APPLICATION OF THE STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI) IN BENIN-OWENA RIVER BASIN, NIGERIA

BY

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CERTIFICATION

I certify that this project was carried out by **OGUNDARE PETER OMONIYI** with Matric Number WMA/11/0050 under the supervision of Water Resources Management And Agrometeorology Federal University Oye Ekiti, Ekiti State , Ikole Campus.

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ABSTRACT

Precipitation deficit and its daily, seasonal and annual oscillations are inherent characteristics of Nigeria's climate. Droughts are generally characterized by a prolonged and abnormal moisture deficiency. In drought studies it is important to characterize the start and end of a drought as well as its intensity, duration, frequency and magnitude. The objective of this study was to apply the Standardized Precipitation Evapotranspiration index (SPEI) for drought assessment in the Benin-Owena River Basin, Nigeria. The SPEI was used in drought analysis based on the data from Climate Research Unit (CRU) for meteorological stations located inside the study area and three time scales including the 3-, 6- and 12-month SPEI were evaluated. After determining the dry and wet periods, drought durations, intensity, frequency and magnitudes were computed. Drought characteristics of the basin was detected and some moderate and severe droughts were captured. The result of relative frequencies show the mean relative frequencies of 47.62% for drought occurring in the basin at 12 month timescales. The observed Peak Intensities of SPEI values during 1980–2015 illustrate some severe droughts $(-1.5\ to\ -1.99)$ across the basin. These severe droughts are valuable tools for water resources managers interested in either short- or long- term or water supply.

CHAPTER ONE

INTRODUCTION

1.1 WHAT IS DROUGHT?

Drought can be defined from a water supply perspective as persistent extreme events that produce significant effects on the hydrological cycle by, for example, decreasing rainfall, lowering stream-flow, reducing reservoir levels, or causing reductions in soil moisture.

Drought can also be defined Sectorally, Agricultural drought, for example, is defined as the difference between water supply and crop demand. For rain agriculture, a year of normal precipitation may actually be water stressed (i.e., suffering drought conditions) if the Growing season is abnormally warm. Drought can be defined from a water supply perspective as persistent extreme events that produce significant effects on the hydrological cycle by, for example, decreasing rainfall, lowering stream-flow, reducing reservoir levels, or causing reductions in soil moisture.

Also Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event. It occurs in virtually all areas, whatever their normal climate may be, and the characteristics of a drought may be very different from one region to another. Technically, drought is a "temporary" condition, even though it may last for long periods of time. Drought is an insidious hazard of nature. Unlike many disaster which are sudden, droughts result when there is less than normal precipitation over an extended period of time, usually a season or more. The decreased water input results in a water shortage for some activity, group, or environmental sector. Drought can also occur when the temperature is higher than normal for a sustained period of time; this causes more water to be drawn off by evaporation. Other possible causes are delays in the start of the rainy season or timing of rains in relation to principal crop growth stages (rain at the "wrong" time). High winds and low relative humidity can make matters much worse.

1.1.1 Drought Definition by a Meteorologist

Meteorological and climatologically drought is defined in terms of the magnitude of a precipitation shortfall and the duration of this shortfall event. Agricultural drought links the various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, and soil moisture deficits.

1.1.2 Drought Definition by a Hydrologist

Hydrological droughts are related to the effects of periods of precipitation shortfall on surface or subsurface water supply, rather than to precipitation shortfalls directly. Hydrological droughts are typically out of phase with or lag the occurrence of meteorological and agricultural droughts. More time elapses before precipitation deficiencies show up in these components of the hydrological system. As a result, impacts are out of phase with those in other economic sectors. Where irrigation is necessary for agriculture, agricultural drought is really determined by hydrological drought.

1.1.3 Socioeconomic Impact of Draught

Socioeconomic drought is associated with the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought. This approach to defining drought suggests that the time and space scales of supply and demand should be included in an objective definition of drought.

1.1.4 Drought in Nigeria

Nigeria is divided into six distinct vegetation zones of Coastal Mangrove Swamp Forest, Rain forest, Southern Guinea, Northern Guinea, Sudan and Sahel savannah vegetation zones. The vegetation varies regionally in consonance with the climatic pattern. Drought which is defined as the protracted absence, deficient or poor distribution of precipitation, is one of the anomalies that have plagued the Northern part of Nigeria since the beginning of the 20th century. Drought is as an extended period – a season, a year, or several years – of deficient rainfall relative to the long term average rainfall for a region. It is the inability of rainfall to meet the Evapotranspiration demands of crops resulting in general water stress and crop failures. The probability of drought at the on-set and towards the end of the rainy season is usually very high in Northern Nigeria (ICRISAT,1984; Adeoye, 1986; Tenkouano et al., 1997;). Dry spells at the beginning of the season usually result in multiple plantings and low or no yields leading to low food security index. In the same vein, end of season drought could brings about water stress at critical periods of need during the reproductive stages of most crops thus resulting in crop failures and shrinking of yields. Large areas of Northern Nigeria falling within the Sahel and Sudan ecological zones between latitude 9-14oN are prone to recurrent droughts in one form or the other (Glantz and Katz, 1977; Apeldoorn, 1981; Adeoye, 1986; Nyong et al., 2007). In fact, the 20th century started in the region with droughts and the resultant famines of 1903 and 1911-1914, respectively (Kolawole, 1987). Other droughts included those of 1919, 1924, 1935, 1951-1954, 1972-1973, 1984-1985, 2007 and 2011 (Apeldoorn, 1978, 1981; Kolawole, 1987; Mortimore, 1989; FME, 2000). Large number of inhabitants of the drought prone areas are smallholder farmers, who depend mostly on the highly variable rainfall for crop cultivation and maintenance of their herds. This paper attempts to look at the causes, effects and ways of reducing the risk of drought in Benin-Owena river basin.

1.2 AIMS AND OBJECTIVES

The objectives are to:

I. Use the Standardized Precipitation Evapotranspiration index (SPEI) for drought assessment in the Benin-Owena River Basin, Nigeria.

II. Analyze drought characteristics in terms of their intensity, duration, magnitude and frequency in the basin using this index

CHAPTER TWO

LITERATURE REVIEW

2.1. DROUGHT AS HAZARD

In order to quantify droughts and monitor wet and dry periods, various indices (e.g. SPI; Palmer 115 Drought Severity Index (PDSI); Rainfall Anomaly Index (RAI); Crop Moisture Index (CMI); the 116 Surface Water Supply Index (SWSI), the Standardized Precipitation - Evapotranspiration Index 117 (SPEI)) have been developed (Heim, 2002; Vicente – Serrano et al., 2010).

Drought is not a disaster for nature itself, the disaster occurs when we consider the demand people place on their water supply. Human beings often increase the impact of drought because of high use of water which cannot be supported when the natural supply decreases. Droughts occur in both developing and developed countries and can result in economic and environmental impacts and personal hardships.

Studies of the effect of drought have linked extreme events to increased risk of mortality, reduction in growth of ecosystem dominant species, reduction in ecosystem primary productivity and alteration of ecohydrological regimes (Breshears*et al.* 2005; Ciais*et al.* 2005; Bigler*et al.* 2006; Gitlin*et al.* 2006; Adams *et al.* 2012

All societies are vulnerable to this "natural" hazard. Drought is an insidious natural hazard that results from lower levels of precipitations than what is considered normal. When this phenomenon extends over a season or a longer period of time, precipitation is insufficient to meet the demands of human activities and the environment. Drought must be considered a relative, rather than absolute, condition. There are also many different methodologies for monitoring drought.

The SPEI is most sensitive to the PET radiation term, which separates the observed radiation methods (P-M FAO-56 and Priestley-Taylor) from the temperature-proxy methods (P-M Hargreaves and Hargreaves) and the Thornthwaite equation.

However, the long-term effects of extreme drought and the recovery of surviving trees are poorly documented (Martínez-Vilalta, Lloret&Breshears2011).Droughts are regional in extent and each region has specific climatic characteristics. Droughts that occur in the North American Great Plains will differ from those that occur in northeast Brazil, southern Africa, western Europe, eastern Australia, or the North China Plain. The amount, seasonality and form of precipitation differ widely between each of these locations.

Moreover, Keyantash and Dracup (2002) indicated that drought indices must be statistically robust and easily calculated, and have a clear and comprehensible calculation procedure. All these requirements are met by the SPEI.

Temperature, wind and relative humidity are also important factors to include in characterizing drought. Drought monitoring also needs to be application-specific because drought impacts will vary between sectors. Drought means different things to different users such as water managers, agricultural producers, hydroelectric power plant operators and wildlife biologists. Even within sectors, there are many different perspectives of drought because impacts may differ markedly. Droughts are commonly classified by type as meteorological, agricultural and hydrological, and differ from one another in intensity, duration and spatial coverage.

