AIACC Final Reports

Food Security, Climate Variability and Climate Change in Sub Saharan West Africa

A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 23

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Food Security, Climate Variability and Climate Change in Sub Saharan West Africa

A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 23

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About AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) enhances capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. These activities are supporting the work of the United Nations Framework Convention on Climate Change (UNFCCC) by adding to the knowledge and expertise that are needed for national communications of parties to the Convention.

Twenty-four regional assessments have been conducted under AIACC in Africa, Asia, Latin America and small island states of the Caribbean, Indian and Pacific Oceans. The regional assessments include investigations of climate change risks and adaptation options for agriculture, grazing lands, water resources, ecological systems, biodiversity, coastal settlements, food security, livelihoods, and human health.

The regional assessments were executed over the period 2002-2005 by multidisciplinary, multi-institutional regional teams of investigators. The teams, selected through merit review of submitted proposals, were supported by the AIACC project with funding, technical assistance, mentoring and training. The network of AIACC regional teams also assisted each other through collaborations to share methods, data, climate change scenarios and expertise. More than 340 scientists, experts and students from 150 institutions in 50 developing and 12 developed countries participated in the project.

The findings, methods and recommendations of the regional assessments are documented in the *AIACC Final Reports* series, as well as in numerous peer-reviewed and other publications. This report is one report in the series.

AIACC, a project of the Global Environment Facility (GEF), is implemented by the United Nations Environment Programme (UNEP) and managed by the Global Change SysTem for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). The project concept and proposal was developed in collaboration with the Intergovernmental Panel on Climate Change (IPCC), which chairs the project steering committee. The primary funding for the project is provided by a grant from the GEF. In addition, AIACC receives funding from the Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation. The developing country institutions that executed the regional assessments provided substantial in-kind support.

For more information about the AIACC project, and to obtain electronic copies of AIACC Final Reports and other AIACC publications, please visit our website at www.aiaccproject.org.

Summary Project Information

Regional Assessment Project Title and AIACC Project No.

Food Security, Climate Variability and Climate Change in Sub Saharan West Africa (AF 23)

Abstract

The focus of the Project is the impact of contemporary climate variability and potential climate change on crop yield and human livelihood in Sub-Saharan West Africa. There are evidences to the effect that crop yield is sensitive to variability in the time of onset and cessation of the rainy or growing season. However, departures from normal levels of crop yield amounting to crop failures are observed only at decadal range of intervals in years with unusually low rainfall. Crop yield is also sensitive to potential climate change as derived from outputs of Hadley M2 General Circulation Models. These provide evidences to the effect that increased crop yield could characterize the first half of the 21st Century as a consequence of improvements in water availability, increased solar radiation and higher concentrations of atmospheric carbon dioxide. However, crop yield projections for the second half of the century indicate depressed yields resulting from an over-ruling effect of supra optimal temperature levels. Vulnerability of peasant households to climate variability and climate change is assessed to be primarily determined by their dependence on agriculture, a sector that is by itself vulnerable to climate drivers. Vulnerability of the same livelihood group is also a function of existent poverty, high child dependence burden, low health status as well as low levels of educational attainment which impose limits on their adaptive capacity. The northern, drier regions tend to be more vulnerable than the southern, wetter, coastal zone. Extended range weather forecasting is assessed as the fundamental strategy for adapting to the vagaries of climate. It is demonstrated that the skill level of the existing weather forecasting capacity has some room for improvement. Such improvements could be achieved with more predictors especially those of a synoptic nature. Higher time and spatial resolutions of forecasts are also required to meet the needs of the farmers. Models are formulated with these deficiencies in mind as a way of fine-tuning the existing capacity. Capacity building has been enhanced as evidenced by the improved academic statuses of researchers and students. During its lifetime the project contributed a chapter to Nigeria's First Communication forwarded to the UNFCCC in 2004. Policy recommendations are for: strengthening the resilience of the crop production systems, improving human adaptive capacity and developing an early warning system based on extended range weather forecasting.

Administering Institution

Obafemi Awolowo University, Ile-Ife, Nigeria

Participating Stakeholder Institutions

University of Lagos, Lagos; Mosunmolu Ltd, Lagos; and University of Maiduguri, Maiduguri.

Country of Primary Focus

Nigeria

Case Study Areas

Nigeria as a case study for Sub Saharan West Africa; Bornu and Yobe states as case studies for the Nigerian Arid Zone; Konduga Local Government Area as a case study for the Sahel Ecological Zone; Askira/Uba Local Government Area as a case study for the Sudan Ecological Zone; Irepo Local Government Area as a case study for the Northern Guinea Savannah Zone; Oorelope Local Government Area as a case study for the Southern Guinea Savannah Zone; and Atakumosa Local Government Area as a case study for Rain Forest Ecology.

Systems Studied

Food security

Sectors Studied

Agriculture: Crop production

Groups Studied

Peasant households

Sources of Stress and Change

Primary sources: climate change, climate variability and drought; and Secondary sources: economic stagnation and population growth.

Project Funding and In-kind Support

AIACC: US$ 180,000 grant; NOAA: US$ 20,000; START: US$ 21,000 (Fellowship awarded the Principal Investigator in 1999 afforded the opportunity to develop the project at Penn State University) and CIRA*: US$ 2,000 (Price of ArcView Programme Software).

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Executive Summary

Research problems and objectives

In August 2000, in response to a proposal earlier submitted, NOAA released a grant for a pilot research project titled: "Extended weather forecasts as a management tool for the enhancement of cereal crop productivity in Sub-Saharan West Africa". The project was designed as a component of the START Climate Prediction and Agriculture (CLIMAG) initiative, a collaborative effort of the World Climate Research Program, IGBP, IHDP and START.

The primary objective of the pilot project was to undertake an exploratory study of the vulnerability of cereal crop production to inter-annual climate variability in West Africa and to assess how extended-range climate forecasts could be mobilized to enhance the productivity of cereal crops, including: maize, rice, sorghum and millet.

A proposal with the same title was adopted by AIACC (Assessment of Impacts of and Adaptations to Climate Change) for funding in 2001. The AIACC proposal was broader in scope in several major respects. First, attempts were to be made to fine-tune regional weather forecasts for local consumption. Second, attempts were to be made to extend forecasts to March-April-May, i.e., the earlier parts of the year, which is critical to agriculture in coastal areas. Third, the outlook for climate change during the 21st Century was to be examined and attempts made to anticipate and forestall any negative impacts of the change on food security. Fourth, two other major crops (cassava and yam) were to be modelled in addition to the cereal crops that were the focus in the pilot study.

Subsequently, after interactions with the AIACC Science Director and his team, the title of the proposed study was changed to "Climate Change, Climate Variability and Food Security in Sub-Saharan West Africa". While the core of the research was still to be dominated by sensitivity analysis and impact assessment, the outlook in the AIACC Project was to extend to the state of the human development of the peasant farmers.

Among the deliverables envisaged by the AIACC project were: a set of empirical procedures for fine-tuning the forecasts of the Meteorological Organizations for use at the local level; a simple procedure for downscaling GCM climate change forecasts for the 21st century; a set of crop-yield forecasts (based on EPIC simulations and driven by potential climate change) indicating the potential impacts of, and the potential vulnerability to expected climate change; a suite of adaptation options that could be adopted as strategies to ensure maximum crop productivity under each category of anticipated seasonal weather or future climate; a plan for the use of the information by key players in the agricultural sector; a crop of young, well-trained specialists in agricultural meteorology of West Africa with emphasis on Climate Change; and peer-reviewed publications.

Nigeria was adopted as a sample area for Sub-Saharan West Africa. This decision was justified in the study proposal by the fact that the country truly represents the climatic profile from the per-humid to the semi-arid ends of the project region. All the indicator vegetation types of the various climate types are present in the country. Thus, northwards from the very humid, eastern, coastal locations, to the boundary with the desert, the vegetation profile includes Moist Evergreen Rain Forests, Dry Semi-Evergreen Rain Forests, Derived Savannah, Southern Guinea Savannah, Northern Guinea Savannah, Sudan Savannah, and Sahel Savannah.

What is potentially at stake, providing the justification for this study, is the social, cultural and economic development of West Africa, based on a sustainable use of the resources of the environment.

One of the more frequently applied indices of the level of development is the status of Food Security and that of its antithesis – Hunger. The standard definition of food security according to the World Bank is 'access by all peoples at all times to enough food for an active, healthy life'. The security envisaged should be at all levels of human organization, including the individual, the household and the community.

The potential significance of the current study can be seen in the context of the deteriorating state of socio-economic development in Sub-Saharan West Africa, compared with other continental regions of the world. A confluence of rapidly increasing population, explosive growth of urban centres and largely unsustainable agricultural practices leading to land degradation, is set to make sub-Saharan Africa lag behind other regions in development during the 21st century. Added to these are the negative impacts of the potential changes in global climate as a result of increasing concentration of greenhouse gases in the atmosphere.

Approach

Characterization of current climate was based on the data for the period after 1960 and on 28 synoptic weather stations in Nigeria. The latter are the stations where data on rainfall, temperature, solar radiation, humidity and cloud cover are collected on a regular basis by the Nigerian Meteorological Agency. The stations are equipped, manned and operated by the Agency. For climate change projections, we used observed and model simulated data available at the IPCC'S Data Distribution Centre in 2002. This was justified on the need to use scenario and baseline data from the same source.

In describing current climate, we first attempted to capture the totality of inter-annual variability of climate with respect to monthly maximum temperature, monthly minimum temperature and monthly rainfall for locations representative of the main climate and ecological zones between the coast and the Sahara Desert. Variability indices were computed as the coefficients of variability. The latter is the standard deviation divided by the mean. The resulting fractions were converted to percentages. In addition to the computation of the indices of variability, linear graphs based on actual records and showing the actual changes in rainfall from one year to the other were also drawn. Regression analysis was used to demonstrate the long-term trends in rainfall. The rainfall data were also subjected to spectral analysis in order to detect any tendency for periodicity.

The tools for climate change projection are the General Circulation Models. The Climate Change Scenario used in this analysis is an output of Hadley M2 General Circulation Model. The IPCC has defined a set of criteria that have been applied to identify GCM experiments whose results could be deposited at the IPCC DDC. These criteria led to an initial selection of experiments from five modelling centres one of which was Hadley Centre. Many others have since been added. MAGICC – SCENGEN Version 2.4, an IPCC recognized data storage model, has on its list 16 models from nine modelling centres to select from (Hulme et al, 2000).

The main source of data on socio economic attributes of the country is the Federal Office of Statistics, which collates data from ministerial and non-ministerial departments and generates primary data through continuous and special surveys. The data from departmental sources are available in serial publications for example, the *Annual Digest of Statistics* and the *Annual Abstract of Statistics.* The data generated through the surveys are also made available in the reports of special or annual surveys. For example, there is an on-going National Integrated Survey of Households (NISH), which is reported on an annual basis in a number of publications.

Data on land use changes were sourced mainly from space and air borne remotely sensed imageries. These include: Side-Looking Airborne 1976 (SLAR) Imageries acquired by the Federal Department of Forestry and 1990 low altitude aerial photographs acquired for the Nigerian National Livestock Survey.

Population was projected from a base of 85 million in 1990 with an initial growth rate of 33 per thousand declining to 25 per thousand by 2050. The changes in land use between 1976 and 1990 were projected into the 21st century with the assumption that the core element in land use change is related to how much land is used for crop production. The latter is driven by population growth and resisted by the finite nature of land. Projections of the economy were based on stated government policy and demonstrated executive capacity. The trends indicated by crop production statistics between 1970 and 2000 were explained and the active factors were adopted as bases for projecting crop production to 2050.

For the analyses of sensitivity to inter-annual and intra-annual climate variability we adopted bivariate correlation and multiple regression methods. Since one of our primary objectives was also to estimate the relative contributions of each climate independent variable in determining the variability of crop yield, we opted for the backward selection procedures for the regression in the case of inter-annual variability. For the intra-annual study, we used the stepwise approach.

We indexed impacts of annual climate variability by a parameter computed as annual yield minus mean annual yield divided by the standard deviation. The results produced a Z- distribution array with values varying from approximately –3 to approximately + 3. Values < –1.6 or > 1.6 indicate impacts that are significant at 95 percent confidence levels. Higher confidence limits could be set. For example values < –

2.3 and > 2.3 define impacts that are significant at 99 percent. The interpretation is that the anomalies in yield observed during the years with significant V.I. (Variability Index) could not have happened by chance.

The assessment of the impacts of climate change on crop productivity was undertaken in ten case studies. Five of the studies adopted incremental scenarios and were designed to demonstrate the relative effects of individual climate elements on crop yield. Using EPIC Crop Model, the elements investigated include: rainfall, relative humidity, temperature, solar radiation and carbon dioxide. EPIC data file for Ilorin, in the southern Guinea Savannah ecological zone, was used in the rainfall and relative humidity study. The data file for Jos, representing high altitude ecology was used for the studies of the relative sensitivities to changes in temperature, CO_2 and solar radiation.

The other five case studies adopted GCM scenarios. Each of the studies in this group was designed to demonstrate changes in simulated yield of a particular crop, from the baseline of 1961-1990 through three other time slices including: 2010-2039; 2040-2069 and 2070-2099. Only five crops including: maize, millet, sorghum, rice and cassava were investigated. The other major crop, yam, was not in the crop list of EPIC.

The target of the vulnerability assessment is the Nigerian Peasant Household. In the present report, vulnerability is conceived simply as a function of exposure, sensitivity and adaptive capacity. V = f (exposure, sensitivity, adaptive capacity). Vulnerability of the peasant households is assessed at the level of the component states of the Nigerian Federation. Index of vulnerability was derived from measures of the drivers of sensitivity of crop yield to climate, and measures of adaptive capacity.

The extent to which adaptive capacity is constrained by existent household characteristics was derived as the proportion of the households affected. Thus in the case of poverty, the first question addressed was: "how poor is the poor household?" The second question pertains to what proportion of the households was poor. This proportion was adopted as a measure of lack of adaptive capacity of householders within each social structure, including: household, community, society, nation and world system. The data available allows us to compare householders at state level and at regional levels.

The skill of the existing capacity for extended range weather forecasting was assessed by comparing observed and forecast weather for the period from 1996 to 2000. Multivariate regression was used to construct additional weather forecasting models with sea surface temperature anomalies, land and sea thermal contrasts, ITCZ positions and synoptic weather information as predictor variables.

Scientific findings

Current climate

Three anticyclones control general circulation in West Africa. These are the Azores and the Libyan anticyclones in the Northern Hemisphere and the St. Helena anticyclone in the Southern Hemisphere. While the Azores anticyclone is permanent; the Libyan anticyclone may become relatively weak during the summer in the Northern Hemisphere. The St. Helena anticyclone normally oscillates northwards during Northern Hemisphere winter. Between the three sub-tropical high pressure cells are: the Sahara Desert, sub-Sahara West Africa and the Gulf of Guinea.

West Africa is in the sphere of influence of two air masses, which migrate in concert with the high-pressure cells. There is a tropical continental (cT) Air, warm, dry and dusty, whose source is the Sahara Desert and a mass of Tropical Maritime (mT) Air, warm and humid, which has its source region over south Atlantic. Between the two air masses is the Inter Tropical Convergence Zone (ITCZ).

Because the boundary between the two air masses moves in sympathy with the oscillation of the controlling anticyclones, the belt of ITCZ weather also moves north and south. Such movement is responsible for the characteristic intra-annual patterns of rainfall distribution. Specifically, they are responsible for the differentiation of the dry and the rainy seasons. The varying degrees of persistence of the ITCZ, over east-west aligned zones are also the main cause of the regional disposition of the main climatic types in the sub-continent.

Perennially humid climate (Koppen's Af) characterizes areas south of latitude 7.5^o N. A sub-humid climate (Koppen's Aw) characterizes the region between latitudes 7.5^o and 9.5^o N. Between the area characterized by the sub-humid climate and the Sahara Desert, the climate is recognized as semi-arid with dominant, arid tropical conditions (Koppen's BS).

Contemporary climate variability

Inter-annual variability of temperature is spectacularly low, averaging less than 5 percent across climate zones and from January to December. By comparison, the coefficient of variability of monthly rainfall varies between 0 and 600 percent. The generally low variability of temperature provides the explanation for the little regard accorded to temperature related parameters in the literature on climate variability in tropical areas and the emphasis placed on rainfall.

During most of the 20th century there was a general trend towards aridity in most of the stations studied. All the rainfall time series, when smoothed with the 5-year moving average, revealed patterns characterized by oscillations. The fluctuations demonstrate some periodic tendencies, which were regular in nature. The fluctuations were also characterized by strong persistence and temporal dependencies and there was a general lack of correspondence in the patterns of the fluctuations between seasons. In other words, a wet March-April-May is not necessarily followed by a wet June-July-August. Also, there were inter- regional disparities in terms of the rainfall fluctuations. That is while major droughts may be sub continental in terms of area affected; the majority of droughts experienced in each area are local.

Climate change

The most significant changes in climate expected during the 21st Century are with respect to temperature and temperature related parameters. Based on the emission scenarios adopted in the study, changes in minimum and maximum temperatures of the order of 5^{o} C or more could be expected in certain parts of the country. This is likely to create a significantly different world with implications in vulnerability and adaptive capacity. The impacts of such changes will be felt in multiple sectors including: health, water, biodiversity, agriculture and forestry.

Night temperatures will in general increase at a higher rate than day time temperatures. This has a potential to alter the thermo-period to the detriment of biodiversity. Crops and other plants requiring low temperature conditioning during one stage or the other of their life cycles may in the short run survive through autonomous adaptations, but in the long run may have to contend with the possibility of extinction. Day temperatures may in future attain levels unknown to areas outside the hot desert regions. In areas with perennially humid air, this has the potential to produce sultriness and the oppressive heat usually associated.

On the average, vapour pressure may rise by as much as 5 to 8 h*Pa with the potential for a significant increase in atmospheric energy. One would expect from this scenario, an increase in the frequency and intensity of stormy weather. A general decrease in cloudiness is projected. This could improve the availability of sunlight for primary biological productivity. The observed trend towards aridity in Sub-Saharan West Africa during the 20th Century will be put on hold or reversed as the 21st century progresses. There are possibilities, however, that the additional water need created by higher temperatures may not be met by the increases in rainfall.

Uncertainties regarding climate change will most likely be in terms of magnitude rather than of direction. The more significant uncertainties pertain to temperature and temperature related parameters in respect of which the expected changes are relatively large. With respect to moisture, the projections are for an increase rather than a decrease.

Socio economic futures

Vision 2050 portends a completely new world for Nigeria. The outlines of this new world lie within the range of reasonable conjecture. A national population of between 400 million and 600 million will determine the nature of the environment, the political economy, and the totality of human security. However, targets of population control measures meant for 2010 would have by the year 2050, hopefully, been achieved. Significant decreases in the rate of growth will put the population on a course towards stabilisation and ultimate decline. By 2050 the country would have exhausted all its options of increasing agricultural production through the expansion of cultivated land and through the shortening of the fallow period. Areas used for continuous food crop production would dominate the agricultural landscape. Especially in the semi-arid zones, mixed farming will dominate agricultural practice and the use of organic and inorganic fertilizers will be the order. Forests will be confined to the reserves and the mangrove and fresh water swamp forest ecological zones. Prevailing circumstances would have forced modernization and commercialization on the agricultural sector.

Impacts of climate variability

Crop yield demonstrates little or no sensitivity to inter- annual changes in total annual or total rainy season rainfall. However, yield of some of the crops are sensitive to inter-annual changes in the rainfall of the periods of onset and cessation of the rainy season. Crop yield is also significantly sensitive to intra-annual changes in relative humidity, temperature and solar radiation. Significantly depressed yields that could be described as crop failures correspond to significant negative anomalies of rainfall that is, droughts. However, significant positive anomalies of crop yield are not similarly related to significant positive anomalies of rainfall.

In general, climate impacts are least on the yield of rice among the crops considered in the arid zone case study (maize, rice, sorghum, millet, groundnut and cow peas). This was evident from the values of the coefficients of correlation. It was also evident from the low magnitudes of the yield anomalies over the 17-year period (1983 – 1999). This could be due to the fact that rice is more likely to be irrigated than the other crops. The crop whose yield is most likely to be impacted by climate variability turned out to be cow peas. The next is maize followed by millet. Negative impacts of climate are more likely to result from inadequate rainfall in June, September or both months. These are the months of onset and cessation of the rainy season in the case study area.

Impacts of climate change

The indications are that, in general, there will be increases in yield for all crops across the ecological zones as the climate changes during the 21st century. In most cases, the increases will continue until mid-century. However, towards the end of the century, the rate of increase will slow down. In other words, lower yields will be realized during the last quarter of the century, compared with the second and third quarters, although yields will still be higher than what they were at the beginning of the century. As should be expected, there will be significant differences between the various ecological zones. For example, there will be substantial increases in the yield of cassava in the drier areas compared with the rain forest zone where there may be a net decrease in yield. The implication of this is that the cassava-growing region will extend northwards. Yields in the wetter forest areas will, however, still remain much higher than yields in the north. Another exception to the general trend is that yield of all the crops will continue to increase right to the end of the century on the high altitude of Jos Plateau.

The increases in crop yield during the first half of the century are probably related to lower water stress as a result of increased rainfall, higher levels of incident solar radiation resulting from less cloud cover and higher levels of greenhouse gas concentration resulting from unmitigated increases in carbon dioxide emissions. The reduction in the yields towards the end of the century could be ascribed to the attainment of supra-optimum levels of temperature and carbon dioxide concentration.

Vulnerability of the peasant household

The projected climate represents both opportunities and risks for the peasant householder in the country. Because of his dependence on agriculture, a sector that is by itself exposed and sensitive to climate, the peasant householder’s livelihood, including his food and nutrition, is indirectly exposed to the projected climate change. Vulnerability of the Nigerian peasant household to changes in climate will also be determined by a number of existent characteristics, which imposes limits on its adaptive capacity. Among these, the most significant is existent poverty, which signifies lack of resources necessary for adapting to climate change. In addition, relatively low levels of educational attainment could also constrain the ability to acquire the technological capacity for combating the negative consequences of climate change. The rates of population increase which at present stand at 28 per thousand could increase the rates of child dependency burden, increase pressure on social infrastructure, and also constrain the capacity to adapt to possible negative impacts of climate change. Based on the analysis, it could be observed that considerable contrasts in vulnerability to climate change exist between the various regions of the country.

Extended-range weather forecasting: a basic adaptation strategy

Extended-range weather forecasting in West Africa has been recognized as the first basic step for all adaptation studies. This is in view of the fact that no reasonable plan can be made regarding the variable climate of the region, without gaining insights into future meteorological conditions of each locale. Given this background, the skill of the existing capacity for extended–range weather forecasting for enhanced crop productivity of the region was assessed. The study noted a number of inadequacies in both the prediction skill and the usefulness of the existing capacity for extended–range weather forecasting to the end users. The prediction skill seems inadequate because of the low percentage of the "high skill" categories obtained in its assessment. Inadequacies in terms of the usefulness to the end users include: (a) lack of forecasts on the prominent rainfall characteristics such as onset, retreat, length of the growing season and rain-days; (b) lack of forecasts for specific localities, instead of extensive zones; and (c) concentration on the Sahel and relative neglect of the coastal and middle belts of West Africa.

This study attempted making up for the various inadequacies. Prediction models were generated for the relevant rainfall parameters including onset, retreat, and rain-days. Also, the models generated represent an improvement on the existing tools as they could be used to make forecasts for specific location (i.e. towns), and for all the zones from the coast to the Sahel. The study concluded that rainfall characteristics of the region can be reliably predicted, using the rainfall engendering factors of SST and land/sea thermal contrast alone.

Capacity building

One of the cardinal objectives of the project is capacity building, the need for which became acute when, five years ago the country emerged from a fifteen-year period of a most brutal military rule. When the project was approved for funding, morale within the academic community had sunk to its lowest level ever. The brightest and the best had emigrated to green pastures in other countries. The country was yet to submit its first communication to the UNFCCC ten years after the Rio Earth Summit.

Our assessment of the present situation is that resident capacity for research on climate change has increased considerably compared with what obtained three years ago when the project was approved for funding. Contributing to this improved situation were the increase in the number of participating researchers from seven to seventeen, the AIACC- organized workshops in which ten of the core research personnel participated, the in-house project seminars, the two-day stake holders workshop held from September 20 to 21 2004, the stock of equipment including four desk top and one lap top computers; participation by students, especially at the undergraduate level; the visit of Professor C.G. Knight of Pennsylvania State University; and the study visit of one of our students to the University of Cape Town South Africa. The visit of another student to Oxford University, United Kingdom has been postponed till the summer of 2005.

Three solid evidences of our successes in capacity building could be cited. First is the generally high level of performance by the undergraduate students who opted for Climate Change as a speciality. One of them was awarded the third first class honours in the 43-year history of the Department of Geography and has been admitted to the University of Oxford, pending the completion of her National Youth Service assignment and availability of sponsorship. Second, Dr Adeolu Ayanwale, a member of the Research Team, was awarded a START Fellowship based on a proposal, which was derived from the AF 23 Project and his experience when he attended the AIACC Workshop in Trieste, Italy in 2002. Third, Odeyemi Odekunke who was the most junior member of the research team as approved for funding is the sole author of three of the publications submitted with this report and a joint author of two others.

