CHAPTER THREE

EVALUATION OF THE RAIN-GAUGE NETWORK AND DATA BASE

3.1 INTRODUCTION

A primary objective of this study, as outlined in section 1.3.1 of chapter one, is to examine and describe the spatial and temporal characteristics of the rain-gauge network in Sierra Leone, and to evaluate both the quantity and quality of the available rainfall information. This is considered to be a necessary prerequisite, and indeed an important consideration, in the choice of appropriate analytical methods, and in the selection of representative stations and a study period for detailed analysis. Such information is also useful in assessing the agricultural usefulness of the results for both local and regional planning and decision-making.

3.2 OBSERVATION AND MEASUREMENT OF RAINFALL

Information about rainfall in Sierra Leone has come from a variety of sources, which for the purpose of this study are discussed under two broad categories: (a) pre-instrumental historical documents, and (b) instrumental records.

3.2.1 Pre-instrumental Rainfall Observation

The earliest documentary information about rainfall in Sierra Leone comes from historical records based on descriptive accounts by European mariners who visited the area in the 15th and 16th centuries. The meteorological contents and quality of these reports undoubtedly vary from a mere reflection of discomfort and frustration in a strange environment, to purposeful, scientific appraisals of prevailing weather conditions.

Hair and Kenworthy (1985) have examined and analysed the contents of ship journals kept by two English scientific expeditions to the site of the present-day capital, Freetown. One of the expeditions took place from 20th August to 13th October 1582, and the other between 16th August and 23rd September 1607. These documents provide a vivid picture of the rainfall climatology of the area during the "monsoon" and "post-monsoon" seasons (August-October) that can be summarised as follows.

In August, the "monsoon" season, there was a strong emphasis in the reports on the frequent occurrence of heavy, and persistent day-time rainfall with associated southerly and southwesterly winds. Little or no reference was made to thunder activity, which is a characteristic feature of the West African Monsoon season. These reports are typified by the journal entries of the 9th and 20th August 1607.

> "9th August (1607) - Verie much raine and the wind westerly (U)".
>
> "20th August (1607) - Wee had blusteringe westerly windes, and such extreme raine that littlle or noe busines could bee despatched (U)".

These comments are remarkably consistent with present day observations of a seasonal peak in rainfall, accompanied by a distinctive trough in thunder activity in August, as illustrated in figure 3.1.

As the season progressed there was a reported increase in thunderstorm activity and storminess in September, which is also consistent with instrumental records (figure 3.1). Most of the rainstorms (erroneously referred to as 'tornadoes') were reported to occur at night, and to be associated with heavy rainfall, and strong northeasterly winds, as illustrated by the following two ship entries.

> "12th Sept.(1582) -- About one a clocke after midnight we had a tornado, which continued 3 houres at East next hand (H652). This nyghte we had 2 turnadoes (H210V)".

> "12th Sept. (1607) - In the eveninge much lightening at the northeast, and about midnight exceedinge much thunder and rayne with a gale at northeast (H)".

These extraordinary accounts, though descriptive in nature, provide an early insight into the characteristics of rainstorms that mark the end of the rainy season.

One of the outcomes of these and subsequent scientific expeditions to the area was the selection in 1778 of Sierra Leone as a 'homeland' for freed slaves,

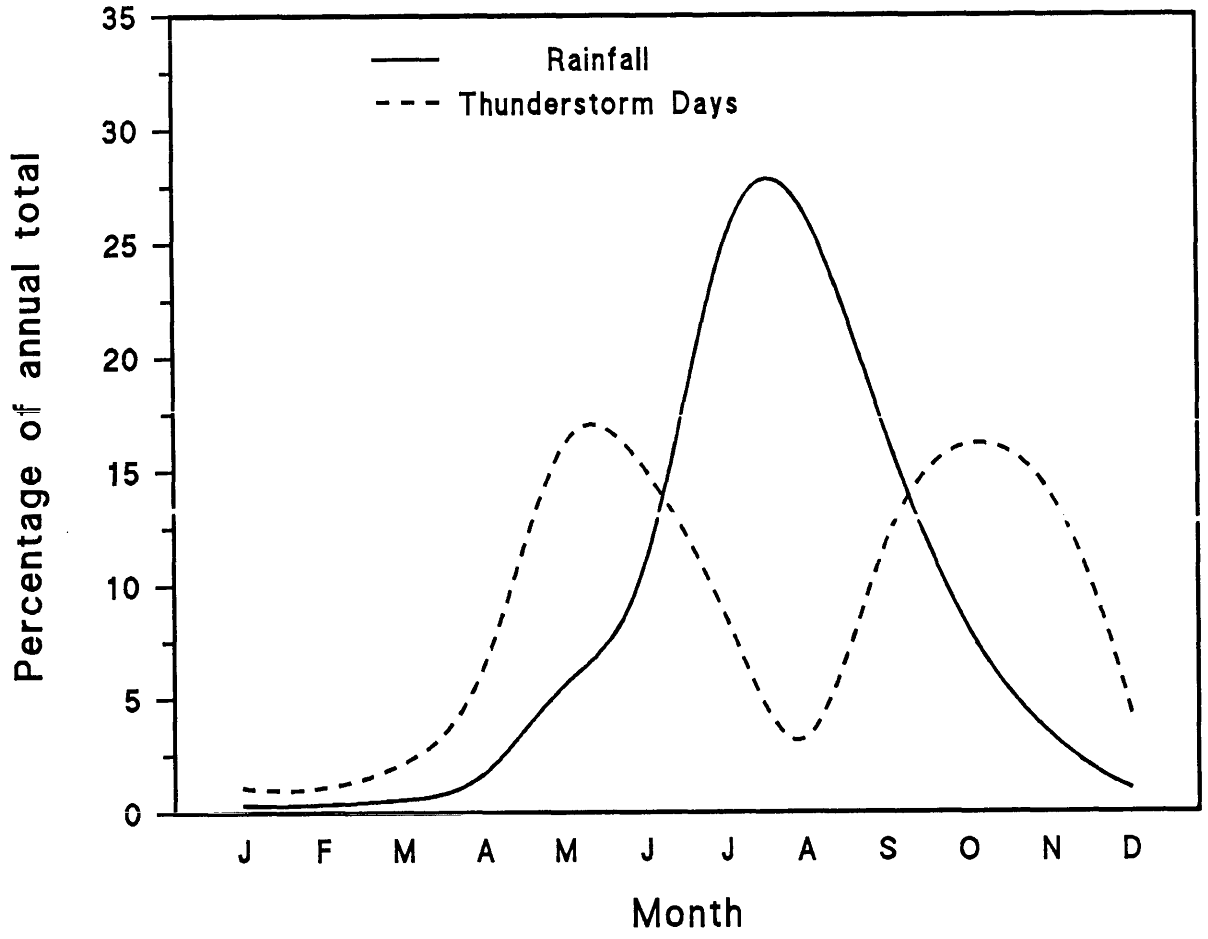


Fig. 3.1 Monthly variation in rainfall and thunderstorm days at Freetown (1930–88).

following the abolition of the Slave Trade, apparently because of its abundant rainfall which could support a wide range of food crops, both local and introduced. Ironically, heavy rainfall turned out to be a major nuisance to the first settlers whose crops and settlements were repeatedly obliterated by torrential rainstorms. Such was the preoccupation with problems of excessive rainfall that Dr James Africanus Horton (1867), a descendant of the early settlers, made the first attempt to quantify the amount of rain falling over Freetown during the rainy season as follows:

> " ---the quantity of rain which fell in all Freetown for --- three months in 1829, if measured, will not be less than (12.7) billion gallons of water --- which is an enormous quantity for only 80 days of rain!"

There are numerous other historical documents, mostly in the form of scattered references, which, when assembled and analysed, greatly increase our current understanding of both the long-term and short-period characteristics of rainfall in Sierra Leone (Hair and Kenworthy 1985).

3.2.2 Instrumental Observation Of Rainfall.

The main sources of instrumental rainfall records in Sierra Leone are stations operating the standard rain-gauges with either the 127 mm or the 203 mm orifice, and autographic recorders which measure the amount, duration, and intensity of rainfall. The latter are found mainly at Synoptic stations operated by the Meteorological Department. Attempts to introduce radar technology in the 1970's to provide additional rainfall information, especially for shorter-period conditions, and for ungauged areas, soon ran into technical problems after a few years. A second attempt was made in the late 1980's through the assistance of the World Meteorological Organisation, and involving equipment and supporting infrastructure worth thousands of dollars. Due to minor technical problems, the station housing this equipment is yet to be commissioned, more than two years after the equipment was installed (Sierra Leone Met. Department Staff, personal communication).

The history of rainfall measurement in Sierra Leone is closely related to the recent political history of the country. Settlement in the territory by the British in the eighteenth and nineteenth centuries was a major stimulus to the early beginning of instrumental weather observation. The earliest regular observations were made at the old Military Hospital at Tower Hill, in Freetown, in 1874 (figure 3.2). Although the actual site of the gauge has changed several times, rainfall observations at Tower Hill continue to the present day. In 1886 a second rain-gauge was installed at the Colonial Hospital (now Connaught Hospital) where observations continued until 1896 (Sierra Leone Met. Dpt. 1951).

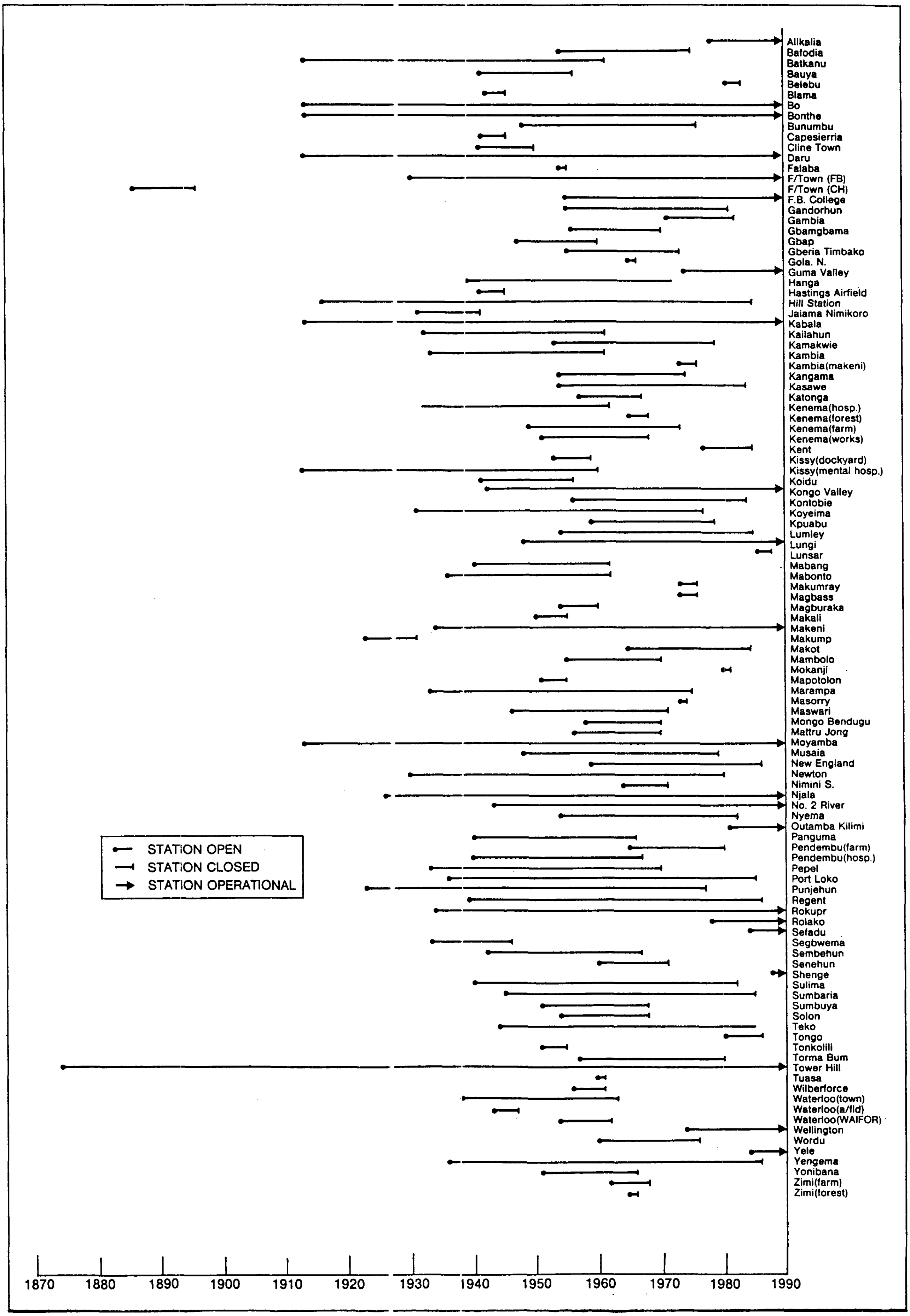


Figure 3.2 History of rainfall stations (1870-1990).

