

A COMPARISON OF METHODS TO DETECT
THE ONSET OF THE GROWING SEASON AND ITS TRENDS
FOR SOME STATIONS IN THE
SUDAN SAVANNA OF NORTHERN NIGERIA

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IN GEOGRAPHY

DECLARATION


I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been presented in any previous application for a Higher Degree. All sources of information are specifically acknowledged by means of references.

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DEDICATION

Dedicated to the **ANCIENT OF DAYS. THE ONLY POTENTATE; THE THRICE
HOLY GOD: THE FATHER, THE SON, AND THE HOLY GHOST.**

AND

To my present and future families.

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"For none of us liveth to himself, and no man dieth to himself." (**Romans 14:7**). Our lives are all wrapped up in people and people's in ours. What we are today is a product of the various contributions (both directly and remotely, positively and negatively) of other people. Whichever way the contributions are made, "all things work together for good to them that love God, to them who are the called according to his purpose". (**Romans 8:28**).

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ABSTRACT

For rainfed agriculture, the major interest of the farmer is in the probability that, at certain moments in time (i) the rains will become fairly continuous and enough to ensure sufficient moisture in the soil at the time of planting and (ii) that this level will be maintained or even increased as the season advances.

In the semi-arid tropics the start of the rains is seldomly abrupt. Rather, it is preceded by a succession of isolated showers of uncertain intensity with intervening dry periods of varying duration. Besides, what happens at the beginning of the rainy season to a certain extent determines the characteristics of the season. The ability of effectively predicting the start of the effectively productive rains would have great consequences for the total agricultural production of the season.

Five methods for the determination of the onset date were selected. One is based on a traditional technique; two on accumulated rainfall totals; and two on rainfall evapotranspiration relationships. These were applied on data from eight stations in the Sudan Savanna of Nigeria. The data span several years. The performance of these methods were tested for each station. The techniques were further tested for false starts.

The traditional "**Ramadan**" technique performed most poorly of all the methods. The techniques based on accumulated rainfall totals performed diversely. **Walter's** method gave early onsets and was closer in its poor performance to the traditional "**Ramadan**" method. Sivakumar's method gave very late onsets, thereby shortening the growing season. The techniques based on rainfall/ evapotranspiration relationship behaved closely to each other and

fell in between **Walter's** and **Sivakumar's** methods. They are, however, significantly affected by false starts (up to 33% of the years).

To avoid the trap of false starts and shortening of the growing season, a combination of **Kowal's** and **Sivakumar's** criteria (omitting the three consecutive rainy days) were used to propose an alternative technique. This proved to work well for determining the onset date in the study area.

Both the rainfall series and the onset series for Kano were tested for trends. While the rainfall series showed a negative trend, the onset series did not indicate any statistically significant trend. An abrupt change was discovered for the rainfall series around 1967. Also an abrupt change was discovered for the onset series around 1987 for the first time. There is also a strong inverse relationship between the rainfall series and the onset series. The nearing abrupt change in the onset data makes the use of average onset dates questionable.

Due to uncertainty in the use of average onset dates, it is suggested that an advisory body should be constituted. This body would be responsible for calculating the date of onset for any year and disseminate such date to the farmers.

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CHAPTER ONE

GENERAL BACKGROUND TO THE STUDY

1.1 Introduction.

In spite of the rapid growth of the oil sector in Nigeria, agriculture still plays a central role in the lives of its people. Close to 70% of Nigeria's labour force is engaged in agriculture. This shows how important agriculture is to the survival of the people of this country. The bulk of the food crop production is largely subsistent and comes from numerous small farms. There is also livestock production, which is still predominantly in the hands of nomadic herdsmen (Abba et al., 1985; Iloabachie, 1986; Aina and Salau, 1992). The sudan savanna of Nigeria plays an important role in its agriculture. It is responsible for the bulk of the grains produced in the country. Also, over 70% of the range-land belongs to this zone.

Agriculture in this sudanian zone, with its seasonal and highly variable rainfall, is largely rain fed. One of the two major limiting factors to agricultural production next to soil fertility, therefore, is the insufficiency of water supply (Hargreaves and Zamani, 1982; Forest and Lidon, 1984; Lal, 1991; Wallace, 1991; Oladipo, 1993). The small holdings or the irrigation farms depend on the amount of water received during the rainy season. The characteristics of the rainy season, therefore, become of great interest to the farmer. Next to the difficulty to quantify rainfall distribution, the attributes of the rainy season that are important to the farmer are its onset, length and termination. It is agreed among most researchers to assume 'the effective start of the rains' as marking the 'beginning of the growing season' (Olaniran, 1984). The terms 'start of the rains' and 'start of the growing season' were, therefore, used

interchangeably in this thesis.

The study presented here is concentrated only on the start of the growing season. It has been suggested that the start of the growing season determines what happens within the season. According to Stewart (1991), "the onset date is a key variable to which all other seasonal rainfall attributes are related. It is the onset relations that determine how the season's rainfall is expected to behave."

The work is an attempt to use meteorological data to do a comparative analysis of various methods of determining the optimum planting date. It is also an attempt to determine, for a long series of rainfall data of Kano station, whether there is any significant trend in the onset date in the period concerned. The emphasis of the study is on sudan savanna environment, but particularly areas around the Yambawa shelter-belt. It was carried out as a supportive study to **determination of crop protection from multiple shelterbelts at Yambawa, near Danbatta, 75km north-east of Kano, in the *Traditional Techniques for Microclimate Improvement (TTMI) Project***. The TTMI Project is a research training collaboration project between Ahmadu Bello University, Zaria and Wageningen Agricultural University, The Netherlands. Maximum crop protection is obtained when the growing season is well determined. In this project set-up a traditional method and a scientific method of determining the onset of the growing season are being used to compare with respect to yields between these multiple shelterbelts (Onyewotu, personal communication, 1994).

1.2 *Objectives of the Study.*

The objectives of this study are :

- (i) To make a comparative analysis of four scientific methods for identifying the optimum planting date.
- (ii) To compare these scientific methods with the traditional "Ramadan" method, to see if there is any justification for preferring the scientific methods.
- (iii) To find out for one sufficiently long series of rainfall data whether there is any significant trend in the rainfall or in the onset of the rainy season over the period of study.
- (iv) To use observed onset features to advise farmers on how to determine when to plant.

1.3 Justification of the Study.

The effectiveness of farming in the semi-arid tropics is a product of many factors. These factors include the type of crop, availability of soil nutrients, pest and disease conditions, the soil moisture content and the climatic environment. Of all these factors, soil fertility and rainfall generally have the greatest effect in determining the potential of any semi-arid area, the crops which it is practicable to grow, the farming systems which can be followed, and the nature and sequence of farming operations. According to **McCown et al. (1991)**, the efficiency with which land, capital, and labor are used in producing crops in the semi-arid climates is reduced by a high probability, provided by chance, that rainfall in a given season will not match the yield potential set by the farmer's selection of crop, plant population and soil fertility amendment (if any). In dry years the inputs are not fully utilized by the crops and this makes water deficits economically worse. In years of good water supply opportunities for high returns are foregone (because the farmer in expectation of water deficit may be tempted to plant very late into the

season). Therefore, the farmer who practices agriculture in a rain dependent environment has to contend with not just the amount and distribution of rainfall received annually but also with the problem of variability in the onset, duration and cessation of the rainy season (Mortimore, 1989).

In the sudan savanna, the start of the rains is seldomly abrupt, but it is usually preceded by a succession of isolated showers of uncertain intensity with intervening dry periods of varying duration. There are false starts followed by prolonged dry spells whose duration may last for two or more weeks. This dries out the top soil and prevents the germination or emergence of plants. Conversely, yields can decline or fail completely with late planting. This is a result of the shortfall created in the growing season (Benoit, 1977; McCown et al. 1991; Oladipo and Kyari, 1993; Jolliffe and Sarria-Dodd, 1994) In general, yields may decline significantly with either a late start or early cessation of the growing season as well as with a high frequency of damaging dry spells within the season, making the rainfall distribution unreliable.

The heavy dependence of agriculture on the seasonal characteristics of rainfall in the sudan savanna calls for the ability to effectively predict the start and the length of the growing season. According to Walter (1967), the agriculturist is only interested in a high probability that, at certain moments in time (i) the rains will become fairly continuous and enough to ensure sufficient moisture in the soil at the time of planting and (ii) this level will be maintained or even increased as the season advances. If there is not at least the ability to predict effectively the nature of the pending season, economic benefits from yield improving technologies in risky climates will always be less than in reliable ones.

All seasonal attributes, as discussed elsewhere in this thesis, are hinged on the start of the rains. It is as a result of this that much work has been committed to the determination of the onset of the growing season. The number of definitions call for the need to examine their comparative performance.

1.4 The Background to the Study Area.

The study area of the Yambawa shelterbelts and surrounding regions is located within the Sudan savanna bio-climatic zone. The wider area covers the **old Kano State (now Kano and Jigawa state)**. This section discusses the physical environment of the study area. This includes climate, geology and soils, and water resources. There is also a brief description of the agricultural production of the area.

1.4.1 The Climatic Environment of the Study Area.

The climate of the region is the savanna type with alternating wet and dry seasons. The rainfall in this region is less than 1000mm per annum in only about five months in the year, especially between May and October. Rainfall in this zone is highly variable and the onset of the rains is erratic. The rainfall intensity is very high between the months of July and August. As a result, though the environment is generally dry, crops are frequently lost through too much rain. It also results in rapid surface run-off, soil erosion and water logging (**Pollock, 1968; Udo, 1970**). The region suffers from frequent droughts as particularly witnessed during the 1968 - 1974 and 1983 - 1987 periods. There is intra-zonal difference in the amount of rainfall received by the

sudan savanna. The southern part receives more rain and is less variable compared to the northern section (Ayoade,1971; Afi, 1990).

The daily sunshine duration is 7-8 hours (Oguntoyinbo, 1983). The air temperatures are consistently high, with high evaporative demands. The **potential evapotranspiration** is only exceeded by actual rainfall in June, and not very often even in that month. The mean monthly temperatures drop slightly with the rains in July, August and September. High temperatures have the effect of reducing working efficiency and increasing lassitude (Mortimore and Wilson, 1965; Sivakumar et al., 1991).

1.4.1.1 Rainfall Producing Mechanism in the Study Area

The climate of the study area corresponds to the Köppen's Aw climate, with alternating wet and dry seasons. Rainfall is generally less than 1000mm per annum, in only about five months in the year, especially between May and October. The gross features of rainfall patterns in this region, as in other parts of the country are usually in association with what is often called the Inter Tropical Discontinuity [ITD] (Nicholson 1981; Kanote, 1984; Hayward and Oguntoyinbo, 1987; Oladipo, 1993). The movement of the ITD northwards across the country, between January and August, and its retreat from the southern fringe of the Sahara desert, after August, cause much of Nigeria to experience seasonal rainfall (Olaniran and Sumner, 1989). The ITD itself is the boundary at the ground between the dry Tropical Continental [cT] air of northern origin and the moist Tropical Maritime [mT] air of southern origin.

Five weather zones are associated with the ITD. These zones fluctuate with the seasonal oscillation of the ITD. Weather conditions over a particular place depend upon the characteristics

one season to another. It is periodically traversed by 'disturbance lines' which may range from a well defined line squall, through a line, possibly broken, of thunderstorms, to a heavy belt of clouds without rain. Rain is often associated with disturbance lines. Periods of rain are short and the rains are of high intensity. The total rainfall in a month is unlikely to exceed 130mm and it tends to be associated with the northern and central portions of the zone rather than the south. There are ill-defined regions of local thunderstorms giving widespread, but variable and sporadic rainfall.

At the coast and in the north, there is less cloud at night than in zone B, but convective development is more marked by day. Over the higher parts of the country night fogs and low stratus persist. Winds are generally light south-westerly in the night and early morning, freshening somewhat in the afternoon. Temperatures are about the same as in zone B, day-time temperatures vary more and very high temperatures may be recorded.

Zone D is south of zone C with an average width of about 300km. Rain is an almost daily occurrence in showers commonly five to six hours long, but sometimes persisting all day. Rainfall is less intense. Thunderstorms are infrequent, especially in the west. Skies are cloudy and overcast, but two to three hours of sunshine may still be recorded on most days. Days are relatively cool (27-29°C), but night temperatures are much the same as in zones B and C. Winds are south-westerly at the surface and somewhat stronger than in zone C. Humidity is as in zone C.

Zone E is the most southerly zone affecting only the southern-most coastal areas in July and August. The weather is relatively dry and cool with day temperatures of 26-30°C and night temperatures of about 21°C. Winds are south-westerly and are at their steadiest and strongest.

associated with the prevailing weather zone (Ojo, 1982). An idealized atmospheric cross-section of the relationship between the different weather zones and the location of the ITD is shown in figure 1.1. The zones are identified by means of letters. The weather conditions associated with each weather zone are described below after Walker (1958) in Ojo (1982) and Hayward and Oguntoyinbo (1987).

Zone A lies to the north of the ITD. Its southern boundary marks the farthest penetration southward of the dry hamattan air at the surface. It is a rain-less zone with relatively cool nights (18-21°C) and hot days (35-40°C). Water vapor pressure is usually below 15hPa. It is also characterized by very low cloudiness, just cirrus clouds at great heights. Surface winds are generally light, east to north-easterly in the morning with a common nocturnal temperature inversion near the ground, strengthening to light to moderate rather gusty winds about mid-day with increasing convection.

Zone B is south of the ITD extending for 240-320km. Conditions are mainly dry, with in comparison to zone A rather warmer nights (21-24°C) and somewhat hotter days (35-43°C) inland but less warm 29-32°C on the coast. Exceptionally, on 1-5 days in a month, isolated thunderstorms break out in the afternoon or evening which may bring rain. Cloud development is restricted. There may be some mist or stratus at night, but normally fair weather cumulus are dominant. Winds are generally light south-westerly at night and early in the morning, freshening slightly with an easterly component during the early afternoon. On the coast, offshore breezes may develop between midnight and early morning.

Zone C is bounded on the north by Zone B and extends southward for 600-800km. The boundaries are not at all well defined and the width is subject to considerable variations from

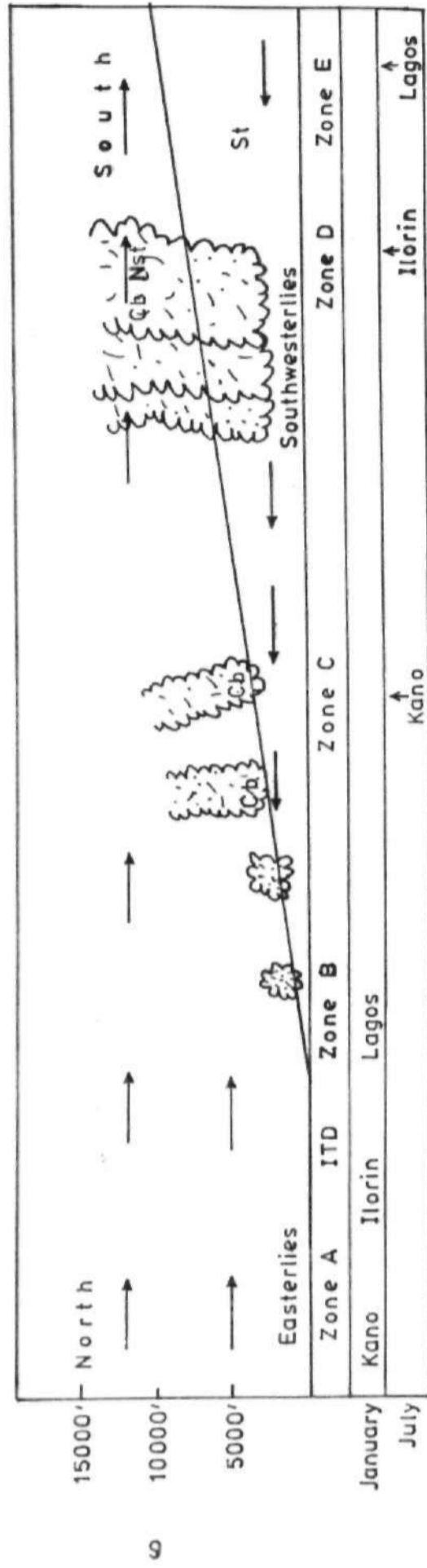


Fig. 1.1 The ITD and weather zones in Nigeria.

Source: After Ojo, 1982

The weather is generally cloudy with little sunshine and much stratus cloud with a base of only 200-300m. Relatively stable conditions and sometimes temperature inversions are prevalent above this level. Such a situation inhibits upward movement and is sometimes regarded as responsible for the little 'Dry Season'.

It has been argued that the convergence of trade wind and monsoonal airflow, in the region of the ITD, is unable to produce sufficient vertical motion (and depth of clouds) to induce rainfall (Hulme and Tosdevin, 1989). The relevance of the ITD therefore lies in its provision of a framework for following the south/north motion of the rain bearing maritime air mass. Within the mT air mass is enclosed a number of rainfall producing systems, such as the disturbance lines (especially the easterly waves), squall lines and the two tropospheric jet streams. It is the magnitude of these systems that influences the amount and seasonal distribution of rainfall over the region.

The south-west monsoon is overlain at a height of 3000m by winds of predominantly eastern components. Near the 3000m these upper easterly winds concentrate into narrow bands of jet streams, known as the Tropical Easterly Jet (TEJ) and the African Easterly Jet (AEJ) respectively (Kamara, 1986).

The Tropical Easterly Jet is limited to the summer period, lasting from late June into early September. Its development is related to the thermal wind pattern during northern summer. The axis of the jet is situated close to the 1200m level where wind speeds exceed 25ms^{-1} . During the rainy season, the axis lies near latitude 10°N . This incidentally is also the axis of the rain belt over the area at this time of the year. Air uplift with attendant widespread cloud development and rainfall occurs on the right (northern) rear quadrant and the front left (southern)

quadrant of the jet axis. This corresponds with patterns of rainfall distribution over West Africa (Kamara, 1986; Hastenrath, 1991).

The African Easterly Jet seems to have originated from the strong horizontal temperature gradient between the hot saharan air and the relatively cooler, but still warm monsoonal air of equatorial origin, which penetrates to latitudes 10°N and 22°N. Its appearance in the wind field coincides with periods of enhanced development of lower level synoptic disturbances such as easterly waves, line squalls and vortices.

Easterly wave disturbances are believed to originate from east-central Africa between longitudes 15°E and 30°E on the southern side of the AEJ. They then proceed westward across West Africa at a speed of 9ms⁻¹. Ahead of the wave trough there are strong surface convergence, thunderstorms and rainfall, while to the rear there are subsidence and fair weather.