The future should not create any problem because many of the research personnel demonstrated a high level of promise and there is the hope that the University will continue to be a centre of excellence for climate change studies. It is recommended that the former undergraduates who opted for graduate work in climate related areas of study should be helped to realise their respective ambitions. Most of them have applied for admission to graduate school in the United Kingdom. Their individual progress should be monitored with the aim of attracting them back to the Department.

National communications and stakeholder engagement

The Principal Investigator of AIACC Project AF 23 is a member of the National Committee on Climate Change, the body that formulates Federal Government Policy on Climate Change. As a member of this committee, he participated in two workshops respectively in 1997 and 2000 designed to facilitate the preparation of the First Communication to the UNFCCC. During the first half of the year 2002, the P.I. was invited to edit a draft of the Communication. It was quite obvious to him that much still needed to be done before the project could be brought to a successful conclusion. One of the deficiencies in the draft was the absence of a chapter on Climate Change Scenarios, which should serve as the point of departure for any meaningful characterization of Impacts, Vulnerabilities and Adaptations. He was then commissioned by the National Committee to prepare a draft of such a chapter. The draft he submitted, which is part of the outputs of this project, was accepted as Chapter 4 of Nigeria's First National Communication, which was submitted in 2004.

Policy implications and future directions

Policy formulation is handicapped by the large measure of uncertainties attached to the potential climate change and the much larger measures of uncertainties regarding the potential impacts of climate change. It is, therefore, recommended that policy should be directed towards implementation of the "no regrets options" of adaptation to, and mitigation of climate change.

Regarding the foregoing, perhaps the most important policy implication of the research reported here is the need to improve the adaptive capacity of the peasant householder in terms of poverty alleviation, reduction in the level of child dependency burden, higher levels of educational attainment, improved state of home environment, and improved personal and public health. These are issues included in the design of the United Nations Millennium Goals to be achieved by the year 2015. They are also included in the mandate of many United Nations Agencies including the UNEP, the UNDP, the UNESCO, and the WHO etc.

There is also the need to develop strategies with the aim of building resilience into the crop production systems and making them less sensitive to climate variability and climate change. In this respect, five main lines of activities could be identified. These include: 1) development of institutional capacities in the area of agricultural extension, 2) investment in the development of improved seeds and cultivars, 3) strategies to neutralize biological constraints including those pertaining to pests and diseases, 4) strategies for the management of soil constraints and 5) strategies targeted at reducing recognized socio economic-constraints.

The strategy of developing an early warning system for anticipating and forestalling the negative impacts of climate variability is also a "no regrets" option. This strategy is dictated by the understanding that a fore-knowledge of the weather of a growing season will enable farmers to plan with greater confidence to forestall its negative consequences and exploit its beneficial opportunities. The logic of this realization is that skilful weather forecasting is an invaluable asset in any plan to adapt crop production systems to a variable climate. Since variability will remain a significant element in any future climate, skilful weather forecasting will also remain a valid adaptation strategy, whether or not the climate changes.

1 Introduction

1.1 The Pilot Project

In August 2000, in response to a proposal earlier submitted, NOAA released a grant for a pilot research project titled: **"Extended-Range Weather Forecasts as a Management Tool for the Enhancement of Cereal Crop Productivity in Sub-Saharan West Africa"**. The project was a component of the START Climate Prediction and Agriculture (CLIMAG) initiative begun in March 1996 as a collaborative effort by the World Climate Research Program, IGBP, IHDP and START. International workshops held in 1997 and 1999 outlined the importance of seasonal to inter-annual climate forecasts for agriculture. The Strategic Plan for CLIMAG describes an ambitious, interdisciplinary program of research, leading to practical applications and capacity building. CLIMAG seeks to develop the capacity for integrated climate and agricultural simulation and prediction for a range of farming systems. The goal of CLIMAG is to utilize the ability to predict climatic variability on the scale of months to a year to improve management and decision-making in respect of crop production at farm and up to national scales.

The primary objective of the pilot project was to undertake an exploratory study of the vulnerability of cereal crop production to inter-annual climate variability in West Africa and to assess how extended range climate forecasts could be mobilized to enhance crop productivity. The methodological approach included documentation, analysis, and modelling of actual and potential cropping strategies in recent years using contemporary climate forecasts, actual cropping activity, production results, and models based on best practice uses of existing and future forecasting potentials. *Ex ante* decisions that might be influenced by forecasts of growing season climatic conditions were to be identified. Based on the analysis, a suite of options for the mitigation of existing problems in agricultural timing was to be developed. The four major cereal crops involved were sorghum, millet, rice and maize.

While work was progressing on the pilot project, a proposal with the same title was submitted to AIACC (Assessment of Impacts of and Adaptations to Climate Change) for funding on a competitive basis. Partly as a result of the progress already made on the pilot project, the new proposal was among those selected for funding. However, the AIACC proposal was broader in scope in seven major respects. First, attempts were to be made to fine-tune regional weather forecasts for local consumption. Second, attempts were to be made to extend forecasts to March-April-May, i.e., the earlier parts of the year, which is critical to agriculture in coastal areas. Third, the outlook for climate change during the 21st Century was to be examined and attempts made to anticipate and forestall any negative impacts of the change on food security. Fourth, two other major crops (cassava and yam) were to be modelled in addition to the cereal crops that were the focus in the pilot study. Fifth, localities for farm level modelling were to be increased from 8 to 31 to provide a more intensive coverage of the ecological profile from the coast of the Gulf of Guinea to the Sahel. Sixth, a cost-benefit analysis of farm level operations schedules based on crop yields and farm inputs were to be used in assessing vulnerability to climate variability at the selected sites. Seventh, the existing graduate level *Applied Climatology* program in the Obafemi Awolowo University was to be modified to accommodate CLIMAG STUDIES and CLIMAG specializing students so as to ensure a sustained interest in food security issues. The project, as originally conceived, placed emphasis on biophysical vulnerability of crop productivity. Subsequently, after interactions with the AIACC Science Director and his team, the title was changed to "Climate Change, Climate Variability and Food Security in Sub-Saharan West Africa". While the core of the research was still to be dominated by biophysical sensitivity analysis and impact assessment, the outlook in the AIACC Project extends to the state of the human development of the peasant farmers.

The AIACC proposal envisaged seven main deliverables. The first was a set of empirical procedures for fine-tuning the forecasts of the Meteorological Organizations for use at the local level. The second was a simple procedure for downscaling GCM climate change forecasts for the 21st century. The third was a set of crop-yield forecasts (based on EPIC simulations and driven by seasonal climate forecasts, as well as potential climate change) indicating the potential impacts of, and the potential vulnerability to, expected seasonal weather and expected climate change. The fourth was a suite of adaptation options that could be adopted as strategies to ensure maximum crop productivity under each category of anticipated seasonal weather or future climate. The fifth was a plan for the use of the information by key players in the agricultural sector. The sixth was a crop of young, well-trained specialists in agricultural meteorology of West Africa with emphasis on Climate Change. The seventh was peer-reviewed publications.

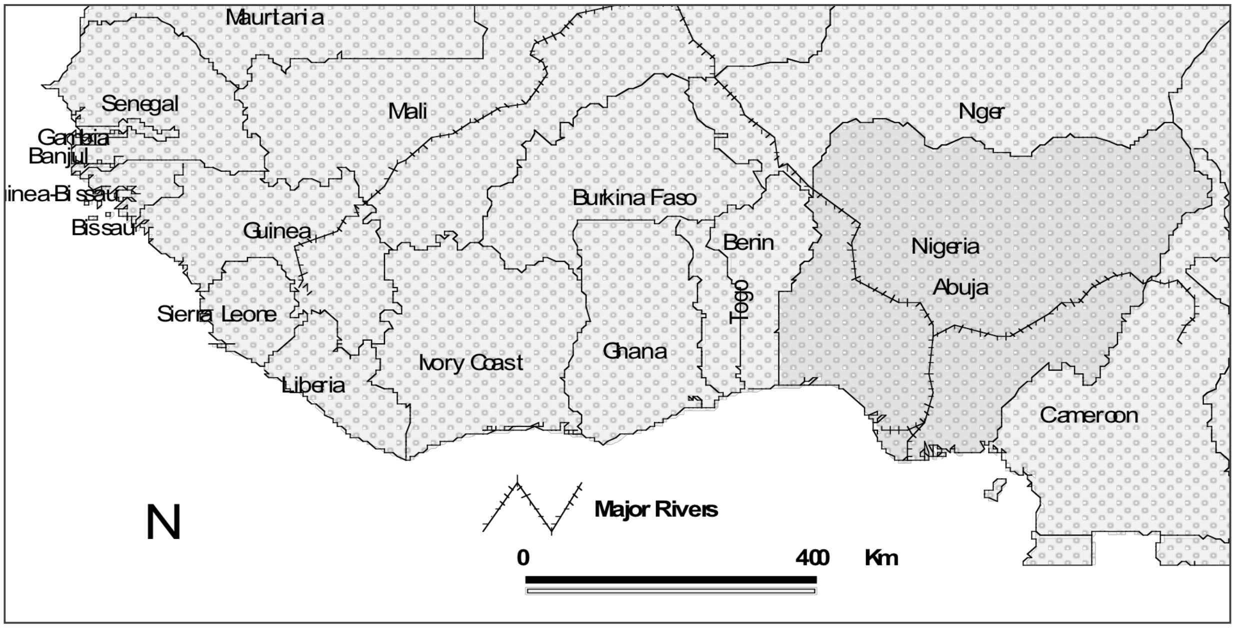

Fig. 1.1: Nigeria in West Africa

1.2 Nigeria as the Case Study

In the study, Nigeria was adopted as a sample area for Sub-Saharan West Africa (Fig. 1.1). This decision was justified in the study proposal. The chief justification was that it would be difficult to find data sets that cover the entire region uniformly at acceptable levels of accuracy, given the rigorous analytical techniques proposed. Another justification was that as a sample, Nigeria truly represents the climatic profile from the per-humid to the semi-arid ends of the project region. All the indicator vegetation types of the various climate types are present in the country (Fig. 1.2). Thus, northwards from the very humid, eastern, coastal locations, to the boundary with the desert, the vegetation profile includes Moist Evergreen Rain Forests, Dry Semi-Evergreen Rain Forests, Derived Savannah, Southern Guinea Savannah, Northern Guinea Savannah, Sudan Savannah, and Sahel Savannah (Keay, 1959a, 1959b; White, 1983).

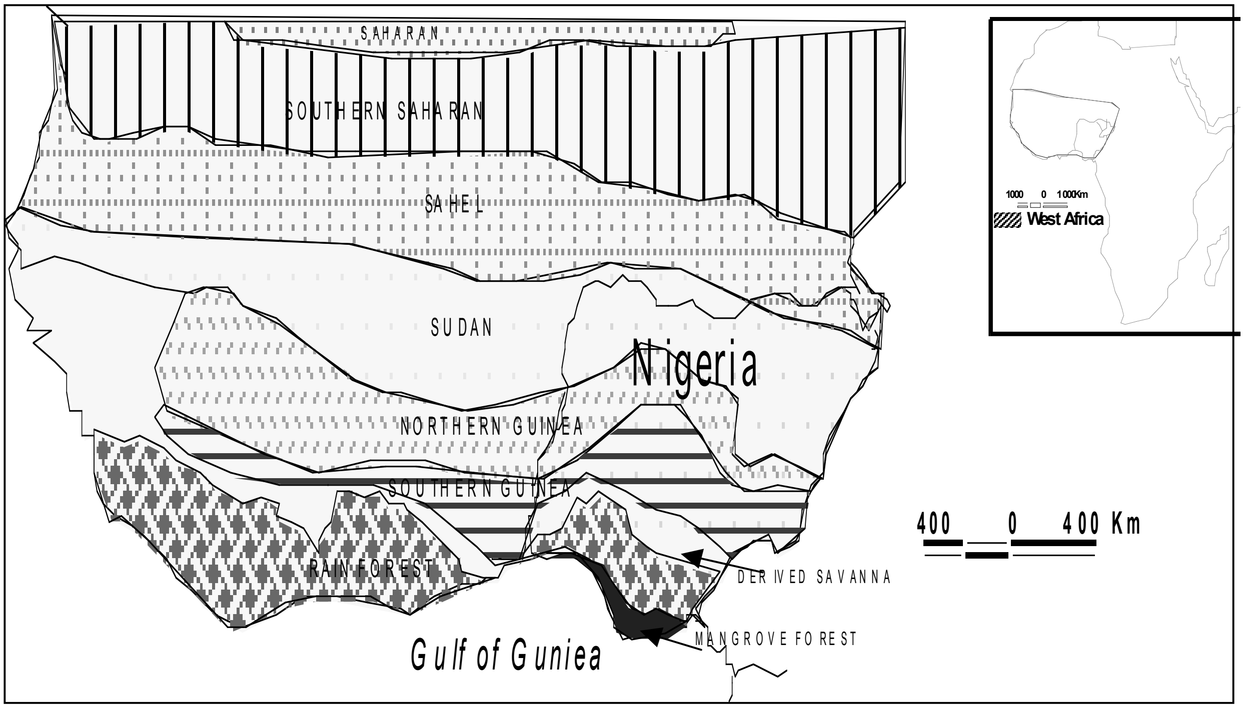

Fig. 1.2: Nigeria and the ecological zones of West Africa

The choice of Nigeria for the intensive field studies was considered appropriate for four other reasons. First, with a population of nearly 108 million in 1999 (ADB, 2001), the country is responsible for more than half the population of the entire project region. Second, there is a large community of well-trained research personnel in the relevant disciplines. Third, Nigeria maintains a network of data gathering bodies whose serialized and occasional publications include a large body of reliable historical and statistical data. The central organization for data collection is *The Federal Office of Statistics*. Fourth, the large community of socio-economic, agricultural and meteorological experts in the research institutions and the universities author a long list of research publications, which contain considerable relevant analogue information.

1.3 What is Potentially at Stake

What is potentially at stake providing the justification for this study is the social, cultural and economic development of West Africa, based on a sustainable use of the resources of the environment (WCED, 1987; Ishida, 1998; World Development Report, 2003). It is not a subject for contention, that every human being is entitled to, and should have access to the fruits of development which include: adequate food, clean water and energy, safe shelter, a healthy home environment, qualitative education, and satisfying employment. However, notwithstanding the spectacular gains in the means of development, such as the advances in science, technology and medicine during the just concluded century, the process has been skewed to the detriment of certain major regions of the world. The result is that indices depicting the quality of human life continue to paint very depressing images lending credence to the concepts of "Developed" and "Less Developed" Countries. Sub Saharan West Africa is probably the least developed of the world's major regions going by the statistics available at the end of the 20th Century (ADB, 2001). Moreover, the prospect for the type of accelerated development needed to bridge the gap between this region and the other regions is not bright.

One of the more frequently applied indices of the level of development is the status of food security and that of its antithesis – hunger. The standard definition of food security according to the World Bank (1986) is 'access by all peoples at all times to enough food for an active, healthy life'. Statistics of food security are usually computed for individual nation states. These may be aggregated for the world's major regions to demonstrate interregional disparities at global scales. National food security is a derivative of a balance sheet in which the population nutritional requirements are balanced by supply either from production or through international trade. Computed in per capita terms, national food security, usually assumes equitable sharing of available food stock between regions, between social classes, and between members of the same household. A food secured world cannot be adequately represented at either the regional or the national level. The security envisaged should be at all levels of human organization, including the individual, the household and the community.

At the individual household level, appropriate and sufficient food could be secured with income available for food purchases, from farmland harvests, or from a combination of these and other sources. Therefore basically, food security is a function of agricultural production, which may be constrained by physical, biological and economic factors. However, a total failure of agricultural production to provide the required food will not automatically result in food insecurity provided the household can earn enough from employment and other engagements to purchase from the market. In fact most of the households in the developed countries buy their own needs of food. But it is not every family divorced from land and agriculture that can buy its own food requirements. Thus, most of the worst fed households are those with inadequate or unsuitable land to farm and who, at the same time, are not gainfully employed. Such households may constitute a majority in countries with poorly developed economies.

When employed at the level of individual household members, food security implies an intake of food and absorption of nutrients sufficient to meet differential individual needs for activity, health, growth and development. These requirements vary with gender, age, size, health status and level of physical activity. Individuals within households with sufficient resources to provide adequate food may still lack appropriate and sufficient food because of occupational or lifestyle demands as well as inadequate nutritional knowledge. The availability of food to individuals within the household may also be constrained by the prevailing religious, social and cultural norms. It is now becoming clear that the context of food security is very broad indeed. It encompasses issues pertaining to the physical and biological environment and the current changes being brought to bear on these by increasing intensities of human activities.

According to Kates (1996), the easiest way to observe food security is to examine its absence, which is the persistence of hunger in its many guises. Chen and Kates (1996) direct attention to the most detailed long-term computer simulation of future food availability, which finds as many, or more hungry people, in the year 2060 as there are today. About a sixth of the world's population, that is about one billion people are hungry today.

Hunger is manifested in four main ways, each of which portrays a dimension of food and life insecurity (Kates, 1996). First, there is starvation, which often occurs in the course of famines, where there is an absolute shortage of food within a bounded area, caused by crop failure or destruction (Kates, 1993). Examples of such food shortages were experienced in the wake of the droughts of 1973-74 in the Sahel countries of Africa. More frequent localized droughts also could result in food shortages in districts isolated by inadequate transport connections. In the past, widespread food shortages automatically followed such calamities as locust invasion affecting continental or sub-continental land areas. Such invasions and their consequential famines are recognized in African historiography as landmarks for dating family and community events before the advent of the culture of documentation. The countryside remains unsafe for peasant farmers to operate in many countries including: Cote d’ Ivoire, Sudan, Democratic Republic of the Congo, Burundi, Rwanda Somalia and Uganda ravaged by internecine warfare (Messer, 1990). Advances in the science of pest control, the linkage of major ecological zones with rail lines and all season roads and the establishment of democratic institutions and governments have considerably reduced the scourges of such famines in more recent times. However, there are no mitigation strategies available to prevent sub continental droughts. Even when there is no food shortage, individuals and households could be subject to starvation as a result of inequitable distribution of wealth or national policies that raise the price paid for food items far above the means of such households. In every community throughout the world, there are people usually categorized as poor, that are subject to such social injustices and state imposed economic disabilities and live under a constant threat of starvation. However, the proportion of the population falling into this class varies from negligible in industrialized countries to more than half in some of the less developed countries (Kates, 1996).

A second manifestation of hunger is undernourishment, a situation in which needed food proteins and caloric energy are chronically or seasonally absent (Kates, 1996). Undernourishment is measured in terms of the number of people who live in households that cannot provide food sufficient for health, moderate physical activity, and children's growth. Because undernourishment affects a much larger proportion of human population than famine, it is considered to be the most serious manifestation of hunger. Undernourishment has devastating impacts on the growth and development of children in particular. The most easily observed evidence of undernourishment is the relatively low rate at which they gain weight. Comparing with age-related values for well-fed children in the industrialized countries, undernourished children fall behind in both weight and height. Undernourished children are to be found in every human community. However, the proportions of the children who are undernourished in each household in areas of endemic hunger are much higher. Apart from affecting their physical capabilities, and increasing their vulnerability to illness, undernourishment may permanently damage their capacities for cognition.

A third way in which hunger is manifested is as micronutrient deficiency (Kates, 1996). For the human body to function optimally, it requires a number of chemical compounds, the most important of which include calcium, iron, iodine and a long list of vitamins. In particular, dietary shortages of iron, iodine and vitamin A are regarded as another type of hunger. Iron deficiency is due largely to the relatively low content and poor availability of iron in most foods of plant origin, including grains, legumes, and vegetables. Mild to moderate iron deficiency lowers mental performance, impairs immunity, increases susceptibility to infection, lowers physical work capacity, and leads to increased morbidity and mortality. Iodine comes from seafood or seaweed or from plants grown on soils that were once the floor of ancient seas. Thus, the soils of high mountain areas and of many flood plains are deficient in this essential micronutrient. Disorders resulting from iodine deficiency during pregnancy could produce feeble-minded dwarfs known as cretins or manifest in less obvious neurological problems including deaf-mutism, lowered intelligence, and simple goitres. Vitamin A is readily obtained from animal food sources and from leafy green, red, and yellow vegetables and fruits. These foods may be only seasonally available, or are sometimes not usually fed to young children. A deficiency in vitamin A leads to eye diseases that affect up to 14 percent of small children, and to blindness, and death. In some countries it doubles mortality in young children (Chen, 1990).

Even when available food is sufficient, diseases such as diarrhoea, measles, and malaria are capable of lowering the absorption of nutrients within the body. This represents the fourth type of hunger manifestation. Intestinal parasites such as giant roundworms share from the solid food consumed before the body is able to absorb it. Others such as hook worm feed on food already in the blood stream and may draw nutrition directly from the blood itself. It is estimated that intestinal parasites affect more than one billion people world wide lowering the nutritional efficiency of available food and contributing indirectly to hunger and food insecurity (Kates, 1996). Diarrhoea limits solid food intake and reduces the absorption of nutrients. The disease can, in its acute manifestations cause endogenous nutrient loss. Measles is associated with poor food intake, mal-absorption, weight loss and growth faltering. The most common nutritional consequences of malaria are anaemia and stunted growth (Grant, 1991).

It is not unusual to limit the estimates of the number of people affected by hunger to the population subject to starvation. However, only about 15-35 million people, or less than 1 percent of the global population, are at risk of famine in any recent year. Indeed, there has been a consistent decline in the last fifty years in the number of people who are so affected.

The decline was quite dramatic as the focus of famine shifted from large, heavily, populated countries, such as China and India, to smaller and more sparsely populated nations such as Ethiopia and still smaller countries such as Somalia and Rwanda. As a result of this, the numbers of hungry people have decreased by 17 percent over the last two decades (Kates, 1996), and the proportion of hungry people has almost halved, despite the addition of about 1.4 billion people. But the decline has taken place primarily in China and Southeast Asia; over these two decades, hunger in absolute numbers has risen in Africa, Latin America, and South Asia.

On the other hand, 20 percent of the world population, and 34 percent of the children live in households at the risk of undernourishment. A recent United Nations' estimate found 786 million people, worldwide, in such households (UN, 1992). By such a standard, 184 million children under 5 years of age, over a third of the world's children, was estimated in 1990 to be underweight. The number has risen in the course of increased population growth, even though the proportion of children who are underweight has declined since 1975. Compared to the data that pertain to entire households in the worst affected countries, including adult members, the proportions of children who are undernourished are more than two times larger. These differences may reflect differences in vulnerability between age groups.

	Sub Saharan Africa		Near East and N.Africa		Middle Americas		S. America		South Asia		East Asia		China	
	10^6	%	10^6	%	10^6	%	10^6	%	10^6	%	10^6	%	10^6	%
1970	94	35	32	23	21	24	32	17	255	34	101	35	406	46
1975	112	37	26	17	21	20	32	15	289	34	101	32	395	40
1980	128	36	15	10	18	15	29	12	285	30	78	22	290	22
1990		37		5		14		13		24		17		16

Table 1.1:Under-nutrition the in world's major regions (Source, Kates, 1996)

Table 1.1 shows the patterns of undernourishment in the major regions of the developing world over the 20 years from 1970 to 1990. Overall there has been a decline in the number of people undernourished from 942 million to 886 million notwithstanding an increase of 1.3 billion in the world's total population. China accounts for most of this decrease where the population of undernourished people declined from 406 million to 290 million. Substantial decreases were also achieved in the Near East and North Africa, the Middle Americas, South America, and East Asia. The only two regions with increased number of people undernourished between 1970 and 1990 are South Asia and Sub Saharan Africa. However, a slightly different picture emerges from a close look at the changes in the percentage of the population that is undernourished as depicted in the first part of the table. The overall decline from 36 to 20 percent reflects declines in all the regions with the exception of Sub-Saharan Africa. In fact, in Sub-Saharan Africa, there was an increase from 35 to 37 percent. In 1970 the percentage of the population undernourished was respectively, 35, 34 and 35, in Sub-Saharan Africa, South Asia and East Asia. In 1990, while that of Sub-Saharan Africa had risen to 37, the percentage of the population undernourished had declined to 24 in South Asia, and 17 in East Asia. All these indicate a major challenge in the African Region to the World's Food Security Problem.

1.4 Food Security in West Africa

Recent studies indicate that while the world food supply does not appear to be seriously threatened by the projected global changes in climate, food insecurity in Africa will worsen and the population at the risk of hunger will increase both in terms of percentage and absolute numbers during the coming century (Downing, 1992; Fischer et al., 1996; Norse, 1992). However, available statistics at the conclusion of the 20th century give a much less gloomy picture for West Africa than for the rest of Sub-Saharan Africa. In general, there has been an upward trend in national food production in the sub-continent. Though not as spectacular, increase in per capita food production has also been recorded in most countries. Such increases were achieved in the context of a rapidly growing human population. There are exceptions to this general pattern. From 1988 to 1999, food production per capita actually declined in the Gambia, Guinea Bissau, Mauritania, Senegal and Sierra Leone (FAO, 2001; ADB, 2001/2002).

