

**AGROSTATISTICAL ANALYSIS
OF RAINFALL DATA FOR THE
HUMID AND SUB HUMID
STATIONS OF NIGERIA**

BY



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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirements of the Department of Agricultural Engineering, Federal University of Technology, Akure for the award of Master of Engineering in Soil and Water Conservation Engineering.



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DECLARATION

I hereby declare that this thesis is a record of my research work. It has neither been presented nor accepted in any previous application for a higher degree.

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DEDICATION

This project work is dedicated to my grandfathers in the lord, Late Archbishop Benson Idahosa, Pastor Enoch Adejare Adeboye, and my father in the lord, Bishop David Oyedepo. Your words are producing stars out of weaklings.

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LIST OF SYMBOLS

SYMBOL	UNIT	NOMENCLATURE
AET	mm of water	Actual Evapotranspiration
PET	mm of water	Potential Evapotranspiration
S_w	mm	Soil water on day i
T	$^{\circ}\text{C}$	air temperature
K_p	mmHg	Pan coefficient
e_a	-	Saturation vapour pressure of water at air temp.
e_d	-	Saturation vapour pressure at dew point
U	mm/day	Wind speed
R	-	Incoming solar radiation
R_a	-	Outgoing terrestrial radiation
R_s	-	Short-wave radiation
α	-	Albedo or reflection coefficient
n		Actual hour of bright sunshine
N		Possible hour of bright sunshine
σ		Stefan's constant
γ	mmHg/ $^{\circ}\text{C}$	Psychometric constant
Δ	mmHg/ $^{\circ}\text{C}$	Slope of saturation vapour pressure curve
P	mbar	Mean atmospheric pressure
L	J/g	Latent heat of vapourization
E	m	elevation above sea level
ρ	Kg/m^3	air density
C_p	J/Kg $^{\circ}\text{C}$	specific heat of the air
r_a	s/m	aerodynamic resistance
r_s	s/m	bulk stomata resistance
R_{sa}	s/m	effective aerodynamic resistance

SYMBOL	UNIT	NOMENCLATURE
I	-	annual heat index
m	-	cubit function of I
l	-	monthly heat index
rf	-	radiation ratio
RH	%	relative humidity
LAI	-	Leaf area index

ABSTRACT

Agroclimatological information provides the basic tool for proper and profitable agricultural planning. The study was aimed at carrying out detailed analysis of rainfall data of long term duration in humid and subhumid stations in Nigeria using Onne and Ibadan meteorological data.

Data were analysed to obtain general rainfall characteristics such as precipitation index, distribution and variability of the two stations. The shortcoming of these methods led to the development of further analysis of the rainfall data to obtain daily soil water budget the falling rate soil water budget based on some reasonable assumption and this was used to calculate daily water supply budget which was further analysed to obtain the runs of consecutive days with wet soil thus enabling determination of time of sowing and harvesting.

The rainfall data was modelled using the first order Markov chain to determine the dependence of wet and dry days. The probability of a dry day following a dry day for Ibadan varies between 0.44 - 0.98 and 0.64 - 0.99 for Onne. The study indicate that for the purpose of agricultural planning in these zones, there is the need to take into account the weather condition of at least two previous days in order to predict the occurrence of wet or dry spell during the growing season.

Significant reduction of about 20 days was recorded in the length of the growing season over the period under study for both sites. Also a significant decline in rainfall total was observed particularly in Onne.

The result obtained would be useful for agricultural planning and mapping on regional scale. It is equally adaptable to growing season determination.

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

Change in climate is a global concern today. Shifts or variation in rainfall in its extent and distributions have direct implication for mankind food supply. This aspect is of particular concern in sub-Saharan Africa, where per capita food availability declined consistently over the past three decades (IITA, 1992). The success of nearly every farm operation or farm management strategy depend on the current weather and even the weather of the next few hours. Thus climatic information is a necessity for a successful agricultural planning and development. For accurate decision making, information from processed data are required and hence the need to look into all the possible ways of analysing data generated from the environment.

Simple climatic analyses of record had been carried out for different climatic zones and were used for different purposes. Example are, the long term average of temperature and rainfall, precipitation index computation, ambiothermic curve analysis, e.t.c. (Mollar and Cook, 1996; Lamb, 1982; Vispy, 1995). Rainfall analyses are carried out on yearly, monthly, decadal (10 days) and on weekly basis in most studies (Sivakumar et al. 1993, Oladipo and Kwaghsaa, 1994). However, most of them fail to adequately take into consideration the effect of variation of the weather on agricultural practices and often are inadequate to provide solution to pressing agricultural problems or situations.

Weather variability, particularly that of rainfall have been and are still being studied in the developed countries and many of the models generated are in use even in less developed countries. In Nigeria, for example, where adequate records are not available and not much work have been done.

Various indices (water efficiency and, thermal indices, heat units, etc.) have been developed in the past to relate climatological data to agricultural problems such as crop growth, yield and production for the purpose of land use planning and crop zonation. This often involved relating rainfall record to temperature data to obtain evapotranspiration and which in turn is related to crop water requirement and length of growing season based upon certain indices.

Mathematical models for calculating the crop water requirement at various stages of growth have been developed from which crop yield can be predicted provided that all the physical conditions upon which the model is based are satisfied. Most of these models are based on soil physical characteristics, climatic condition available and the crop phenology and characteristics. The models vary in their degree of sophistication depending on the input data required. Unfortunately, most of these models require data which are not readily available, particularly, in a developing nation like ours where accurate record taking is not given the desired attention. Moreover, they are sometimes complex and therefore cannot be handled by the peasant farmers.

This project work is mainly based on the analysis of rainfall data which are readily available in most meteorological stations. It evaluates the impact of these data on crop production and agricultural practice and attempts to model the dependence of wet and dry day sequences by the examination of the past record. It is believed that

this will aid the study of persistent wet and dry spell. This is of particular interest in Nigeria where agriculture is still the highest employer of labour. The ever increasing population and consequently increase in demand for food and the increasing exploitation of the land justifies the need for adequate studies on this important factor affecting agricultural production.

1.1 Objectives

The major objectives of these study are to:

- i. Analyse the pattern of rainfall and their effects on agriculture and environment in the humid and sub-humid zones of Nigeria for the past 20 years;
- ii. Develop a simple water balance model based on rainfall data from which the soil water can be estimated for each day of the year and evaluate the impact of this on agriculture and the environment;
- iii. To model the dependence of wet and dry days in the two zones;

In order to achieve these objectives, meteorological data from Onne were taken as representative of the humid zone and those of Ibadan as representative of the sub-humid zone of Nigeria. The choice of these two cities is based on the availability of accurate and reliable data.

The study is an attempt to analyse historical data to characterise past events in order to foretell future probabilities. This approach assumes that what happened over some long period in the past will be repeated with similar averages and probabilities over some long period in the future. The possibility of forecasting trends or cycle is beyond the scope of the study.

CHAPTER TWO

LITERATURE REVIEW

Many research works are being carried out on climate due to its wide application to all facets of life. Meteorologist in particular have been concerned with spectral and atmospheric meteorology while physicist have at different times work on radiation and solar component of the atmosphere. These works lead to development of models which are applicable to almost all aspect of live today

In Nigeria there is a need for climatic study of climate from the agricultural point of view, since all phases of agricultural production is weather dependent (Oladipo and Kwaghsaa, 1994)

2.0 Climatic Variables

Agrometeorology is the study of the influence of various climatic factors on agriculture. However, these climatic variables never act in isolation but are interactive (FAO, 1978). The climatic variables have combine effect on water balance, yield and evapotranspiration models etc.; all which have direct consequence on agricultural production and are being used as basis for agricultural production forecasting. The different climatic parameters which are of direct influence in agriculture are discussed below:

2.1.1 Air Temperature

Air temperature is a result of the energy balance at the surface of the earth.

This parameter is important in agrometeorological studies because:

- i. It conditions the level of physio-chemical reaction of the plant and therefore their biological activities and finally their biomass production. It also influence the rate of development of the plant and thus the length of the vegetative cycle.
- ii. It conditions the water vapour contained in the air mass and the evaporative phenomena.
- iii. It has direct influence on soil temperature near the surface, conditioning the rate of decomposition of the organic matter into a simple component.

Temperature is directly dependent on altitude and this affect length of growing season. Bristow (1992) for example, derived a model for estimating the daily mean vapour density from daily minimum temperature in Australia.

$$P_v = h p_v^s(T_a) \quad (1)$$

where

P_v = vapour density g/m^3 , T_a = air temperature $^{\circ}C$, P_v^s saturated vapour density g/m^3

Vapour density (P_v) is a widely used agroclimatological variable which qualifies the water status of the lower atmosphere. The knowledge of atmospheric water status is required for computing evaporation, transpiration, evapotranspiration, vapour density deficit and emmissivity (Penman, 1948). Brisson et. al. (1992) modelled the maximum rooting depth (Z_r) from temperature and water stress thus:

$$Z_r = \sum T \times gr \times Sr \quad (2)$$

where

$\sum T$ = cumulative degree - days since growing began

gr = root growth rate and

Sr = root stress factor

This was used as a sub-component for a soil water balance model for crop simulation in France.

Mailhol et al. (1997) used the concept of Thermal time (TT) to model the leaf area index (LAI) which could be used to predict crop yield. The thermal time ($^{\circ}\text{C}/\text{day}$) is calculated using the relationship below (Sepakhah and Hampour 1995),

$$TT(j) = \sum_{k=1}^{<:j} (\text{daily maximum temp } (k) + \text{daily min. Temp } k / 2 - \text{base temp}) \quad (3)$$

where j is the daily subscript.

The base temperature is the temperature threshold below which many crops physiological activities (annual in particular) are greatly reduced and the plant is dormant. These threshold value vary from 5°C for wheat to over 12°C for rice, FAO, (1992).

Similarly McIntyre et. al. (1993) predicted dry matter accumulation in both irrigated and non-irrigated millet in Northern Nigeria using the thermal time index. They also related the radiation interception to the thermal time concept. Ellis et. al., (1993) concluded that, leaf appearance rate, the leaf number at panicle emergence and panicle development rate are strongly influenced by the temperature of the air.

The experiment was carried out for rice in Reading in the United Kingdom. This factor was observed to be the major parameter that determines the yield of rice.

2.1.2 Air Humidity

Humidity is often expressed as vapour pressure, a parameter based on saturation deficit i.e. this is the difference in saturation and actual vapour pressure. Humidity is studied due to its effect in plant protection. Lema (1986), Pedgely (1986) and Renfro (1986) concluded that the development and sensitivity of most plant diseases are linked to high air humidity. Humidity is also widely studied for its influence on conservation of stored product. Renfro (1986) showed that loss of crop in storage is closely associated with high humidity.

2.1.3 Precipitation

Precipitation provides the gain for the crop water system. Rainfall is the most important single meteorological parameter which conditions agriculture because, it provides the water necessary for the functioning of the soil - plant - atmosphere system (FAO, 1986, Oladipo and Kwaghsaa, 1994). It regulates the flow of sap through the plant and the elaboration of the dry matter which is then harvested as products.

Rainfall study is extremely important because while other parameters are rather conservative in time and space, rainfall amount and distribution are extremely variable in time and space. This is why when calculating weekly or decadal water balances, it is possible to use climatological values for the assessment of evaporative processes for a given location since the actual daily values of the same parameter, taken over weekly and decadal periods, will not be significantly different from average

climatological value for the same decade or week (Stern and Coe, 1985). Many workers, for example Krajewski (1987), worked on radar simulation of rainfall and imagery analysis. However most of these predictions can not be used for calculating rainfall amount because of compounding problem of individual errors over successive period FAO, (1986).

The following general characteristics of rainfall observation are of interest.

i. The seasonal average quantity which will give a first idea of the broad suitability of a given area for a given type of crop and in particular the knowledge of the 70% probability of rainfall, which is sometimes called dependable rainfall. Sivakumar et al. (1993) used this concept to model the dependable rainfall in Niger from which the agricultural map for Niger was produced. Researchers from Ibadan IITA (1992) concluded that there was a general decline of rainfall in Nigeria over both time and space. They reported that there was a reduction of 100-313 mm in annual rainfall from 1961-1990 in Nigeria in different areas depending on topography and location. Real drought was reported in the year 1973 and 1983 and they concluded that, a continuation of such trend will lead to desert encroachment in the nation. Similarly, Hess et al. (1995) analysed rainfall trend in the North East of the Arid Zone of Nigeria using 1961-1990 record of Nguru (12.53° N, 10.28° E, alt 343m), Potiskum (11.42° N, 11.02° E, alt 415 m) and Maiduguri (11.51° , 13.05° E, at 354m). They concluded that there was a consistent decrease of 8 mm / year in annual rainfall in all the stations. They observed that majority of the reduction occurred in August or September and that the main reason for the decrease was a reduction of 6.25 days in the number of rain days observed during the rainy season.

ii. The decadal or weekly rainfall probability enable us to assess the following agricultural dates and periods:

a) Sowing date: The initial period of a rainy season often consist of some rainy events, which may be followed by a dry spell before the actual rainy season acquires the continuity required for a good emergence and vegetative growth of the crops. The decade of the sowing rains is taken to be the period during which a rainfall amount of over 30 mm was received in a decade and when there is no dry spell of more than 5 days. Bennoit (1977) worked on the start of growing season in Northern Nigeria and concluded that the growing season may safely begin in 80% of years when accumulated rainfall for the year reaches 75 mm at Samaru and Kano, both in northern Nigeria and when accumulated rainfall reaches 100 mm at Mokwa in central Nigeria. Otherwise "false start" of the rainy season may give heavy rainfalls but are followed by long dry spell. Owonubi and , (1985) also established that, there was no correlation between the time of the first rain and the annual total rainfall or time of the start of the growing season at Samaru. However, there was significant linear but negative relationship between the time of start of the growing season and the annual total rainfall. With this as a guide, he concluded that rain must stabilise early enough for the growing season to begin, that is, by day 166 DOY (14th June) at Samaru to avert drought.

b) The length of growing season: Decadal or weekly analysis of rainfall can enable us to determine the start and cessation of the rainy season. Sivakumar et al., (1993); Vispy, (1995) analysed decadal average rainfall with air temperature to obtain a graph that indicated the beginning and end of the rainy season which determined the growing season. In the same vein, FAO (1986) also used the potential

vapotranspiration with 100 mm maximum soil water retention capacity to determine the length of the growing season. This principle was equally used to produce the length of the humid season which may be characterised by the period when rainfall is greater than potential evapotranspiration.

In addition to a general characterisation of agroecological zone, based on average rainfall, potential evapotranspiration and water balance, the variability of rainfall is extremely important as it is mainly responsible for wide fluctuations in agricultural production (Oladipo and Kwaghsaa, 1994). This is particularly of a serious concern in developing nation which do not yet have the mechanism to obviate serious food crisis situation.

2.2 Rainfall Models

Rainfall is also an important input to the design of water resources engineering projects, and other environmental related projects. They are often needed for the prediction of extreme floods in watershed rainfall occurrence, amount and sequence etc. and in the design of irrigation and drainage requirement (Ekwue et al. 1997). Rainfall analysis can be undertaken at different time scales such as hourly, daily, weekly, monthly or seasonally. However according to Sivakumar et al. (1993) and Oladipo and Kwaghsaa (1994) analysis of rainfall on daily basis is most useful especially for agricultural purposes. Rainfall analysis including amount, intensity and spatial coherence are relevant to agriculture, however the dependence of wet and dry sequence or days is an interesting starting point for agronomically relevant analysis (Oladipo and Kwaghsaa, 1994). Investigation of persistence in weather and climate is not new and various worker / researcher have developed models to fit the characteristic dependence of daily rainfall. Delleur et al. (1989), Jacob and Lewis,

(1977); Daniel (1989); Oladipo and Kwaghsaa (1994), Mollar and Cook, (1996), Ekwue et al. (1997).

Delleur et al. (1989) defined a rainy or wet day as the day with measurable precipitation (i.e. larger than a trace) occurring and a dry day defined as when no measurable precipitation occurs. The Poisson process was used to model the arrival of storm. However owing to the statistical dependence in storm arrival due to clustering in time and space, the Neyman-Scott point process was later proposed. This process based on discrete autoregressive moving average (DARMA) uses Markov chain analysis. It produces a model which follow a 3 step process of identification estimation and model selection that produced the persistence of dry spells and wet spells useful for forecast of drought and flood. This model was tested on rainfall data from Indiana and it produced an excellent result and was used for scheduling irrigation of crop in Central United States.

Daniel (1989) worked on chain dependent stochastic daily precipitation model and this was used to fit dry (near normal) and wet subset of monthly precipitation using 30 forecasted rainfall value. The result showed that the unconditional model produce distribution of total monthly precipitation having too few dry and wet months as compared to observed data while the mixture of three conditional precipitation model generated consistent daily data.

Foufouia and Lattermaier, (1987) developed a Markov renewal model of rainfall occurrence. This was a clear deviation from point process often used to model stochastic structures of short term rainfall. It observed that the DARMA model had been criticised for lacking physical motivation for the model structure and that it exhibited discontinuous memory. The point process theory permits more elegant

mathematical formulation of intuitively appealing dependence properties on the process such as the condition intensity function or the index of dispersion, which also provides a measure of clustering. This explain further that the daily occurrence of rainfall is a result of interaction of several rainfall generating-mechanism. In the same sense, time between events may come from different probability distributions. It concluded that the sequence of event (wet or dry) is governed by transition probabilities with higher probability of having secondary event after a primary event or after a small number of secondary event. The transition probability matrix of Markov chain is given as

$$P = \begin{pmatrix} a_1 & 1-a_1 \\ 1-a_2 & a_2 \end{pmatrix} \quad (4)$$

where

$$a_j = P(X_j = X_{j+1}) \quad (5)$$

$$j = 1, 2.$$

Closely associated with the Markov chain are the limit or equilibrium probabilities

$$e_j = \lim_{i \rightarrow \infty} p_{ij}(x_i) = j, \quad j = 1, 2 \quad (6)$$

which are the unconditional probabilities of any interval x_i being of type 1 or type 2

$$e_2 = 1 - e_1 \text{ and from Markov theory}$$

$$e_1 = (1 - a_2) / (2 - a_1 - a_2) \quad (7)$$

Smith (1987), developed a Markov-Bernoulli process by the combination of Bernoulli point process and Markov chain point process, to model daily rainfall. This produce a complex model for the wet day sequence by approximate choice of the

sequence of randomised success probability. The result is good for evaluation of significance of parameter estimates. Ekwue et al. (1997) reported on the statistical analysis of Caribbean rainfall data and formulated a linear model for relating dependable mean monthly rainfall. The model was tested using the data collected from English speaking Caribbean region which adequately predicted it. It was found very useful for prediction even in places with insufficient data.