Line squalls are bow shaped convex lines of storms 300 - 500km long, arranged in a north/south direction and propagating westward against the surface wind, at speeds exceeding 18ms⁻¹. These line squalls form under strong lines of instability in the upper layers of the atmosphere, and the humidity is supplied by the southern current. They are preceded by a day or two of high temperatures and oppressively still air. Heavy clouds roll in, accompanied by lightning and thunder and the noise of rushing wind. The rains are initially of very high intensities and in an hour or two the rain may stop and the surface winds become south westerly (Ojo, 1982; Kamara, 1986; Hayward and Oguntoyinbo, 1987; Muller and Oberlander, 1987; Ayoade, 1988).

The daily sunshine duration is 7-8 hours (Oguntoyinbo, 1983). the air temperatures are consistently high, with high evaporative demands. The potential evapotranspiration is only

exceeded by actual rainfall in June, and not very often even in July, August and September. High temperatures have the effect of reducing working efficiency and increasing lassitude (Mortimore and Wilson, 1965; Sivakumar et al., 1991).

1.4.2 Geology and Soils of the Study Area.

The study area is underlain by granitic rocks of the Basement Complex. These are normally covered by either eolian drifts or by weathered rock, but unweathered granitic rock occasionally emerges along valley sides and watersheds from which the overlying material has been removed. The surface is characterized by gentle undulations, with broad convex inter-fluvial regions and shallow valleys with a local relief of 10-18m. The landscape is also characterized by rock outcrops or inselbergs scattered about.

The soils of the area are semi-arid brown and reddish brown soils. The topsoil has a low organic matter content which is nearly constant to considerable depths. They are generally low in fertility and productivity (Maduakor, 1991). The other class of soils is the one found in lowland areas and fadamas. These are grey soils of partly alluvial origin. They possess a relatively high clay fraction and a fine grain structure. These are richer compared to the ones occurring elsewhere in the area (Mortimore and Wilson, 1965; Agboola, 1979). Soil erosion by water poses serious problems to the valley sides, where steepest slopes occur, and along gullies, frequently working back from the river banks and along footpaths and cultivation furrows aligned at right angles to the banks.

1.4.3 Water Resources of the Study Area.

In terms of water resources, the surface is mostly covered with seasonal streams. The larger streams are wide and shallow, with a lot of sand dunes distributed over their beds. The flow is restricted to the wet season and fluctuates widely, reaching a peak after rain storms. This surface water condition has led to the creation of dams for domestic water and irrigation purposes. Such dams include; Tiga, Challawa Gorge, Gari, Jakara and Bagauda (Mortimore and Wilson, 1965; Falola et al., 1993).

A major source of water is the ground water. This is tapped through wells. The water table can be as low as 19 meters at the end of the dry season (May), but during the wet season, the water level rises considerably. The wells are generally sited at either interfluvial regions, or stream beds, where water can be found at about 1 meter even at the end of the dry season or at the foot of inselbergs (Mortimore and Wilson, 1965).

1.4.4 Agricultural Production in the Study Area.

Agricultural production in the study area is a rhythmic one centered on the passage of the seasons (Yayock and Owonubi, 1986). For most of the dry season, secondary occupations like weaving (of caps and mats) are practised. The people also are engaged in house construction and repairing.

Agriculture is largely of the subsistence type and land holdings are characteristically small and fragmented. It is based on extensive land cultivation. About 80% of the area is brought under cultivation in any one year. There is much dependence on manure and, recently, artificial fertilizers to prevent loss of soil fertility.

The arrival of the first rains is a signal for tremendous activity. The first heavy showers help to loosen the soil from its hard dry season consistency. Generally, it starts **(June/July)** with the application of animal manure, by distributing it in the furrows between the previous year's ridges and subsequently filling them with soil. Sometimes manure is heaped later on around the feet of the growing plants. Farmers who have access to chemical fertilizers apply it around the feet of the growing plants. The harvest period starts at the end of August and lasts until mid-November.

The predominant species of crop is millet (**P. maiwa - Gero [Hausa]**). It is a cereal of the driest regions and matures faster than most sorghum. The species maturity depends on the length of the rainy season. It requires hot temperature in the night to germinate. It germinates with less moisture than almost any other crop and is often grown in areas with rainfall as low as 280mm per annum and generally needs less than 310mm of rainfall. It does best in areas of low humidity. Excessive rain causes harm to it and the fruit needs to set in hot, dry weather. It does better than any other cereal crop in poor conditions (**Rosenberg, 1984; Deneth et al., 1981**).

1.5 Organization of the Study.

A general background to the whole thesis has just been discussed. This includes the objectives and the need or justification for the study. Included also in this **chapter one** is the description of the physical environment taking into consideration the climate, geology and soils, and the water resources of the study area. Also discussed is the agricultural production of the area. **Chapter two** is a brief review of relevant literature on the determination of rainy season

onset date. **Chapter three** deals with the mode of data collection and the methodology for analysis of the data collected. **Chapter four** contains the results of the calculated onset dates, using five selected methods of analysis. The methods chosen are: **the traditional "Ramadan" method; Walter's (1967) method; Sivakumar's (1988) method; Kowal's (1972) method and Benoit's (1977) method.** These methods were compared to see which one best fits the study area. Based on the observed behaviour of all the chosen methods, a **Hybrid** method was proposed for use instead of the selected ones. This **Hybrid** combines properties of **Kowal's** and **Sivakumar's** methods.

Trends are analyzed for both the rainfall series and the onset series for Kano in **chapter five**. Finally, the summary and conclusions of the study are presented in **chapter six**.

CHAPTER TWO

LITERATURE REVIEW

2.1 *Introduction.*

Many studies have been carried out on the onset, duration and retreat of the rainy season in Nigeria and elsewhere (e.g. Walter, 1967; Ilesanmi, 1972; Benoit, 1977; Olaniran, 1983 and 1984; Hulme, 1987; Olaniran and Sumner, 1989; Kasei and Afuakwa, 1991; Oladipo and Kyari, 1993). Benoit as well as Oladipo and Kyari concentrated on the northern part of Nigeria and by inference on the Sudan savanna. For agriculture in the semi-arid tropics, the start and length of the rainy season are important considerations for understanding crop yields (Forest and Lidon, 1984; Olaniran, 1984).

2.2 *Definitions of the Date of Onset of the Growing Season.*

Several models have been proposed for determining the date of onset of the rainy season. This ranges from **traditional** to **semi-empirical** and **scientific** techniques. The traditional techniques are worthy of study because they are a product of man's interaction with his environment. Through observation, trial and error, the traditional farmer is able to see some pattern in the behaviour of the rains and adapts his farming to take advantage of the observed features. Though there may not be any scientific backing, the traditional methods cannot be discarded off hand without some considerations. Most assumptions concerning traditional methods are based on a poor knowledge of the decision making of the traditional farmer. A close analysis would show that the traditional farmer is dynamic

in his decision making (Stigter, 1989).

The traditional farmer, from experience, has also ways of determining the date of onset of the rains. A risk avoiding farmer with enough seed will go into the field to plant as soon as there is sufficient rain to cause apparent wetness of the soil. The seed may soon get burnt because of the long dry spells that usually follow first rains. This process may be repeated three to four times before the rains stabilize. Others have a defined way of determining when to start planting, often based on **traditional weather lore**. Some use the **change in wind direction**. Others, the **arrival of seasonal migratory birds**. Some, the **behavior of heavenly bodies like stars**. Around **Danbatta** (area of specific interest to this study, see **section 1.1**), the common traditional technique is the "**Ramadan**" method (named after the Muslim fasting period). This rule states that planting can begin with the first rains after the Ramadan, provided it is close to seven months from the last rain of the immediate past season. *If these dates are not close, the seven months rule is applied.*

Semi-empirical and scientific techniques have also been employed in calculating the onset of the growing season. The former are based on **accumulated rainfall totals** while the latter are based on **rainfall/evapotranspiration relationships**.

The use of accumulated rainfall totals is based on the assumption that after a particular level of rainfall is reached, the probability of a long dry spell sufficient to lead to crop failure is small.

The rainfall evapotranspiration models assume that rainfall equal to or more than half the potential evapotranspiration and maintained throughout the season would be enough to sustain crop growth. *Evapotranspiration is the combined process by which water*

is transferred from the soil (evaporation) and plants (transpiration) to the atmosphere (Mbagwu, 1988). Physically there is no difference between these two processes. Only to distinguish potential evaporation from open water and from a well watered crop often the term *evapotranspiration* was used in the latter case. Doorenbos and Pruitt (1977) therefore introduced the term **reference crop evaporation** to indicate potential evapotranspiration. Although this is a better terminology, we have kept here the earlier wording because this was used in the literature on rainy season onset data. Potential evapotranspiration refers to the water evaporated from a large area covered completely and uniformly by a short actively growing green vegetation, and never physiologically short of water (so a reference crop) under the atmospheric conditions measured above it (Stigter and Kisamo, 1978; McQuarrie and Nkendirim, 1991).

The remaining part of this literature review will discuss succinctly some of the semi-empirical and scientific methods of determining the date of onset.

Both categories can be sub-divided according to the measurement used:

- Months (e.g. Walter, 1967)
- Pentads (e.g. Hesanmi, 1972)
- Decades (e.g. Kowal, 1972)
- Days (e.g. Benoit, 1977)

The simplest and most common definition of the wet season is the first month which possesses more than a certain quantity of rainfall. Köppen and Geiger (1936), cited

in Hulme (1987), defined the start of the wet season as the month having more than 60mm of rain. Darnault (1947), also cited by Hulme (1987), used a much lower threshold. He took the first month having more than 30mm of rainfall as the start of the wet season.

Others used monthly rainfall values but were able to give an exact date when a predetermined cumulative rainfall threshold was crossed. Example is the approach of Walter (1967). This author, initially using daily rainfall for a number of stations in Nigeria, asserted that rains become fairly continuous after 76.2mm (3 inches) have fallen which would allow adequate soil moisture to maintain crop growth. He described rainfall of 50.8mm (2 inches) as the point for the earliest start of the rains, giving a reasonable probability that the planting could be successful if started two weeks later. This is based on the results from work with data of over 39 years for Samaru, Nigeria (11° 11'N and 7°E). He found that on only eight occasions did it take longer than fourteen days for accumulated rainfall totals to increase from 50.8mm to 76.2mm. On one occasion this increment required a period of 26 days. The daily series used for the calculation gave a more accurate determination of the start of the rains than monthly values. However, monthly rainfall totals could also be used. Using the month in which the accumulated rainfall totals equal to or exceeded 50.8mm (i.e. the month with so called effective rain [MER]), the actual date of the onset of the rains was derived empirically by Walter (1967) as:

Days in MER multiplied by (50.8 - accumulated total of previous months)

divided by total for MER.

Using Kano as an example, the rainfall distribution for the rainy months (April-September) of 1971 (given in mm) was;

A	M	J	Jl	A	S
13.00	68.85	24.23	174.68	223.89	204.26

Using the above relationship, the optimum planting date is calculated as:

- (i) MER is May with 31 days and rainfall of 68.85mm.
- (ii) accumulated rainfall of previous months (Jan to April) is 13.00mm.

From this, the onset date would be determined as:

31 multiplied by $(50.8-13.0)$ divided by 68.85 .

This gives 17.0 for 1971, so the required day is the **17th of May**, following Walter's empirical formulation.

However, because the relationship is semi-empirical, it does not satisfy all situations. For example, it does not account for dry spells which are common in the semi-arid areas.

This shortcoming of Walter's empirical derivation was discussed by Olaniran (1983). He showed that the dates of onset of the rains computed according to Walter's derivation are usually followed by prolonged dry spells in the semi-arid area of Nigeria. He postulated that **the model can only be accepted if it is not followed by a month with less than 51mm of rainfall**. With this provision, it may then become possible for the available moisture to continue to meet the evaporative demands of the atmosphere. If the rainfall of the month succeeding the calculated onset date is less than 51mm, the rainfall for MER should be disregarded. Consequently, Olaniran (1984), developed a modified version of Walter's relationship to calculate the start of the growing season. Olaniran's version of Walter's derivation for those cases is given by:

Days in MER multiplied by (50.8 - rainfall of succeeding month to MER) divided by rainfall of the second month after MER.

From our example, again using the 1971 rainfall distribution for Kano, the calculated date of May 17 was ignored since the rainfall of the following month June (24.23mm) was less than 51mm. Therefore, by the modified version, the onset becomes:

- (i) rainfall of the succeeding month (June) 24.23mm.
 - (ii) rainfall of the second month after MER (July) 174.68mm.
- i.e. 31 multiplied by (50.8 - 24.23) divided by 174.68.**

This gives, for 1971, 4.7. So, the required day following the modified derivation is the

5th of July.

Stewart (1991) defined the onset of the growing season as "the first acceptable (risk wise) point in time at which, assuming zero run-off, the new rains have wetted the soil sufficiently to germinate a newly seeded crop, plus a further amount of water which, when combined with assured rainfall to follow (at a selected level of risk), will fulfil the water requirements of the seedling crop until the initiation of rapid vegetative growth." In other words, onset should assure water conditions adequate for full crop establishment. Based on this definition, the onset date may be: **the first day after June 1st (or another designated critical date) when stored soil water from the new rains equals or exceeds 40mm (or another selected amount). Earlier onset is acceptable providing soil water storage exceeds -in this case- 40mm by an additional designated amount per day of earliness (e.g. 2mm per day).**

Davey et al. (1976), defined the start of the growing season as **the first ten-day period with 20mm or more of rain.** This definition may give rise to false starts, because it does not consider the possibility of a day with significant rainfall being followed by a dry spell of many days. To take care of false starts, **Stern, et al. (1981,1982)** identified the start of the rains as **20mm in one or more consecutive days with no dry spell of 10 days or more within the next 30 days.**

Sivakumar (1988), working on 58 locations in the sahelian and sudanian zones of Niger and Burkina, comparably defined the date of onset of the growing season as **the date after May 1 when rainfall accumulated over three consecutive days was at least 20mm and when no dry spell within the next**

30 days exceeded 7 days.

Rees et al. (1991) considered **rainfall of 40mm falling in a five day period** sufficient to wet the soil to a depth of **10-15cm**. This is enough for planting to commence.

Kasei and Afuakwa (1991), in determining the optimum planting date of maize in the northern savanna zone of Ghana, defined the onset date as **the first decade in which the total rainfall is not less than 30mm, provided there is no dry spell longer than 7 days in the next 30 days**. In this respect, the methodology is rather similar to Sivakumar's work and the method of Stern et al. given above.

Based on **Stern et al. (1981)**, **Jolliffe and Sarria-Dodd, (1994)** defined the start of the wet season as:

- (i) a period of 5 days (pentad) with at least 25mm of rainfall occurring.**
- (ii) the start day and at least two other days in this period are wet, i.e. equal to or more than 0.1mm rainfall received.**
- (iii) no dry spell of 7 days or more occurs in the following 30 days.**

This is an improvement on the definition of **Stern et al**, which uses only two consecutive days and increases the chance of a false start. The 5 days period with at least 3 wet days was chosen because, in the tropics, it is common to find heavy rains in a short period of time. In some cases two consecutive wet days could correspond to a single rainfall event overlapping two days.

Definitions based purely on accumulated rainfall totals (absolute measures) have the

disadvantage of being area specific and hence are not widely applicable (Hulme, 1987). To give room for regional comparisons, there is the need to introduce relative criteria into the definition of the rainy season. This could be based on a certain percentage of the annual total or the contribution of daily or pentad rainfalls to the annual total (e.g. Ilesanmi, 1972).

Ilesanmi (1972) used accumulated rainfall to derive the onset date in the following manner:

- (i) derivation of the percentage of the mean annual rainfall that occurs at each 5 days interval for every station;
- (ii) accumulation of the computed percentage at 5 days intervals;
- (iii) plotting the cumulative percentages at 5 days intervals through the year;
- (iv) identification of the time of the onset of the rainy season as the first point of maximum curvature on the slope of the cumulative percentage graphs of 5 days rainfall.

From these calculations, the first point of maximum curvature on the graph for each station was found to coincide with the 7 to 8 cumulative percentage. This implies that **the onset of rainfall at every station begins with an accumulated 7 to 8 percent of the annual rainfall.** According to Olaniran (1983), this technique does not assume a fixed threshold value of accumulated rainfall for defining the onset of the rainy season.

Hulme (1987) reasoned that for a definition of the wet season to be acceptable, it;

- (i) must not vary with annual rainfall totals;
- (ii) must be relative and standardized by daily potential evapotranspiration;
- (iii) be calculable on a year to year basis;
- (iv) utilize the most detailed scale of data available (i.e. daily rainfall data); and
- (v) detect dry spells within the wet season and make allowance for false starts.

Hulme (1987) used a simple water balance approach consisting of daily rainfall (r) and daily potential evapotranspiration (ETP). This daily water balance equation is given as:

$$W_i = W_{i-1} + r_i - f(\text{ETP}) \quad (2.1).$$

where, W_i is the water balance of day i and

r_i is the rainfall of day i .

In the original model, run-off and deep through flow were initially set at zero and soil moisture capacity is infinite. The onset date (O_j) is calculated by the method:

O_j is taken as the smallest i where $W_i > 0$ and all from W_i to $W_{i+x} > 0$.

Here $f(\text{ETP})$ in equation 2.1 and x were taken equal to 0.5 ETP and 10 respectively.

Awadulla (1981), cited by **Hulme (1987)**, constructed a water balance model for central Sudan using pentad rainfall, potential evapotranspiration and certain assumptions about soil moisture storage capacities. He defined the onset as the first pentad where 80%

of the evaporative demand of germinating sorghum (the staple rainfed crop of central Sudan) was met by rainfall and/or soil moisture storage, provided that the succeeding two pentads also met this condition.

Kowal (1972) also used the relationship between rainfall and evapotranspiration to calculate the date of onset of the growing season. He defined the onset date as **the decade in which rainfall is greater than 25mm and where subsequent decades of rainfall are greater than 0.5 potential evapotranspiration. For the purpose of calculation, the date is taken as the sixth day from the beginning of the decade in this work.** This is based on the premise that the recharge of the surface by 25mm of water will allow cultivation of land and that an amount of rainfall in the following decades of at least 0.5 potential evapotranspiration will sustain growth.

Another related rainfall/evapotranspiration model for Nigeria is the one proposed by **Benoit (1977)**. This model requires the use of daily data. Onset is taken as **the date when accumulated daily rainfall exceeded 0.5 accumulated potential evapotranspiration for the remainder of the season, provided that no dry spell longer than five days occurs immediately after this date.** This is based on the surmise that planting can start when rainfall is adequate to provide water equivalent to or greater than 0.5ETP. The second assumption is that a dry spell of more than five days immediately after planting will dry out the top soil and produce a failure to germinate. But once the plants have germinated and their roots have extended downwards into the soil, it would require a prolonged dry spell to deplete soil moisture and produce crop failure.

The above review shows that the definition of the onset date could be problematic

and that opinions are diverse. In general, because of the extreme variation of tropical rainfall, its use to define the start of the growing season has been a challenging task.

