CHAPTER ONE

INTRODUCTION

1.1 GENERAL ASPECTS OF THE STUDY

Water availability is a major limiting factor in tropical agriculture. It determines both **where** and **when** to grow crops. For optimum production, the water supply must be regular, predictable, and of sufficient quantity and quality to meet specific requirements. But for many areas in the tropics the water supply, which is provided mainly by rainfall, is far from ideal.

The water constraint in tropical agriculture is mainly due to the inherent variability and unpredictability of rainfall, which creates considerable risks and uncertainties to crop production. The main features of tropical rainfall that affect the water regime of an area, and hence crop production potential, include its marked seasonality, and high inter-annual and spatial variability in amount and occurrence.

Rainfall distribution during the year regulates the agricultural calendar, and through its direct influence on crop germination, growth and development, affects yields. Inter-annual variations in rainfall amount, intensity and distribution, increase climatic risk in crop production. Under rainfed conditions, cropping patterns are directly related to rainfall patterns. These aspects often result in significant variations in crop yields within, and between farms, from one season to another, and from year to year.

This study was therefore undertaken with the main purpose of increasing an understanding of the short-period characteristics of rainfall (and hence water supply), focusing on those aspects that are relevant to rainfed agriculture in Sierra Leone.

1.2 THE RESEARCH PROBLEM

In Sierra Leone, as in many other areas of the humid tropics, rainfall is by far the most important element of the agricultural environment, being not only the most variable and least predictable, but also the least amenable to a certain degree of manipulation by the farmer. The degree of rainfall variability, and the sensitivity of agriculture to these variable conditions, appear to increase in magnitude from annual, to seasonal and daily conditions.

Rainfed, and low-resource agriculture, which forms the bulk of Sierra Leone's food production systems, is especially sensitive to daily variations in rainfall. While the long-term rainfall regime determines the types of crops that can be profitably grown in different parts of the country, and the appropriate methods of their cultivation, its daily distribution dictates the calendar of agricultural activities and the yields obtainable.

It is because of the significance which rainfall assumes in practically every aspect of agricultural production that makes a knowledge of its daily characteristics (including variability) an important asset to the farmer, especially for making improved management decisions in order to optimise yields. Unfortunately, compared to annual and monthly totals, daily rainfall analysis has received relatively little attention in previous climatic studies in Sierra Leone.

1.3 AIMS AND OBJECTIVES OF THE STUDY

Given the importance of daily rainfall variability as a source of climatic risk in rainfed agriculture, as broadly outlined above, this study has been undertaken with the main aim of providing a detailed understanding of the major characteristics of daily rainfall, and their associated risks and benefits to rainfed agriculture in Sierra Leone. To achieve this aim the study was divided into four separate, but related themes, each with its own specific objectives.

1.3.1 Evaluation of the Rainfall Data Base

It can be argued that the choice of appropriate analytical methods, and the agricultural value of the results of any rainfall analysis, are to a large extent determined by both the quantity and quality of the available data. With these considerations in mind, the rainfall data base was examined with two main objectives.

(a) to assess the adequacy of the rain-gauge network in providing a reasonable estimate of the spatial and temporal characteristics of rainfall over the country.

(b) to evaluate both the quantity and quality of historical rainfall records, and hence their reliability and potential usefulness as a guide to farmers on how best to cope with rainfall uncertainties, while maximising the use of the available resource.

1.3.2 Characterisation of the rainfall regime through an analysis of dryday and rainday sequences.

The main objectives of this part of the study are:

(a) to define and characterise raindays and drydays as they pertain to rainfed crop production.

(b) to determine the frequency of occurrence and duration of dryday and rainday sequences, as well as their spatial and long-term variability.

1.3.3 Identification and characterisation of agro-hydrologic seasons.

An identification of seasons relevant to rainfed cropping was undertaken with the purpose of determining:

(a) their times of onset, termination, and duration in different areas.

(b) their structure and characteristics based on the frequency of drydays and raindays.

1.3.4 Applications to rainfed rice production.

Results obtained from the above analysis were then used to determine the frequency of occurrence of rain-related constraints at various phases of the rice farming calendar, focussing on the risks of:

(a) unseasonally early rainfall to pre-season farm operations such as bush burning.

(b) deficient or excess rain during the early, middle and late parts of the rice growing period.

1.4 IMPORTANCE OF THE STUDY.

Because of the influence it exerts on agriculture and other related economic activities, rainfall has been the subject of several scientific investigations in Sierra Leone, including the work by Gregory (1965), Mukherjee and Massaquoi (1973), (LRSP 1980), and Kamara (1982). With the exception of the FAO-sponsored Land Resources Survey Project (LRSP 1980) which considers 10-daily averages, most of the previous studies are mainly concerned with annual, seasonal, and monthly conditions. While providing a very useful insight into the rainfall climate of the country, as well as a broad indication of the types of agricultural systems that can be supported by rainfall in different areas, the potential usefulness of the results of these studies as a guide to farmers in making day-to-day farm decisions is limited in scope.

An analysis of daily records aimed at increasing an understanding of the short-period characteristics of rainfall will provide relevant technical information and improved guidance to the farmer. This will help the farmer to maximise the use of rainfall resources by taking advantage of the good effects, while avoiding the bad consequences of rainfall variability.

This study also has broad implications in terms of the provision of water for agricultural use. In the absence of large-scale irrigation projects, rainfall serves as the primary source of water for agriculture and related activities. With over 95% of agricultural land being unirrigated, this means a heavy reliance on the natural supply of water through rainfall. Both a deficiency and an excess rainfall supply can contribute to instability in agricultural production. A detailed understanding of the short-period characteristics of rainfall will therefore facilitate a more efficient and sustainable use of rainwater for agricultural development.

Apart from being a source of water, rainfall also has a direct and significant impact on other factors of agricultural production, as described in section 1.5 below. A knowledge of daily rainfall characteristics, and a wise application of this information in agricultural decision-making, will therefore lead to a reduction in weather-related production losses, and increased productivity.

Most of the assessments of the agroclimatic impact of tropical rainfall that have been undertaken in the past are mainly concerned with issues related to water deficits which result from inadequate and ill-distributed rainfall over time and space. Relatively little is therefore known about problems related to water excess due to unseasonal rainfall, heavy rainstorms, and prolonged rainspells, which are prevalent during the rainy season in some parts of the tropics. Yet these issues are as important to the productivity of an agricultural system as those of water deficits. A knowledge of the frequency of occurrence and the magnitude of excess water, and duration of wet spells is therefore important for management decisions aimed at reducing production losses resulting from excess water.

Another useful aspect of this study stems from its treatment of the entire farming calendar, unlike many other tropical agroclimatic studies whose focus is often on rainfall behaviour during the growing season, with little or no consideration of pre-season conditions. In Sierra Leone, as in many other wet tropical areas with low population densities and large forest tracks, the annual practice of cutting down and burning the bush to create new farmlands (the so-called "slash-and-burn" method) must be completed before the rains start in earnest. In such a farming system, the entire success of the year's farming enterprise, and hence the welfare of the farmer may depend on a successful burn. A poor burn means more labour requirements, a delay in subsequent farm operations, less available potash (a major natural source of plant nutrients), more weed infestation, and significantly lower yields (Richards 1986). Of the several factors that cause a poor burn, rainfall is by far the most important. Information on pre- and early-season rainfall probabilities will therefore be useful in planning farm burning operations.

The primary potential beneficiaries of this study are the peasant farmers who form over 90% of the farming population, and produce most of the domestic food supply. Through centuries of informal experimentation, based largely on trial and error and a keen observation of the local rainfall regime, has developed an environmentally sustainable farming system with an in-built flexibility to cater for expected rainfall variability. Increasingly, however, this traditional mode of food production is under threat due to the introduction into the farming equation of new, "exogenous" factors such as exotic crop types and varieties, a rapid population growth, and changing tastes and attitudes. For the farmer, this means having to make improved management decisions within the limits of his ability to predict and cope with rainfall uncertainties. Access to scientific information to supplement local knowledge about the rainfall regime will help the farmer to more adequately meet these challenges.

1.5 IMPACT OF RAINFALL ON TROPICAL AGRO-SYSTEMS

To underscore the significance of this study further, a brief outline of the general impact of rainfall on the physical, biological, and human factors of agricultural production in the humid tropics is presented in this section. These relationships are summarised in the form of a schematic diagram in figure 1.1.