Mollar and Cook (1996) worked on the rainfall variability and agriculture in the semi-arid tropics. They observed that there were variabilities in seasonal rainfall and rainday over the 103 season data used for the analysis. But more variability was observed from fortnightly period analysis. The report showed that regardless of further climatic change, there was considerable variation in rainfall which affected agriculture in the Northern territory of Australia used for the analysis.

In Nigeria, Fasheun (1983) modelled the rainfall sequence of Ibadan using the first order, two state Markov chain with the system attaining equilibrium after about 3 days. He reported an exponential relationship between the frequency of the dry spells and their duration. This result was used to formulate the farm operation planning strategy in Ibadan. In addition, Oladipo and Kwaghsaa (1994) studied the dependence of wet and dry days at three stations in savanna area of Nigeria. This was done using the Markov chain models of first, second and third order and their respective adequacies were tested using the X^2 test. They reported that the first Markov chain order produce probability estimates of consecutive wet (dry) day that are too conservative to describe adequately the conditional dependence of rainfall occurrences. The study also showed that, for the purpose of agricultural planning in the savanna zone of Nigeria, there was the need to take into account the weather

condition of at least the previous two days in order to predict the probability of occurrence of wet spells during the growing season. This approach was adopted in this present study.

2.3 Soil Water Model

Detailed water balance models provide information about soil water content under a crop at any time and about the rate of crop water use (Landsberg, 1988). Soil water model is thus a submodel to crop yield models.

Soil water model are usually based on water balance equation. Several researcher have used this model as the basis of their water balance model. Robertson (1988), for example, produced a simple water balance model using long term averages of monthly rainfall and potential evapotranspiration. However this model was later developed into a complex model that takes into account several soil layers using the knowledge of rooting depth and the habit of specific crops and the knowledge of the water holding capacity and water release characteristic of each layer. The model has been tested extensively for specific crops and studies of cropping problem. It is at present being adapted to the specific problem of estimating soil water and actual evapotranspiration from two interplanted crops.

Landsberg (1988) also developed a soil water model using essentially basic hydrological equation for a specified crop and soil situation:

$$P + R_0 + D_r + \Delta Q + ET = 0 \quad (8)$$

where

P = Precipitation

R₀ = Runoff

D_i = Drainage of out root zone

ΔQ = Change in soil moisture content in the crop root zone (the soil water holding capacity of the root zone is $(Q_{s,max} - Q_{s,min})$ and

ET = Evapotranspiration.

Campbell and Diaz (1988) also presented a well developed water balance model and the theory included sufficient detail to meet most requirements of complex models. They, however, specified that specific investigations may be needed to determine value for the functional relationship used for crop grown in different drought prone areas.

Banting and Kossan (1988) related total available amount of water stored in the soil (S) to soil water at field capacity (soil water potential of -0.01 to -0.03mpa) minus that at wilting point (soil water potential (of -1.5mpa). It was found that S varies widely between soil depending on texture and bulk density. Stern (1992) also developed a simple daily water balance equation:

$$W_n = W_{(n-1)} + R_n - E_n \quad \{ 0 \leq W \leq 100 \} \quad (9)$$

where

W_n and R_n are the available soil water and rainfall respectively in day 0 and year 1 and

E_n is the evaporation on day n

W_n is set equal to 0 to 100 mm, and outside this range, the maximum value of 100 mm is assumed. This model is however useful for daily analysis but limited in application.

Detailed water balance models are deterministic, involve fewer assumptions than simple water balance models, but require more input data and hence can be

expected to produce more accurate results. They are important for crop yield studies and good for drought modelling. This is because it is only by development and careful testing of these models that estimates of crop water use, growing season length can be defined and the potential for improved water use and hence dry matter production (an index of total yield) by crop are accurately evaluated.

CHAPTER THREE

MATERIALS AND METHOD

3.0 Description of the Study Areas

Ibadan and Onne constitute the area under study and are both located in the southern part of Nigeria. Ibadan lies within latitude $7^{\circ} 30'$ and longitude $3^{\circ} 54'$ and Onne lies on latitude $4^{\circ}43'N$ and longitude $7^{\circ} 1'E$. The mean annual rainfall for Ibadan and Onne are 1250 mm and 2400 mm. Ibadan is classified under the sub-humid zone while Onne is classified in the humid tropical zone. (Jagtap and Alabi, 1997).

In both sites, the maximum air temperature varies between $27^{\circ}C$ and $34^{\circ}C$ and the minimum temperature ranges between $20^{\circ}C$ and $23^{\circ}C$. The vegetation varies from mild hot farmland /settlement to farmland /swamp.

The soil at Ibadan is classified as ferric luvisols while at Onne the soil is classified as thionic fluvisols (Jagtap and Alabi, 1997a and b). The agroecological features, type and accuracies of instruments used for the meteorological measurement at both sites are presented in Tables 3.1 and 3.2

Table 3.1: Summary of Agroecological and Weather characteristic of Ibadan and Onne.

Agroecological features	Ibadan	Onne
Longitude	3° 54' E	7° 01' E
Latitude	7° 30' N	4° 43' N
Climatic zonation	Sub humid	Humid
Rainfall pattern	Bimodal	Unimodal
First season	April July	March-November
Second season	August-November	March-November
Soil type	Ferric luvisols	Thionic Fluvisols
Vegetation	Mild hot farmland	Swamp farmland
Maximum temperature	30.5°C ± 3.5	29.5°C ± 1.5
Minimum temperature	21°C ± 1.5	22.5°C ± 1.5
Mean annual rainfall	1250 mm	2400 mm

Table 3.2: Instrumentation at both sites and their accuracies

Parameter	Instrument	Accuracy	Unit
Evaporation	U.S. Class A Pan	0.01	mm
Temperature	Casella Min. & Max. Thermometer	0.1	°C
Rel. Humidity	HMP35C Temp/RH Probe	2%	%
Solar Radiation	LI200X Pyranometer	3%	MJ/m d
Rainfall	Universal Self-recording Rain gauge	0.1	mm
Wind Speed	MET-ONE 014A Wind Speed Sensor	1.5%	m/s

Source: Jagtab and Alabi, (1997b)

3.1 Data Source And Collection

Meteorological data for the two stations were obtained from the International Institute for Tropical Agriculture, Ibadan, a renowned agricultural research station in Nigeria. Twenty four years record of data were collected for Ibadan (1974-1996), and some twenty years record for Onne (1977-1996). The data were collected by the well trained personnel of the crop ecology and modelling unit of the institute suggesting the degree of reliability of the data source. This is essential because reliable data are not easy to come by. The meteorological parameters collected on the daily basis include; rainfall, pan evaporation; wind speed, minimum and maximum air temperature, solar radiation and minimum and maximum relative humidity (%). All the parameters were found to be consistent except the solar radiation, whose measuring instrument was changed in Ibadan in 1990 and in 1989 at Onne. There were however, few cases of missing data due to instrument failure.

3.2 Validation of Data

Data validation was done in the case of single missing data by weighing the surrounding (nearest) data and the use of regression method (Mollar and Cook, 1996). Long period missing data were substituted with data of a year with similar trend. This however occurred once. Data processing was carried out using Microsoft Excel version 5.0 software and INSTAT package, an agrometeorological package designed by the University of Reading, UK.

3.3 Computational and Statistical Methods

Various computational and statistical methods were adopted in the process of the preliminary analysis of the study and they are as given below

3.3.1 Evapotranspiration

The Penman's approach was adopted for computing evapotranspiration in this study due to its proven consistency and application in various climate. The method of computation was adopted using a guide contained in the appendix of FAO (1978, 1986). The Penman's method uses vapour pressure deficit and empirical wind speed function. The parameters for computation are temperature, relative humidity, solar radiation and wind speed.

The PET was calculated on decadal and monthly basis, but the monthly value was eventually used for further computation. This conforms with the findings of Robertson (1988), that PET varies only slightly from month to month. The calculated potential evapotranspiration was multiplied by 0.8 as recommended in FAO (1978) for the sub-humid and humid tropical zones.

Penman (1948) combined the energy-budget and aerodynamic approaches to eliminate the theoretical difficulties and measurement problems inherent in the use of either of the two approaches.

Basically, there are two equations in penman's treatment. The first equation is of the aerodynamic type and is a measure of the drying power of the air. It is given as:

$$E_a = 0.35 (e_s - e_d) (1 + u_2/100) \quad (10)$$

where e_a is the saturation vapour pressure of water at the mean air-temperature in mm of mercury, e_d is the saturation vapour pressure at the dew point temperature, and u_2 is wind speed in miles per day at 2 meters above the ground.

The second equation is for estimating values of net radiation where measured value is not available and is of the form,

$$R_n = R_i - R_E \quad (11)$$

where : R_n is the net radiation (mm /day), R_i is the incoming solar radiation (mm/day), and R_E is the outgoing terrestrial radiation (MJ/m²/day).

For estimating values of R_i Penman gave the equation of the form:

$$R_i = (1 - \alpha) * R_a(0.18 + 0.55n/N) \text{ mm/day} \quad (12)$$

where

R_a is the theoretical radiation that would be received at the ground surface in the absence of an atmosphere, α is albedo or reflection coefficient of the evaporating surface and n/N is the ratio of actual (n) to possible (N) hours of bright sunshine.

The equation for estimating R_E is

$$R_E = \sigma T_a^4 (0.56 - 0.09e_d) (0.10 + 0.90n/N) \text{ mm/day} \quad (13)$$

where : σT_a^4 is the theoretical back radiation which would leave the surface in the absence of an atmosphere, T_a is the mean air temperature, σ is the stefan's constant, and e_d is the saturation vapour pressure of water at the dew point temperature

Penman (1948) combined the above equations and came out with an evapotranspiration equation of the form:

$$PET = \frac{\Delta P_o + \gamma E_d}{\Delta + \gamma} \quad (14)$$

where PET is the potential evapotranspiration (mm), Δ is the slope of the saturation vapour pressure-temperature curve for water at the mean air temperature in mm Hg/ $^{\circ}$ C, γ is the constant of wet and dry bulb psychrometer equation in mmHg/ $^{\circ}$ C, R_n is the net radiation and E_s is as previously defined.

Performance of the classical Penman equation has been improved by a group of FAO experts resulting in to the world-wide known "FAO 24 corrected Penman method" (Doorenbos and Pruitt, 1977). The equation is given as:

$$PET = \frac{(p_0 / p) D (0.75R_s(a + b n/N) - \sigma T_a^4(0.56 - 0.079e_d) (0.10 + 0.40 n/N) + 0.26(e_s - e_d) (1.00 + 0.54u))}{(P_0 / P) (\Delta / \gamma) + 1.00} \quad (15)$$

where

P_0 is the mean atmospheric pressure expressed in millibar at sea level,

P = mean atmospheric pressure expressed in millibar based on elevation of the station;

R_s = short-wave radiation received at the limit of the atmosphere expressed in mm of evaporated water;

a & b = coefficient for the estimation of total radiation from the sunshine duration,

PET, Δ , γ , e_s , δT_a^4 , T_a , e_d , and u are as previously defined.

A review of literature clearly indicates the superiority of Penman when the required data are available and when compared to all other commonly used methods.

The performances of classical Penman and FAO Penman in USA and Europe are reported in Sequin (1975), Jagtab and Alabi (1997a).

Expressions to obtain some of the parameters in the above equations are proposed as follows:

e_s and Δ are given as a function of temperature by Bosen (1960) as

$$e_s = 33.8639 [(0.00738T_s + 0.8072)^8 - 0.000019(1.8T_s + 48) + 0.001316] \quad (16)$$

and

$$\Delta = 3.8639[0.05904(0.00738T_s + 0.8072)^7 - 0.0000342] \quad (17)$$

The Psychometric constant is given as

$$\gamma = 1.61452P/L \quad (18)$$

where, 1.61452 (J/gram) is the ratio of the specific heat of dry air to the ratio of the mass of water vapour to dry air, P is the barometric pressure of the air (mbar), and L the latent heat of vaporisation of water (J/gram). L is calculated as follows (Jensen, 1981):

$$L = 4.1855(595 - 0.51T_s) \quad (19)$$

P for given altitude was proposed as

$$P = 1013 - 0.1093E \quad (20)$$

where E is the elevation above sea level in metres.

3.3.2 Precipitation Index

Precipitation Index (PI) is a measure of the contribution of each year to the rainfall value over a period of time. It is calculated using the following equation

$$PI = (X_i - X) / S \quad (21)$$

Where X = annual rainfall total for the year i ; (mm)

\bar{X} = mean of annual rainfall total (mm) for the period under study;

S = Standard deviation of the rainfall total for the years under study;

Precipitation index is often called the cumulative deviation of rainfall and can be related to water storage, flooding and drought (Mollar and Cook, 1996), all which are common to the two areas under study.

3.3.3 Annual Rainfall and Five Years Moving Averages

On the basis that the trend is a function of the length of record moving averages were calculated. The 5 years moving average was chosen in preference to 2 or 3 years moving averages which are more susceptible to extreme wet or dry years and the 10 years moving averages tend to mask the changes in trend (Mollar and Cook, 1996). It will also allow the identification of "epoch" within the overall data thereby enhancing further analyses of variability.

Number and percentage of rainfall days

The number of rainfall days and the percentage of the rainy days were computed. A threshold value of rainfall amount was chosen to define a rainday. The International Institute of Tropical Agriculture weather station uses 0.2 mm as minimum rainfall threshold. For agricultural purposes however, a higher threshold is required to define a useful rain. This is important from the context of evaporation rate, soil type, ground cover, land use pattern, type of crops, stages of growth, recent rainfall history. It was noted that some use other thresholds of 2 mm, 5 mm and 10 mm. (Molar and Cook, 1996). After due consideration, a threshold value of 5 mm was chosen for Ibadan and Onne for the purpose of this study.

3.4 Rainfall probabilities

Mabbut (1989) observed that in regions with short growing seasons and with rainfall as limiting factor, the climatic limit of regular cropping tends to be set by the level of probability of rainfall. Hence probabilities are essential for the examination of variability. The probabilities for the specified amounts of rainfall occurring in a single season is calculated by using the methods described by Gregory, (1969, 1975) cited by Mollar and Cook (1996). Tables of normal distribution function of the value was used as reference for the computation.

From this probability, the binomial frequency of distribution was used to calculate the probability of receiving at least the set amount of rainfall on the average of four years out of five. Such calculations are based on the assumption of a normal frequency distribution of the data.

3.5 Length of Seasonal Drought or Dry Period

Dry period was obtained using two approaches. They are;

(a) Rainfall and Air Temperature Method

A plot of the monthly average rainfall value and air temperature produce the ambiothermic curve which allows the fixing of the beginning and the end of a dry period. This analysis was carried out for the two study areas.

(b) Potential Evaporation (PET) Method

This method states that a dry period start when the water received by the soil is smaller than the (PET) or equal to half or 35% of PET, that is

$$RR < PET \text{ or } RR < \frac{1}{2} PET \text{ or } RR = 35\% PET \text{ depending on the}$$

geographical location.

where RR is the rainfall

3.5.1 Dry Year Definition

A dry year is defined as the year with annual rainfall total below the mean rainfall for all the years under study that is

$$X_i < \bar{X}$$

where

X_i = annual rainfall for the year i ;

\bar{X} = mean rainfall value for the years under study

The mean depends on the period of study but will be more representative as the number of year under study increases. Elle (1996) gave a dissymetry between the number of dry years and wet years when the period contain many years of exceptionally dry and humid years. That is;

$$D_y \approx 10\% - X$$

$$H_y \geq 10\% + X$$

and where D_y and H_y are dry and humid years respectively
connotes Humid years.

3.6 Markov Chain Analysis

The short term correlation of rainfall incidence on successive days have frequently been modelled with Markov chain (Fasheun, 1983; Oladipo and Kwaghsaa,

1994). This method assumes that the occurrence of rainfall depends on whether the previous was wet or dry. This is the first order two state Markovian chain. In this study, a day is conventionally defined wet if the rainfall on that day was at least 1 mm and dry otherwise (Medhi, 1978 cited by Oladipo and Kwaghsaa, 1994).

If $P (X_i / X_{i-1}, X_{i-2}, \dots, X_{i-j})$ is the probability that a day i will be wet (or dry) "given that" (/) each days of $i - 1, i - 2, \dots, i - j$ had a particular condition (wet or dry), then the transitional probabilities can be obtained for dry conditions (D) as:

$$P(D_i / D_{i-1}) = \frac{\text{No. of days day } i \text{ and day } i-1 \text{ were dry}}{\text{No. of days the } (i-1)\text{th day was dry}} \quad (22)$$

$$P(D_i / D_{i-1}, D_{i-2} / D_{i-3}) = \frac{\text{no of days day } i \text{ and day } i - 1, i - 2, i - 3 \text{ were dry}}{\text{no of days } (i - 1)\text{th}, (i - 2)\text{th}, (i - 3)\text{th day were dry}} \quad (23)$$

where

$P(D_i)$ is the initial probability for the sequence and it is the probability that the (i)th day of the year will be dry irrespective of what occurred on the preceding days.