2.3 Relationship Between the Onset Date and the Growing Season.

There is a strong relationship between the onset date and the growing season (Kasei and Afuakwa, 1991). The onset date is a key variable to which all other seasonal rainfall attributes are related. As already stated in section 1.1 it is the onset relations that determine how the season's rainfall is expected to behave (Stewart, 1991). There is a general awareness that rainfall seasons with early onset are different in character from late onset seasons and generally superior for crop production. Early onset most often means a longer season.

Sivakumar (1988) showed that early onset of rains relative to the computed mean date of onset, for a given location, resulted in a longer growing season. For Niamey in Niger Republic (data base 1904-1984), the average onset date was computed as June 12, giving an average length of growing season of 94 days. However, when rains arrive as early as mid-May, growing season length will in many cases exceed 110 days. In years when rains are delayed until the end of June, growing season length will in many cases be considerably shorter.

Romano Rao (1988), cited in Stewart (1991), showed that also for Anand and Gujzat in India later starting seasons tend to end earlier and are therefore much shorter than early starting seasons.

The effective prediction of the start of the rainy season would in some cases result

in avoidance of losses through false starts and in other cases through an unnecessarily short growing season.

CHAPTER THREE

DATA AND METHODOLOGY

3.1 Data Collection.

Data on rainfall were collected for eight stations in the old **Kano State** (now Kano and Jigawa States). Most of the stations are close to the shelterbelts at Yambawa (see section 1.1) and some are away from the belt area. The data were collected from the Water Resources Engineering and Construction Agency, Kano, and the Kano State Agricultural Development Agency.

The distribution of the stations selected is shown in **figure 3.1** and their geographical co-ordinates are given in **table 3.1**.

Table 3.1: Stations and their geographical co-ordinates.

Station	Latitude	Longitude	No. of Years	Period
Kano	12° 01'	8° 32'	70	1922-1991
Maigatari	12° 47'	9° 22'	6	1986-1991
Gadanya	11° 54'	8° 26'	14	1978-1991
Danbatta	12° 32'	8° 27'	28	1961-1991
Roni	12° 58'	8° 06'	6	1986-1991
Kazaure	12° 40'	8° 25'	14	1978-1991
Bichi	12° 15'	8° 15'	6	1986-1991
Karaye	11° 44'	7° 48'	14	1978-1991

Data on other meteorological parameters were collected from the International Institute for Tropical Agriculture sub-station in Kano. Only the data on Minjibir for 1992 were collected. It is assumed that the potential evapotranspiration of one year will provide a good indication of the nature of potential evapotranspiration in the region for our

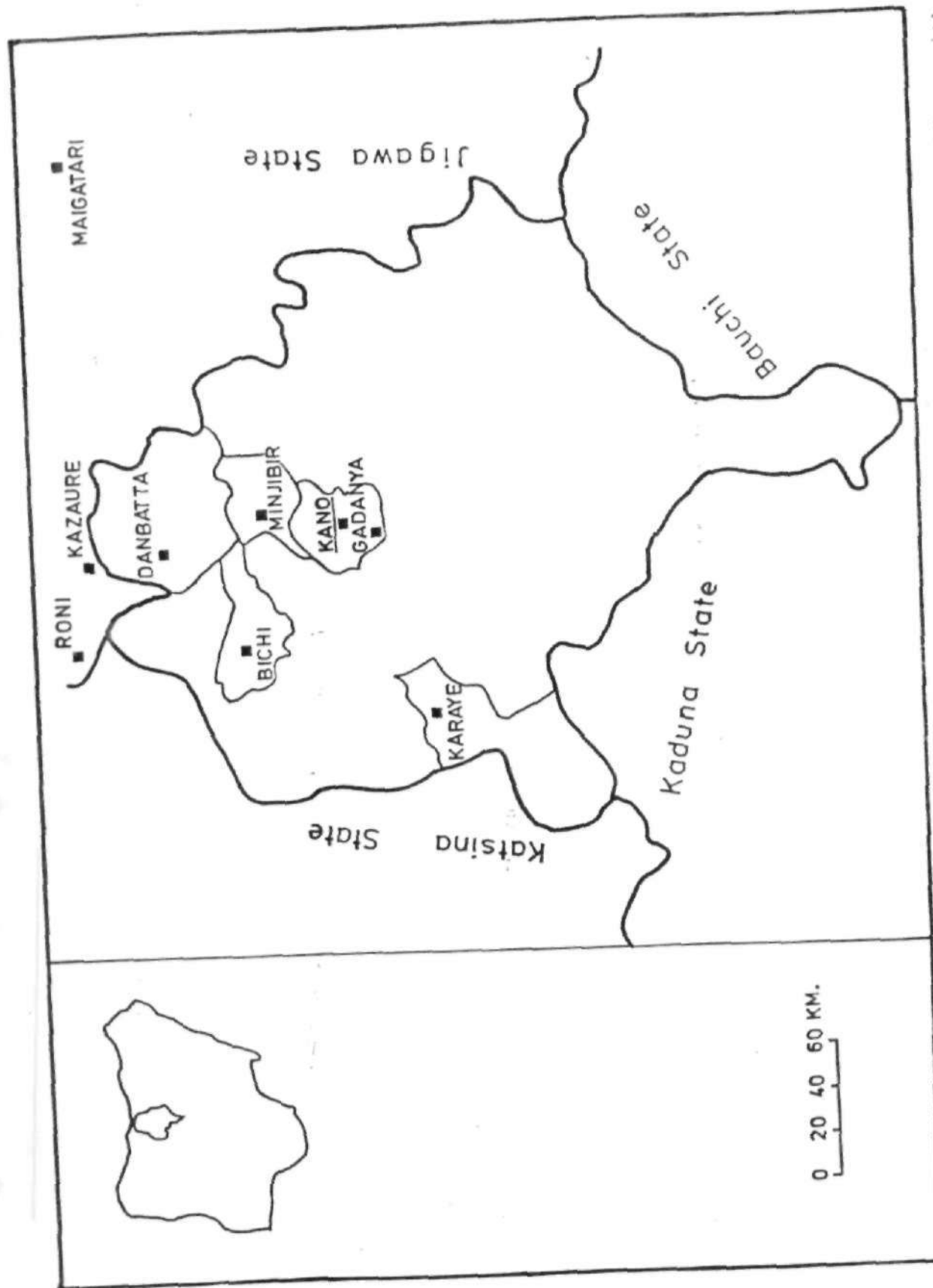


Figure 3.1 Map of Kano State showing the various stations with some stations in Jigawa State. Source: Falola and Sengari, 1993.

comparison.

The major problems encountered during data collection include (i) paucity of information, (ii) discontinuous records and missing data and (iii) short term records.

3.2 Methodology

3.2.1a Determination of the Date of Onset

As indicated in section 1.5, the selected methods in the comparisons made are the "Ramadan" method and the methods of **Walter (1967)**, **Kowal (1972)**, **Benoit (1977)** and **Sivakumar (1988)**. These methods were discussed in section 2.2 above.

3.2.1b Calculation of Potential Evapotranspiration

Experimental determination of potential evapotranspiration is cumbersome, time consuming and often involves the use of lysimeters, which are difficult and costly to construct, set up and maintain. To avoid this, many workers have evolved semi-empirical as well as scientific models for computing the potential evapotranspiration. The models vary in complexity, and some of them are truncated versions of others, in which no attempt is made to simulate processes which are not of direct interest for the particular application (**Stewart, 1983; Mbagwu, 1986**).

Comparisons have been made of the various methods for Nigerian conditions (**Duru, 1984; Mbagwu, 1986**). **Duru** proposed a model for estimating potential evapotranspiration for Nigeria. He adopted the **Blaney - Morin (BMN)** model.

The **BMN** formula as derived by **Duru (1984)** for Nigerian conditions is:

$$PE = rf \{ [0.45T + 8][520 - R^{1.31}] \} / 100 \dots (3.1)$$

where **PE** = daily potential evapotranspiration.

rf = daily maximum possible radiation divided by the maximum annual total. The maximum annual total is the sum of the daily maximum possible radiation over the period of 365 days (1 year).

T = monthly mean temperature = summation of the daily mean temperatures (°C) over a month divided by the number of days in that month, where the daily mean temperature is obtained by averaging the daily maximum and minimum temperatures.

R = monthly mean relative humidity = summation of the daily means of relative humidity at 0900 hours GMT and 1500 hours GMT over a month and dividing by the number of days in that month. The daily mean is obtained by averaging the relative humidity at 0900 hours GMT and 1500 hours GMT.

The empirical constants 0.45, 8, 1.31 and 520 have been found to be applicable to all parts of Nigeria.

Based on Alnaser and Almudaifa (1992), the daily maximum possible radiation is derived as:

$$HO = [24 \times 3600 / \pi] I_{sc} E_0 \{ [\cos\phi \cos\delta \sin\omega] + [2\pi/360] [\sin\phi \sin\delta] \} \quad (3.2)$$

where **I_{sc}** = the solar constant, which is taken as 1367 Wm⁻² according to the latest report

ϕ = the latitude of the location

The hour angle (ω) is given as,

$$\omega = \text{Cos}^{-1} \{-\tan\phi \tan\delta\} \quad (3.3)$$

The declination angle (δ) is calculated as,

$$\delta = 23.45 \text{Sin} \{360 [284+N]/365\} \quad (3.4)$$

Where N is the day number with January 1 as 1 and December 31 as 365.

E_o = eccentricity correction factor given as,

$$E_o = 1.00011 + 0.034221 \text{Cos } \Gamma + 0.001280 \text{Sin } \Gamma + 0.000719 \text{Cos } 2\Gamma + 0.000077 \text{Sin } 2\Gamma \quad (3.5)$$

Where Γ is defined as

$$\Gamma = 2\pi (2N - 1)/365 \quad (3.6)$$

Duru compared the model to the highly accredited Penman (1948) model and discovered that the BMN - Model is a better predictor under Nigerian conditions than the Penman model. He concluded that the BMN-model is satisfactory for use in place of Penman's approach, because it is easy to apply, accepts commonly available meteorological parameters and predicts evapotranspiration with sufficient accuracy. This view is supported by Fapohunda and Ude (1992).

3.2.2 Test for Trends and Changes in both the Rainfall series and Onset series in the Study Area.

Due to the absence of long term records and discontinuous data for the other stations, Kano was chosen for time series analysis.

3.2.2.1 Normality Tests.

The normality of a sequence can be determined by several tests, some of which are rather complicated. The most commonly used are **Skewness** and **Kurtosis**. The standardized co-efficients of **Skewness** (Z_1) and **Kurtosis** (Z_2) as defined by **Brazel and Balling (1986)** were used to test both the rainfall series and the onset series for normality.

The first one was calculated as:

$$Z_1 = \left\{ \left[\sum_{i=1}^N (x_i - \bar{x})^3 / N \right] / \left[\sum_{i=1}^N (x_i - \bar{x})^2 / N \right]^{3/2} \right\} / (6/N)^{1/2} \quad (3.7)$$

The other coefficient was computed as:

$$Z_2 = \left\{ \frac{\sum_{i=1}^N (x_i - \bar{x})^4}{N} / \frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N} \right\} / \sqrt{24/N - 3} \quad (3.8)$$

where, x_i are the yearly rainfall totals, and for the onset series yearly onset dates (in Julian days), \bar{x} is the long term mean rainfall and N is the number of years in the sample.

The skewness is a measure of asymmetry of a distribution and is equal to zero for a normal distribution. It measures whether more of the values in a distribution are concentrated to one side or the other of the mean. If more values are less than the mean, the distribution is said to be positively skewed. If on the other hand there are more values greater than the mean the distribution is negatively skewed (**Ike, 1985**).

Kurtosis measures the extent to which the values are concentrated in one part of a frequency distribution. A negative value of kurtosis indicates that a greater proportion of the data is concentrated near the mean than is expected in a normal distribution, it is

referred to as **leptokurtic**. A positive kurtosis value indicates the reverse and is referred to as **platikurtic**. A distribution which has a moderate degree of kurtosis is **mesokurtic** (Ike, 1985).

Brazel and Balling (1986) gave the normalizing limits as 95% of the error margin. According to them, if the absolute value of skewness and kurtosis are greater than 1.96, a significant deviation from the normal curve is indicated at 95% confidence level.

3.2.2.2 Test for Trends

A climatic trend is a climatic change characterized by a smooth, monotonic increase or decrease of average value in the period of record (Berger, 1986). The following statistics were used to test for these trends and changes.

Mann-Kendall rank statistics were used to investigate secular trends in both series, in order to show whether there were any monotonic increases or decreases in the average values between the beginning and the end of the series. A statistical parameter is derived as:

$$\tau = \frac{4 \left(\sum_{i=1}^{N-1} n_i \right)}{N(N-1)} \quad (3.9)$$

where n_i represents the number of subsequent terms (x_{i+1} to x_N) in the time series that exceeded x_i . A test statistical parameter is equal to

$$Z = \frac{\tau}{\sqrt{2(2N+5)/9N(N-1)}} \quad (3.10)$$

$$t_d = (x_1 - x_2) / \left\{ \left[\frac{(n_1 s_1^2 + n_2 s_2^2)}{n_1 + n_2 - 2} \right] \cdot \left[\frac{1}{n_1} + \frac{1}{n_2} \right] \right\}^{0.5}$$

(3.13)

where x_1 and x_2 are the means of the different sub-periods (n_1 and n_2) of the record and s_1 and s_2 their respective standard deviations (Hammond and McCullagh, 1977; Oladipo, 1987).

3.2.2.3 Test for Abrupt Changes.

An abrupt climate change is defined as a rather abrupt and permanent change during the period of record from one average value to another (Berger, 1986). To determine any abrupt change in the series, a sequential version of the Mann-Kendall rank statistic was applied.

The Mann-Kendall rank statistics are a non-parametric test based on the fact that under the hypothesis of in our case a stable climate, the succession of climatological values must be independent and the probability distribution must remain always the same. Let x_1, \dots, x_n ($1 < i < n$) be the time series in which we want to detect a trend or change. For each element x_i , the numbers m_i of elements x_j preceding it ($i > j$), such that $x_i > x_j$, are computed and summed as

$$dN = \sum_{i=1}^N M_i \quad (3.14)$$

N

For large N (N is the total number of terms in the series), under the null-hypothesis of no

If Z exceeds the critical value of 1.96 at 95% confidence limit, we may conclude that some form of trend exists in the non random variance structure.

The Spearman's rank correlation statistic was also calculated for the series. Ten-years means and the ten-years running means were calculated to further specify the character of the rainfall series and the onset date series.

The standard deviations and coefficients of variation were calculated for the sub-periods 1922-1931 through 1982-1991.

On the assumption that both series are independent, the sub periods 1922-1931 through 1982-1991 were compared to the whole period and their significance tested by the Cramer's test derived as

$$t_k = [n(N-2) / N-n(1+t_k^2)]^{1/2} \cdot \tau_k \quad (3.11)$$

Where τ is a standardized measure of the difference between means given as

$$\tau_k = (\bar{x}_k - \bar{x}) / s \quad (3.12)$$

in Eqn. 3.16 above \bar{x} and s are the mean and standard deviation of the entire record respectively. \bar{x}_k is the mean of the sub-period of n years and t_k is the value of Student's t with $N-2$ degrees of freedom. Comparisons between the non-overlapping sub-periods were carried out for both series and their significance tested by the Student's statistic, t_{12} , with $n_1 + n_2 - 2$ degrees of freedom.

change, d_N is normally distributed with an expected value of

$$E(d_N) = N(N-1)/4 \quad (3.15)$$

and a variance of

$$\text{Var}(d_N) = N(N-1)(2N+5)/72 \quad (3.16)$$

In testing the statistical significance of d_N for this null-hypothesis, the two-tailed significance test is used, the null hypothesis being rejected for large value of $U(d_N)$ which statistically is given by:

$$U(d_N) = (d_N - E(d_N)) / \sqrt{\text{Var}(d_N)} \quad (3.17)$$

The null-hypothesis H_0 of no trend is to be rejected when the absolute value of the standardized statistical parameter $U(d_N)$ exceeds a critical value of 1.96 at the 95% significance level.

The sequential version of the **Mann-Kendall rank statistics** proposed by **Sneyers (1990)** allows the detection of the approximate beginning of a change through a graphical technique. This method is based on the computation of all $U(d_i)$, for $1 \leq i \leq N$, where d_i is given for the i first terms by:

$$d_i = m_1 + m_2 + \dots + m_i \quad (3.18)$$

The graphical computation of this ensemble of all $U(d_i)$ for $1 \leq i \leq N$, along the time axis, allows in the time axis will be denoted as C_1 . The sequential application to C_1 of the rule issued for $U(dN)$ allows us to detect a change in the time series as soon as $U(d_i)$ becomes larger than 1.96 at 95% confidence level.

In order to localize the beginning of the change, the same principle is applied to the retrograde series. The graphical representation of this ensemble will be denoted by C_2 . In this case, we compute for each term x_i , the number m_i of terms x_j such that $x_i > x_j$ with $i < j$. If we put $i' = (N+1)-i$ and $m_{i'} = m_i$, the values of $U'(d_i)$ for the retrograde series are given by:

$$U'(d_i) = - U(d_i') \quad (3.19)$$

which gives, $U'(d_i) = - U(dN)$.

The intersection of curves C_1 and C_2 localized the change, provided it is located between the critical values of the 5% level of significance. In fact, this change will be termed here an abrupt climatic change (Berger, 1986).

3.2.5 Correlation Test.

The test statistic of Pearson's product moment correlation coefficient (r) was used to test for any significant relations between the annual rainfall amount and the date

of onset of the season.

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8

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CHAPTER FOUR

RESULTS AND DISCUSSIONS ON THE ONSET OF THE GROWING SEASON.

4.1. Introduction

It has been established earlier in this work (**Chapter 2**) that onset characteristics have great implications for other seasonal rainfall attributes. The ability to effectively predict the date of onset, therefore, is of paramount importance to rainfed agriculture particularly in the semi-arid climates where the beginning of the rains is seldomly abrupt. What exists is an erratic start characterized by initial isolated showers of uncertain intensity with intervening dry periods of varying duration.

This chapter is devoted to the results obtained from an analysis of onset characteristics in the study area. Onset dates were computed based on five selected methods. The methods used were the **traditional "Ramadan" method; Walter's (1967) method; Sivakumar's (1988) method; Kowal's (1972) formula; and Benoit's (1977) formula.** Detailed descriptions of each method were given in **Chapter 3** under methodology. The onset dates calculated by each method were tested for the probability of yielding false starts.

4.2. Determination of the onset date using the selected methods.

Results of the calculations are presented in **Tables 4.1-4.8** and graphically represented in **Figures 4.1-4.8**. There are two possible explanations for missing data in the tables and figures. Either a particular method could not be applied in the given year (indicated with -) or the data for that year is missing (indicated with *). Mean onsets for such cases were calculated using only the years in which the onset could be calculated and years with available data. The station by station account is given below.