Following the proclamation of the hinterland as a protectorate by the British Government in 1896, there was a growing demand for climatological information for many kinds of scientific research and applications. In the following decades several rainfall stations were established throughout the country. But as table 3.1 shows, the period of most rapid expansion was between 1931-1960 when a total number of seventy-two new stations were established, compared to nineteen closures during the same period.

At independence in 1961 there were seventy-three fully operational rainfall stations. Since then there has been a noticeable contraction of the rain-gauge network, with a total of 70 stations ceasing operations, while only 25 new ones were established during the same period. By 1990 only 21 stations were sending regular monthly rainfall reports to Metecrological Headquarters in Freetown.

An important feature of the rain-gauge network in Sierra Leone is the large number of stations (89% of the total) operated by Government Departments and institutions other than the Meteorological Department (table 3.2). During the first 60 years of a 118-year history of instrumental weather monitoring all meteorological observations in the country were undertaken by the Medical Department. In the Freetown area rainfall measurements were taken by the Department from 1874 to 1937 when the responsibility was delegated to the Ministry of Education (S. Leone Met. Dpt. 1951).

DECADE	NEW STATIONS ESTABLISHED	STATIONS CLOSED	TOTAL STATIONS IN OPERATION
1871-1880	1	0	1
1881-1890	1	0	2
1891-1900	0	1	1
1901-1910	0	0	1
1911-1920	8	0	9
1921-1930	4	0	13
1931-1940	21	1	34
1941-1950	19	7	54
1951-1960	32	11	77
1961-1970	7	27	73
1971-1980	12	23	58
1981-1990	6	20	41
TOTAL	111	90	111

Table 3.1 Number of rainfall recording stations per decade (1874-1990).

OBSERVING AUTHORITY	TOTAL NUMBER OF STATIONS	PERCENTAGE OF TOTAL
MEDICAL DEPARTMENT	28	25.2
AGRICULTURE & FORESTRY DPTS.	45	40.5
METEOROLOGICAL DEPARTMENT	12	10.8
EDUCATION DEPARTMENT	6	5.4
PUBLIC WORKS DEPARTMENT	4	3.6
LOCAL AUTHORITIES	4	3.6
MINING COMPANIES	9	8.4
MISSIONARY	2	1.8
INDUSTRY	1	0.9
TOTAL	111	100

Table 3.2 Rainfall recording agencies (1887-1990).

In the hinterland (Protectorate) regular rainfall observation by the Medical Department commenced in 1913 and continued until 1933 when the Department of Agriculture took over operations. Following the establishment of the Sierra Leone Meteorological Department in 1939 as part of the British West African Meteorological Service, responsibility for collecting, processing, archiving, and publishing of all meteorological and hydrological data was soon passed on to the new Department. It was also mandated to oversee the establishment and maintenance, through regular inspection, of all meteorological stations, including those operated by non-governmental organisations such as mining companies, local authorities, Christian Missionary groups, industrial concerns, and voluntary observers.

It is disappointing to note that the Meteorological Department has not significantly expanded its operations over the years. For instance, of the ninety-seven stations established since its inception in 1939, only twelve (12% of total) are directly operated by the Department (table 3.2). Most of these are first-class (Synoptic) stations, whose reports are largely targeted at the aviation industry.

This reliance on non-professional observers (most of whom were expatriates) has had a most telling effect on the meteorological network. After Independence in 1961, Government Ministries and Departments were handed over to local staff who had little or no interest and experience in the running of weather stations. The result was an unprecedented decline in standards and a rapid contraction of the network.

Another contributing factor has been the shortage of trained manpower due to unattractive salaries and poor conditions of service, and inadequate funding by successive governments, as evidenced by the low status accorded to the Department in national budgetary allocations. Many Government Officials continue to hold a very narrow concept of the role of the meteorological service. A parliamentary representative once suggested during a debate on the Budget that the Meteorological Department be closed temporarily every Dry Season, since "there normally was no rainfall to measure", as a way of cutting back on expenditure to support other income-earning Departments (Met. Dept. Staff, Personal Communication).

3.3 SPATIAL CHARACTERISTICS OF THE RAIN-GAUGE NETWORK.

The rain-gauge network (figure 3.3) has evolved largely in response to a number of physical and human factors, including relief features, historical antecedents, and population distribution. With regard to relief, there is a general tendency for rain-gauges to concentrate in the Coastal and Central lowlands where fifty-seven (51% of all gauges ever in operation) have been located. This gives an average density of 797 sq km per gauge, which is within the recommended minimum density of 900 sq km per gauge for tropical lowlands (WMO 1965). But even within the lowlands, fewer gauges are

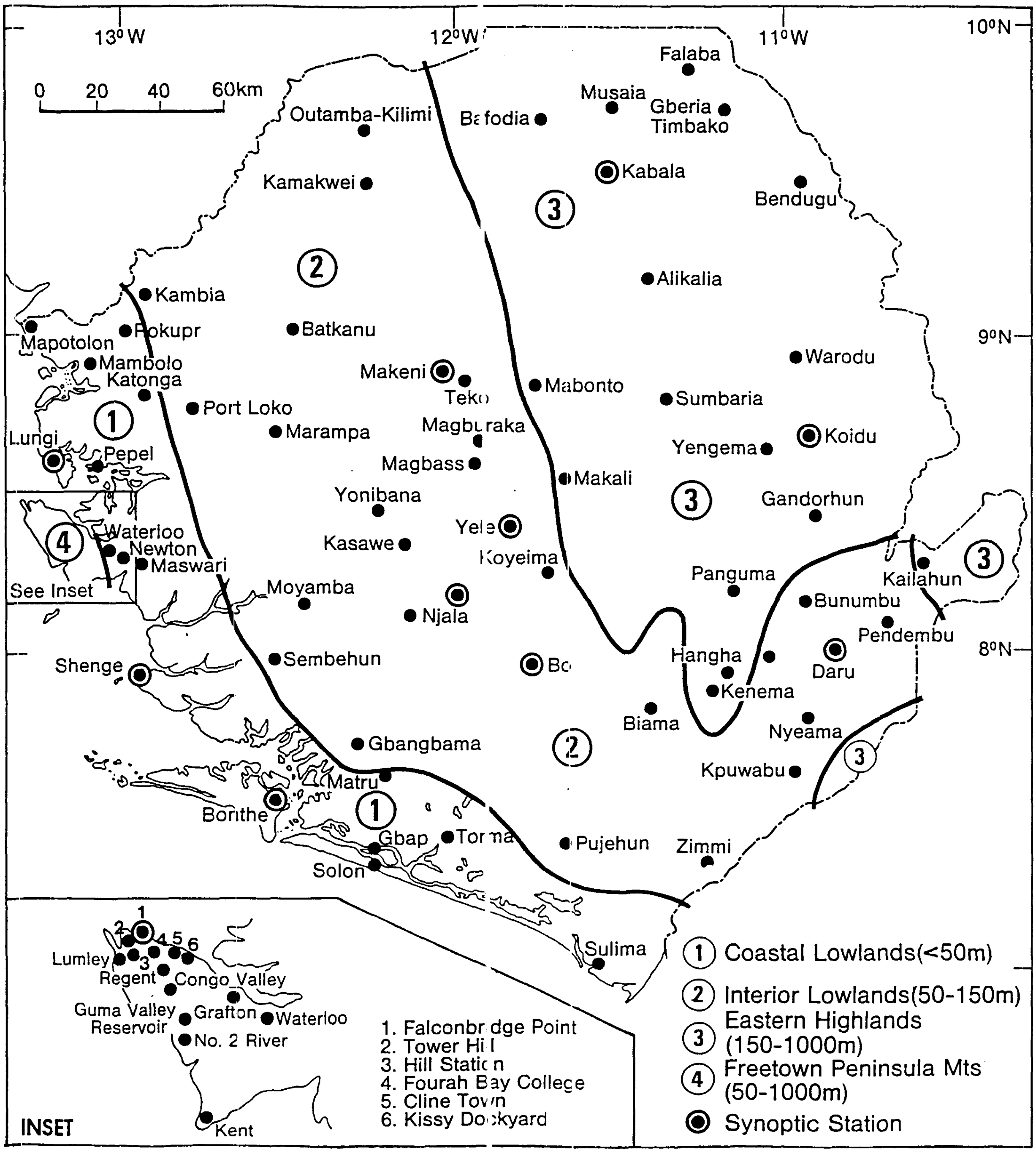


Figure 3.3 Location of rainfall station (1874-1990).

located in areas with extensive marshlands, such as the seasonally-flooded inland swamps (bolilands) of Bombali District in the Northern Province, and the Riverine areas of Pujehun and Bonthe Districts in the South.

The Eastern Highlands Region, with its rugged terrain, has had only thirty gauges (30% of total), with an average density of 876 sq km per gauge, which is more than three times the required minimum of 250 sq km per gauge for tropical highlands (WMO 1965). Most of these gauges are located in areas that are relatively accessible, often in settlements along major lines of communication.

The Freetown Peninsula Mountains are a notable exception, with twenty-four rain-gauges (21% of the national total), and an average density of 23 sq km per gauge. Most of the rain-gauges in this area, however, are found in old Colonial reservations and mountain settlements where the main determinants for their location were the availability and convenience of an observer, rather than site suitability, or climatological need.

Historically, the pattern of development of the rain-gauge network is closely related to that of the modern road and railway systems, which served as the main arteries for innovation diffusion into the hinterland in the late nineteenth and early twentieth centuries. The construction of a railway (served by a network of feeder roads) linking the coastal port and capital, Freetown, and Pendembu in the rich agricultural Districts of the

East Province in 1908, and then Kamabai in the North in 1916, led to a rapid growth of 'railway' towns. These settlements, which served as both commercial and administrative centres also became ideal locations for monitoring the weather by the various agencies mentioned earlier. Out of a total of fifty-three rainfall stations in operation between 1930 and 1950, twenty were located at 'railway' towns, with a further nine located at settlements along feeder roads linking the railway and the interior.