2.2. TYPES OF DROUGHT

1. Meteoroligical Drought
2. Hydrological Drought
3. Socioeconomic Drought
4. Agricultural Drought

2.2.1 Meteorological Drought

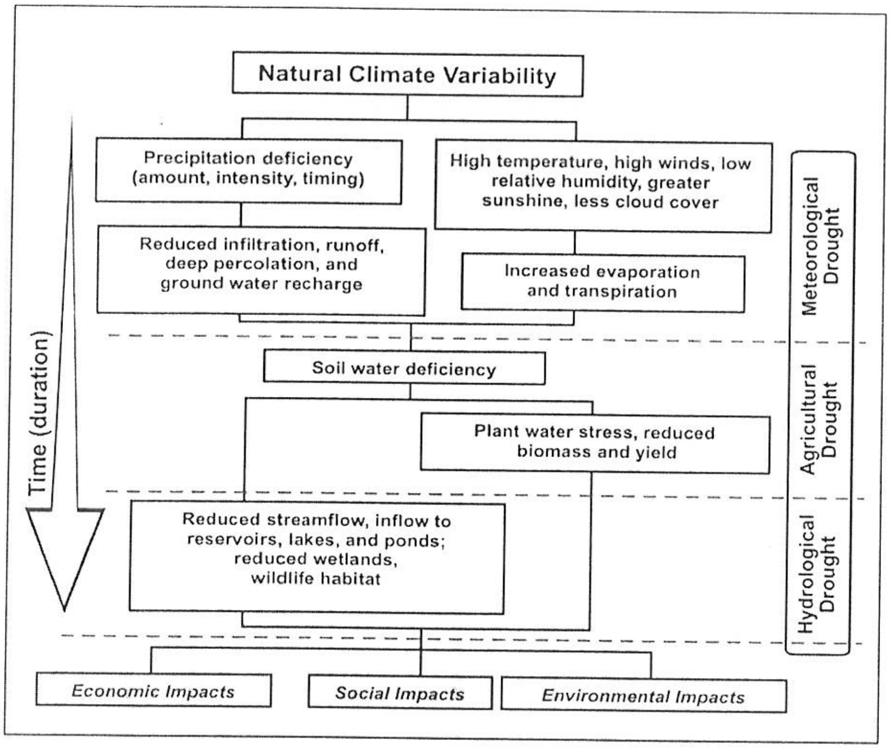


Fig 1.*(www.drought.unl.edu)*

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. For example, some definitions of meteorological drought identify periods of drought on the basis of the number of days with precipitation less than some specified threshold. This measure is only appropriate for regions characterized by a year-round precipitation regime such as a tropical rainforest, humid subtropical climate, or humid mid-latitude climate. Locations such as Manaus, Brazil; New Orleans, Louisiana (U.S.A.); and London, England, are examples. Other climatic regimes are characterized by a seasonal rainfall pattern, such as the central United States, northeast Brazil, West Africa, and northern Australia. Extended periods without rainfall are common in Omaha, Nebraska (U.S.A.); Fortaleza, Ceará (Brazil); and Darwin, Northwest Territory (Australia), and a definition based on the number of days with precipitation less than some specified threshold is unrealistic in these cases. Other definitions may relate actual precipitation departures to average amounts on monthly, seasonal, or annual time scales.

2.2.2 Hydrological Drought

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, streamflow, and groundwater and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors. For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to agriculturalists, but the impact of this deficiency on reservoir levels may not affect hydroelectric power production or recreational uses for many months. Also, water in hydrologic storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., flood control, irrigation, recreation, navigation, hydropower, wildlife habitat), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly

2.2.3 Socioeconomic Drought

Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is ample in some years but unable to meet human and environmental needs in other years. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. For example, in Uruguay in 1988–89, drought resulted in significantly reduced hydroelectric power production because power plants were dependent on streamflow rather than storage for power generation. Reducing hydroelectric power production required the government to convert to more expensive (imported) petroleum and implement stringent energy conservation measures to meet the nation's power needs. In most instances, the demand for economic goods is increasing as a result of increasing population and per capita consumption. Supply may also increase because of improved production efficiency, technology, or the construction of reservoirs that increase surface water storage capacity. If both supply and demand are increasing, the critical factor is the relative rate of change. Is demand increasing more rapidly than supply? If so, vulnerability and the incidence of drought may increase in the future as supply and demand trends converge.

2.2.4 Agricultural Drought

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

2.3. CHARACTERISTICS OF DROUGHT

2.3.1 **Intensity:** Intensity commonly refers to the magnitude of the precipitation deficit and how quickly it develops. History shows us that each drought is unique, but common features of the most severe droughts include long duration, and large moisture deficits with a large areal extent, particularly during a climatological wet season. These are the droughts with the most far-reaching human and ecological impacts. Drought as the sum of the integral area below zero of each event. Intensity for each month that the drought continues.

2.3.2 Duration: Drought duration as the number of months in drought conditions, and drought severity as the sum of the integral area below zero of each event.

Therefore, duration defined by its beginning and end. The duration might span over a long time during a particular occurrence while in other occurrences it might be a very short duration.

2.3.4 Magnitude: Drought magnitude (DM) is an important parameter in drought analysis. Although the drought magnitude is commonly computed for negative SPEI values, for analysis the wet years besides drought conditions. Drought magnitude is the great size or the extent of the drought. The positive sum of the SPEI for all the months within a drought event can be termed the drought's "magnitude".

2.3.5 Frequency: Drought frequency is defined as the number of drought events occurred. There might be an increase in the frequency of drought over a noted number of years. This depends on series of factors causing drought in the area.

Intensity-duration-frequency

The relations between drought intensity, duration and frequency can be studied with conceptual models, which deal with meteorological droughts lasting at least one year, with specific applicability to subtropical and mid latitudinal regions.

The climate types are defined across the climatic spectrum in terms of the ratio of mean annual precipitation to annual global terrestrial precipitationP_{ma} / P_{agt} , and additionally, on the ratio of annual potential evapotranspiration to mean annual precipitation E_{ap} / P_{ma} . To complete the description, the length of rainy season L_{rs} across the climatic spectrum is also indicated.

For any year with precipitation P, drought intensity is defined as the ratio of the deficit $(P_{ma} - P)$ to the mean (P_{ma}) . For drought events longer than one year, intensity is the summation of the annual intensities. The conceptual model of drought intensity-duration-frequency

2.4 PREDICTION AND WARNING

Intelligent monitoring of drought precursors and historical perspective remains the best tool for drought prediction and warning. However, progress in understanding large-scale global and regional atmospheric–oceanic phenomena continues to provide hope for drought prediction and warning with longer lead times. Droughts are manifestations of persistent large-scale variations in the global circulation pattern of the atmosphere. Drought typically results from a synergistic interaction between regional and remote influences. Forecast model experiments during the past few years indicate that drought conditions themselves may play a role in the perpetuation of the drought through a feedback between the land surface and the overlying atmosphere that reinforces drought-sustaining circulation features. In a global context, extensive research during the past two decades clearly indicates one important influence to be tropical Pacific sea surface temperature variations, associated with the El Niño–Southern Oscillation (ENSO) phenomenon, in year-to-year global climate variations. The effect of these ocean variations is transmitted to remote areas of the globe through recurrent, seasonally varying patterns of atmospheric circulation anomalies referred to as teleconnections. These teleconnections affect the precipitation regime over much of the Tropics, and over large areas of the extratropics as well, including Australia, eastern Asia, southern Africa, and regions of both North and South America. Experiments with coupled atmosphere–ocean forecast models, that is, models that predict the simultaneous evolution of the ocean and atmosphere, provide promising evidence that the ENSO cycle fluctuations may exhibit a useful degree of predictability for up to a year in advance. Observational studies and model experiments have also demonstrated a significant link between Atlantic sea surface temperatures and precipitation over the drought-prone areas of the African Sahel and northeast Brazil. In addition, ocean-atmosphere oscillations at longer time scales have recently been recognized as leading to extended decadal and longer periods of wetter or drier

2.5 PREPAREDNESS

We cannot avoid drought, and our predictions will never be perfect, but we can reduce its impacts. One way is to plan ahead. The impacts of past droughts have been exacerbated by the absence of preparedness plans. Plans can improve the coping capacity of local, state, and federal governments, reducing impacts and the need for government intervention. Since 1982, the number of states with drought plans has increased from 3 to 36 and several states are in the plan-development process. Generally these plans are aimed at providing a more organized, better coordinated response rather than reducing long-term vulnerability to future drought episodes. These plans, however, represent an important first step in recognizing that our ability to effectively cope with drought is currently limited. Drought plans should include the development of an integrated climate monitoring and delivery system for distributing information to decision makers in a timely manner. Such a plan also should include development of a drought monitoring system, based largely on meteorological, climatic, and hydrologic information. An effective monitoring system will aid in the development of improved drought assessment methodologies by providing early warning of drought impacts, and well as a context for planning for drought events against the backdrop of longer-term climate trends and variations. Policies that promote the development and implementation of regionally appropriate drought mitigation measures today will help to reduce the future costs of drought, whether or not future changes in climate alter the frequency and intensity of meteorological drought.

2.6 CAUSES OF DROUGHT

2.6.1 Precipitation deficiency

Mechanisms of producing precipitation include convective, stratiform, and orographic rainfall. Convective processes involve strong vertical motions that can cause the overturning of the atmosphere in that location within an hour and cause heavy precipitation, while stratiform processes involve weaker upward motions and less intense precipitation over a longer duration. Precipitation can be divided into three categories, based on whether it falls as liquid water, liquid water that freezes on contact with the surface, or ice. Droughts occur mainly in areas where normal levels of rainfall are, in themselves, low. If these factors do not support precipitation volumes sufficient to reach the surface over a sufficient time, the result is a drought. Drought can be triggered by a high level of reflected sunlight and above average prevalence of high pressure systems, winds carrying continental, rather than oceanic air masses, and ridges of high pressure areas aloft can prevent or restrict the developing of thunderstorm activity or rainfall over one certain region. Once a region is within drought, feedback mechanisms such as local arid air, hot conditions which can promote warm core ridging, and minimal evapotranspiration can worsen drought conditions.

2.6.2 Dry season

Within the tropics, distinct, wet and dry seasons emerge due to the movement of the Intertropical Convergence Zone or Monsoon trough. The dry season greatly increases drought occurrence, and is characterized by its low humidity, with watering holes and rivers drying up. Because of the lack of these watering holes, many grazing animals are forced to migrate due to the lack of water and feed to more fertile spots. Examples of such animals are zebras, elephants, and wildebeest. Because of the lack of water in the plants, bushfires are common. Since water vapor becomes more energetic with increasing temperature, more water vapor is required to increase relative humidity values to 100% at higher temperatures (or to get the temperature to fall to the dew point). Periods of warmth quicken the pace of fruit and vegetable production, increase evaporation and transpiration from plants, and worsen drought conditions.