4.2.1 Dates of Onset by Each of the Five Selected Methods for Kano (Table 4.1 and figure 4.1).

The results show that the "**Ramadan**" rule gave indications for an earlier onset, with a mean onset date of **May 6**. The next is **Benoit** with a mean onset date of **May 22**. **Walter's** and **Kowal's** methods gave mean onset dates of **May 26** and **June 2** respectively. **Sivakumar's** method gave the mean onset of **July 1**. Figure 4.1 shows that, with little exception, the "**Ramadan**" method gave earlier onset data throughout the period, while **Sivakumar's** method gave the latest data for onset of the growing season.

Table 4.1 Onset dates calculated based on five selected methods for Kano.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1961	May 4	June 12	July 20	June 25	May 31
1962	May 1	May 13	June 3	June 5	May 1
1963	May 9	June 2	July 21	May 6	May 20
1964	May 4	May 26	May 29	May 25	May 27
1965	May 29	June 6	June 8	June 5	June 6
1966	April 26	May 10	May 25	May 26	May 21
1967	May 20	May 27	July 10	May 16	June 14
1968	April 20	April 25	July 7	April 25	April 20
1969	April 4	June 4	July 6	June 15	May 10
1970	May 22	June 18	July 9	July 5	July 1
1971	May 9	July 5	July 5	July 5	June 20
1972	MAY 8	April 19	August 2	May 25	May 23
1973	June 4	July 2	July 18	July 15	June 25
1974	May 3	June 7	July 4	July 5	July 2
1975	May 13	May 25	July 24	May 26	May 30
1976	May 17	June 1	July 15	May 16	May 17
1977	May 9	August 1	June 19	June 5	May 28
1978	April 22	May 7	June 19	June 5	May 5
1979	May 5	June 5	July 12	July 15	May 26
1980	May 3	May 17	May 3	May 5	May 3
1981	April 22	May 27	June 19	July 5	June 17
1982	April 29	May 15	August 6	June 25	May 20
1983	May 16	June 15	August 3	May 26	May 24
1984	May 5	May 30	July 13	June 4	May 27
1985	May 8	June 1	June 16	June 5	May 16
1986	May 15	June 9	July 19	June 15	June 14
1987	May 25	May 19	July 25	June 5	June 24
1988	May 25	June 2	July 12	June 4	April 20
1989	May 6	June 19	August 4	June 25	June 20
1990	May 13	July 2	July 21	July 5	June 25
1991	April 13	May 4	July 9	May 16	May 11
	x = May 6	x = May 26	x = July 1	x June 2	x = May 22

Key to tables 4.1-4.8.
 (-) Unapplicable Years
 (*) Missing Data.

Legend for fig. 4.1

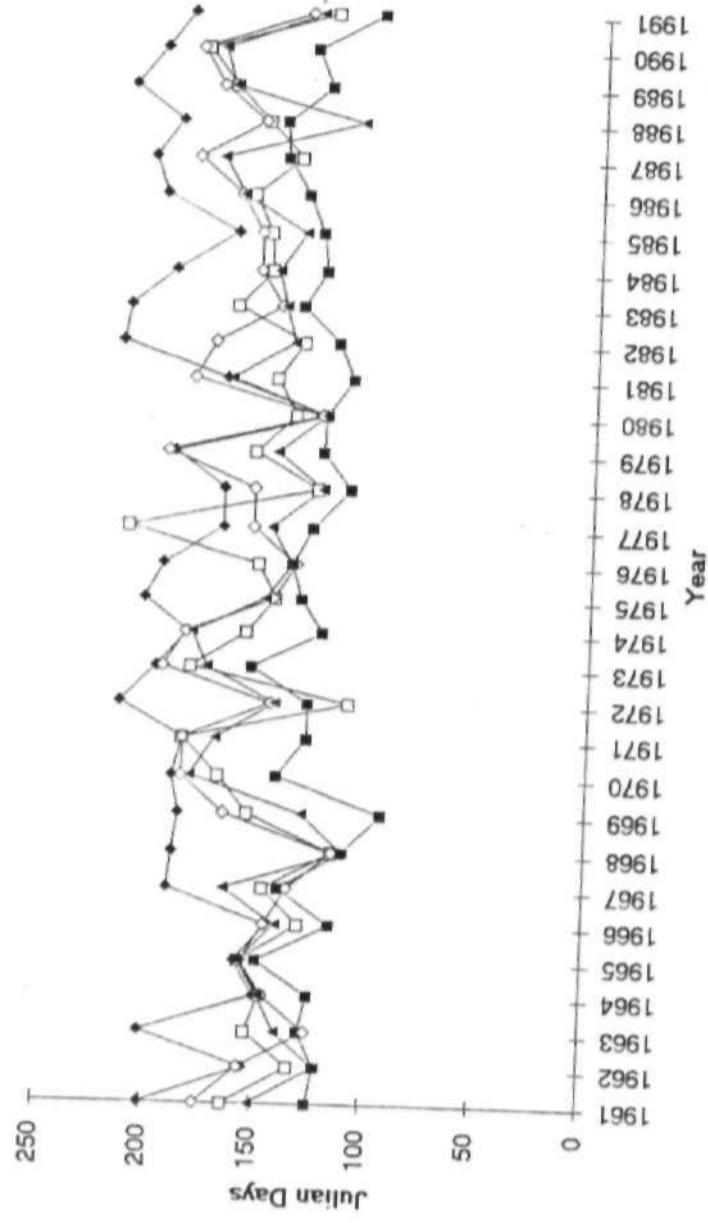
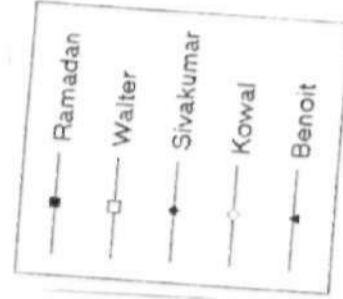


Figure 4.1 Dates of Onset by Each of The Five Selected Methods for Kano.

4.2.2. Dates of Onset by Each of the Five Selected

Methods for Danbatta (Table 4.2 and Figure 4.2).

For Danbatta, there are no records for 1974, 1975, 1984 and 1985. The station was chosen for analysis because of its closeness to the shelterbelt area. In this station, the earliest mean date of onset was given by the "**Ramadan**" rule with the date of **May 18**. This is followed by **Walter's** method with the mean onset date of **June 6**. The next are **Kowal (June 18)** and **Benoit (June 20)**. The mean onset according to **Sivakumar's** method was **July 19**. Figure 4.2 shows a picture comparable to that of Figure 4.1.

4.2.3. Dates of Onset by Each of the Five Selected

Methods for Karaye (Table 4.3 and Figure 4.3)

An early mean onset was given again by the "**Ramadan**" method. **Walter's** method followed with the date of **May 20**. **Benoit's** and **Kowal's** method gave the dates of **May 21** and **May 28** respectively. **Sivakumar's** method gave the onset date of **July 2**.

4.2.4. Dates of Onset by Each of the Five Selected

Methods for Roni (Table 4.4 and Figure 4.4).

The earliest mean date of onset was still given by the "**Ramadan**" method with the date of **May 8**. This is tagged on behind by **Walter** with the date of **June 8**. **Kowal's** and **Benoit's** methods gave the mean onsets of **June 14** and **18** respectively. A later mean onset of **July 26** was given by **Sivakumar**. The picture in figure 4.4 remains similar to the earlier ones as for earliest and latest dates of onset.

4.2.5. Dates of Onset by Each of the Five Selected

Methods for Gadanya (Table 4.5 and Figure 4.5)

The earliest mean onset date was indicated by the "**Ramadan**" method with the date of **May 5**. **Walter's** method followed with the date of **May 22**. **Benoit's** method gave **June 1** and **Kowal's** method **June** **Sivakumar's** method gave the latest mean onset of **July 20**. **Figure 4.5** shows indeed again a picture comparable with the earlier ones.

Table 4.2 Onset dates calculated based on five selected methods for Danbatta

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1961	July 3	July 6	August 9	July 15	July 16
1962	May 3	June 3	July 28	June 25	July 21
1963	May 24	June 4	-	June 25	June 21
1964	May 28	June 2	August 7	June 14	June 28
1965	June 6	June 5	June 5	June 5	June 6
1966	-	-	-	-	August 2
1967	-	-	-	July 5	July 16
1968	April 22	May 13	-	May 25	May 19
1969	August 3	August 30	-	-	August 3
1970	May 6	June 19	July 12	July 5	June 30
1971	May 14	May 21	July 9	June 25	July 3
1972	May 28	June 2	-	June 4	June 22
1973	May 27	June 22	August 4	July 15	July 2
1974	*	*	*	*	*
1975	*	*	*	*	*
1976	-	May 25	-	May 15	June 14
1977	June 3	June 27	June 29	June 25	June 23
1978	May 9	May 24	July 4	June 5	May 23
1979	May 5	June 11	July 16	June 25	June 15
1980	May 4	May 18	-	May 15	May 4
1981	May 17	May 26	-	June 25	June 22
1982	April 27	June 17	-	July 5	June 28
1983	June 14	June 16	-	June 25	June 14
1984	*	*	*	*	*
1985	*	*	*	*	*
1986	-	June 7	August 19	July 5	June 22
1987	May 28	May 23	August 11	May 25	May 28
1988	April 26	June 14	-	June 4	June 8
1989	June 9	July 5	August 10	July 25	June 21
1990	March 14	May 26	-	August 4	June 22
1991	March 14	May 17	July 21	May 16	June 6
	x = May 18	x = June 6	x = July 19	x = June 18	x = June 20

Table 4.3 Onset dates calculated based on five selected methods for Karaye.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1978	April 22	May 12	August 26	May 26	May 8
1979	April 30	May 14	July 8	May 16	May 26
1980	May 2	May 10	May 28	May 5	May 5
1981	April 28	April 20	June 19	April 26	May 2
1982	May 23	June 2	July 10	May 26	May 23
1983	May 25	June 10	July 3	June 15	June 4
1984	May 6	May 16	July 26	May 15	May 18
1985	May 9	May 5	July 10	June 5	May 9
1986	May 9	June 3	July 25	June 15	June 10
1987	May 29	June 12	June 26	July 5	June 24
1988	May 12	June 4	July 30	June 24	May 26
1989	May 20	June 8	June 21	June 25	June 15
1990	May 7	May 24	July 4	May 16	May 13
1991	May 1	May 12	May 21	May 6	May 16
	x = May 8	x = May 20	x = July 2	x = May 28	x = May 21

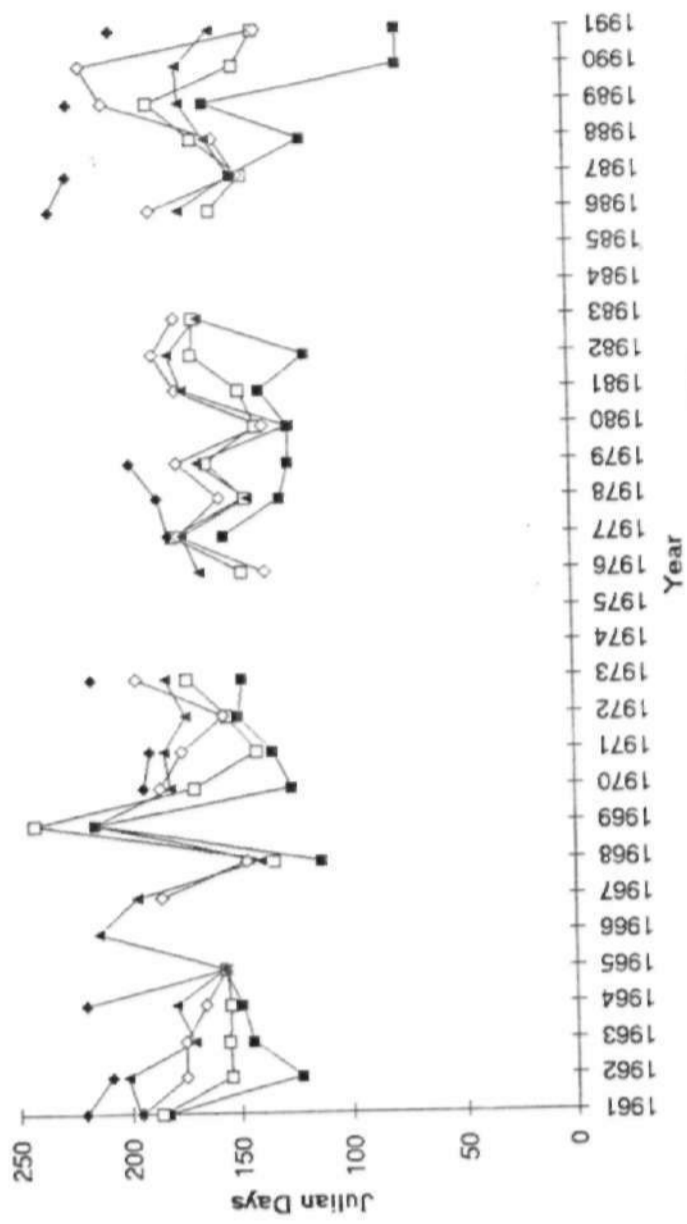


Figure 4.2 Dates of Onset by Each of The Five Selected Methods for Danbatta.

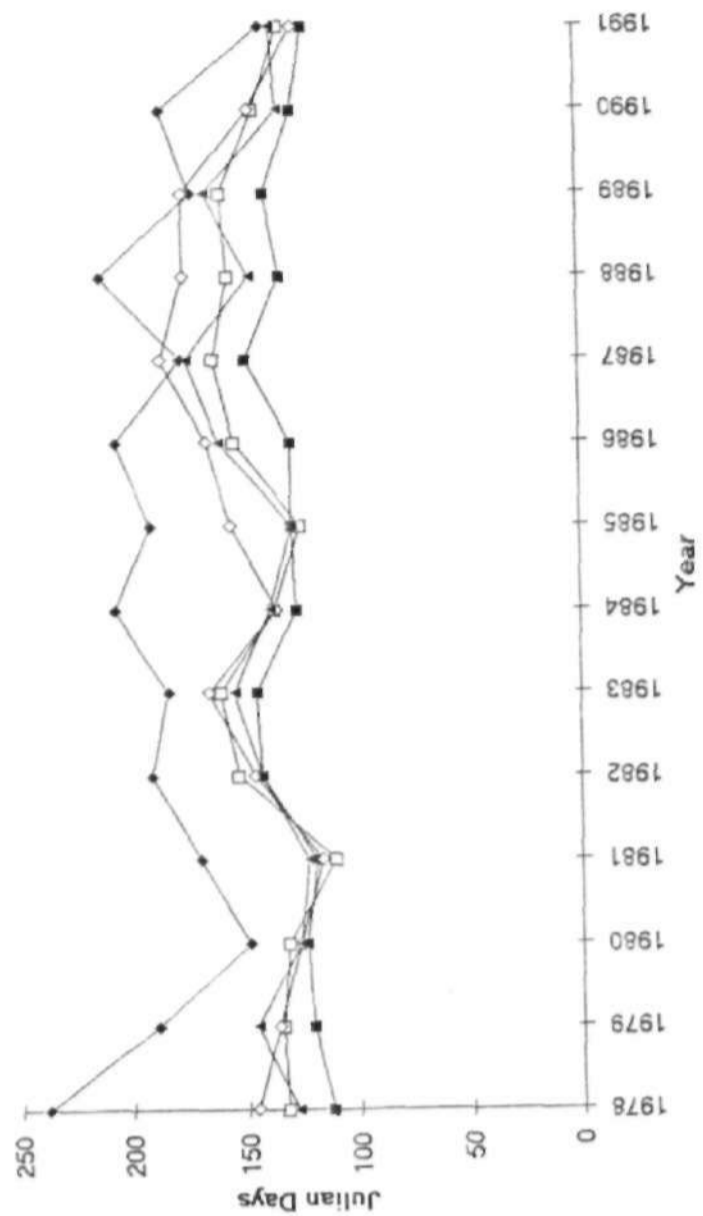


Figure 4.3 Dates of Onset by Each of The Five Selected Methods for Karaye.

Table 4.4 Onset dates calculated based on five selected methods for Roni.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1978	-	June 4	-	June 5	June 17
1979	April 2	June 1	-	June 5	June 13
1980	May 15	May 18	May 29	May 25	June 12
1981	April 30	June 20	September 7	June 25	July 5
1982	May 23	June 20	August 19	June 25	June 24
1983	May 22	June 14	August 19	June 25	June 13
1984	May 8	June 7	-	June 14	June 21
1985	April 30	June 15	July 1	June 25	June 30
1986	May 16	June 12	Sept. 21	June 25	June 17
1987	June 3	July 3	June 5	July 15	June 19
1988	June 5	June 4	August 25	July 4	July 4
1989	April 17	June 3	August 9	July 5	June 20
1990	May 6	June 6	-	June 25	June 2
1991	May 10	May 8	June 11	May 6	June 2
	x = May 8	x = June 8	x = July 26	x = June 14	x = June 18

Table 4.5 Onset dates calculated based on five selected methods for Gadanya.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1978	April 23	May 6	July 25	May 26	May 21
1979	May 16	May 23	July 13	June 5	May 27
1980	May 2	May 11	May 30	May 25	May 28
1981	April 28	June 3	August 30	May 16	June 8
1982	April 18	June 1	-	June 5	May 20
1983	May 25	May 29	August 21	June 15	June 15
1984	April 27	May 7	July 23	May 25	May 5
1985	May 30	March 30	August 3	June 5	June 10
1986	May 17	June 5	July 23	June 15	June 5
1987	May 26	June 13	August 7	June 25	June 21
1988	April 20	June 9	-	June 4	June 6
1989	May 7	June 18	July 11	June 25	June 21
1990	May 6	June 9	July 3	June 25	June 16
1991	May 2	May 12	July 10	May 16	May 16
	x = May 5	x = May 22	x = July 20	x = June 4	x = June 1