The development of air and water transport has also had an effect on the rain-gauge network. The Lungi Synoptic station, which, apart from being the main forecast centre, now has one of the most complete and reliable rainfall records, as well as being one of the few stations with autographic records, started operations in 1948, following the establishment of the International Airport. A few other rainfall stations have also been established at important water transport settlements, such as Gbangbama, Sumbuya, Mattru, Sembehun, and Pepel.

Another important characteristic of the rain-gauge network is the relative concentration of rainfall stations in areas of high population densities. Notable among these are the rice-growing areas of the northwest (Kambia and Port Loko District), and the south (Bonthe District); and the coffee- and cocoa-growing areas of the Upper Moa basin in the Eastern Districts of Kenema and Kailahun. The relatively sparse rain-gauge network in the northern parts of the country is due to a combination of low population densities and rugged terrain. A correlation coefficient of 0.583 was established between district population densities and rain-gauge densities.

The uneven distribution of rain-gauges, combined with the marked spatial variability that characterizes tropical rainfall, raises the important question of how representative the rain-gauge network is, of the whole country it is supposed to sample? To address this issue an objective approach involving the use of a Geographic Information System (G.I.S) was adopted.

Based on the recommended rain-gauge densities for tropical lowlands and highlands (WMO 1965) mentioned in section 2.2 of chapter two, appropriate buffer zones were drawn around all rain-gauges, using PC ARC/INFO (1992), a vector-based Geographic Information System. The aim of this part of the analysis was to determine which parts of the country are adequately sampled, and which areas are poorly represented by the existing rain-gauge network.

Two maps, one showing the four relief regions and the other showing the location of the rainfall stations (figure 3.3) were both digitized using the sub-commands "DIGITIZE", and "ARCEDIT'. In the case of the relief map, the "CLEAN" sub-command was also used to assemble the various arcs into "polygons" and to create attribute information for each "polygon". The two relief regions with an average height under 300 metres were treated as lowlands, and the two with 300 metres or more as highlands. An item called "ALT", representing the average height (in metres) of each polygon was then added to the polygon attribute table (PAT) using the sub-commands "ADDITEM" and "UPDATE". Sixty-five percent of the total area, and 73% of all gauges were found to lie below 300 metres.

For the map of rainfall stations, the "BUILD" sub-command was used to build a "point topology" and to create attribute information. The two coverages or maps were then superimposed on each other using the "IDENTITY" sub-command, which also created a common attribute table. An item called "DIST" was then added to this table using the "ADDITEM", "RESELECT", and "CALCULATE" sub-commands. For all polygons with "ALT" 300 metres or more (mountain areas), "DIST" was set at 8.9 km, while for polygons with "ALT" less than 300 metres (lowlands), "DIST" was set at 16.9 km.

Using the "VARIABLE' option of the sub-command "BUFFER", a 250 sq km circle with a radius of 8.9 km was drawn around all rainfall stations located within polygons designated as highlands. Similar circles of 900 sq km with 16.9 km radii were drawn around all stations in lowlands polygons (figure 3.4). Buffer areas that overlapped were automatically "DISSOLVED", while those that were outside the boundaries of the study area were trimmed off by overlaying the country outline map with the buffer coverage using the "INTERSECT" sub-command.

Table 3.3 presents a summary of the results of the analysis. Based on these results, about 48.8% of the total land area can be assumed to be reasonably sampled by the raingauge network during the period 1874-1990.

However, on a physical regional basis the proportion of the sampled area varies from 100% for the Freetown Peninsula Mountains to 61.7% for the Coastal and Interior Lowlands, and 23.7% for the Eastern Highlands region.

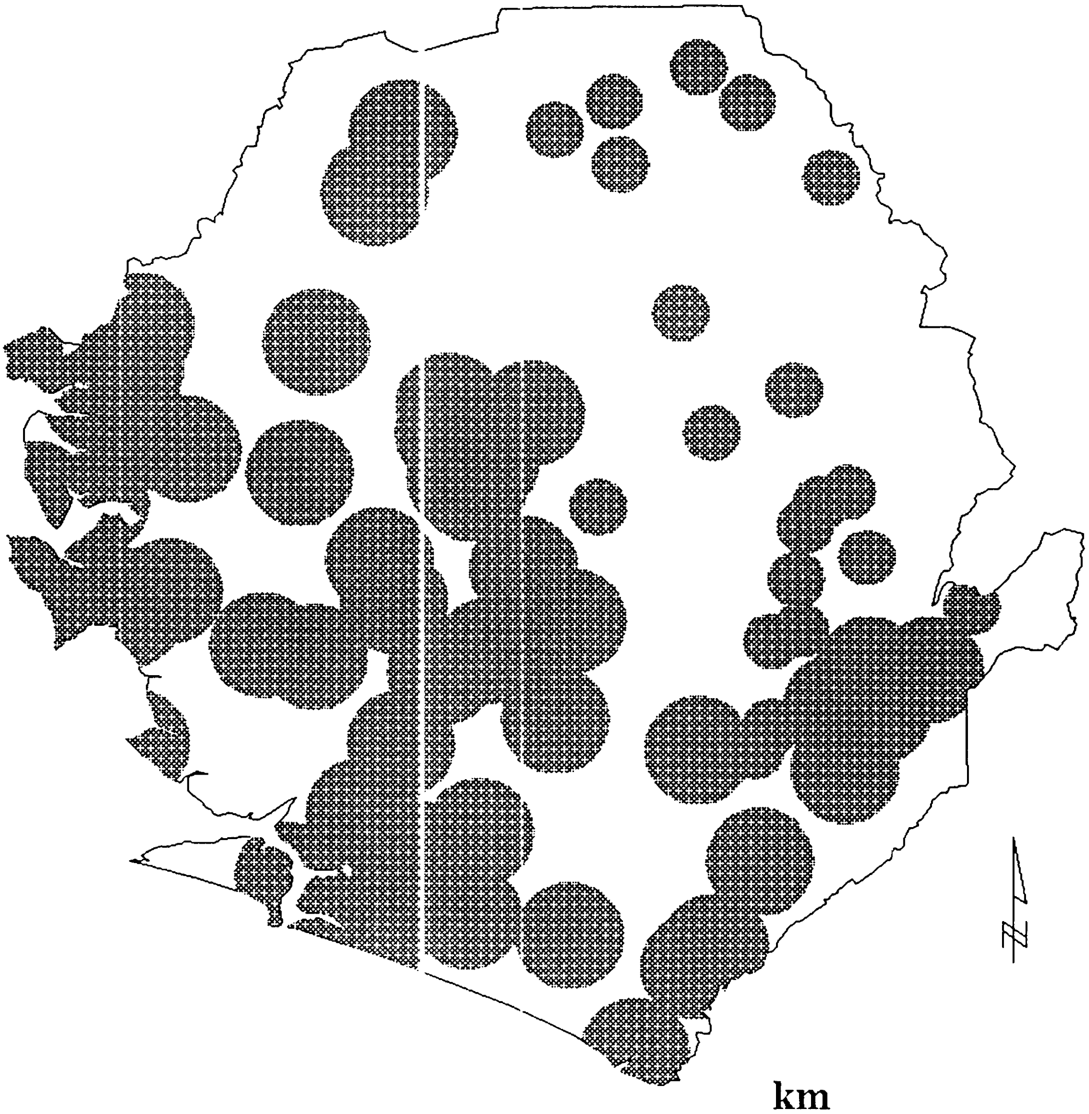
RELIEF REGION	PERCENTAGE COVERAGE
Eastern Highlands (-> 300 m)	23.7
Coastal and Interior Lowlands (< 300 m)	61.7
Freetown Peninsula Mts. (-> 300 m)	100
WHOLE COUNTRY	48.8

Table 3.3 Areal coverage of the rain-gauge network for different relief regions (1874-1990).

Figure 3.4 also gives an indication of the "connectivity" of the rain-gauge network. There is considerable overlap in buffer areas in the lowlands and the Freetown Peninsula Mountains, with some stations lying exclusively within the same area. To determine the extent to which this was the case, inter-station distances were computed using the "POINTDISTANCE" sub-command in PC ARC/ANFO, and setting the search radius at 8.9 km for highland stations, and 16.9 km for lowlands stations. Table 3.4 is a summary of that analysis.

In the Eastern Highlands there is no case of two stations lying within the same area, unlike the Freetown Peninsula Mountains, and the Coastal and Interior

Figure 3.4 Spatial coverage of raingauge network (1874-1990)



Lowlands where there are eleven, and twenty-eight pairs of such stations, respectively. However, such overlapping of stations is not an indication of duplication of rainfall patterns, in view of the tendency for rainfall in the tropics to vary markedly within relatively short distances.

RELIEF REGION	NUMBER OF STATION PAIRS
Eastern Highlands (-> 300 m)	0
Freetown Penin. Mts. (-> 300 m)	11
Coastal and Interior Lowlands (< 300 m)	28
Whole Country	39

Table 3.4 Total number of station pairs with lying within the same area.

Based on the WMO criteria for optimum rain-gauge densities mentioned earlier, the rain-gauge network can be considered to be representative of most of the coastal and interior lowlands, with the exception of some parts of the northwest. The Freetown Peninsula Mountains are also adequately represented. The areas of most concern are the Eastern Highlands and Plateau in the north and east where less than a quarter of the total area has ever been sampled by the network. Since this area constitutes an important source for rainstorms, apart from being the watershed for all but one of the country's major rivers, an improvement of its rain-gauge coverage is important for increasing an understanding of the rainfall climatology and water resource potential of those parts of the country. However, considering the financial, technical, and manpower constraints outlined earlier, prospects for future expansion of the network in these, and other areas seem remote without increased recognition by Government of the potential role of meteorology in economic development.

3.4 ASSESSMENT OF THE QUALITY OF RAINFALL DATA

Although there are over 100 stations for which rainfall records are available, it is important to evaluate the quality of the data in terms of record lengths, missing values, and consistency before embarking on any detailed analysis. Such an exercise will also provide an objective basis for the choice of sample stations and an appropriate study period.

3.4.1 Length of records.

Table 3.5 shows the total number of stations with a given record length. Cumulative totals and percentages were computed starting from the lowest to the highest value. The length of rainfall records varies from 1-118 years, although the latter record consists mainly of monthly totals. Only thirty-four stations (30% of the total) have more than thirty years of records, which is the standard period often used to determine the "normal" climate of a place. Six stations (5% of total) have more than seventy years of records.

Apart from the short records for most of the stations, there is the additional problem of non-uniformity in the

RECORD LENGTH (YEARS)	TOTAL NUMBER OF STATIONS	CUMULATIVE TOTALS	PERCENTAGE OF TOTAL	CUMULATIVE PERCENTAGE
1-10	31	110	28.18	100.0
11-20	26	79	23.64	71.83
21-30	19	53	17.27	48.19
31-40	8	34	7.27	30.92
41-50	13	26	11.82	23.65
51-60	5	13	4.55	11.83
61-70	2	8	1.82	7.28
71-80	5	6	4.55	5.46
> 80	1	1	0.91	0.91

Table 3.5 Total number of stations with a given rainfall record length (1870-1990)

observation periods which is clearly illustrated in figure 3.5. This assortment of different record lengths and observation periods creates many problems in choosing representative stations and an appropriate study period for a detailed analysis of the spatial and temporal characteristics of rainfall.