The main climatic elements of importance to agriculture that are related to rainfall are radiation,

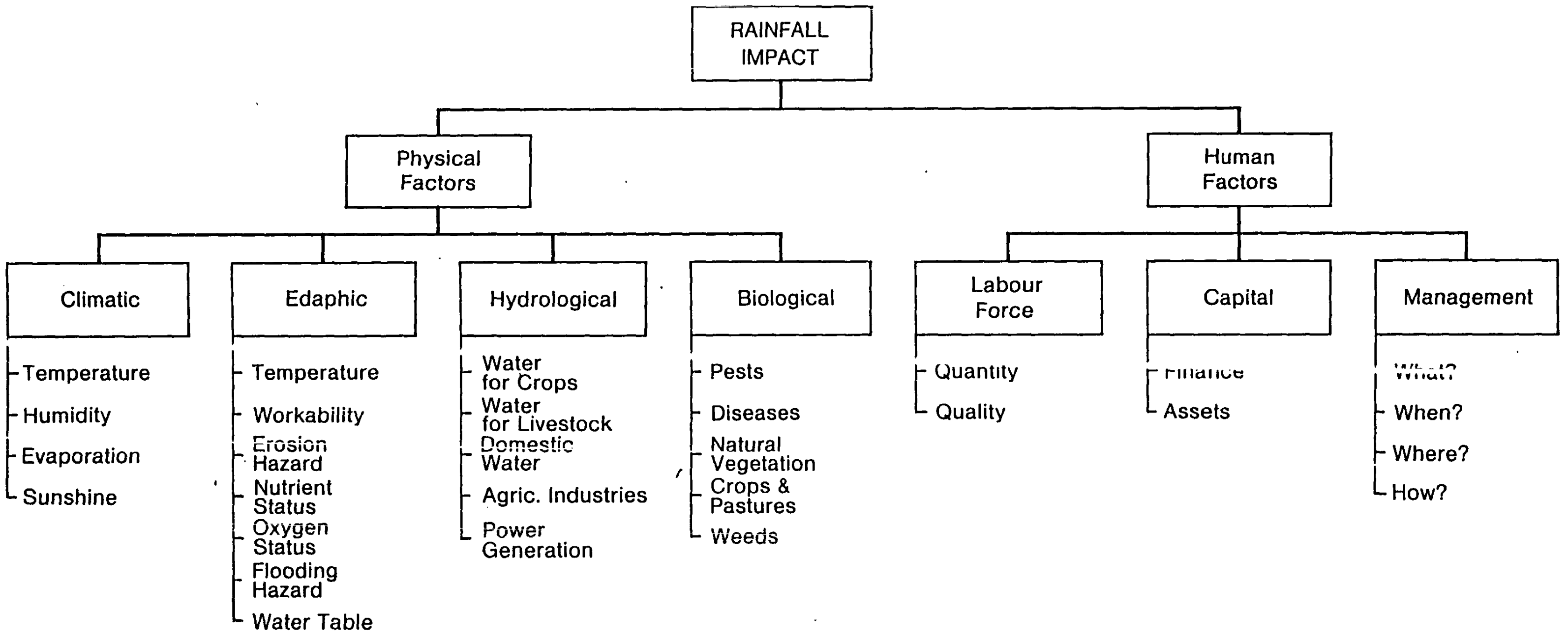

Figure 1.1 Schematic representation of agriculture impact of rainfall.

sunshine, temperature, humidity, and evaporation. Rainfall incidence is indirectly related to solar radiation and sunshine through cloud cover. Periods and areas of high rainfall are generally associated with low solar radiation levels and fewer hours of sunshine. Based on experiments in The Philippines, Venkateswarlu and Visperas (1981) observed that rice yields were 30-60% lower during the rainy season than the dry season. This was attributed to low light intensities during the cloudy, overcast conditions of the rainy season. On the other hand, both temperature and evaporation are generally lower during periods, and in areas of high rainfall, while humidities are higher under the same conditions.

Soil properties and land quality are also greatly influenced by rainfall. High soil temperatures, which are a major agronomic constraint in many tropical areas, are tempered by rainfall. Extended periods of dry weather results in diminished soil moisture reserves, unless water is added through irrigation or underground sources. On the other hand, high intensity rainstorms compact the surface layers, thereby reducing the soil's infiltration capacity, with a resultant increase in surface runoff, and hence less soil water per unit of rainfall received.

Rainfall also affects such important land qualities as workability, erosion and flooding hazards, nutrient and oxygen status. Tropical soils often become extremely hard and compact during the dry season, making both manual and mechanical cultivation difficult. For the peasant farmer working with traditional hand implements, this means having to wait for the soil to become sufficiently moist to facilitate cultivation, and hence perhaps planting is delayed past the optimum time. On the other hand, excessive rain and wet spells can also hamper land cultivation, especially where the use of heavy machinery is involved.

Soil erosion by rainwater is a major hazard to tropical farmlands, especially during the transition from Dry to Wet Season(s) when there is minimum plant cover to protect the soil from direct raindrop impact. The problem is compounded by the traditional "slash-and-burn" method of cultivation which greatly increases the risk of erosion. In high rainfall areas leaching of mineral nutrients, and poor soil aeration are common problems, while in seasonally wet/dry climates, fluctuations in the watertable in response to seasonal rainfall variations results in the development of ferrogenous concretions or lateritic surfaces that are poor in nutrients.

As a provider of water for agriculture, rainfall patterns are closely related to cropping patterns and farming systems in an area. Rainfall is also a source of water for a wide range of domestic uses by farming populations, including personal hygiene, food preparation, and drinking. The availability and reliability of water supply for agro-based industries, and agro-power generation are strongly influenced, and to some extent determined by, the rainfall regime and its long-term variability.

The links between rainfall and the life cycles of many tropical agricultural pests and diseases are fairly well-established. Many egg-laying insect pests multiply rapidly after the first rains, when their eggs hatch, followed by a notable decline in numbers during the peak of the Rainy Season. Outbreaks of migratory pests like armyworms, locusts, and grasshoppers are associated with unseasonally early rainfall, while the survival of their young depends on the availability of food in the form of green vegetation whose growth is also supported by rain.

Soil nematodes increase in population with rainfall, thereby increasing the likelihood of severe crop damage. Under waterlogged conditions due to continuous heavy rainfall, however, soil fauna decline in population, which in turn affects soil aeration and subsequently crop performance and yields.

Like plant and animal diseases, the incidence and spreading of certain human diseases within farming communities are also influenced by rainfall. In malaria-endemic areas, illnesses related to the disease usually reach a peak during the early part of the Rainy Season when standing rainwater provides a suitable medium for breeding of the vector mosquito. During the same period water-related diseases like diarrhoea, dysentery, and cholera, are also rampant, as rainstorms wash effluent into streams and ponds used as major sources of domestic water supply by rural populations (Edmonson et al 1992).

The phenology of natural vegetation of many low-lying areas is a manifestation of the local rainfall regime with many plant communities shedding their leaves or withering during the drier parts of the year, and blossoming during the Rainy Season.

Apart from the constraints imposed by biological and physical environmental factors, human and economic factors are also a major hindrance to progress in the advancement of agriculture in the tropics. Problems of labour supply, capital, and management decisions are influenced in varying degrees by the characteristics of tropical rainfall.

The agricultural labour force is directly influenced by rainfall in a number of ways. In many areas seasonal migration of agricultural labour to cities and mines, often during the Dry Season, and during 'slack' periods in the Rainy Season, is seen as a major form of income generation to supplement the low farm returns, at the expense of food production. In southern Sierra Leone, for instance, Richards (1986) observed that hired labour was relatively scarce at the start of the Rainy Season when demand was greatest.

Indirectly, rainfall affects the agricultural labour force through its influence on the incidence of certain illnesses and diseases. The work force is often at risk of infection by malaria and other parasitic diseases, whose populations peak during the Rainy Season(s). These infectious diseases undermine the health and efficiency of the labour force. According to a study in Ghana by Cotton(1976), quoted by Edmonson (1992), reduced efficiency of labour due to malaria caused a significant fall of 10-30% in the yields of several crops.