It is given as the relative frequency of dry days such that

$$P(D_i) = \frac{\text{No of year day } i \text{ was dry}}{\text{No of year of record}} \quad (24)$$

In a similar manner, the probabilities of wet conditions (W) can be obtained as:

$$P(W_i) = 1 - P(D_i) \quad (25)$$

$$P(W/D_{i-1}) = 1 - P(D_i/D_{i-1}) \quad (26)$$

$$P(D_i/W_{i-1}) = [P(D_i) - P(D_{i-1}) * P(D_i / D_{i-1})] + P(W_{i-1}) \quad (27)$$

$$= [P(D_i) - P(D_{i-1}) * P(D_i / D_{i-1})] \div [1 - P(D_{i-1})] \quad (28)$$

$$P(W_i / W_{i-1}) = 1 - P(D_i / W_{i-1}) \quad (29)$$

For the two sites, these formulations were used to calculate the probability of the sequence of wet and dry days to obtain the monthly transition probability table.

The system assumes that if a day is in state 0 (dry) at time t, the probabilities of that system to be in a state 1 (wet) and state 0 (dry) at time t+1 are A and 1-A, respectively. Similarly, if the system is in state 1 (wet) at time t, the probability of it to be in state 0 (dry) and state 1 (wet) at time t+1 are 1-B and B, respectively. This transition probabilities can be written in matrix array as

$$P = \begin{matrix} & \begin{matrix} 1-A & A \end{matrix} \\ \begin{matrix} 1 \\ 2 \end{matrix} & \begin{matrix} B & 1-B \end{matrix} \end{matrix} \quad (30)$$

which in turn can be summarised as

$$P = P_0(t) \cdot P_1(t-1) \quad (31)$$

After a sufficiently long period, the system settles down to a steady state in which the state occupation probabilities are independent of the initial conditions. The relationship between the length of the wet (W) and dry (D) species in this model is defined as

$$L(W) = A+B / A \quad (32)$$

$$L(D) = A+B / B \quad (33)$$

with the cycle C as

$$L(C) = L(W) + L(D) \quad (34)$$

3.7 Quantification of Soil Water

The model used for the quantification of soil water is a modified form of the simple monthly budget described by Robertson, (1988). The model involves the knowledge of the rooting depth and habit of the specific crop and a knowledge of the water holding capacity and water releasing characteristics of the soil and it is computed with daily meteorological data. The falling rate soil water budget is used. Here the rate of evapotranspiration is dependent on the potential evaporation weighed according to the percentage of crop available water remaining in the soil at the time the computation is made. The potential evapotranspiration is assumed to vary only slightly within a month, thus the monthly potential evapotranspiration average was assumed for all the days of the month. Rainfall is assumed to evaporate at the potential evapotranspiration rate following a day of rain. For the purpose of this study, the soil was assumed to hold 100 mm of crop available water. Soil water above 100 mm are assumed to be lost as runoff or deep percolation. The Markov chain analyse the daily soil water to obtain the monthly transition probability in a similar manner as described earlier. It involves estimating probabilities of occurrence of the run of consecutive days with wet soil (50 mm soil water threshold was used to define the wet soil and anything below is classified as dry soil), by counting the number of days with wet soil given that the previous day had a wet soil. These frequencies were then converted to probability $P(W)$ and the $P(W_i/W_{i-1})$ respectively. Similarly, other probabilities were calculated, for example $P(D)$, $P(D_i/D_{i-1})$, and $P(D_i/W_{i-1})$ and $P(W_i/D_{i-1})$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Annual Rainfall Variability

As stated earlier, temporal and spatial variabilities are distinct characteristics of tropical regions. Significant features of rainfall variability in West Africa were discussed by Nicholson (1981) as in Sivakumar et al, 1993. Since rainfall fluctuation for an extended period of time can lead to instability in the traditional agricultural practices and production, this section therefore presents and discusses the result on the variability of rainfall within the area of study (i.e. Ibadan and Onne areas).

Table 4.1 shows the annual rainfall total (in mm) for Ibadan and Onne. The mean annual rainfall for the 24 years record for Ibadan was 1295.0 mm while at Onne the mean annual rainfall for 20 year (1977-1996) record was 2220.0 mm. Detailed examination of rainfall amounts revealed that annual rainfall amount for 12 years fall below the annual average for the 24 years record of Ibadan, while 8 of the 20 years record for Onne were below the mean value. The maximum amount of rainfall was recorded at Ibadan (1673.0 mm) and Onne (3094.0 mm) in 1985. The lowest value was recorded in Ibadan in 1982 (908.3 mm) and in Onne in 1994 (1063.9 mm). Using each decade as the basis of comparison, annual rainfall total value during the second decade (1987-1996) is greater than the annual total for the first decade (1977-1986). This is a sharp contrast to the prevailing condition of declining rainfall in many part of the world (IITA, 1994). However in Onne, the first decade (1977-1986) rainfall total is higher than that observed

Table 4.1 Annual rainfall summary for Ibadan and Onne

Year	Ibadan (mm)	Onne (mm)
1973	1398.6	na
1974	1180.6	na
1975	1470.8	na
1976	1011.7	na
1977	916.9	2263.8
1978	1357.5	2045.6
1979	1527.1	2511.8
1980	1550.2	1898.9
1981	1156.7	2373.5
1982	908.3	2748.5
1983	996.6	2029.4
1984	1360.5	2190.3
1984	1673	3094.3
1986	1233	2359.9
1987	1655.4	2798.5
1988	1540.7	2551.7
1989	1268.3	1960.7
1990	1144.4	2560.9
1991	1406.9	1406.9
1992	1171.2	1171.5
1993	1308.1	2506.9
1994	1063.9	1063.94
1995	1435.9	2592.7
1996	1343.8	2222.4
Sum	12478.4	44351.8
Average	1295	2217.6
Standard deviation	221.3	527.7
Coefficient of Variation	5.85	4.20

in the second decade (1987-1997). This follows the similar trend of event in many studies around the world.

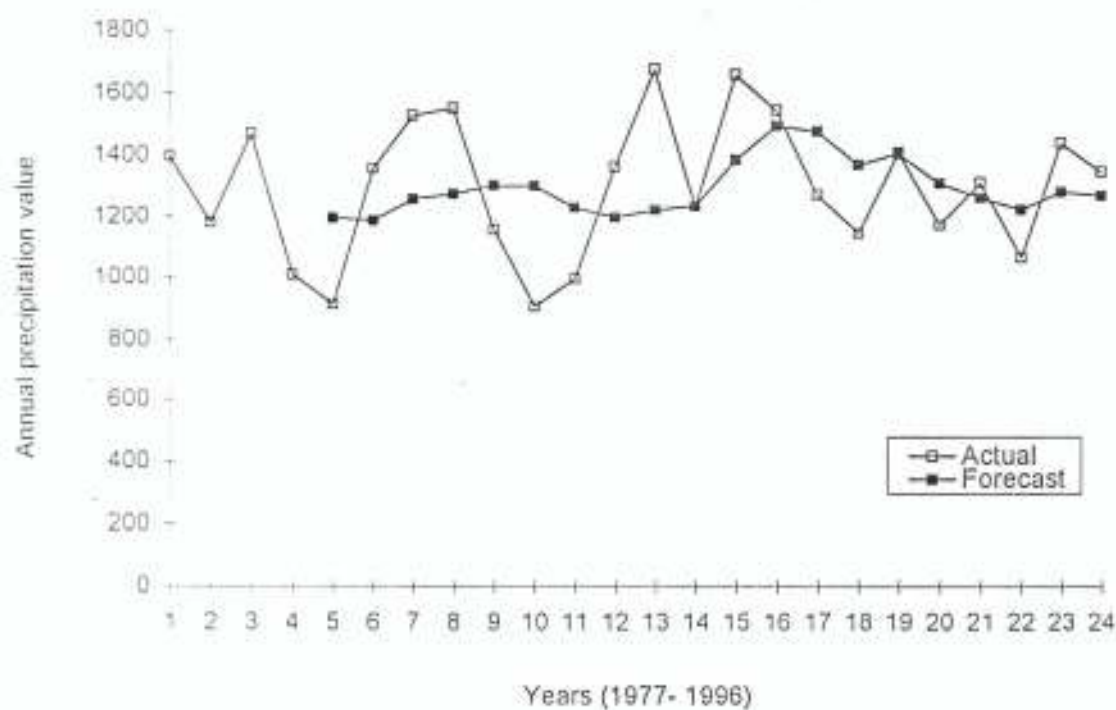
The rainfall trend is as shown in the 5 years moving average curve shown in (Figures 4.1 a, b). This trend curve for Ibadan revealed that the most part of the 1970's decade were in the dry epoch and a change towards the wet epoch was observed in the 1980's. Since the beginning of this decade, the dry epoch have been the situation as shown by the forecast curve. For Onne, more wet epoch were recorded in the 1970's and 1980's. A ziz-zag dry and wet epoch have characterised the trend in the last few years. It is however clear that the drier epoch is more prominent suggesting possibilities of fewer rainfall event if this persist.

The coefficient of variation of the rainfall values in Ibadan and Onne are 5.85 and 4.20, which indicates some degree of variability of rainfall values in these areas.

Precipitation index is an indication of the water that can be stored in the soil. It can also, to a large extent, determine what is available for runoff. Figures 4.2a and b show the precipitation index charts for Ibadan and Onne. They confirm that the year 1985 had the largest contribution to the available soil water in both Ibadan and Onne as can also be seen from the magnitude of the rainfall total for the year. Consequently, and all other factors being equal, crops with high water consumption would have thrived well in both sites in 1985. The high negative values of the index for Ibadan and Onne were observed in 1982 and 1994.

The average number of rainy days at Ibadan was 109 out of which 89% occurred between April and October. This accounts for the reason why the period beginning from of 1st April to 31st of October is assumed to be the rainfall

(a)



(b)

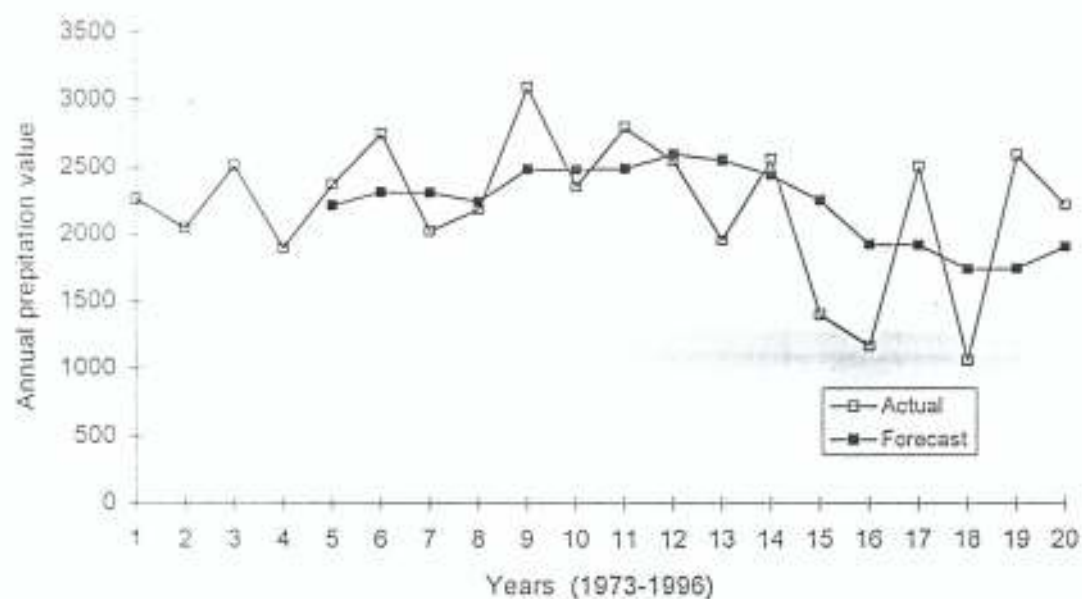


Fig 4.1: Five years moving average curve for (a) Ibadan , (b) Onne

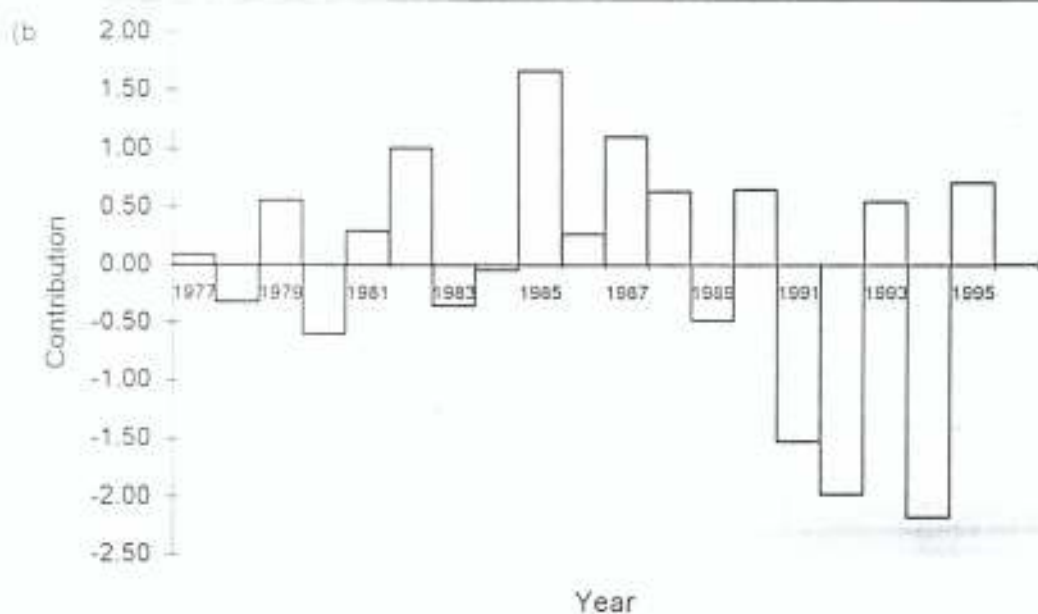
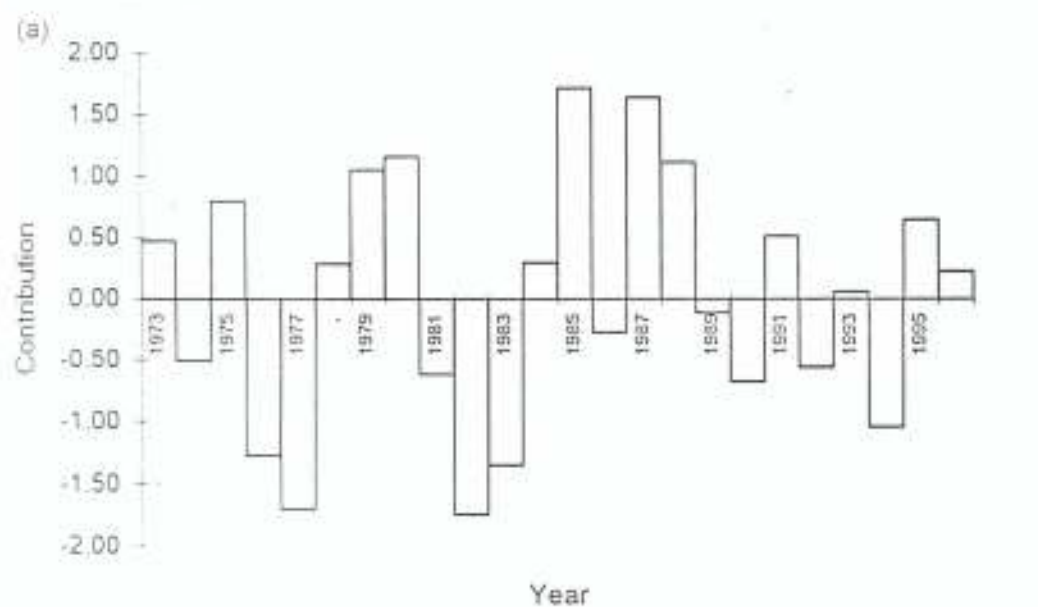


Fig 4.2: Precipitation index chart for (a) Ibadan, (b) Onne

season at Ibadan and other sub-humid zone of Nigeria. The average number of rainy days for Onne was 150 out of which 90% also occurred between 1st March and 30 November. This period is referred to as rainfall season for Onne and the humid zone of Nigeria.