3.4.2 Missing data

One justification for this study not mentioned in chapter one, is the opportunity it presents for the entire rainfall record in Sierra Leone to be computerised for the first time. The data collection took place during two months of intensive field work at Meteorological Headquarters in Freetown between September and November 1991, and involved both manual transcription and photocopying of the original manuscripts. A further six months were spent computerising the data using a specially written Fortran Program (INPDRF), and cross-checking the output against the manuscripts for errors and omissions.

Although the collection and initial processing of the data proved to be extremely tedious and painstaking, it nonetheless gave the researcher a "feel" of the data, and a greater appreciation of the enormous problems associated with the recording and storage of rainfall and other climatic data. But more importantly, it was possible to make preliminary checks for errors and inconsistencies during the initial processing of the data.

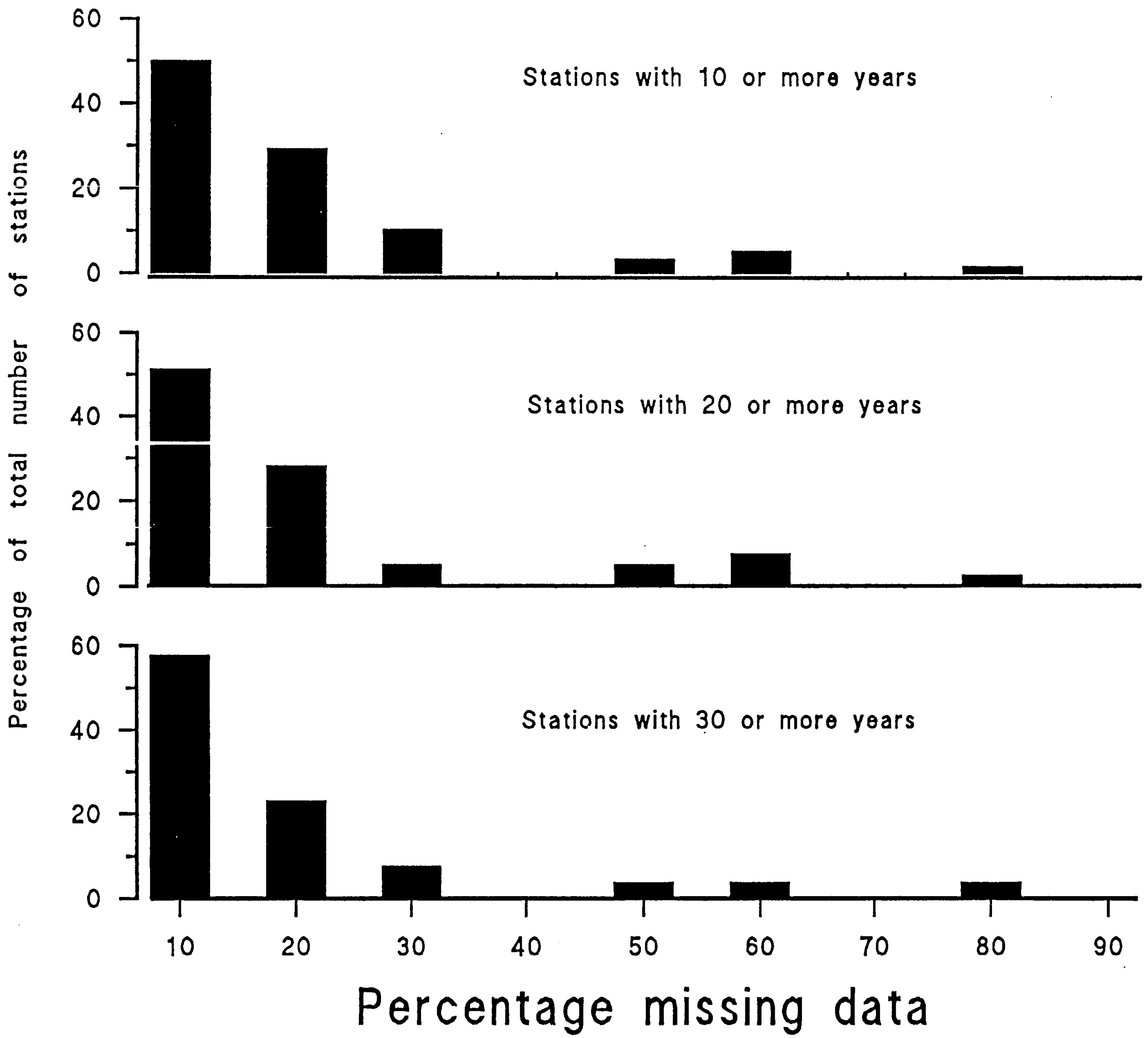


Figure 3.5 Proportion of missing data for stations with various record lengths

Several rainfall records, including a few from stations operated by the Meteorological Department, had many gaps. These gaps were found to be due to three main causes; (i) rainfall was not recorded at the time of its occurrence, (ii) the records were missing, assumed lost while being transmitted to Meteorological Headquarters by postal returns, or misplaced within the archives of the Department, and (iii) the records had depreciated beyond recognition under high temperature and humidity conditions.

Another Fortran Program (DRTOMR) was written to scan the daily rainfall record of each station for missing values. The output includes a count of the total number of days with missing data per month, per year, and for the entire period on record. Also included is the count of the total number of months with more than a given number of days with missing data. Figure 3.5 is a summary of the amount of missing data for all stations with ten or more years of daily rainfall records. Over one-half the stations with both long and short records have 1-10% of their data missing. The value of the records is further reduced since stations often do not overlap.

Three long-term stations have a large part of their records missing. At Hill Station on the Freetown Peninsula Mountains the entire daily record for 1939-1966 (56% of the total) was missing. At Sulima, the most southerly station, data for the 1951-1980 (71% of the total) was also missing, while at Moyamba in the central south no data could be traced for the period 1957-1974

(43% of the total). It is possible that duplicate copies of the original manuscripts of these data are still available at the respective stations, although efforts to get copies of these records by correspondence proved futile.

Preliminary attempts to estimate missing daily rainfall values based on data from neighbouring stations, and employing regression analysis techniques and the Normal-Ratio method produce rather disappointing results. This is perhaps due to the great variability in daily rainfall conditions between neighbouring locations. For this reason, and also since this study is concerned mainly with daily rainfall conditions, it was decided to exclude all stations and/or years with a large number of missing values and suspect data in subsequent analyses.

3.4.3 Consistency in the data

Following the principles of data quality control outlined in section 2.3.2 of chapter two, consistency checks were carried out on all station records that are (i) continuous over a ten-year period or longer, and (ii) at the same time have 10% or less of the records missing. These, shown in Appendix A, are the station records used in later analyses.

Several aspects of the internal consistency of the rainfall records were taken into account, including the occurrence of logically inconsistent observations, and values beyond the probable range. Observations that were found to be highly suspect were omitted, and treated as missing values.

One basic cause of data inconsistency relates to observation procedures. Since details about the observer(s) and methods of observation are not included on the records, it was decided to carry out a visual inspection of the data, especially that from "private" stations for evidence of inconsistency. Two curious anomalies were detected at one station. With the exception of a few occasions, it was observed that every sixth and/or seventh day during the rainy months was reported as a dryday, while every seventh and/or eighth day had the highest daily rainfall totals.

These rather curious coincidences prompted a closer scrutiny of the records, which revealed that on many occasions the drydays coincided with weekends and public holidays when the gauge was not read, while the days of maximum rainfall were often Mondays and days following public holidays when the cumulative total for the previous days was recorded. However, only at a few stations, and for a few years was this found to be the case, involving stations operated by mining companies, and other Government Departments. Figure 3.6 illustrates the case for Pepel on the Atlantic coast, which was operated by the now-defunct Iron Ore Mining Company (DELCO), between 1933 and 1975.

Another possible cause of inconsistency in climatic data is related to changes in units of measurement. Such a change occurred in 1975 when metric units based on the

International System of Units (SI) were adopted for all meteorological measurements in Sierra Leone. One consequence of this change was the redefinition of minimum measurable rainfall (or rainday) from a threshold value of 0.01 inches (0.25 mm) to 0.10 mm. Such small minimum values may easily be "flash" evaporated in a sun-heated gauge.

It was suspected that a change from a higher to a lower threshold might produce inconsistencies in the data, especially in the total number of raindays. To determine the extent to which this is the case, sample data for 1975-1990 from four synoptic stations representing the west coast (Lungi), the eastern interior (Daru), the central (Bo) and northern (Kabala) parts of the country were analysed, and the results are presented in table 3.6.

Clearly, the difference in total annual number of raindays between the two categories is very small, being in the order of 1-2 days per year in most areas, except at Daru in the east where the difference is about 7 days per year. Also, most of the observed differences seem to occur during the rainy season (June-October) when an additional rainday is hardly important as far as moisture supply for plant growth is concerned.

In order to make the data consistent with the pre-1975 records (which, incidentally, constitute over 75% of the available data at most stations), the earlier threshold of 0.25 mm has been adopted for the definition of measurable rainfall in this study, and all days with rainfall below this amount are treated as dry days.

3.5 Summary

The results of this analysis show that: (i) despite the recent closure of several rainfall stations, the quantity and quality of the available rainfall data is sufficient for an agroclimatic assessment of problems and prospects for rainfed agriculture in Sierra Leone; (ii) while some parts of the country are adequately sampled by the existing rain-gauge network, some areas, especially the east and the north require more, and better located rainfall stations. (iii) to stem the recent contraction of the network, greater financial support must be given to the Meteorological Department in order for it to recruit and train more staff, establish more weather stations, increase and strengthen its supervisory role for private, and other stations operated by various Government Departments.