Food production is of course a direct correlate of agricultural productivity. There have been substantial increases in agricultural productivity in recent years (FAO, 2001). From an average of 100 around 1990, the index of agricultural productivity increased to 186.8 in Benin, to 167 in Ghana, to 156 in Nigeria, to 142.9 in Burkina Faso and to 142 in Guinea in 1999. In these same countries, increases in per capita agricultural output were equally robust.

However, because of a high rate of population increase, per capita increases in agricultural productivity have, like in the case of per capita food production, been less spectacular in many countries. In Cote d'Ivoire, Mali, Niger and Togo the index of agricultural productivity per capita increased only marginally, that is by less than 10 points, up to 1999. Percentage increases in population was greater than percentage increases in agricultural productivity in a number of countries including Guinea Bissau, Gambia, Mauritania, Senegal and Sierra Leone from 1988 to 1999. In such countries, per capita increases in food productivity were negative.

In 1998, the daily calorie supply per capita varied between 1,966 kilo calories in Niger Republic and 2,288 kilo calories in Nigeria; while the per capita daily supply of protein varied between 35 kilo calories in Liberia and 64 kilo calories in Nigeria, (ADB, 2001). According to the same source, there was a general improvement in nutritional status in most countries with regard to total calorie intake per capita, during the period from 1970 to 1998. The notable exceptions were Liberia, Sierra Leone and Senegal. However, compared to other parts of the world, the standard of nutrition in West Africa is still very poor. While the depth of hunger, measured by the average dietary energy deficit of undernourished people, expressed in kilocalories per person per day varies from 110 to 160 in the developed countries, it varies in West Africa between 210 for Nigeria, and 390 for Liberia (FAO, 2000). The higher the number, the deeper is the hunger. Based on the degree of food deprivation, the FAO (2000) classified countries into five groups. West African countries fall into the groups that suffer the most food deprivation. Nigeria, Benin, Togo, Ghana, Cote d'Ivoire and Mauritania fell into a group described as having moderate prevalence of hunger and moderate depth of undernourishment. Mali, Burkina Faso, Senegal, Gambia, and Guinea Bissau fell into another group in which there is a high prevalence of hunger coupled with a moderate depth of undernourishment, or a moderate prevalence of hunger and a high depth of undernourishment. Four other countries including Guinea, Liberia, Sierra Leone and Niger fall into a group that suffer high prevalence of hunger and high depth of undernourishment. No West African country was listed among those with either low prevalence of hunger or low depth of undernourishment. It is worthy of note that the low nutritional status of West African population is achieved while spending more than half, and in some cases, as much as three quarters of household income on food (FOS, 1996a).

Notwithstanding the recent increases in agricultural and food production, all West African countries, except Nigeria, received food aid from international donors in 1999 (ADB, 2001). The aid was received mainly in form of wheat products. From 1994 to 1999, no country in the region was self-sufficient in cereal production. The rate of self-sufficiency, in cereal production was as low as 35 percent in Mauritania, 40 percent in Liberia and 47 percent in The Gambia (ADB, 2001). The cases of war torn Liberia and Sierra Leone and the Sahelian states of Niger and Mali are understandable. However, among the major food aid recipients are such coastal, peaceful countries as Senegal, Ghana and Cape Verde Islands.

1.5 Socio Economic Development in West Africa

The potential significance of the project can also be seen in the context of the deteriorating state of human development in sub-Saharan West Africa, compared with other continental regions of the world. A confluence of rapid increases of population, explosive growth of urban centres and largely unsustainable agricultural practices leading to land degradation, is set to make sub-Saharan West Africa lag behind other regions in development during the 21st century. The sub-region appears to be lagging behind in all departments of development, not just in food production. This is evident from health and housing related statistics. Less than 2% of the Gross Domestic Production is allocated to the health sector (ADB, 2001/2002). It is, therefore, not surprising that health infrastructure is poorly developed. Less than half the population of Benin, Guinea Bissau, Mali, Liberia and Sierra Leone has access to orthodox medical services. As a result, most sicknesses go unreported to qualified practitioners. In many localities, sick people are forced to patronize quarks and the practitioners of alternate medicine often with disastrous consequences. Facilities for immunization of children against such communicable diseases as polio, tuberculosis, and measles are not always available. Annual campaigns are usually mounted by governmental and non-governmental organizations to reach the children outside the premises of the health institutions. Despite this, a large number of children are not immunized.

Statistics provided by The African Development Bank (2001/2002) show that the number of doctors per 100,000 persons is less than 20 in all the countries. There are only three doctors per 100,000 persons in Burkina Faso, 4 in Gambia and in Niger Republic, five in Mali, and six in Benin Republic and in Ghana. Availability of nurses is also dismally low. The number of nurses per 100,000 persons is less than 25 in Benin, Burkina Faso, Gambia, Liberia, Mali, Niger Republic and Senegal.

The same World Bank source indicates that the home environment in general lacks essential facilities for healthy living. Most of the buildings are not supplied with electricity. In almost all countries, the rate of electricity supply to buildings is less than 25 percent. In Nigeria, which is definitely among the most developed countries in West Africa, most people do not have access to potable water, less than 10 percent of the buildings have flush toilets, while less than 15 percent have refuse disposal bins (FOS, 1996a).

The main result of the poor feeding habits and inadequate health infrastructure is the generally low state of health of the West African population. The children are particularly vulnerable. According to the World Bank source, the percentage of children with low birth weights is as high as 15 on average across the sub continent. Clearly, more than one quarter of the children less than 5 years in age are underweight. Also, susceptibility to endemic diseases such as malaria, measles, dysentery, diarrhoea, typhoid, cerebra-spinal meningitis, cholera, and chicken pox could be very high. Measles is one of the main causes of death. Also of significance are cerebra-spinal meningitis, chicken pox and malaria. The significance of malaria does not lie in the number of deaths it causes, but in its contribution to the morbidity in the population at large. The death rate among malarial patients is less than one per thousand of cases serious enough to require medical attention. But the disease can incapacitate in chronic cases and is normally debilitating in the less serious cases. Chicken pox and measles affect children. They can, so to speak, wipe out a whole neighbourhood of children who happen to be born during an epidemic.

National crude birth rates of between 40 and 50 per thousand are among the highest worldwide. This is fundamentally responsible for the high population growth rate of around 30 per thousand, which tends to create a chronic population to resource imbalance. Health and educational infrastructures are easily overwhelmed by rapid growths in population. However, death rates also tend to be very high, averaging 12 to 15 per thousand. The death rates in areas of conflict such as Liberia, Sierra Leone and Guinea Bissau are particularly very high, nearing 20 per thousand. In general, about one third of the population is not expected to attain the age of 40 years. The percentage of the population not expected to attain the age of 60 years is, with respect to most countries, above 50. Children are particularly vulnerable as the mortality rates among children under 5 years old, for most countries in the region, lie between 100 and 200 per thousand. In Sierra Leone, as many as one quarter of life births die before attaining the age of 5 years.

Based on the Human Development Indices computed for 1998, 13 of the region's 16 countries are among the 30 least developed countries in the world. Four of these, Niger Republic, Burkina Faso, Guinea Bissau and Sierra Leone are among the six least developed countries (ADB, 2001/2002). According to the Federal Office of Statistics, Nigeria (FOS, 1999a), Sub-Saharan Africa "is noted for the prevalence of absolute poverty in all its characteristic features". Poverty in these countries is assessed to be massive, pervasive and chronic, engulfing a large proportion of the society. Resulting from the large-scale poverty, human conditions in Nigeria have greatly deteriorated particularly during the last two decades of the 20th Century. Real disposable incomes have dwindled, and malnutrition rates are on the increase. This view is shared by the World Bank in its conclusion that "the depth of poverty in Sub Saharan Africa is typically greater than elsewhere in the world" (World Bank, 1995).

Most West Africans live below a poverty line defined as "an income of less than US$2.00 per day" (ADB, 2001/2002). The percentage of national populations living below this line is over 90 in Nigeria, Mali, and Guinea Bissau, above 70 in Sierra Leone, Niger and Burkina Faso, and above 50 in Guinea and Senegal (ADB, 2001/2002). The FOS (1999a) estimated that 65.5 percent of Nigerians were poor in 1996. This proportion has varied over time. When the estimates were first compiled in 1980, the level of poverty stood at 27.2 percent. By 1985, it had gone up to 46.3 percent. There was a decline to 42.8 percent in 1992. After 1992, poverty incidence increased with greater intensity, engulfing two-thirds of the population in 1996.

1.6 Human Induced Environment Degradation

The human environment has in recent times come to feature prominently in the collective consciousness of the informed elite. It is being feared that the earth's physical environment may be losing its capacity to support human life and, therefore, may be imposing another set of constraints on the development process. There is a growing concern; which is centred on the undesirable impacts of a rapidly growing human population, the application of technology to the production and distribution of goods and services, and the increasing per capita consumption of the earth's resources; that the environment is being degraded. This concern has, and is continuing to engender virtually irreconcilable conflicts within and between communities from local to global levels of scale. The need to disturb, and even modify ecosystems in providing the irrefutable necessities of life are in direct conflict with the conscientious, responsible and engaged appeals of scientists for a minimization of disturbances in order to prevent irrevocable modifications to our ecological systems. As soon as the fears of the scientists are seen to have substance, the conflict becomes a controversy on who was responsible and who should make the necessary restitution. In the final analysis, it is a conflict of values; between those of a commonwealth, which used to prevail in traditional and ancient communities, and those of competition and profit motivation on which the successful modern man, or the modern nation subsists.

At the core of the of the more critical potential environmental challenges in the developing countries of Africa is a self reinforcing, downward spiralling nexus, compounding escalating population growth, stagnant agricultural productivity, with the degradation of vegetal, wildlife, and soil resources. To feed the rapidly increasing population in these areas, agricultural land has been expanding, and it is still expanding at the expense of standing biomass, biodiversity, clean unpolluted fresh water, and agreeable local and micro- climates. In the worst hit areas, when this could not meet the additional food requirements, cultivation has been intensified leading to accelerated soil erosion, and rapid, uncompensated loss of soil nutrients. As a result, in the Sahel zone of Northern Africa, desert conditions are now extend hundreds of kilometres from the natural, climate determined boundaries of the desert (personal observation). In some districts, when the population continues to increase rapidly, the natural carrying capacity of the land has been exceeded and the environment is hard put to the task of meeting the needs of the population. To improve productivity per unit area, more intensive methods, requiring more hands would be adopted. These would encourage greater family sizes and lead to further growths in the population, greater demand for food, further degradation of vegetal and soil resources, and further declines in per capita productivity; all in a vicious cycle. As life becomes unbearably difficult in the rural areas, emigration to urban centres ensues. The influx of poor, unskilled and largely unemployable people leads to an explosive and uncontrollable growths of these centres, setting the stage for the gestation of a new set of environmental problems which include; substandard housing, squatter settlements, solid waste menace, unsatisfactory sewage disposal, urban floods, urban water pollution, apart from the characteristic problems of large cities such as crime and general insecurity (Adejuwon, 1998).

1.7 Potential Impacts of Climate Change

As if this catalogue of woes will never come to an end, earlier predictions of scientists are being confirmed as serious threats to the global environment. First, there is the threat to the global commons in the forms of climate change, the depletion of stratospheric ozone, the degradation of marine environment and resources, and the issue of persistent organic pollutants. Second, there are other issues, which are world wide in dimension, though may not directly involve the global commons. It is among these that are listed loss of biodiversity, fresh water degradation, desertification, land degradation, deforestation, and unsustainable use of forest resources (Watson et al, 1998). In particular, Climate Change poses some threats, which are yet to be accurately measured, to Agriculture and Food Supply.

According to the United Nations Framework Convention on Climate Change, '*climate change*' refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. The IPCC has evolved its own usage of the term *climate change* as any change in climate over time whether due to natural variability or as a result of human activity. Attribution of climate change to natural forcing and human activities has been addressed by Working Group I in *Climate Change 2001* which is the most recent assessment of research on the topic of Climate Change. The Working Group I Report concludes that globally averaged surface air temperature is projected to warm 1.4 to 5.8ºC by the year 2100 relative to 1990, and globally averaged sea level is projected to rise 0.09 to 0.88 m by the year 2100 (IPCC, 2001b). The projections also indicate that the warming would vary by region, and would be accompanied by increases and decreases in precipitation. In addition, there would be changes in the variability of climate, and changes in the frequency and intensity of some extreme climate events. These general features of climate change will have impacts on agro ecological systems that are determined by higher concentrations of carbon dioxide in the atmosphere, higher minimum and maximum temperatures, changes in the amounts, intensities and variability of rainfall, and higher incidences of climate extreme such as droughts storms and floods. Indirectly, the impacts could result from accelerated soil erosion, higher incidences of pests and diseases and sea level rise. Climate change could also be beneficial to agriculture and food security when it comes with increased precipitation and atmospheric humidity in arid regions.

2 Current and Future Climate

2.1 Activities Conducted

Characterization of current climate is based on the data available in the archives of the Nigerian Meteorological Agency for the 28 synoptic weather stations. The latter are the stations where data on rainfall, temperature, solar radiation, humidity and cloud cover are collected on a regular basis. The stations are equipped, manned and operated by the Agency. For climate change projections, we used observed and model simulated data available at the IPCC'S Data Distribution Centre in 2002. This was justified on the need to use scenario and baseline data from the same source. The research project was designed with the hope that a more versatile version of MAGICC-SCENGEN would be available in the months following the publication of the Third Assessment Report. If what the authors promised had been realized, we would have had climate scenario data covering the country at a resolution of 0.5 x 0.5 degrees latitude and longitude; and for any time slice of choice. When it appeared to us that the promised version would no longer be available in good time for our purpose, we decided to use data available at the IPCC Data Distribution Centre(IPCC, 1999), downscaled by simple empirical methods. Extraction was manually conducted for the 0.5 x 0.5 degrees latitude and longitude cells in which each of the weather stations in the country is located. The data for such cells were directly allocated to the respective weather stations. We have adopted Hadley M2, Members 1, 2, 3,4 and Total, and scenarios assuming 1 % and 0.5 % annual increases in CO_2 equivalents. Our scenarios were constructed with the following time slices: 1961 – 1990; 2010 – 2039; 2040 – 2069; and 2069 – 2099. We also used SRES data derived from MAGICC-SCENGEN.

2.2 Description Of Scientific Methods

2.2.1 Analysis of climate variability

In our analysis of climate variability, we first attempted to capture the totality of inter annual variability of climate with respect to monthly maximum temperature, monthly minimum temperature and monthly rainfall for locations representative of the main ecological zones from the coast to the Sahel (Figure 2.1}. The spatial disposition of these zones is depicted in Figure 2.2. Variability indices were computed as the coefficients of variability. The latter is the standard deviation divided by the mean. The data used in the analysis of variability were for the period, 1961 to 2000. The resulting fractions were converted to percentages. In addition to the computation of the indices of variability, linear graphs based on actual records showing the actual changes in rainfall from one year to the other were also drawn. Regression analysis was used to demonstrate the long-term trends in rainfall.

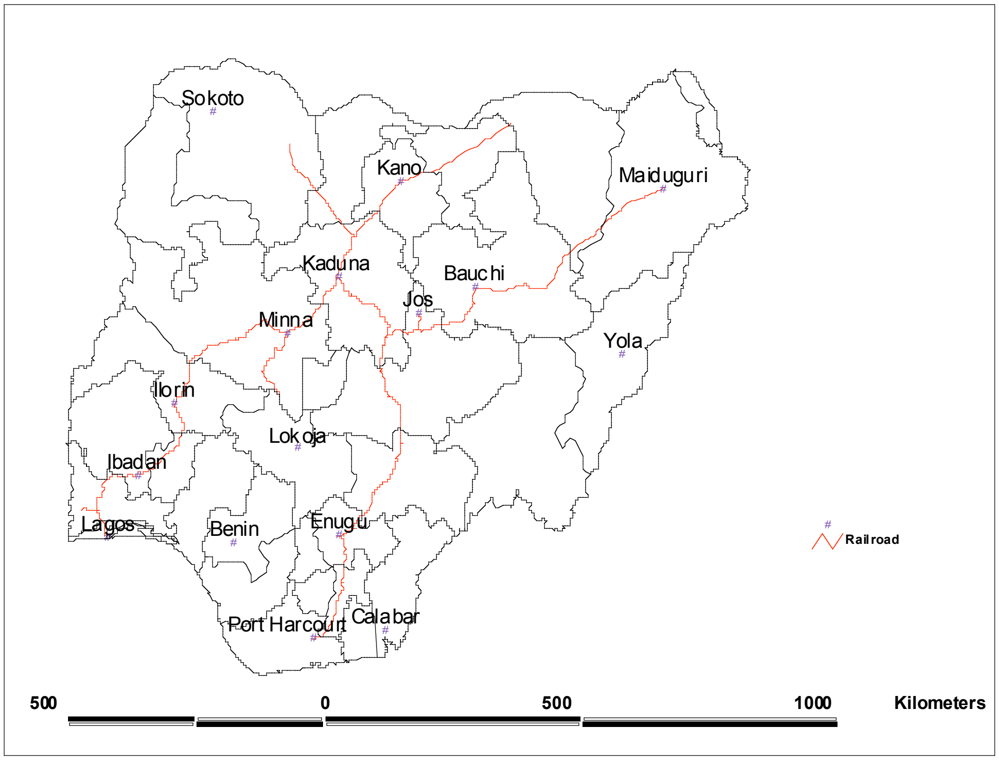

Fig. 2.1: Meteorological stations used in data analysis

The rainfall data were also subjected to spectral analysis in order to detect any tendency for periodicity. In our studies, of trends and periodicities, we did not only investigate the records for the individual climate stations separately, we also examined the records for five critical, seasonal components of rainfall separately. The components include, in addition to the total annual rainfall: the 'onset rainfall', the 'peak rainfall', the 'wet season rainfall', and the 'retreat rainfall'. We define the onset rainfall as the rainfall of the first month of the year in which mean cumulative rainfall is equal to or exceeds 8 percent. On the other hand, we define retreat (cessation) rainfall as the rainfall of the first month of the year during which mean cumulative rainfall exceeds 90 percent. These definitions are based on the findings of Ilesanmi (1972 a, b). In addition, we define peak rainfall as the rainfall of the month with the highest mean monthly rainfall, while wet season rainfall is defined as the amount of rain that falls from the onset to and including the retreat month in a particular year.

2.2.2 Developing a climate change scenario for Nigeria

The most common scenarios adopt outputs from general circulation models (GCMS) that are usually constructed by adjusting a baseline climate by the absolute or proportional change between the observed present and simulated future climates. The great majority of scenarios represent changes in mean climate at very coarse spatial resolutions. Regional detail is obtained from the coarse-scale outputs of GCMS by using three main approaches: simple interpolation, statistical downscaling, and high-resolution dynamical modelling. Probably because the other approaches are much more computationally demanding, the simple method, which merely reproduces the GCM pattern of change, is the most widely applied in scenario development. For most of the studies undertaken in this project we adopted outputs from General Circulation Models, downscaled using simple interpolation.

The potential climate of Nigeria during the 21st Century was extracted from the data available on the website of IPCC Data Distribution Centre in February 2002 (IPCC-DDC, 1999). It is an output of Hadley M2 General Circulation Model based, respectively, on a 0.5% and 1% per annum compound increase in CO_2 concentrations. An increase of 1.0 percent per annum will result in a concentration level of over 855 parts per million by the year 2100. The data represent a choice of GCM experiment and a choice of emission scenario. Each choice was made from a dozen or more that are equally plausible. However, the data based on 1.0% increase was selected

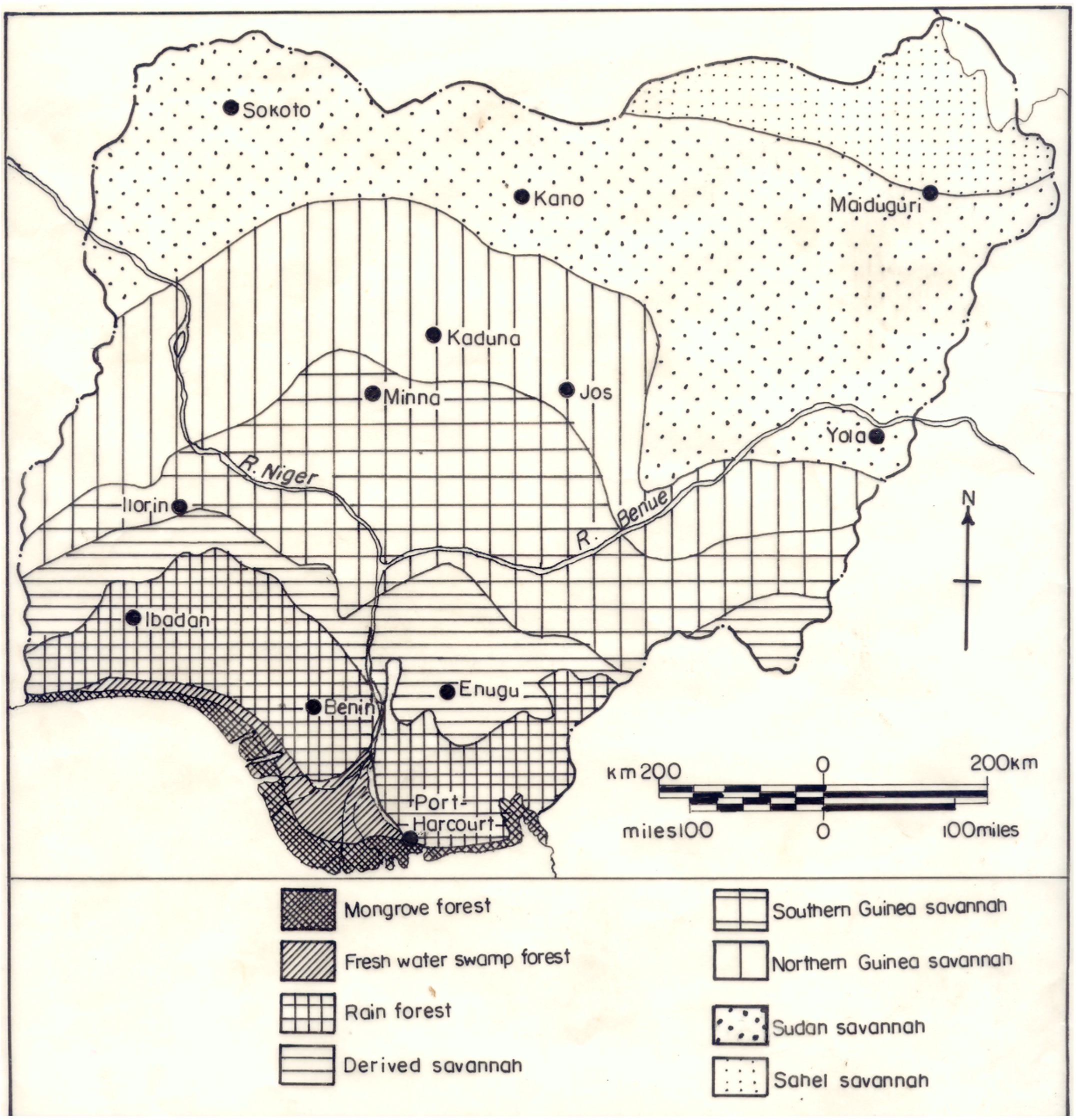

Fig. 2.2: Nigeria ecological/vegetation zones (After R.W.J. Keay (1959a)

as a "worst case". The strategy of the selection is to hope for the best while preparing for the worst. It is a "worst case" because it falls into a group including: IS92e, IS92f, SRES A1F1 and SRES A2, each of which is projected to result in concentrations of greenhouse gases of more than 800 parts per million by the year 2100. With such a concentration, radiative forcing will be at about the maximum possible (IPCC, 1995, 2000). The overall IPCC assignment is based on the agreement among scientists and concurrence by stakeholders, that it is a bad thing for the climate to change. Otherwise there would have been no mitigation agenda, no Kyoto Protocol.

Theoretically, the "best case" is one in which there is no change in climate as a result of human induced increases in the concentration of greenhouse gases in the atmosphere.. Our practical "best case" scenario is one based on an annual increase of 0.5% per annum, which falls into the group of low emission scenarios including: IS92d, SRES B1 and SRES A1T. An increase of 0.5 percent per annum will result in a concentration of 560 ppm by the year 2100. However, it is the "worst case" that is first presented while the "best case" is used to highlight the uncertainties.

The tools for climate change projection are the General Circulation Models. The Climate Change Scenario used in this analysis is an output of Hadley M2 General Circulation Model. The IPCC has defined a set of criteria that have been applied to identify GCM experiments whose results could be deposited at the IPCC DDC. These criteria led to an initial selection of experiments from five modelling centres one of which was Hadley Centre. Many others have since been added. MAGICC – SCENGEN Version 2.4, an IPCC recognized data storage model, has on its list 16 models from nine modelling centres to select from (Hulme et al, 2000).