With regards to capital, the reliability of rainfall determines the willingness of the farmer to invest his capital on a specific agricultural enterprise. Banks and other agencies often require assurance on the likelihood of success before issuing loans to farmers. Adverse weather conditions such as floods, drought, and hail can cause severe losses which may reduce the farmer's ability to repay loans. Much of the conservatism attributed to farmers in adopting improved crops and varieties, and farming methods can be interpreted as an attitude of avoiding risk of failure due to variability of rainfall. A severe deficiency in rainfall with adverse effects on crops and animals can cause serious shortages of staple foods, necessitating imports from other regions within the country, or from abroad. The latter affects foreign exchange reserves, with broad micro-economic implications.

As mentioned in section 1.1, agricultural decisions on what can be produced in an area, when, and how to produce it are also influenced by the local rainfall regime. Long-term rainfall statistics give an indication of the types of crops and animals that can be supported by the local rainfall regime. In low rainfall areas farmers chose a particular crop or variety that fits the current season's rainfall. Cultural methods and planting decisions are also dictated by the rainfall regime.

1.6 BACKGROUND TO THE STUDY AREA.

(i) Geographical location and physical features.

Sierra Leone lies on the West Coast of Africa between latitudes 6^{O} 55 and 10^{O} N, and longitudes 10^{O}W to 13^{O} W (figure 1.2). It is bounded to the west by the Atlantic Ocean, to the north and northwest by the Republic of Guinea (Conakry), and to the south and southeast by Liberia. The country covers a total area of 73,326sq km, which can be divided into four distinctive physical regions.

Stretching for some 30-40 km from the Atlantic is a Coastal Plain with sandy soils and beaches, and mangrove swamps in creeks and tidal estuaries. The Freetown Peninsula Mountains form a distinctive region along the coast where the land rises abruptly from sea level to a maximum height of 1000 metres.

Farther inland are the Central Lowlands which are characterised by an undulating topography (most of which is below 150 metres above sea level), and a vast area with seasonally flooded swamps (bolilands) that form rich agricultural lands. The Eastern Plateau Region, which is an extension of the Guinea-Fouta Djallon Mountain ranges, is separated from the Central Lowlands by an escarpment that runs through the centre of the country. Much of this region is between 200-1000 metres above sea level. The highest peak, Mount Bintumani is 1945 metres.

The country is drained by ten major river systems. All but two (Great Scarcies and Kpangbar Rivers) flow from the Eastern Plateau southwestwards into the Atlantic

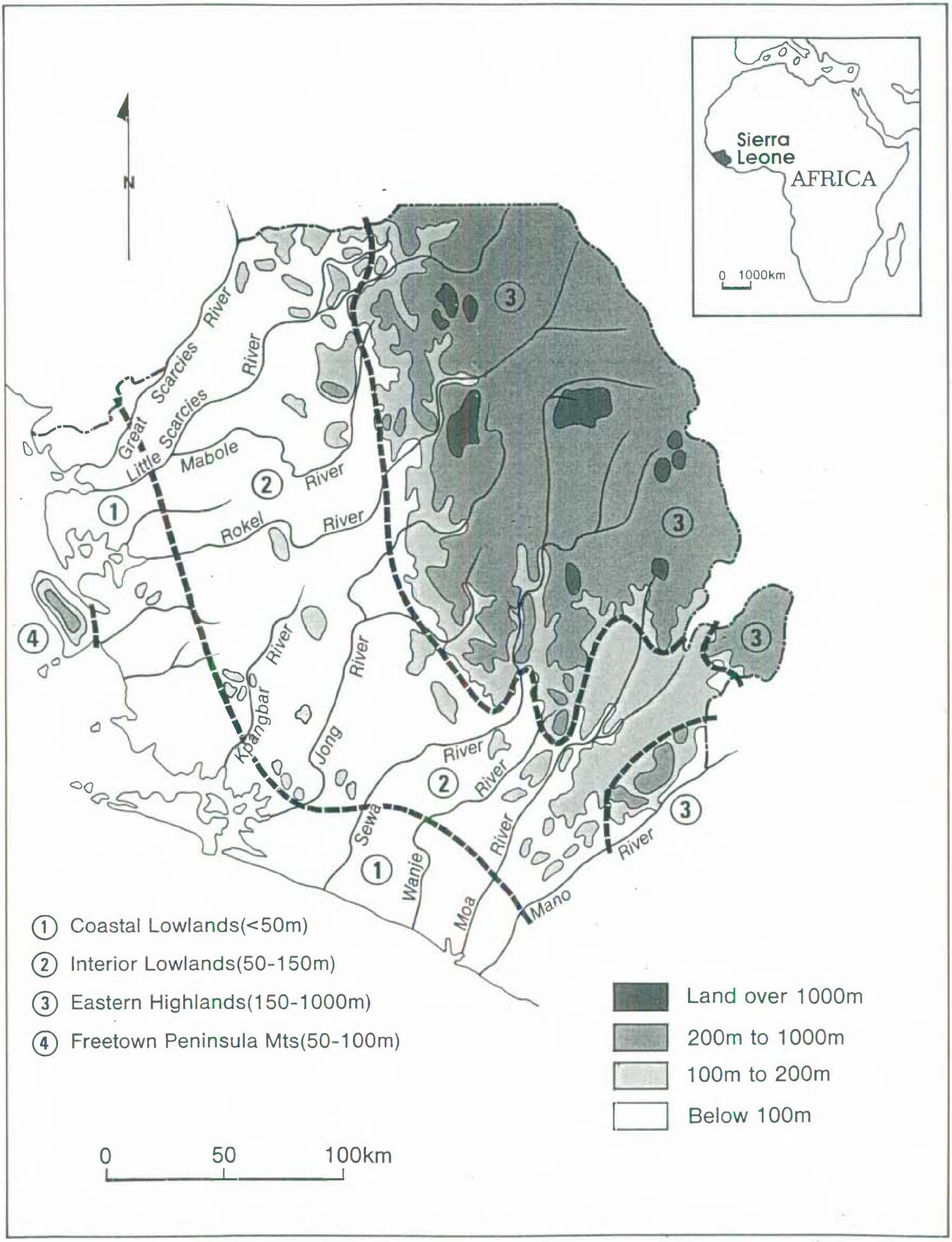

Figure 1.2 The Area: relief and drainage characteristics.

Ocean through a series of rapids and waterfalls. Wide river valleys in the Central Lowlands and Coastal Plains are ideal for irrigation development, but flooding during the rainy season, and low flow during the dry season are major limitations.

The country's geographical location and physical characteristics have a great impact on its climate, which in turn has a direct influence on crop adaptability, and agricultural practices. Like other parts of West Africa, Sierra Leone is subject to the influence of two dominant air masses, the warm, moist Monsoonal air from the South Atlantic, and the hot, dry Continental air from the Sahara Desert. The alternating influences of these air masses, coupled with upper air circulation, produce a distinctive wet season from May to November, followed by a dry season from December to April each year. Separating these two air masses is a moisture divide (otherwise known as the Inter-tropical Discontinuity - ITD), which migrates fairly regularly northwards and southwards, following the overhead sun. Since cloud formation and precipitation occur mainly to the south of this dividing zone, the approximate times of onset and termination of the rains can be monitored on synoptic charts.

The country's coastal location means that maritime influences are pronounced. The constant advection of moist air from the Atlantic by regional and local wind systems creates humid conditions almost throughout the year. Apart from creating a high potential for precipitation, the high humidities also modify other climatic elements such as temperature and evapotranspiration rates.

Orographic influences on the monsoonal air by the Freetown Peninsula Mountains and the Eastern Plateau help to produce some of the highest rainfalls in Africa. The perpendicular alignment of the coastline to the rain-bearing southwesterly winds creates additional instability and increased rainfall. Atmospheric conditions over the Eastern Plateau also favour the development of instability phenomena such as local and linesquall disturbances between May/June and October/November, which produce most of the rainfall received during these times of the year.

Because of its tropical location and altitude, temperatures and solar radiation are high throughout the year. No month receives a mean maximum temperature below 18^{o}c. This means that the duration of the growing season is exclusively dependent on water, rather than on temperature and solar radiation. Also, seasonal variations in daylength or photoperiod are minimal. The difference between the longest day in June and the shortest day in December is about 54 minutes, such that plants in the region have developed a short-day or neutral-day habit of growth (LRSP 1980).