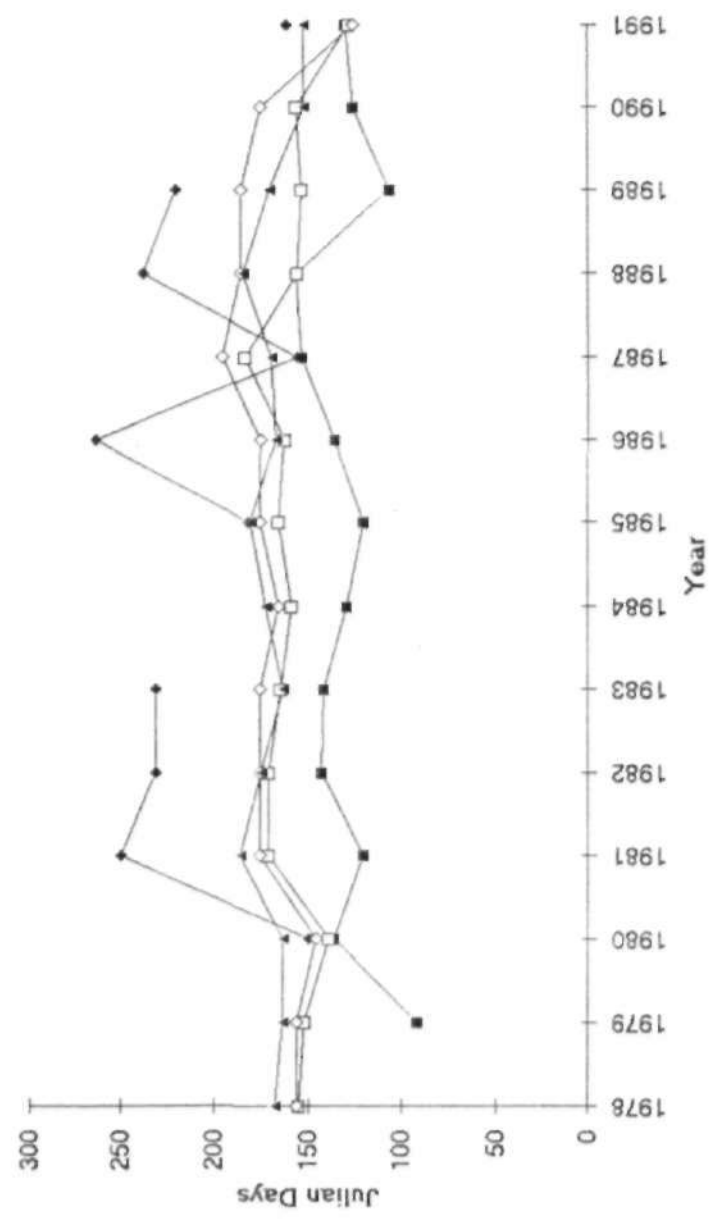


Figure 4.4 Dates of Onset by Each of The Five Selected Methods for Roni

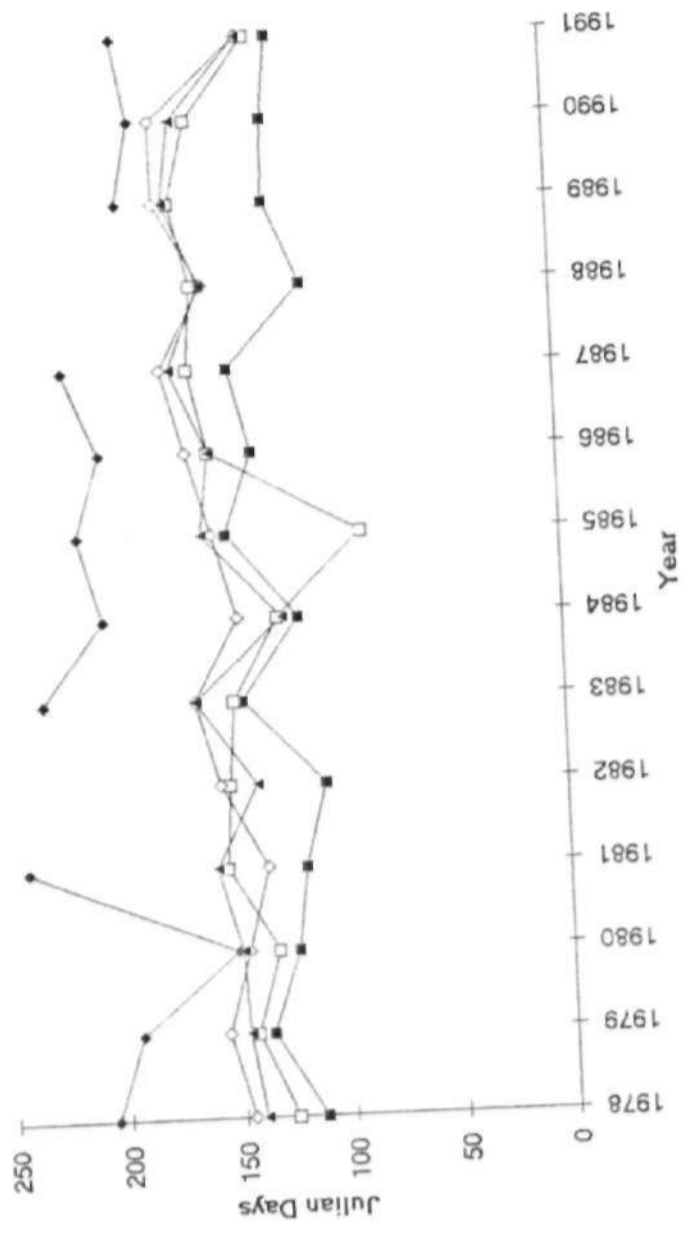


Figure 4.5 Dates of Onset by Each of The Five Selected Methods for Gadanya

4.2.6. Dates of Onset by Each of the Five Selected

Methods for Kazaure (Table 4.6 and Figure 4.6)

The "Ramadan" rule gave an indication of earliest mean onset of **May 25**. This is followed by **Walter** with **June 14**. **Kowal's** and **Benoit's** methods gave the mean onsets of **June 25** and **June 26** respectively. For **Sivakumar's** method the mean onset of **July 7** was found. Figure 4.6 also presents a picture similar to the earlier ones.

4.2.7. Dates of Onset by the Five Selected Methods for

Maigatari (Table 4.7 and Figure 4.7).

"Ramadan" rule gave the earliest mean onset of **May 14**. **Walter's** and **Kowal's** methods gave the mean onsets of **June 23** respectively. **Benoit's** method gave the mean onset of **July 7**. For **Sivakumar**, most of the years the method was not applicable, except for 1991 with the date of **August 7**. This is because rainfall in most of the years could not satisfy onset criteria as defined by **Sivakumar**. Figure 4.7 describes the same pattern as the earlier figures.

4.2.8. Dates of Onset by Each of the Five Selected

Methods for Bichi (Table 4.8 and Figure 4.8)

The earliest onset date was given by the "Ramadan" method with the mean date of **May 17**, followed by **Walter's** method with the mean onset date of **May 25** then **Kowal** (**June 13**) and **Benoit** (**June 16**). **Sivakumar** gave again the latest mean date **July 21**. The picture shown in figure 4.8 is not different from that of the earlier ones.

Table 4.6 Onset dates calculated based on five selected methods for Kazaure.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1986	-	June 5	-	June 5	June 30
1987	May 28	June 20	-	July 25	June 17
1988	June 5	June 12	June 7	June 4	June 19
1989	June 14	June 8	-	July 15	July 4
1990	May 7	August 8	-	August 4	August 4
1991	May 17	May 12	August 8	May 16	June 2
	x = May 25	x = June 14	x = July 7	x = June 25	x = June 26

Table 4.7 Onset dates calculated based on five selected methods for Maigatari.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1986	-	July 7	-	July 5	July 30
1987	June 23	July 6	-	July 15	July 17
1988	April 25	June 13	-	June 24	June 27
1989	May 7	July 1	-	June 25	June 23
1990	May 10	July 1	-	July 5	June 30
1991	May 12	June 2	August 7	May 15	July 1
	x = May 14	x = June 23	x = August 7	x = June 23	x = July 7

Table 4.8 Onset dates calculated based on five selected methods for Bihi.

Year	Ramadan	Walter	Sivakumar	Kowal	Benoit
1986	-	June 1	July 19	June 25	June 20
1987	May 28	June 27	August 14	July 25	July 17
1988	April 20	June 5	July 29	June 4	June 5
1989	June 14	April 5	July 10	June 5	July 4
1990	-	-	-	-	-
1991	May 11	May 20	July 9	May 16	May 15
	x = May 17	x = May 25	x = July 21	x = June 13	x = June 16

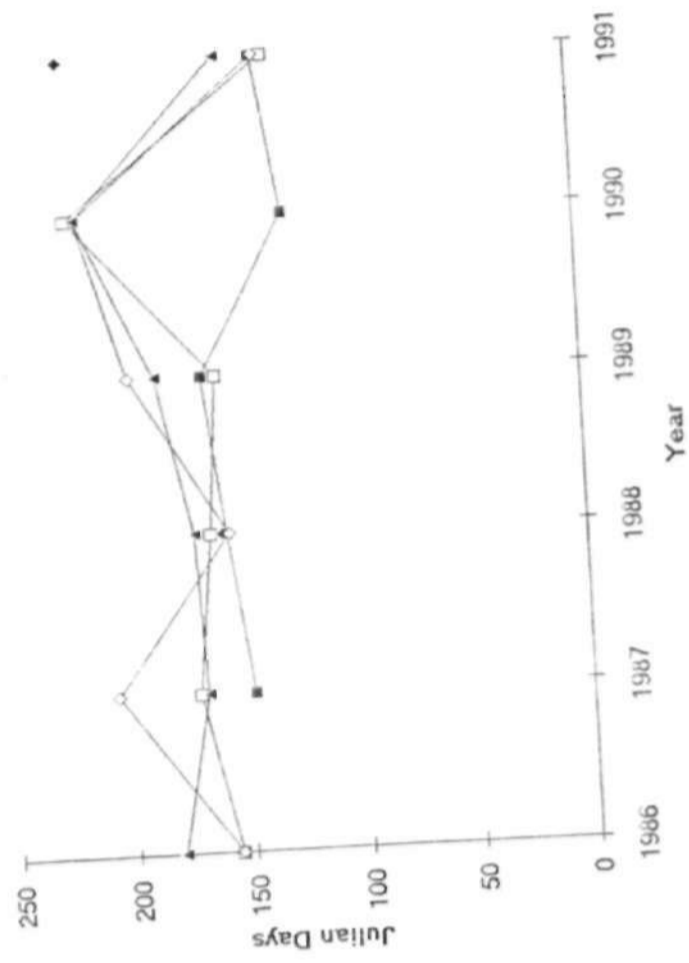


Figure 4.6 Dates of Onset by Each of The Five Selected Methods for Kazaure

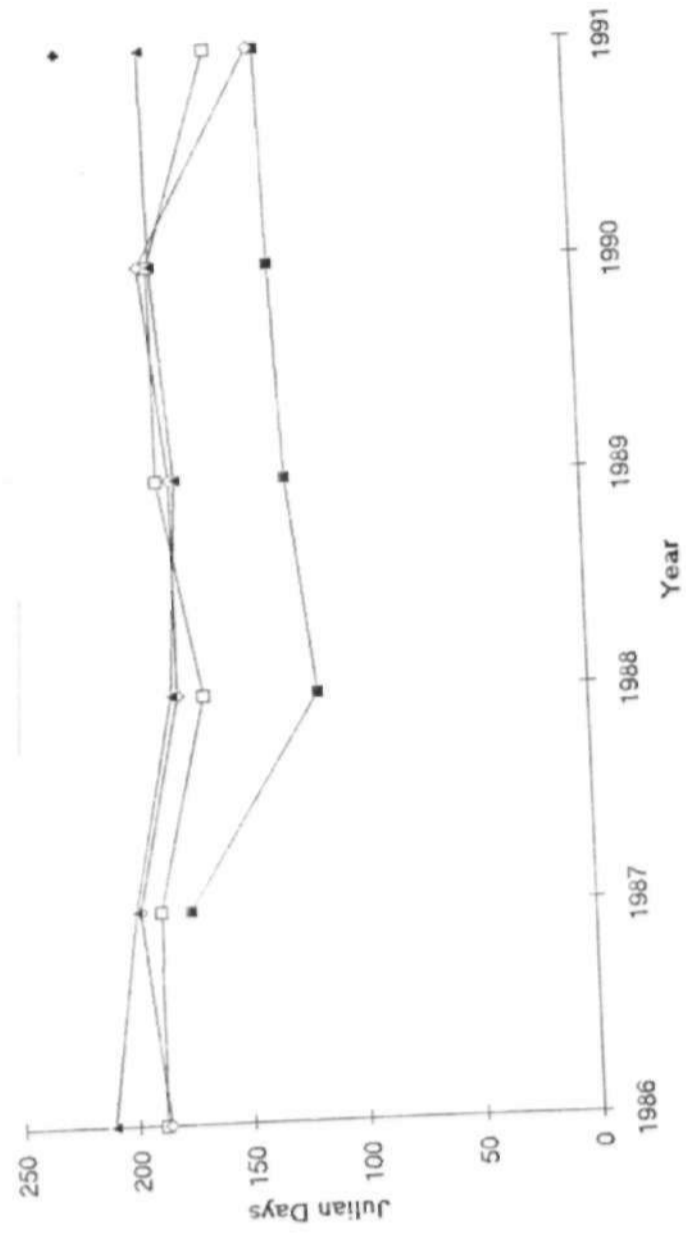


Figure 4.7 Dates of Onset by Each of The Five Selected Methods for Malignant

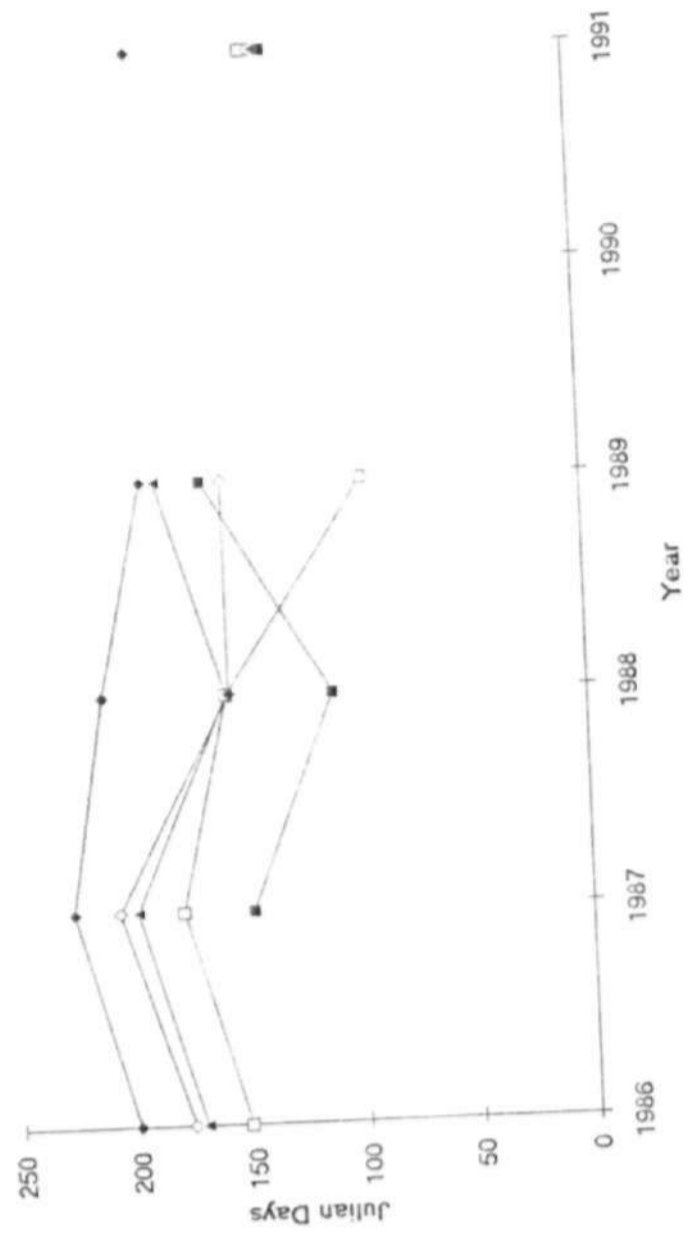


Figure 4.8 Dates of Onset by Each of The Five Selected Methods for Bichi

4.2.9. Test for False Starts

A prolonged dry spell before full crop establishment could spell disaster for the crop. A dry spell of longer than 7 days within the next 30 days of the date of onset could lead to crop failure (Sivakumar, 1988; Kasei and Afuakwa, 1991; Jolliffe and Sarria-Dodd, 1994). Based on this the selected methods were subjected to the test for the possibility of dry spells of more than 7 days within 30 days of the calculated onset dates and the mean onset dates. It is difficult to test for false starts with the Sivakumar's method because the above 7 days dry spell criterion forms part of the original formula. Therefore, only four of the five methods were tested. Results of the analysis for each station is presented in tables 4.9 and 4.10. From the results of the mean dates of onset and the annual actual dates of onset, the "Ramadan" method leads to the detection of greater number of damaging dry spells (i.e. dry spells of more than 7 days within 30 days of the calculated date of onset of the growing season) than the other three methods. This was followed by Walter. Benoit's and Kowal's methods did not differ much from each other although Benoit's method gives a smaller percentage on the average. In fact, Benoit's method is the only one giving on the average a percentage lower than 50%. Using Kano as example (see Table 4.9A), based on the mean date of onset, the "Ramadan" rule could not satisfy the above 7 days dry spell criteria in 28 (90%) out of the 31 years analysed. For Walter's method this was 17 years (55%). Benoit's and Kowal's methods gave (32%) and (42%) respectively.

Using the yearly onset dates for Kano (see Table 4.10A), damaging dry spell were experienced by the "Ramadan" rule for 28 (90%) out of the 31 years analysed. For

Walter's and Benoit's methods this was 11 years (36%) respectively. Kowal's method gave 10 years (32%).

Table 4.9 The degree of false starts experienced by each method for:
A. Kano.

	Ramadan	Walter	Kowal	Benoit
I	31	31	31	31
II	28	17	13	10
III	90	55	42	32

B. Danbatta.

I	23	25	25	27
II	21	17	19	17
III	91	68	76	63

C. Karaye.

I	14	14	14	14
II	10	11	10	11
III	71	79	71	79

D. Roni.

I	13	14	14	14
II	11	9	7	6
III	85	64	50	43

E. Gadanya.

I	14	14	14	14
II	14	8	6	6
III	100	57	43	43

F. Kazaure.

I	5	6	6	6
II	4	2	3	3
III	80	33	50	50

(i. Maieotari

I	5	6	6	6
II	5	4	4	2
III	UJO	67	67	33

II. Biohi.

I	4	5	5	5
II	4	4	2	1
III	100	80	40	20

-f

Table 4.III The degree of false starts experienced by each method using the annual actual ouzel dales lor; dates.

A. Kano.

	Ramadan	Walter	Kowal	Kin-lit
I	31	31	31	31
II	28	11	10	11
III	90	36	32	36

H. Danbatta.

I	2.)	25	25	27
II	20	19	10	10
III	87	76	40	37

i'. Karayc.

I	14	14	14	14
II	10	9	7	8
III	71	64	50	57

1). Roni.

i	13	14	14	14
II	10	7	6	6
III	77	50	43	43

E Gadanya.

I	14	14	14	14
II	12	7	4	3
III	86	50	29	21

F. Kazaure.

I	5	6	6	6
II	4	3	3	1
III	80	50	50	17

G. Maigatari.

I	5	6	6	6
II	5	2	4	3
III	100	33	67	50

H. Bichi.

I	4	5	5	5
II	3	3	3	2
III	75	60	60	40

Key to tables 4.9 and 4.10.

I = total number of years analyzed.

II = number of years with damaging dry spells.

III = percentage of years with damaging dry spells.