2.6.3 Erosion and human activities

Human activity can directly trigger exacerbating factors such as over farming, excessive irrigation, deforestation, and erosion adversely impact the ability of the land to capture and hold water. In arid climates, the main source of erosion is wind.[1] Erosion can be the result of material movement by the wind. The wind can cause small particles to be lifted and therefore moved to another region (deflation). Suspended particles within the wind may impact on solid objects causing erosion by abrasion (ecological succession). Wind erosion generally occurs in areas with little or no vegetation, often in areas where there is insufficient rainfall to support vegetation.

2.6.4 Climate change

Activities resulting in global climate change are expected to trigger droughts with a substantial impact on agriculture throughout the world, and especially in developing nations. Overall, global warming will result in increased world rainfall. Along with drought in some areas, flooding and erosion will increase in others. Paradoxically, some proposed solutions to global warming that focus on more active techniques, solar radiation management through the use of a space sunshade for one, may also carry with them increased chances of drought.

2.6.5 IMPACTS OF DROUGHT AND DESERTIFICATION

The impacts from drought tend to follow predictable progressions that vary as a function of societal wealth and socioeconomic activities. In the past, and in less developed regions of the world, the primary impacts were crop failures followed by food shortages, clean drinking water shortages and eventual related health problems, famine, energy shortages, mass migrations, and political unrest. In the developed nations of the world, food shortages and severe health hazards are less of a problem. Instead, the impacts are more economic–related, such as crop production losses, higher food costs, higher costs of transportation and energy as well as reduced recreational opportunities, and domestic and industrial water restrictions. Ecological impacts also are very important but more difficult to track and quantify. Wildfire is the one drought impact that is most like other natural disasters in that the impacts are immediate and structural and can affect both rich and poor in similar way. The economic, social, and environmental impacts suffered because of drought are the product of both the natural event (i.e., meteorological event) and the vulnerability of society to extended periods of precipitation deficiency. The impacts of future drought occurrences will be determined not only by the frequency and intensity of meteorological drought, but also by the number of people at risk and their degree of risk. The degree of risk is a function of exposure, vulnerability, and response. As demand for water and other shared natural resources increases as a result of population growth and migration to drought-prone areas, urbanization, environmental degradation, government policies, land use changes, technology, and other factors, future droughts can be expected to produce greater impacts, with or without any increase in the frequency and intensity of meteorological drought.

If projected changes in climate because of increasing concentrations of greenhouse gases or other factors do occur, there will be concomitant changes in regional hydrology, possibly aggravating the nation's sensitivity to climate variability. Indeed, the 2001 Third Assessment Report of the Intergovernmental Panel on Climate Change states that it is likely that the frequency and intensity of droughts will increase during the 21st Century, especially over mid-latitude continental interiors. In addition, the 2001 U.S. National Assessment of Climate Change finds that reduced water runoff in summer and increased winter runoff coinciding with increased water demands are likely to compound current stresses, including those to agriculture, water-based transportation, water supplies and ecosystems.

2.6.6 Effects of Drought

The impacts of drought in general include mass starvation, famine and cessation of economic activity especially in areas where rain fed agriculture is the main stay of the rural economy. It is common knowledge that drought is the major cause of forced human migration and environmental refugees, deadly conflicts over the use of dwindling natural resources, food insecurity and starvation, destruction of critical habitats and loss of biological diversity, socio-economic instability, poverty and climatic variability through reduced carbon sequestration potential. The impacts of drought and desertification are among the most costly events and processes in Africa. The widespread poverty, the fact that Nigeria's economy depend on climate-sensitive sectors mainly rain fed agriculture, poor infrastructure, heavy disease burdens, high dependence on and unsustainable exploitation of natural resources, and conflicts render the country especially vulnerable to impacts of drought. The impacts of droughts are well known and have been analyzed and elucidated by several authors (Apeldoorn, 1978; 1981; Kolawole, 1987; Mortimore,1989). Jibrin (2010) highlighted the effects of Drought as follows: low or no crop yields resulting in low food security index; mass famine; death of livestock; low groundwater levels resulting in dry wells (which needed to be dug deeper and deeper to obtain water for drinking); drying of lakes and dams; loss of biodiversity and impoverishment of ecosystem; acute shortage of water for domestic use and for livestock; decline in GDP; migration into urban areas; separation of families; and increased indebtedness. 3.1 Effect of drought on agriculture and food security. The majority of the populations in the drought prone states live on marginal lands in rural areas practicing rain-fed agriculture. Drought threatens agricultural production on these marginal lands, exacerbating poverty and undermining economic development. The impact of drought and climatic variability in both economic and mortality terms is generally larger for

relatively simple and predominantly agricultural economies. The drought of 1971-72 for example reduced Agricultural contribution to GDP in Nigeria from 18.4% in 1971-72 to 7.3% in 1972-1973. The poor crop yields or total crop failure due to drought result in mass poverty and starvation as agriculture is the 172 Abubakar et al mainstay of Nigeria's rural economy. Although agriculture will remain for many years as major contributor to the economies of most developing countries (Van Crowder et al., 1998), in some countries, however, its share of GDP will progressively decline as drought and desertification take their toll with food shortages increasing at the same time.

The poor households that are affected by drought and desertification do not have adequate resources to deal with food shortages leading to food insecurity and hunger that affects millions of people. Agriculture is one of the main economic activities in Nigeria (which account for around

40 percent of the country's GDP and employs about 60 percent of the active labour force), thus drought would lead to a catastrophe with unprecedented repercussions. The most severe consequence of drought is famine. Effect of drought on water availability Drought influences water availability, which is projected to be one of the greatest constraints to economic growth in the future. Reduced annual average rainfall and its run-off would increase desertification in Nigeria. Most of the rivers and streams in the drought prone areas flow into Lake Chad. Drought, therefore exacerbate the shrinking of the lake. The rivers in addition to contributing in recharging Lake Chad are catchments to several dams built for irrigation and domestic water supply. This means that the regions will not have sufficient water resources to maintain their current level of per capita food production from irrigated agriculture - even at high levels of irrigation efficiency - and also to meet.

Effect of drought on biodiversity one of the most important effects of drought is the depletion of biodiversity. Existing fauna and flora that are not resistant to drought are likely to go extinct. Several animal and plant species are disappearing in the drought prone region of Nigeria. The combined effects of drought and bush burning (during dry season) have made the flora to go extinct and the animals to migrate to safer havens. Drought, land degradation and desertification have had serious impact on the richness and diversity of plants and animals in the region. Plant biodiversity will change over time, unpalatable species will dominate, and total biomass production will be reduced.

2.6.7 Effect of drought on energy availability.

The impacts of drought and desertification on the energy sector are felt primarily through losses in hydropower potential for electricity generation and the effects of increased runoff (and consequent siltation) on hydropower generation. In Nigeria, electricity is largely generated through hydropower thus drought is likely to reduce the volume of water in the dams and rivers and consequently lead to reduction in hydroelectricity generation and hence load shedding of electricity in the country. Load shedding as result of low water volume in Kainji and Jebba electricity projects has become more pronounced during the dry season thus compounding the energy crisis in Nigeria, Energy impacts can also be experienced through reduction in the growth rates

2.7. THE NEED FOR DROUGHT MONITORING

Routine monitoring of all components of the hydrologic cycle is the basis for objective recognition of drought and preparing to deal with impacts. Tracking precipitation departures from average over long periods of time is an important first step. Unfortunately, the precipitation observational record is barely more than a century long in most populated regions of the U.S., and much shorter in remote and mountainous locations. This limits our ability to characterize trends and variations in average precipitation over long time scales. Use of "proxy" data that are related to precipitation variations, such as tree rings, has been successful in extending the record up to several thousand years in some areas. Monitoring other climatic variables, as well as stream flow, groundwater and reservoir levels, snowpack, and soil moisture, provides a more comprehensive perspective.

Vegetation conditions can often be monitored using satellite-derived data. Critical information can thus be provided to decision makers in a timely manner. Our ability to monitor and disseminate critical drought-related information has been enhanced by new technologies such as automated weather stations, satellites, computers, and improved communication techniques. Some of the deficiencies of previous drought response efforts have simply been associated with the lack of adequate monitoring.

2.9 DROUGHT MONITORING INDEX

A drought index assimilates thousands of data on rainfall, snowpack, stream flow and other water-supply indicators into a comprehensible picture. A drought index is typically a single number, far more useful than raw data for decision making. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Some indices are better suited than others for certain uses. The Palmer Drought Severity Index (PDSI) has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance. The PDSI is better suited for large areas with uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement the PDSI with other indices such as the Surface Water Supply Index (SWSI), which takes snowpack and other unique conditions into account. Drought is a natural feature of climate variability in all parts of world, even in those having very different hydrological balances. Drought is a phenomenon that is basically linked with a sustained lack of precipitation, and in some case also with excess evapotranspiration.

It is difficult to precisely define drought, since meteorological drought results from precipitation deficits, while agricultural drought is identified by total soil moisture deficits, and hydrological drought is related to a shortage of streamflow (Keyantash and Dracup, 2002).Another important feature of drought is their characteristic timescales, which can vary substantially. A single month of deficient rainfall can adversely affect rainfed crops while having virtually no impact on a large reservoir system.

At present, the most advanced drought indices (e.g. the PDSI, SPI and SPEI) take into account the role of antecedent conditions in quantifying drought severity.

Moreover, and given the varied response times of different hydrological, agricultural and environmental systems to water availability, the timescale chosen for analyzing drought is important, and some of the most advanced indicators may be calculated for different timescales. Recently, a new drought index, the Standardized Precipitation-Evapotranspiration Index (SPEI), developed by Vicente-Serrano et al. (2010), has been proposed for identifying drought periods.