(ii) Agriculture and the economy

Agriculture is the mainstay of Sierra Leone's economy, contributing more than 30% of the GDP, and nearly 40% of the total export earnings in 1985 (Bank of

Sierra Leone 1985). About 75% of a population of 3.5 million derive a livelihood from agriculture and related activities. The agricultural sector is characterised by a large number of small holder farmers operating a rotational bush fallow system with small fragmented plots (2 hectares), totalling approximately 400,000 hectares per year. Over 95% of agricultural land is unirrigated, and everywhere there is a notable decline in crop yields due to a decrease in the fallow period alongside a rapidly increasing population. The above facts have two major implications for the present study.

First, since most of the agricultural land is unirrigated, there is a total dependence on the natural supply of water through rainfall. Secondly, there is very little prospect for supplementing rainfall through irrigation, mainly due to the land tenure system and the high costs involved in developing and operating an irrigation system. What this therefore suggests is that, any efforts to improve food production in the country must be based on the use of production systems that make optimum use of rainwater. To achieve this requires a more complete and adequate understanding of the short-period characteristic of rainfall.

(iii) Sources of rainfall

The spatial and temporal characteristics of rainfall in Sierra Leone are determined by the nature of the rainfall producing systems, in conjunction with other physical factors such as relief. To appreciate these features, and some of the problems associated with the amount and quality of rainfall information a brief description of the rainfall mechanisms over the West African region is a logical first step. A more detailed account of these processes can be found in Kamara (1986).

Two pressure systems dominate the West African region during the rainy season, the thermally induced Low over the Sahara whose axis is located between latitudes $18^{O}N$ and $22^{O}N$, and the Subtropical Anticyclone over the South Atlantic. The resulting gradient between the two pressure systems induces a warm, moist southwesterly air stream (Southwest Monsoon) that penetrates deep into the region, reaching latitudes $20-22^{O}N$ in August.

Figure 1.3 shows basic features of tropospheric circulation at one coastal and one inland stations in West Africa. The depth of the Southwest Monsoon decreases inland from a maximum of 3000 metres in July on the Guinea Coast ($5^{O}N$), to about 1000 metres near $13^{O}N$. Within the easterly winds that overlay the Southwest Monsoon are two jet streams, the African Easterly Jet (EAJ) around the 3km level, and the Easterly Tropical Jet (ETJ) around 12km. Both jet streams are linked to synoptic-scale, meso-scale, and local surface disturbances that produce rainfall over the region, the most prominent being:

(i) Local Convective Rainstorms associated with strong surface heating which results in rapid convection and subsequent development of towering cumulus and cumulonimbus clouds. It is also common for these clouds

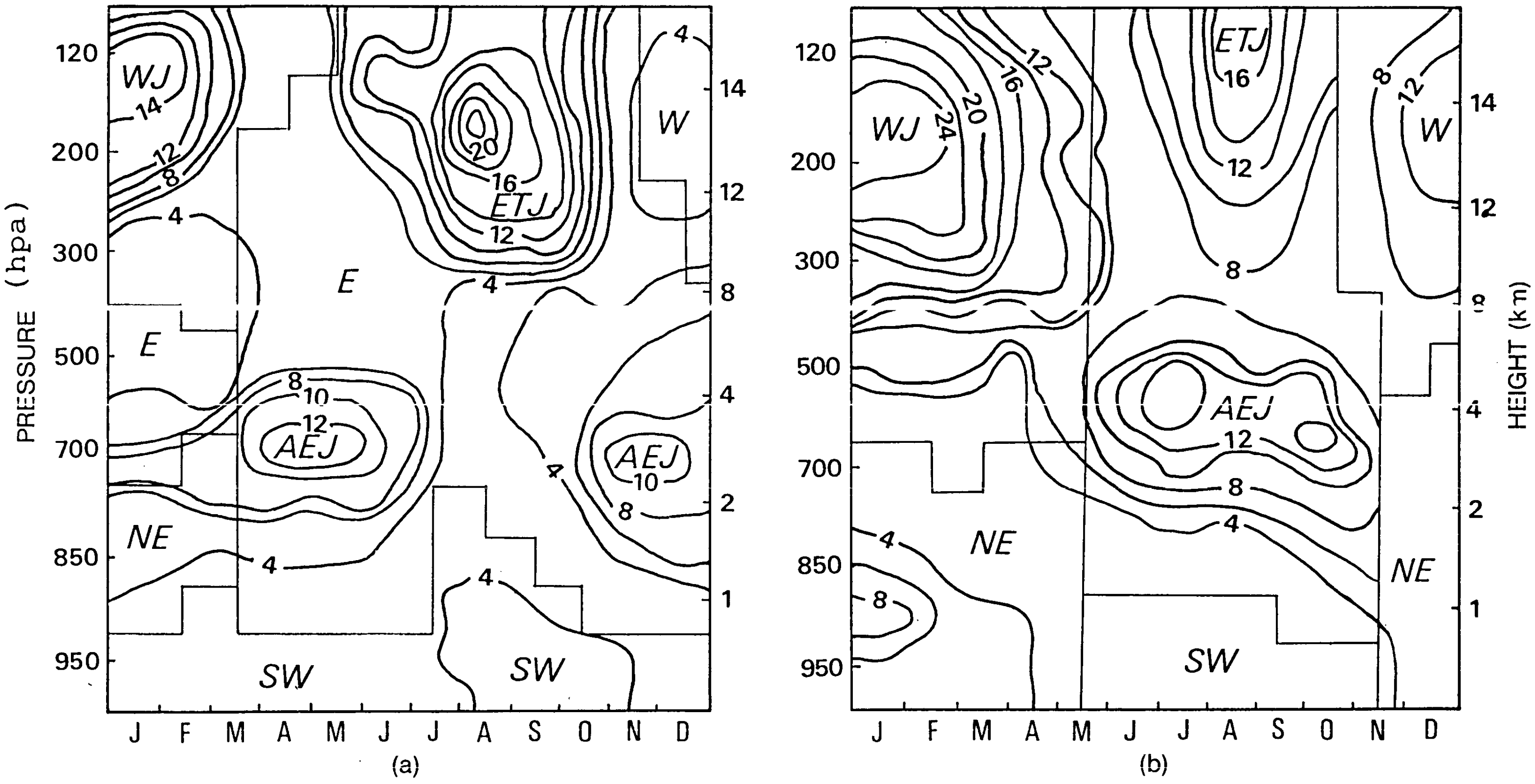

Figure 1.3 Basic features of tropospheric circulation at (a) Abidjan and (b) Bamako. Source: ASECNA rawinsonde monthly reports (Jan. - Dec. 1975). AEJ = African Easterly Jet; ETJ = Easterly Tropical Jet; SW = Southwest Monsoon; W = Upper Westerlies; WJ = Westerly Jet; E = Easterlies; NE = Northeasterlies.

to develop during farm burning, which is part of the "slash-and-burn" method of farming, or due to bush fires in the savanna region. Local Convective Rainstorms are largely stationary weather systems, affect limited areas, and often last for a less than an hour.

(ii) Linear Rainstorms or Line Squalls are meso-scale phenomena that occur at the beginning and end of the rainy season. They consist of long belts of thunderstorms (300-500km) that have a north/south orientation, and move westwards at high speeds. Periods of active line squall development normally coincide with the appearance in the wind field of the African Easterly Jet (AEJ). In Sierra Leone most of the line squalls occur between the late afternoon and the early morning hours. Also large areas are affected by the passing rain cloud, although rainfall amounts vary considerably from place to place.

(iii) Orographic rainfall is restricted to areas of high relief, especially where the high ground lies at a direction perpendicular to the Southwest Monsoon winds. In Sierra Leone relief influences are most prominent on the Freetown Peninsula Mountains where they help produce some of the highest rainfall (5500 mm per annum) in Africa. The Eastern Highlands and Plateau in the east and north, and isolated hill masses in the Interior Lowlands also experience relief rainfall.

(iv) Monsoon vortices associated with large scale convergence below the Tropical Easterly Jet Stream produce widespread instability, cloudiness, and light to moderate rainfall between July and September. Rain spells lasting from a few hours to several days are a common occurrence.

Figure 1.4 shows the spatial distribution of mean annual rainfall for the thirty-year period 1948-1977. Annual rainfall varies from 4000mm along the south coast to under 2000mm in the extreme north. This trend is distorted by a relative increase in rainfall amounting to over 3250mm along the central escarpment zone. But the greatest falls are recorded on the western slopes of the Freetown Peninsula Mountains where up 5500mm may fall on an average year.