4.3 Discussions

4.3.1 Comparison of the Various Method for calculating the Optimum Planting Date.

Generally, from **Tables 4.1 - 4.8**, it is discovered that the "**Ramadan**" rule gave the earliest yearly onset and mean onset dates for all the eight stations. Apart from Kano, where it followed Benoit's method, Walter's method was closest to the "**Ramadan**" rule. Sivakumar's method in all the stations gave the latest yearly onset date in most of the years and also the latest mean onset date. The two techniques based on the rainfall/evapotranspiration relationships (**Benoit's and Kowal's methods**) were close to each other in their behaviour, and onset dates calculated by these methods were between those obtained by Walter's and Sivakumar's methods.

The test for a prolonged dry spell within the first few days of the calculated annual actual onset dates and the mean onset date, indicates that the "**Ramadan**" method led to the detection of the greatest number of such dry spells in all stations. Walter's formula was on the average closest to the "**Ramadan**" rule in its performance. **Benoit's and Kowal's** methods led to the experience of such prolonged dry spell after the calculated yearly onset dates and mean onset date in a fewer number of the years. It should be observed that the percentages in many cases decrease appreciably when using yearly onset dates. This is also shown by the averages. For "**Ramadan**" method the average becomes 83% using the yearly onset dates from 90% using the mean. For Walter this is 52% against 63%, for Kowal 46% against 55% and for Benoit 38% against 45%.

It follows from the above that the Ramadan method is the least reliable of all the

methods selected to calculate the onset date. It leads to more false starts and planting by this method could lead to a lot of wastage of seed. The danger is that after planting by this rule, a prolonged dry spell within the first few weeks will very often burn up the plants. This would necessitate replanting. Walter's formula performed poorly too. The tendency for a prolonged dry spell at the germinating period is here also very high. The method's of **Benoit** and **Kowal** also gave a high tendency for false starts (at least 33%). There is still a rather high probability of crop failure at germination if planting is done in the area by the dates calculated by any of these four methods.

Sivakumar's method was not subjected to the same test because the criteria forms a part of the original formula. Crop failure at germination is reduced when farmers plant by this method. However, the major problem with the formula is that it greatly shortens the planting season and in some years it can not be applied.

The standard date for calculating the onset date by Sivakumar was changed from May 1 to April 1 to see if it can account for the late onset given by the method. All the eight stations were analyzed. There was no single year out of all years that the onset date was altered by the change. This means that the date of May 1 was alright for the calculations. The late onset, therefore, must be a consequence of the other criteria used. The three consecutive days of rainfall required by the formula could not be satisfied for most of the years until well into the rainy season. In other cases, the whole season could pass without a period fulfilling the condition.

4.3.2 Relationship between calculated onset dates and the experience of prolonged dry spells.

In general, and rather logically from the foregoing analysis there is a clear relationship between the dates of onset and the experience of a prolonged dry spell after the onset. The earlier the calculated onset date, the greater the risk of a prolonged dry spell after the calculated date of onset. This accounts for why the "Ramadan" rule led to the greatest number of prolonged dry spells after the calculated onset. Benoit's and Kowal's methods, with moderately early onset dates, showed the least experience of prolonged dry spells after the calculated onset.

4.4 Proposal of a more reliable method for calculating the Onset Date in the Study Area.

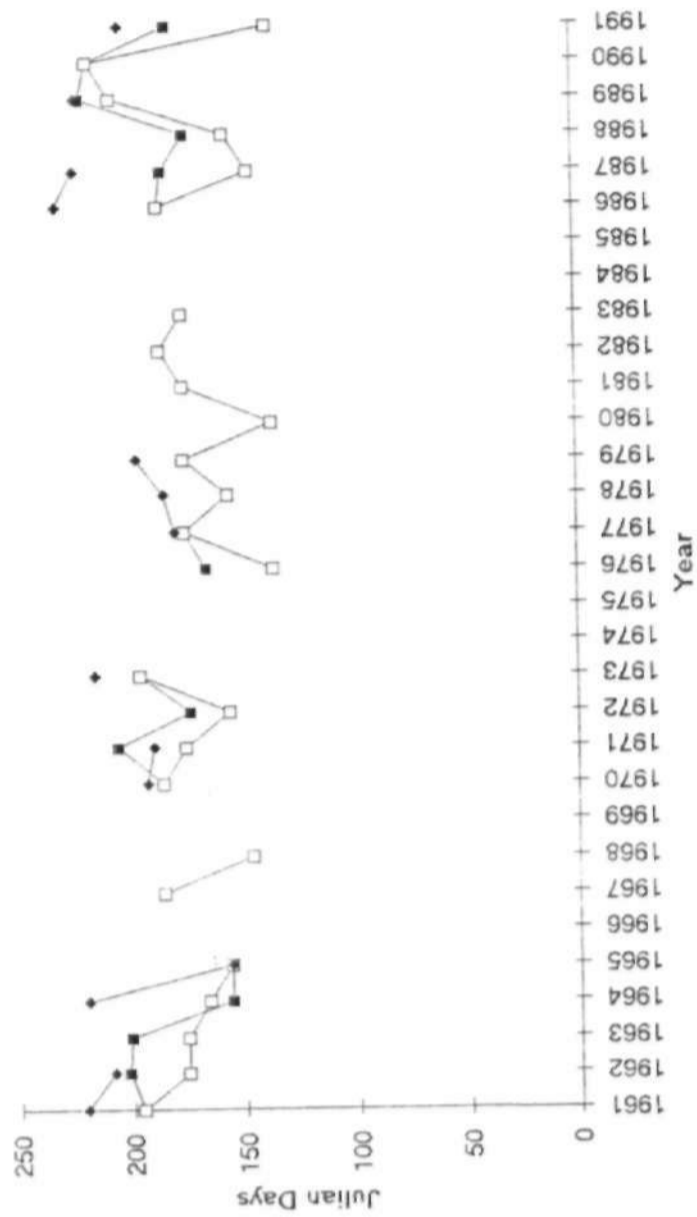
To avoid the problem of false starts on the one hand and a shortening of the growing season on the other hand, the dry spell factor was introduced into Kowal's method, to give a more reliable onset date for the area. This proposal assumes that though the evaporative demands of the crop may have been satisfied at the calculated date of onset, a dry spell of long duration shortly after planting could spell disaster for the crop. We have learned this from Sivakumar's results.

The onset date can therefore now be defined as **the decade in which rainfall is greater than 25mm and where subsequent decades of precipitation are greater than 0.5 ETP (the actual date, for the purpose of calculation, is taken to be six days from the start of the decade), and where there is no dry spell of more than 7 days within**

the next 30 days of the date on which the above criteria were satisfied. If such dry spells exist, the onset date would be the date of the first rains after the prolonged dry spell.

This proposal was used to calculate the onset dates for all the stations (see appendix 1). This was compared with the original formula (Kowal and Sivakumar formula) for Danbatta, Kano and Karaye (Figs. 4.9, 4.10 and 4.11). Two stations (Kano and Karaye) were chosen because of their consistent data series. Also, Kano station is close to the shelter belt while Karaye is further away. This would allow for any spatial difference(s) to show up. Danbatta was chosen inspite of its porous data because of its closeness to the shelterbelt area.

The proposed method was found to present a mean onset falling between Kowal's method and Sivakumar's method (see Figs. 4.9, 4.10 and 4.11). The mean onset dates by the proposed method were tested for the fulfillment of the dry-spell criteria. For Karaye none of the years experienced any false start after the new mean date of onset. For Kano, 5 (16%) out of the 31 years still recorded false starts. All the years involved (1973, 1974, 1982, 1984, and 1987) were obvious drought years. For Danbatta 7 years (33%) of the 23 years recorded false starts. Based on the annual onset dates only 1 of the years recorded a false start.



Legend for fig. 4.9-4.11

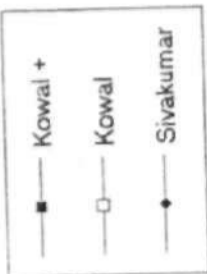


Figure 4.9 Onset dates Calculated based on Sivakumar's, Kowal's and the Hybrid Methods for Banbatta

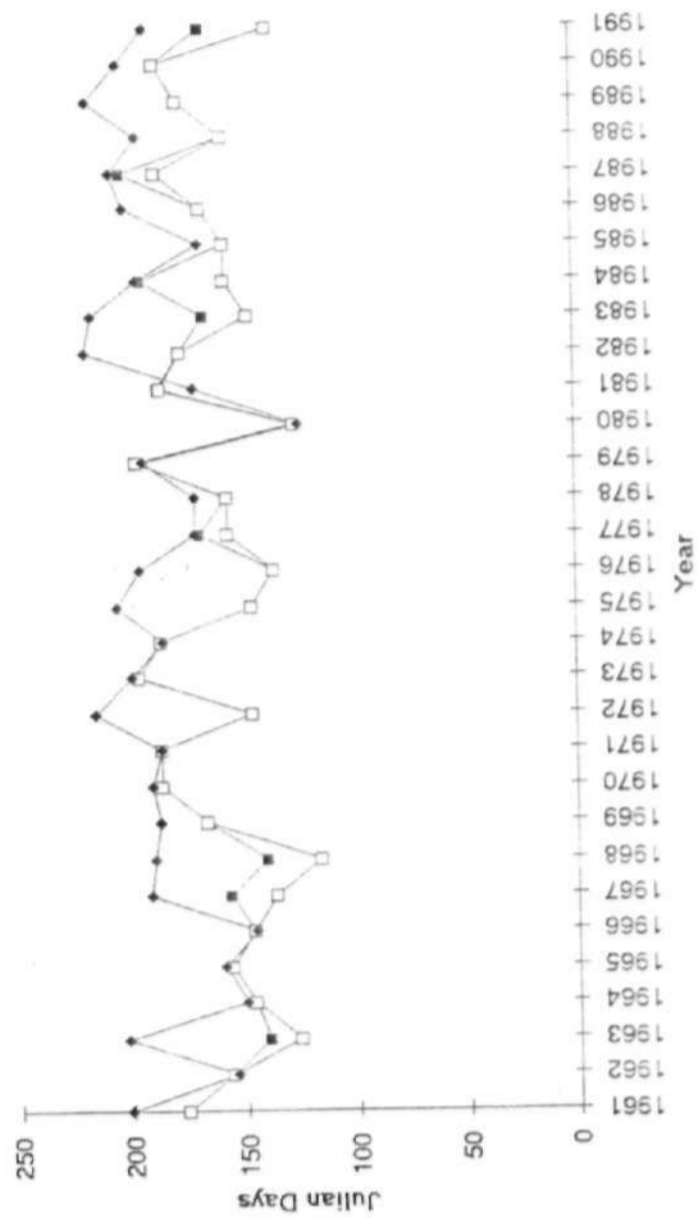


Figure 4.10 Onset dates Calculated based on Sivakumar's, Kowal's and the Hybrid Methods for Kano

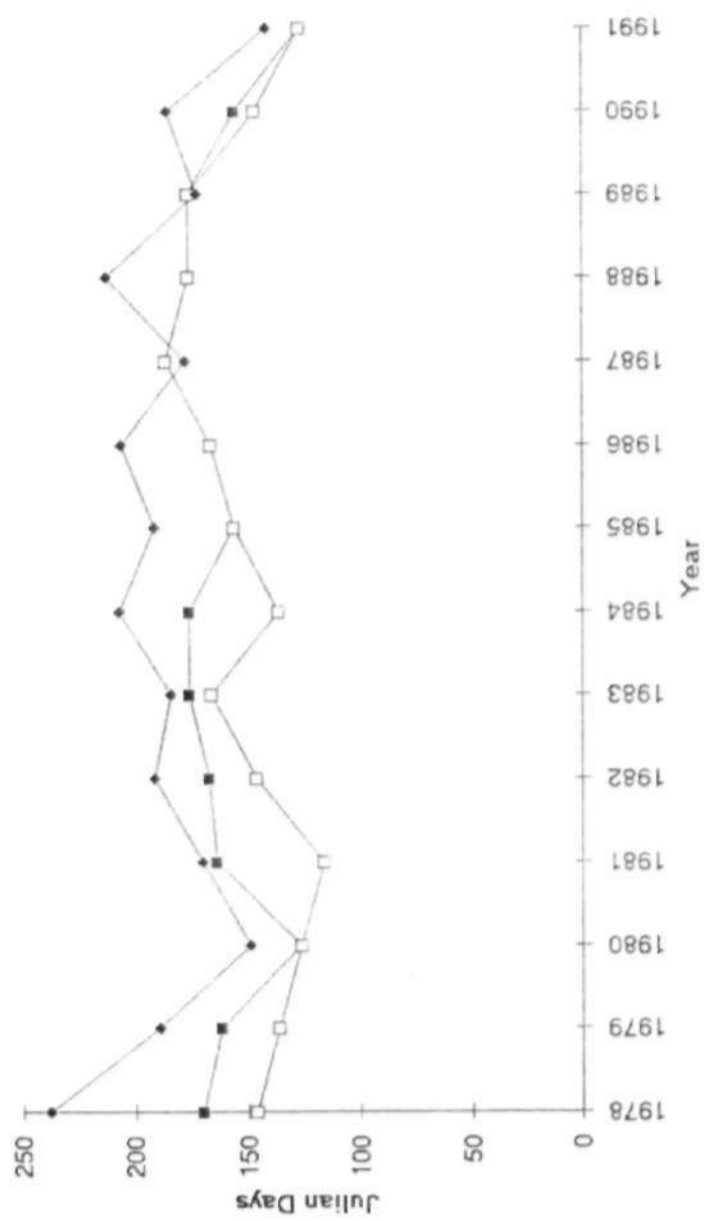


Figure 4.11 Onset dates Calculated based on Sivakumar's, Kowal's and the Hybrid Methods for Karaye

4.5 Conclusions

Comparison of the various method for calculating the date of onset leads us to the following conclusions:

The traditional "**Ramadan**" method leads to a too early onset date compared to all the other methods. The methods based on accumulated rainfall totals behave quite differently. While **Walter's** method gives a quite early onset, **Sivakumar's** method leads in all cases to a too late onset. In some cases the criteria for the calculation of the date of onset by **Sivakumar's** method can not be satisfied at all. On the other hand, the methods based on a rainfall/evapotranspiration relationship gave onset dates that are quite near to one another. The onset dates produced by these methods (**Kowal's** and **Benoit's**) fell between those of **Walter** and **Sivakumar**.

Rather logically, the earlier the onset date calculated, the greater the probability of a long dry spell during the germination period of the plant. The later the calculated onset date, of course the more danger of encountering a short growing season, though the risk of damaging dry spell is greatly reduced if not eliminated.

Though calculated mean onset dates give a ready date for the farmers to start planting, it is more save to plant using the onset date determined by monitoring the characteristics of the early rains for that particular year (referred to as the on line method). With the Kowal method, for example, the use of actual annual onset data in most cases decreased the number of false starts compared to the use of the mean onset data.

All the methods analysed lead to significant no of false starts even with the use of yearly onset dates. And Sivakumar's method that was able to reduce false starts led to a shortening of the growing season. There is therefore, the need need to have a formula that would avoid or at least greatly diminish false starts without the risk of shortening the season too much. To achieve this, a combination of **Kowal's method** with the absence of a long dry spell of more than 7 days should be used. The combination was found to give appreciable improvements over all the other methods. When tested for Kano and Karaye only obvious drought years for Kano still gave false starts. For Danbatta using the actual yearly onset, only one year experienced any dry spell. This could not be related to the drought years because of porous data from the station.

ITS ONSET SERIES IN THE STUDY AREA.

5.1 Introduction

Climates had varied in the past on different time scales. In recent times apparently climate variability (and eventually climate change) has been increasing. This has generated a lot of interest and concern among agrometeorologists and climatologists. Much effort has been put into trying to prove and understand any global climate trend in the last few decades (Repapis and Philandras, 1988; Oladipo, 1992)

Defining variability in climate and trying to prove actual climate change are very complex endeavors. Much of the data taken has been designed to observe weather rather than climate change (Folland et al, 1990).

In recent times, however, several parameters of variability and possible change have been studied. These include changes in average sea level (e.g. Titus, 1986; Warrick and Oerlemans, 1990) changes in average carbon dioxide levels (e.g. Schneider and Chen, 1982;). Temperature trends in recent years have also been studied (e.g. Sahsamanoğlu and Makrogianis 1992).

Changes in rainfall characteristics have also been studied, particularly in the seasonally arid tropics (Hulme, 1987; Oladipo and Kyari, 1993). The practice of agriculture would be seriously affected by increased variability and trends in the seasonal

characteristics of rainfall in an environment where one of the major factors of agricultural production is the amount of water available through rainfall. This chapter is therefore dedicated to the analysis of trends and changes in both the rainfall series and its onset series in the study area.

For any meaningful time series analysis to be carried out, there is need for long term, consistent and high quality data. This explains the selection of only Kano, out of all the stations, for the present analysis (see also section 3.2.2). The data considered cover a period of 70 years (1922 to 1991).

Each of the series (rainfall and onset) was subjected to the normality test to see if it is normally distributed. Each was then tested for trends and abrupt changes. The onset series was calculated based on the hybrid method.

5.2 Trends and Changes in the Rainfall Series for Kano

(a) **Normality test:** the rainfall series was subjected to the normality test using the coefficients of skewness (Z_1) and kurtosis (Z_2) described by **Brazel and Balling (1986)** and explained in section 3.2.2. The coefficient of skewness (Z_1) was 0.106 and that of kurtosis (Z_2) was 0.825. This indicates that the rainfall series has no significant deviation from the normal at 95% confidence level.

(b) Test for Trends.

The rainfall series was subjected to the **Mann-Kendall's test statistics (τ)** and the **Spearman's rank correlation (r_s)**. The calculated τ was - 0.303 with a **Z** value of -

3.710). This indicates a strong negative trend at 95% confidence limit. The calculated r_s was -0.429 with a t value of -3.916 and this also indicates a negative trend at the 95% confidence limit.

To further specify the character of the rainfall during the period, the ten-year means were calculated and the ten-year running mean was used to filter the series (figure 5.1). The ten-year running mean was tested for normality and found to be normally distributed with respect to skewness (with a calculated value of 1.200) and kurtosis (with a value of 1.787) at 95% confidence limit with the standard value of 1.96.