The SPEI is based on a monthly (or weekly) climatic water balance (precipitation minus evapotranspiration), adjusted using a three-parameter log-logistic distribution to take into account common negative values. The values are accumulated to different timescales, following an approach similar to that of the SPI drought index. The evapotranspiration is calculated using the method by Thornthwaite (1948). The SPEI combines the sensitivity of PDSI to changes in evaporation demand (caused by temperature fluctuations and trends) with the simplicity of calculation and multi-temporal nature of the SPI. Among the significant advantages of the SPEI is that it can, like the SPI, be calculated for different timescales to monitor droughts with respect to severity, duration, onset, extent and end.

The SPEI's main advantage over other widely used drought indices lies in its ability to identify the role of evapotranspiration and temperature variability on drought assessment in the context of global warming. This fact is demonstrated on the basis of metadata from 11 observatories located in different climatic zones in the world (Vicente-Serrano et al. 2010).

2.9.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The raw precipitation data are typically fitted to a gamma or a Pearson Type III distribution, and then transformed to a normal distribution. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. The SPI can be created for differing periods of 1-to-36 months, using monthly input data. For the operational community, the SPI has been recognized as the standard index that should be available worldwide for quantifying and reporting meteorological drought. Concerns have been raised about the utility of the SPI as a measure of changes in drought associated with climate change, as it does not deal with changes in evapotranspiration.

2.9.2 Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months. At longer timescales (>~18 months), the SPEI has been shown to correlate with the self-calibrating PDSI (sc-PDSI).

If only limited data are available, say temperature and precipitation, PET can be estimated with the simple Thornthwaite method. In this simplified approach, variables that can affect PET such as wind speed, surface humidity and solar radiation are not accounted for. In cases where more data are available, a more sophisticated method to calculate PET is often preferred in order to make a more complete accounting of drought variability. However, these additional variables can have large uncertainties.

2.9.3 Palmer Drought Severity Index (PDSI)

The structure of the Palmer Drought Severity Index (PDSI), which is perhaps the most widely used regional index of drought, is examined. The PDSI addresses two of the most elusive properties of droughts: their intensity and their beginning and ending times. Unfortunately, the index uses rather arbitrary rules in quantifying these properties. In addition, the methodology used to standardize the values of the PDSI for different locations and months is based on very limited comparisons and is only weakly justified on physical or statistical grounds. Under certain conditions, the PDSI values are very sensitive to the criteria for ending an "established" drought and precipitation during a month can have a very large effect on the PDSI values for several previous months.

The distribution of the PDSI conditioned on the value for the previous month may often be bimodal. Thus, conventional time series models may be quite limited in their ability to capture the stochastic properties of the index. The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that spans -10 (dry) to +10 (wet). It has been reasonably successful at quantifying long-term drought. As it uses temperature data and a physical water balance model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration. Monthly PDSI values do not capture droughts on time scales less than about 12 months; more pros and cons are discussed in the Expert Guidance.

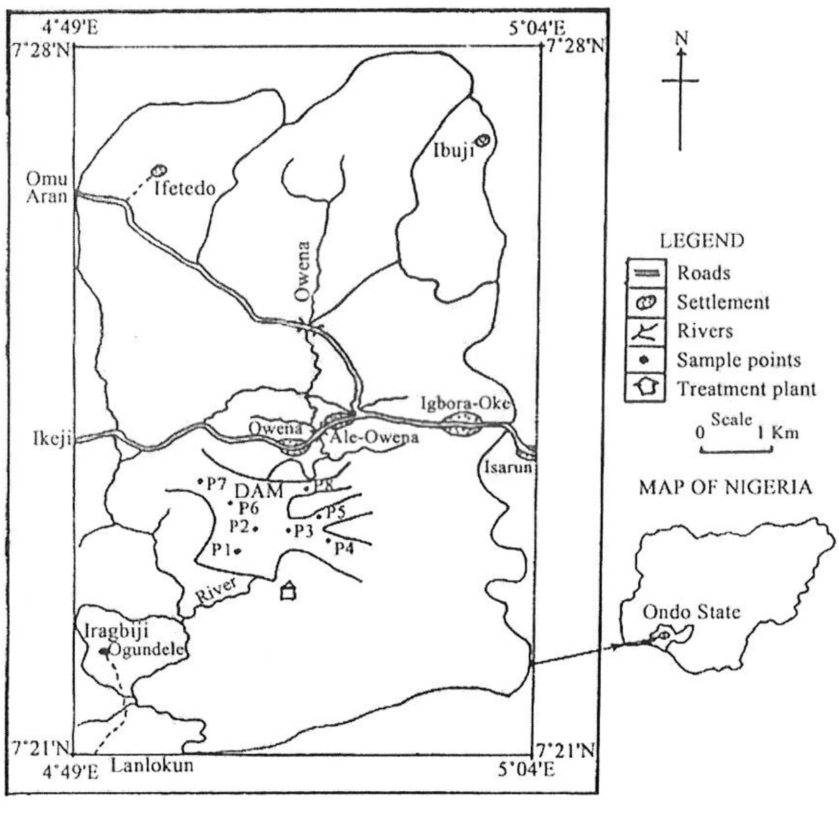
CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

The study analyzed climate data from four stations: Iworoko, Essa-Oke, Oba-ile and Awopeju in the Benin-Owena river basin. Benin-Owena catchment lies between longitude 5°01' and 5°45'E and latitude 7°17' and 8°15'N. The basin area is about 51,400 km^2 and covers 3 states of southwestern-Nigeria vis-à-vis Ondo, Edo and Delta (Fig.). The major river in the basin is River Benin with River Owena as main tributary and many other short course tributaries.

. Map of Ondo showing the study area Benin-Owena



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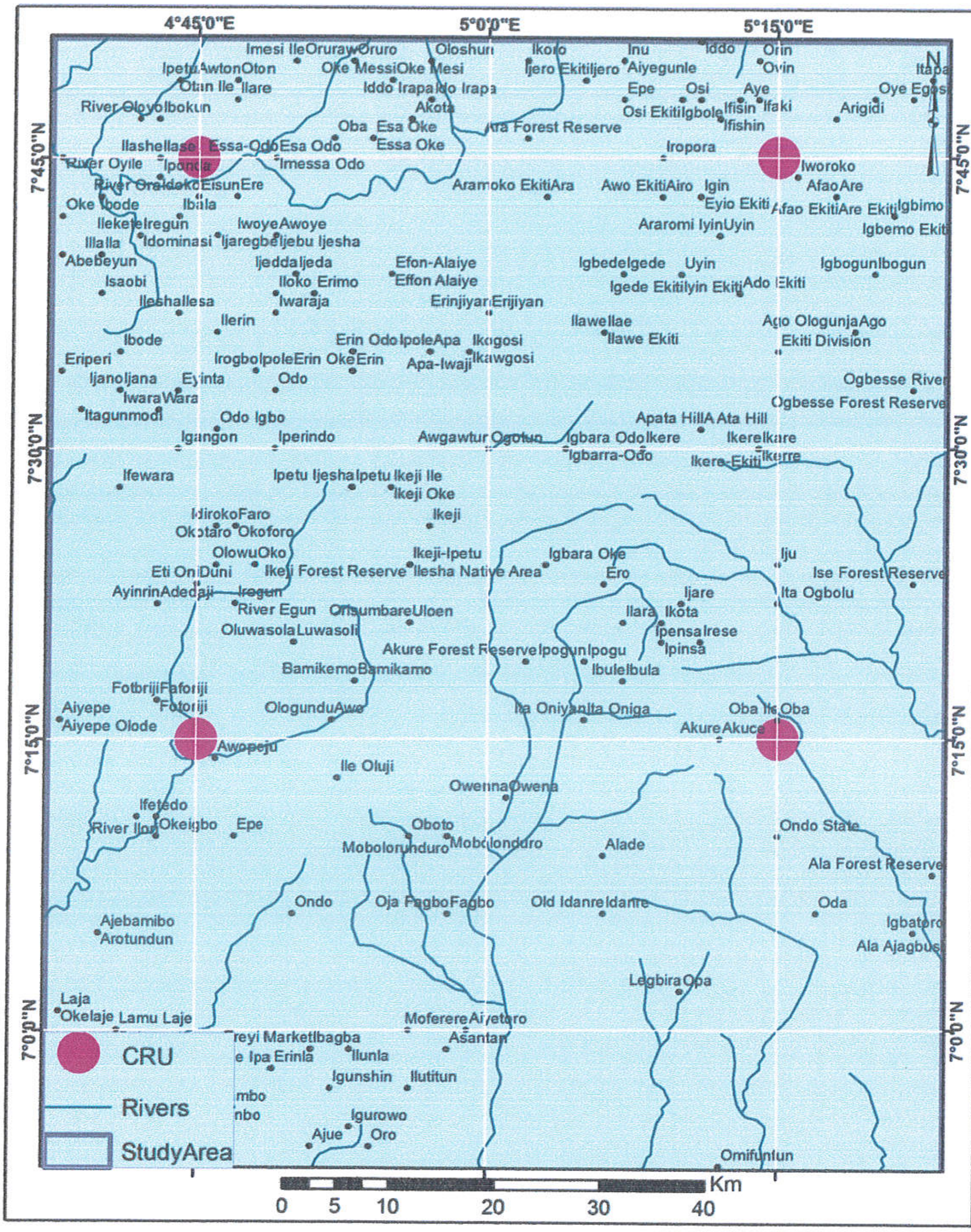
3.1.1 Location

The study area is the **Benin-Owena River Basin** Area that lies between the west bank of the Niger **River** in the east and the Oni **River** in the west, and occupies the territory covered by Ondo, Ekiti, Edo and Delta states

3.1.2 BRIEF HISTORY OF BENIN OWENA RIVER BASIN AUTHORITY, AKURE AREA OFFICE

As delineated by the River Basin Development Authorities Decree No. 25 of 1976, the area of jurisdiction of BORBDA is "the area between the West bank of the Niger River in the East and the Oni River in the West drained by the Forcados, Benin, Siluko, other rivers and their tributaries, and the associated creeks and lagoon which flow into the sea".