4.1 Daily and Monthly Rainfall

The rainfall amount, number of rainy days, standard deviation and the coefficients of variation of rainfall data on monthly basis were computed for the two stations. The results are presented in Tables 4.2 a, b. The rainfall pattern in Ibadan had a bi-modal distribution typical of the Western zone of Nigeria. This was characterised by a rapid increase in rainfall and number of rainy days occurring from April to June and thereafter by a small recession in August. After the recession, rainfall and the number of rainy days increase and attain the maximum in September. The month of October marks the beginning of the cessation of rain leading to the dry season for Ibadan. In the case of Onne the rainfall values and the number of rainy days increase from the month of February and attain the peak in August. Contrary to cases of Ibadan rainfall distribution in Onne was Uni-modal and was characterised by high intensity. Figures 4.3 a, and b present the rainfall pattern for the period under study

Table 4-29: Monthly rainfall summary for Ibadan (1974-1995)

Month	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan	1.20	2.00	0.00	0.00	53.00	17.10	0.00	0.00	0.00	1.60	0.00	0.00	0.80	3.20	10.00	0.30	0.00	0.00	0.00	0.00	0.00	1.40	0.00
Feb	13.30	0.50	76.40	13.40	0.00	10.40	3.60	26.20	6.90	47.20	3.90	2.70	0.20	43.10	10.60	32.00	23.50	18.70	44.40	0.00	60.00	3.20	12.90
March	64.40	127.90	89.60	79.70	20.00	123.10	84.00	52.10	80.20	90.20	3.20	90.10	126.60	105.80	139.60	93.60	67.20	33.40	25.20	55.40	176.50	64.60	137.60
April	124.40	131.00	194.20	97.10	94.00	268.40	171.30	50.10	105.30	83.90	97.00	85.40	144.40	161.90	75.90	203.00	65.40	152.50	127.50	140.30	49.30	47.00	170.90
May	69.50	127.00	203.70	137.10	101.30	137.10	208.00	193.90	150.40	169.00	303.10	311.00	183.20	70.70	130.70	105.00	157.40	169.10	245.40	96.10	158.20	97.54	205.00
June	193.40	175.60	190.60	265.30	146.50	118.00	136.00	133.20	202.50	133.60	152.00	136.30	109.50	279.10	218.20	293.50	201.30	84.10	262.50	178.40	211.30	89.20	146.20
July	166.50	228.50	208.90	44.80	94.60	194.80	314.00	203.80	173.30	125.70	108.60	103.90	376.00	135.50	201.90	168.10	235.70	205.50	277.10	221.70	106.10	146.20	211.30
Aug	209.50	73.00	32.20	22.00	59.50	62.50	186.70	367.80	42.90	75.60	36.10	262.90	233.10	33.50	323.60	86.10	204.20	72.50	133.40	60.90	118.60	78.30	159.94
Sept	276.10	109.00	156.00	78.20	142.00	166.90	254.50	248.90	250.00	79.60	139.30	186.00	290.00	216.70	410.00	274.50	185.40	208.40	175.40	226.10	219.40	366.60	208.30
Oct	161.60	172.20	242.10	232.60	206.00	182.90	156.40	208.40	145.60	80.00	38.30	127.70	166.50	177.10	124.60	259.00	128.20	133.90	122.20	187.85	156.70	149.50	140.20
Nov	0.20	33.80	67.30	41.70	0.00	82.30	18.10	66.70	0.00	9.10	26.60	54.40	37.70	0.40	0.00	14.30	0.00	0.80	0.00	4.40	58.00	15.00	36.30
Dec	7.40	0.00	9.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.90	0.10	0.00	0.00	0.20	10.40	0.00	64.90	3.80	0.00	2.00	0.00	7.40
	1368.60	1180.60	1470.80	1011.70	916.90	1357.50	1527.10	1550.20	1156.70	905.30	996.60	1300.50	1673.00	1233.00	1655.40	1548.70	1268.30	1144.40	1406.90	1171.15	1308.10	1063.94	1435.94
AVE	189.85	166.633	209.317	156.242	197.43	229.042	169.117	132.525	251.892	196.63	233.21	212.642	163.392	213.408	118.45	97.5058	208.817	87.5261	216.058	185.202	3498.33	184.349	
STD	184.5	99.0	141.4	113.3	148.4	157.0	134.8	125.5	168.2	140.8	158.8	154.0	114.4	205.9	164.2	84.1	163.7	93.6	163.0	137.1	2284.4	121.6	
CV	1.0	1.7	1.5	1.4	1.3	1.5	1.3	1.5	1.5	1.4	1.5	1.4	1.4	1.0	1.1	1.2	1.3	0.9	1.3	1.4	1.5	1.5	

Table 4-2b: Monthly rainfall summary for Onne (1977-1996)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1995 20 years total	Monthly Average	
Jan	70.6	5.8	0	21.6	58.7	0	0	0	58.5	15.5	0	17.9	0	17	0	0	1.5	1.4	1.4	0	199.3	13.495
Feb	22.8	100.2	118.8	8.1	47	18.3	1.3	56.5	4	84.3	59	10.9	0	78.3	44.4	0	41.7	9.2	78.6	43.6	804.2	41.35
March	101.3	161.2	114.1	126.8	110.5	123.5	42	146	183.2	122.4	285.2	115.2	162.7	23.3	15.7	55.4	250.8	51	196.1	158.4	2443.5	127.24
April	125.7	166.5	177.8	143.3	63.8	277.7	128.6	97.4	263.6	107.1	94.2	191.5	279.4	107.4	127.5	140.3	129.4	43.8	72.8	288.1	2900.2	151.295
May	201.3	290	198.8	365	376	300.8	314.9	216.6	455.8	216.7	319.6	234.4	141.8	277.7	245.4	96.1	212.1	101.3	300.9	203.4	4867.34	253.432
June	315.9	289	405.4	183.2	329.8	380	324.8	294.3	270.3	333.5	250.1	319.3	203.8	198.9	220.5	177.8	320	75.6	318.7	243.5	5138.5	272.72
July	210.6	122	384.4	303.7	394.8	270.6	263.9	370.5	398.6	364.6	363.1	265.1	345.5	570.1	300.7	221.1	512.5	159.8	312.2	153.8	6005	315.08
Aug	405.2	253.7	238.4	266.7	336.6	422.4	242.1	251.2	534.2	400.3	413	422.3	265.8	629.9	133.8	62.1	438.2	72.5	433.7	403.5	6240.4	332.28
Sept	628.8	230.7	365.8	191.3	327.1	402	361.5	350	252.7	302.2	474.8	429.6	183.4	351.5	159.4	224.5	248.1	250.2	375	332.4	5812.2	322.05
Oct	149.9	281.7	342	120.6	229.3	367.6	230.8	195.5	348	307.1	323.1	388.1	180.7	118.9	126.6	154.5	262.8	269.7	422.4	328.3	4997.87	257.3785
Nov	25.7	93.7	166.3	151.1	95.6	153.3	40.2	210.5	236.1	105.9	197.2	70.7	175.7	109.5	11.6	39.4	40.7	15.8	76.7	52	2042	103.385
Dec	0	43.5	0	17.5	0	32.3	79.3	1.8	17.7	0	19.2	86.7	1.9	78.4	3.8	0	48	0	4.2	15.4	449.7	22.485
SUM	2264	2038	2512	1899	2389	2749	2029	2190	3023	2360	2789	2552	1961	2561	1397	1171	2506	1050	2593	2222	41980.01	2212.1905
AVE	186.7	169.8	209.3	158.2	197.4	229	169.1	182.5	251.9	196.6	233.2	212.6	163.4	213.4	116.5	97.6	208.8	87.53	216.1	185.2	3498.3342	184.3492083
STD	184.5	99.0	141.4	113.3	148.4	157.0	134.8	125.5	168.2	140.8	158.8	154.0	114.4	205.9	104.2	84.1	183.7	93.0	163.8	137.1	2284.4	121.6
CV	1.0	1.7	1.5	1.4	1.3	1.5	1.3	1.5	1.5	1.4	1.5	1.4	1.4	1.0	1.1	1.2	1.3	0.9	1.3	1.4	1.5	1.5

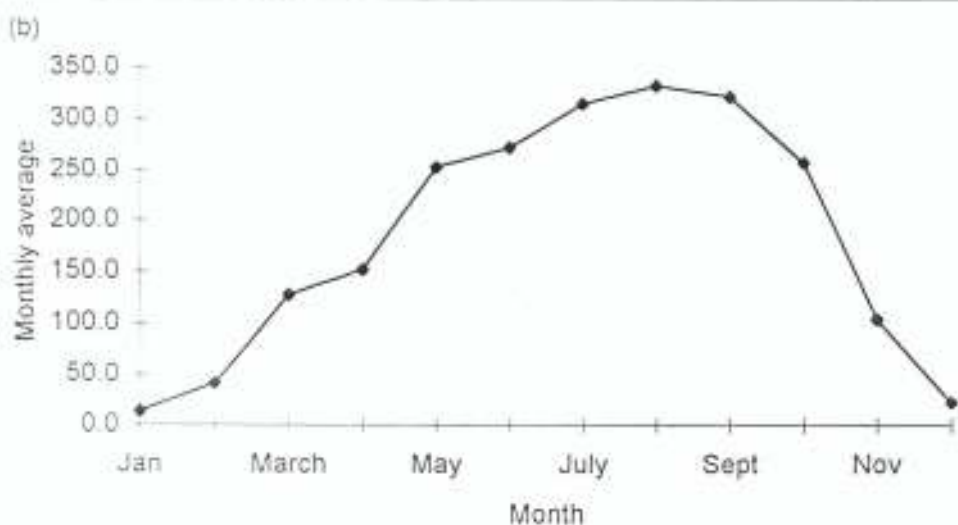
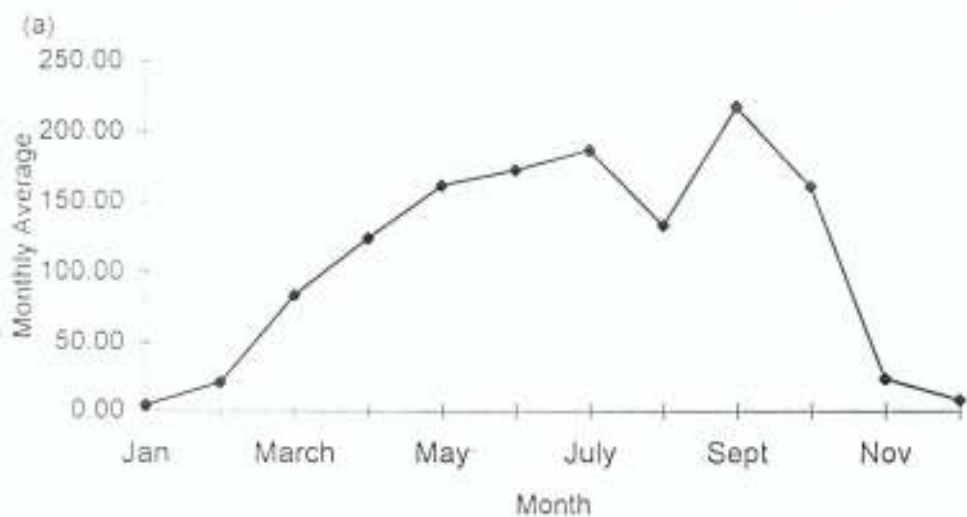


Fig 4.3 Rainfall pattern for (a) Ibadan, (b) Onne

4.2 Onset, Cessation of Rainfall and Length of Growing Season

The date of the onset of rains is an important factor in planning agricultural operations such as land preparation and sowing. Various definitions of the beginning of the rain" exist. Bennoit (1977) cited by Sivakumar et. al (1993) indicated that a dry spell of more than 5 or more days in the 12 day following the potential start constitute a false start. Hence, he proposed that the date of the Onset of rain is the date after the 1st of April (depending on rainfall characteristic of the area) when rainfall accumulated over 3 consecutive days is at least 30 mm and when no dry spell within the next 30 days exceeds 7 days. This was adopted in this study. Using this concept, it was observed that rain always started at Onne and its environs by 1st March.

The first occurrence of long dry spell after 31st October was used to define the cessation of rain in Ibadan and after 30th of November in Onne. The length of the growing season is the difference between the dates of onset and cessation of rainfall (Sivakumar et al, 1993).

Analysis of long term daily rainfall date for Ibadan and Onne were carried out and the result on the relative date, day of the year (DOY) of Onset and Cessation of rainfall and the average length of the growing season are presented in Table 4.3. The earliest onset of rain was on 14th March (73 DOY) while the latest was 17th of May (137 DOY) at Ibadan. In Onne, the earliest Onset was 12 day earlier than that at Ibadan i.e. 2nd March (71 DOY) and the latest was on 10th April (100 DOY). Cessation of rainfall ranged between 18th Oct. (303 DOY) and 6th Nov. (310 DOY) at Ibadan and between 26th Oct. (299 DOY) to 27th Nov. (331 DOY) at Onne. Average

Table 4.3 a Dates of Onset and Cessation of Rainfall and Length of Wet season in Ibadan

Year	Onset (DOY)	Date	Cessation (DOY)	Date	Length of Season	of Rainday %
1973	81	22- March	304	31 - Oct.	223	61.1
1974	81	23- March	306	2 - Nov.	225	61.6
1975	77	18 - Mar	299	26 -Oct.	222	60.8
1976	105	15 - April	309	5 -Nov.	204	55.9
1977	113	23 - April	299	26 - Oct.	186	51.0
1978	96	6 - April	310	6 -Nov.	214	58.6
1979	73	14 - March	300	27 - Oct.	227	62.2
1980	112	22 - April	308	4 - Nov.	196	53.7
1981	86	27- March	310	6 - Nov.	224	61.4
1982	110	20 - April	307	3 - Nov.	197	54.0
1983	121	1 - May	280	7 - Oct.	159	43.6
1984	103	13 - April	303	30 - Oct.	200	54.8
1985	91	1 - April	292	9 - Oct.	201	55.1
1986	100	10 - April	304	31 - Oct.	204	55.9
1987	137	17 - May	297	24 - Oct.	160	43.8
1988	105	15 - April	294	21 - Oct.	189	51.8
1989	116	26 - April	292	19 - Oct.	176	48.2
1990	92	2 - April	291	18 - Oct.	199	54.5
1991	91	1 - April	297	24 - Oct.	206	56.4
1992	94	4 - April	307	3 - Nov.	213	58.4
1993	116	26 - April	306	2 - Nov.	190	52.1
1994	118	28 - April	307	3 - Nov.	189	51.8
1995	83	24 - March	306	2 -Nov.	223	61.1
1996	60	1 - March	300	27 - Oct.	240	65.8
Mean	98	8 - April	301.2	28 - Oct.	202.79	55.56
SD	17.93		7.44		20.58	5.64
C.V.	0.18		0.025			

Table 4.3 b Dates of Onset and Cessation of Rainfall and Length of Wet season in Onne

Year	Onset (DOY)	Date	Cessation (DOY)	Date	Length of Season	Rainday %
1977	100	10 - April	299	26 - Oct.	199	54.5
1978	79	20 - March	310	19 - Nov.	244	66.8
1979	81	22 - March	300	12 - Nov.	235	64.4
1980	53	23 - Feb.	308	26 - Nov.	277	75.9
1981	61	2 - March	310	23 - Nov.	266	72.9
1982	71	12 - March	307	14 - Nov.	247	67.7
1983	73	14 - March	280	18 - Nov.	249	68.2
1984	76	17 - March	303	12 - Nov.	240	65.8
1984	65	6 - March	292	23 - Nov.	262	71.8
1986	67	8 - -March	304	17 - -Nov.	254	69.6
1987	78	19 - March	297	27 - Nov.	253	69.3
1988	80	21 - March	294	15 - Nov.	239	65.5
1989	87	28 - March	292	14 - Dec.	261	71.5
1990	87	28 - March	291	18 - Nov.	235	64.4
1991	98	8 - April	297	1 - Nov.	207	56.7
1992	91	1 - April	307	1 - Nov.	214	58.6
1993	83	24 - March	306	6 - Nov.	227	62.2
1994	87	28 - -April	307	4 - Nov.	221	60.5
1995	93	3 - April	306	15 - Nov.	226	61.9
1996	80	21 - March	300	30 Oct.	223	61.1
Mean	79.5	21 - March	318.45	15 - Nov.	238.95	65.5
SD	12.14			11.55	20.48	5.61
C.V.	0.15			0.036		

SD - Standard deviation, C. V. = Coefficient of Variation

length of growing season in Ibadan ranged between 159 and 240 days and 199 to 277 days in Onne. Figures 4.4a and b present the Onset and cessation of rainfall in Ibadan and Onne. The dates of cessation of rainfall did not vary significantly when compared with the date of onset of the rain at both sites. The coefficients of variation (C.V.) for the onset of rain in Ibadan and Onne were 0.18 and 0.15. These C.V. for the date of cessation of rain in Ibadan was 0.025 and for Onne was 0.036. The date of cessation of the rain was more consistent in Ibadan than in Onne as indicated by the coefficient of variation of the cessation of rainfall is, the reverse is the case for onset of the rains.

For agricultural purpose, the date of the onset of rain is more important than, the date of cessation of rain since the major problem facing farmers is when to start tilling and planting. The C.V. for the onset of rain in Ibadan was higher than in Onne. It would be expected that the agricultural risk associated with false start of rain in Ibadan would be higher in Ibadan than Onne. Significant crop losses have been reported in parts Oyo and Osun States of Nigeria (IITA, 1994).