1.7 SUMMARY

Rainfall, and through its influence on soil moisture, exerts a major influence on agriculture and related activities in the tropics. The future development of rainfed agriculture in Sierra Leone therefore depends, among other things, on a proper understanding of the short-period characteristics of rainfall and a wise application of that knowledge in decision-making. This chapter outlines major areas of research that will fill gaps in knowledge about rainfall behaviour on a daily basis. It is suggested that rainfall and other climatic characteristics are closely linked to the geography of the area. Chapter two presents a review of methods of collecting, processing, and applying rainfall information in agricultural decisions.

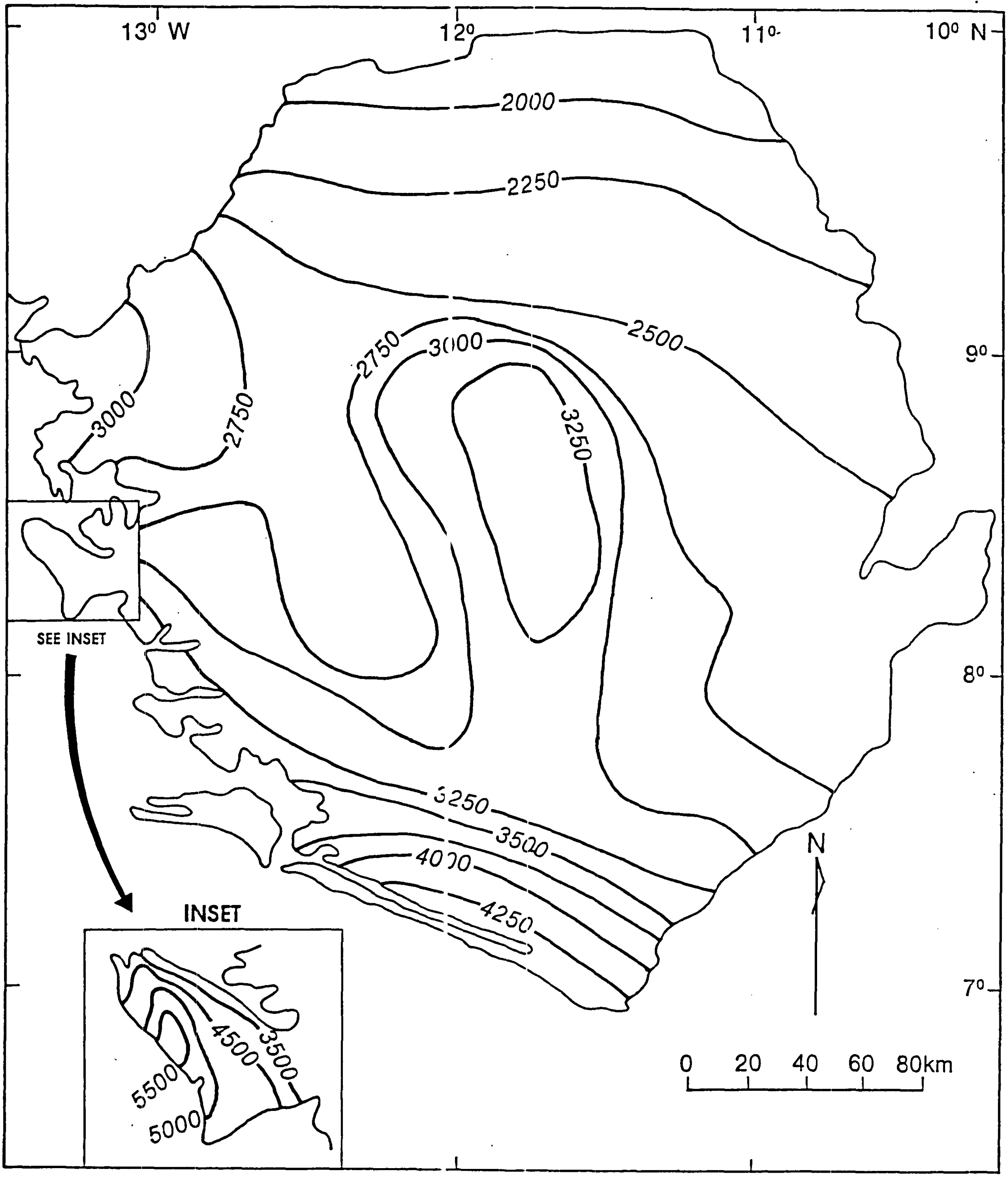

Figure 1.4 Mean annual rainfall distribution (1947-77).

CHAPTER TWO

REVIEW OF APPROACHES TO THE ACQUISITION AND APPLICATION OF RAINFALL INFORMATION IN AGRICULTURE.

2.1 INTRODUCTION

The role of rainfall in tropical agriculture is ambivalent. It is both a vital resource input, and at the same time a major agroclimatic constraint. This ambivalence makes rainfall information an important component in tropical agricultural management decisions at the national, regional, and individual farmer levels. But two question that immediately come to mind are "how" to acquire this vital information, and "how" to apply it at different levels of the agricultural decision matrix.

There are four important stages involved in the acquisition and use of rainfall information. In the first instance the rainfall information must be collected through a network of recording stations over the area in question. But as discussed later, the point measurement of rainfall presents considerable problems.

The second stage involves the application of quality control procedures to ensure that the data are as free of errors as possible. The third and fourth stages involve the analysis of the data and presentation of the results in a way that can be interpreted and applied in decision making.

The main objectives of this chapter, therefore, are:

(i) to review the range of approaches that have been used in the acquisition and application of rainfall information to various aspects of agriculture.

(ii) to provide a basis for selecting appropriate methodological approaches for this study.

2.2 APPROACHES TO RAINFALL MONITORING AND OBSERVATION

2.2.1 Need for rainfall monitoring

Rainfall affects agriculture in diverse ways, ranging from land preparation to planting, harvesting and storage. Some aspects of rainfall are favourable to the production process, while others have adverse effects. An understanding of the good and bad effects of rainfall, and the effective use of that knowledge in agriculture depends on proper monitoring and recording of its distribution over time and space.

Rainfall monitoring networks differ in the time interval of measurements, spatial coverage or gauge density, type of station, level of automation, and observing agency. These factors are all very highly inter-related. For instance, observation intervals, which can vary from once a month or even longer, to continuous (instantaneous) recording of storm events mainly by autographic gauges, depend on the category of station (rainfall, climatological, or synoptic), level of automation (ranging from manual measurements to the use of telemetric equipment), and the observing agency which can either be official or private.

A large number of ground-based, airborne and spaceborne technologies for measuring rainfall by remote sensing techniques have also been developed over the past 2-3 decades. Some of the methods and problems of observing tropical rainfall using various platforms, and analysing and interpreting the data are illustrated in papers presented at an "International Symposium on Tropical Precipitation Measurement" held in Tokyo, Japan (Theon and Fugono 1988). Although remote sensing presents a great potential for rainfall measurement, especially for remote areas, the technology is presently out of reach of many poor tropical countries.

2.2.2 Problems and considerations in rainfall monitoring

The establishment of a rainfall monitoring network requires careful planning and organisation of operations if it is to meet its stated objectives and be useful to the target users. An important consideration at the inception stages of the network is an assessment of user requirements to determine the scope and methods of data acquisition and dissemination. Noar (1991) reports the results of two surveys on farmers' perception of agricultural information and forecasts in Australia and the United States of America. He recommends that such surveys would be useful in the formulation of more functional and cost-effective agrometeorological services, both in terms of the type of service required (eg seasonal outlook and/or weekly forecasts), and which weather parameters are considered to be major constraints (e.g rainfall likelihood, amounts and duration etc). However, such surveys must also incorporate specific local circumstances for them to be relevant.

Apart from user requirements, consideration of an optimum network density is also important. This is determined by such factors as the availability of adequate human and financial resources, spatial variability of the local rainfall regime (Linsley et al 1982, and Brass 1990), and the purpose for which data are needed.

The issue of spatial representativeness assumes special significance in the tropics where rainfall is known to be highly variable in space, often displaying sharp gradients over relatively short distances (Jackson 1989). Under such circumstances, a fairly dense rain-gauge network is desirable, with each gauge located at a site that meets the normal exposure requirements and accessibility.