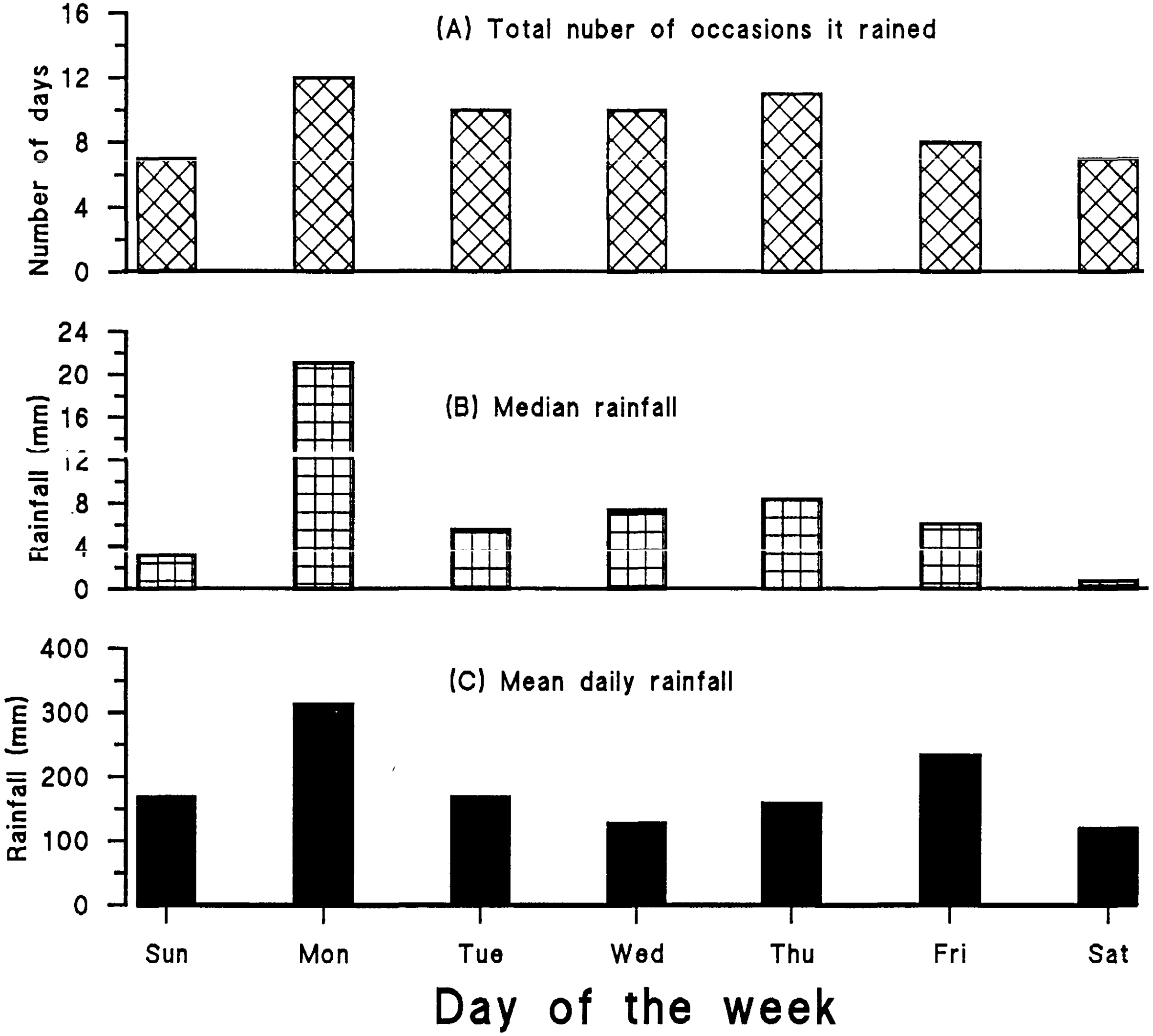


Figure 3.6 Variations in rainfall by day of the week at Pepel, July–Spt 1955

STATION	RAINFALL THRESHOLD	M O N T H J	F	M	A	M	J	J	A	S	O	N	D	ANN
BO (CENTRAL)	->0.10 mm	0.3	1.7	3.9	9.5	15.7	21.2	24.3	26.1	24.4	22.4	10.9	1.5	161.9
	->0.25 mm	0.3	1.6	3.9	9.5	15.6	20.9	24.0	25.9	24.1	22.0	10.9	1.5	160.2
	Difference	0.0	0.1	0.0	0.0	0.1	0.3	0.3	0.2	0.3	0.3	0.0	0.0	1.7
BONTHE (S. COAST)	->0.10 mm	0.9	1.2	3.4	6.4	16.4	24.6	25.7	26.7	23.6	21.5	12.7	3.0	158.0
	->0.25 mm	0.8	1.0	3.2	6.2	16.0	24.0	25.4	25.7	23.4	20.9	12.3	3.0	155.0
	Difference	0.1	0.2	0.2	0.2	0.4	0.6	0.3	1.0	0.2	0.6	0.4	1.0	3.0
DARU (E. INTERIOR).	->0.10 mm	1.3	1.6	6.0	12.4	18.4	19.8	24.4	26.4	25.0	24.1	13.0	2.6	175.0
	->0.25 mm	1.2	1.6	5.7	11.8	17.8	19.4	23.0	25.1	24.1	23.4	12.6	2.3	168.0
	Difference	0.1	0.0	0.3	0.6	0.6	0.4	1.4	1.3	0.9	0.7	0.4	0.3	7.0
KABALA (N. INTERIOR).	->0.10 mm	0.5	0.9	2.4	7.7	14.6	19.0	22.8	26.4	24.6	20.9	7.0	0.5	147.0
	->0.25 mm	0.5	0.8	2.4	7.6	14.6	18.8	22.6	26.2	24.5	20.8	6.9	0.5	146.0
	Difference	0.0	0.1	0.0	0.1	0.0	0.2	0.2	0.1	0.1	0.1	0.1	0.0	1.0
LUNGI (W. COAST)	->0.10 mm	0.3	0.5	1.1	4.3	13.6	22.4	26.8	27.2	23.9	21.2	8.4	1.7	151.3
	->0.25 mm	0.3	0.5	1.1	4.3	13.5	22.1	26.7	26.1	23.8	20.9	8.1	1.6	149.5
	Difference	0.0	0.0	0.0	0.0	0.1	0.3	0.1	1.1	0.1	0.3	0.3	0.1	1.8

Table 3.6 Average raindays with ->0.1 mm and ->0.25 mm at five stations (1975-90).

CHAPTER FOUR

RAINDAYS AND DRYDAYS: CONCEPTS AND DEFINITIONS

4.1 INTRODUCTION

In Sierra Leone, as in many other tropical areas where seasonal variations in temperature are not a major limiting factor to plant growth, the timing, duration, and quality of the growing season(s) are mainly determined by the local rainfall regime, although other factors such as evaporation rates, soil and crop types are also important. Among the variety of rainfall attributes that determine the character of the local rainfall regime, and hence the growing season(s), the number of raindays and their distribution during the year are of major significance. A number of studies, including those by Harrison (1982), de Jardins (1982), and Jackson (1986), have shown significant relationships between the number and characteristics of raindays, and the total amounts of seasonal and annual rainfall, as well as fluctuations in these amounts.

The general importance of daily variability in rainfall for agriculture was outlined in chapter one. From that discussion, it is apparent that in a predominantly rainfed agricultural system, such as obtains in Sierra Leone, a complete understanding of the characteristics and seasonal distribution of raindays is important in determining the availability and reliability of the moisture supply for successful cultivation.

This chapter is therefore concerned with theoretical issues related to rainday/dryday concepts and definitions, with an emphasis on the tropical situation. After reviewing a wide range of existing rainday definitions based on disciplinary perspectives, a proposed definition and classification of raindays and drydays based on combined rainfall and soil moisture characteristics is presented.

4.2 RAINDAY/DRYDAY DEFINITIONS

Despite the frequent and common use of the "rainday", or its complement, the "dryday", both as a climatic parameter (De Jardins 1982, Jackson 1986) and as an agroclimatic variable (Wang 1967, Stern et al 1982a), there is no universal definition which suits all circumstances. The question of what constitutes a rainday is still a matter of debate among scientists in different, as well as within the same, fields of study. Apart from the confusion this disagreement creates in the climatic literature, it also tends to limit the potential usefulness of the concept in characterising moisture aspects of the agricultural environment, which is essential to understanding the nature and likely impact of dry and wet weather conditions at a given locality. Another related problem in the literature is the lack of distinction between a "rainday" and a "wetday', and between a "rainspell" and "wetspell". Often these terms are used interchangeably.

An extensive survey of the literature in this study has revealed three basic ways in which approaches to rainday definition differ: (a) by scientific discipline, (b) by geographical area of study, and (c) by the system of measurement used to record the rainfall data. Clearly, one reason for the different definitions relates to the purpose for which the definition is used.

However, for the purpose of this study, existing rainday definitions have been grouped into two broad categories, namely, "Meteorological", and "Agricultural".

4.2.1 Meteorological Rainday Definitions

"Meteorological" rainday definitions are widely used in the atmospheric sciences, especially where the main interest is in the distinction between occurrence and non-occurrence of rainfall. These definitions are often not concerned with the effects of rainfall on a particular human activity, or its adequacy in satisfying a specific need like crop-water requirements. To the atmospheric scientist, a rainday is generally defined as a period of twenty-four hours with total rainfall equal to or greater than the minimum measurable amount, as distinct from a dryday when either no rain falls at all or when its amount is non-measurable (trace) by standard methods.

The definition of "minimum measurable" rainfall also varies greatly betweer countries. In many English-speaking, and other countries where rainfall measurements are made in imperial units, the "minimum measurable" rainfall is normally set at 0.01 inches (0.25 mm). In this system days with at least 0.04 ins (1.00 mm) are described as "wetdays". French-speaking countries, and others which operate on the metric system, on the other hand, use a threshold value of 0.10 mm of rainfall for a rainday. But even countries that operate on the same system of measurement can have different rainfall thresholds. Among the Francophone West African countries, for instance, the threshold value for a rainday has been found to vary from 0.1 mm to 2.0 mm (Snijder 1986).

Jackson (1986) analysed daily data from sixteen tropical countries to determine, among other things, the impact of using different thresholds, and the relationship between number of raindays and total monthly rainfall. Of the twenty-eight stations that formed his sample, seven used a threshold of 0.1 mm, while eighteen used 0.25 (0.3) mm, and three 1.0 mm.

Many researchers have questioned the reliability with which small amounts of rain are measured, especially by non-professional observers. Another related problem is the common practice in rainfall observation to round off measurements to the nearest hundredth of an inch or millimetre, so that a reading of, say, 0.05 mm becomes 0.1 mm. Concerns have also been raised about the possibility of atmospheric water vapour condensing directly into the gauge overnight, to be read as rainfall the following morning by an unsuspecting observer. For these, and other reasons, a value higher than the minimum measurable rainfall amount has been suggested by some researchers as being more appropriate for the "meteorological" definition of a rainday, as described below.

Table 4.1 shows some examples of "meteorological" rainday definitions that have been used in different parts of the tropics. The threshold values range from 0.1 mm to 12.7 mm. In India, Banerji and Chabra (1963) recommend 4.0 mm or more, while they quote the Indian Meteorological Department's specification of a 2.5 mm threshold. In West Africa Garbutt et al (1981) considered only days with 0.85 mm or more as raindays, pointing out that in many parts of the region rainfall less than 1.0 mm accounts for 20% of the raindays, but only 2% of the annual rainfall total. In his analysis of raindays in Nigeria, Olaniran (1987), omitted all days with rainfall less than 2 mm, in support of Nieuwolt's (1977) assertion that they are not significant in the warm tropics. Hutchinson and Sam (1984) used the rather large threshold of 12.7 mm to describe the first significant fall of the season in The Gambia.

Despite the misgivings about the accuracy with which small rainfall amounts can be measured, it would be wrong to ignore them completely. From a physical climatological point, the occurrence of light rainfall following a period of continuous dry weather may signify a major change in atmospheric conditions over an area, and hence an increased chance for rainfall in the following day(s) if those conditions persist. Yap (1973), Jackson (1981), and many other studies have shown that indeed rainfall

AUTHOR	GEOGRAPHIC REGION	RAINFALL THRESHOLD
Barnerji and Chabra (1963)	Asia (India)	4.00 mm
Subbaramayya and Kumar (1978)	Asia (India)	2.50 mm
De Jardins (1982)	Eastern Australia	0.25 mm
Garbutt et al (1981)	West Africa	0.85 mm
Hutchinson and Sam (1984)	W. Africa (Gambia)	12.70 mm
Jackson (1988)	Northern Australia	0.25 mm
Nieuwolt (1977)	Tropics (General)	2.00 mm
Olaniran (1987)	W. Africa (Nigeria)	2.00 mm
Olaniran and Sumner (1989)	W. Africa (Nigeria)	1.00 mm
Raman and Krishan (1958)	Asia (India)	0.25 mm
Sierra Leone Met. Department	W. Africa (Sierra Leone)	0.25 mm (0.10 mm since 1975)
Sumner (1988)	Tropics (General)	0.25 mm
Yap (1973)	Asia (Malaysia)	0.25 mm

<u>Table 4.1</u> Selected "meteorological" definitions of tropical raindays.

occurrence in the tropics is strongly dependent on conditions on the previous day(s). In many of the cases they examined, conditions during the previous two days were found to be significant. However, it is also important to mention the concerns about the problem and existing methods of testing the nature of dependence which have been raised by other researchers (Gates and Tong 1976, Katz, 1981).