4°45'0"E
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7°45'0"N
7°30'0"N
7°15'0"N
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CRU
Rivers
StudyArea
Km
0
5
10
20
30
40
Imesi Ile
Oloshun
Ikoro
Inu
Iddo
Orin
Ovin
Aiyegunle
Epe
Osi
Aye
Ifaki
Arigidi
Oye Egbo
Ifishin
Iropora
Iworoko
Afao Are
Akota
Oba
Essa Oke
Imessa Odo
Esa Odo
Ipetu
Otan Ile
Ilare
Ibokun
Ilashe
Ipole
Ibala
Oke Ibode
Ilekete
Iregun
Idominasi
Iwoye
Awoye
Ijebu Ijesha
Abebeyun
Isaobi
Ijeda
Iloko
Erimo
Iwaraja
Ilesha
Ilerin
Ibode
Eriperi
Ijanoljana
Eyinta
Iwara
Itagunmodi
Odo Igbo
Igangon
Iperindo
Efon-Alaiye
Effon Alaiye
Erinjiyan
Erijiyan
Erin Odo
Ipole
Apa
Ikogosi
Apa-Iwaji
Ikawgosi
Odo
Awgawtur
Ogotun
Igbara Odo
Igbarra-Odo
Ilawe
Ilawe Ekiti
Igbede
Igede Ekiti
Uyin
Iyin Ekiti
Ado Ekiti
Igbogun
Ibogun
Ago Ologunja
Ago
Ekiti Division
Ogbesse River
Ogbesse Forest Reserve
Apata Hill
A Ata Hill
Ikere
Ikerre
Ikere-Ekiti
Araromi Iyin
Uyin
Eyio Ekiti
Afao Ekiti
Are Ekiti
Igbemo Ekiti
Aramoko Ekiti
Ara
Awo Ekiti
Airo
Igin
Ifewara
Ipetu Ijesha
Ipetu Ikeji Ile
Ikeji Oke
Ikeji
Okotaro
Okoforo
OlowuOko
Eti Oni
Duni
Ikeji Forest Reserve
Ikeji-Ipetu
Ilesha Native Area
Igbara Oke
Ero
Iju
Ise Forest Reserve
Ita Ogbolu
Ijare
Ilara
Ikota
Ipensa
Irese
Ipinsa
Ayinrin
Adedaji
Iregun
River Egun
Orisumbare
Uloen
Oluwasola
Luwasoli
Akure Forest Reserve
Ipogun
Ipogu
Ibule
Ibula
Bamikemo
Bamikamo
Fotoriji
Aiyepe
Aiyepe Olode
Ologundu
Awo
Awopeju
Ita Oniyan
Ita Oniga
Oba Ile
Oba
Akure
Akure
Ile Oluji
Owena
Owena
Ifetedo
River Ilori
Okeigbo
Epe
Oboto
Mobolorunduro
Mobolonduro
Alade
Ondo State
Ala Forest Reserve
Ondo
Oja Fagbo
Fagbo
Old Idanre
Idanre
Oda
Ajebamibo
Arotundun
Igbatoro
Ala Ajagbusi
Legbira
Opa
Laja
Okelaje
Lamu Laje
Moferere
Aiyetoro
Asantan
Ilunla
Erinla
Igunshin
Ilutitun
Igurowo
Ajue
Oro
Omifunfun

The main north-south flowing rivers and streams of the area of the Authority are Oni, Siluko, Owena, Benin, Escravos, Forcados, Ose, and many other numerous streams, all of which drain into the Bight(corner) of Benin which has become one of the sources from which the authority derived its name. The Authority's area of operation covers Ondo, Edo, Ekiti and part of Delta State. This involves a total area of 59,787.3 km square. The basin is topographically made up of the northern highlands, the southern lowland plains and the intermediate region of varying elevations.

The Benin-owena catchment lies between longitude 5°01' and 5°45'E and latitude 7°17' and 8°15'N. The basin area is about 51,400km2 and covered 3 states in the southern-Nigeria vis-à-vis ondo,Edo, and Delta. The National Water Resources matter plan, in the report by the Japan international Cooperation Agency (JICA) has arranged the river in Nigeria into five drainage system. These are the Niger, the Benue, the Chad inland drainage, the cross and the littoral. These are further demarcated into eight hydrological areas (HA's) as follows:

HA	DIVISION
I	Niger North
II	Niger Central
III	Upper Benue
IV	Lower Benue
V	Niger south
VI	West Littoral
VII	East Littoral
VIII	Lake Chad

The Benin-Owena River Basin area falls almost completely into the West Littoral hydrological area. The old Owena Water Supply Scheme, completed as far back as 1960 has a design capacity to supply 10 million litres of water to some towns and villages in the present Ondo and Ekiti States of Nigeria. The water demand in this area increased tremendously over the years making the facility to become grossly inadequate for the intended towns and villages, a development that called for a much larger supply scheme. Consequently, the Ondo State Government in 1976, commissioned the design of the Owena River Dam with the objective of supplying raw water from the resulting reservoir for the existing water scheme, but taken over by the Federal Government of Nigeria (through Benin-Owena River Basin Development Authority) and converted it to a multipurpose use in line with the functions of the River Basin Development Authorities. The design was reviewed to include in addition to provision of potable water, usage for irrigation of 3000 hectares of farmland, fisheries, as well as generation of hydro-electric power. The dam, sited on the Owena River about 14 km upstream of the old Owena water scheme, was designed to create an impoundment of 36.25 million cm^3 gross capacity, covering an area of approximately 7.38 km^2 at the normal water level.

3.2 MISSION AND VISION STATEMENT

3.3 MISSION

To develop and manage surface and ground water resources within our area of coverage, and provide access to safe and adequate water for domestic, industrial, flood control and agriculture purposes to enhances quality of life of the people and promote the socio economic development of the country.

3.4 VISION

To be an effective and efficient Government Establishment committed to total quality service delivery in water resources management for sustainable development of the communities covered by our operation.

3.5 FUNCTION

Water is a precious agricultural resource. The importance of water in agricultural production is underscored by the objective of the Nigeria government water resources development policies. The policy objectives stated among others are to:

- undertake a comprehensive development of both underground and surface water sources for multi-purpose use;
- Undertake schemes for control of erosion or floods and for water shed management including afforestation.

- construct and maintain dam, dykes, polder wells, boreholes, irrigation and drainage systems and other works necessary for food production and human water need;
- Provide water for reservoirs and lakes for irrigation purposes to farmers and other groups of people as well as for urban water supply schemes;
- Control the pollution of waters, lakes, lagoons, and creeks in the country; and
- Assist in the development of fisheries and improved irrigation on the rivers, lakes and reservoirs, lagoons and creeks in the country (FMAWRRD, 1990)

BORBDA's enabling decree No.35 of 1987 spells out its statutory function as follows:

- To undertake comprehensive development of both surface and underground water resources for multipurpose use; with particular emphasis on provision of irrigation infrastructure and the control of floods and erosion and for watershed management.
- To construct, operate and maintain dams, dykes, polders, wells, boreholes, irrigation and drainage systems and other works necessary for the achievement of the Authority's functions and hand-over all land to be cultivated under irrigation schemes to farmers.

Federal Government in 1976 set up the River Basin Development Authorities (RBDA) in each of the five agro-ecological zones of the country. The main focus of the RBDA is to develop the Nigeria water resources to facilitate agriculture and rural development and to solve the problem of drought and unemployment. The Benin-Owena River Basin and Rural Development Authority (BORBRDA) is one of the RBDA, set up to implement the agricultural development plan in the South-West agro-ecological zone.

The primary aims of the agricultural development in BORBRDA project area include increasing the income of farmers; increasing the production of basic food crops, increasing the production of fruits and vegetables for sale as well as initiating livestock husbandry as supplementary farm enterprises in the rural areas(NCEA,1999). The means of realizing this aim by BORBRDA are through broadening the range of products on individual farms by crop diversification, increasing crop yields per unit area or by adding new lines of production to the existing ones by increasing the cropping periods per year through irrigation

3.5.1 APPROVED ORGANISATIONAL CHART FOR BORBDA

(EDO, ONDO, EKITI STATE AND DELTA NORTH SENATORIAL DISTRICT)