The second version of the Unified Model of the UK Meteorological Office is a 19 layer high resolution atmospheric GCM coupled to a 20-layer ocean model. The surface horizontal resolution of the atmosphere-ocean model is 2.5 degrees latitude by 3.75 degrees longitude. This has produced a grid-box resolution of 96 x 73 grid cells with each cell 417 km x 278 km at the equator reducing to 295 x 278 km at 45 degrees N and S. The resolution of 2.5 degrees latitude by 3.75 degrees longitude is a relatively fine one compared with those on which the outputs of the other modelling organizations are based. This makes the Hadley products a better choice over the products of the other models available at IPCC'S Data Distribution Centre. Apart from this, it is a warm start simulation. This simply implies that the green house gases integrations simulated the changes in forcing of the climate system since early industrial period; that is, since 1860.

For the current exercise, we have adopted the averages of HadCM2GGa and the HadCM2GGd Ensemble Integrations. These include: the experiments with: 1% per annum increase in equivalent CO_2 concentration and the experiments with 0.5 % per annum increase in equivalent CO_2 concentration from 1990, through to 2100. Each set of climate change integrations consists of four members. According to IPCC (1995), each member represents a separate simulation using the HADCM2 model with identical forcing but with different initial conditions, a so called ensemble experiments, the historic forcing for each simulation being introduced at 150 year long interval in the control integration.

2.3 The Regional Climate Pattern

2.3.1 General circulation over West Africa

Three anticyclones control general circulation in West Africa. These are the Azores and the Libyan anticyclones in the Northern Hemisphere and the St. Helena anticyclone in the Southern Hemisphere. While the Azores anticyclone is permanent; the Libyan anticyclone may become relatively weak during the summer in the Northern Hemisphere. The St. Helena anticyclone normally oscillates northwards during Northern Hemisphere winter. Between the three sub-tropical high pressure cells are: the Sahara Desert, sub-Sahara West Africa and the Gulf of Guinea. This is the sphere of influence of two air masses, which migrate in concert with the high-pressure cells. There is a tropical continental (cT) Air, warm, dry, and dusty, which extends from the Sahara, reaching its maximum southern extent in January between 5° and 7° N. Alternating seasonally with this is the mass of Tropical Maritime (mT) Air, warm and humid, which has its source region over south Atlantic. It moves overland from the ocean, reaching its maximum northern extent in August at about 17° N on the coast and about 21° N inland. The cT Air is characterized by dry, north-easterly winds while the mT Air is characterized by moisture laden south-westerly winds. The seasonal climate of West Africa is largely determined by the migration and pulsation of the two air masses.

The boundary between the two air masses slopes southwards so that for a distance of 50km to 100km, a wedge of warm humid air underlies the mass of overriding cool and dry air. The presence of the moist southwest air stream makes itself felt in the scattered cumulus clouds, which develop as the sun climbs in the sky. The bases are generally around 800 to 1000m above the surface, but rarely do they grow to any great heights. The air above 1200-1600 m is still dry; hence the cumulus clouds rapidly dissipate as they rise to higher levels. South of the wedge, and extending for about 600 to 800 km, the moist air is not vertically restricted by an overburden of dry air. This zone is characterized by scattered and linear convection leading to the ascent of most air, the development of cumulus and cumulonimbus clouds, thunderstorms and heavy tropical rainfall; characteristics which earn it the name of Inter-tropical Convergence Zone (ITCZ). South of this zone and extending far into the South Atlantic the mT air continues to prevail.

Most of the precipitation in West Africa is a product of the ITCZ and its associated weather mechanisms (Adedokun, 1978). At the boundary of West Africa with the Sahara Desert, Lat 15º N, nearly all the rainfall occurs as a result of perturbations within the zone of convergence. Ninety percent of the precipitation results from ITCZ weather at Latitude 9 º N, However in certain parts of the sub-continent, notably in the coastal area; rainfall is not significantly correlated with the ITCZ. For example, in the coastal areas of Ghana, only 30 percent of the precipitation is related to these weather mechanisms (Adedokun, 1978).

Because the boundary between the two air masses moves in sympathy with the oscillation of the controlling anticyclones, the belt of ITCZ weather also moves north and south. Such movement is responsible for the characteristic intra-annual patterns of rainfall distribution. Specifically, they are responsible for the differentiation of the dry and the rainy seasons. The varying degrees of persistence of the ITCZ over east-west aligned zones are also the main cause of the regional disposition of the main climatic types in the sub-continent. Perennially humid climate (Koppen's Af) characterizes areas south of latitude 7.5º N. The atmosphere in this zone is always humid as it lies permanently south of the ITCZ. However, there may be up to three months without rain. A sub-humid climate (Koppen's Aw) characterizes the region between latitudes 7.5° and 9.5º N. As the area is alternately covered by dry northern and moist southern air, there are two distinct seasons, wet and dry, corresponding to the period of occurrence of each of the two dominant air masses. The climate is described as sub-humid because the dry season is much less in length than the wet season. Between the area characterized by the sub-humid climate and the Sahara Desert, the climate is recognized as semi arid with dominant, arid tropical conditions (Koppen's BS). The diagnostic feature of the humid climate is the Tropical Rain Forest (White, 1983). Within it, one could recognize a moist evergreen forest where mean annual rainfall is more than 2,000 mm and a dry evergreen rain forest where the mean annual rainfall is between 1,250 mm and 2,000 mm. The diagnostic feature of the sub-humid climate is the Guinea savannah vegetation characterized by mesophytic tall grasses and deciduous trees. There is sufficient contrast between the northern and the southern parts of the Guinea savannah to justify the recognition of a Northern Guinea Savannah zone and a Southern Guinea Savannah zone. The vegetation of the semi-arid zone is characteristically xeromorphic in its tree layer. However, two zonal types are recognized including the Sudan in the wetter, southern areas and the Sahel in the areas abutting on the Desert. The main difference in the vegetation is in the grass layer, which tends to be mesophytic in the Sudan and xeromorphic in the Sahel. Thus, from the coastal southern areas, to the boundary with the Sahara Desert, five zonal climate and ecological types can be recognized, including: Rain Forest, Southern Guinea Savannah, Northern Guinea Savannah, Sudan Savannah and Sahel Savannah. Sometimes within the rain forest belt, drier and wetter sub-types are recognised. Also there is substantial support for the recognition of a Derived Savannah vegetation zone, which was formerly under rain forest, but whose plant cover has since been converted to savannah as a result of intensive agricultural practice (Keay, 1959a).

2.3.2 Contemporary climate

2.3.2.1 Maximum temperatures

Mean monthly maximum temperature varies between 28 º C and 40 º C. In coastal locations mean monthly maximum temperatures are lowest in August at about 28º C and highest in March at around 34 º C. In the Middle Belt (the Guinea zones), mean monthly maximum temperatures are also lowest in August and highest in March or April. However, the mean maximum temperatures are higher than what they are along the coast, varying between 30 º C in August and 38 º C in March or April. In the far North, that is, in the Sudan and Sahel zones, maximum temperatures are still much higher than in the Middle Belt. The highest maximum temperatures are recorded in May and could be as high as 40 º C. On the other hand the lowest maximum temperatures of around 28 º C are experienced in December or January. This perennially high temperature should be expected as normal for a tropical environment.

2.3.2.2 Minimum temperatures

On the average mean minimum temperatures are about 8 º C lower than the mean maximum temperatures in coastal locations varying between 21 º C in January and 24 º C in April. While the highest minimum temperatures are observed in May, that is the same month in which the highest maximum temperatures are observed, the month with the lowest minimum temperatures has shifted from August to January. Differences between minimum and maximum temperatures being of the order of 10 º C are higher in the Middle Belt than in the coastal and forest based locations. For Lokoja (Middle Belt) at the confluence of Rivers Niger and Benue, the lowest monthly minimum temperatures are recorded in January, while the highest are observed in April. The mean monthly minimum temperature for January is 17 º C while the mean minimum for April is 24 º C. In the Sudan and Sahel zones, the differences between minimum and maximum temperatures average about 15 º C. For Kano in the Sudan zone, the lowest mean minimum monthly temperature, which is for January, is 12 º C compared to the lowest mean maximum temperature of 28 º C, which is also for January. For the same location, the highest mean minimum and the highest mean maximum both of which are for May, are respectively, 26 º C and 40 º C. All these go to confirm the usual conceptualization of the night as the winter of the tropics.

2.3.2.3 Precipitation

In locations along the coast and within the forest zone, mean annual rainfall could be as high as 3000 mm, but usually not less than 1250 mm. Although rain could be expected during each month, there is usually a relatively dry period of two to four months with significantly low rainfall. During this period, the air which comes in from the ocean to the south keeps the coastal locations very humid. Garnier (1961) submits that a rainfall of 75 mm per month is needed to balance potential evapotranspiration and therefore supply the water needed by plants. According to Garnier in his prescriptions for delimiting the Humid Tropics, any month with rainfall lower than 75 mm could be regarded as dry while months with rainfall more than 75 mm are regarded as humid. Using this rule, the dry season is about two months long in the southeast and four months long in the southwest. In the Guinea Savannah zones constituting the Middle Belt, the year is sharply divided into a rainy season and a dry season. The dry season is about seven months long in the northernmost areas while it is only five months long in the south. For about two out of the five to seven months of the dry season, the area is overlaid by a dry air mass, which comes in from the Sahara Desert. Dryness is expressed in terms of both low rainfall and low humidity of the air. There is little difference between the northern, drier boundary and the southern wet boundary in terms of total annual rainfall. The boundary between the Middle Belt and the Sudan zone corresponds to a sharp drop in mean annual rainfall from 1000 mm to about 750 mm. In the Sahel, the rainy season is barely three months long, while in the Sudan, the rainy season extends over a period of four months.

2.4 Climate variability

2.4.1 Coefficients of variability

In this analysis of climate variability, we shall first attempt to capture the totality of inter-annual variability of climate with respect to monthly maximum temperature, monthly minimum temperature and monthly rainfall for locations representative of the main climate zones from the coast to the Sahel. Variability indices have been computed as the coefficient of variability. The latter is the standard deviation divided by the mean. The data used in the analysis are for the period, 1961 to 2000. The resulting fractions have been converted to percentages.

Climate Zones	Climate Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sahel	Maiduguri	5	6	3	2	3	10	4	4	4	5	3	5
Sudan	Kano	9	7	4	3	5	2	4	5	3	2	3	9
N.Guinea	Bauchi	10	6	3	2	5	3	10	3	3	2	4	5
N.Guinea	Jos	6	5	1	2	5	3	6	3	2	2	1	2
S.Guinea	Minna	3	3	3	3	5	3	2	3	2	1	3	2
S.Guinea	Ilorin	6	2	2	3	4	2	2	3	2	2	3	2
S.Guinea	Lokoja	4	2	3	4	3	2	1	1	1	2	2	2
Forest	Enugu	3	3	4	4	2	2	2	2	1	2	2	3
Forest	Ibadan	2	3	3	3	2	2	4	3	3	2	3	2
Forest	Benin	1	2	5	3	2	3	3	2	7	2	2	2
Forest	Lagos	3	2	2	2	1	2	2	2	2	1	1	2
Forest	Calabar	2	2	4	3	1	2	4	3	2	1	1	2
Forest	Port Harc	3	2	4	1	1	3	11	3	1	1	2	2

Table 2.1: Coefficient of variability of monthly maximum temperature (1961 – 2000)

2.4.1.1 Maximum temperatures

Inter annual variability of maximum temperature as depicted in Table 2.1 is spectacularly low, averaging less than 5 percent across climate zones and from January to December. The implication of this is that each year is very much like the other with respect to daytime temperatures. The monotony of high daytime temperatures from month to month and from year to year is a well-known trademark of typical tropical climates. This not withstanding, one could discern temporal and spatial patterns in the variability of mean monthly variability of maximum temperatures. In coastal locations, variability is uniformly low from one month to the other compared with the Middle Belt and the Sudan and Sahel climate zones. In the latter zones, coefficients of variability appear to be relatively higher in the months of December, January and February compared with the other months of the year.

2.4.1.2 Minimum temperatures

The coefficients of variability of minimum temperature depicted in Table 2.2 demonstrate an unmistakable contrast between December-January-February on the one hand and the rest of the year on the other. In almost all the stations, the highest coefficients are for January followed by December. This pattern is much more pronounced in the drier northern areas than in the south. While the average for December is more than 10 percent the averages for April, May, June, July, August, September and October are respectively less than 5 percent. The generally low variability of temperature depicted in tables 2.1 and 2.2 provides the explanation for the usual relegation of these parameters in the literature on climate variability in tropical areas and the emphasis placed on rainfall.

Climate Zones	Climate Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sahel	Maiduguri	13	9	9	4	4	4	3	4	4	6	9	12
Sudan	Kano	13	7	10	4	3	3	4	3	3	5	5	8
N.Guinea	Bauchi	12	8	9	3	12	2	3	12	2	3	6	8
N.Guinea	Jos	13	18	7	5	3	3	2	3	4	6	8	12
S.Guinea	Minna	4	3	7	2	4	2	1	2	2	2	2	5
S.Guinea	Ilorin	10	6	2	3	4	3	2	2	2	2	5	11
S.Guinea	Lokoja	18	17	12	6	4	4	2	1	1	1	5	16
Forest	Enugu	8	6	2	3	2	2	2	2	2	3	5	8
Forest	Ibadan	8	3	2	2	2	2	2	3	1	2	3	3
Forest	Benin	10	4	3	3	3	8	6	2	1	2	4	3
Forest	Lagos	6	4	4	4	4	4	4	4	2	3	5	4
Forest	Calabar	5	3	4	3	4	2	3	4	3	3	2	4
Forest	Port Harc	10	3	3	2	2	2	2	1	1	1	2	4

Table 2.2: Coefficients of variability of monthly minimum temperature (1961 – 2000)

Climate Zones	Climate Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sahel	Maiduguri	0	0	493	183	74	59	41	39	59	174	0	500	22
Sudan	Sokoto	0	500	292	148	76	65	37	32	44	145	600	0	21
Sudan	Kano	0	415	477	176	72	51	39	46	63	160	0	0	26
N.Guinea	Bauchi	0	500	240	102	50	45	29	23	51	72	50	0	18
N.Guinea	Yola	0	0	228	78	76	41	31	28	40	76	271	0	16
N.Guinea	Kaduna	0	321	211	82	43	31	29	30	33	83	462	0	14
N.Guinea	Jos	379	326	128	68	34	18	23	24	18	80	291	0	9
S.Guinea	Minna	582	372	138	102	49	33	27	29	34	61	244	0	26
S.Guinea	Ilorin	308	162	75	52	40	31	50	66	35	67	187	384	24
S.Guinea	Lokoja	296	204	89	62	37	37	48	57	31	43	225	489	16
Forest	Enugu	188	143	75	46	32	35	38	41	32	45	137	226	18
Forest	Ibadan	223	136	71	41	44	38	39	105	49	32	109	165	25
Forest	Benin	170	175	51	38	28	29	36	53	28	42	82	96	11
Forest	Lagos	143	100	63	53	41	38	73	115	49	63	75	136	20
Forest	Calabar	115	116	52	37	27	33	35	32	35	26	60	152	12
Forest	Port Harc	104	76	62	49	31	31	35	39	23	36	68	102	14

Table 2.3: Monthly coefficients of variability of precipitation (1961 – 2000)

2.4.1.3 Precipitation

Table 2.3 depicts the monthly coefficients of variation of rainfall. Compared with monthly rainfall, the variability of the annual total is low. While the coefficients for annual totals vary from 9 percent to 26 percent, those of monthly totals vary from zero to 600 percent. There is no significant spatial pattern in the variability of annual total rainfall. Among the seven weather stations with variability of more than 20 percent, two are located in the forest zone, two in the Guinean zones and three in the Sudan and Sahel zones. However, one can still discern a tendency for variability of annual totals to increase as the totals decrease. The station with the least variable annual total, Jos, has the distinction of being the only high altitude location among the list selected for this analysis.

December and January are perennially dry in Northern Guinea, Sudan and Sahel zones. Therefore the coefficients of variability for these months and for these stations are zero. In general, very high coefficients are recorded for dry season months throughout the country. The dry season months with coefficients greater than 100 percent in Sudan and Sahel zones are February, March, April, October and November. In the Northern Guinea zone, the affected months are February, March, April and November. In the areas extending from the coast through the forest zone to the Southern Guinea, coefficients greater than 100 percent are recorded for December, January and February. In summary, the percentage periodic change is greatest in months with the smallest average precipitation and decreases as rainfall increases.

2.4.2 Rainfall trend analysis (1922-1985)

For a greater part of the 20th Century, there was a general trend towards aridity in Nigeria and the rest of West Africa (Adejuwon et al. 1990, Nicholson, 2001, Hulme, et al. 2001). The analysis of rainfall trend in Nigeria from 1922 to 1985 by Adejuwon et al (1990) is summarized in Table 2.4. The dominance of negative signs of the correlation coefficients (55 out of 75) is indicative of the general trend towards aridity. Also in favour of this conclusion is the fact that all the significant correlations with the exception of peak rainfall for Benin have negative signs. Annual total rainfall demonstrated more significant trends than the seasonal components. The correlation coefficients of the onset rainfall series were of the least magnitude compared with the other seasonal rainfall components. The trend towards aridity was more pronounced in the Sudan and Guinean ecological zones than in the Forest zones and Sahel zones. None of the coefficients of correlation for Maiduguri in the Sahel was significant. The twenty out of twenty significant correlation coefficients were for stations in the Sudan aand Guinea zones. However, increased rainfall during the last decade of the century seemed to have put the trend towards aridity on hold.

Climate zones	Climate stations	Annual	Wet Season	Onset	Peak	Retreat
Sahel	Maiduguri	-0.21	-0.18	0.07	-0.21	-0.06
Sudan	Kano	-0.41**	-0.41**	-0.14	-0.42**	-0.30*
Sudan	Sokoto	-0.34**	-0.31	-0.11	-0.19	-0.30*
N. Guinea	Kaduna	-0.26*	-0.25*	-0.05	-0.17	-0.15
N.Guinea	Jos	-0.33**	-0.34**	0.01	-0.10	-0.14
N.Guinea	Yola	-0.22	-0.20	-0.03	-0.12	-0.38
N. Guinea	Minna	-0.26*	-0.25*	-0.03	-0.32**	-0.32**
S. Guinea	Ilorin	0.01	0.09	-0.17	-0.12	-0.10
S. Guinea	Lokoja	-0.09	-0.04	-0.05	0.00	-0.25*
Forest	Ibadan	0,06	0.11	-0.06	0.06	-0.05
Forest	Lagos	-0.39**	-0.37**	-0.30*	-0.12	-0.15
Forest	Benin	0.26	0.24	0.08	0.38**	-0.11
Forest	Warri	0.05	0.06	0.05	-1.10	-0.06
Forest	Enugu	-0.09	-0.04	0.02	0.01	0.28*
Forest	Calabar	-0.23	-0.17	-0.25	-0.04	-0.12

'r' is significant at 0.05 level (*) and at 0.01 (**). (After Adejuwon, et al, 1990)

Table 2.4: Correlation coefficients (r) – rainfall and time (1922-85).

2.4.2.1 Trends and annual fluctuations (1961-2000)

As depicted in Figures 2.3 – 2.5, the general trend towards aridity observed with respect to the 1922 – 1985 periods is not evident in the analysis of the 1961-2000 data. In fact, in the arid zone represented by Maiduguri, the general trend was towards a wetter climate. The trend investigated with simple regression analysis is a straight line, which gives the impression of continuous and regular decline/increase in rainfall. However, in reality, the actual annual values fluctuate around the straight line to which the series have been fitted. The examples in Figures 2.3 – 2.5 demonstrate the relationship between the regression line and the changes from one year to the other. The regression analysis only gives a general direction of change. The trend appears not to be significant in the cases of the more humid areas, while in the arid zone it is toward a wetter climate. This did not preclude the occurrence of droughts in 1973-74 and 1982-83. The yearly fluctuations may at first appear irregular or random. Further investigation of the series with the technique of five-year moving averages indicated a tendency for periods of above normal rainfall to alternate with periods of below average rainfall whether in terms of the total rainfall or in terms of any of the components of seasonal rainfall.

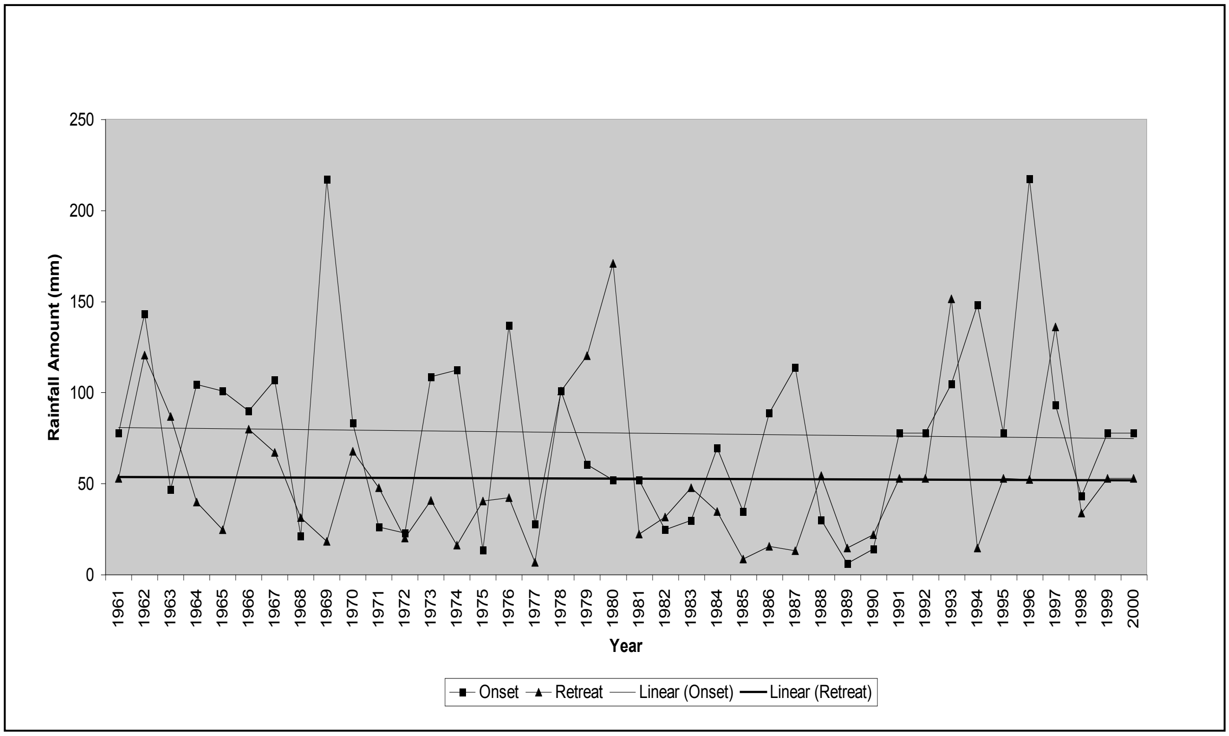

Fig. 2.3: Rainfall onset and retreat trends and fluctuations in Lagos, humid zone {1961-2000)

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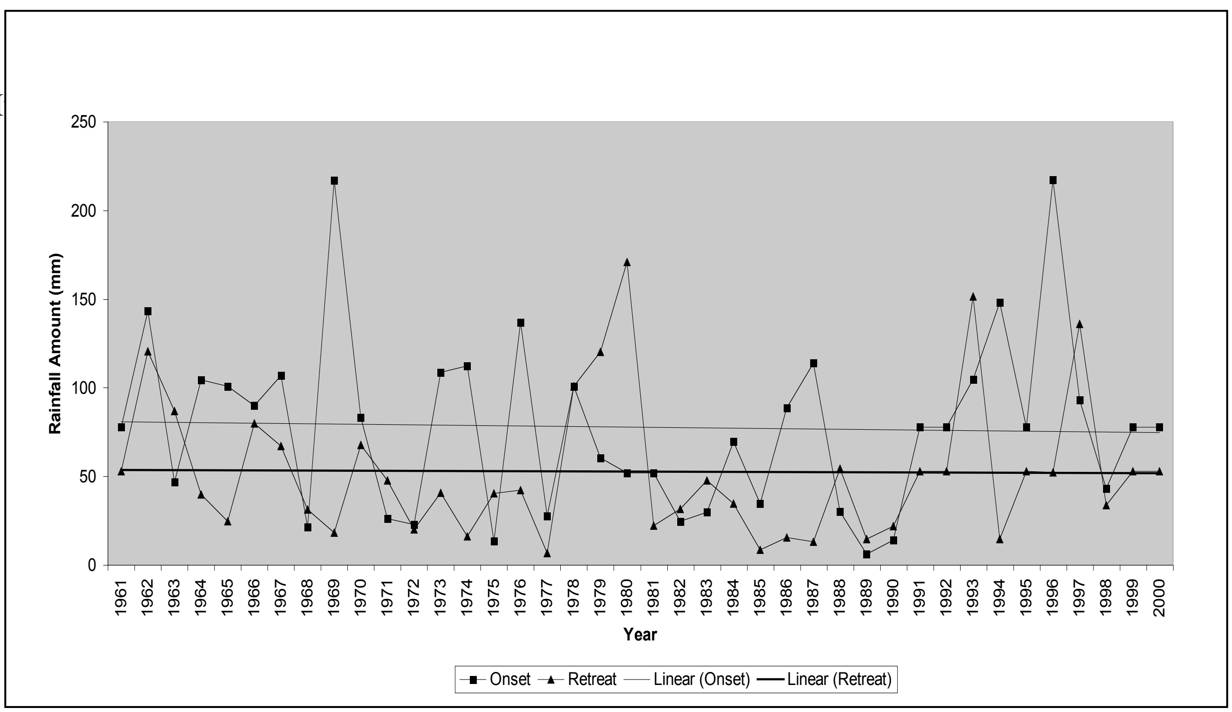