Temporal variabilities of growing season also have significant impact on agricultural potential of any area. Protracted dry season have been known to affect crop production. The size and the quality of a fruit such as oranges is adversely affected by protracted dry season while on the other hand, protracted wet season could delay the harvest and encourage infestation by pests and diseases. The variability in the length of the growing season on both sites can affect therefore the choice of a particular cropping strategy to be adopted in a given year. For planning purpose, an approach is to calculate the probabilities of the growing season length variation for a known or given date of onset of rain. The approach was used

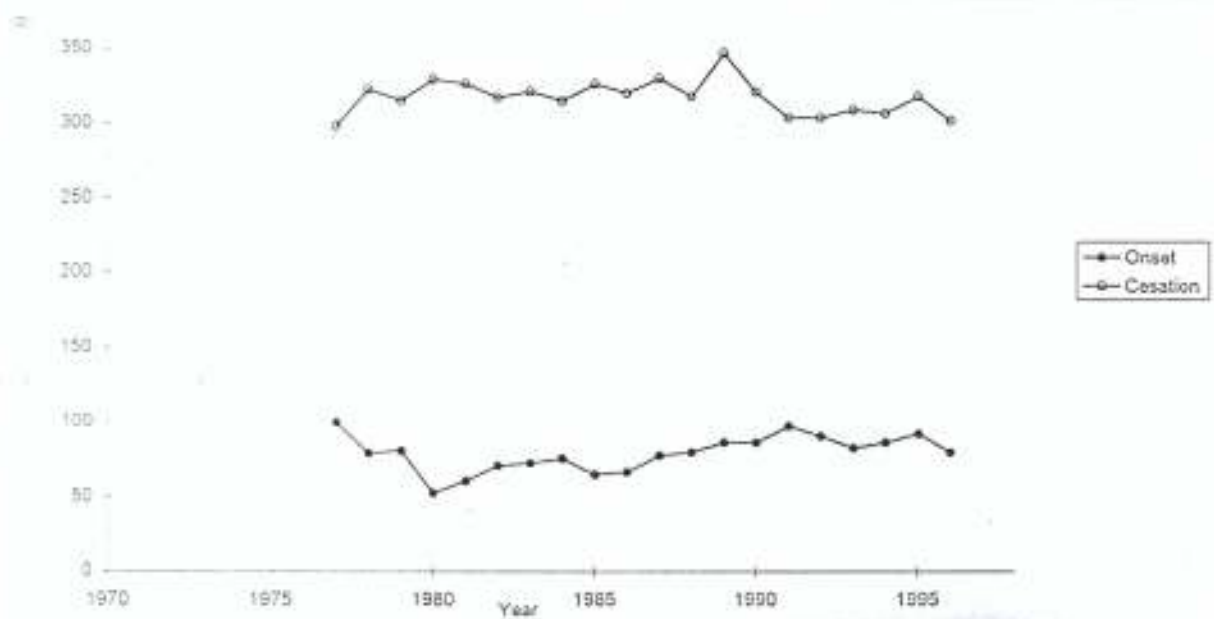
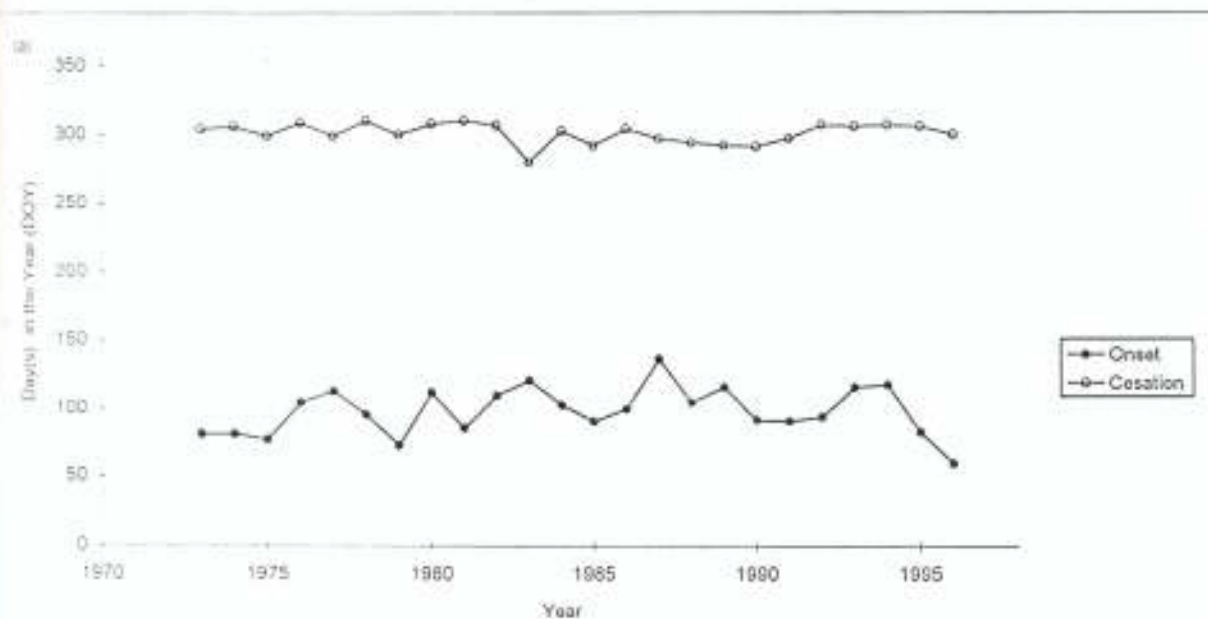


Fig 4.4 Date of Onset and Cessation (DOY) of Rainfall in (a) Ibadan,
(b) Onne

by Sivakumar et. al (1993). It is based on two assumptions; first, that the date of the end of the rain season is normally distributed and secondly that there is no correlation between the start and end of rain.

The probability of a season length greater than 203, 180, and 200 days for example in Ibadan and Onne is as shown below using the relationship

$$P = N - X / \delta \quad (35)$$

where

N is the proposed season length,

X, is the average length of growing season in the area in days , and

δ , is the standard deviation of the length of the growing season.

Table 4.4a: Probability of varied growing season length in Ibadan.

N	$(N - X) / \delta$	P
180	$(180 - 203) / 20.58$	-1.12
200	$(200 - 203) / 20.58$	0.15
220	$(220 - 203) / 20.58$	0.83
250	$(250 - 203) / 20.58$	2.28

Since Onne had a longer length of growing season than Ibadan, the probability of the following length will be calculated, 230, 250, 280, 300. The result re given below

Table 4.4b: Probability of varied growing season length in Onne

N	$(N - X) / \delta$	P
230	$(230 - 239) / 20.48$	-0.44
250	$(250 - 239) / 20.48$	0.54
280	$(280 - 239) / 20.48$	2.00
300	$(300 - 239) / 20.48$	2.98

Figures 4.4 a, b show that early onset of rain produce a longer growing season length while delayed onset of rain results in short growing season.

4.3 Analysis of Air Temperature

Ambiothermic Curve

Ambiothermic curve is a graph of air temperature and rainfall plotted against time. It can be used to estimate the onset, cessation and length of growing season (Vispy, 1995). Selected graphs for different years of the ambiothermic curve are presented to show the inconsistency of the curve and are presented in Figures 4.5 a - d. The method did not produce consistent results thus showing the short coming of ambiothermic curves in predicting onset, cessation and length of growing season. However, it was observed that in years where there were significant monthly variation in the mean air temperature, the curve predicted the length of growing season accurately.

4.4 Variability in Potential Evapotranspiration Values

Potential evapotranspiration (PET) is a vital component in estimating crop water requirement (FAO, 1986) The monthly potential evapotranspiration (PET) value for Ibadan are presented in Figures. 4.6 a and b. They are generally high in the dry season due to an increase in the air temperature and solar radiation, which are vital terms in the PET formula. In Ibadan and Onne, the average PET values were in the peak in December at about 8 mm/day at Ibadan and 5 mm/day at Onne. The difference in the peak values between the two stations could be attributed to the differences in atmospheric humidity, solar radiation and maximum and minimum air

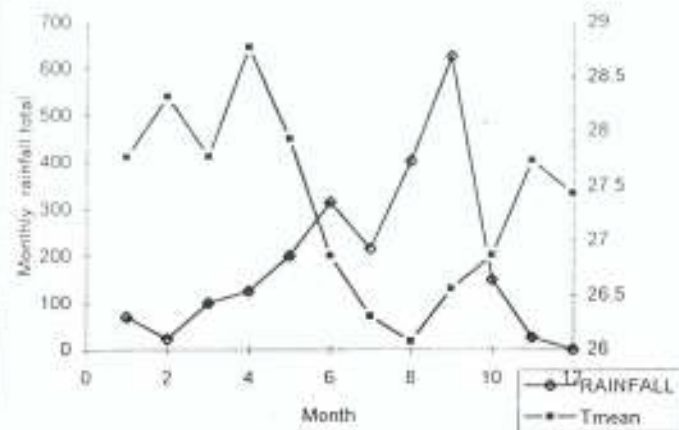


Fig. 4.5e: Ambiothermic curve for Onne (1977)

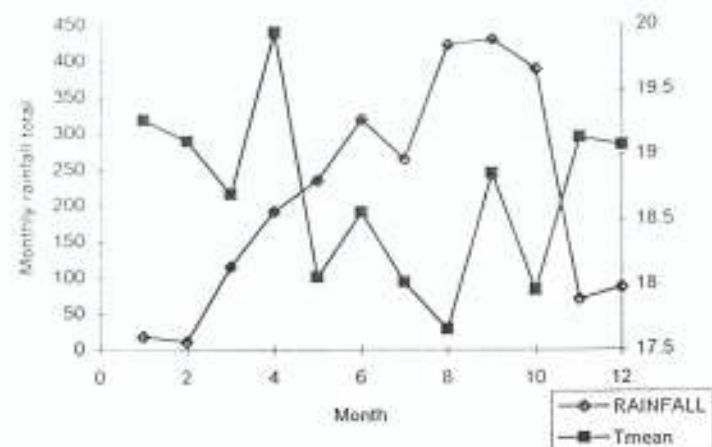


Fig. 4.5f: Ambiothermic curve for Onne (1988)

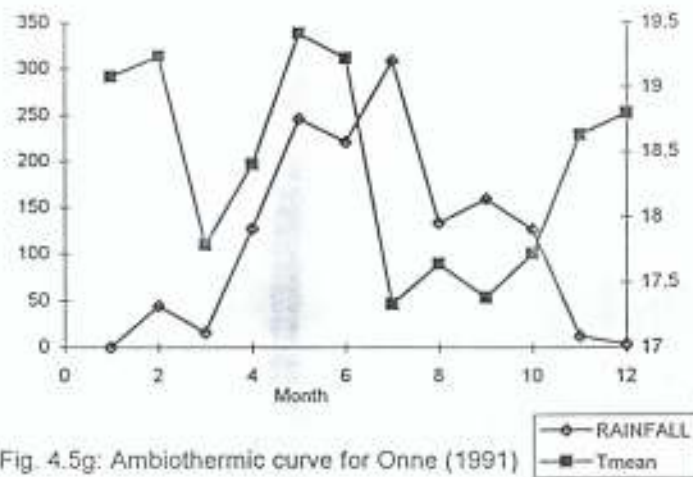


Fig. 4.5g: Ambiothermic curve for Onne (1991)

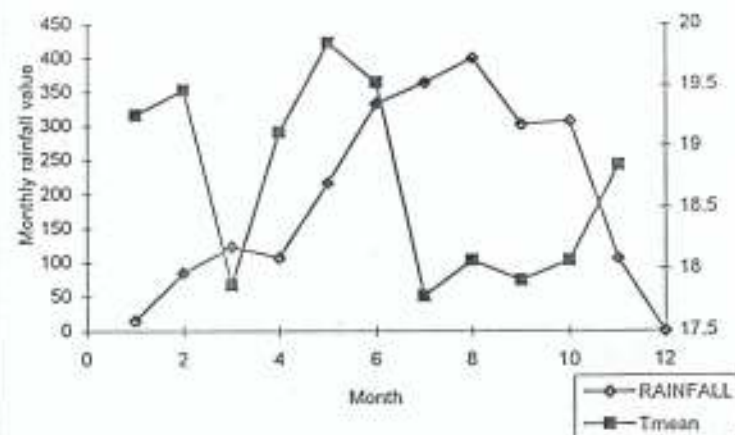


Fig. 4.5h: Ambiothermic curve for Onne (1986)

1986

1991

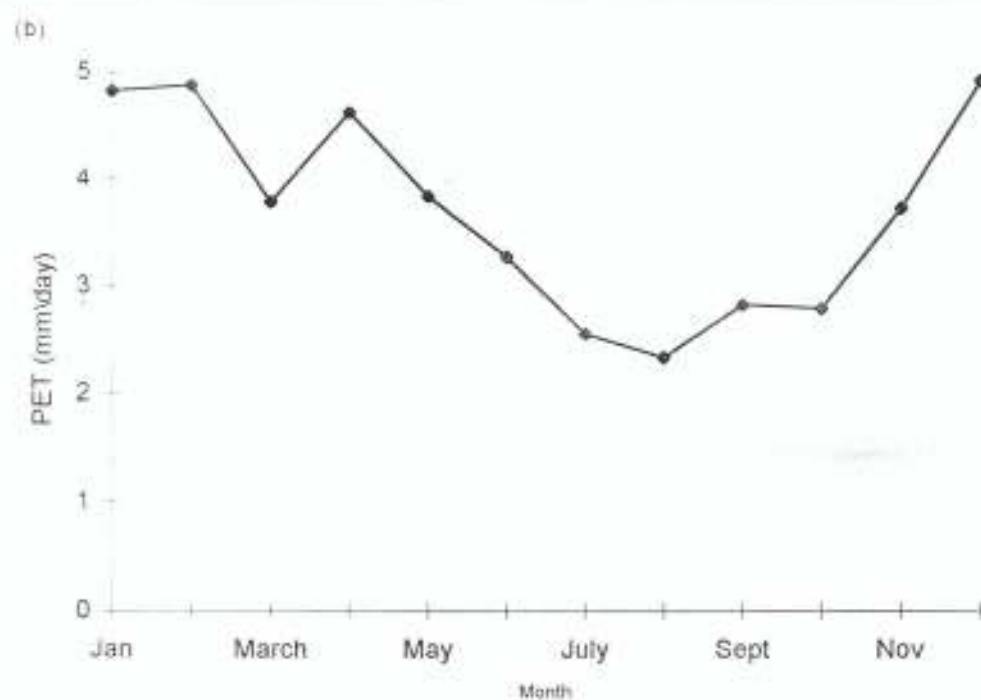
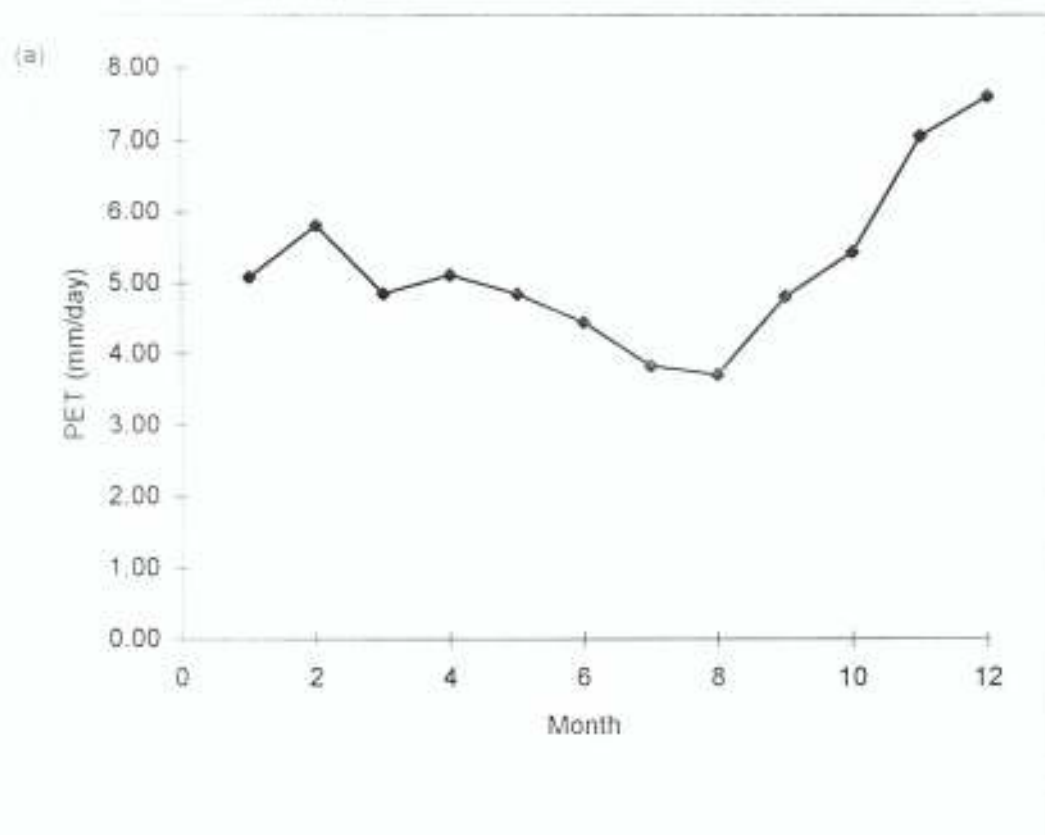


Fig. 4.6 Variability in PET(monthly) value for (a) Ibadan (b) Onne

temperature, all which are major terms in PET formula. In both Ibadan and Onne the PET reached the lowest value in August (i. e. about 3.75 mm/day for Ibadan and 2.5 mm/day for Onne). The decrease in the value could equally be attributed to the prevalent humid weather at this period and the fall in sunshine hours which reduced the n/N (actual sunshine hour to maximum sunshine hour) ratio, thus reducing atmospheric demand. PET values are used in many hydraulic engineering designs and in the estimation of the crop water requirement for irrigation purposes, hence the variability of these value over time is important consideration. For Ibadan the water needed for supplemental irrigation will be high during the period with high PET value. In a typical humid zone like Onne, there may be little need for supplemental irrigation, but drought resistant crops like sorghum may yield poor results.

4.5 Soil Water Balance

The growth and development of crops in any area or place highly depend on the availability of soil water. Soil water dissolves the soil nutrients in the soil and provide the needed moisture for crop metabolic activities. The amount of moisture available in a soil mass at any time would be a function of the soil characteristics such as soil texture, soil structure, etc., the available water (which in turn depend on rainfall or irrigation), and the type of crop planted in the area.

A study of the soil water balance based mainly on rainfall values was carried out. A falling rate water balance model based on daily rainfall and other meteorological data was formulated and used to compute the daily water storage for Ibadan and Onne. In this study daily rainfall values were used in order to reduce

variation that might occur if the weekly or monthly record was used (Robertson, 1988).

A macro function was written using Excel-5 spread sheet software based on the equation for the water balance. The essentials of the macro function is as follows:

Condition A - If soil water on the previous day is greater than 100 mm ($Sw_{i-1} \geq 100$ mm)

$$\text{then } S_w = 100 + P_i - AE_A \quad (36)$$

$$\text{where } AE_A = PET_i \quad (37)$$

Condition B - If soil water on the previous day is less than 100 mm ($Sw_{i-1} < 100$ mm),

$$\text{then } S_w = Sw_{i-1} + P_i - AE_B \quad (38)$$

$$\text{where } AE_B = Sw_{i-1} / 100 * PET_i \quad (39)$$

S_w Soil water on day i (mm)

Sw_{i-1} Soil water level in mm, the previous day

AE_A Actual Evapotranspiration on day i with $Sw_{i-1} \geq 100$ mm

AE_B Actual Evapotranspiration on day i with $Sw_{i-1} < 100$ mm

PET_i Potential evapotranspiration on day i and

P_i Rainfall

A 100 mm soil water storage capacity was assumed. The daily water balance for each year was then calculated and the result on daily soil water surplus or deficit from which the runoff value and amount of water available for deep percolation are presented in appendix I.

It was reasoned that soil water level greater than 20 mm would support agricultural operations in the fields. It was generally observed that the soil water followed the pattern of the rainfall, it began to rise at the onset of the rain in the 10th

decade of the year (April) and reached the maximum in the 16th decade (June) in Ibadan. From the 16th to the 30th decade of the year (October) there were only little fluctuation/deviation from the maximum water holding capacity related to rainfall amount. Consequently high water demanding crops like cassava will be highly favoured. In the dry period of (34th to 9th decade of the following year i.e. Oct. to March), the soil water were of the order of 5 mm in most years with few exceptions. However, in 1979 and 1980, a prolonged zero soil water level ($S_w = 0$) corresponding to complete dryness of soil was observed in Ibadan. It can then be deduced that drought resistant crops like sorghum and millet might be cultivated during the period commencing from the date of the cessation of rain.

