W,i+1|D,i)
       wwdi = wwdi + 1: GOTO 200
160     dwdi = dwdi + 1: GOTO 200

170    IF R(j, i + 2) < rain THEN 180         '(D,i+2|D,i+1|D,i)
       wddi = wddi + 1: GOTO 200
180     dddi = dddi + 1: GOTO 200
200   NEXT i
     wwwj = wwwj + wwwi: wwdj = wwdj + wwdi
     wdwj = wdwj + wdwi: wddj = wddj + wddi
     dwwj = dwwj + dwwi: dwdj = dwdj + dwdi
     ddwj = ddwj + ddwi: dddj = dddj + dddi

  NEXT j


'++++++++++++++++++++++++++++++++++++++++++++++++++++++
  '   Result
  '   ======
     pw = wj / (wj + dj): pd = dj / (wj + dj)
     sw1 = wwwj + wwdj: sw2 = wdwj + wddj
     sd1 = dwwj + dwdj: sd2 = ddwj + dddj
```

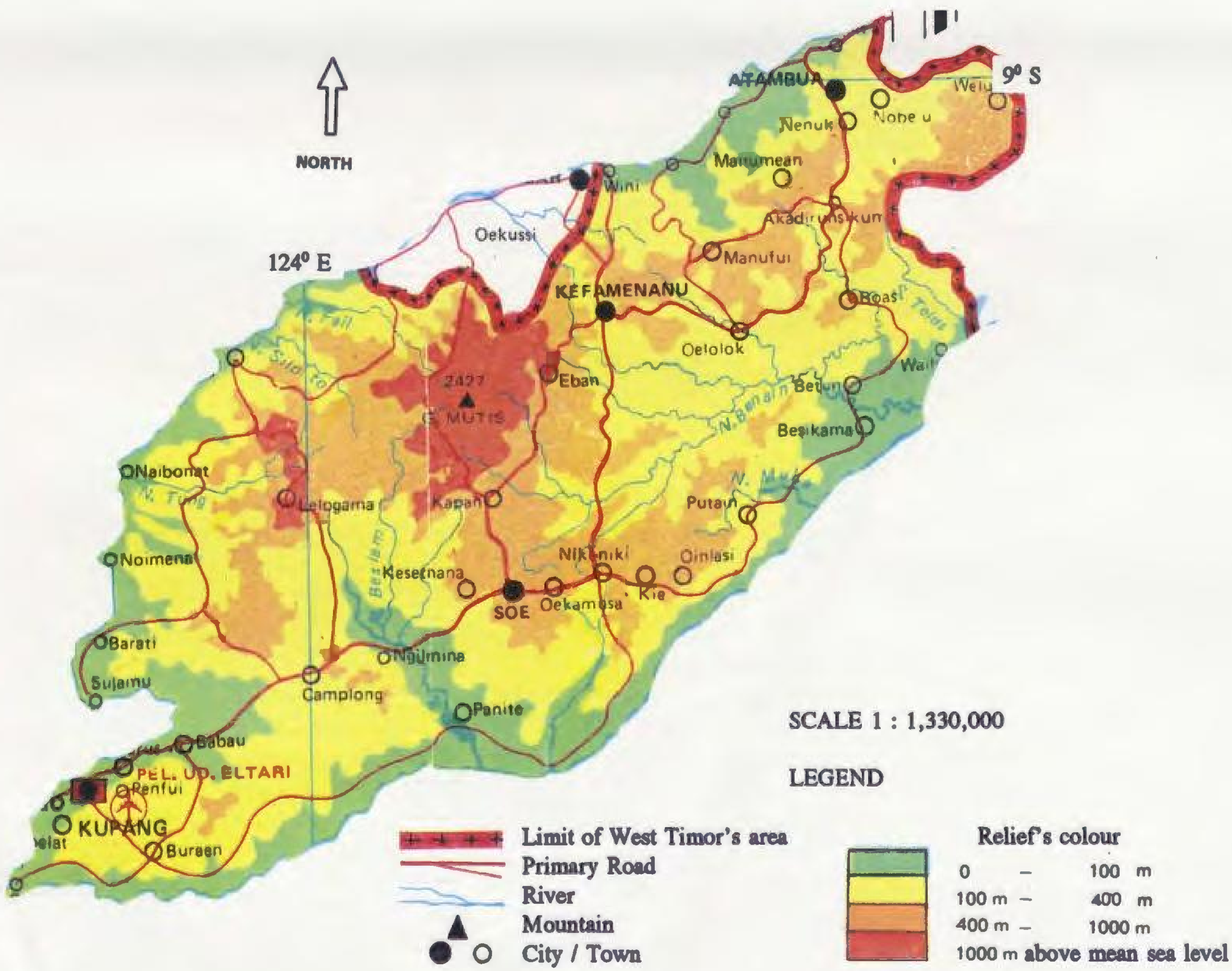
```
      pwww = wwwj / sw1: pwwd = wwdj / sw1
      pwdw = wdwj / sw2: pwdd = wddj / sw2
      pdww = dwwj / sd1: pdwd = dwdj / sd1
      pddw = ddwj / sd2: pddd = dddj / sd2