Fig 2.4: Rainfall onset and retreat trends in Lokoja sub humid zone (1961 – 2000)

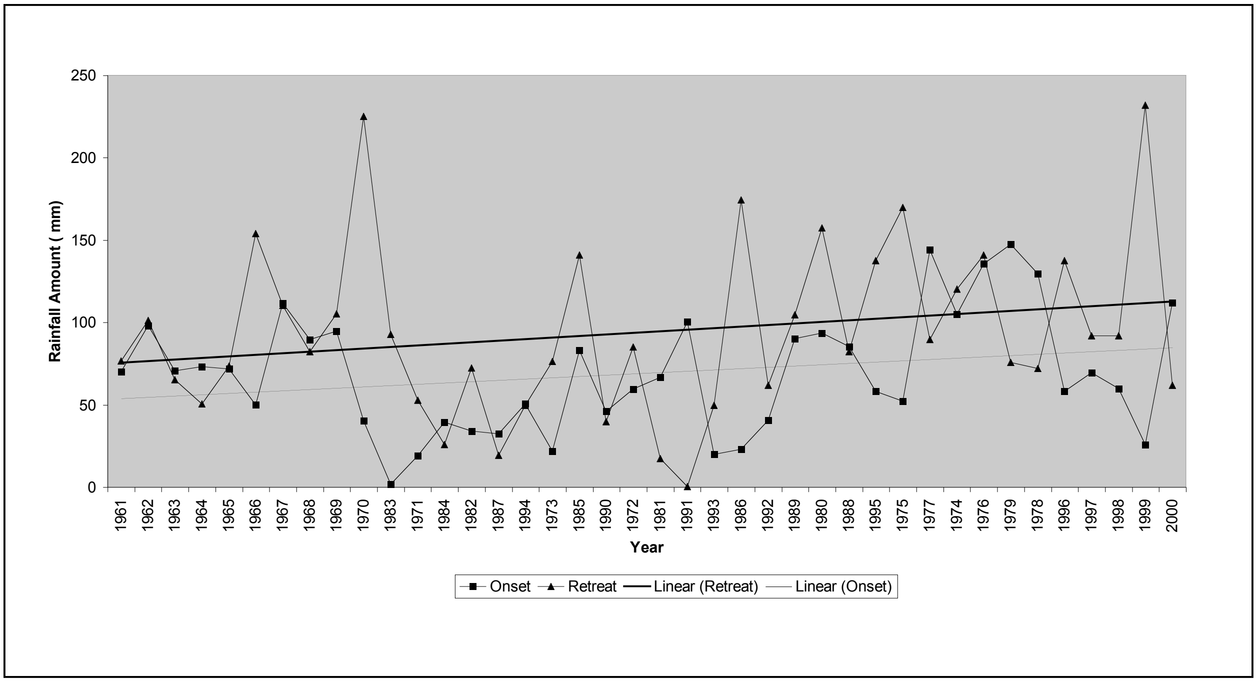


Fig. 2.5: Rainfall onset and retreat trends and fluctuations in Maiduguri arid zone (1961-2000)

Stations	Annual			Wet Season			Onset			Peak			Retreat		
Sokoto	62.5	9.2	10.6	12.8	10.6	32.2	21.3	32.3	15.9	2.0	2.1	12.8	15.8	2.4	8.0
Kano	6.0	2.5	2.4	3.1	2.6	2.4	2.4	2.3	5.8	2.8	2.7	3.6	4.0	3.8	4.3
Maiduguri	10.6	32.3	9.2	32.2	10.6	9.2	9.2	10.6	21.3	62.5	32.3	4.3	5.3	5.0	21.3
Kaduna	4.0	4.2	5.3	5.3	4.3	4.0	2.9	3.0	21.3	21.3	2.8	8.0	5.8	6.4	5.3
Jos	3.0	2.9	3.2	3.0	2.9	4.0	6.4	7.1	4.3	4.3	5.8	4.6	5.8	2.1	2.2
Minna	2.0	2.6	2.1	2.0	2.1	2.2	8.0	7.1	4.0	2.1	21.3	2.2	5.8	5.3	8.0
Yola	2.9	3.0	2.8	2.9	2.8	3.0	2.1	2.1	2.2	62.5	2.0	32.3	2.4	2.5	2.3
Ilorin	3.2	3.0	3.4	3.2	3.0	2.7	2.6	2.0	2.1	3.8	8.0	2.0	3.4	3.2	2.4
Lokoja	32.3	21.3	5.0	32.3	3.4	21.3	62.5	32.3	21.3	5.8	5.3	6.4	2.5	2.4	3.2
Ibadan	5.8	5.3	6.4	5.8	6.4	5.3	2.0	2.1	2.9	2.1	2.0	6.4	5.8	6.4	5.3
Ondo	5.8	5.3	6.4	5.8	5.3	6.4	5.0	4.6	5.3	2.1	5.8	5.3	5.8	6.4	5.3
Lagos	2.0	2.1	5.8	2.0	2.1	5.8	2.4	2.5	9.2	2.0	2.1	21.3	2.6	2.3	2.5
Benin	2.0	2.8	2.7	2.0	2.8	2.7	12.8	10.6	15.9	3.6	2.3	3.0	2.7	2.6	21.3
Warri	3.0	2.9	3.2	3.2	3.4	2.9	3.8	2.6	3.6	3.8	3.6	4.0	4.0	5.8	4.3
Enugu	2.7	8.0	2.6	2.6	2.7	8.0	8.0	3.4	3.6	8.0	4.6	9.2	2.5	2.0	2.4
Calabar	12.8	10.6	15.9	15.9	10.6	15.9	21.3	3.0	2.9	2.0	3.4	3.2	4.6	4.3	2.4

All peaks between 2- and 8- years are significant at 95 percent confidence level.

Table 2.5: The three highest spectral peaks for each station and each rainfall series

2.4.2.2 Periodicities

An attempt was made to detect periodicities or cycles in the fluctuations of rainfall with the technique of spectral analysis based on the data from 1922 to 1985 (Adejuwon, et al 1990). The results are presented in Table 2.5. The table shows for each rainfall series the three highest spectral peaks in order of magnitude. From the table, it can be observed that spectral peaks in the range of 2- to 8- year cycles are dominant. These make up about 80 percent of the three highest spectral peaks for each of the five series and each of the 16 stations considered. Slightly more than one third of the peaks lie between 2- and 2.9- year cycles. About 12 percent of the cycles are in the range between 3 and 3.9 years. Also, spectral peaks of between 5- and 5.9 year cycles represent about 12 percent. Spectral peaks representing cycles of more than 10 years are relatively few. However, they are distinctive for three main reasons. First, almost all of such peaks refer to one of four stations – Sokoto, Maiduguri, Lokoja, and Calabar. Second, a great majority of the peaks are in respect of annual, wet season and onset rainfall series. Third, almost all the peaks correspond to cycles that are approximates or multiples of 5.9-, 8-, and 11 year cycles. These are 10.6, 12.8, 15.9, 21.3, 32.3 and 62.5.

The dominant shorter cycles suggest an explanation based on the interaction between the sea surface and the air lying above it. Such interaction is manifested in the Quasi-Biennial Oscillation (QBO) and El Nino Southern Oscillation (ENSO). These are mechanisms capable of affecting rainfall, with irregular cyclic behaviour spanning over a wide range of periodicities between 2 and 8 years. While the QBO oscillates every 2 to 2.5 years (Partharrasathy and Dhar, 1976), ENSO oscillates on a cyclical period of between 2.8 and 8 years (WMO, 1988). The medium to longer periodicities observed, are not statistically significant probably because of the inadequacy of the data used. It is usually recognized that the data should include at least six complete cycles before the particular periodicity could be considered well established. However, similar periodicities observed in other parts of the world, where the peaks were around 10 and

21 years have been linked to single and double sunspot cycles, respectively (Vines and Tomlinson, 1985); Vines, 1986).

2.5 Climate change 1961 - 2099

For the projections in the following sections of the chapter, four time slices were used. These include: 1961-90; 2010-2039; 2040-2069 and 2070-2099. The 1961-90 data are observed data and are the baseline from which projections were made to the other time slices. Downloaded from the IPCC Data Distribution Centre, baseline data were presented on a resolution of 0.5 degrees latitude x 0.5 degrees longitude; each cell thus has an area of about 50 km x 50 km. Within Nigeria, with an area of about 923,000 square km, there are as many as 360 such cells. Thus the resolution is finer than the pattern of distribution of the 28 Nigeria standard meteorological stations to which the data are ascribed for further analysis. Each of the meteorological stations is ascribed the data of the 0.5^{0} latitude x 0.5^{0} longitude cell in which it is located. The data in respect of the other time slices are on a resolution of 2.5 x 3.75 degrees latitude and longitude and are in the form of changes relative to the observed 1961-90 data. To project the climate of the meteorological stations to the 21st century time slices, the changes, relative to the observed data for the larger cells in which the stations are located were used. The technique used is simple interpolation. Four climate parameters were used in the projections including: precipitation, minimum temperature, maximum temperature, and vapour pressure. Analysis and discussion of climate change were based on well-known ecological zones aligned east to west and following one another from the coast of the Gulf of Guinea to the Sahara Desert in the north.

2.5.1 Mean monthly precipitation projections

2.5.1.1 The forest zone

Precipitation projections are depicted in Figure 8. Rainfall in the Forest Zone of Nigeria follows the typical Tropical Rain Forest Climate pattern. There is rainfall during each month. However, there is a relatively dry part of the year from December to February when monthly rainfall is low. Usually in the Forest Zone of Nigeria, there is a 'Little Dry Season', which occurs from the middle of July to the end of August. There is no indication from the projections that this pattern will change during the coming century. The projections however indicate an increase in rainfall during the rainy season months and a decrease during the dry season months. Thus there is the probability of the dry season becoming drier while the rainy season becomes wetter. The example of Port Harcourt presented in Fig 8 clearly demonstrates this. While the rainfall of each of the dry season months of December, January, and February is projected to decline respectively by 18 mm, 15 mm and 10 mm, the respective rainfall of June, July and October will increase by 65 mm, 20mm and 47 mm. It should be noted that the 'Little Dry Season is not well represented in the Port Harcourt example.

2.5.1.2 Southern Guinea zone

In the Southern Guinea Savannah Zone, rain could be expected during any month of the year. However in most years, November, December, January and February are rainless. This pattern characterizes the baseline period and is projected to continue into the 21st century. The case of Ilorin is presented in Fig 2.6 to demonstrate the projections of rainfall during the 21st century. A decrease in rainfall is projected for the first four months of the year. This means that these normally dry months will become drier as the century rolls on. Substantial increases are projected for May, June, October and November. There is no discernible trend in the projections for July, August, September and December. For example, the projections for July are for rainfall varying between 177mm and 180 mm.

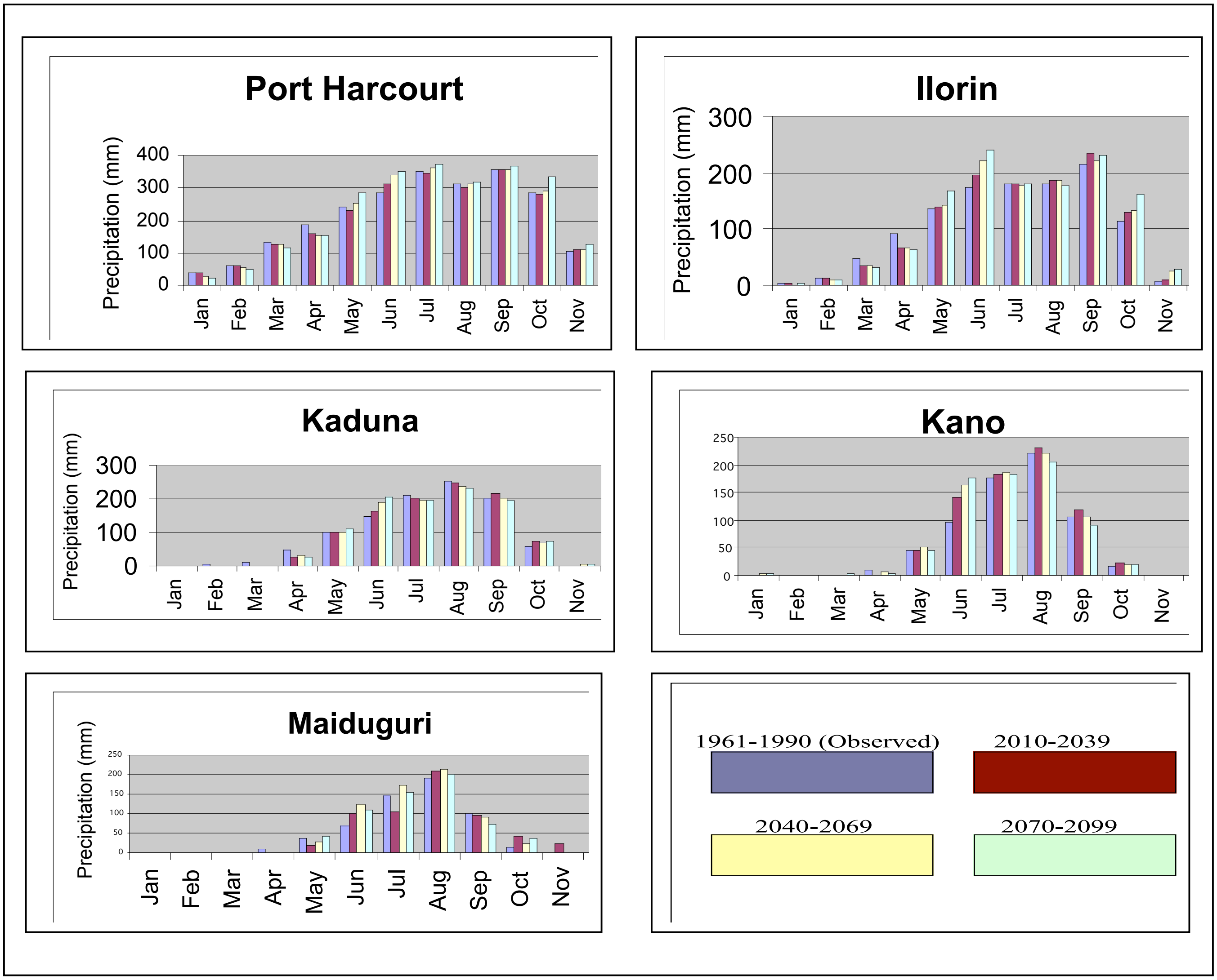


Fig. 2.6: Mean monthly precipitation projections; 1961 – 2099

2.5.1.3 Northern Guinea zone

In the Northern Guinea Savannah Zone, November, December, January, February and March are usually rainless. In very dry years, the rainless period may start in October and terminate in

April. The heavy downpours begin in May and terminate early in October. Peak rainfall is received in August. While the onset of the rainy season is gradual, its cessation is often quite abrupt. The projections presented in Fig 2.6 indicate the maintenance of the same pattern observed today. However, there will be a trend towards wetter conditions during the onset and the cessation months. Thus the trend will be significant with respect to June, September and October resulting in a rainy season longer by about one month.

2.5.1.4 The Sudan zone

Baseline period conditions in the Sudan Zone indicate an effective rainy season only four months long. Six of the dry season months are rainless. Although the onset of the season is in May in most years, the fields are not sufficiently wet for cropping until June. Peak rainfall comes in August, and the season terminates at the end of September. The projections for the rest of the 21st century in Kano indicate significant increases in June. The rainfall of July, August and September are projected to remain as they were for the baseline period from 1961 to 1990.

2.5.1.5 The Sahel zone

For the Sahel zone, baseline climate indicates a rainy season three to four months long. The dry season is eight months long and largely rainless. Although the onset of the season is in May, June in some years may not receive as much rain as to make planting feasible. Rain falls in sufficient amounts only in July and August. Projections of rainfall for Maiduguri during the 21^{st} are depicted in Fig 2.6. These indicate an increase in rainfall for June, July and August up to 2069 followed by a decrease during the final thirty years of the century. The significant increases in the rainfall of June will tend to bring that month more effectively into the planting season.

2.5.2 Mean monthly minimum temperature projections

2.5.2.1 The Forest zone

In the tropics, the lowest temperature during each day, which is usually described as minimum temperature is experienced during the night. Mean minimum temperature as an element in the Forest Zone climate is lowest in January with about 21 ^{0}C and highest in March or April at about 23 ^{0}C. There is thus a correspondence between the period of low angle of incidence of the solar radiation and the period of low minimum temperature. However, the period of high altitude sun does not correspond to the period of high minimum temperature. According to climate change projections, this general pattern will be maintained as the climate changes during the 21^{st} Century. However, there are indications in the projections, as it is going to happen world wide, that as the century progresses, the night will become significantly warmer. For example, in the Port Harcourt example presented in Fig 2.7, January minimum temperature is projected to rise from 21.4 ^{0}C to 24.61^0 C towards the end of the century. In the same vein April minimum temperature is projected to rise from 23.1 ^{0}C to 26.73^0 C.

2.5.2.2 Southern Guinea zone

In general, the nights in the Southern Guinea Zone are usually cool and pleasant, with temperatures in the range of 18 ^{o} C to 25 ^{o} C. As is the case in the Forest Zone, the month with the lowest mean minimum temperature is January while the month with the highest mean minimum temperature is April. However January's mean minimum temperature is lower in the Guinea Zone while April's mean minimum temperature is higher than in the Forest Zone. This implies that seasonal contrasts are higher in the Southern Guinea Zone than in the Forest Zone. At Ilorin, the January mean minimum temperature is 19.3^o C, while the April mean minimum is 23.9 ^{o} C. Projections for the 21^{st} Century indicate a general increase in minimum temperature for all the months. The increases are consistent in terms of direction and steady with regard to magnitude. They vary from as high as over 5^o C for January to less than 3.5 ^{o} C for August. With these increases, the nights are still expected to remain cool and pleasant with temperatures in the range of 20 ^{o} C to 28 ^{o} C.

2.5.2.3 Northern Guinea zone

For most of the year, mean minimum temperatures are lower in the Northern Guinea Zone than in the Southern Guinea Zone. However for April and May, it is the northern zone that records higher minimum temperatures. This notwithstanding, the nights are still cool and pleasant with temperature in the range of 15 ^{o} C to 25 ^{o} C. There are occasions in November, December, January and February when the nights are chilly. As is the case in the Forest and Southern Guinea zones, the lowest night temperatures are experienced in January while the highest are recorded in April. Climate Change projections for the century are for steady and consistent increases in mean minimum temperatures. In the case of Kaduna, presented in Fig 2.7, increases of up to 5^{o}C are projected. Such increases suggest that the nights could become less pleasant. Frequent occurrence of minimum temperatures of over 30^o C could make the nights uncomfortable.

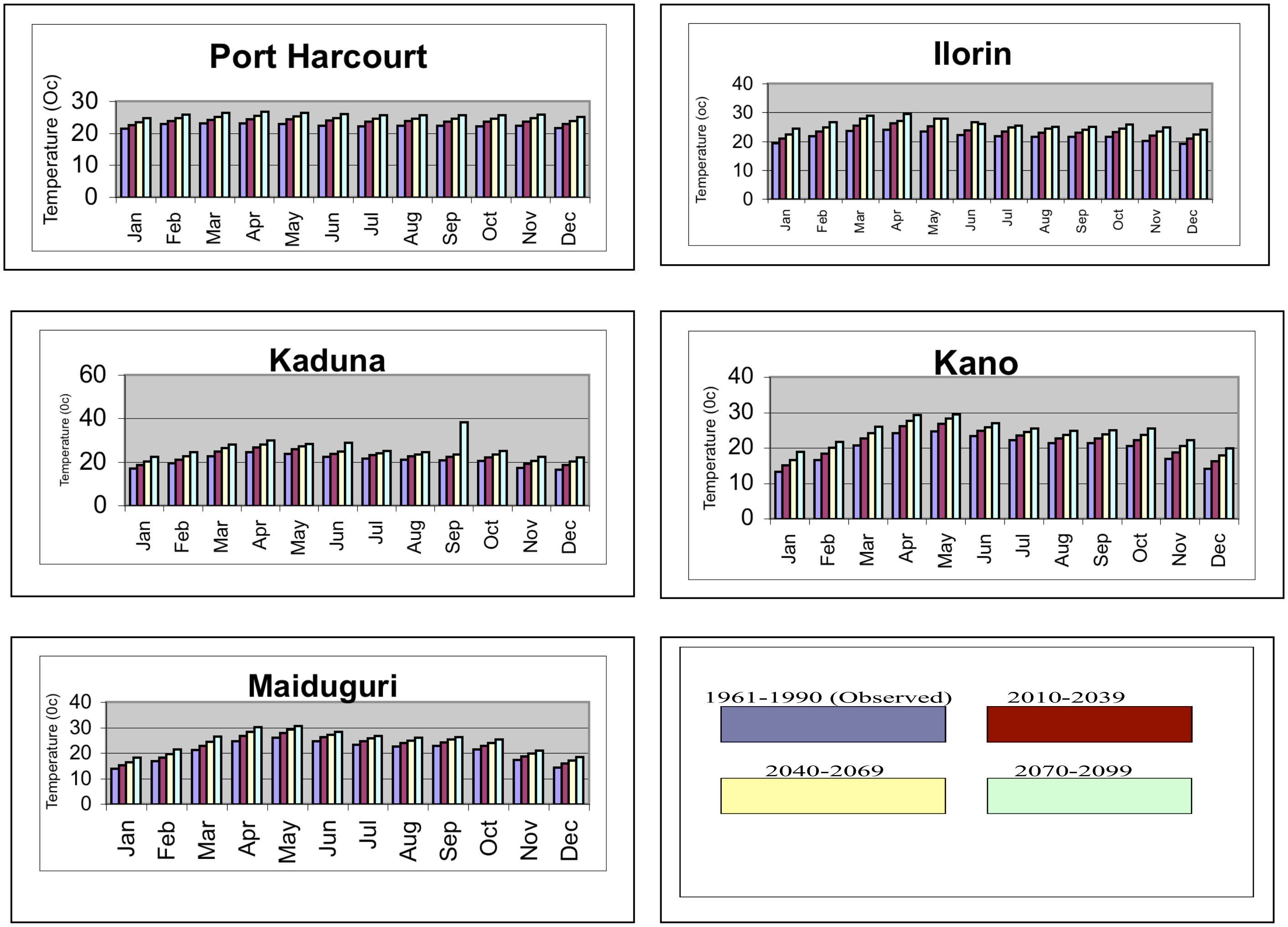


Fig. 2.7: Mean monthly minimum temperature projections

2.5.2.4 Sudan zone

In the Sudan Zone, January still remains the month with the lowest mean monthly minimum temperature. The highest mean minimum is recorded for May instead of April in the Guinea

Zones. On the basis of the disparity between seasonal values of mean minimum temperatures, one could recognize a season with cool nights extending from March to October and another season with cold nights extending from November to February. The season of cold nights corresponds to the season of occurrence of dry continental air mass advected from Asia and Europe, which is at this time in the winter hemisphere. The dry Harmattan winds from the Sahara Desert contribute to the discomfort with a chilling factor related to its gustiness and its capacity for evaporative cooling. Projections of minimum temperatures into the 21st century indicate steady and consistent increases. Increases of from 4^{o} C to 5^{o} C were projected for all the months up to the end of the century. This implies that the seasonal patterns in which the lowest temperatures are experienced in January and the highest temperatures are recorded in April will be maintained. However, the really cold nights will be replaced by cool and pleasant nights. Some of the nights in May could become uncomfortable because of high temperatures coupled with high humidity of the air.

2.5.2.5 Sahel zone

With regard to mean minimum temperatures, there is but little difference between the Sudan and the Sahel ecological zones. By less than a fraction of a degree in most months, mean minimum temperatures are higher in the Sahel than in the Sudan every month of the year. The seasonal distribution is more or less the same. The lowest minimum temperatures are expected in January, while the highest occur in May. In Maiduguri, mean minimum temperatures range from 13.8 ^{o} C in January to 25.9 ^{o} C in May. The nights of November to February are cold while the nights of the other months are by comparison cool. For Maiduguri, increases of between 4 ^{o} C and 5 ^{o} C are projected for all the months. The nights will still be cool for most of the year. However, during the three months preceding the onset of the rains nights will be relatively warm and also uncomfortable because of the associated high humidity.