In Onne the trend is similar to the one obtained for Ibadan except for the fact that the maximum soil water was attained in the 8th decade (March) and was maintained till the 32nd decade (November). The dry period was very short and there was no prolonged period of complete dryness. Thus certain crops like sorghum might not be favoured in this area.

It should be noted that the soil water holding capacity is crop and location specific since crops differ in their ability to extract water. The value of 100 mm chosen in this report would correspond to the case of crop like maize, cowpea and cassava which are grown in these areas. Nonetheless the methodology of approach adopted in the estimation of soil water is valid irrespective of the value of maximum storage capacity adopted. Figure 4.7 a and b and Figures 4.8 and b shows the graph of the water balance shape for Ibadan and Onne.

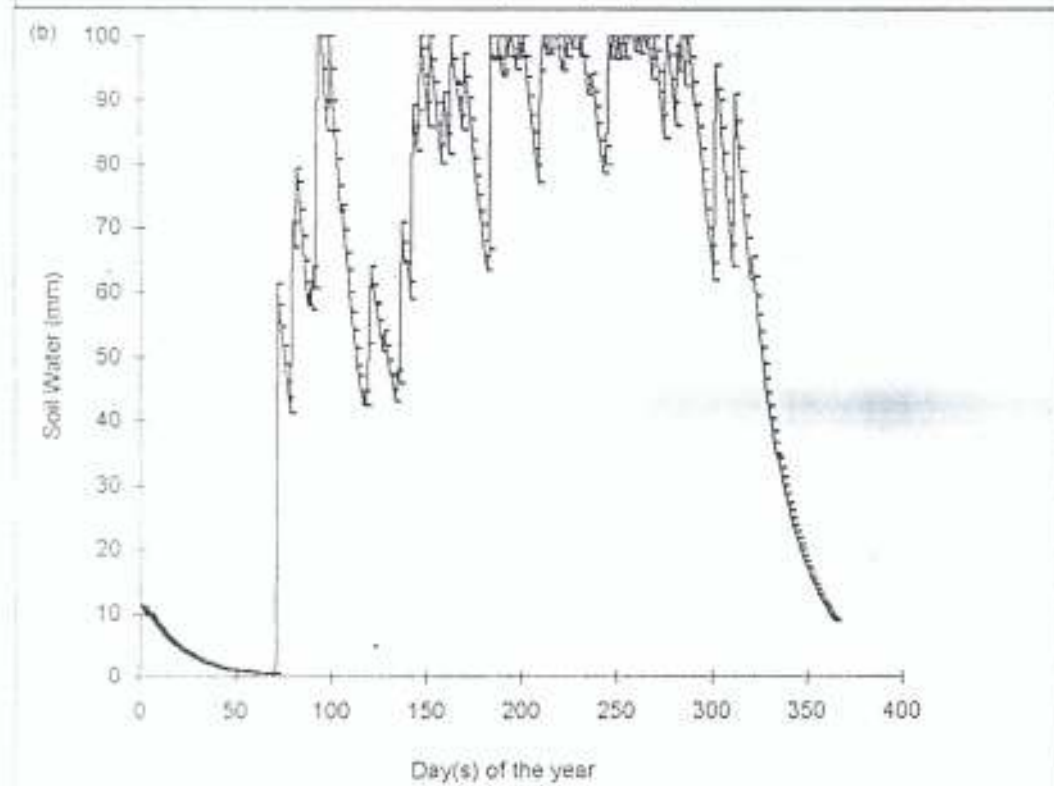
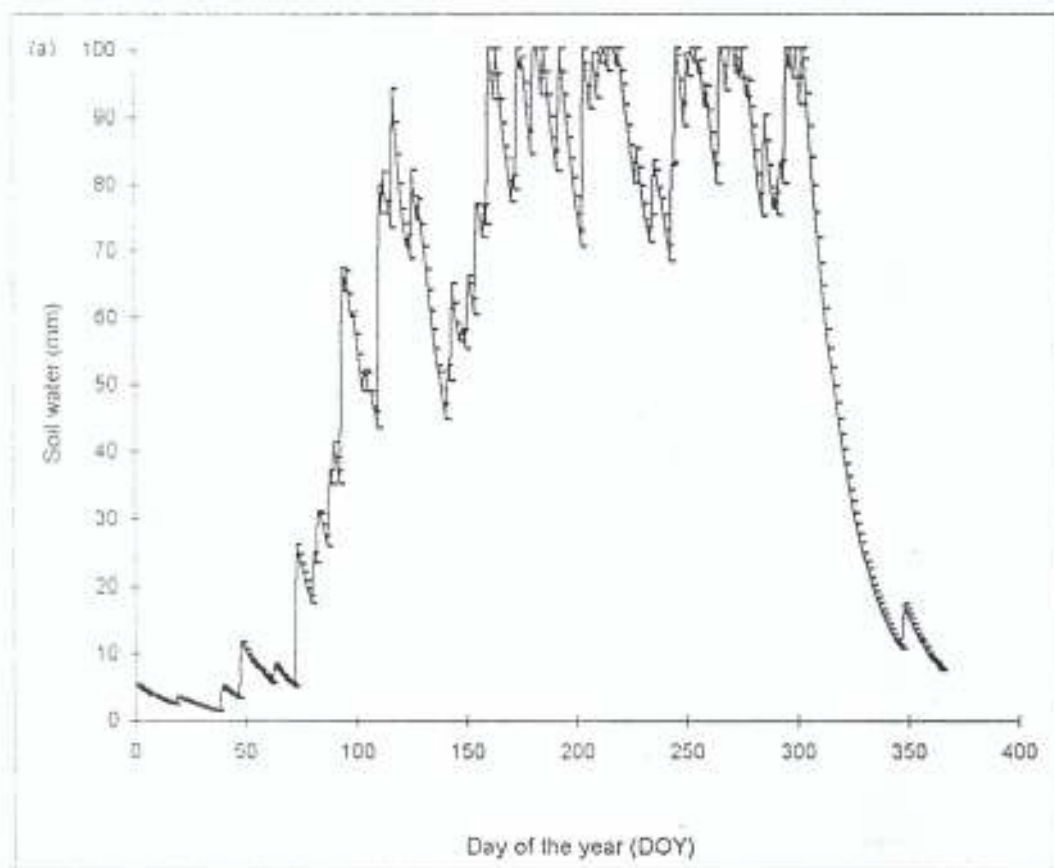


Fig 4. Waterbalance curve for Ibadan (a) 1973 (b) 1985

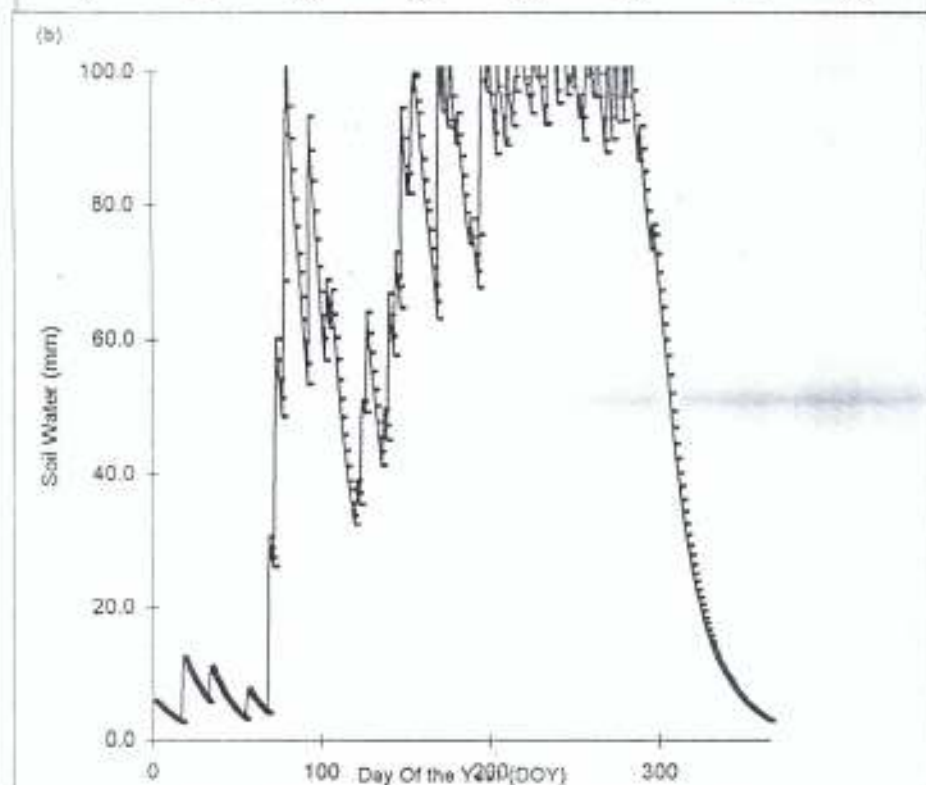
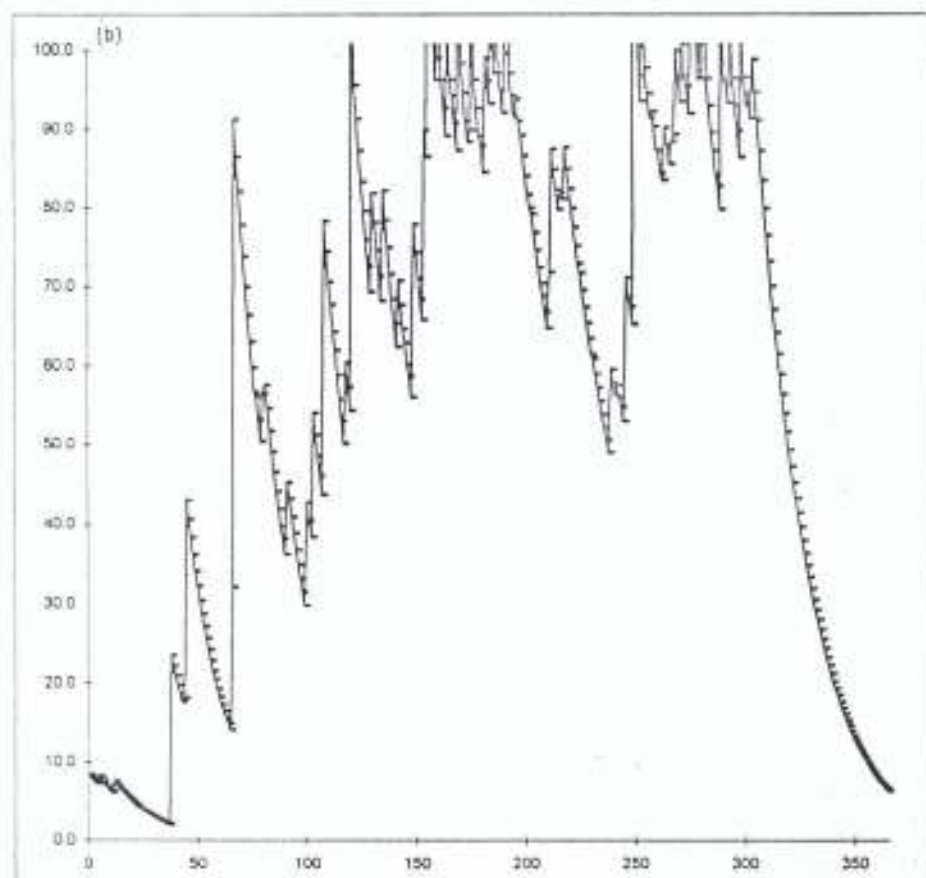


Fig 4.7 : Water balance curve for Onne (a) 1970; (b) 1985

4.6 Markov Analysis of Soil Water

Robertson, (1988) stated that characterising the dependability of soil water is a better agroclimatic approach for the estimation of length of the growing season than the rainfall dependability characterisation. Thus the daily soil water balance for the two sites were subjected to Markov analysis (first order) to determine the probability of dependence of availability of water. A five day wet spell per decade was assumed for the calculation and sufficient to support productive crop growth. The decadal probabilities are shown in Figures 4.8 a and b. The curves show that the seasonal characteristics of the soil water followed that of rainfall. Water was always available in the soil for cultivation and crop growth from the month of April to October in Ibadan and from March to November in Onne. The curves also provide a very good reflection of the start and the end of the rainy season in the two locations. Assuming that successful farming is based on good crop being produced at least in 7 out of 10 years ($P_s = 0.7$), the length of the wet season for successful farming can be readily determined.

4.7 Markov Analysis of Daily Rainfall

TRANSITION PROBABILITY

Using the basic Markov probability equation (chapter II), the transitional probability matrix obtained are:

$$P = \begin{pmatrix} 0.82 & 0.18 \\ 0.66 & 0.34 \end{pmatrix}$$

Table 4. 5a Monthly Transition Probability Table for Ibadan

Month	$P(D_i/D_{i-1})$	$P(W_i/D_{i-1})$	$P(W_i/W_{i-1})$	$P(D_i/W_{i-1})$
January	0.98	0.02	0.02	0.98
February	0.93	0.07	0.07	0.93
March	0.86	0.14	0.17	0.83
April	0.63	0.37	0.25	0.75
May	0.57	0.43	0.28	0.72
June	0.55	0.45	0.49	0.51
July	0.56	0.44	0.58	0.42
August	0.58	0.42	0.51	0.49
September	0.44	0.56	0.56	0.44
October	0.57	0.43	0.51	0.49
November	0.94	0.06	0.19	0.81
December	0.97	0.03	0.01	0.99

$P(W_i/W_{i-1})$ = Probability of a wet day following a wet day;

$P(W_i/D_{i-1})$ = Probability of a dry day following a wet day;

$P(D_i/D_{i-1})$ = Probability of a dry day following a dry day; and

$P(D_i/W_{i-1})$ = Probability of a wet day following a dry day

Table 4.5b: Monthly Transition Probability Table for Onne

Month	$P(D_i / D_{i-1})$	$P(W_i / D_{i-1})$	$P(W_i / W_{i-1})$	$P(D_i / W_{i-1})$
January	0.95	0.05	0.02	0.98
February	0.86	0.14	0.10	0.90
March	0.75	0.25	0.25	0.75
April	0.57	0.43	0.36	0.64
May	0.46	0.54	0.45	0.55
June	0.47	0.53	0.61	0.39
July	0.44	0.56	0.76	0.24
August	0.37	0.63	0.75	0.25
September	0.29	0.71	0.76	0.24
October	0.45	0.55	0.51	0.49
November	0.75	0.25	0.28	0.72
December	0.92	0.08	0.30	0.70

$P(W_i / W_{i-1})$ = Probability of a wet day following a wet day;

$P(W_i / D_{i-1})$ = Probability of a dry day following a wet day;

$P(D_i / D_{i-1})$ = Probability of a dry day following a dry day; and

$P(D_i / W_{i-1})$ = Probability of a wet day following a dry day.

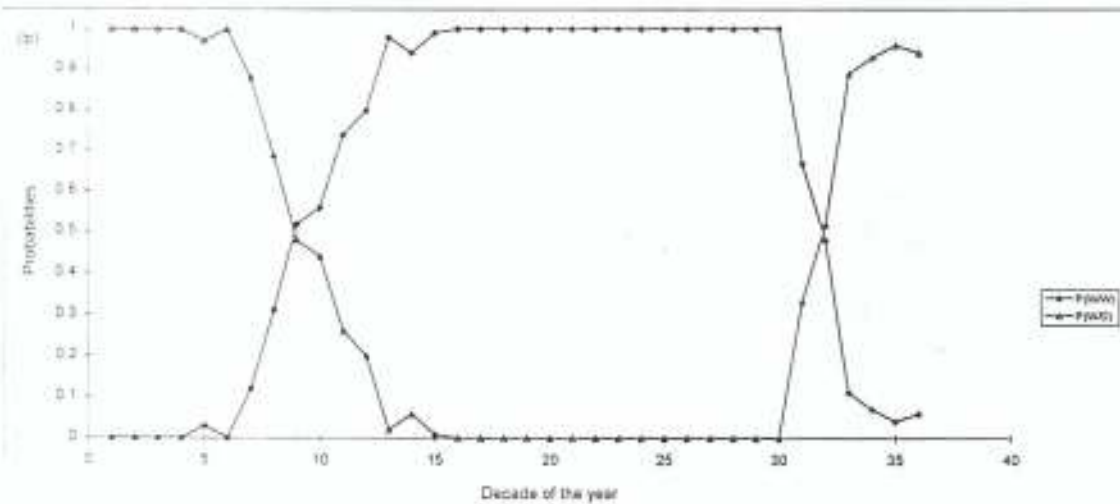
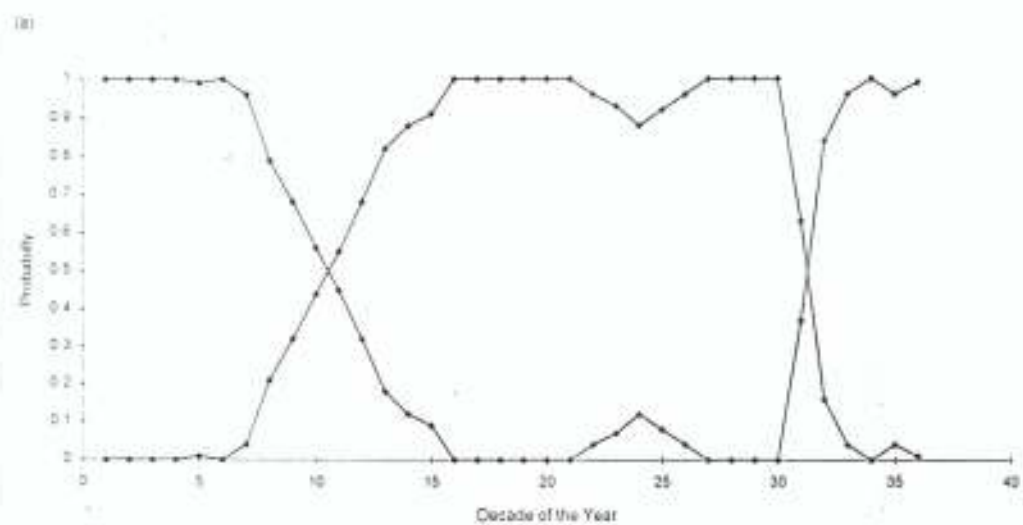


Fig. 4.6 Decadal transition probability of Soil Water for (a) Ibadan, (b) Onne

for Ibadan (1973-1996) and

$$P = \begin{pmatrix} 0.78 & 0.22 \\ 0.60 & 0.40 \end{pmatrix}$$

for Onne (1977-1996)

Thus in Ibadan, if Jan 1st of a year is taken as the reference date i.e. day (0) and given January 2 as a dry day, there is a probability of 0.82 that January 3rd is a dry day. Given that January 2 is wet there is a 0.34 probability that January 3 is wet and the interpolation can be continued using the QSB+ software defining the number of state required or desired.