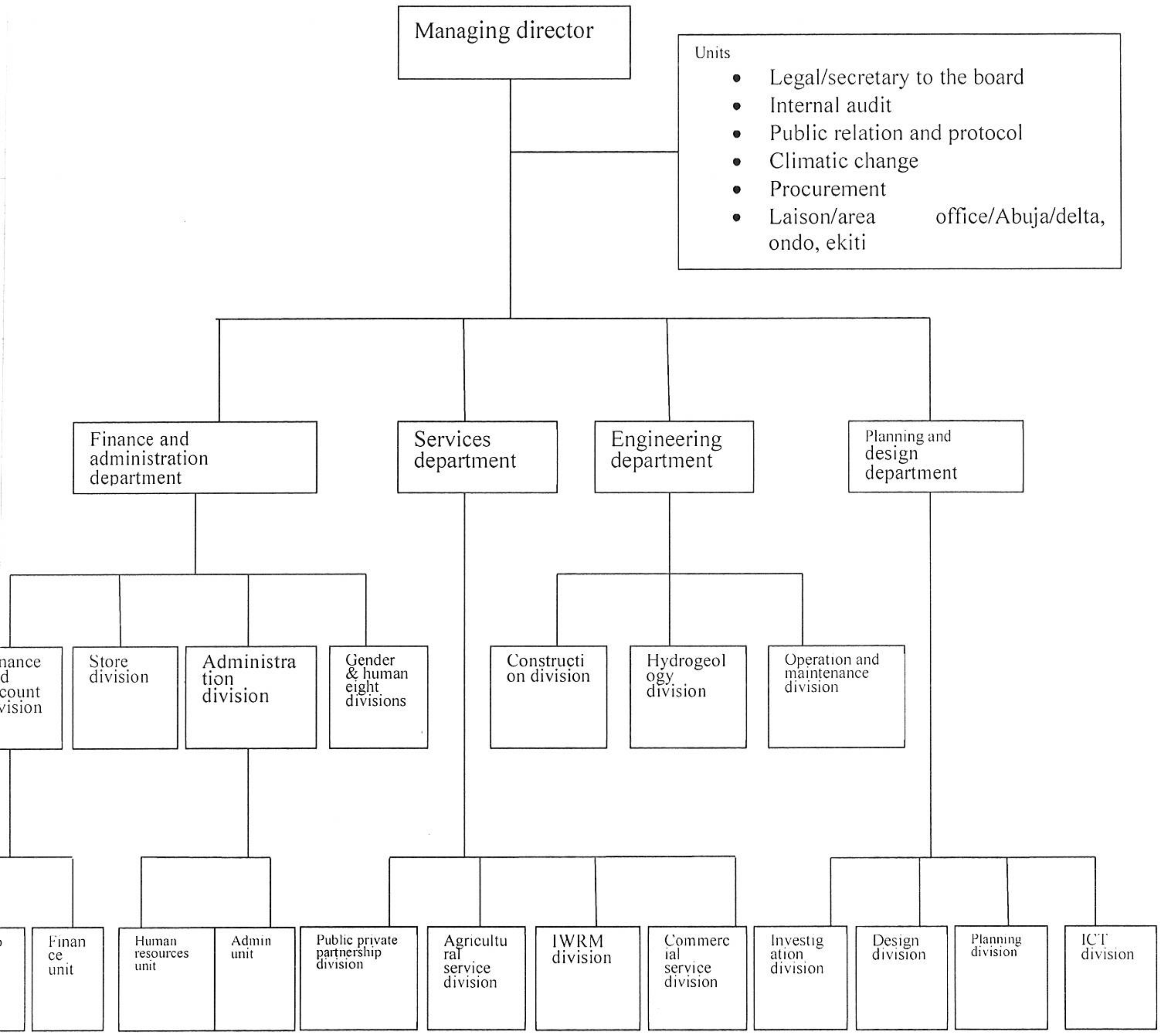

Fig.2 BORBDA ORGANISATION CHART

3.7 DATA SOURCE

3.7.1 Climate Research Unit (CRU)

For the study, climate data for the four stations were obtained from the Climatic Research Unit CRU (Mitchell*et al.*, 2004).We employed monthly precipitation and monthly temperature from 4 stations within the basin for the period of January1980- December 2015 (35 years). The ClimateResearch Unit Time Series 3.22 (CRU TS3.22) is a high resolution (0.5°X0.5°grid resolution) dataset which covers the entire globe excluding the oceans.

3.7.2 Calculation of drought index (SPEI)

This study used SPEI, developed by Vicente-Serrano *et al.* (2010), to characterize droughts atthe stations. SPEI uses water balance to describe drought at any location. The value of SPEI typically ranges from -3 to 3 in depicting the intensity of dryness (negativevalues) to wetness (positive values) as depicted in Table 1. This study adopted the SPEIlibrary (Beguería and Vicente-Serrano, 2013) in the R software (R Development Core Team,2012) to compute the SPEI over each station at 3-, 6-, and 12-month scales, using the monthly rainfall and monthly temperature data. These time scales stand for arbitrary characteristic time scales for precipitation insufficiency to aff ect the three types of usable water resources.The parameters of the SPEI are a time-series of monthly precipitation (*P*) and monthly potentialevapotranspiration (*PET*). Monthly *PET* was calculated by the Thornthwaite equation **(Thornthwaite, 1948**) that onlyrelies on mean monthly temperature (*T*) and latitude (*L*).The details of the SPEI computation, as thoroughly described in Vicente-Serrano *et al.* **(Vicente-Serrano, S.M***et al.* 2010) are as follows:

3.7.3 Climate Water Balance

A simple climate water balance was calculated as the differences between precipitation P and PET for month j according to:

$$D_j = P_j - PET_j \qquad (1)$$

Where monthly *PET* is calculated, using the Thornthwaite method. The main advantage of the Thornthwaite method over others is that it requires only temperature and the latitude of the location where we need to compute it. This simplicity of the Thornthwaitemethodmakes it eligible for places such as Benin-Owena river basin where Meteorological observationsare scanty. The PET using the Thornthwaite method is calculated as follows:

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \qquad (2)$$

Where T is the monthly mean temperature (°C), I are heat index calculated as the sum of the 12 monthly index values, m is the coefficients dependent on I:

$m = 6.75\times10^{-7} \bullet I^3 - 7.71\times10^{-7} \bullet .I^2 + 1.79\times10^{-2} \bullet .I + 0.492$, andK is a correction coefficient computed as a function of the latitude and month.

3.7.4 Normalize the Water Balance

The log-logistic distribution was used for normalizing the *D* series to obtain the SPEI. The probability density function of a three-parameter log-logistic distributed variable is expressed as

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \qquad \textbf{(3)}$$

Where α, β and γ are scale, shape, and origin parameters for D values in the range $(\gamma > D < \infty)$. These Parameters obtained following Singh et al., (1993).

Calculate the SPEI Series:

The SPEI can easily be obtained as the standardized values of $F(x)$. Following the classical approximation of Abramowitz et al.,(1965)

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \qquad (4)$$

Where:

$$W = \sqrt{-2In(P)} \quad for\ P \le 0.5 \qquad (5)$$

And P is the probability of exceeding a determined *D* value, $P = 1 - F(x)$. If $P > 0.5$, then P is replaced by $1 - P$ and the sign of the resultant SPEI is reversed. The constants are

$C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269 \textit{ and } d_3 = 0.001308$

Monthly SPEI values for each meteorological station were computed by SPEI Calculator Santiago et al (2013),Table 1. The more negative the SPEI value, the more severe the drought.

The SPEI can be calculated at any timescale, but in this study the 3-, 6-, and 12- monthsare used. Drought at these time scales is relevant for agriculture (3- and 6-month), hydrology (12-month) Potop et al (2014). In addition the 3-month SPI provides a seasonal estimation of precipitation Ji et al (2003); the 12-month SPIalso reflects medium-term trends in precipitation patterns Potop et al (2012) and may provide an annual estimation ofwater condition. Therefore, this study used the SPEI values at 3-, 6- and 12-month scales to explore thedrought variation at inter-seasonal and inter-annual time scales, respectively.Therefore SPEI values at these time scales were used to identify drought events andtheir related indicators including duration, intensity, and frequency.

Table 1. The Classes of SPEI Category According To Value (Potopet al., 2013).

SPEI	**Category**
≥ 2	Extreme Wet
1.5 to 1.99	Severe Wet
1.49 to 1.00	Moderate Wet
0.99 to -0.99	Normal
-1.00 to -1.49	Moderate Drought
-1.50 to -1.99	Severe Drought
≤ -2.00	Extreme Drought

3.7.5 Drought Evaluation Indicators

According to McKee *et al.* (1993), a drought event is a period in which the Standardized Precipitation Index SPI is persistently negative and the SPI reaches a value of -1.0 or less. Drought begins when the SPI value is less than zeroand ends when SPI value becomes positive. Because of the sameness in the principle of calculation, SPEI drought event is also defined by the same criterion as the SPI. After determining a drought event with a start and end month, duration, severity, intensity and frequency were then assigned.

3.7.6 Duration, magnitude and Intensity of Drought Events

The duration (D) of a drought event is the number of months between its commencement and end month Spinoni*et al.* (2014). The magnitude(M) is equal to the sum of all SPEI values during a drought event. Intensity (I) of a drought event refers to magnitude divided by duration. The larger the (I) value is, the more severe the drought.

3.7.7 RELATIVE FREQUENCY OF DROUGHT EVENTS

The relative Frequency presented in Figure 5, is calculated by:

$$F_s = \frac{n_s}{N_s} \times 100\% \qquad (6)$$

where ns is the number of drought events corresponding to each time scale and drought category, Ns is total number of drought events record in the same time scale and s is a station.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Temporal Variability Characteristics of Drought in Benin-Owena River Basin

Different types of drought can be detected by SPEI at different time scales. The temporal drought patterns of the four stations of the Benin-Owena river basin (Awopeju, Essa-Odo, Oba-Ile, Iworoko) were studied using the SPEI drought index. This allowed for the evaluation of years according to drought duration and severity/magnitude (Fig. 2-4). SPEI-3 months (Fig. 2) shows the recurrent feature of drought in a short-term drought, it reveals alternating dry-wet spells with no distinct pattern all through 1980-2015. By increasing the time scales, both the duration and severity is clearer for the SPEI -6 months and SPEI -12 months. Figure 3 and 4 shows decreased response to short-term temperature and precipitation. The drought variation as revealed by this longer time scale was stable, the obvious cycles clearly reveal variability of long term characteristics of drought. As shown in Figure 4, the early 1980s and the late 21st century for the period of observation were the more dry periods in Benin-Owena river basin.