2.5.3 Mean monthly maximum temperature projections

2.5.3.1 Forest zone

Maximum temperatures in the tropics are usually recorded during the day. One would hence expect maximum temperatures to be high during the summer months with high angle of incidence of sunlight and relatively longer days. However, in the Forest Zone of Nigeria, the highest maximum temperatures are recorded during winter and spring, while the lowest maximum temperatures are recorded during the summer months of June, July and August. In the Port Harcourt example presented in Figure 2.8, the highest maximum temperatures are recorded during the winter month of February, while the lowest maximum temperatures are recorded during the summer month of August. As it is well known, temperature in the Forest Zone of Nigeria is determined by what proportion of incident solar radiation penetrates through the atmosphere to be converted to heat at the earth's surface. Thus it is the rainy season months with their thick cloud cover that record the lowest maximum temperatures while the dry season months, despite the low angle of the sun, record the highest maximum temperatures. This pattern of seasonal distribution of maximum temperature will be maintained during the century. The highest temperatures will continue to be recorded in February while the lowest maximum temperatures will continue to be recorded in August. The difference in maximum temperatures between the two months will remain at about 4 ^{0} C. However, our projections indicate that as the century progresses, the forest zone in Nigeria will become warmer as day time temperatures rise by about 3 to 4 ^{o}C.

2.5.3.2 Southern Guinea zone

It appears that the same factors that determine the temporal pattern of mean maximum temperatures in the Forest Zone are also the most active in the Southern Guinea Zone. Thick clouds and heavy rainfall downpours depress maximum temperature levels at the height of summer. This leaves the winter and spring temperatures to become the highest. Mean monthly maximum temperatures are over 30 ^{o} C from October to May and less than 30 ^{o} C from June to September. Projections for Ilorin in the zone are depicted in Figure 2.8. Day temperatures are projected to increase as the expected climate change unfolds. The magnitude of the increase will be of the order of 4 to 5 ^{o}C. Towards the end of the century, mean day time temperature will be higher than the normal human body temperature. How to get rid of such excessive heat will become a problem. Living with such high levels of heat could result in increased morbidity and mortality due to heat related ailments.

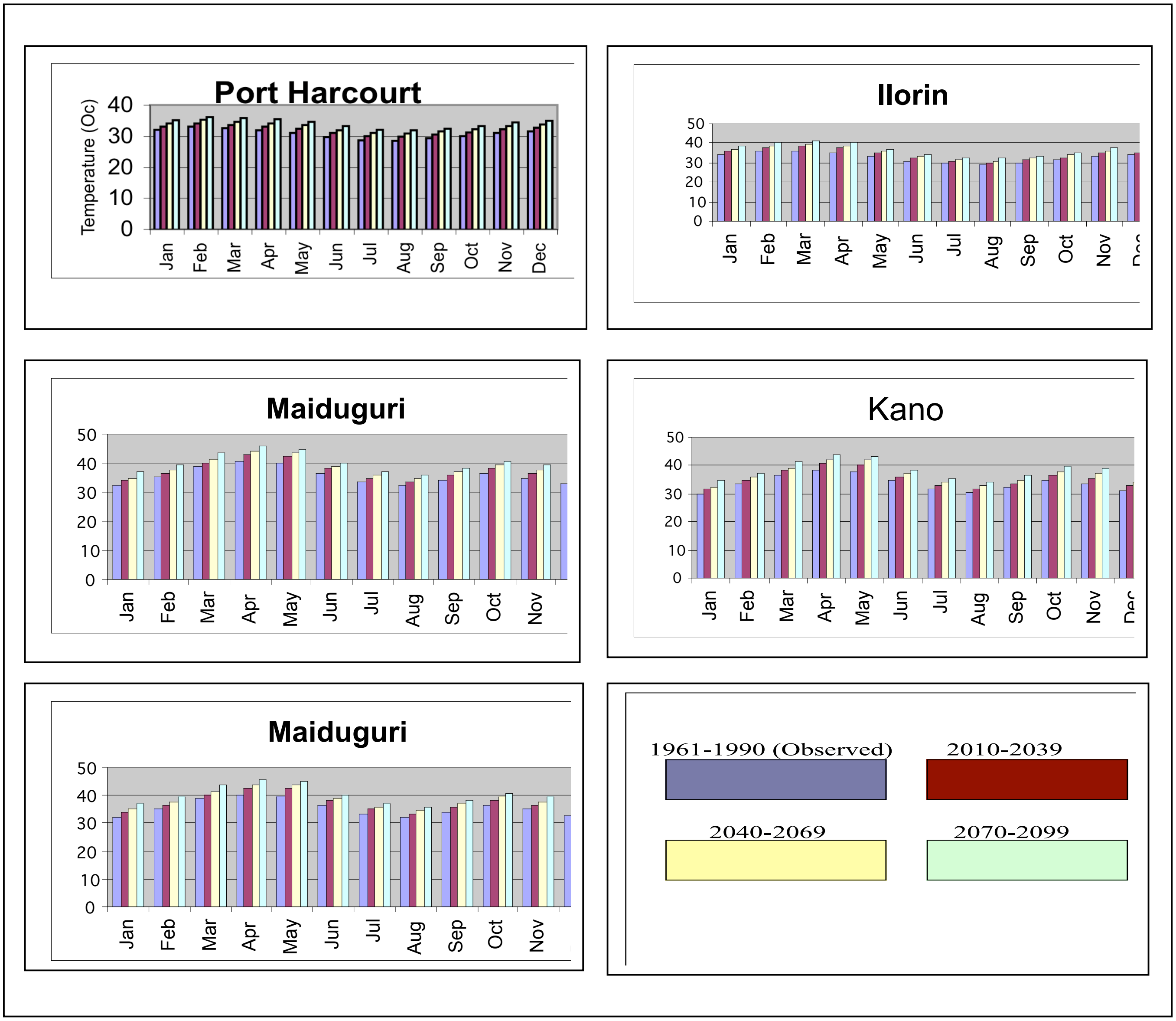


Fig. 2.8: Mean monthly maximum temperature projections

2.5.3.3 Northern Guinea zone

There is very little difference between the two Guinean zones in the seasonal pattern of mean monthly maximum temperature distribution. As is the case in the Southern Guinea Zone, very high maximum temperatures characterize the period from January to May, while comparatively low maximum temperatures characterize the period from July to September. A comparison of the

1961-90 observed measurements for Kaduna, the representative climatic station for the northern zone, and those for Ilorin, representing the southern zone, demonstrates the similarities in magnitude. Lower figures were recorded for Kaduna in respect of January, February, September and December. The same figures were recorded for July and September, while for the other months higher values were recorded for the more northerly station. Projections based on the scenario adopted for this exercise indicates steady and consistent increases up to the end of the century. The highest increase of more than 5 °C is projected for April. For December, January, February, March, May and June increases of between 3 º C and 4 º C are projected. For the other months, the increases projected are less than 3 º C. The hottest part of the year according to these projections will be December to May when maximum temperatures above human body temperature will be experienced on a regular basis. Heat stress may be mitigated by the dry Harmattan winds, which are expected during this season. Increased humidity is likely to raise sensitive temperature beyond tolerable limits during the period from June to September. Heat related health problems are hence more likely to increase as the century unfolds.

2.5.3.4 Sudan zone

The observed mean monthly maximum temperatures for 1961 to 1990 show that day temperatures in the Sudan Zone are lowest in January and highest in April. Mean monthly maximum temperatures vary between 29.8º C in January and 38.3º C in April. The differences between the Sudan Zone and Northern Guinea Zone are similar to the differences between the two Guinea zones. Lower temperatures were recorded for the more northerly zone from November to February while higher temperatures were recorded for the period from April to October. This pattern is explained by the differences in the factors influencing the temperature during the dry and the wet seasons. Dry season temperatures are lower in the north because of the lower angle of incidence of sunlight. Wet season temperatures are depressed in the more southerly locations by a higher rate of cloud cover which reduces the penetration of sunlight. Projections based on the selected scenario indicate an increase in mean monthly temperatures of 3 to 5º C. As depicted in Figure 2.8 for Kano, these increases will raise mean monthly maximum temperatures to a range from 34 to 43º C. There is hence the possibility of an increase in heat related health problems by the 2070 to 2099 time slice.

2.5.3.5 Sahel zone

During the baseline period from 1961 to 1990, mean monthly maximum temperatures were higher for each month of the year, in the Sahel zone than in the Sudan Zone. The differences in maximum temperature between the two zones average about 2º C. At Maiduguri, the lowest mean monthly maximum temperature is 32.2º C, recorded for January and August, while the highest is 40.4º C, recorded for April. Here again two temperature-depressing factors are active. The relatively low temperature for January is a result of the low angle of the incident radiation while that of August is caused by minimum penetration of sunlight as a result of thick clouds. Projections of mean monthly maximum temperature based on the selected scenario are depicted in Figure 2.8. Increases over the hundred-year period vary from about 3.5º to over 5º C. The increases are steady in that they are uniform over time. They are consistent in the sense that they consist of changes in one direction. For the time slice extending from 2070 to 2099, mean monthly maximum temperatures are expected to be perennially higher than human body temperature. For April, the difference between human body temperature and the mean maximum would be as high as 8º C. Some of the heat could be mitigated by high rates of evaporative cooling when the dry continental air mass is prevalent. This notwithstanding, high day temperatures are likely to constitute a major health hazard.

2.5.4 Mean monthly vapour pressure projections

2.5.4.1 Forest zone

Vapour pressure is one of the parameters used to express the amount of moisture present in the atmosphere as water vapour. For a given temperature, there is a maximum amount of water vapour that the atmosphere can hold. This amount is described as saturation vapour pressure. Relative humidity, which is the other parameter used to express the amount of water vapour, is the vapour pressure expressed as a percentage of the saturation vapour pressure. For the baseline period of 1961 to 1990, vapour pressure in the forest zone is as high as it could be given the prevalent ambient temperature. It is lowest in January and highest in March. In Port Harcourt, vapour pressure of 27.5 h*Pa was recorded in January while 30.7 h*Pa was recorded in April. For the rest of the 21st Century, a significant rise in vapour pressure is projected in consonance with the rise in the temperature. Thus with respect to Port Harcourt in Figure 2.8, it is projected that January vapour pressure will rise from 27.5 h*Pa for the baseline period to 33.4 h*Pa for the 2070 to 2099 period. For April, a similar rise from 30.7 h*Pa to 38.18 h*Pa is projected. This will not necessarily imply a significant rise in relative humidity or an increase in the probability of rainfall. What is projected is a significant rise in specific humidity while the relative humidity remains the same. This could imply a significant rise in the level of atmospheric energy, and consequently an increase in the intensity of stormy weather.

2.5.4.2 Southern Guinea zone

The mean monthly vapour pressure is significantly lower for every month in the Southern Guinea Savannah Zone than in the Forest Zone. The difference in vapour pressure in January is as high as 10 h*Pa, but only 2 h*Pa in July. This is quite understandable given the fact that the Atlantic Ocean, which is the main source of atmospheric moisture in West Africa, is closer to the Forest Zone than to the Southern Guinea Zone. For this reason, lower levels of vapour pressure should characterize the successive ecological zones from the Forest to the Sahel. Moreover, the northward and southward movements of the ITCZ (Inter Tropical Convergence Zone) separating the dry continental air mass originating over the Sahara Desert and the moist maritime air mass originating over the Atlantic Ocean ensures that the northern zones are overlaid more by the dry air mass than the moist air mass. The reverse is true of the more southerly zones, which are overlaid more by the moist air mass than the dry air mass. The result is that aggregate vapour pressure is lower in the north than in the south. This explains the wide gap between the vapour pressure of the Forest and the Southern Guinea zones in January when one zone is overlaid by the dry air mass and the other zone is overlaid by the moist air mass. Vapour pressure projections for Ilorin, based on the selected emission scenario are depicted in Figure 2.9. These indicate substantial increases in mean vapour pressure corresponding to the increases in mean temperature. As was the case for the baseline period, the lowest vapour pressure values are recorded for January while the highest are recorded for May. This does not necessarily imply higher levels of precipitation since the saturation vapour pressure must also have increased substantially.

2.5.4.3 Northern Guinea zone

The trend towards lower vapour pressure as distance increases from the sea is maintained in the Northern Guinea Zone. For all the months of the year, with the exception of August, vapour pressure is lower in the Northern Guinea than in the Southern Guinea zone. Also large differences of about 10 h*Pa in the monthly mean vapour pressure between the two zones is observed not only with respect to January, but also with respect to November, December, February and March.. Increases of from 4 to 5 h*Pa are projected for January to April while increases of 6 to 7 h*Pa are projected for June to November and respectively increases of 9.6 h*Pa and 5.75 h*Pa are projected for May and December. The increases are relatively small in the earlier part of the century and appear to become much larger within the time slice from 2070 to 2099.

2.5.4.4 Sudan zone

The trend towards lower vapour pressure with distance from the sea continues into the Sudan Zone. Therefore, for every month of the year, mean monthly vapour pressure is lower in the Sudan than in the Northern Guinea Zone. During the year, monthly mean vapour pressure varies between 6.3 h*Pa in January and 25.8 h*Pa in August. Very low values of mean monthly vapour pressure of less than 10 h*P are recorded for December to March, while for the rest of the year, mean monthly vapour pressure is above 15 h*Pa. Projections of mean monthly vapour pressure are depicted in Figure 2.8. There are increases of more than 3.5 h*Pa for each month between 1961-90 and 2070-2099. The increases are of the order of 6 to 7 h*Pa for May to October and 3 to 5 h*Pa from November to April.

2.5.4.5 Sahel zone

Within the Sahel Zone, there is a partial reversal of the tendency for a reduction in mean monthly vapour pressure with distance from the sea. Mean monthly vapour pressure is higher in Maduguri than in Kano for the months of November, December, January, February, March, August and September. However, lower mean monthly vapour pressure was observed in Maiduguri compared with Kano during the months of April, May, June and July. It is difficult to find an explanation for this partial reversal. There is, however, the factor of the Lake Chad which during pluvial periods extends over an area of more than 20,000 square kilometres.

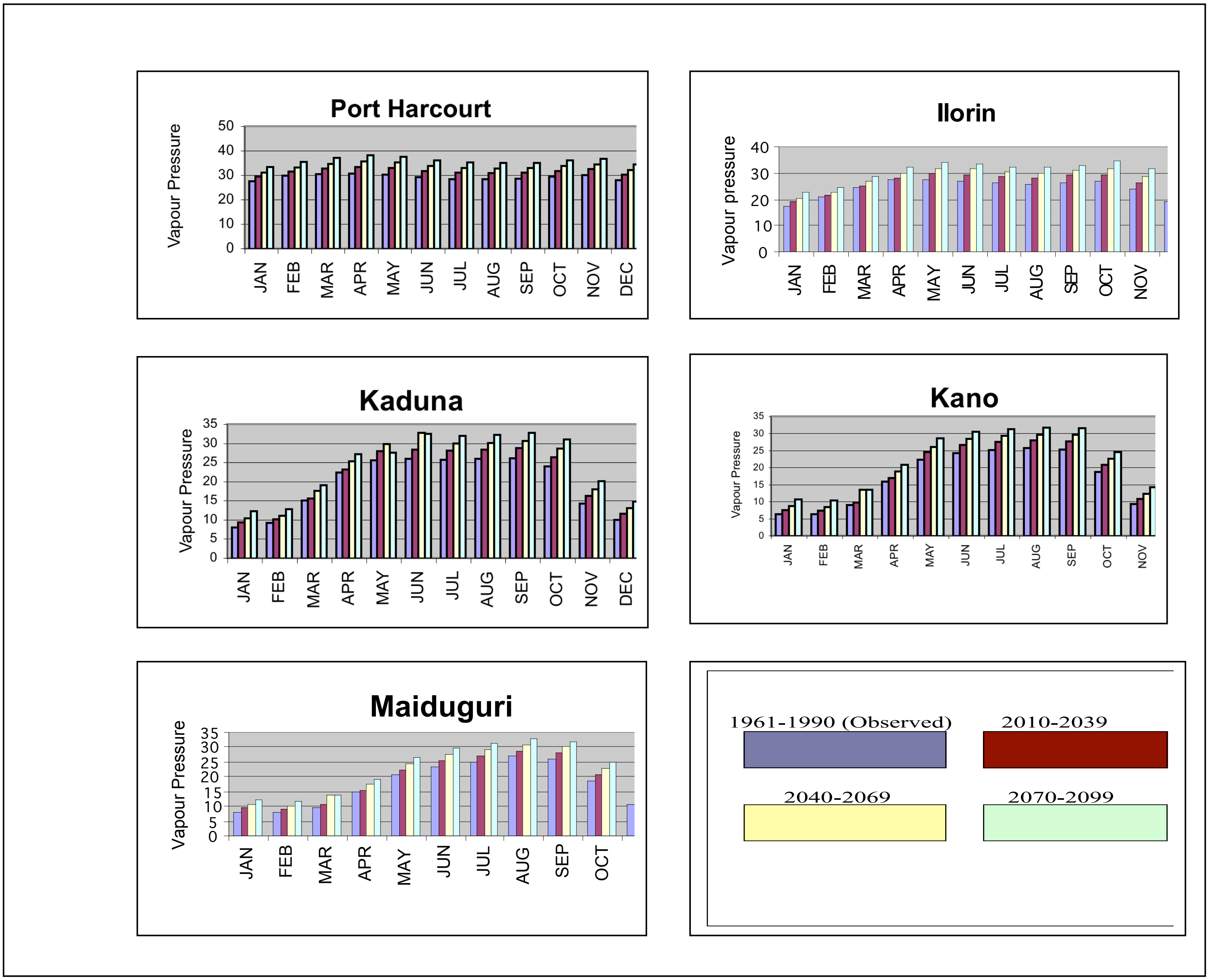


Fig. 2.9: Mean monthly vapour pressure projections 1961 - 2099

Could nearness to Lake Chad make a difference to vapour pressure in Maiduguri about 150 km to the east? However, as in the other zones, projections depicted in Figure 2.9 indicate increases over time until the end of the century. The increases are about 4 h*Pa for January to April, and 6 h*Pa from May to December.

2.6 Uncertainties

2.6.1 Uncertainties due to varying CO_2 concentration scenarios

Given the fact that global warming is largely determined by the concentrations of the greenhouse gases in the atmosphere, it is hardly surprising that a large proportion of climate change uncertainties are a reflection of the uncertainties inherent in the socio-economic scenarios underlying the greenhouse gas emission scenarios. In the case study based on Ibadan, we compare changes in climate, from the baseline period of 1961 – 1990 to a target period of 2070 – 2099, based respectively on 0.5% and 1.0% increases in equivalent CO_2 per annum. The results are depicted in Table 2.6.

Projections of mean monthly rainfall based on the two scenarios have yielded a mixed bag of outputs. In general, there is a decrease in rainfall for the first four months of the year. The scenarios are not clearly separated on the basis of whether the reductions in rainfall are higher with one or lower with the other. There is an increase in rainfall indicated by the projections based on the '1% scenario' for the months of May, June, September, October and November. Projections based on the '0.5% scenario' indicate increases only with respect to June, July, August and September. Hence, the results of the projections cannot be clearly separated on the basis of the scenarios adopted.

Projections based on either of the two scenarios indicate very clear and consistent increases in mean minimum temperature between the baseline period and the target period 2070 - 2099.These increases carry with them the characteristic seasonal distribution in which relatively low minimum temperatures are recorded in January and August and relatively higher minimum temperatures are recorded in March, April and May. During the baseline period, mean minimum temperatures vary between 21.6º C in January and 23.9º C in March. Projections of minimum temperatures based on the '0.5%' scenario indicate a target period mean monthly temperature varying between 24.7º C in January and 26.43º C in May. The projections based on the'1%' scenario indicate a much higher changes in mean minimum temperature, varying between 26.7 º C in January and 29.3ºC in May. Uncertainty is clearly an issue with respect to minimum temperature. Different environmental worlds are created with each scenario. While the '0.5%' scenario will make Ibadan warmer by about 3º C, the '1%' scenario will create an environment 5 º C warmer than what was experienced between 1961 and 1990.

Just as global warming is classified among the robust findings of the IPCC in its Third Assessment Report, so could one describe warming trend in Ibadan as a certainty whatever may be the scenario. This case has been made with respect to minimum temperature and the data in Table 2.6 seem to support this view with respect to mean maximum temperature. While an increase of about 3º C is projected on the basis of the '0.5%' scenario, projections based on '1%' scenario indicate increases of at least 5º C in the mean monthly maximum temperature between the baseline period and the 2070 – 2099 time slice. These increases are associated with the characteristic seasonal changes in which lower temperatures are recorded in August and higher temperatures recorded in February, March and April. The clear distinctions between the day time temperatures to be expected, given each of the scenarios, are sufficient evidences of the uncertainties which are the issue here. Are we to expect an environment in which heat related health problems are more frequent as the case could be with the '1%' scenario or an environment with more tolerable day time temperatures? The implications of these distinctions go beyond human health since uncertainties are also created in other sectors including energy, water, food and agriculture.

		CO_2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Precipitation	**1960/90**		9.3	28	80.6	138	167.4	222	198.4	136.4	198	151.9	60	9.3
	2070/99	0.5	7.75	22.68	64.79	117	166.2	275.1	212.9	131.4	218.4	132	176.8	7.44
	2070/99	1	8.06	22.4	64.17	107.1	195.92	287.1	197.16	134.23	213.3	199.02	81.9	10.85
Min Temp	**1960/90**		21.6	23.2	23.9	23.7	23.1	22.4	22.1	21.8	21.9	22.2	22.6	21.7
	2070/99	0.5	24.73	26.19	27.14	27.31	26.43	24.81	24.46	24.1	24.17	24.66	25.65	24.95
	2070/99	1	26.69	28.12	29.23	29.23	29.27	27.78	26.1	25.62	25.46	26.3	27.13	26.62
Max Temp	**1960/90**		33.1	34.6	34.2	33	31.8	30.1	28.3	28.2	29	30.4	32.4	32.5
	2070/99	0.5	35.78	37.32	37.53	36.66	34.89	32.05	30.33	30.29	31.14	33.78	35.13	35.36
	2070/99	1	37.43	38.81	38.95	38.42	36.03	33.2	31.54	31.4	32.39	33.77	36.12	36.59
Vapour P	**1960/90**		24.4	27.3	28.9	29.5	29.1	28.1	27	26.4	27	28.2	28.3	25.6
	2070/99	0.5	27.6	29.55	30.92	32.2	32.95	32.1	31.07	30.35	31.1	32.37	32.69	28.83
	2070/99	1	29.68	31.26	33.02	34.37	35.85	34.8	33.43	32.83	33.68	35.7	36.01	32.17

*Precipitation in mm; temperature in ^{o}C; Vapour pressure in h*Pa*

Table 2.6: Ibadan climate change based on respective assumptions of 0.5% and 1.0 % per annum increases in CO_2 concentrations

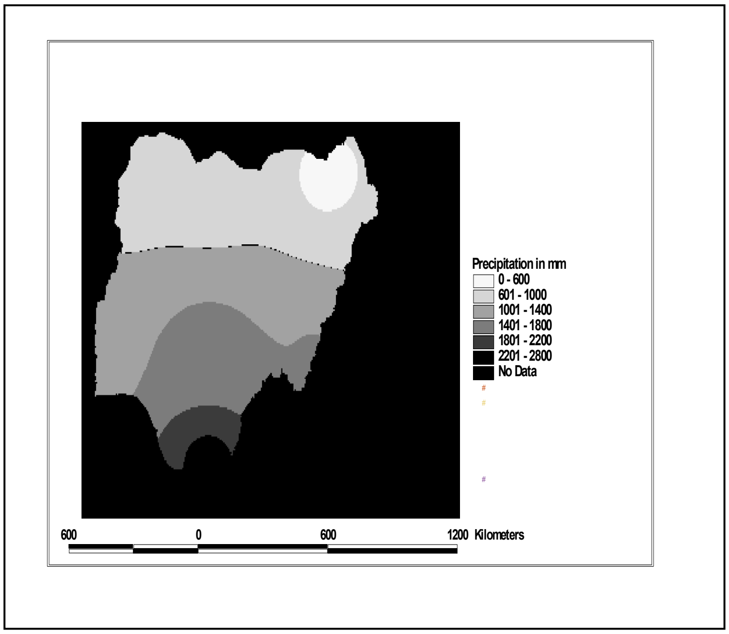
During the baseline period, observed mean monthly vapour pressure at Ibadan varied between a minimum of 24.4 h*Pa in January and a maximum of 29.5 h*Pa in April. There is a secondary minimum point in August (26.4 h*Pa) and a secondary maximum point in November (28.3 h*Pa). This seasonal pattern is carried forward into the target time slice with projections based on either of the two CO_2 concentration scenarios. Also, irrespective of which CO_2 concentration scenario is adopted, substantial increases in vapour pressure levels are projected. With the lower CO_2 concentration scenario, increases of 2.2 to 3.8 h*Pa are projected. On the other hand, using the higher CO_2 concentration scenario, increases of 3.8 to 7.7 h*Pa are projected. These contrasts in future climate, based on differences in CO_2 concentrations, are indicative of a high degree of uncertainty.