For agricultural purposes, Holtan et al (1962) recommend the following gauge densities (table 2.1).

Although a dense rain-gauge network such as the one suggested above is desirable, the cost of establishing and operating it can be restrictive. Expansion of networks should therefore go hand in hand with other developments, or provision of infrastructural facilities such as those required for centralisation of operations (WMO 1976).

AREA (HECTARES)	MINIMUM NO. OF GAUGES
0-12	1
12-40	2
40-80	3
80-202	1 gauge per 40 hectares
202-1011	1 gauge per 101 hectares
1011-2024	1 gauge per 260 hectares
> 2024	1 gauge per 780 hectares

Table 2.1 Recommended rain-gauge densities for agricultural purposes (after Holtan et al 1962).

As a general guide the World Meteorological Organisation (WMO 1965) recommends the following gauge densities for tropical areas (table 2.2)

	Area per gauge (km^2)	
Nature of area	Normal tolerance	Extreme tolerance
Small tropical mountainous islands with irregular precipitation	25	
Tropical mountains	100-250	250-2000
Flat tropical areas	600-900	900-3000
Tropical arid areas	1500-10000	

Table 2.2 Recommended minimum rain-gauge densities for different types of topographic areas in the tropics (after World Meteorological Organisation, 1965).

In many tropical developing countries, like Sierra Leone, existing rain-gauge networks were set up with no rigid design criteria, clearly defined goals or intended uses of the data. As a consequence, many rain-gauge networks are too sparse and the general distribution of gauges unsuitable in providing a realistic estimate of the spatial organisation of rainfall. Also, there is an obvious concentration of gauges in lowland areas and centres of population (Sumner 1988). Remote and highland areas are often poorly served by a few or no gauges, although these areas sometimes have great agricultural and water resource potentials. In addition to the problem of meeting acceptable levels of gauge densities, local factors many significantly affect the representativeness of gauges.

Another important consideration at the inception stage of a rainfall monitoring network is the provision of adequate communication facilities for transmitting the rainfall information quickly and efficiently from the recording station to a central collecting point for subsequent checking, processing, publication, and/or archiving and distributing the information to users. Smedley (1969) discusses some of the problems involved in establishing a data processing centre for the Caribbean Meteorological Institute. The most outstanding problems he outlines include financial limitations, communication and storage facilities, equipment and maintenance costs, and lack of trained personnel.

The traditional method of collecting data by postal returns, which is slow and sometimes leads to depreciation or complete loss of data, is now being replaced by telecommunication systems in many countries, although this is also fraught with technical problems in many developing countries.

Another dimension to the organisational problems of meteorological networks pertains to the management of the data which requires adequate facilities for data processing, storage, and rapid retrieval (Hassan 1990). Deterioration and loss of data due to poor storage facilities is a common problem in many developing countries. The Data Rescue Project of the World Climate Data Programme was initiated by WMO to arrest the steady deterioration of many original manuscripts and data records by placing them on microfiches (Callender 1990).

The operation of a rain-gauge network requires manpower of both a technical and non-technical nature. Observers (at least more than one per station) must have basic training in elementary meteorology and/or observational procedures and data recording. Also required are adequate financial resources for the payment of staff salaries, and for the procurement of the required equipment, spares and consumables. Regular inspection, servicing and maintenance of equipment is also important to ensure that proper observing procedures are maintained.

A survey by the World Meteorological Organisation reported by Bernard (1975) on costs of meteorological services to member countries revealed the following;

(a) a significantly lower budgetary expenditure of about US$ 0.035 per capita on meteorology in developing countries, compared to US$ 0.532 in developed countries.

(b) on average, budgets of meteorological services in developing countries (except in some Asian and Latin American countries), declined steadily at a rate of 2% per year between 1967 and 1972.

(c) the salaries of meteorological and non-meteorological personnel represent 54% of the meteorological budgets of developing countries. This leaves only 46% to be spent on equipment and other services.

The significance of these, and other problems, for the rainfall observing network in Sierra Leone is examined in chapter three.

2.3 QUALITY CONTROL OF RAINFALL DATA

2.3.1 Need for quality control of data

Data quality is an important consideration in the use of rainfall information for agricultural and other purposes. The main concerns relate to length of records, data consistency, missing values, and areal representativeness.

Errors in the data, especially large errors, can result in false conclusions and misleading forecasts of rainfall conditions. It is therefore necessary to determine and correct these errors before analysing the data and making the results available to the final user. According to Gandin (1969) and Filippov (1969), error sources in rainfall and other climatic data can be grouped into the following categories.

(a) technical errors resulting from installation and equipment faults.

(b) subjective errors by observers.

(c) errors during transmission and reception of the information.

(d) errors in processing and computation.

Apart from these general problems, there are other errors that are specific to rainfall. These include, among others, errors due to the design, mounting and siting of the rain-gauge, the evaporation of rainwater from, and condensation of atmospheric water vapour into the gauge.

2.3.2 Methods of quality control of rainfall data

Godeske (1969) outlines three basic principles in checking climatic data for errors:

(1) The data must be "logical in time", or consistent, meaning that changes in a weather element between successive periods of observations must be probable. Changes in the history of a rain-gauge regarding its location, exposure, installation, and observation procedures, and units of measurement may result in a substantial change in recorded rainfall

amounts. Often these changes are not disclosed in the published record.

A number of techniques for testing the consistency of a rainfall record exist in the literature. The most commonly used is the double-mass plot which compares the accumulated rainfall over a specified period of the suspect station, with the accumulated rainfall of a number of surrounding stations. Under normal circumstances, the two quantities should show a linear relationship. A change in slope suggests unilateral changes at the suspect station whose records must be adjusted using the ratio of the slopes of the two segments of the double-mass curve.

(2) Another consideration in checking for errors in rainfall data is that it must be "logical in space". In other words the differences in rainfall measurements between neighbouring stations must be realistic. Where data at a given station is considered to be suspect, appropriate interpolation techniques must be applied, and by comparing the observed to the computed values, the likelihood of the former can be assessed. Spatial interpolation techniques range from the simple use of surrounding stations to estimate values based on the average or weighted average, taking inter-station distances into account, to the use of regression analysis, surface fitting by polynomial functions, double fourier series, and krigging (Brass 1990).

In areas of sparse networks it is also important to have an idea of how representative the rain-gauge network is of the area it is meant to serve. A common technique is the use of correlation distance-decay curves for pairs of stations, and deciding on a minimum correlation to determine whether a network is too sparse or not. However, the degree of spatial correlation tends to vary according to the meteorological circumstances that produce the rainfall and the time scale used (Sumner 1988).

(3) The third principle in checking rainfall data for errors is that it must be "logical in elements", since certain combinations of weather elements are highly improbable. For example, in Sierra Leone it is highly improbable to have rain with dry air (low humidities) under Harmattan conditions in the early part of the Dry Season, or for a rainless spell longer than say, ten days, to occur during the middle of the Rainy Season.

Many rainfall records have gaps due to instrument breakdowns, lack of observations or data being lost during transmission and processing at the data collecting centre. It is often necessary to fill these gaps with estimated values using one of several techniques. One such method is to select data at three stations evenly spaced around and as close as possible to the station with the missing data. If the normal rainfall at each of the index stations is within 10% of that for the station with missing data, a simple arithmetic average of the rainfall at the index stations provides a reasonable estimate of the missing value (Linsley et al 1982).

The Normal-Ratio method is also widely used in estimating missing rainfall data. This technique is similar to the previous method in many respects. Three neighbouring stations which are highly correlated with the station of interest are selected. An estimate of the missing value is given by the following expression.

$$R4 = 1/3\ [N4/N1 \times R1 + N4/N2 \times R2 + N4/N3 \times R3]$$

where R4 = missing rainfall
R1, R2, R3 = rainfall at the index stations
N1, N2, N3, N4 = longterm normal rainfall at each station

Other methods of estimating missing data include the use of weighted averages which is identical to the approach for checking data described above, and regression analysis.

2.4 RAINFALL ANALYSIS AND INTERPRETATION.

2.4.1 Need for analysis of rainfall data

To be of any practical value in agricultural planning and decision-making, the raw rainfall data must be processed, using appropriate analytical procedures, and the results presented in a form that can easily be understood and interpreted by the user. For many practical purposes in rainfed agriculture, the main questions that need to be answered are "when", "how much", "how long", and "where" it rains in an area.