'++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   '   Print out the result
   '   ====================
   PRINT #2, "     TRANSITION MATRIX AND THE CONDITIONAL PROBABILITY"
   PRINT #2, "     ***************************************************"
   PRINT #2, " Name of stasion and years of record are: "; stasion$
   PRINT #2, " Length of spell is     "; spell$
   PRINT #2, " Seasonal basis is      "; season$
   PRINT #2, " Rainfall amount is(mm) "; rain
   PRINT #2, "************************************************************"
   PRINT #2, "No. of Wet = ", wj, " PW = ", pw
   PRINT #2, "No. of Dry = ", dj, " PD = ", pd
   PRINT #2, ""
   PRINT #2, "No. of WWW =", wwwj, "PWWW =", pwww
   PRINT #2, "No. of WWD =", wwdj, "PWWD =", pwwd
   PRINT #2, ""
   PRINT #2, "No. of WDW =", wdwj, "PWDW =", pwdw
   PRINT #2, "No. of WDD =", wddj, "PWDD =", pwdd
   PRINT #2, ""
   PRINT #2, "No. of DWW =", dwwj, "PDWW =", pdww
   PRINT #2, "No. of DWD =", dwdj, "PDWD =", pdwd
   PRINT #2, ""
   PRINT #2, "No. of DDW =", ddwj, "PDDW =", pddw
   PRINT #2, "No. of DDD =", dddj, "PDDD =", pddd
   PRINT #2, ""
   PRINT "       TRANSITON MATRIX AND THE CONDITIONAL PROBABILITY"
   PRINT "       ***************************************************"
   PRINT "  Name of stasion and years of record are:"; stasion$
   PRINT
   PRINT "                Length of spell is "; spell$
   PRINT "         Moth/Season/Yearly basis is  "; season$
   PRINT "              Rainfall amount is(mm) "; rain
   PRINT "     ************************************************************"
   PRINT "     No. of Wet =", wj, "PW   =", pw
   PRINT "     No. of Dry =", dj, "PD   =", pd
   PRINT
   PRINT "     No. of WWW =", wwwj, "PWWW =", pwww
   PRINT "     No. of WWD =", wwdj, "PWWD =", pwwd
   PRINT
   PRINT "     No. of WDW =", wdwj, "PWDW =", pwdw
   PRINT "     No. of WDD =", wddj, "PWDD =", pwdd
   PRINT
   PRINT "     No. of DWW =", dwwj, "PDWW =", pdww
   PRINT "     No. of DWD =", dwdj, "PDWD =", pdwd
   PRINT
   PRINT "     No. of DDW =", ddwj, "PDDW =", pddw
```

```
     PRINT "     No. of DDD =", dddj, "PDDD =", pddd

'+++++++++++++++++++++++++++++++++++++++++++++++

CLOSE #1
CLOSE #2
INPUT " Do you wish to analyse another station? Type y or n"; y$
IF y$ = "y" THEN 5
300 END
```



Appendix C Relief Map of West Timor