Also in Onne, if Jan 1st of a year is taken as the reference date i.e. day (0) and given January 2 as a dry day, there is a probability of 0.78 that January 3rd is a dry day. Given that January 2 is wet there is a 0.40 probability that January 3 is wet and the interpolation can be continued using the QSB+ software.

Interactive equation (2) gave

$$P(3) = (0.75, 0.25) \text{ for Ibadan and } P(3) = (0.78, 0.22) \text{ for Onne.}$$

This connotes that the system has settled to a condition of statistical equilibrium after 3 days. that is, the state of occupation probabilities are independent of the initial condition after 3 days.

Table 4.5 a and 4.5 b show the monthly transition table for Ibadan and Onne and the table clearly reflect the rainfall pattern described for the two cities. The variation in the number of days to attain equilibrium was observed to coincide with the changes in the season. In the month of July and August in Ibadan, which is often referred to as "little dry season" for example, the system attained stability on day 4.

The transition probability of dry day following dry day increased from 0.57 in October to 0.98 in January at Ibadan and in Onne 0.45 in October to 0.95 in January after which it decreased to 0.55 and 0.47 in June respectively. This reflected the seasonal pattern of the sub-humid and humid climate of Nigeria which was also observed by Fasheun (1983).

Probabilities of Dry And Wet Days

The transitional probability of a wet day $P(W_t)$ following a wet day $P(W/W_{t-1})$, a wet day following a dry day $P(W_t/D_{t-1})$, a dry day following a dry day $P(D_t/D_{t-1})$ and a dry day following a wet day $P(D_t/W_{t-1})$ for Ibadan and Onne are shown in tables 4.5a and b. In Ibadan most of the months had lower than 50% probability of being wet. The number of months having the probability >0.5 of obtaining a wet day after a wet day is low and only prominent in June and October, thus it can be concluded that continuous (persistent) rain events are mostly possible in these months. Most of the months have probabilities > 0.5 of a dry day following a dry day, thus it is much more likely that a dry yesterday implies a dry today. The result also shows that the possibilities of a dry day following a wet day was most likely in September. However, the probability of a wet day following a dry day was >0.5 most of the months. In Onne, the probability of a dry day following a dry day was less pronounced. The probability of a wet day following a dry day was high in most part of the year i.e. >0.5 between April and November, this implied that, there were more likelihood of rain event most times of the year. The probability of continuous rainfall was very high (>0.5) between the months of June and October but was at peak (>0.7) between July and September, implied that rainfall event was most likely on a daily basis in these months.

Generally, the likelihood of a rainfall event independent of the previous condition using initial probability value was higher in Ibadan than Onne. Again, Ibadan showed the classical bi-modal feature of the "little dry season" while the Unimodal feature was shown by Onne.

The pattern of the transition probabilities was similar to that obtained from the initial condition, though there were evidences of intraseasonal fluctuations. Generally, as the rain season progressed, the probability of a day being wet was greater when the previous day was wet than if it was dry. ($P(W_i/W_{i-1}) > P(W_i/D_{i-1})$). Conversely, the probability of a day being dry was smaller for a previous dry day than if the previous day was wet [$P(D_i/D_{i-1}) < P(D_i/W_{i-1})$]. The difference between $P(W_i/W_{i-1})$ and $P(W_i/D_{i-1})$ decreased as the rainy season progressed suggesting that the probabilities of a wet day became less dependent on the condition of the previous day as the rains became more steady. In the same vein, the difference between $P(D_i/D_{i-1})$ and $P(D_i/W_{i-1})$ increased during the rainy season to show that the conditional dependence of dry days was inevitable even during the core of the rainy months of June and October in Ibadan and July to October in Onne.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

Adequate analyses of climatological data are helpful in vital decision making in agricultural practices. This study analysed long term climatological data to determine general rainfall characteristics and daily soil water budget in Ibadan and Onne representing the sub humid and humid zone of Nigeria.

The result showed that there were variation in the rainfall distribution on annual, monthly and daily basis. The amount of total rainfall declined over the time of study, and there were fluctuations in the onset of rain. The delay in the onset of rain shortened the length of the growing season by about 20 days in the two areas over the period of study. This of course will be consequential in the type of crops that can be grown successfully in the areas and the no of cycle of growth in a typical growing season. During the period considered in this study (1973 - 1996) for Ibadan and (1977 - 1996) for Onne, it was observed that there was a reduction in the number of rainy day while the monthly mean temperature increased. It was also noted that rainfall distribution in Onne is characterised by high intense rainfall which continued for days. This would suggest the area could be susceptible to constant erosion and flood and other negative consequences.

The limitation in the attempt to characterise the dependability of rainfall led to the use of the dependability of soil water to determine a useful practical agronomical factor, the estimated length of a growing season, thus, the result of

the falling rate soil water budget analysis was used to calculate the probability of days with wet and dry soil and runs of consecutive days with wet soil from which the beginning, duration, and ending of the rainy season were calculated at various probability levels. The rainfall data modelling equally shows that there are greater tendency of continuous rainfall in Onne than in Ibadan. The result obtained was consistent with the findings of the beginning and cessation of rainfall obtained from the rainfall data analysis. The result obtained from this study agrees that with the finding of Fasheun, (1983), and Oladipo and Kwaghsaa, (1994) on the usefulness of the Markov chain for hydrological analysis. The study also showed that, there is the need to cultivate early maturing plant as it is clear that the growing season is reducing in length over the year. It can be concluded that full scale irrigation may not be profitable in these places as soil water seem enough to facilitate the growth and development of many arable crops but the practice of supplemental irrigation will go a long way to boost food production round the year.

5.1 Recommendations

The methodology adopted in this study is not only useful for making decision at the farm and regional level, it can also be used for establishing agroclimatic atlas for a region or a nation. Thus the followings are recommended:

1. The methodology should be adopted for all ecological zone of Nigeria for crop zonation and land use planning.
2. That further work be done to make the study crop - specific as the assumption of 100 mm of soil water capacity does not hold for all crops.

3. That the model used in the study be subjected to sensitivity analysis to evaluate the accuracy of the assumptions considered in the model.

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Appendix I: Daily water balance for Ibadan (1973-1996)

DOY	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	5	7	5	24	8	0	1	0	9	4	4	37	11	8	6	3	9	3	40	8	6	18	7	2
2	5	7	5	23	7	0	1	0	9	3	4	35	11	8	6	3	9	3	38	7	5	15	8	2
3	5	6	5	22	41	0	1	0	8	3	4	33	10	8	5	3	8	2	36	7	5	15	8	2
4	4	6	4	21	30	0	1	0	8	3	3	32	10	7	5	2	8	2	34	7	5	14	8	2
5	4	6	4	20	37	0	1	0	8	3	3	30	10	8	5	2	8	2	33	6	5	13	5	2
6	4	6	4	19	35	0	1	0	7	3	3	29	9	8	5	2	7	2	31	6	4	13	5	2
7	4	5	4	18	33	0	1	0	7	3	3	27	8	7	4	2	7	2	30	6	4	12	5	2
8	4	5	4	18	31	0	1	0	7	3	3	26	9	7	4	2	7	2	28	6	4	11	5	2
9	3	5	4	17	30	0	0	0	6	2	3	25	8	7	4	2	6	2	27	5	4	11	4	1
10	3	5	3	16	28	0	0	0	6	2	3	23	8	6	4	2	6	2	25	5	3	10	4	1
11	3	4	3	15	27	0	0	0	6	2	3	22	7	6	4	2	6	2	24	5	3	10	4	1
12	3	4	3	15	26	0	0	0	5	2	3	21	7	6	3	2	5	2	23	4	3	9	4	3
13	3	4	3	14	24	0	0	0	5	2	2	20	7	7	3	2	5	2	22	4	3	9	4	3
14	3	4	3	13	23	0	0	0	5	2	2	19	6	7	3	1	5	1	21	4	3	9	3	2
15	3	4	3	13	22	0	0	0	5	2	2	18	6	6	3	1	6	1	20	4	3	8	3	2
16	3	3	3	12	21	0	0	0	4	2	2	17	6	6	3	1	4	1	19	4	2	8	3	2
17	2	2	2	12	20	10	0	0	4	2	2	17	5	6	3	1	4	1	18	3	2	7	3	2
18	2	2	2	11	19	17	0	0	4	2	2	16	5	6	13	1	4	1	17	3	2	7	3	2
19	2	2	2	11	18	16	0	0	4	1	2	15	5	5	12	1	4	1	16	3	2	7	3	2
20	2	2	2	10	17	15	0	0	4	2	2	14	5	5	11	1	4	1	15	3	2	6	2	2
21	2	2	2	10	16	14	0	0	4	2	2	14	4	5	11	1	3	1	15	3	2	6	2	2
22	2	2	2	9	15	13	0	0	3	2	2	13	4	5	10	1	3	1	14	3	2	6	2	2
23	2	2	2	9	14	12	0	0	3	2	2	12	4	4	10	1	3	2	13	2	2	6	2	2
24	2	2	2	8	14	12	0	0	3	2	2	12	4	4	9	1	3	1	13	2	2	6	2	2
25	2	2	2	8	13	11	0	0	3	2	1	11	4	4	9	1	3	1	12	2	1	6	2	2
26	2	2	2	8	12	11	0	0	3	2	1	11	3	4	8	1	3	1	11	2	1	6	2	1
27	2	2	1	7	11	10	0	0	3	2	1	10	3	3	8	1	3	1	11	2	1	6	2	1
28	2	2	1	7	10	10	0	0	3	2	1	10	3	3	7	1	2	1	10	2	1	6	2	1
29	2	2	1	7	9	9	0	0	2	2	1	9	3	3	7	1	2	1	10	2	1	5	2	1
30	2	2	1	6	8	9	0	0	2	2	1	9	3	3	7	1	2	1	9	2	1	5	1	1
31	2	2	1	6	8	8	0	0	2	2	1	8	3	3	6	1	2	1	9	2	1	5	1	1
32	2	2	1	6	8	8	0	0	2	2	1	8	3	3	6	1	2	1	8	1	1	5	1	1
33	2	2	1	6	8	7	0	0	2	1	1	7	2	3	6	1	2	1	8	1	1	4	1	1
34	2	2	1	5	7	7	0	0	2	1	1	7	2	2	11	1	2	1	7	1	45	4	1	1
35	1	2	1	5	7	6	0	0	2	1	1	7	2	2	10	1	2	1	7	1	43	4	1	1
36	1	2	1	5	6	6	0	0	2	1	1	6	2	2	10	1	2	1	7	1	40	4	1	1
37	1	2	1	5	6	6	0	0	1	1	1	6	2	2	9	1	1	1	6	1	38	3	1	1
38	1	2	1	5	6	5	0	0	1	1	1	5	2	23	0	4	1	1	6	1	36	3	1	1
39	1	2	1	5	6	5	0	0	1	1	1	5	2	22	8	4	1	1	6	1	34	3	1	1
40	1	2	1	4	5	5	0	0	1	1	1	5	2	21	8	32	1	1	5	1	32	3	1	1
41	1	2	1	4	5	4	0	0	1	1	1	5	1	20	7	20	1	1	5	1	30	3	1	1
42	1	2	1	4	5	4	0	0	1	1	1	4	1	19	7	20	1	1	5	1	28	12	1	12
43	1	2	1	4	5	4	0	0	1	1	1	4	1	18	6	27	1	1	5	1	27	11	1	11
44	1	2	1	3	5	4	0	0	1	1	0	4	1	18	6	25	1	0	5	1	25	11	1	10
45	1	2	1	3	5	4	0	0	1	1	0	4	1	18	6	24	1	0	5	1	24	10	1	10
46	1	2	1	3	5	4	0	0	1	1	0	3	1	17	5	23	1	0	18	1	22	9	1	10
47	1	2	1	3	5	3	3	23	1	1	0	3	1	18	5	21	1	0	17	1	21	9	1	9
48	1	2	1	3	5	3	3	22	1	1	0	3	1	18	5	20	1	0	16	1	20	8	1	11
49	1	2	1	3	5	3	3	21	1	1	0	3	1	17	5	19	1	0	15	1	19	8	0	11
50	1	2	1	3	5	3	3	20	1	1	0	3	1	17	4	18	1	19	14	0	18	8	0	10
51	1	2	1	3	5	3	3	19	1	1	0	3	1	16	4	17	1	10	10	0	17	7	0	9
52	1	2	1	3	5	3	3	18	1	1	0	3	1	16	4	16	1	17	15	0	16	7	0	9
53	1	2	1	3	5	3	3	17	1	1	0	3	1	15	4	15	1	16	14	0	15	6	0	8
54	1	2	1	3	5	3	3	16	1	1	0	3	1	15	4	14	1	15	14	0	14	6	0	8
55	1	2	1	3	5	3	3	15	1	1	0	3	1	14	3	13	1	14	13	0	13	6	0	7
56	1	2	1	3	5	3	3	14	1	1	0	3	1	14	3	13	0	13	12	0	12	6	0	7
57	1	2	1	3	5	3	3	13	1	1	0	3	1	13	3	12	0	13	11	0	11	6	0	7
58	1	2	1	3	5	3	3	12	1	1	0	3	1	12	3	11	0	12	11	0	10	6	0	6
59	1	2	1	3	5	3	3	11	1	1	0	3	1	11	3	11	0	11	10	0	9	6	0	6
60	1	2	1	3	5	3	3	10	1	1	0	3	1	10	3	10	0	10	9	0	8	5	0	6
61	1	2	1	3	5	3	3	9	1	1	0	3	1	9	3	9	0	9	8	0	7	4	1	25
62	1	2	1	3	5	3	3	8	1	1	0	3	1	8	3	8	0	8	7	0	6	4	1	24
63	1	2	1	3	5	3	3	7	1	1	0	3	1	7	3	7	0	7	6	0	5	4	1	23
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65	1	2	1	3	5	3	3	5	1	1	0	3	1	5	3	5	0	5	4	0	3	2	1	21
66	1	2	1	3	5	3	3	4	1	1	0	3	1	4	3	4	0	4	3	0	2	1	1	20
67	1	2	1	3	5	3	3	3	1	1	0	3	1	3	3	3	0	3	2	0	1	0	1	19
68	1	2	1	3	5	3	3	2	1	1	0	3	1	2	3	2	0	2	1	0	0	0	0	18
69	1	2	1	3	5	3	3	1	1	1	0	3	1	1	2	1	0	1	0	0	0	0	0	17
70	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	16
71	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	15
72	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	14
73	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	13
74	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	12
75	1	2	1	3	5	3	3	0	1	1	0	3	1	0	1	0	0	0	0	0	0	0	0	11
76	1	2	1	3	5	3	3	0	1	1														

Appendix I: Daily water balance for Ibadan (1973-1996)