Although each of these aspects can be treated separately, the strong links between individual attributes often suggests a need for simultaneous consideration of two or more aspects. As in previous sections the aim here is not to evaluate different analytical methods, but to discuss various approaches which will form a basis for selecting an appropriate methodology in this study.

2.4.2 Methods of analysis of rainfall data

Styles of rainfall analysis for agricultural purposes vary in five different ways - (i) in temporal scale (ii) in areal scale (iii) by analytical method(s), (iv) by rainfall attribute(s), and (v) by purpose of analysis. Needless to say, these approaches are all very highly inter-related.

The temporal character of rainfall can be analysed using different time scales. The shortest time period is normally the storm event itself whose characteristics can be analysed over durations ranging from one minute to a day and longer. Storm characteristics or system signatures (Sumner 1988) are important in distinguishing between short duration, but high-intensity local rainstorms, and low-intensity, continuous downpours from large-scale disturbances. They are also useful in determining the effectiveness of rainfall in agriculture. High intensity rainstorms are more likely to be lost as surface runoff and drainage, while light showers often enter the soil profile and become available to plants. High intensity rainstorms also cause soil erosion problems. In West Africa, Kowal and Kassam (1978) observed that about 58% of rainstorms are erosive. Elsewhere in the tropics a value of 30-49% has been suggested (Sumner 1988, Jackson 1989).

The main limitation in the analysis of rainstorm characteristics is the general scarcity of reliable rainstorm data. Apart from this, measurement errors in pluviographic records also tend to increase with decreasing time scale. Except for hydrological investigations and erosion studies, rainstorm analysis for other agricultural purposes is seldom attempted.

Another aspect of the temporal distribution of rainfall that is of interest to agriculturists is its distribution during the day, which also affects its effectiveness. At night there is a relative decrease in evaporation due to a combination of less energy, lower wind speeds and stable atmospheric conditions which reduce turbulent diffusion of water (Oliver, 1965). This means that even moderate showers can enter the soil profile and become available to plants. Heavy day-time falls can seriously hamper farm work, and transportation of agricultural inputs and produce.

Two diurnal rainfall regimes have been identified in the tropics - a maritime regime with night and early morning maxima in coastal districts, and an inland or continental regime with afternoon and evening maxima (Riehl 1979). But considerable variations do occur from season to season and place to place, these differences being largely a function of local relief and wind systems.

Despite its potential usefulness, the analysis of diurnal rainfall variations for agricultural purposes is very seldom attempted due to the relative scarcity of hourly rainfall measurements in many areas.

The distribution of rainfall on a day to day basis is also of interest to the agriculturist. This temporal aspect of rainfall has received considerable attention in recent years (Stern et al 1982a, 1982b, Hills and Morgan 1981). A daily rainfall record can depict the distribution of wet and dry sequences which are important for planning agricultural operations. Variations in daily rainfall occurrence, amounts and duration also have serious implications for plant growth, and for soil and water management practices. In Sierra Leone, for instance, the occurrence of unseasonally early rainfall can disrupt the entire farming calender and cause a notable decline in crop yields (Richards 1985).

For both hourly and daily rainfall, the quantity of data to analyse can be very large, especially if the record is long, and a large number of parameters are involved. However, with recent advances in computing facilities this is less likely to be a problem now and in the future. Often, it is found convenient to group the data into arbitrary periods of 5-daily, 10-daily, monthly, seasonal, and annual totals, thus "throwing away" vital agricultural information (Stern et al 1982). Rainfall totaled over long time units can give quite misleading impressions about rainfall conditions over an area. The effects of short period rainfall variations (i.e. within seasons and years), which must be taken into account at all levels of agricultural planning, are often disguised by annual and monthly averages. Beside, as agricultural decisions are often taken at time scales ranging from hours to years in advance, it is therefore appropriate to record and analyse rainfall information in equivalent time scales.

Spatial variations in rainfall are particularly marked in the tropics. These variations occur at all time scales. At the storm level, amounts vary considerably within individual systems, often with distinctive cells of heavy rainfall separated by areas of light or no rainfall (Sumner 1988, Hammer 1972, Henry 1974). On a daily, weekly or monthly basis, rainfall also varies in occurrence and amount over small areas. At the seasonal and annual scales, contrasts over small areas are less marked as permanent, large-scale influences become dominant. However, variations may still persist for lengthy periods, even though long term averages are similar. The magnitude and implications of such variations are discussed in detail by Jackson (1989).

The implications of these spatial variations for rain-gauge network design have been outlined in section 2.2 Except for specific catchment studies, spatial analysis of shorter period rainfall like hourly totals, is seldom attempted. Yet these characteristics are important in determining the spatial dependence of rainfall occurrence over an area.

Spatial variability in rainfall exerts a great influence on agriculture in the tropics. It is common, within relatively short distances, for rainfall to support good crop growth and yields in one area while neighbouring areas experience poor harvests due to a shortfall in the season's supply of rainfall (Jackson 1989). Differences in rainfall regimes, strongly linked to local relief, or weather types with contrasting tendencies to instability, may produce different farming systems between adjacent districts.

To reflect these differences, agroclimatic analyses are often performed at different areal scales. At the micro-scale level emphasis is placed on the energy and moisture balances of the active surface over relatively small areas ranging from a few square metres to several hectares. In the tropics where water availability is the main limiting factor to agricultural production, daily estimates of water balances are useful for assessing crop-water needs and consumption patterns, and soil conditions. Radulovich (1987) for Costa Rica, and Musembi and Griffiths (1986) for Kenya have demonstrated the use of simple water balance models for identifying potential growing seasons for rainfed crops.

Also, given the very "patchy" nature of tropical rainfall (due to the small sizes of most of the rain-producing systems), small-scale studies seem the most appropriate in terms of the information requirements of the peasant farmer operating only a few hectares or even less, of land at any given time. But often data required for such small-scale analysis are not readily available, and attempts to acquire it by direct measurements can be costly in terms of time and money involved. This sometimes necessitates extrapolation from a reference station(s).

At the intermediate or meso-scale, studies are limited to areas the size of districts, provinces, or a small country. Some examples of meso-scale agroclimatological analyses include the studies by Radulovich (1989) and Lomas and Herrera (1985) for Costa Rica, and Schouwenaars (1988) for Mozambique.

Macro-scale studies involve large-scale inventories and evaluations of rainfall and other climatic resources over areas the size of continents and large countries. Some examples include the FAO Agroecological Zones Project (FAO 1978), the FAO/UNESCO/WMO Agroclimatological Surveys of Africa South of the Sahara (Cocheme, and Franquin, 1967) and the Highlands of East Africa (Brown and Cocheme 1975) For both meso- and macro-scale analyses, a knowledge of the dynamic systems that produce rainfall is of fundamental importance in understanding the temporal and spatial character of rainfall (Molion 1986).

Analytical styles of rainfall for agricultural purposes are either "descriptive" or "quantitative", or both. Descriptive methods are especially useful in preliminary analysis and final presentation of the results, and often involves the use of tables and graphs (Cox and Snell 1981). Quantitative analyses present numerical summaries of the data, together with measures of precision such as standard errors and/or standard deviations. Where an indication of likelihood in the conclusions is required probabilistic methods are also used in quantitative analyses.

Stern et al (1982a, 1982b) demonstrate the relative merits and limitations of each of the two analytical approaches to agroclimatological studies. However, the choice of a specific method(s) seems to be determined largely by the quantity and quality of the available data, the nature of the problem to be investigated, and to some extent the mathematical competence of the investigator. Simple, descriptive methods require long records if the results are to be meaningful for planning purposes. Daily observations are also considered to be better than data summed up over arbitrary 5-day, weekly, 10-day, or monthly totals. Models have the advantage of making better and more efficient use of rainfall data. Further details on the advantages of modeling over traditional methods of rainfall analysis are discussed in section 3.4.3 of the following chapter.

The focus of an agroclimatic analysis can also depend on those characteristics of rainfall that are considered to be major constraints to agriculture in an area. In this respect two approaches are evident. In seasonally dry/wet tropical climates the focus of many analyses is on the agricultural risks associated with inter-annual and inter- and intra-seasonal water deficits due to inadequate and unreliable rainfall, a long Dry Season, mid-season dry spells, and uncertainties in the onset, end, and duration of the local Rainy Season. Examples of agroclimatic studies focusing on the risk of water deficits include those by Radulovich (1989) for Costa Rica, De Jardins (1982) for part of Queensland in Australia, Giambelluca et al (1991), and Nullet and Giambelluca (1988) for Pacific Islands.