2.6.2 SRES scenarios

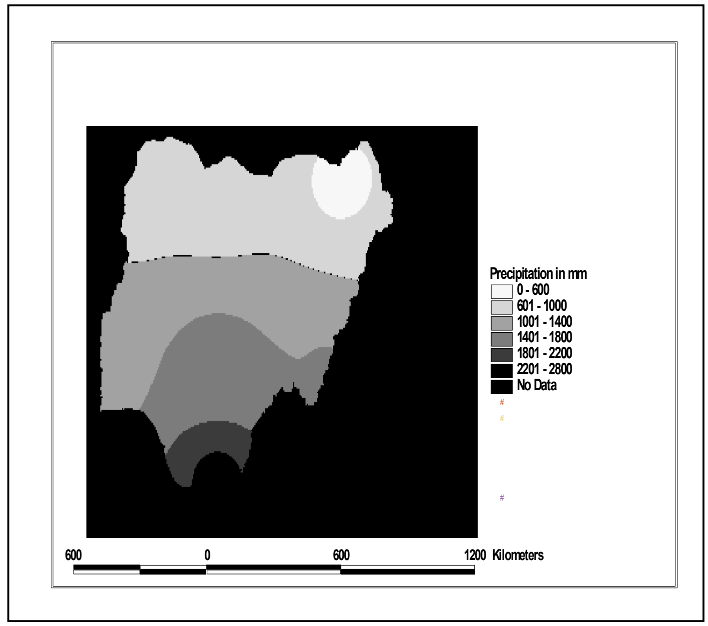
SRES scenarios were developed on commission by the IPCC. Data from experiments based on SRES scenarios are contained in MAGICC – SCENGEN Version 2.1 (Hulme at al, 2000). They were adopted for climate change projections in IPCC'S Third Assessment Report (IPCC, 2001a, b, c). The usefulness of the data from MAGICC-SCENGEN is limited by their coarse spatial resolution of 5 x 5 degrees longitude and latitude. In other words, each data point represents a cell of about 500 km x 500 km. Only one of these cells lies entirely within the territorial limits of Nigeria. Six other cells include a share of Nigeria's land area. Also, only three climate parameters: rainfall, cloud cover and mean temperature were included. To demonstrate an aspect of uncertainty due to change from one emission scenario to another, we adopted SRES A2 and SRES B1 and used them separately to project mean annual rainfall from the baseline period to the 2070 – 2099 time scenario. We also used a GIS procedure to interpolate and downscale from the data points to cells of less than 1 km squared in area. The results are summarized in Figure 2.10 and Table 2.7.

Projections with either of the two scenarios indicate steady and consistent increases in annual rainfall. The magnitude of the projected increases is highest in the south, near the coast and declines with distance from the sea. In general, SRES A2 projections result in rainfall increases much higher than those of SRES B1 projections. With respect to the SRES A2 scenario, annual rainfall was projected to increase from 730 mm in the year 2000 to 839 mm in the year 2100 at Birni Kebbi in the Sudan Zone. In Port Harcourt within the Forest Zone, corresponding increases were from 2373 mm in the year 2000 to 2628 mm in the year 2100 mm. On the other hand, with respect to the SRES B1, annual rainfall at Birni Kebbi was projected to increase from 730 mm in the year 2000 to 803 mm in the year 2100, while in Port Harcourt, the corresponding increase was from 2372 to 2518 mm.

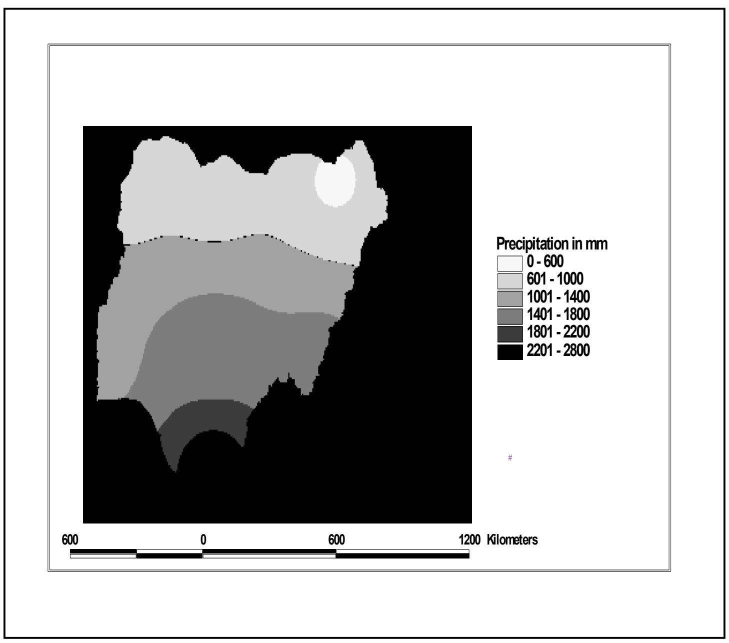
The maps in Figure 2.10 are cartographic representations of the data in Table 2.7, columns 5 and 10. It could be observed with respect to each set of maps that the area with the lower rainfall contracted while the area with the higher rainfall expanded between 2000 and 2100. In general areas with the higher rainfall expand faster under an SRES A2 scenario than under an SRES B1 scenario. The main conclusion here is that significantly different climate patterns will occur given each of the alternate emission scenarios. This is the essence of the uncertainties concerning climate change in Nigeria.



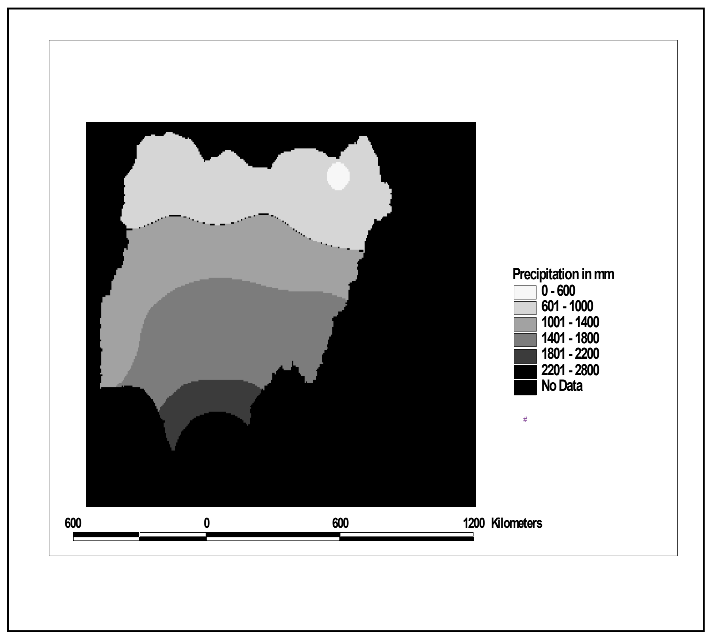
SRES B1: Total Annual rainfall, Year 2000



SRES A2: Total Annual rainfall, Year 2000



SRES B1: Total Annual Rainfall Year 2000



SRES A2: Total Annual Rainfall Year 2000

Fig. 2.10: Projections of rainfall element based on SRES B1 and SRES A2

Data points	Nearest Town	Long Latt..	Scenarios	Mid Thirty-Year Time Slice					
				2000	2020	2040	2060	2080	2100
A	Birni Kebbi	2.5	SRES B1	730.00	730.00	730.00	766.50	766.50	803.00
		12.50	SRES A2	730.00	730.00	766.50	803.00	803.00	839.50
B	Gusau	7.50	SRES B1	693.50	693.50	730.00	730.00	766.50	766.50
		12.50	SRES A2	693.50	730.00	730.00	766.50	803.50	839.50
C	Dama-turu	12.50	SRES B1	511.00	511.99	511.00	547.50	547.50	547.50
		12.50	SRES A2	511.00	511.00	547.50	547.50	584.00	584.00
E	Meko	2.50	SRES B1	1241.00	1241.00	1241.00	1277.50	1277.50	1277.50
		7.50	SRES A2	1241.00	1241.00	1277.50	1277.50	1277.50	1314.00
F	Ankpa	7.50	SRES B1	1606.00	1642.50	1642.50	1679.00	1679.00	1715.50
		7.50	SRES A2	1606.50	1642.50	1679.00	1715.50	1715.50	1752.00
G	Gasaka.	12.50	SRES B1	1423.50	1423.50	1460.00	1496.50	1496.50	1533.00
		7.50	SRES A2	1423.50	1460.00	1496.50	1533.00	1569.50	1606.00
H	Port Harcourt	7.50	SRES B1	2372.50	2409.00	2445.50	2482.00	2482.00	2518.50
		2.50	SRES A2	2372.50	2409.00	2445.50	2518.50	2555.00	2628.00

Table 2.7: Mean annual rainfall projections based on SRES B1 and B2 Scenario (mm)

2.7 Conclusions

There was a general trend towards aridity in most of the stations studied during the greater part of the 20th century. However, there was increased rainfall during the last two decades. There were fluctuations which demonstrated periodicity that were regular in nature. The fluctuations were also characterized by strong persistence and temporal dependencies. There appeared to be a general lack of correspondence in the patterns of the fluctuations between seasons. In other words, a wet March-April-May is not necessarily followed by a wet June-July-August. Also, there appears to be regional variations in terms of the rainfall fluctuations. In other words, dry years in one region are not necessarily dry years in other regions.

We also attempted to give an outline of the potential climate change in Nigeria in the aftermath of observed current global warming. The outline was provided with respect to the ecological zones including: Forest, Southern Guinea, Northern Guinea, Sudan and Sahel. The climatic parameters presented include precipitation, minimum temperature, maximum temperature, and vapour pressure. The most significant changes expected are with respect to temperature and temperature related parameters. There has been a tendency to emphasize changes in temperature in the temperate latitudes and to imply that similar changes will not occur in tropical areas. Given some of the emission scenarios discussed in this chapter, changes in minimum and maximum temperatures of the order of 5^{o} C or more could be expected in certain parts of the country. This is likely to create a significantly different world with implications in vulnerability for crops and human livelihood groups. The impacts of such changes will be felt in multiple sectors including: health, water, biodiversity, agriculture and forestry. Night temperatures will in general increase at a higher rate than day time temperatures. This has a potential to alter the thermo-period to the detriment of biodiversity. Crops and other plants requiring low temperature conditioning may in the short run survive through autonomous adaptations, but in the long run may have to contend with the possibility of extinction or relocation. Day temperatures may in future attain levels unknown to areas outside the hot desert regions. In areas with perennially humid air, this has the potential to produce high sensitive temperature known as sultriness. On the average, vapour pressure may rise by as much as 5 to 8 h*Pa with the potential for a significant increase in atmospheric energy. One would expect from this scenario, an increase in the frequency and intensity of stormy weather. Our findings are to the effect that the trend towards aridity, which characterized most of the 20^{th} century will be put on hold or reversed as the century progresses. There are possibilities, however, that the additional water need created by the higher temperatures may not be met by the increases in rainfall. One aspect of the current climate pattern that will be carried forward into the potential climate of the future is zonation. All the parameter values are still likely to increase or decrease with distance from the coastline. Rainfall and humidity will decrease, while temperature will increase in summer and decrease in winter with distance from the sea. Uncertainties regarding climate change will most likely be in terms of magnitude rather than of direction. The more significant uncertainties pertain to temperature and temperature related parameters in respect of which the expected changes are relatively large. With respect to moisture, the projections are for an increase rather than a decrease.

3 Socio Economic Futures

3.1 Introduction

As stated earlier in Chapter One, what is at stake, providing the justification for this study is the social, cultural and economic development of West Africa, based on a sustainable use of the resources of the environment. The main resource concerned in the study is food, specifically the crops used in its production. In designing the study, climate was hypothesized as a major determinant of changes in crop productivity. It is realized that the impacts of climate on crop productivity is invariably moderated by the human factor in multiple dimensions. This chapter affords the opportunity to set the stage on which crop and climate will interact during the 21st century. In this context, population, land use, national economy and crop production are the human attributes used to establish socio-economic futures of the study area.

The chapter is organized into 7 sections including this introduction. Section 2 gives the details of the activities conducted that have been found useful in meeting the stated objectives. Section 3 is concerned with contemporary population changes from which we make inferences on the future of population in the country. The subject matter of Section 4 is the developments leading to changes in land use. Section 5 is concerned with the dynamics of the national economy while section 6 presents an analysis of contemporary trends in food crop production and the implications for future developments. Section 7 is the summary and conclusions in which we attempt to make suggestions on the state of population, land use, national economy and food production in the year 2050.

3.2 Activities Conducted

As part of the preparations for the investigations reported in this chapter, the activities conducted include literature review, data collection and data analysis. Literature review was directed at the developing economies in general and Sub-Saharan Africa in particular. On the other hand, the data collected and analyzed as well as the case studies were based in Nigeria.

The main source of data on socio-economic attributes of the country is the Federal Office of Statistics which collates data from ministerial and non-ministerial departments and generates primary data through continuous and special surveys. The data from departmental sources are available in serial publications, for example, the *Annual Digest of Statistics* and the *Annual Abstract of Statistics.* The data generated through the surveys are also made available in the reports of special or annual surveys. For example, there is an on-going National Integrated Survey of Households (NISH), which is reported on an annual basis in a number of publications. Among the latter are: Central Household Survey and Rural Agricultural Sample Survey. There are modules within the NISH that are regularly but not annually conducted. For example, data generated through the National Consumer Survey, which has now gone through four rounds: 1980/81, 1985/86, 1992/93, and 1996/97, are made available in publications on occasional basis, following each survey. Special Reports sponsored by the FOS, also include valuable statistics as appendices. For example *Poverty Profile for Nigeria (1980-96)* includes 28 tables of relevant statistics summarized at state level in Appendix I. Similarly useful tables are also available in such other publications as *Socio Economic Profile of Nigeria, Poverty and the Agricultural Sector in Nigeria* and the *Review of the Nigerian Economy 1997.* There are also special surveys not included in NISH that are conducted under the auspices of the FOS. Examples include: *Family Planning Survey* (FOS, 1994) and *Multiple Indicator Cluster Survey* (FOS, 1995), data from which were made available in special reports. Some of the ministerial departments do put their own data in the public domain, independent of the FOS. The Central Bank publishes on an annual basis: *Annual Report and Statement of Accounts* and a *Statistical Bulletin.* The Federal Ministry of Health also publishes its own reports, including the *Nigeria Health Profile* 1992/93 (FMH, 1994).

Going by the *foregoing* review, there should be no problem encountered in conducting research on the socio-economic attributes of Nigeria. However, the most recent issue of the Annual Abstract of Statistics available anywhere is for 1998. Data on land use changes were sourced mainly from space and air borne remotely sensed imageries. These include: Side-Looking Airborne Radar 1976 (SLAR) Imageries acquired by the Federal Department of Forestry and 1990 low altitude aerial photographs acquired for the Nigerian National Livestock Survey.

3.3 Population Growth

3.3.1 Current demographic trends

The basic determining factors of socio-economic futures reside in the population. The general census conducted in the country in 1990 gave the population as 85 million. The National Policy on Development, Unity, Progress and Self Reliance enunciated in 1988 gave the growth rate of the population as 33 per 1000. The estimates for 1998 are as depicted in Table 3.1.

Total Size	115,224,312 (NPC, 1998)
Median Age	17.4 years (NPC, 1998)
Rural	63.7% (NPC, 1998)
Urban	36.3% (NPC, 1998)
Fertility Rate	5.15 (NPC, 1998)
Adolescent Fertility Rate	112 birth per 1000 of age 15-19 yrs (NPC, 2000)
Infant Mortality rate	105 per 1000 live births (FOS/UNICEF)
Under- Five Mortality	178 per 1000 live births (FOS/UNICEF)
Maternal mortality rate	704 per 100,000 (FOS/UNICEF, 2000)
Life Expectancy	Female: 48.2 yrs, Male : 46.8yrs (WHO, 2000)
Crude birth rate	47.7 births per 1000 population (NPC, 2000)
Crude Death rate	13.9 deaths per 1000 population (NPC 1998)
Population Growth rate	2.83 (CBN, 1999)

Source: United Nations System in Nigeria (UNSN) NPC is Nigerian Population Council

Table 3.1: Demographic *indicators*

3.3.2 Bases for population projections

Population growth, whether the population is that of human beings or of any other organism, tends to follow the logistic or sigmoid growth form. The logistic equation may be written as Odum (1971 p 184)

$$N = K \ / \ 1 + e^{a-rt}$$

Where:

'N' is the population size,

'K' is the maximum population size possible or upper asymptote or carrying capacity

'r' is the intrinsic growth rate (this is a biological function peculiar to each species)

'e' is the base of natural logarithm

'a' is the constant of integration which defines the position of the curve relative to the origin.

The growth in population is driven by two main factors, namely: the capacity to procreate and a density-dependent environmental resistance that increases as the population to resource ratio decreases. The logistic growth form normally assumes an S-shape with three main segments. From the origin, the population increases slowly (establishment or positive acceleration phase), then more rapidly (logarithmic growth phase), but slows down gradually as environmental resistance increases percentage-wise (the negative acceleration phase) until a more or less equilibrium level is reached and maintained.

With respect to human populations, the carrying capacity may be increased by technology or positive changes in the value of elements of the environment. It may be reduced by the requirements of newly assumed cultural norms in education, health, appearance, nutrition and housing which tend to increase consumption per capita. There is also the tendency for the society not to allow purely environmental factors to determine the upper asymptote. As the population approaches the carrying capacity, density dependent stresses that may impinge upon the quality of human life increase. To avoid the deleterious consequences of such stresses, programmes of self censorship are embarked upon. An example of such censorship is directed at reducing intrinsic growth rate through family planning.

The Nigerian population which is basically youthful continues to grow at an explosive rate (FOS, 1996a). Going by what happened in Europe and what is happening in the Far East, the next stage is that of significant declines in fertility engendered by the desire to reduce the high child dependency burden. In the classical model of population decline, the development levels of the communities involved was considered as basic. New aspirations, changes in the functions of the family, and new perceptions of costs and benefits of children were seen as the necessary and almost incidental consequences of the developmental changes that led to the demand for fewer children (Freedman, 1979). The current dominant viewpoint as expressed by Freedman is that reduced fertility can be achieved, and in fact, has been achieved in countries at much lower levels of development than was previously assumed. Much earlier, fertility declined in such places as the Sri Lanka, Kerala, Thailand and China. It is, however, not clear just how much change and in which subset of conditions is sufficient to motivate fertility decline. It was observed, however, that the countries mentioned, by the time they recorded fertility declines had a few developmental goals already achieved. For example, there was better health and longer life which meant fewer births were needed for the survival of any desired number and which encouraged investments in the future. According to Freedman, standard of education was higher for both boys and girls. This increased the costs and decreased the benefits of having children when they were in school. It dawned on prospective parents that fewer better educated children could provide greater satisfaction than more poorly educated children. The idea is now gaining ground that a reduction in fertility decline does not have to wait for the accomplishment of full scale industrialized system. The necessary and sufficient conditions could be limited to a good communication network which spreads the message of the benefits of family planning (Caldwell, 1976). In other words, Western values and ideas could creep into traditional societies through the back door of radio, television and the written word. Thirty-three per thousand' is close to the maximum biological rate of human population growth. It is generally believed that this rate cannot continue indefinitely. This explosive rate has got to slow down at one point in time.

In Nigeria, the most recent statistics are hardly encouraging. It appears that the rate of population increase is yet to stabilize. It was noted that even though fertility rates declined, mortality rates have also continued to decline significantly (FOS, 1996a). For example, a decline in crude birth rate from 46 to 38 per thousand between 1981 and 1994 was matched by a decline of infant mortality rate from 115 to 88. The main problem is related to lack of concrete achievements with the programme of population control through family planning. The specific objectives of the National Population Policy enunciated in 1988 include the reduction of the percentage of women who start bearing children before the age of 18 by 50 percent by the year 2000 and a reduction of the number of children a woman was likely to have which was 6 in 1988 to 4 by the year 2000. There is no evidence to the effect that these objectives were achieved. The latest statistics depict a low rate of adoption of family planning. In three states, namely: Sokoto, Jigawa and Katsina, the rate of adoption of modern contraceptive devices was zero. More worrisome are the statistics indicating that rather than discourage, post secondary education encourages higher family sizes in some parts of the country (NISH Survey). Neither the general nor the specific objectives spelt out in the policy statement have been achieved. The main problem has to do with entrenched cultural and religious practices. The use of modern methods of contraception remains very low in spite of significant increases between 1982 and 1984 and between 1993 and 1995 (FOS, 1996b). It is, therefore, not surprising that the Nigerian population remains youthful; that the percentage of the population in the age range 0-15 years is above 40 and that the rate of population increase remains very high. With a growth of 33 per thousand, the population will double itself once in 21 years. In other words, starting from 1990 and a population of 85 million, Nigeria's total population will climb to 170 million in 2011, 340 million in 2032, and 680 million in 2053.

3.4 Land Use Changes

3.4.1 Land cover before human intervention

Human use of land resources gives rise to "land use" which varies with the purposes it serves, whether they be agricultural, forestry, construction of human habitation, mining, industrial or the extraction and processing of natural products into forms in which they could be used for one purpose or the other. Hence, land use involves both the manner in which the biophysical attributes of land are manipulated and the intent underlying that manipulation. Land use dynamics are a major determinant of land cover changes. Changes in the uses of land occurring at various spatial levels and within various periods are the material expressions, among others, of environmental and human dynamics and of their interactions, which are mediated by land. This has increasingly been recognized as one of the key research imperatives in global environmental change research (e.g. Turner et al, 1995).

Before human activities began to change the natural surface attributes of the territory now known as Nigeria, there were three types of mature or climax plant cover. These were: the rain forest, the deciduous forest and the xerophytic woodlands. These were in a state of dynamic equilibrium respectively with the three regional climate types. The "Guineo-Congolian Rain Forests" which were in a state of dynamic equilibrium with a regional climate (Koppen's Af climate) characterized by perennial humid tropicality (Garnier, 1961), consisted essentially of a continuous stand of trees with canopies varying in height from 10 to 50 meters (White 1983). The Deciduous forests were the most widespread climax in Africa before the human factor became the ecological super dominant (Keay, 1960, Adejuwon, 1971). In Nigeria, they were characteristic of the Guinean (Northern and Southern) ecological zones where humid, tropical conditions prevail for most of the year, alternating with a shorter period of aridity (Koppen's Aw climate). The xerophytic woodlands, when they existed, were in dynamic equilibrium with the semi arid (Koppen's BS) climate and were found in the zones now described as Sudan and Sahel.

3.4.2 The processes of land use change

There are five main processes by which most of the present vegetation categories have been derived from the original forests and woodlands. Three of these are related to agriculture while the other two are related to forestry practices.

3.4.2.1 Shifting cultivation

The chief enemies of the natural forests and woodlands are shifting cultivation and rotation bush fallow systems of cultivation. These involve the clearing of the woody elements, in small patches, in preparation for the cultivation of field crops. After a harvest or two, the land is allowed to rest under fallow vegetation. Under a "normal" condition of low farming population, such patches are cultivated again after a period of five to ten years (rotational bush fallow). It may however remain longer under fallow and have enough time to develop into secondary forest or woodland (shifting cultivation). But it is not common to have the original natural plant cover re-established as mature vegetation. The resulting cultural vegetation is a mosaic consisting of field crop plots and fallow vegetation at various stages of recovery (see Figure 3.1). In the drier ecological zones, the fallow vegetation consists mainly of grass or savannah while in the forest areas; the vegetation consists mainly of woody secondary forests. There is however, a transition zone where the original vegetation was rain forest but the man-made derivatives are savannah. This is the zone known as Derived Savannah (Keay, 1959a). The major elements in the resulting anthropogenic vegetation can therefore be classified into two broad groups of mosaics – forest and savannah. In Figure 3.1, the mosaic details are imposed on the basic zonal pattern.

3.4.2.2 Permanent cultivation

With a high density of population and relatively good soils, an area long used for shifting cultivation can adopt a system of permanent cultivation. This can lead to further vegetation degradation. In the vicinity of the larger towns in northern Nigeria, continuous cultivation based on simple crop rotations and the use of manure and fertilizer on permanent and well-defined holdings has replaced shifting cultivation. Because of the intensity of cultivation, the vegetation cannot be described as savannah since the surface is covered by one type of crop or the other during the rainy season and left bare during the dry season. However, the landscape is dotted with scattered trees that appear to have been protected. From these, food, medicinal and industrial products are derived. Among the best known of such trees are *Acacia albida, A. arabica, A. seyal, A. senegalensis, Adansonia digitata, Azadiracta indica, Butyrospermum parkii and Parkia filicoidea*.