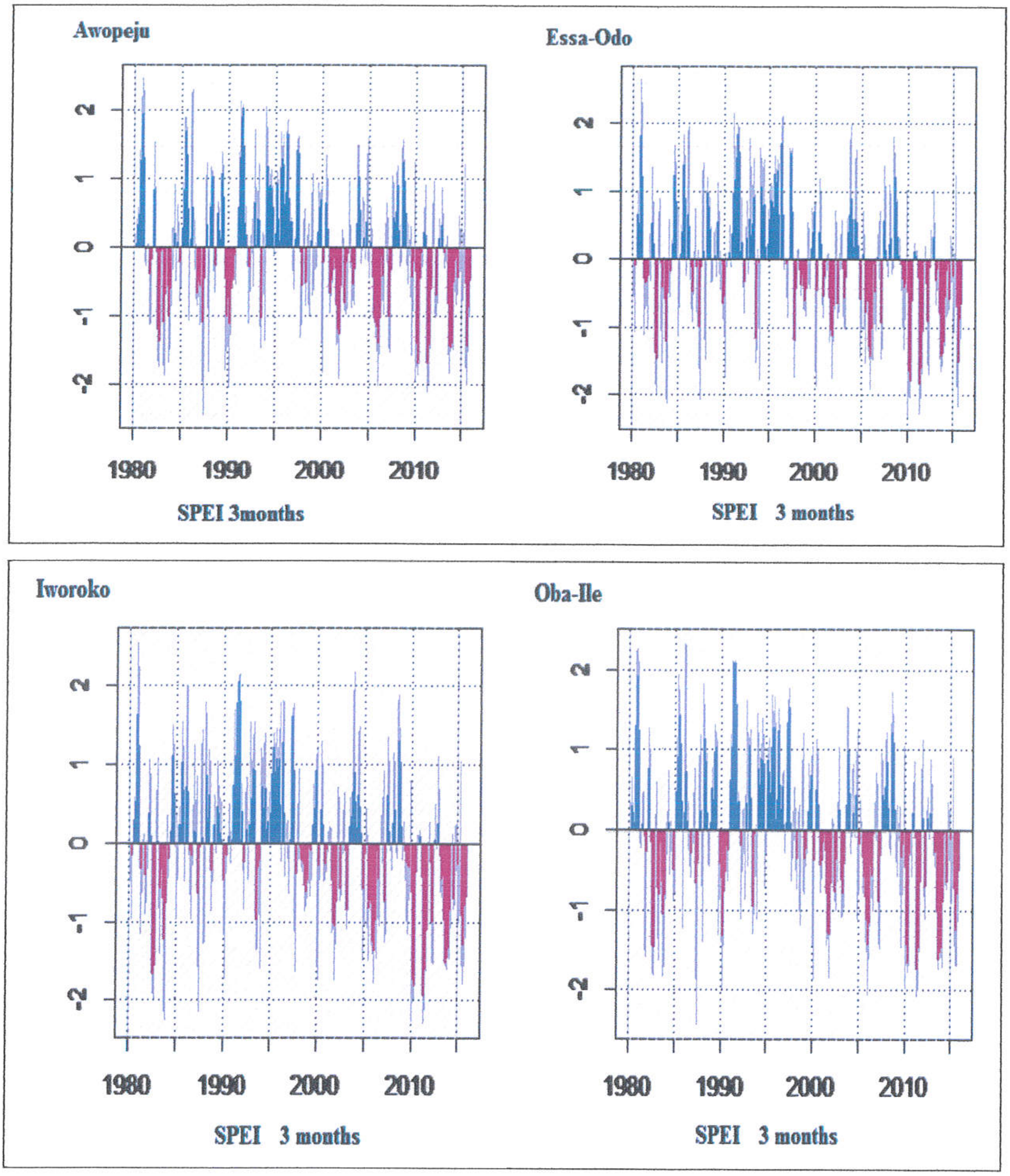

Fig. 3 SPEI series calculated on timescales of 3-month four weather stations (1980–2015)

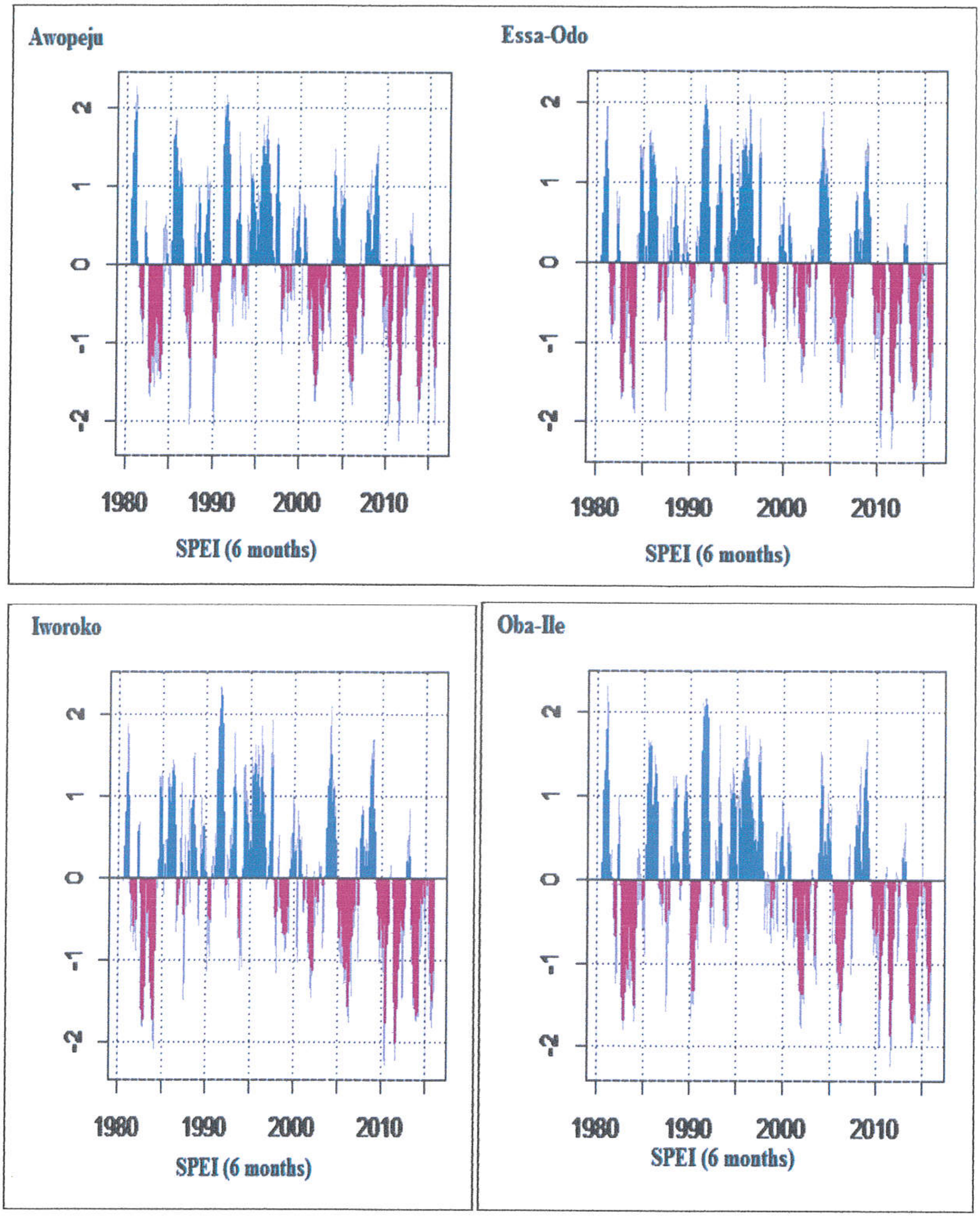

Fig. 4 SPEI series calculated on timescales of 6-month four weather stations (1980–2015)

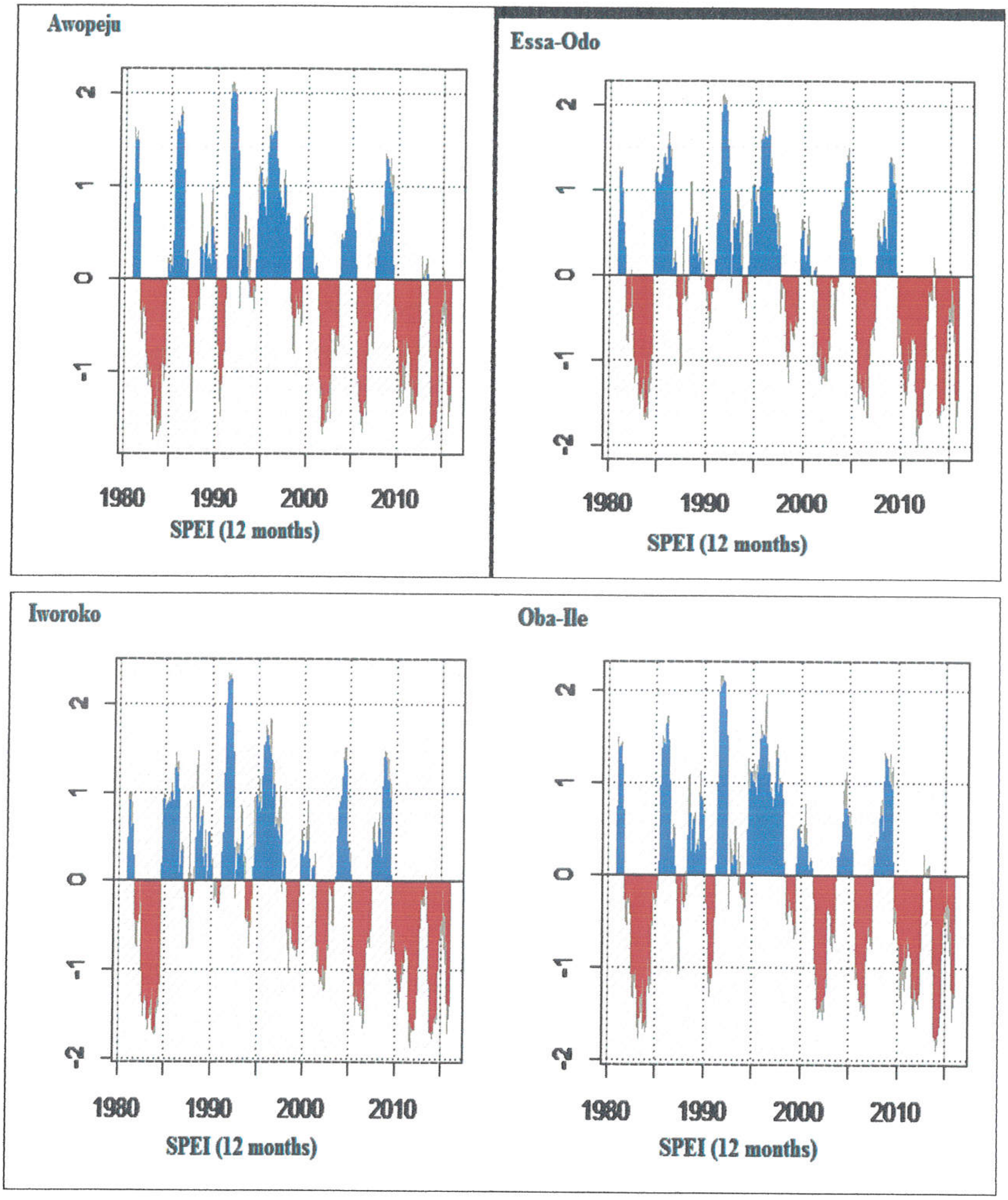

Fig. 5 SPEI series calculated on timescales of 12-month four weather stations (1980 –2015)

4.2 RELATIVE FREQUENCY OF SPEI AT DIFFERENT TIME SCALES

Results of the relative frequency of SPEI at different time scales, during the 35years record period show that maximum frequency occurs at the normal level at all the stations (Figure 5).The highest frequency is observed in 3 month time scale of the normal class. The results show that for a given time scale normal condition occur most frequently in the area and almost no case of extreme drought. It was also found that SPEI gave comparable values of drought frequencies across each drought category.