The second approach focuses on the assessment of agricultural risks associated with excessive rainfall, prolonged wet spells, heavy and erosive rainstorms, the occurrence of unseasonal rainfall, and dry and wet periods. These aspects, though less frequently studied compared to problems of water deficits, are also damaging to rainfed agriculture in humid tropical areas (Radulovich 1989). The high concentration of tropical rainfall in only a few days has serious implications for plant growth, and for soil and water management. It is estimated that, between 30-50% of the total rainfall is produced by about 10% of the raindays (Rheil 1979).

With regard to purpose of analysis, two broad approaches can also be distinguished in the literature, "generic" and "problem-specific". In "generic" or evaluatory studies the analysis is not aimed at any specific weather-sensitive agricultural problem. Agroclimatic parameters and indices derived from single or combined variables are used to characterise the agroclimate of large areas. In water-limiting environments indices of drought and precipitation effectiveness are widely used to determine growing seasons, and agricultural potentials of different areas (Parry 1991). The results are often presented in tables, graphs, and/or maps. These reports are then used as guides for recommending appropriate crops and animals that will be most successfully reared, how they can best be reared, and the best protective measures to adopt in the event of inclement conditions (see Stern et al 1982a 1982b, Nieuwolt 1986).

The main advantages of the "generic" approach are its suitability for large-scale inventories of agricultural potentials and the fact that long-term averages can be used in the absence of continuous records. The main limitation, however, is that additional information is required if the results of the analysis are to be used for operational planning purposes. For example, if the introduction of new crops to an area is the purpose of the analysis, additional knowledge of the climatic requirements of different crop species and their patterns of development, varietal characteristics and tolerances and soil conditions, is also required (Sastry 1976, Robertson 1980).

In "problem-specific" studies the nature of a specific weather-sensitive agricultural problem(s) is examined in relation to its main weather or climatic limitations such as too much or too little rainfall, extreme weather events like droughts, floods, hail etc. Agroclimatic analysis can be targeted at specific crops or animals with their own specific temperature and water requirements. For some crops these requirements could vary with the phase of development. The analysis may involve the use of statistical-emperical models and/or simulation models (Parry 1991). Modeling has the disadvantage of producing results that are often site or area specific and are therefore not suitable for large-scale studies.

2.5 APPLICATION OF RAINFALL INFORMATION TO AGRICULTURE.

2.5.1 Need for application of rainfall information

The practical and economic value of rainfall and other weather information to agriculture depends on its effective use in agricultural decision-making processes. For this the information must be received by the user in suitable form and time (Omar 1980). The main aim is to help the farmer make rational decisions regarding the optimization of the good, and mitigation of the bad effects of the weather that will ultimately lead to increased agricultural output. This section outlines three approaches to the use of rainfall information in various facets of agricultural planning. The distinction is based on (a) the level of decision-making (b) the time-scale involved in the decision-making process and (c) the stage of agricultural development and operation.

2.5.2 Approaches to the agricultural use of rainfall information.

Agricultural planning and operational decisions are often taken at four distinct, but highly inter-related levels in the organisational hierarchy of production systems; at the farmer level, the sectoral, the national, and international levels (Revelle 1981). Each level requires a different type of rainfall information.

At the farmer level, a distinction should be made between subsistence and market-oriented production. In predominantly subsistence economies farmers' decisions as to **what**, **where**, and **when** to produce are based purely on ethno-scientific knowledge derived from centuries of careful observation of local climatic and other environmental phenomena. The role of indigenous knowledge systems in traditional agriculture, and their implications for modern scientific enquiry has been highlighted by Richards (1985).

However, the need to feed a rapidly growing population has meant that every season the farmer has to decide on **what**, **when**, and **how** to produce with increasing precision if he is meet these challenges. For this, additional information to ethno-scientific knowledge of the local weather regime is essential. For instance, rainfall information can help the Sahelian farmer to decide on whether to grow millet instead of maize, to plant at the first rains or wait, how many plants per unit of land will maximize the use of incident rainfall, and whether to apply fertilizers and pesticides or not etc. (Revelle 1981).

Agricultural decisions at the sectoral level have also become important in recent years as the need to secure adequate food supplies for a growing population becomes fairly urgent. Rainfall information has a role to play in water management decisions such as the design, operation and management of irrigation and drainage systems, flood control programmes, planning the timely distribution of agricultural inputs such as fertilizers and seeds, and plant protection measures based on rainfall forecasts.

At the national level, rainfall information can be used in the planning of regional agricultural programmes, allocation of resources, setting up prices, making projections on future food imports and/or export levels, and in redistribution of food from anticipated areas of surplus to areas of deficit. At the international level, rainfall forecasts are widely used by organisations such as the F.A.0. and relief agencies in decision-making regarding the location of food-storage facilities, estimation of both the types and quantities of food reserves, and estimated tonnage of ships for international food transfers (Revelle 1981).

The requirements and applications of rainfall information can also vary according to the stage of agricultural development. For large-scale projects, Robertson (1980) identified six progressive stages in agricultural development and operations, with each stage having its own requirements for weather information.

The first stage is the pre-project planning phase when technical decisions are taken on the most appropriate type of land use, crop types and cropping patterns, land and crop management practices, disease control and infrastructural requirements. For this, long-term climatic data and their expected variability are required. An indication of probability and frequency of occurrence of extreme events such as floods, droughts, frosts and other hazards is also essential.

At the investment planning stage, planners determine and assess the risks and potentials of project success or failure due to a number of factors, including climate. Daily rainfall or water balances can be used to assess the risks of dry and wet spells, and heat or cold stresses from temperature records. Extrapolation of records may be necessary where the available data is inadequate for detailed analysis.

Project implementation involves taking decisions on weather-sensitive operations such as land preparation, and construction of basic infrastructural facilities. Information on seasonal occurrence and frequency of wet/dry and hot/cold spells is required by those responsible for implementing the project.

Project management involves the farmer, the project administration, the Ministry or sector, and the national government. At this stage, seasonal weather forecasts are useful for making decisions regarding the procurement and distribution of inputs like fertilizers and seeds, provision of credit and storage facilities, transportation, marketing and distribution of agricultural products.

The fifth stage is the operations stage where the farmer has to make day-to-day decisions on appropriate times to sow crops, to apply fertilizer and/or pesticides, when to irrigate, harvest and sun-dry the crops, etc. These decisions require daily weather information and forecasts.

Monitoring and evaluation of project achievements is normally done at the end of each cropping season, and at the end of different project phases. An object assessment of project successes and failures must consider the effect of weather on crop performance at different stages of the growth cycle. Daily and weekly data are useful pointers to germination, growth and maturation rates, disease incidence and severity.

Another perspective to the use of rainfall and other weather information in agriculture is the time frame of the decision, which varies from the long-term to the medium- and short-terms. Long-term decisions for which climatic information is required for sensible planning include site selection and/or improvement for a given agricultural enterprise, selection of suitable crops and varieties, cultural methods, construction of basic infrastructure, including farm buildings, roads, and storage facilities. Annual, seasonal, and monthly averages and their variability are widely used.

Medium-term decisions are made annually or seasonally, and include such issues as timing of irrigation, seed-bed preparation, and resource allocation, based on anticipated weather of the current season. On the other hand, farmers often have very short time leads in which to make crucial decisions on the best sowing dates, fertilizers and pesticide application, weeding, harvesting, drying, marketing etc. This requires daily and hourly information on weather and its variability.

Two points stand out from this review of various methodologies and approaches to the application of rainfall and other weather information in agricultural decision-making and planning; (a) that the type and form of information required depend on (i) the type of the decision in terms of long or short-term objectives; (ii) the decision- maker, i.e. the farmer, extension agent, or the bureaucrat; and (b) that to be of economic value the data must be predictive.

2.6 SUMMARY

Problems of establishing and operating rain-gauge networks are outlined, as are methods of quality control, analysis, and application to agriculture of rainfall data. The aim is not to evaluate individual approaches but simply to highlight the wide range available, and to provide a framework for formulating an appropriate research strategy for this study. The various analytical methods adopted in the following chapters emanated from this overview.