4.2.2 AGRICULTURAL RAINDAY DEFINITIONS

"Agricultural" rainday definitions are mainly concerned with the effects of rainfall on various facets of agriculture. Most "agricultural" definitions emphasis the adequacy of rainfall in meeting plant-water needs. Such an emphasis is a simplification of reality, since plants basically get their water not directly from rainfall, but from the soil.

In the tropics, light rainfall is normally considered to be ineffective because of the high evaporative demand of the atmosphere. It is generally believed that rainfall up to 2.0 mm may be held entirely by foliage, or such rain may simply "wet" the surface layers without actually entering the soil profile and becoming available to plants. For these and other reasons, it is argued that higher thresholds are more appropriate in defining an "agricultural" rainday in the tropics. But as discussed later, not only is light rainfall useful for some purposes, the factors and processes that govern the amount of rainfall that enters the soil profile, and the proportion of that amount that eventually becomes available to plants, are both numerous and very complex.

Table 4.2 shows some examples of "agricultural" rainday definitions that have been suggested in the literature. Wang (1967) for instance, defines a crop rainy day as a day in which the amount of rainfall is "effective" for crop growth. He proposes the following criteria for "effective" rainfall, and distinguishes between "isolated' and "continuous" crop rainy days;

(i) for an isolated crop rainy day, total rainfall of the day must either be equal to or greater than 5.1 mm; or it can be less than 5.1 mm but at least 3.8 mm, provided the interval between that day and the previous rainy day is not more than two days.

(ii) if total rainfall on two consecutive days is 5.1 mm or more, rainfall on the first day must be at least 2.5 mm for both days to be counted as crop rainy days.

Wang's (1967) rationale for adopting lower thresholds for continuous crop rainy days compared to isolated days, is based on the assumption that the former are associated with more cloudiness, higher humidities and lower evaporation rates. Light rainfall on several consecutive days may therefore be more useful in terms of meeting plant-water needs, than the same amount of rain falling on one day, with others being dry.

AUTHOR	GEOGRAPHIC REGION	RAINFALL THRESHOLD
Alusa and Gwange (1978)	East Africa (Kenya)	1.00 mm
Jackson (1981)	Tropics (General)	1.00 mm
Jackson (1986)	Tropics (General)	0.30 mm
Nieuwolt (1968)	Tropics (General)	0.25 mm
Nieuwolt (1989)	Tropics (General)	1.00 mm
Rees et al (1991)	East Africa (Somalia)	2.00 mm
Sastry (1976)	Asia (India)	6.00 mm
Sivakumar (1992)	W. Afirica (Niger)	0.85 mm
Stern et al (1981)	W. Africa & India	0.85 mm
Stern et al (1982a&b)	W. Africa & India	0.10 mm
Wang (1967)	General	2.2-5.1 mm

Table 4.2 Selected "agricultural" definitions of tropical raindays.

In his analysis of rainfall for planning rice cropping systems in Asia, Sastry (1976) defines a "dry" day as "a day with rainfall less than 6 mm in 24 hours, which is based on the fact that the average potential evapotranspiration rate is about 5mm/24hr". Stern et al (1982), and Nieuwolt (1989) propose a much lower threshold of 1.0 mm per day for a tropical rainy day, pointing out that rainfall less than this amount does not significantly contribute to the moisture requirements of crops in the tropics. It is also argued that total rainfall amounts produced on days with less than 1.0 mm is usually relatively small.

The assumption that rainfall must enter the root zone for it to be agriculturally significant is somewhat erroneous since plants can directly utilize at least some amount of rainwater on the surface of leaves (Chang 1968). Also in seasonally wet-dry climates, or in low rainfall areas, occasional light showers can be useful for the growth and survival of plants. Glover and Gwynne (1962) have demonstrated the significance of light rainfall to the growth of maize under arid and semi-arid conditions in East Africa. By concentrating intercepted rainwater at the base, maize plants were able to survive during dry periods.

Moreover, light rainfall can be of major epidemiological significance. Leaf-wetness conditions or increased surface humidities from rainfall, combined with high temperatures, provide ideal microclimatic conditions for the growth and spread of animal and plant fungal, viral and bacterial diseases (Emmett et al 1991). According to Magory and Watchel (1991) the occurrence of 1-3 mm of rainfall during a warm night can lead to severe secondary infection (i.e. leaf-to-leaf and leaf-to-branch movement) of downy mildew disease in grapes. Also, in disease control programmes through spraying, water droplets on the surface of leaves prior to spraying can act as a "sticking agent", which is beneficial, whereas the occurrence of rainfall within one to two days after spraying may dilute the chemicals, or when heavy acts as a "washing agent", thereby reducing the effectiveness of the treatment (de Villiers 1966, Wang 1967).

Other critical agricultural operations that may be affected by the occurrence of light, but frequent rainfall include harvesting, and the sun-drying of crops and produce in the open.

Apart from the direct effects on crops and diseases, light rainfall may also affect the evaporative demand of the atmosphere (which is one of the main factors that influence crop-water needs), by modifying the surface temperature and humidity of the micro-environment. According to Israelsen and Hansen (1962) rainwater on the surface of leaves or the soil may evaporate, thereby increasing ambient humidities, and lowering both surface temperature and evapotranspiration rates. Additionally, the use of heat energy to evaporate water on plant surfaces helps to cool, and hence reduce the heat load on the growing plants.

4.3 ADOPTION OF A RAINDAY/DRYDAY DEFINITION

Although both the "meteorological" and "agricultural" rainday definitions discussed above may be useful for particular purposes, they also suffer from a number of limitations. For instance, in the "meteorological" definitions the key issue may be simply whether or not it rains, in which case low values matter, or the concern may be with the meteorological occurrence of heavier falls. With regard to rain-fed agriculture these definitions have the major disadvantage of being limited only to rainfall supply and ignore losses through evaporation, runoff, and percolation, which are important considerations in evaluating crop-water availability.

"Agricultural" definitions, on the other hand, may be concerned with meeting plant-water needs, in which case the use of large amounts is justified, although clearly light falls can also be important. Even where the concern is in meeting plant needs, the focus is usually on large rainfall amounts on individual days, without taking into consideration the cumulative effect of rainfall on soil hydrology.

Because of the above limitations, there is a felt need for an "integrated" rainday definition with a wider appeal in many areas of scientific enquiry. Since the main aim of this study is to produce results that are relevant to rainfed agriculture in Sierra Leone, an operational rainday definition that takes into account the points raised in the discussion above is proposed.

The proposed definition is based on a number of considerations. First, it is based on the premise that although rainfall is the primary source of water for agriculture, plants mainly get their water from the soil. Non-occurrence of rainfall, therefore, does not necessarily imply lack of moisture for crop use, even under rain-fed conditions. Indeed occasions do exist when the soil contains abundant moisture reserves from the previous rains to sustain a crop during a dry (rainless) spell till the next rain falls. In other words, "meteorological" dryness does not necessarily coincide with "agricultural" dryness.

On the other hand, rain may fall several times after a period of dry weather, without necessarily resulting in a build up of soil moisture that is sufficient to launch and/or sustain a crop. The complexity of the atmosphere-soil-plant water system is discussed later on in this section. Additionally, however, small daily totals may also have agricultural significance, and this must be taken into account.

The rainday definition that is proposed in this study must therefore meet the following conditions:

(i) it must indicate the occurrence of rainfall, including the smallest measurable amount, not only because small falls can be important, but also because of the dependence question mentioned earlier.

(ii) it must take into account plant-water requirements.

(iii) it must reflect not only conditions on individual days, but antecedent conditions as well.

The first condition was satisfied by adopting a "meteorological" definition that specifies the minimum measurable rainfall as a threshold. To illustrate the significance of small rainfall amounts, especially their capacity to modify the surface micro-climate, ten-year (1980-90) sample data from the Agrometeorological Station at Njala have been analysed, and the results are presented in figure 4.1.

As the graph shows, strong relationships were established between the total number of days per 10-day period with a given rainfall amount, and the mean maximum temperature, relative humidity, and saturation deficit. These are factors that influence the evaporative demand of the atmosphere, and hence plant-water requirements. Days without rainfall were generally associated with relatively high maximum temperatures and saturation deficits, and low relative humidities. In the case of maximum temperature and relative humidity, there was a noticeable charge in both the strength and direction of the relationships on days with rainfall, including those with the minimum measurable amount (0.1-0.25 mm). With increasing rainfall amount the relationships became completely reversed compared with drydays.

The second and third conditions for the proposed definition required the computation of a cumulative water balance based on daily rainfall and estimated

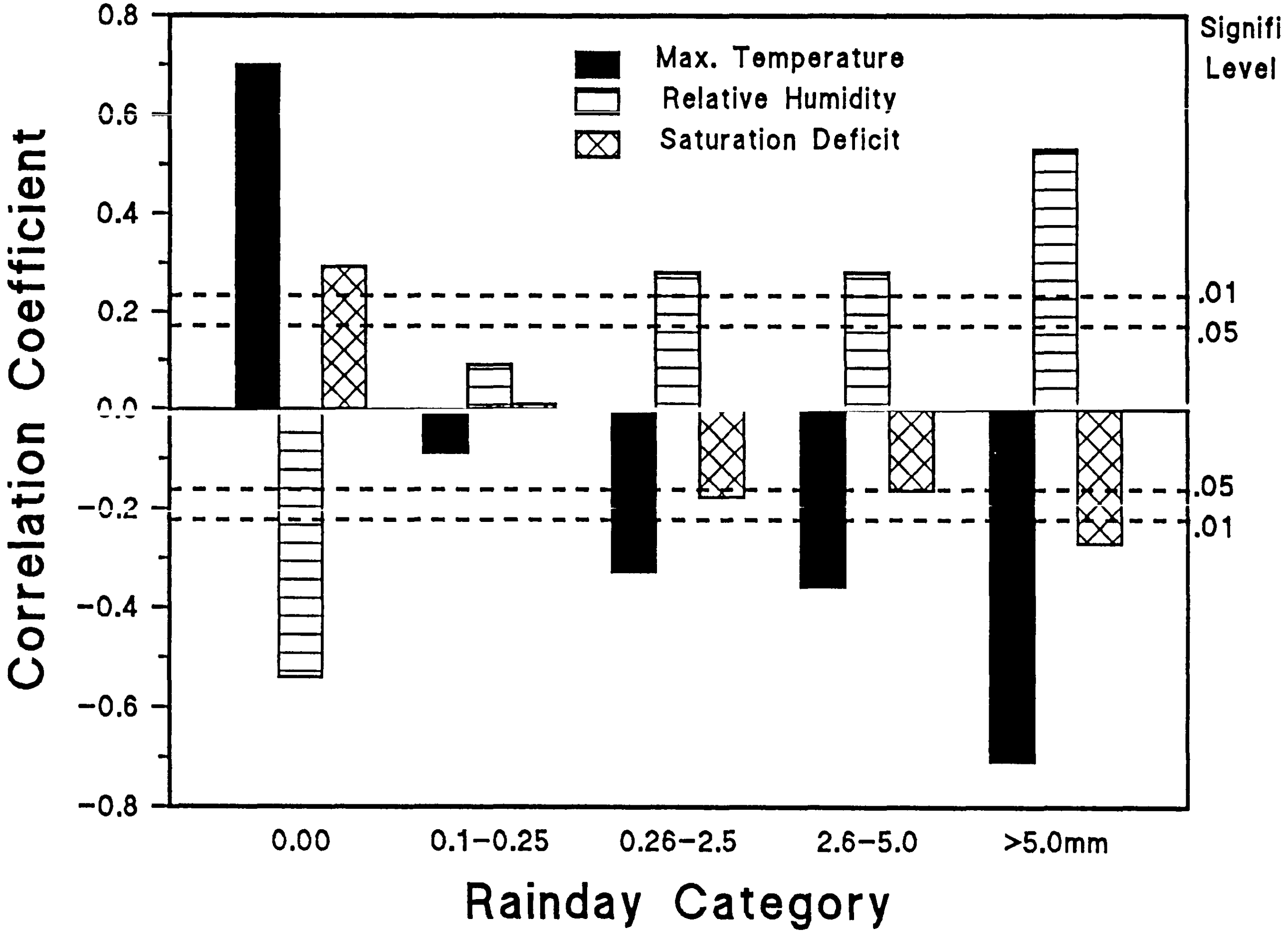


Fig.4.1 Correlation between three weather elements and the total number of days per 10-day period with given rainfall amount - Njala (1980-90)

evapotranspiration. Jackson (1989) presents a comprehensive review and discussion of water balance models, one of the aims being to highlight the complexity of the hydrological system which water balance studies attempt to model.