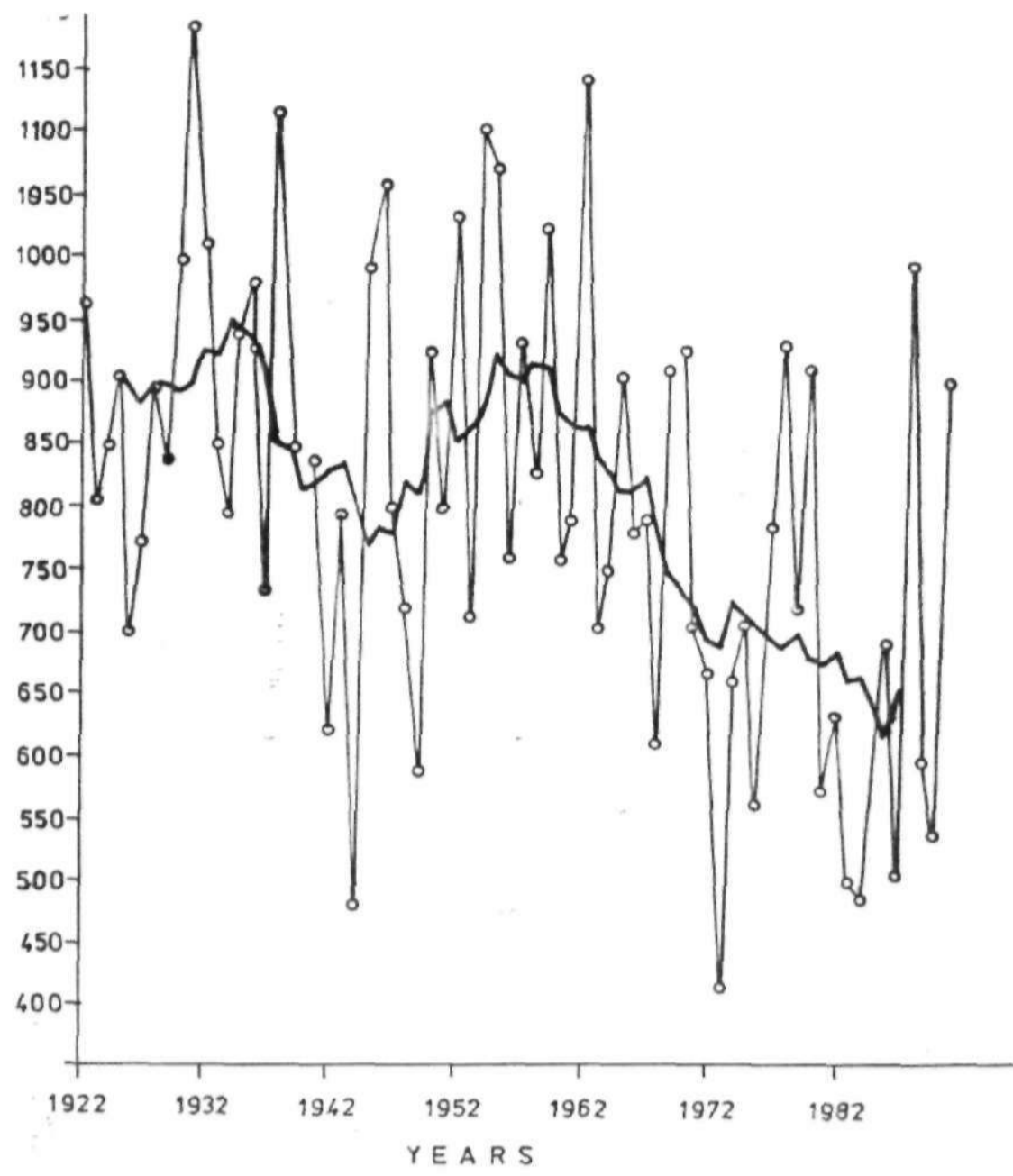


Figure 5.1 Annual variation in the rainfall series for Kano. Smooth curve is the ten-year running mean.

Table 5.1 Ten-year means of the rainfall series for Kano with the standard deviation, coefficient of variation, skewness, and kurtosis and Cramer's t_k .

Decades	Decadal \bar{x}	s	C.V.(%)		Z_1	Z_2	t_k
1922-1931	887	127	14.3	12.3	1.27	0.47	1.43
1932-1941	894	110	22.2		0.82	-0.37	1.55
1942-1951	780	173	15.8		0.02	-0.61	-0.50
1952-1961	904	143	17.5		0.15	-1.0	1.67
1962-1971	825	144	21.4		0.93	-1.74	0.40
1972-1981	696	149	25.5		-0.07	-0.39	-1.79
1982-1991	651	166			1.27	-0.19	2.24

In order to further identify the structure of the long-term temporal variance structure in the rainfall series, it was sub-divided into decadal periods (1922-1931, 1932-1941 1982-1991). The subperiods were tested for normality and their standard deviations and coefficients of variation compared (see Table 5.1). The decadal data were found to be normal at 95% confidence limit. The standard deviations and coefficients of variation have been decreasing in the last 3 decades. This shows a tendency towards drier conditions. This is supported by Oladipo (1993).

Decadal averages of the seasonal rainfall series were also examined to see if they differed from the mean of the entire period by using Cramer's test statistic (t_k). Only the last decade (1982-1991) showed any significant t_k values at 95% confidence level.

Comparisons between the non-overlapping subperiods, 1922-1931 through 1982-1991, were carried out for the rainfall data using Student's t test (t_d). The results are listed below;

Between 1922-1931 and 1932-1941 (0.14); 1932-1941 and 1942-1951 (1.59); 1942-1951 and 1952-1961 (1.57); 1952-1961 and 1962-1971 (1.11); 1962-1971 and 1972-1981 (1.77); 1972-1981 and 1982-1991 (0.58). This shows there is no statistically significant difference between the means of the subperiods through time.

Both the ten-year means and the ten-year running mean indicated a decreasing amount of annual rainfall and increasing variability.

(c) Test for abrupt changes.

Sneyer's method was applied to the rainfall series (see Appendix 2). Fig. 5.2 shows Sneyer's graph for the rainfall series. C_1 refers to the series beginning in 1922 and C_2 refers to the retrograde series. For the series the abrupt change towards decreasing rainfall is located in 1967. This is in agreement with Adedoyin (1989) and Oladipo (1992).

5.3 Trends and Changes in the Onset series of Kano.

The onset series based on the proposed hybrid method was used for the present analysis.

(a) Normality test.

The normality test was conducted on the onset series using the coefficients of skewness (Z_1) and kurtosis (Z_2) as described by Brazel and Balling (1986). The coefficient of skewness (Z_1) was 0.140 and that of kurtosis (Z_2) was 1.04. This indicates that the series was normally distributed at the 95% confidence limit.

(b) Test for trends.

The Mann-Kendall's rank statistical parameter (τ) and the Spearman's rank correlation (r_s) were applied to the onset series to test for trends. The calculated (τ) was 0.105 with a Z value of 1.29. There is no significant relationship shown by this test. The

calculated r_s for the same series was 0.151 with a t value of 1.26. This indicates no significant relationship at 95% confidence level. The ten-year means were calculated (Table 5.3) and the ten-year running mean used to further test for trends (figure 5.3). The ten-year running mean was subjected to the normality test and was found to be normally distributed at the 95% confidence limit with a critical value of 1.96. The calculated skewness was 0.198 and that of kurtosis was 1.169. The last few decades (1962-1991) indicated a tendency towards a much later onset than the long term mean.

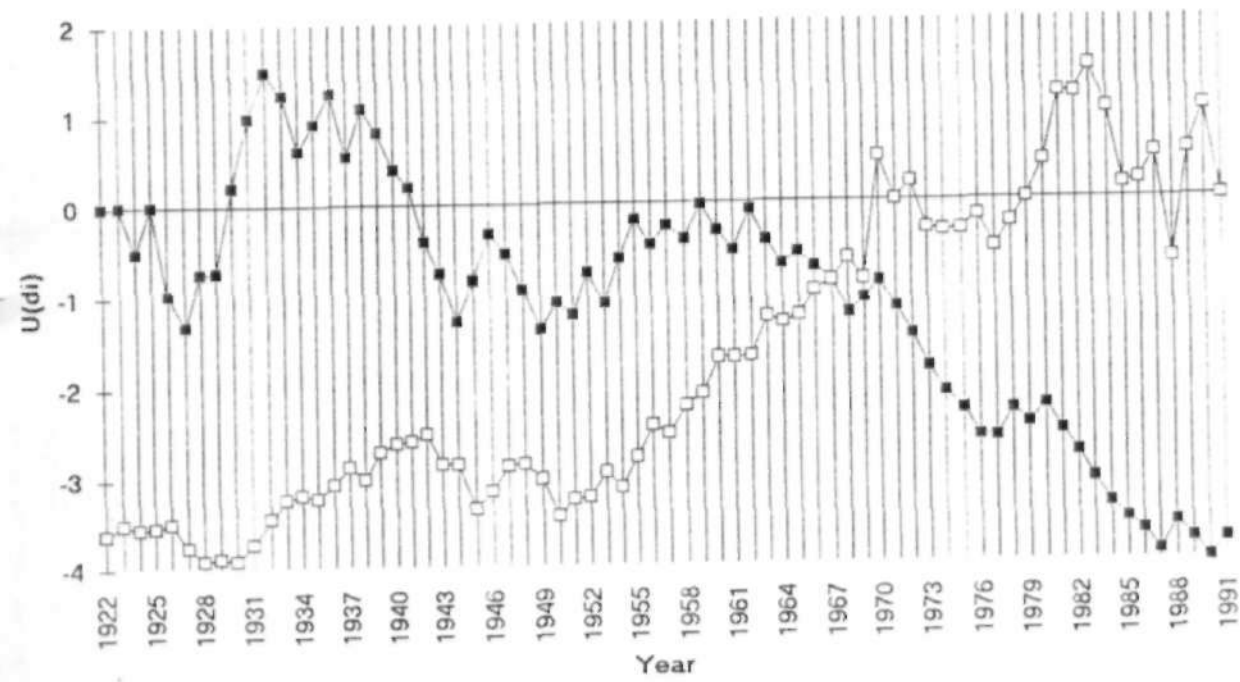


Figure 5.2 Evidence of Abrupt Change in the Rainfall Series for Kano

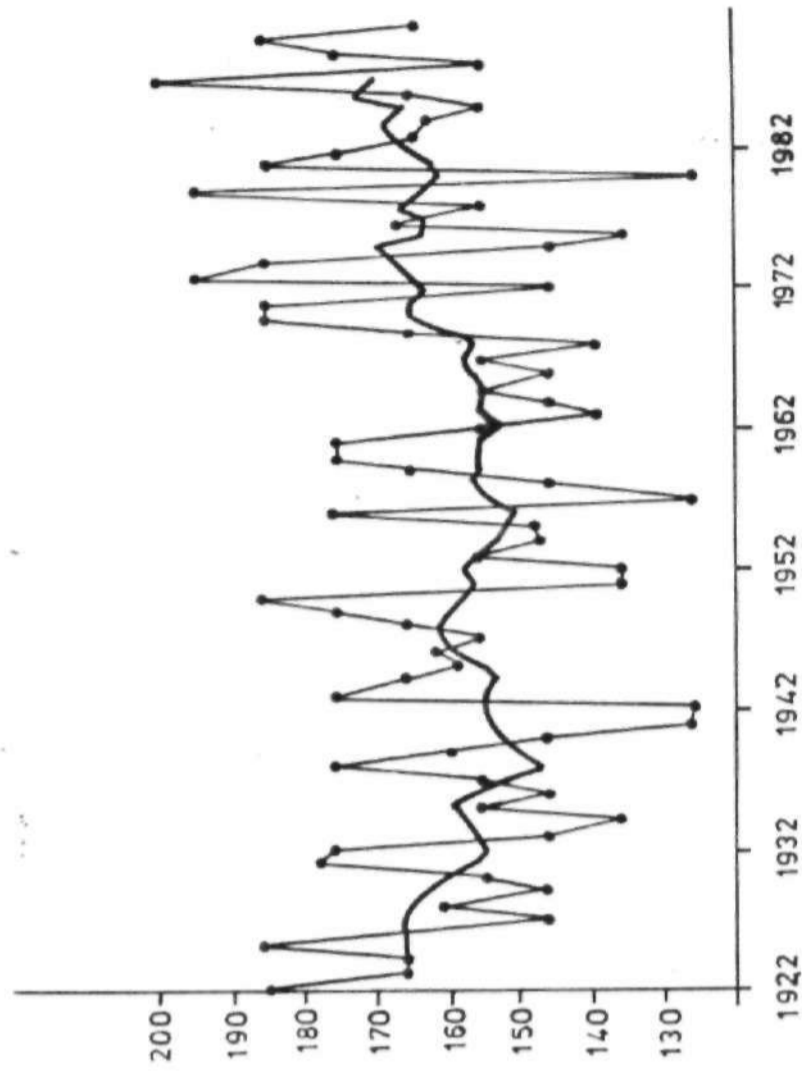


Figure 5.3 Annual variation in the onset of the growing season in Kano. Smooth curve is the ten-year running mean.

Table 5.2 Ten-years means for the onset series for Kano.

Decades	Decadal x	s	C.V. %	Z ₁	Z ₂	t _k
1922-1931	June 14	14	8.4	-0.05	-0.72	0.98
1932-1941	May 31	15	9.9	1.53	-0.46	-1.51
1942-1951	June 9	17	10.6	-0.89	-0.23	0.00
1952-1961	June 3	17	11	1.22	-0.78	-1.06
1962-1971	June 6	16	10.1	0.91	-0.50	-0.56
1972-1981	June 12	24	14.6	-0.02	-0.95	0.56
1982-1991	June 19	13	7.6	1.23	0.03	1.62

In an attempt to determine significant changes in the temporal patterns of the onset series, the entire period of 70 years of continuous data was divided into non-overlapping decadal subperiods (1922-1931, 1932-1942 1982-1991). The onset series for each subperiod were tested and found to be normally distributed at 95 % confidence level. The standard deviations and the coefficients of variation were found to be decreasing revealing a tendency towards an abrupt change in the trend (see Table 5.2).

The means of the subperiods were compared with the mean of the entire period using Cramer's test statistic (t_k). Only the decade 1922-1931 showed any statistically significant difference at 95 % level of confidence. Comparisons of the decadal means using the Student's t test (t_d) produced the following results;

Between 1922-1931 and 1932-1941 (**2.07**); 1932-1941 and 1942-1951 (**1.18**); 1942-1951 and 1952-1961 (**0.74**); 1952-1961 and 1962-1971 (**0.39**); 1962-1971 and 1972-1981 (**0.62**); 1972-1981-1982-1991 0(**0.75**). From the results above only the subperiods 1922-1931 and 1932-1941 showed any significant difference in their means.

(c) **Test for abrupt change**

Sneyer's method was applied on the onset date series (see Appendix 3). Fig. 5.4 gives the graphical representation of the anomalies in the onset series for Kano. C_1 refers to the series beginning in 1922 and C_2 refers to the retrograde series. For the onset series, the abrupt change towards late onsets is located in 1987.

5.4 Relationship between the Rainfall Series and the Onset Series.

Pearson's product moment correlation coefficient (r) (see 3.2.5) was used to test for any significant relationship between the rainfall and the onset series. The r value of -0.876 shows that there is a strong inverse relationship between the rainfall series and the onset series. That is as the rainfall is decreasing in value, there is the increasing tendency to lateness in the onset date.

5.5 Discussions.

In general, both the rainfall series and the onset series were found to be normally distributed as tested by their coefficients of skewness (Z_1) and kurtosis (Z_2) at the 95% confidence level.

The result of both Mann-Kendall's (τ) and Spearman's rank correlation (r_s) tests indicated that there is a significant negative trend in the annual rainfall totals. This showed tendency towards decreasing values. The ten-year means and the ten-year running mean further confirm these decreasing annual rainfall totals. This result is in agreement with that of Agnew (1991). It shows statistically what can be observed from simple data

that the areal rainfall has been below the long-term mean for the last 20 years. For the decade 1972-1981 it was 696 mm and for 1982-1991 it was 651 mm compared to the long term average of 805mm. From the moving average analysis (**figure 5.1**) a drop in annual rainfall totals became pronounced from before 1960 (when they were above the long term average). Since then there has been a downward trend in the amount of rainfall received annually. It fell below the long term average around 1967.

The **sequential version of Mann-Kendall's statistical** revealed abrupt change towards decreasing annual rainfall totals around 1967, in line with the simpler reasoning above. Considering the onset series based on the test statistic of **Mann-Kendall's (τ) and Spearman's rank parameter (r_s)**, there was no significant trend noticed. This shows that though there were high tendencies towards decreasing annual rainfall totals, the onset characteristics have not been sufficiently affected to warrant a conclusion on any significant trend in the onset over the area. The ten-year means, when compared, showed that the last three decades (1962-1991) gave indication of a later onset compared to the lower decade of 1952-1961. From the analysis of the running mean the tendency towards a later onset was indicated in the last three decades (1962-1991). This is in good agreement with the conclusions of **Oladipo and Kyari (1993)**.

Evidence of nearing abrupt change towards a later onset was first noticed around 1985 (**figure 5.4**), but the two curves have not separated definitely yet. These findings nevertheless questions the use of average onset dates.

Pearson's product moment correlation co-efficient (r) indicated a strong inverse relationship between the annual rainfall series and the onset dates. From this it is clear

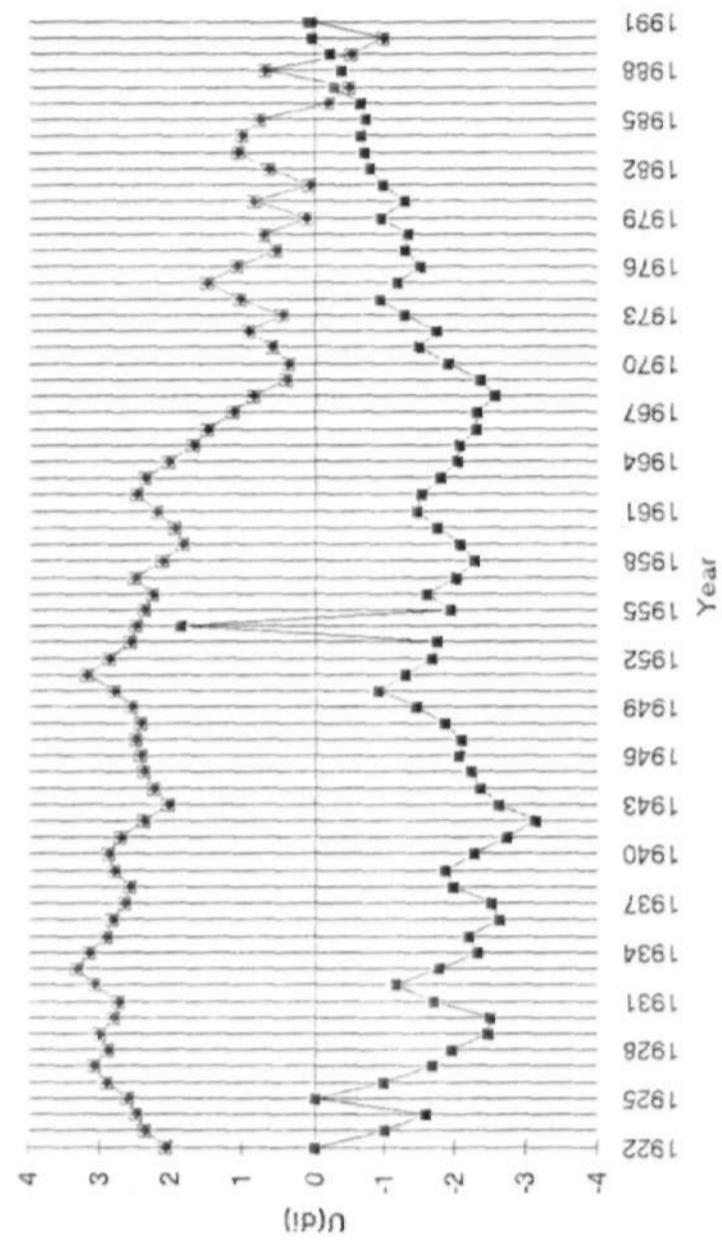


Figure 5.4 Evidence of Abrupt Change in the Onset of the Growing Season for Kano

that with decreasing rainfall amount, the tendency towards late onset is increasing.