84	31	65	67	57	4	59	26	26	7	43	0	69	73	49	81	39	15	2	19	38	58	37	85	32
85	29	61	64	54	4	56	24	44	8	41	0	66	69	47	77	37	14	2	18	36	53	36	81	30
86	28	58	61	68	4	52	22	42	29	77	0	62	65	44	73	35	13	2	17	35	50	33	77	29
87	26	55	57	64	3	50	20	38	27	73	0	61	61	42	70	34	53	2	16	33	47	32	73	27
88	37	52	66	61	16	57	32	37	28	69	0	57	58	40	68	32	51	2	18	31	63	30	69	32
89	35	49	62	58	19	54	29	35	50	66	4	54	61	38	63	30	50	2	15	29	78	28	66	58
90	41	48	59	55	18	51	27	33	47	62	3	51	57	35	60	29	53	2	14	28	100	27	63	55
91	39	65	58	52	18	48	32	32	63	59	3	49	64	45	57	28	51	2	13	28	95	39	60	52
92	37	82	54	50	15	47	29	30	60	56	54	46	61	43	54	28	43	35	13	25	90	37	63	58
93	35	84	51	43	14	50	92	30	57	53	51	44	100	41	63	25	46	33	21	23	88	35	76	54
94	67	79	49	45	14	47	84	28	70	51	48	56	100	39	88	24	47	31	55	28	81	33	73	63
95	84	75	78	43	13	44	77	27	67	48	45	53	100	37	84	29	45	30	52	45	77	32	68	60
96	67	72	75	41	12	56	70	25	85	48	43	51	95	35	79	27	42	34	50	43	73	32	65	62
97	83	70	71	39	11	55	64	26	81	45	41	56	90	33	75	43	40	34	50	41	70	46	62	77
98	60	67	68	37	13	52	58	25	77	43	48	53	85	31	71	41	38	58	85	39	66	44	59	73
99	61	74	64	39	32	52	57	23	73	41	45	51	100	30	67	39	36	55	62	37	64	42	62	70
100	57	70	68	37	30	49	52	30	69	61	51	48	95	43	64	37	34	50	59	35	61	40	59	66
101	54	66	66	38	34	48	47	28	66	77	49	46	90	40	60	44	33	54	61	62	58	36	58	63
102	51	63	63	40	32	45	43	27	63	73	46	44	85	38	57	42	31	61	58	76	55	36	53	63
103	49	60	60	38	31	65	39	25	60	69	43	50	81	54	69	40	29	51	55	72	52	34	50	60
104	52	77	57	36	29	62	36	24	57	67	41	59	77	51	65	54	28	49	63	68	50	32	48	69
105	52	81	54	35	28	59	33	23	54	64	38	50	73	49	62	51	26	48	50	65	47	32	51	68
106	49	89	53	54	26	64	30	22	57	69	37	63	73	46	67	49	25	75	58	61	45	30	49	67
107	49	84	61	64	24	80	27	20	54	86	35	67	70	44	64	60	74	73	63	100	42	29	70	66
108	48	80	61	61	23	58	25	21	60	62	33	63	68	78	60	57	71	70	50	66	40	27	70	62
109	48	76	77	58	28	55	23	20	65	59	41	60	63	74	57	55	67	67	54	90	61	26	68	62
110	43	72	73	56	26	100	21	19	61	63	39	57	60	71	54	55	63	64	51	85	58	25	63	64
111	80	73	78	53	25	65	19	18	58	63	37	55	57	68	51	53	60	61	68	61	55	23	65	60
112	76	83	73	50	23	100	60	39	56	60	36	62	54	64	49	78	57	58	65	79	52	22	79	90
113	82	91	89	48	48	95	82	37	71	57	34	61	51	62	46	84	54	63	62	75	50	21	75	85
114	77	67	100	67	45	91	75	35	68	54	33	58	49	59	43	80	53	79	59	71	47	20	71	81
115	77	62	100	64	42	90	60	41	69	52	31	55	47	56	41	76	50	96	56	68	45	19	68	77
116	73	78	95	61	40	85	80	38	66	40	20	53	45	53	30	74	53	61	53	64	60	18	64	73
117	84	74	81	72	40	81	81	36	84	54	26	50	42	60	38	76	51	67	57	61	59	17	61	69
118	89	100	86	68	37	76	74	40	61	51	26	48	45	60	36	68	49	83	54	58	62	39	58	71
119	84	95	100	65	63	72	68	38	58	55	25	49	42	57	34	100	48	79	63	77	59	37	100	67
120	80	90	100	70	59	72	62	38	55	62	23	59	52	54	33	95	44	81	60	73	56	38	95	67
121	76	83	96	76	56	68	58	36	75	60	38	56	64	100	39	100	45	100	74	69	53	36	90	63
122	74	85	92	73	53	64	60	100	72	70	37	68	61	56	37	95	43	95	71	66	61	36	89	62
123	70	100	100	70	59	61	59	98	69	67	90	84	58	91	35	100	41	62	68	76	49	35	85	78
124	72	85	96	67	55	56	54	92	77	64	66	62	58	67	51	95	41	100	65	72	47	34	81	74
125	89	91	92	64	52	67	65	88	74	73	62	79	56	63	51	91	42	96	77	69	45	33	100	70
126	82	100	91	85	50	63	59	84	71	70	79	75	53	60	49	66	40	95	100	66	46	43	96	76
127	78	100	97	82	48	60	55	80	68	67	62	72	51	76	64	91	61	62	98	63	44	41	91	72
128	74	99	92	100	46	57	73	77	67	78	78	100	54	73	61	66	62	68	91	100	49	39	100	68
129	78	91	100	100	54	57	68	79	84	75	95	96	52	69	58	82	62	84	67	95	69	54	95	65
130	74	87	98	96	59	54	63	75	74	75	100	91	49	63	55	78	72	81	84	91	68	62	100	62
131	70	86	92	92	56	55	79	72	71	72	96	100	47	78	53	75	100	89	60	89	63	50	95	82
132	67	82	88	88	59	87	73	70	72	69	100	98	47	75	50	71	100	95	78	85	61	47	91	77
133	64	83	84	89	56	82	67	73	69	73	96	91	45	71	48	68	96	91	73	90	58	45	86	74
134	61	79	82	85	56	76	82	70	66	70	100	100	43	68	48	64	92	89	70	88	55	58	90	70
135	58	75	85	61	52	85	61	67	63	67	100	96	48	62	43	90	88	100	77	84	65	95	85	68
136	50	72	81	76	49	84	73	64	61	64	96	91	48	78	41	86	84	96	73	95	62	62	81	71
137	53	69	100	91	46	89	79	61	58	62	91	67	71	75	50	82	82	62	100	91	59	60	77	67
138	57	69	96	67	61	64	70	78	57	59	94	100	68	72	47	78	81	67	100	89	57	48	76	64
139	49	65	100	64	48	89	73	76	54	70	90	100	65	65	45	89	100	93	100	85	94	45	72	63
140	47	62	96	80	48	84	67	73	90	67	86	90	64	65	67	85	90	83	96	81	68	43	68	60
141	45	59	100	68	45	82	68	69	68	64	83	97	62	62	64	61	61	85	100	78	96	43	72	59
142	53	57	96	100	43	79	83	76	84	61	79	100	59	71	61	77	89	82	100	78	92	41	68	63
143	50	54	92	96	40	74	58	72	81	70	100	100	69	68	55	73	69	78	96	79	68	39	65	83
144	65	55	100	100	38	70	61	69	77	72	96	96	88	85	73	70	85	75	100	78	69	61	85	100
145	82	52	96	67	38	67	65	67	74	69	93	91	62	63	69	69	61	63	96	75	65	48	61	65
146	59	50	93	93	36	63	79	65	71	68	89	90	68	60	68	65	78	60	100	78	100	46	77	90
147	56	47	100	90	60	77	73	64	97	69	94	100	100	59	65	62	74	70	96	73	96	56	88	66
148	58	46	96	88	58	73	67	61	100	68	100	96	96	58	65	64	72	73	61	70	100	63	94	67
149	58	44	100	83	55	89	84	97	100	89	96	91	94	78	90	63	73	63	67	67	96	61	68	63
150	55	42	97	79	52	73	78	100	96	100	91	89	90	74	86	60	62	100	84	64	62	56	94	60
151	68	58	93	76	74	84	100	96	91	96	100	100	86	71	82	57	78							

Appendix I: Daily water balance for Ibadan (1973-1996)

252	96	89	71	32	44	62	94	93	83	87	49	90	87	87	85	91	98	100	80	100	85	91	100	
253	100	86	69	31	42	59	100	90	100	85	70	87	100	83	83	90	100	87	79	87	82	88	95	
254	88	83	67	30	41	57	93	100	100	85	87	84	100	100	87	82	87	88	84	77	88	78	82	97
255	100	81	68	29	54	54	86	100	96	82	89	81	87	98	83	89	84	100	81	75	84	75	81	100
256	96	82	66	28	55	52	93	100	100	85	100	78	100	84	90	100	81	88	86	72	91	73	77	100
257	98	79	64	27	60	54	88	97	97	82	87	100	100	91	99	96	91	99	98	100	88	70	73	95
258	95	78	63	26	57	51	83	100	94	96	93	87	100	92	100	84	100	100	93	100	100	89	70	91
259	91	74	61	25	58	67	77	100	93	93	100	93	100	90	100	100	89	97	95	100	100	87	100	91
260	94	79	59	24	100	100	72	100	90	90	98	94	98	87	100	97	95	95	100	100	97	87	100	88
261	91	78	57	23	95	98	71	97	87	87	95	92	100	87	97	84	85	88	97	100	83	88	95	100
262	88	75	56	22	89	91	68	94	86	84	92	88	100	84	96	80	89	100	96	87	90	100	91	100
263	85	73	64	25	100	87	81	100	83	81	89	80	87	83	88	87	88	100	83	100	87	88	88	95
264	83	70	62	83	97	89	57	100	60	84	86	86	100	90	100	84	83	97	89	100	84	95	84	91
265	80	67	68	80	92	85	53	100	93	83	83	83	100	88	100	80	82	93	84	100	91	95	100	92
266	100	74	64	77	86	100	78	97	90	81	100	100	98	88	96	88	89	100	91	100	100	99	95	88
267	100	72	62	75	83	96	100	97	87	78	97	97	100	88	93	85	88	100	88	87	98	95	81	100
268	97	69	70	72	96	98	100	93	84	77	93	93	97	89	90	82	84	87	85	93	100	100	88	96
269	94	66	100	70	95	83	97	91	81	75	90	88	83	100	88	89	81	100	82	87	87	100	82	100
270	100	78	68	67	90	95	90	88	97	72	87	95	100	87	100	85	79	97	98	93	100	100	79	100
271	100	76	100	74	85	91	84	90	98	70	84	100	88	83	97	95	100	100	95	100	100	100	78	100
272	100	73	100	73	81	94	100	87	100	68	91	100	95	100	93	91	98	100	82	100	97	98	74	95
273	96	71	87	74	77	94	94	84	95	65	88	87	91	87	80	85	100	85	100	85	87	70	82	
274	100	89	100	71	73	88	86	94	93	78	88	95	88	95	100	85	100	100	98	81	100	87	88	
275	96	85	98	85	79	83	93	100	89	80	82	82	84	82	96	100	98	96	96	94	88	100	83	83
276	100	81	82	87	75	80	85	98	88	77	100	90	100	100	93	98	99	93	100	97	91	100	80	82
277	96	89	88	83	100	76	78	100	82	74	98	98	100	100	100	93	95	91	100	94	88	98	87	87
278	93	100	100	80	84	81	79	100	88	72	92	100	97	100	100	94	100	88	100	84	84	84	55	83
279	95	90	100	78	91	78	72	100	94	72	88	100	93	96	96	82	100	84	88	87	81	90	77	78
280	91	100	96	75	100	84	86	98	100	70	90	100	90	100	93	91	98	83	95	83	80	100	79	73
281	89	100	94	78	100	88	81	100	96	67	86	96	88	96	100	89	82	82	81	80	81	97	75	69
282	85	100	100	76	94	81	74	100	93	84	82	100	89	100	96	85	95	83	88	77	89	94	74	85
283	81	100	100	80	88	89	68	90	90	79	81	85	80	100	100	91	89	88	88	82	83	90	80	82
284	78	100	96	100	83	91	64	95	93	77	75	94	100	83	100	95	88	100	83	96	100	78	58	
285	75	98	100	98	78	86	88	91	90	90	82	100	98	90	97	93	94	98	83	100	100	98	72	86
286	90	94	96	83	74	88	82	88	100	100	78	96	82	87	84	100	90	93	80	98	98	88	72	69
287	86	90	100	90	89	89	57	84	100	88	75	93	100	84	90	100	100	77	82	82	94	72	83	
288	83	88	96	96	73	85	52	81	100	84	72	89	100	83	87	88	100	74	89	88	82	88	100	
289	79	84	100	100	77	80	47	80	98	90	80	100	97	80	82	83	98	100	81	98	88	95	72	100
290	78	87	98	100	100	84	44	87	100	83	68	100	93	100	88	89	92	100	100	100	100	100	88	100
291	79	83	100	97	94	79	70	84	97	90	84	98	88	88	85	88	90	100	88	88	88	100	85	100
292	75	80	98	97	100	91	68	100	93	87	82	83	88	98	82	100	88	87	83	85	82	98	81	100
293	83	87	98	100	94	87	60	99	89	84	80	89	88	83	79	100	95	93	89	81	89	94	59	95
294	84	83	100	100	88	100	55	98	88	81	57	88	82	100	78	100	92	90	88	98	85	91	58	89
295	80	80	98	100	95	94	68	100	82	79	55	100	78	86	73	100	88	88	83	84	100	87	53	84
296	100	80	100	96	90	89	83	96	79	77	52	98	78	83	77	98	85	83	100	100	100	58	80	
297	97	78	100	93	84	100	68	100	78	77	50	85	73	90	78	83	81	80	96	98	98	100	52	75
298	100	75	97	80	84	95	100	98	88	74	48	82	70	88	73	89	78	88	83	82	82	100	51	71
299	98	74	100	87	83	90	92	83	85	71	48	88	67	100	70	88	75	85	98	89	90	98	100	69
300	100	71	97	100	88	97	88	89	88	89	44	85	85	96	87	82	72	82	95	85	95	83	100	98
301	98	68	93	98	82	100	81	86	82	66	42	82	82	93	65	79	69	78	82	100	82	89	85	82
302	92	66	88	100	77	98	74	95	79	64	40	78	98	95	82	80	87	75	91	98	88	88	89	58
303	100	70	88	97	73	97	88	92	78	65	39	80	92	81	80	77	84	73	88	82	88	85	85	85
304	98	67	83	95	89	91	62	69	78	77	37	77	90	89	59	74	82	70	84	89	84	85	80	52
305	93	65	78	85	83	90	58	87	72	73	35	74	88	85	55	74	69	88	80	100	80	91	78	49
306	86	82	75	81	85	90	51	88	69	89	34	70	82	81	52	70	58	87	77	98	81	88	70	45
307	84	83	72	87	53	100	45	85	68	75	32	67	78	87	49	67	53	64	85	91	77	88	76	42
308	80	88	69	87	49	96	57	97	62	71	30	64	74	83	47	64	50	61	81	87	74	95	71	39
309	76	84	65	100	45	100	51	93	59	88	29	61	71	80	45	61	47	58	77	83	70	90	86	36
310	72	80	62	98	42	94	49	100	57	65	27	59	67	78	42	58	45	58	73	60	87	88	81	33
311	66	76	80	83	38	87	41	100	54	62	28	58	64	73	40	55	43	53	70	76	84	83	57	30
312	64	72	88	89	35	80	38	96	51	59	25	54	91	70	38	52	41	60	87	73	81	70	53	28
313	61	89	55	85	32	74	32	82	49	58	24	51	87	87	38	49	38	48	64	74	58	75	58	26
314	58	85	53	85	30	68	29	88	48	53	22	49	83	84	34	47	38	48	81	70	55	72	71	24
315	50	62	50	82	27	83	28	84	44	51	21	47	79	61	33	45	35	44	58	67	53	69	66	22
316	52	59	48	78	25	59	23	80	42	48	20	45	75	59	31	43	33	42	55	64	50	88	81	20
317	50	56	46	75	23	54	21	77	40	46	39	46	72	58	29	40	31	40	53	61	48	83	57	19
318	47	53	44	71	21	50	19	74	38	44	40	65	68	54	28	38	30	38</						

Appendix 1: Daily water balance for Ibadan (1973-1986)

336	18	22	64	32	5	12	3	37	18	18	19	42	33	24	11	28	12	17	21	26	61	26	14	4
337	17	21	61	31	4	11	3	35	15	17	45	40	31	23	11	27	11	16	20	24	58	25	13	4
338	17	20	59	29	4	10	2	34	14	17	44	38	30	22	10	26	11	15	19	23	56	24	12	3
339	16	19	56	28	4	9	2	32	13	16	42	37	29	21	10	25	10	15	18	22	54	23	11	3
340	15	18	54	27	3	9	2	31	13	15	40	35	27	20	9	23	10	14	18	21	51	22	10	3
341	14	17	51	25	3	8	2	30	12	14	39	34	26	19	9	22	9	13	17	20	49	21	10	3
342	14	16	49	24	3	7	1	28	12	14	37	32	25	18	9	20	9	13	16	18	47	20	10	2
343	13	16	47	23	3	7	1	27	11	13	35	31	24	18	8	20	8	12	15	18	45	19	14	2
344	12	15	45	22	2	6	1	26	11	12	34	30	23	17	8	20	8	12	15	17	43	18	13	2
345	12	14	43	21	2	6	1	25	10	12	31	29	22	16	7	20	8	11	14	17	41	17	12	2
346	11	14	41	20	2	5	1	24	10	11	30	27	21	15	7	20	7	11	13	16	39	16	11	2
347	11	13	39	19	2	5	1	23	9	11	28	26	20	15	7	24	7	12	13	15	38	16	10	2
348	17	12	38	18	2	5	1	22	9	10	26	25	19	14	6	23	7	10	12	14	36	15	9	2
349	17	12	36	18	2	4	1	21	8	10	24	18	13	8	22	6	12	14	14	14	34	14	9	1
350	16	11	34	17	1	4	1	20	8	9	23	17	13	6	21	6	10	11	13	13	33	13	8	1
351	15	11	33	16	1	4	1	19	8	9	20	17	12	6	20	6	10	11	12	11	31	13	7	1
352	14	10	32	15	1	3	0	18	7	8	19	16	12	5	19	5	10	10	12	10	30	12	7	1
353	14	10	30	15	1	3	0	17	7	8	18	15	11	5	18	5	10	11	11	29	12	6	1	
354	13	9	29	14	1	3	0	17	7	8	17	15	11	5	17	5	10	11	11	27	11	6	1	
355	12	9	28	13	1	3	0	16	6	7	16	14	10	5	16	5	10	10	10	26	11	5	1	
356	12	9	26	13	1	2	0	15	6	7	15	13	10	4	16	4	10	10	10	25	10	5	1	
357	11	8	25	12	1	2	0	15	6	7	14	13	9	4	15	4	9	9	9	24	10	5	1	
358	11	8	24	12	1	2	0	14	5	6	13	12	9	4	14	4	9	9	9	23	9	4	1	
359	10	7	23	11	1	2	0	13	5	6	12	11	8	4	14	4	9	9	9	22	9	4	1	
360	10	7	21	11	1	2	0	13	5	6	11	11	8	4	13	4	9	9	9	21	8	4	1	
361	9	7	20	10	1	2	0	12	5	5	10	11	8	4	12	3	9	9	9	20	8	3	1	
362	9	7	19	10	1	1	0	12	4	5	9	10	7	3	12	3	9	9	7	19	8	3	0	
363	8	6	18	9	1	1	0	11	4	5	8	10	7	3	11	3	9	9	7	18	7	3	0	
364	8	6	17	9	0	1	0	11	4	5	7	9	7	3	11	3	9	9	7	17	7	3	0	
365	7	6	15	8	0	1	0	10	4	4	6	8	6	3	10	3	9	8	8	17	6	2	0	
	5		5		1		10		12					10					6			2	0	