Much uncertainty still surrounds the accuracy of rainfall measurement, despite recent advancements in instrumentation, and improvements in observation methods (Sumner 1988, Linacre 1992). The complexity of evaporation processes makes evaluation difficult, although our knowledge of the physical principles involved has increased considerably in recent years. Apart from the characteristics of rainfall and the evaporative demand of the air, the amount of water which becomes available to plants also depends on local environmental factors, including soil characteristics (physical and chemical) the nature of the land surface (vegetation cover and slopes), and plant factors (rooting depth and density). These aspects are discussed in great detail by many excellent texts, including those by Doorenbos and Pruitt (1977), Chang (1968), and Oldeman and Frere (1982).

Due to the numerous and complex physical and biological factors and processes involved in modelling the hydrological system by means of a water balance, and since the aim of this study is not to monitor detailed hydrological processes at specific locations, a simple water balance model, based on the following assumptions and simplifications was adopted.

(i) all incident rainfall is assumed to enter the soil profile, and to progressively add to the soil-water content until the maximum moisture storage capacity within root zone of the soil (SMSC) is reached, following which all excess water is lost to plants. The assumption of a 100% infiltration is a simplification, since the process is controlled by several factors, including the intensity of rainfall, and characteristics of the land surface such as vegetation cover, soil type, and topography.

The SMSC in Sierra Leone, based on the work by Odell et al (1974), and LRSP (1980), varies from under 50 mm per 150 cm of soil depth in the coastal terraces and sand ridges which account for less than 6% of the total land area, to more than 250 mm in the hydromorphic soils of the inland and coastal swamps (less than 11% of the total land area). The remaining 83% of the land area consists of predominantly shallow, upland ferralitic soils, with SMSC of between 50-150 mm. In the absence of measured or estimated SMSC data at individual rain-gauge sites, a constant value of 100 mm SMSC was adopted, which is regarded as a realistic assumption for a study of a regional nature like this one, and also for annual dryland crops (LRSP 1980). In view of the significant differences according to soil texture, however, this constant value could be debated.

(ii) Due to the many factors that influence evaporation, and the uncertainties in estimating this variable, it has been decided to make use of the only available evapotranspiration (Et) data. These data consist of 10-daily mean evapotranspiration values calculated by the LRSP (1980), according to Frere and Popov's (1972) format for computing Penman's (1948) values. The use of mean Et values is unlikely to create many problems, since this parameter is far less variable in time and space than rainfall (van Bavel 1953, Norman et al 1984). Also, these values closely correspond to the daily consumptive use of the reference crop (upland rice) used in this study, according to experimental results by Lawson (1980).

(iii) One common assumption in many water balance studies is that all water that enters the soil profile and lies between field capacity and the permanent wilting point, is freely available for transpiration. This is clearly a simplification, since the proportion of soil water that is available for evaporation has been found to decline with increasing soil moisture tension. For this reason it seems more realistic to adopt a "modulated" approach in which a progressive downward adjustment of Et is made with increasing soil moisture tension (Veihmeyer and Hendrickson (1955), Pierce (1958), Holmes and Robertson (1959).

However, the use of a "modulated" water balance requires actual field measurements or estimates of moisture depletion rates for specific soils, under specific atmospheric conditions. Chang (1968) suggests that, in the absence of such details, any attempt to adjust Et rates can be no more than an educated guess.

Although the "modulated" approach would yield more realistic soil moisture estimates, it has not been adopted in this study, largely due to (a) the wide range of soil conditions over the country, and (b) the problems of deciding on appropriate modulation factors. While acknowledging its limitations, a simple water balance model was therefore used to estimate soil moisture status on individual days at the sample stations. Initially soil moisture content between field capacity (FC) and the permanent wilting point (PWP) was treated as total extractable water (Ritchie 1972). The influence of soil moisture on evapotranspiration rates was recognised by the use of four moisture categories. These soil moisture categories (shown in table 4.3) are based on the fraction of SMSC that may be available for plant growth, as described below.

SOIL MOISTURE CLASS (% of SMSC)	DESCRIPTION
0-29	"Deficit"
30-59	"Limiting"
60-100	"Adequate"
> 100	"Surplus"

Table 4.3 Soil moisture class intervals and their descriptions.

(a) The lower limit of plant-available water was set at 30% of the assumed SMSC. Below this limit (PWP), water was regarded as not being readily available to plants, and "deficit" conditions were assumed to prevail. The adoption of a 30% threshold was based on results obtained from field water balance studies of upland rice in Brazil reported by Jones and Guimaraes (1979) and Jones (1980) where pronounced stomatal closure in the crop were observed when only 33% of the total extractable water remained in the top 60 cm of the soil profile, a condition they described as a "stress day".

(b) Under moderate evaporation conditions (5mm/day or less), crop evapotranspiration for most field crops is little affected if soil water content for loamy-sand soils is about 60% SMSC (Docrembos and Pruit 1977). The 60% lower limit closely corresponds to the recommended "allowable water depletion" (AWD) for shallow rooted crops like rice, which is defined by Jenson et al (1990) as the fraction of available water between FC and PWP that may be depleted by the crop during a dry spell before suffering stress from moisture deficit.

Radulovich (1987), and Raddatz (1992) also suggest that plants suffer stress at moisture levels below 60% SMSC. Based on these suggestions, all days with soil moisture content between the lower limit of extractable water (30% SMSC) and the 60% storage level were therefore considered to experience "limiting" moisture conditions.

(c) Between the 60% storage level and FC water supply was assumed to be "adequate", and freely available to plants, although availability also depends on several factors including rooting depth, soil characteristics, and prevailing weather conditions.

(d) Above FC all "surplus" rain water was assumed lost to plants, although this "surplus" may take some time to drain beyond root range and hence could be available for a time.

Based on the above assumptions, a simple daily water balance model was developed as part of a bigger computer program for analysing the short-period characteristics of rainfall. It is recognised that the adopted definitions are based unavoidably on research findings from elsewhere in tropical areas, since Sierra Leone data are not available. Such transfer of findings must be taken into account in interpreting the results of the analysis.

The rainfall analysis program, named "RAIN CRACKER" was written in FORTRAN 77, and compiled to run on a DEC5500 Mainframe and IBM-PC compatibles. It is flexible and robust, and requires only a daily rainfall record, mean daily values of evapotranspiration for each decade (ten-day period) of the year, measured or estimated soil moisture storage capacities (SMSC), and appropriate soil moisture class intervals. The high degree of flexibility, and interactive nature of the program means that these parameters can be varied for specific cases.

The program is composed of several subroutines as shown in figure 4.2. Subroutine "INPDRF" inputs daily rainfall and converts values to millimetres or inches equivalents, as desired. Subroutine "DRTOMR" scans the data for missing values and provides a summary output of

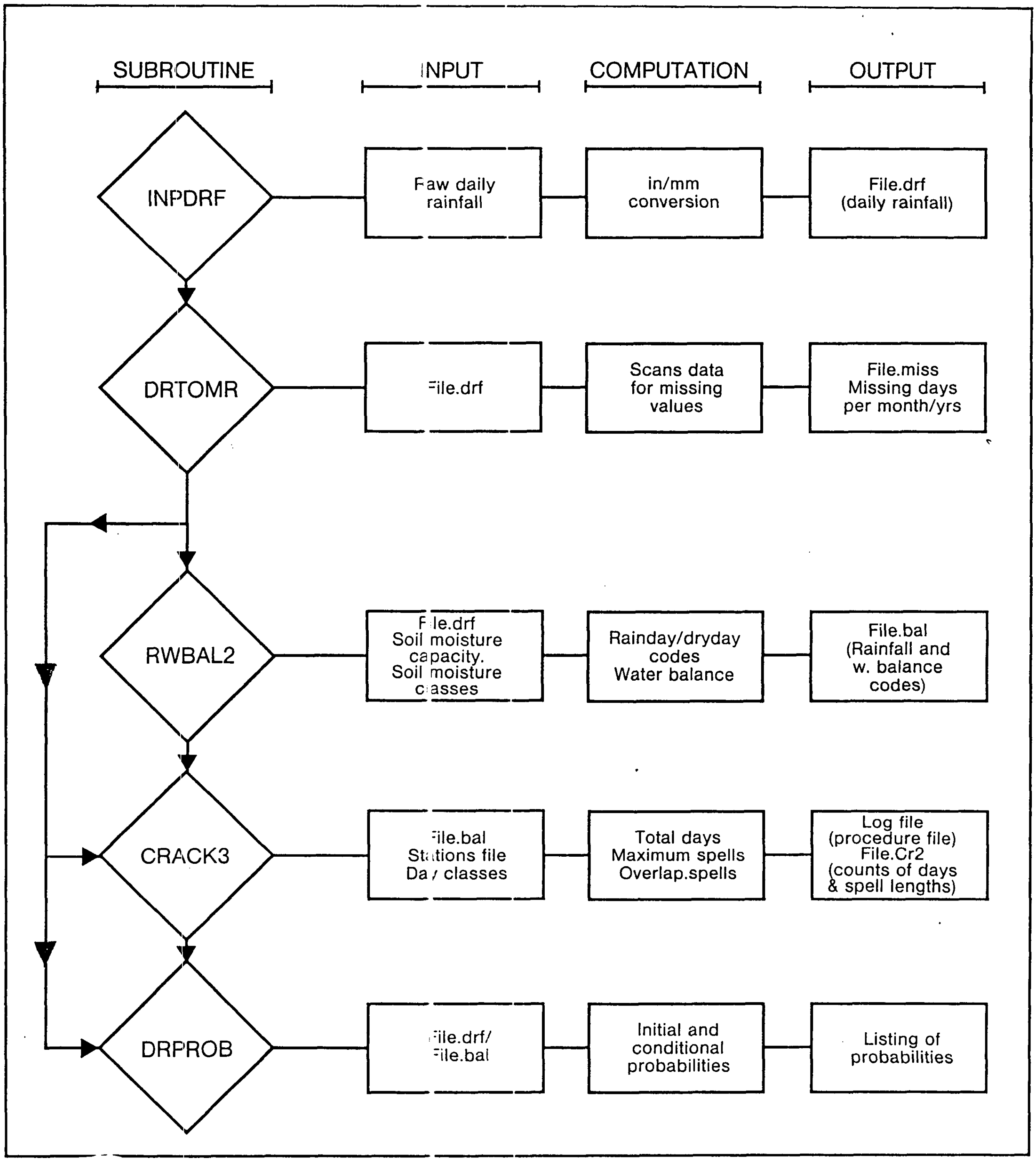


Figure 4.2 Schematic representation of Program "Rain Cracker".

total numbers of days, months, and years with missing data.