5.6. Conclusions

The following conclusions were reached from the analysis of the trends in both the rainfall series and the onset series.

Though there is a trend towards decreasing of annual rainfall totals, the onset characteristics have remained statistically undisturbed. The annual rainfall totals was discovered to have changed abruptly around 1967. For the onset series abrupt change was first indicated only around 1987.

There is a strong negative correlation between the rainfall series and the onset series therefore, if the present downward trend in annual rainfall totals continues, a statistically significant shift towards later onset dates may be expected to occur. This conclusion is strengthened by the finding of nearing abrupt change in the onset series. As a consequence of the above conclusion, the use of average onset dates becomes questionable as a means of advising the farmer on when to plant.

CHAPTER SIX

GENERAL SUMMARY AND CONCLUSION

6.1. *Summary*

The ability to effectively predict the characteristics of the impending rainy season is of paramount importance to farmers in a semi-arid environment where agriculture is largely rain dependent and rain falls for only a relatively short part of the year, the start of the rains not being sharply defined. Close to the start of the rainy season for agricultural use, there is incidence of isolated showers intervened by long dry spells from several days to sometimes weeks. A good method of determining trustable onset dates holds a key to optimal production in these environments. The onset date is known to significantly affect the length and other characteristics of the season.

Five methods for the determination of an optimum planting date were selected. These methods are the traditional "**Ramadan**" method, **Walter's** method, **Sivakumar's** method, **Kowal's** method and **Benoit's** method.

The "**Ramadan**" method was found to perform poorer than all the other methods. **Walter's** method also led to a significant number of false starts. **Benoit's** and **Kowal's** methods, though moderate in their performance, are not sufficiently fit for use in the study area, because of a still significant number of false starts experienced as a result of onset dates calculated with these methods. **Sivakumar's** method gave onset dates that are too late. This would considerably affect the length of the growing season and consequently its

yields. In this work therefore a hybrid method is proposed combining a 7 days dry spell, used by Sivakumar as the criterion of a false start, with Kowal's method of determining the onset dates.

The rainfall series for Kano and the related onset series arising from the proposed hybrid method were tested for trends using the Mann-Kendall's test statistical parameter τ and Spearman's rank correlation (r_s). They were subjected to further tests using the ten-year means and the ten-year running means.

The normality tests using the co-efficients of skewness and kurtosis showed that both series were normal at the 95% significance level. The rainfall series indicated a strong negative trend at the 95% significance level. This was further confirmed by the ten-year mean, and the ten-year running mean. To further determine significant changes in both the rainfall and the onset series, the long term data were sub-divided into decadal subperiods. The data for each decade were tested for normality using skewness and kurtosis. The means, standard deviations and coefficients of variation were calculated for the subperiods. The rainfall from all the tests showed the tendency towards decreasing annual amount. The onset series did not show any significant trend by all these tests. However, since the 1952-1961 decade there is an indication of a slight tendency towards later onset, but this is not enough to make any meaningful generalizations.

The means of the subperiods were compared to the long-term mean using Cramer's test (t_c). For the rainfall data only the last decade showed any statistically significant difference by the test. The onset series did not show any statistically significant difference. The Student's t test (t_d) was used to compare the means of the non-overlapping

subperiods. The rainfall series indicated no significant difference by this test. For the onset data, only 1922-1931 and 1932-1941 showed any significant relationship.

The two series were also tested for **abrupt changes** using a **sequential version of the Mann-Kendall rank statistics by Sneyers**. Evidence of abrupt change was found for the rainfall series around **1967**. For the onset series, abrupt change was first noticed around **1987**.

The **relationship** between the onset series and the rainfall series was tested using **Pearson's product-moment correlation co-efficient (r)**. The test revealed a **strong inverse relationship**.

6.2. General Conclusions

The study conducted on the various techniques for determining the onset of the rainy season, together with the other analysis led to the following conclusions:

The traditional "**Ramadan**" method leads to a too early onset date compared to all the other methods. The methods based on accumulated rainfall totals behave quite differently. While **Walter's** method gives a quite early onset, **Sivakumar's** method leads in all cases to a too late onset. In some cases the criteria for the calculation of the date of onset by **Sivakumar's** method cannot be satisfied at all. On the other hand, the methods based on a rainfall/ evapotranspiration relationship gave onset dates that are quite near to

one another. The onset dates produced by these methods (**Kowal's** and **Benoit's**) fell between those of **Walter** and **Sivakumar**.

Rather logically, the earlier the onset date calculated, the greater the probability of a long dry spell during the germination period of the plant. The later the calculated onset date, of course the more danger of encountering a short growing season, though the risk of damaging dry spell is greatly reduced if not eliminated.

Though calculated mean onset dates give a ready date for the farmers to start planting, it is more save to plant using the onset date determined by monitoring the characteristics of the early rains for that particular year (referred to as the on line method). With the Kowal method, for example, the use of actual annual onset data in most cases decreased the number of false starts compared to the use of the mean onset data.

All the methods analysed lead to significant no of false starts even with the use of yearly onset dates. And Sivakumar's method that was able to reduce false starts led to a shortening of the growing season. There is therefore, the need need to have a formula that would avoid or at least greatly diminish false starts without the risk of shortening the season too much. To achieve this, a combination of **Kowal's** method with the absence of a long dry spell of more than 7 days should be used. The combination was found to give appreciable improvements over all the other methods. When tested for Kano and Karaye only obvious drought years for Kano still gave false starts. For Danbatta using the actual yearly onset, only one year experienced any dry spell. This could not be related to the drought years because of porous data from the station.

Though there is a trend towards decreasing of annual rainfall totals, the onset

characteristics have remained statistically undisturbed. The annual rainfall totals was discovered to have changed abruptly around 1967. For the onset series abrupt change was first indicated only around 1987.

There is a strong negative correlation between the rainfall series and the onset series therefore, if the present downward trend in annual rainfall totals continues, a statistically significant shift towards later onset dates may be expected to occur. This conclusion is strengthened by the finding of nearing abrupt change in the onset series. As a consequence of the above conclusion, the use of average onset dates becomes questionable as a means of advising the farmer on when to plant.

6.3. Suggestions.

The analysis conducted is area specific and all conclusions reached here could be tested for different areas with similar or different ecological settings to the study area. As a very general weather advisory for determination of the onset date of the rainy season in the study area, the proposed hybrid method could be used for to advice farmers in taking decisions on the **optimum planting date**. This could be achieved by the establishment of a group that would determine the onset date from year to year using the proposed method. This group by way of extension services should be responsible for disseminating the onset date to the farmers and monitoring what happens within the season to be able to plan for the next season.

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APPENDIX I

The calculated dates of onset based on the proposed Hybrid method for eight stations.

A. Kano.

1961	June 25	1977	June 17
1962	June 5	1978	June 5
1963	May 20	1979	July 15
1964	May 25	1980	May 5
1965	June 5	1981	July 5
1966	May 26	1982	June 25
1967	June 5	1983	June 14
1968	May 19	1984	July 11
1969	June 15	1985	June 5
1970	July 5	1986	June 15
1971	July 5	1987	July 20
1972	May 25	1988	June 4
1973	July 15	1989	June 25
1974	July 5	1990	July 5
1975	May 26	1991	June 14
1976	May 15		
			x = June 13
			s = 18
			C.V. = 11.2%

B. Danbatta.

1961	July 15	1977	June 25
1962	July 21	1978	June 5
1963	July 20	1979	June 25
1964	June 4	1980	May 15
1965	June 5	1981	-
1966	-	1982	July 5
1967	July 5	1983	-
1968	May 25	1984	*
1969	-	1985	*
1970	July 5	1986	July 5
1971	July 25	1987	July 3
1972	June 22	1988	June 22
1973	July 15	1989	August 8
1974	*	1990	August 4
1975	*	1991	June 30
1976	June 14		
			x = June 27
			s = 21
			C.V. = 11.6%

C. Karaye.

1978	June 19	1985	June 5
1979	June 11	1986	June 15
1980	May 5	1987	July 5
1981	June 13	1988	June 24
1982	June 16	1989	June 25
1983	June 25	1990	June 4
1984	June 24	1991	May 6
			x = June 10
			s = 16
			C.V. = 9.8%

D. Roni.

1978	June 17	1985	June 25
1979	June 5	1986	June 25
1980	May 25	1987	July 15
1981	-	1988	June 4
1982	June 25	1989	August 4
1983	July 23	1990	-
1984	June 29	1991	June 30
			x = June 22
			s = 20
			C.V. = 11.2%

E. Gadanya.

1978	May 26	1985	June 5
1979	June 5	1986	June 15
1980	May 25	1987	July 21
1981	June 8	1988	June 22
1982	June 5	1989	June 25
1983	June 15	1990	June 25
1984	June 29	1991	May 16
			x = June 11
			s = 17
			C.V. = 10.4%

F. Kazarec.

1986	June 25	1989	July 15
1987	July 25	1990	August 4
1988	June 4	1991	June 2
			x = July 1
			s = 24
			C.V. = 13%

G. Maigatari.

1986	-	1989	July 7
1987	July 15	1990	July 5
1988	July 31	1991	June 30
			x = July 10
			s = 11
			C.V. = 5.7%

SICH

1986	June 25	1989	June 14
1987	July 25	1990	-
1988	June 21	1991	June 2
			x = June 22
			s = 18
			C.V. = 10.3%

APPENDIX 2

Application of Sneyer's version of the Mann Kendall Statistics to the rainfall series of Kano station.

i	x_i	m_i	d_i	$U(d_i)$	i	m_i	d_i	$U(d_i)$
1	915	0	0	0.00	70	51	1563	-3.61
2	808	0	0	0.00	69	37	1512	-3.51
3	850	1	1	-0.52	68	42	1475	-3.56
4	903	2	3	0.00	67	44	1433	-3.55
5	703	0	3	-0.98	66	17	1389	-3.50
6	772	1	4	-1.32	65	27	1372	-3.76
7	891	4	8	-0.75	64	41	1345	-3.91
8	837	3	11	-0.74	63	37	1304	-3.89
9	999	8	19	0.21	62	52	1267	-3.91
10	1187	9	28	0.98	61	60	1215	-3.73
11	1010	9	37	1.48	60	52	1155	-3.44
12	852	5	42	1.23	59	39	1103	-3.24
13	799	2	44	0.61	58	32	1064	-3.19
14	942	10	54	0.91	57	45	1032	-3.22
15	983	11	65	1.24	56	46	987	-3.07
16	739	1	66	0.54	55	23	941	-2.88
17	1119	15	81	1.07	54	52	918	-3.02
18	848	6	87	0.80	53	36	866	-2.72
19	815	4	91	0.39	52	33	830	-2.63
20	840	7	98	0.20	51	34	797	-2.60
21	624	0	98	-0.42	50	9	763	-2.52
22	797	4	102	-0.76	49	29	754	-2.86
23	486	0	102	-1.29	48	2	725	-2.86
24	996	19	121	-0.84	47	39	723	-3.35
25	1060	22	143	-0.33	46	42	684	-3.15
26	801	7	150	-0.55	45	38	642	-2.88

i	x _i	m _i	d _i	U(d _i)	i	m _i	d _i	U(d _i)
27	723	3	153	-0.94	44	18	614	-2.85
28	591	1	154	-1.38	43	7	596	-3.03
29	927	20	174	-1.09	42	34	589	-3.44
30	801	9	183	-1.23	41	26	555	-3.26
31	1039	27	210	-0.77	40	36	529	-3.24
32	717	4	214	-1.10	39	17	493	-2.96
33	1109	30	244	-0.62	38	36	476	-3.13
34	1078	30	274	-0.19	37	35	440	-2.80
35	760	7	281	-0.47	36	18	405	-2.45
36	936	24	305	-0.27	35	31	387	-2.54
37	830	14	317	-0.42	34	24	356	-2.24
38	1025	31	350	-0.04	33	31	332	-2.11
39	760	7	357	-0.32	32	18	301	-1.72
40	782	10	367	-0.54	31	18	283	-1.72
41	1144	39	406	-0.09	30	29	265	-1.70
42	707	4	410	-0.44	29	14	237	-1.28
43	753	8	418	-0.70	28	17	223	-1.34
44	908	27	445	-0.57	27	21	206	-1.27
45	781	12	457	-0.74	26	16	185	-0.99
46	792	14	471	-0.88	25	18	169	-0.89
47	613	2	473	-1.24	24	8	151	-0.65
48	913	30	503	-1.08	23	19	143	-0.87
49	926	33	536	-0.90	22	19	124	0.48
50	709	6	542	-1.18	21	13	105	0.00
51	671	4	546	-1.49	20	11	92	0.20
52	418	0	546	-1.84	19	0	81	-0.32
53	664	5	551	-2.12	18	9	81	-0.34

i	x_i	m_i	d_i	$U(d_i)$	i	m_i	d_i	$U(d_i)$
54	716	10	561	-2.31	17	10	72	-0.33
55	565	2	563	-2.61	16	4	62	-0.18
56	786	21	584	-2.63	15	10	58	-0.54
57	931	45	629	-2.33	14	13	48	-0.27
58	723	13	642	-2.48	13	9	39	0.00
59	912	39	681	-2.28	12	10	30	0.41
60	575	3	684	-2.56	11	4	20	1.17
61	638	6	690	-2.80	10	5	16	1.16
62	500	2	692	-3.08	9	1	11	1.46
63	479	1	693	-3.36	8	0	10	0.99
64	656	10	703	-3.53	7	3	10	0.15
65	693	13	716	-3.67	6	3	7	0.19
66	506	4	720	-3.90	5	0	4	0.49
67	996	55	775	-3.58	4	3	4	-0.68
68	598	8	783	-3.77	3	1	1	0.52
69	541	5	788	-3.99	2	0	0	1.00
70	905	47	835	-3.78	1	0	0	0.00

APPENDIX 3

Application of Sneyer's version of the Mann Kendall Statistics on the onset date series of Kano station.

i	x_i	m_i	d_i	$U(d_i)$	i	m_i	d_i	$U(d_i)$
1	185	0	0	0.00	70	59	1004	2.06
2	166	0	0	-1.00	69	40	945	2.36
3	166	0	0	-1.60	68	40	905	2.48
4	186	3	3	0.00	67	57	865	2.60
5	166	0	3	-0.98	66	40	808	2.92
6	146	0	3	-1.69	65	10	868	3.08
7	161	1	4	-1.95	64	34	758	2.90
8	146	0	4	-2.48	63	10	724	3.00
9	155	2	6	-2.50	62	20	714	2.81
10	178	7	13	-1.70	61	51	694	2.75
11	176	7	20	-1.17	60	42	643	3.09
12	146	0	20	-1.78	59	10	601	3.33
13	136	0	20	-2.32	58	4	591	3.16
14	156	5	25	-2.20	57	18	587	2.91
15	146	1	26	-2.62	56	9	569	2.84
16	156	6	32	-2.52	55	17	560	2.65
17	176	12	44	-1.98	54	37	543	2.57
18	160	8	52	-1.86	53	26	506	2.81
19	146	1	53	-2.27	52	9	480	2.88
20	126	0	53	-2.73	51	0	471	2.71
21	126	0	53	-3.14	50	0	471	2.37
22	176	16	69	-2.62	49	33	471	2.02
23	166	13	82	-2.35	48	27	438	2.24
24	159	11	93	-2.23	47	22	411	2.38
25	162	13	106	-2.06	36	22	389	2.43

i	x _i	m _i	d _i	U(d _i)	i	m _i	d _i	U(d _i)
26	156	9	115	-2.09	45	14	367	2.50
27	166	16	131	-1.86	44	24	353	2.43
28	176	21	152	-1.46	43	28	329	2.56
29	186	27	179	-0.90	42	33	301	2.81
30	136	2	181	-1.30	41	2	268	3.19
31	136	2	183	-1.68	40	2	266	2.89
32	156	11	194	-1.75	39	12	264	2.58
33	147	10	204	1.86	38	10	242	2.50
34	148	11	215	1.94	37	10	242	2.38
35	176	26	241	-1.61	36	23	232	2.26
36	126	0	241	-2.02	35	0	209	2.51
37	146	5	246	-2.28	34	4	209	2.12
38	166	23	269	-2.07	33	17	205	1.83
39	167	29	298	-1.75	32	20	188	1.95
40	167	29	327	-1.47	31	20	168	2.19
41	156	15	342	-1.53	30	8	148	2.48
42	140	6	348	-1.79	29	2	140	2.36
43	146	6	354	-2.04	28	3	138	2.02
44	156	17	371	-2.06	27	6	145	1.69
45	146	6	377	-2.31	26	3	129	1.48
46	156	18	395	-2.32	25	5	126	1.12
47	140	6	401	-2.56	24	2	121	0.84
48	166	30	431	-2.36	23	10	119	0.40
49	186	46	477	-1.91	22	14	109	0.37
50	186	46	523	-1.50	21	14	95	0.60
51	146	7	530	-1.75	20	2	81	0.91
52	196	51	581	-1.29	19	16	79	0.46
53	186	47	628	-0.94	18	13	63	1.02

i	x _i	m _i	d _i	U(d _i)	i	m _i	d _i	U(d _i)
54	146	7	635	-1.20	17	2	50	1.48
55	136	3	638	-1.52	16	1	48	1.08
56	168	40	678	-1.30	15	8	47	0.54
57	156	22	700	-1.35	14	1	39	0.70
58	196	56	756	-0.95	13	11	38	0.12
59	126	0	756	-1.30	12	0	27	0.82
60	186	52	808	-0.98	11	8	27	0.08
61	176	43	851	-0.80	10	6	19	0.63
62	165	35	886	-0.72	9	3	13	1.04
63	163	35	921	-0.66	8	2	10	0.99
64	156	23	944	-0.74	7	0	8	0.75
65	166	38	982	-0.66	6	2	8	-0.19
66	201	65	1047	-0.28	5	4	6	-0.49
67	156	23	1070	-0.38	4	0	2	0.68
68	176	48	1118	-0.22	3	1	2	-0.52
69	186	58	1176	0.03	2	1	1	-1.00
70	165	38	1214	0.07	1	0	0	0.00