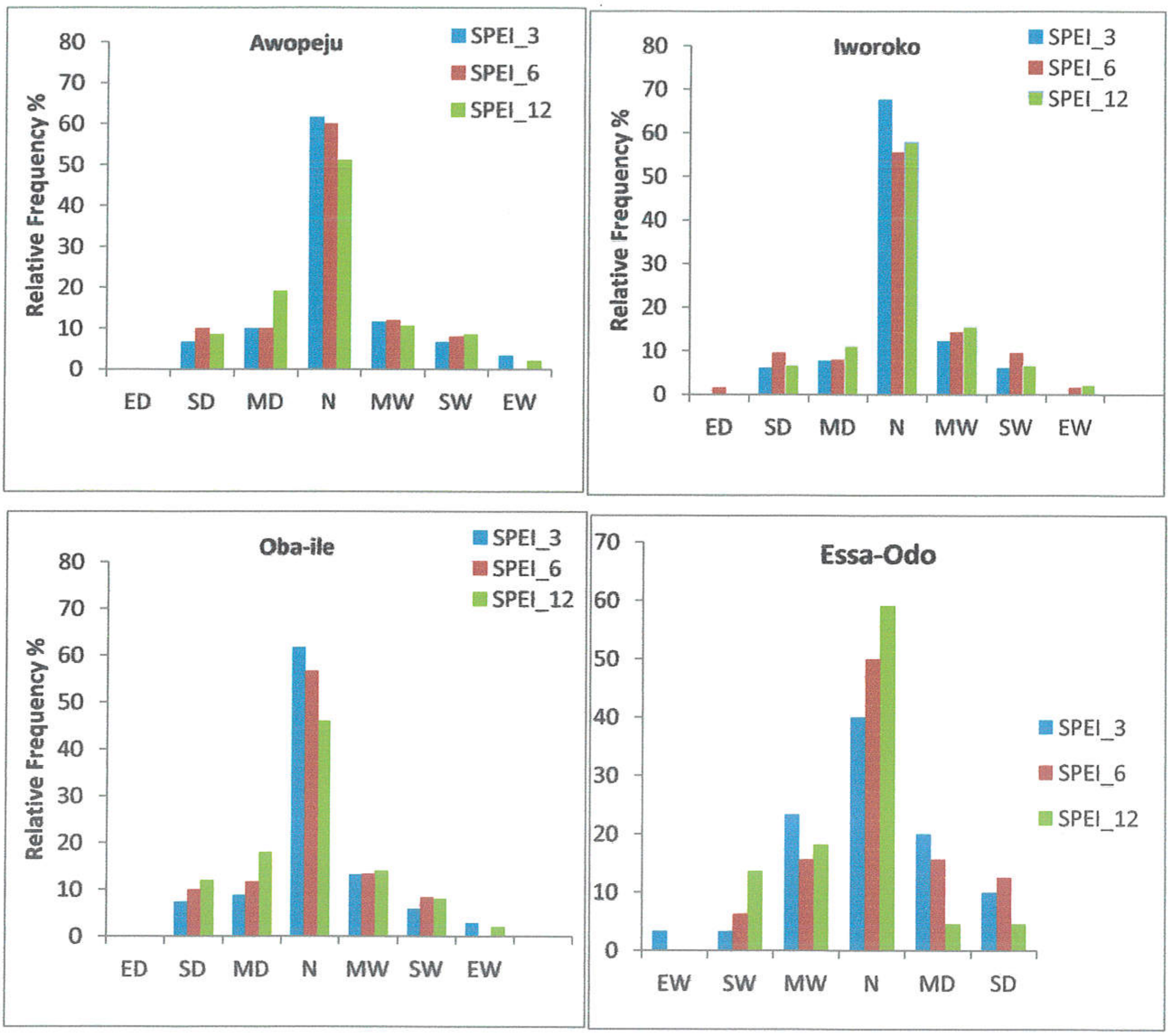

Fig. 6 Drought frequency histograms, for SPEI different category. The symbols are described in Table 1

4.3 Drought characteristics

Table 2 summarizes drought characteristics from 1980–2015 for the stations of the basin based on a 12-month time scale. As observed in Table 2, all the stations have experienced peak intensities of between $-1.5 \text{ to } -1.9$, falling into a severe category classification. Peak period mostly occurred in the 21st century. The highest Intensity $(SPEI = -1.88)$ occurred in January 2014 at Oba-ile. The longest drought lasted 44 months from August 2009 to March 2013 at Essa-Odo. The peak intensity of this drought was −1.85, its magnitude was −42.51, and its mean intensity was −0.97. As shown in Table 3, almost all stations experienced their longest and most and intense droughts during the 21stcentury.The relative frequency is highest at Essa-Odo (48.61%).

Table 2. Drought characteristics of 12-month time scales for the stations used in this study

Station Name	Observed Peak Intensity PI			Longest Duration				Most Intense Duration				
	SPEI	Year	Month	D	Years	M	I	D	Years	M	I	RF%
Essa-Odo	-1.85	2011	Nov	44	2009-2013	-42.51	-0.97	34	1981-1984	-34.46	-1.01	48.61
Awopeju	-1.76	1983	Apr	36	1981-1984	-34.26	-0.95	22	2005-2007	-22.34	-1.01	46.52
Iworoko	-1.77	2011	Sep	43	2009-2013	-41.48	-0.96	34	1981-1984	-39.38	-1.15	47.68
Obaile	-1.88	2014	Jan	43	1981-1985	-38.23	-0.88	31	2013-2015	-32.03	-1.03	47.69

PI: peak intensity, *D*: Duration (month), *M*: Magnitude, *I*: Intensity, *RF*: Relative Frequency

Table 3. Drought characteristics of 6-month time scales for the stations used in this study

Station name	Observed Peak Intensity PI			Longest Duration				Most Intense Duration				
	SPEI	Year	Month	D	Years	M	I	D	Years	M	I	RF%
Essa-Odo	-1.99	2010	Jun	33	1997-1999	-28.40	-0.86	19	2011-2014	-20.22	-1.064	32.34
Awopeju	-1.98	2013	Nov	35	1997-1999	-30.72	-0.87	28	2010-2014	-39.56	-1.41	30.76
Iworoko	-1.96	2011	Jul	38	1997-1999	-34.82	-0.91	25	1984-1987	-32.86	-1.31	38.45
Obaile	-1.98	2010	April	31	2010-2012	-27.56	-0.87	24	2005-2008	-32.82	-1.36	31.76

Table 4. Drought characteristics of 3-month time scales for the stations used in this study

Station name	Observed Peak Intensity PI			Longest Duration				Most Intense Duration				
	SPEI	Year	Month	D	Years	M	I	D	Years	M	I	RF%
Essa-Odo	-1,99	1987	Jun	22	2004-2010	-19.85	-0.902	15	1982-1987	-15.89	-1.059	22.75
Awopeju	-1.97	2013	Feb	28	1997-1999	-21.43	-0.765	21	2001-2005	-22.65	-1.078	26.13
Iworoko	-1.94/-1.94	2010/2011	Apr/Jun	34	1997-1999	-25.78	-0.758	10	2011-2013	-12.78	-1.278	34.43
Obaile	-1.98	2010	Jan.	30	2009-2010	-26.55	-0.885	15	2010-2013	-15.98	-1.065	26.24

CHAPTER 5

CONCLUSIONS

In this study, a drought index SPEI, calculated by both precipitation and temperature was used to provide a comprehensive analysis of the drought characteristics in Benin-Owena from 1980-2015. The patterns and the temporal extent of the drought were evaluated, respectively. The main conclusions are as follows:

Drought characteristics of the basin was detected by SPEI series with different time scales. Some moderate and severe droughts were captured (Figs. 3, 4 and 5).

The relative frequencies reflect the answer of this question: "How many droughts have occurred in the past in the Benin-Owena basin?" The results show that the mean relative frequencies of 47.62% for drought occurring in the basin at 12 month timescales.

A drought with the longest duration is not necessarily the most intense, so it may not result in the largest impacts or damages. Factors such as the onset or the mean intensity must also be looked at in addition to the magnitude and peak intensity (McKee et al., 1995). For example, the longest 12-month SPEI drought at Iworoko, which lasted for 43 months with a Magnitude of −41.48 and a Mean Intensity (MI) of −0.96, had less impacts than the 34 month drought with a magnitude of−39.38 and Mean Intensity of−1.15 (Table 2).

The observed Peak Intensities of SPI values during 1980–2015 illustrate some severe droughts $(-1.5 \; to -1.99)$ across the basin (Table 2). These severe droughts are valuable tools for water resources managers interested in either short- or long- term or water supply.

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