Subroutine "RWBAL2" reads in an existing daily rainfall file and first classifies days into one of two states:

State 1 = no-rain (i.e. <0.25 mm).
State 2 = rain (i.e. 0.25 mm or more).

The sub-program then computes the daily water balance, based on the model in equation (1) below.

$$Wb_x = Wb_{x-1} + R_x - E + S \text{ ------------(1)}.$$

Where Wb_x = Water balance on day "x", denoting water stored in the soil profile, (cannot exceed SMSC).
Wb_{x-1} = Water balance on the previous day.
R_x = Rainfall on day "x".
E = Estimated daily evaporation.
S = Surplus (not available to plants).

The result of the computation is a two column output of actual, and percentage (of the assumed SMSC) soil moisture values.

In computing the water balance, for each day the respective daily evaporation (E) is subtracted from the rainfall (R). If the difference is negative it is set to zero. On the other hand, if the difference is greater than zero, the amount of excess rainfall is assumed to recharge the soil profile until the SMSC is reached. Any surplus (S) beyond the SMSC is assumed lost to plants.

Having computed the water balance for the entire record, "RWBAL2" then classifies and encodes days according to the soil moisture class intervals specified in table 4.3 as follows.

Class 1 = 0-29% SMSC
Class 2 = 30-59% SMSC
Class 3 = 60-100% SMSC
Class 4 = > 100% SMSC

The rationale for the choice of these moisture classes is explained above. The output from "RWBAL2" is written on a file bearing the station name with a ".bal" extension. This output is essentially a two-digit description of each day of the year (see table 4.4 below). The first digit describes the rainfall state, while the second digit describes the soil moisture class.

Output from "RWBAL2" is then read and analysed by two other subroutines. "CRACK3" computes the total number of each day type and its longest sequence per any given period. It also computes the length of spells of day types that span two periods. "DRPROB" computes initial and conditional probabilities of the various day types.

By taking into account both the occurrence/non-occurrence of rainfall as defined above, and the soil moisture status, each day is assigned to one of seven possible states, as shown in table 4.4. A day without measurable rainfall (i.e.<0.25 mm) combined with a "deficit" soil moisture (i.e. <30% SMSC) is coded as 11, and ranked as a "Type I" dryday. A "Type II" dryday (code = 12) is one without measurable rainfall but with "limiting" soil moisture reserves (i.e. 30-59% SMSC). A day without rain, but with "adequate" soil moisture reserves (i.e. 60-100% SMSC) from the previous rain(s) (code = 13) is ranked as a "Type III" dryday.

On the other hand a day may receive measurable rainfall, but at the same time experience a "deficit" soil moisture balance from either the current or previous day(s). Such days (code = 21) are described as "Type I" raindays. A day that receives measurable rainfall, while the soil moisture remains "limiting" (code = 22) is ranked as a "Type II" rainday. A rainday with an "adequate" supply of soil moisture from either the current or previous rains (code = 23) is described as a "Type III" rainday. Finally, any rainday with a water balance greater than the SMSC (code = 24) is ranked as a "Type IV" rainday.

This classification of raindays and drydays provides a more complete, and useful characterisation of water-related aspects of the agricultural environment than descriptions based on either rainfall or soil moisture levels alone. A typology of days based on a combination of rainfall and soil moisture status provides a more objective means of assessing the adequacy of the moisture supply in meeting specific water requirements, or its

RAINFALL STATE	SOIL MOISTURE CLASS (% SMSC)	TWO-DIGIT CODE	DESIGNATION	GENERAL DESCRIPTION
*NO RAIN	0-29	11	TYPE I DRYDAY	No rain with "deficit" soil moisture
	30-59	12	TYPE II DRYDAY	No rain with "limiting" s. moisture
	60-100	13	TYPE III DRYDAY	No rain with "adequate" s. moisture
**RAIN	0-29	21	TYPE I RAINDAY	Rain with "deficit" soil moisture
	30-59	22	TYPE II RAINDAY	Rain with "limiting" soil moisture
	60-100	23	TYPE III RAINDAY	Rain with "adequate" soil moisture
	>100	24	TYPE IV RAINDAY	Rain with "surplus" soil moisture

Table 4.4 Suggested agroclimatic classification of tropical raindays and drydays
* = <0.25 mm ** = ->0.25 mm

impact on different aspects of the agroclimate and production systems. For instance, "Type I" drydays, which are a combination of both "meteorological" and "agricultural" dryness, are generally associated with drought conditions, with adverse effects on crops and water supply, especially if such conditions persist for considerable lengths of time. On the hand, such days can be advantageous for certain agricultural operations. For example, in the "slash-and-burn" system of farming, which is prevalent in the study area, dry spells associated with "Type I" drydays provide ideal "fire weather" conditions during the burning phase of the operation.

Also, in many tropical areas with distinct dry and wet seasons, the soil often becomes bare and loose after a long dry season. Where farmers burn their farm plots as a means of land preparation, there is a heavy reliance on the residual ash for soil fertility. Under such conditions, light rainfall ("Type I" raindays) helps to bind the top soil or loose ash, thereby making it less vulnerable to erosion by local whirlwinds (dust devils), and early season rainstorms.

Although adequate soil moisture may be available at the start of the growing season to ensure the germination and emergence of a crop(s), in many low-lying tropical areas soil temperatures may reach levels fatal to the young plants due to dry spells during the same period ("Types II & III" drydays), unless cooled by frequent wetting by rainfall ('Types II & III" raindays) or through irrigation (Jenson et al 1990).

On the other hand, frequent showers can also produce leaf-wetness conditions, which may lead to increased disease incidence. At the other extreme, raindays with "surplus" soil moisture ("Type IV" raindays) are important in assessing flooding and erosion hazards, as well as leaching of mineral nutrients.

4.4 AN ILLUSTRATIVE EXAMPLE.

To illustrate the usefulness of the proposed approach, daily rainfall records from the Agrometeorological Station at Njala for May 1980 were analysed and the results presented in table 4.5. The month of May was chosen because it marks the transition from the dry to the wet season, and as a result has a fairly equal number of rainy and non-rainy days.

Based on the "meteorological" definition of ->0.25 mm of rainfall, sixteen drydays and fifteen raindays were reported at the station during the month. The longest wet spell was four days, which occurred twice, from the 15th-18th, and from the 23th-26th. The two wet spells were separated by the longest dry spell of four days which occurred from the 19th-22nd. In terms of plant growth, this information is of little value, since it gives no indication of the adequacy of rainfall to replenish soil moisture reserves depleted during the dry season, or its potential to create hazards such as erosion of bare soils.

By adopting a 2.0 mm threshold, the total number of "agricultural" raindays, declines to twelve, while the number of drydays increases to nineteen. The longest wet spells remain the same as those of the meteorological definition, while the longest dry spell doubles to eight days i.e from the 1st-8th.

The proposed approach produced a more detailed breakdown of water-related conditions during the month. The sequence and numbers of different day types are presented in table 4.5. During the first half of the month there were ten "Type I" drydays with extreme dry conditions, and six "Type I" raindays. In terms of plant growth, the wet period commenced on the 17th and persisted till the end of the month, with the exception of two days (21st and 22nd) when soil moisture fell below the critical 30% lower limit of plant extractable water. The occurrence of rainfall when soil moisture levels are high ("Type III" raindays) is likely to create problems of tractionability, especially for loamy/clay soils. "Types II and III" drydays are ideal for planting operations.

4.5 SUMMARY

Water, both in the form of rain and soil moisture, is a leading environmental variable in agricultural production in the tropics. However, existing methods of describing and quantifying this variable are limited by their separate treatment of the two components. The approach proposed in this study considers both forms of water, and days are categorised according to their combined rainfall state and soil moisture status.

DATE	RAINFALL (mm)	CUMMULATIVE SOIL MOISTURE(%)	MET. DEFINITION (->0.25mm)	AGRIC. DEFINITION (->2.0mm)	PROPOSED DEFINITION
1	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
2	1.1	0.0	RAINDAY	DRYDAY	RAINDAY I
3	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
4	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
5	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
6	1.0	0.0	RAINDAY	DRYDAY	RAINDAY I
7	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
8	0.0	0.0	DRYDAY	DRYDAY	DRYDAY I
9	20.8	15.8	RAINDAY	RAINDAY	RAINDAY I
10	0.0	10.8	DRYDAY	DRYDAY	DRYDAY I
11	0.0	5.8	DRYDAY	DRYDAY	DRYDAY I
12	11.0	11.8	RAINDAY	RAINDAY	RAINDAY I
13	0.0	6.8	DRYDAY	DRYDAY	DRYDAY I
14	0.0	1.8	DRYDAY	DRYDAY	DRYDAY I
15	11.9	8.7	RAINDAY	RAINDAY	RAINDAY I
16	24.0	27.7	RAINDAY	RAINDAY	RAINDAY I
17	8.1	30.8	RAINDAY	RAINDAY	RAINDAY II
18	14.6	40.4	RAINDAY	RAINDAY	RAINDAY II
19	0.0	35.4	DRYDAY	DRYDAY	DRYDAY II
20	0.0	30.4	DRYDAY	DRYDAY	DRYDAY II
21	0.0	25.4	DRYDAY	DRYDAY	DRYDAY II
22	0.0	20.4	DRYDAY	DRYDAY	DRYDAY II
23	39.1	54.5	RAINDAY	RAINDAY	RAINDAY III
24	16.8	66.3	RAINDAY	RAINDAY	RAINDAY III
25	4.8	66.1	RAINDAY	RAINDAY	RAINDAY III
26	17.8	78.9	RAINDAY	RAINDAY	RAINDAY III
27	0.0	73.9	DRYDAY	DRYDAY	DRYDAY III
28	0.0	68.9	DRYDAY	DRYDAY	DRYDAY III
29	14.0	77.9	RAINDAY	RAINDAY	RAINDAY III
30	7.6	80.5	RAINDAY	RAINDAY	RAINDAY III
31	1.8	77.3	RAINDAY	DRYDAY	RAINDAY III
<u>TOTALS</u>	DRYDAYS		16	12	
	RAINDAYS		15	19	
	DRYDAYS I				10
	DRYDAYS II				4
	DRYDAYS III				2
	RAINDAYS I				6
	RAINDAYS II				2
	RAINDAYS III				7
	RAINDAYS IV				0

<u>Table 4.5</u>. Raindays and drydays at Njala (May 1980) based on different definitions.

Apart from the limitations imposed by the data and the assumptions that underlie the methodology employed in the analysis, the proposed typology of raindays and drydays are in many ways a better representation of water-related conditions of the agricultural climate, than definitions based on either rainfall or soil moisture alone. In the chapters that follow, a detailed analysis of the frequency distribution and variability of the various rainday and dryday categories is presented.