3.4.2.3 Tree crop cultivation

Tree crop cultivation results in the replacement of the main forests by the permanent (tree) crops among which the most widespread are the oil palm, rubber, cocoa and kolanut. Oil palm trees grow naturally in large numbers in the fallow vegetation created by shifting cultivation. Over extensive areas in the forest zone, a practice of protection creates oil palm groves that once made Nigeria the leading world producer of oil palm products. In many cases, the shade of the foliage crowns of the palm groves, are deep enough to discourage the growth of other crops. In the majority of cases, however, crops such as the shade-loving varieties of *Xanthosoma spp.* (cocoyam) are planted in the shade of the oil palms and where gaps in the foliage canopy are large enough; small plots of yams, maize, and cassava are established.

In Delta, Edo, Ondo and Ekiti states, within the forest zone, the forest is removed to make way for the cultivation of food crops inter-cropped with rubber. When the food crops are harvested, the peasant farmer plots become rubber farms. Such rubber plots exist in a mosaic in which the food crops farmlands may be dominant or sub-dominant. Within the territorial limits of the four states, there are also hundreds of thousands of hectares of land devoted to rubber plantations on which major rubber processing plants are based. Such plantations constitute spectacular features on the landscape whether seen through aerial photographs or other remotely sensed imageries. Cocoa on peasant farmers' plot is established more or less in the same way as rubber, that is, as the last crop in a rotation starting with food crops. In South Western Nigeria, especially in Ogun, Oyo, Osun, Ondo and Ekiti states, cocoa, in association with kola and citrus used to cover as much as 15% of the land on the average not considering the large areas under forest reserves (Adejuwon, 1972). In some localities in Akure, Ife, Ondo and Ibadan divisions, more than 25% of the land was under these crops. Blocks of land extending over thousands of hectares covered exclusively by these crops could be observed to the south east of Ibadan and between Ile-Ife and Ondo towns. The situation now is that most of the tree crop plantations have given way to an encroaching secondary forest as a result of a process of 'die back' due to old age.

3.4.2.4 Establishment of timber plantations

One modern process of land cover changes is the replacement of mature forests by single species timber plantations. The system known as *taungya* is adopted in upgrading the timber productivity of some of the existing forest reserves (Adeyoju 1975). In its essential features, it is not different from the cultivation of tree crops except that instead of crops such as rubber, cocoa or oil palm, *Cassia sieberiana, Gmelina arborea, Tectona grandis, Terminalia superba, T. ivorensis* or *Triplochyton scleronxylon* is planted. Much of the mature forests of the reserves in Oyo State have been converted in this way. Also in Ogun, Osun, Ondo, Akwa Ibom and Kwara States, considerable areas have been brought under *Gmelina arborea* to provide the feedstock for the already commissioned or proposed paper mills.

3.4.2.5 Timber and firewood production

Another process of change results from the exploitation of the wood resources of both woodlands and forests. This involves the selective removal of the larger elements of certain species for timber or firewood. Especially in the rain forests, this process results in considerable modification to the structure and floristic composition of the natural vegetation. The closed foliage canopy of the rain forest becomes broken. Full sunlight may reach the floor in patches to encourage the profuse growth and development of heliophytic species. With the removal of their usual hosts and support, the large woody climbers form thick tangles on the floor to make movement through the vegetation difficult. The resulting vegetation is usually described as disturbed mature forest.

The important timber producing species in the forest zone include: *Celtis* spp, *Chlorophora excelsa, Distemonanthus benthianum, Entandrophragma* spp., *Guarea* spp, *Khaya gradifolia, K. Ivorensis, Lovoa klaineana, Mansonia altissima, Mimusops* spp, *Piptadeniastrum africanum, Terminalia superba, Triplochiton scleroxylon*. The common tree species in the savannah adjudged capable of yielding high quality woods include *Anogeissus leiocarpus, Daniellia oliveri, Diospiros melspiliformis, Isoberlinia doka, I. tomentosa, Khaya senegalensis,* and *Pterocarpus erinaceous.*

3.4.3 Anthropogenic derivatives of natural forests

There is no standard, universally accepted set of categories for classifying land by either use or cover, and the most commonly used are hybrids of land cover and land use. Those employed here, are those of the NEST (1991) and ERGO (1994) inventories. They include:

- **Grassland:** this covers only 3% of the total land area of Nigeria. It is most common in Borno State, around Lake Chad and on the Benue flood plain, between Numan and the Taraba River; Extensive grassland is also found at high elevation in Taraba State, on the Mambila Plateau and also on the Jos Plateau. Apart from those found at high altitudes, they constitute most of the wetlands outside the Forest Zone. Because of their water retaining characteristics, the grasslands constitute an important late dry season grazing resource
- **Rain forest:** this covers only 6% of the country, and is concentrated in the southern states. This category consists mostly of primary forest. Cross River is found to be the most heavily forested state, and contains layered forest, though there is evidence of substantial deforestation
- **Scrub/shrub land:** this covers 11% of the country largely in Borno, Kebbi and Sokoto State. Following land clearance, it has replaced forest in parts of the south. Palm-dominated scrub/shrub land was recorded in much of the coastland. Scrub/shrub land was also found on the periphery of the extensive cultivation in the north, reflecting the effects of agricultural expansion through woodland clearance.
- **Woodland:** According to ERGO (1994) woodland occupied 41% of the country in 1990, extending southwards from 110 150'N to the Atlantic Coast in the Southwest, and to the edges of the Delta in the southeast. It consists of an open canopy tree layer with prominent shrub and herb layer encroachment. This category of forest is also found in the other southern states. Layered forest also occurs on the south-western escarpment of the Mambila Plateau, although it has been threatened by extensive dry season fire penetration.

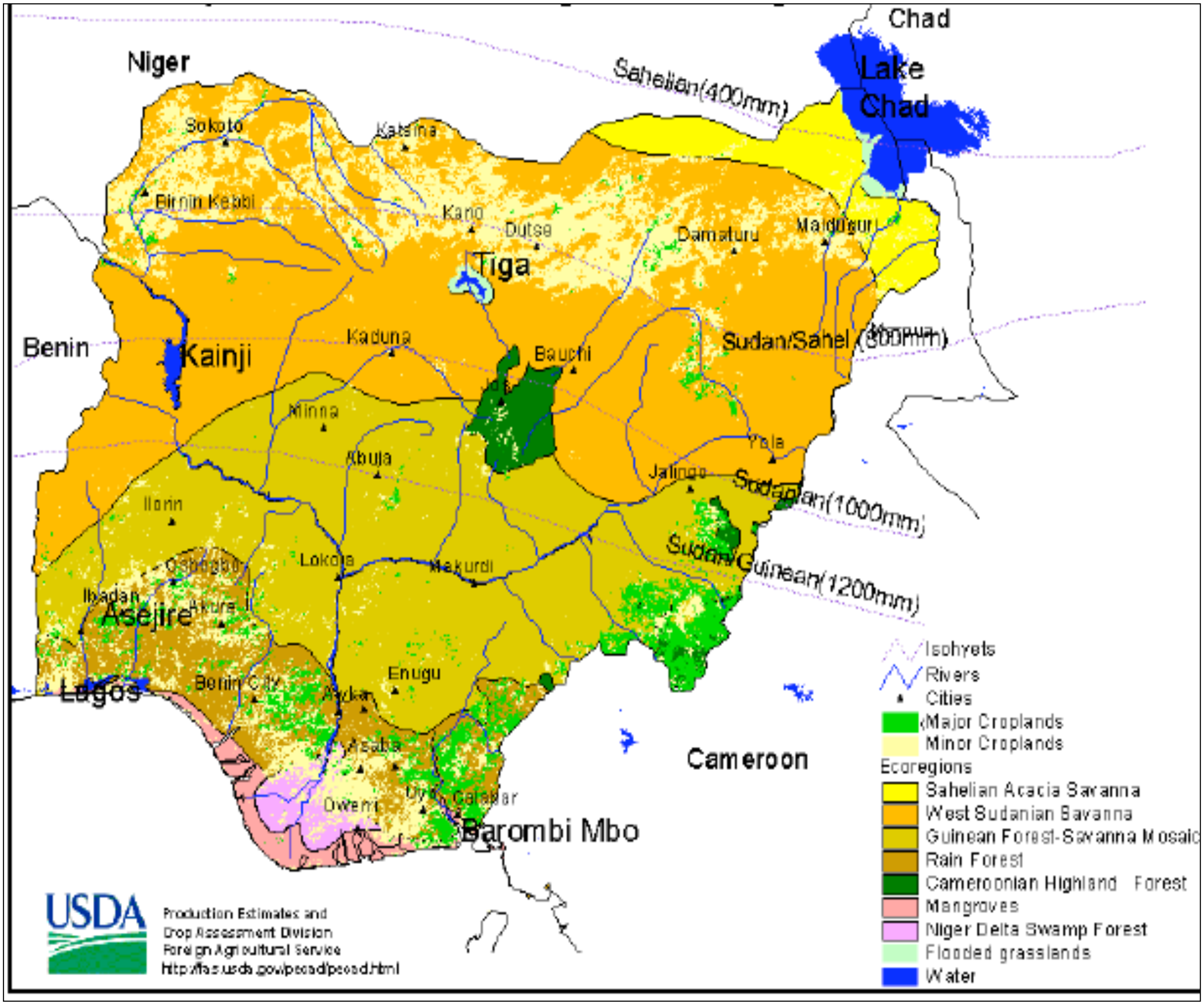


Fig. 3.1: Croplands and ecological regions

- **Mangrove forests:** These cover about 1 percent of the total land area of the country in 1990. They are found mainly in the tidal zone and along the coastal creeks and distributaries of the Niger Delta. When they are well developed, they stand over 3o metres high, sitting on prominent stilt roots.
- **Cultivated land:** According to ERGO (1994), some 31% of the Nigerian land area is within the cultivation cycle, 70% of which was under active cultivation during the 1990 wet season, i.e. 23% of the country as a whole. Cultivated land is divided into three broad categories including:
- **Parkland:** This is a crop land studded with trees, such as the locust bean tree (Parkia biglobosa) and the baobab (Adansonia digitata). It is by far the most widespread of the three categories, and

is found throughout the country except for central and northern Borno State on the Mambila and Jos Plateau, and in the Niger Delta.

- **Palm parkland:** This is a cropped land containing remnants or planted palm trees. It is largely restricted to the southern part of the country i.e. the humid zone, though outliers are found on some of the major watercourses in the north.
- **Open cultivation:** This is a farmland with few or no trees. Although widespread, it appears to be dominant on the Jos and Mambila plateaux, along the stretches of the Benue River, and in parts of the far north.

3.4.4 The bases for land use change projections

The core element in land use change is related to how much land is used for crop production. While one can adopt a geometrical growth form for population, such a growth form is not applicable in the case of land use changes, specifically in the case of changes in the extent of land under crops. The main reason is that there is not the usual feedback loop connecting future rate of changes to earlier growths in the extent of land under crops. It may be argued that population growth being the main driving force for land use changes can transfer its own geometrical growth form to land use. This argument is not valid because increase in the land used for crops is only one of the ways of meeting increasing demands of a growing population. Perhaps more significant in this regard is intensification of production. Intensification in the context of traditional tropical agriculture involved such practices as relay cropping, multiple cropping and inter-cropping. In the modern sense, intensification could include: pest and disease control, effective protection and storage of products, application of fertilizer and irrigation and commercialization. However, before modern intensification techniques became feasible, a major form of intensification had been in place. This involved reduction in the length of the fallow period. When land was more easily available, it was possible to operate a rotation system in which one year of cultivation was followed by up to ten years of fallow. Reduction of the fallow period from six to three years could be used to increase the extent of land available for crops by 100 percent.

Categories	1976 %	Area (km$^{2)}$	1990 (%)	Area (km^2)	Gain (km^2)	Gain (%)	Gain/year (km^2)
Cultivation	23.86	220,228	31.92	294,622	74,394	34	6,200
Grass Land	7.81	72,086	5.63	51,965	(20,121)	28	(1,677)
Scrub	13.94	128,666	11.93	110,114	(18,552)	14	(1,546)
Woodland	44.63	411,935	41.30	381,199	(30,736)	7	(2,561)
Mangrove	1.01	9,322	1.01	9,322	00	00	00
Forest	8.00	73,840	5.91	54,549	(19,291)	26	(1,607)
Settlement	0.75	6,923	2.30	21,229	14,306	207	1,192
TOTAL	100	923,000	100	923,000	00	00	00

Note: Loss is depicted in brackets

Table 3.2: Land use changes 1976 - 1990

Table 3.2 depicts land use changes based on the interpretation of the 1976 and 1990 imageries. The table formed the main basis for the projection of land use patterns to 2050 Table 3.3. By 1990, almost all the forests outside the Reserves had already been cut down to make way for cultivation. The area extent of forests in 1990 was therefore projected unchanged to 2050. From 1976 to 1990, there was no change in the area under Mangrove Forests. It is believed that this situation will continue in the future. The area under Mangrove in 1990 was therefore projected unchanged to the year 2050. Grasslands are fresh water swamps or wetlands in poorly drained areas found throughout the country. Area covered changed from 72.086 km ^{2} in 1976 to 51,965 km ^{2} in 1990. This was a change of 28 percent brought about by need for arable land in the face of a rapidly growing population. The sites are much sought after, especially in the arid and semi- arid locations. Projection for losses of such sites to cultivation was therefore made, using the rate of the period from 1976 to 1990. By 2020, with such projection, the grassland area declined to 1,877 km ^{2}. Given the interests demonstrated by the Government in preserving such sites in recent times, the 1,877 km ^{2} remaining in 2020 was projected to remain until 2050. The area under woodlands declined from 411,000 km ^{2} in 1976 to 389,000 km ^{2} in 1990. This represented a rate of decline of 23 percent. This rate was used to project land under woodlands to the year 2050. At that rate as much as 227, 539 km^2 was still left under woodland by 2050. It should be noted that lands under the woodlands are the main areas to which cultivation can expand without much resistance. In 1976, urban areas covered 6,923 km^2. Urbanized areas increased during the 1976 – 90 period to 21,229 km^2. This represented a growth rate of 17 percent per annum, justified by the phenomenal growth in population already projected. This rate was therefore used to project area covered by settlements up to 2050. Areas under cultivation increased from 220,228 km ^{2} to 294,622 km ^{2} between 1976 and 1990. This represented a rate of increase of 2.8 percent per annum. It is mere coincidence that this rate is close to that of population growth. Using this rate (simple interest formula) to project land under cultivation will result in 666,622 km^2 under cultivation by the year 2050. Over the same period human population would have doubled itself three times at the 1990 rate of 33 per thousand (compound interest formula). As the main driving force propelling other land use changes, an area of 666,622 km^2 under crops by the year 2050 is realistic. However, one could expect resistance all round from those land use types that cultivation traditionally encroaches upon. The cases of grassland and forests have been mentioned. It is therefore conceivable that the part of the expansion of cropland that could have been made at the expense of forests and grasslands represents those that were aborted and replaced by intensification. These were, therefore, subtracted from the 666,622 km^2 of cropland that could have been realized had resistance remained at the 1990 level. The results are depicted in Table 3.3.

Categories	**1990**		**2020**		**2050**	
	Km^2	%	**Km^2**	%	**Km^2**	%
Cultivation	294,622	31.7	432,444	47	519832	56
Grassland	51965	6	1,655	0.12	1655	0.12
Scrub	110114	12	63734	7	17354	2
Woodland	381199	41	304,369	33	227,539	25
Mangrove	9322	1	9322	1	9322	1
Forests	54549	6	54549	5.88	54549	5.88
Settlement	21229	2.3	56989	6	92749	10
TOTAL	923,000	100	923,000	100	923,000	100

Table 3.3: Land use projections (1990 – 2050)

3.5 The National Economy

3.5.1 Vision 2010

The study of the national economy and its future is here undertaken as a review of current government policy. The two policy instruments considered are: "Vision 2010" an agenda developed under the last military regime and the stated economic policy of the present civilian administration. The two policy statements provide a utopian scenario which is assessed against current realities.

On 27th November, 1996, a 250-member committee was set up by government to deliberate and define for Nigeria, its correct bearing and sense of political, socio-cultural and economic direction up to the year 2010. The committee, thereafter known as "Vision 2010 Committee", submitted its report 10 months later on 30 September, 1997. The committee recommended a development strategy that is people oriented, broad-based, self reliant, market oriented, highly competitive and private sector-driven with the government as the proactive enabler. At all times, the well-being of all the people should be the overriding purpose of governance and the economy according to the committee. It was noted in the committee report that the economy was still mono-cultural just as it was during the colonial period, the primary product now being crude petroleum (instead of agricultural produce as it was during the first three-quarters of the 20th century). Production activities were still highly dependent on imports. Imported consumer goods as a proportion of total imports still remained very high at over 30 percent. Crude oil accounted for about 95 percent of the nations total export earnings. It was also noted in the report that inter-sectoral linkages remained weak while unemployment remained high and rising. The goals set for the vision period included a GDP growth rate of about 10 percent per annum and an inflation rate of less than 5 percent. It was envisaged that by 2010, manufacturing would be accounting for about 24 percent of the GDP, while the relative contribution of the oil and gas sector would have declined to less than 20 percent. It was also the hope of the vision that per capita income would have risen to USA$1,600 from a level of less than USA$400 at which it was in 1997. The Vision saw the private sector becoming more active within a market oriented and highly competitive development process.

In essence, the current civilian administration has adopted Vision 2010 as its guiding policy without actually saying so. However, it has gone into greater details in terms of what needed to be done. There was emphasis placed on privatisation, infrastructural development, poverty alleviation and transparency in government. While the Vision was not taken seriously by its originators, the present civilian administration is attempting to live up to its promises. Commendable progress has been made in privatising government run business organisations. Infrastructural development is still lagging behind policy targets, so is reduction of corruption (Adejoro, 2001). In the context of this study, the four-year (1999 – 2003) targets for poverty alleviation represent a guide to the socio economic future of the country. Among the targets were:

- Increase of literacy rate from the current (1999) level of 57 percent to 80 percent
- Increase in access to primary health care from 40 percent to 70 percent
- Immunization of children to increase from 40 percent to 100 percent
- Infant and maternal mortality to be reduced by 50 percent
- Access to safe portable water supply to increase from 40 percent to 60 percent
- Access to electricity in rural areas to increase from 34 percent to 60 percent
- Improved rural transportation through construction of more rural feeder roads, stock routes and jetties
- Development and nation-wide distribution of simple processes and machines for agriculture and small scale industries
- Development and provision of soft funds and management services for small and medium scale industries to enhance employment and value adding to the economy.

The main objective of this section of the study is to address the issue of current developments in the economy and assess how the stated policy objectives have been achieved. For this the available data are analyzed

3.5.2 Economic indicators

The Nigerian economy has experienced stunted growth for the greater part of the period since independence. Even during the 1970s usually described as oil boom period, the country did not experience sustained positive growth rate for any period of six years continuously (Obadan, 1997). Current macro-economic aggregates paint the picture of a stagnant economy, weighed down by the largest and one of the fastest growing populations in Africa. Beyond statistics, the economy is being ravaged by a corrupt political class, to which there is really no alternative, if the country is not to break up into its component ethnic units. As a whole, the Nigerian economy is characterized by chronic inertia, with short periods of growth alternating with equally short periods of recession. Wealth distribution among the populace has in recent years become highly inequitable thus resulting in high poverty rates in all geographical regions (FOS, 1999a).

The economy is dominated by the Agricultural and the Oil and Gas sectors. Agriculture, including crop production, livestock, forestry and fishery, contributes about 40 percent of the Gross Domestic Production. In 1984, agricultural workers constituted 56.61 percent of the work force. Then between 1984 and 1994, a very unusual thing happened, the percentage rose to 60.38 (FOS, 1996a). One would normally expect the proportion of the work force in agriculture to decline. The dominance of the Oil and Gas sector is based, not on its contribution to GDP, but on its being responsible for more than 90 percent of Government revenue and more than 90 percent of foreign exchange earnings. While Oil and Gas accounted for 13.6 percent of the GDP, wholesale and retail accounted for 11.5 percent, financial Institutions accounted for 9.3 percent, another 9.3 percent was derived from Government Services, other industries contributed 9.1 percent and other services contributed 9.3 percent (FOS, 1998)

The GDP which, was at the level of 36.53 billion USA dollars in 1978, was still at the level of 35.04 dollars 21 years later in 1999. In between, it rose to a peak of 64.20 billion dollars in 1980 and fell to a nadir of 20.21 billion dollars in 1986 (FOS, 1998). All the other economic indicators speak of an uncertain and difficult future for the government and the people. When one considers in addition, the factor of a high population growth rate, the bleakness of the future at the individual level is thrown into greater relief (Ajakaiye and Adeyeye, 2001). Thus a GNP per capita of 580 USA dollars in 1978 had declined to 210 dollars in 1995 and had not recovered significantly since then. It appeared that all sectors suffered fates similar to that of the GDP, that is, stagnation and decline when current market prices were used for the computation (Obadan, 1997). Thus government consumption rose from 6 billion dollar in 1978 to 8 billion dollars in 1982, fell to 2.5 billion dollars in 1992 before rising fitfully to 5.2 billion in 1999 (CBN, 2001). A similar trend was recorded for the contributions of private consumption, gross domestic investment, exports of goods and services, imports of goods and services (FOS, 1998)

The various governments, most especially the civilian administration from 1978 to 1983 had been rather profligate in tending the nation's resources (Adejoro, 2001). During the 20-year period from 1980 to 1999, the government operated 15 deficit budgets. The deficits were more than 100 percent of the revenue, including grants and aids, in 1982 and 1983. The five years with surplus budgets were 1990 – 93 and 1995 – 96. During this period, the nation could hardly function under the jackboots of the worst military dictatorship that the nation ever experienced. For 18 out of the 22 years from 1978 to 1999, the country recorded surplus trade balance. This is due largely to the Oil and Gas, which was responsible for more than 90 percent of foreign exchange earnings. Among the significant non-oil foreign exchange earners are: cocoa, rubber and palm product. These agricultural products, it would be remembered formed the pillars of the economy during the colonial administration. Production from the agricultural sector had been on the increase in recent years. Index of agricultural output increased from a base of 100 in 1990 to 156 in 1999 (ADB, 2001). However, it should be noted that most of the products were food items directed at internal markets. The increases, therefore, should be seen as a spirited effort designed to cope with the needs of the rapidly growing population.

The macroeconomic instability reflected above appeared to be caused by the earlier observed political and policy instability and the growth of fiscal deficits, and financial practice of government up till 1999. For instance, the fiscal deficit/GDP ratio increased from 4.0 percent in 1980 to11.0 percent in 1991. The practice of deficit financing resurfaced again in 1997, when the fiscal deficit to GDP ratio of 0.2 percent increased sharply to 8.5 percent in 1999. The picture of the net credit to government shows that the growth in fiscal deficit financing crowded out the private sector and induced high monetary expansion beyond the growth in output. This is obviously responsible for the challenges of exchange rate depreciation, high inflation and the persisting negative position of the balance of payments. Also, this is not unconnected with the high annual average of external debt stock as a percentage of GDP. The ratio was about 75 percent between 1995 and 1999. In some years the external debt stock percentage of GDP was as high as 114.3 per cent.

As regards the business environment, the cost of doing business is quite high due to poor and inadequate basic infrastructures. For instance, the business environment in Nigeria is still plagued with unreliable and inadequate power supply, nagging fuel scarcity/ erratic fuel supply, poor transport infrastructure (i.e. road, railway etc.) and high port and demurrage charges. Thus, operators in the private sector have had to build their own infrastructures and work hard to sustain them at a very high cost in production process. There must be a borehole for water, and a generator for electricity. This is probably why capacity utilization is as low as 34 percent in the manufacturing sector of the economy (Ojo, 1995).

Thus, despite the economic endowment in material and human resources, the Nigerian economy has remained very fragile and highly dependent on the Oil and Gas Sector. On the average, daily crude oil production attained 2.1 million barrels per day in 1997 and has since stayed around this level (FOS, 1998). As narrated above, the bulk of the output is directed to export. The contribution s of crude petroleum to export earnings, which was about 1.4 percent in 1960, rose to 48.4 percent in 1970, 90.6 percent in 1978, and 96.2 percent in 1990. Since 1990, petroleum exports have accounted for over 95 per cent of the total exports. And it has remained the main source of government revenue. Less than 15 percent is consumed within the country while over 85 percent is exported. This shows that the export structure is still highly not diversified. The implication of the excessive dependence on oil is the economy's susceptibility to external shocks. Also, there is large under-utilized productive capacity. Besides, the sharp annual expansion in government expenditure, which did not result in significant expansion in country's productive capacity, suggests that the substantial proportion of revenue from oil was not properly managed.

3.5.3 Implications of the prevailing socio-economic setting for the future

The emerging critical socio-economic issues, which have implication for the future of Nigeria includes, first, high population growth rate estimated at about 28 per thousand in 2001 (ADB, 2001), second, the weak economic structure, that is predominantly driven by oil revenue and heavily dependent on imports to meet the demand of the teeming population, and third, the very high proportion of the poor in the economy, despite the obvious considerable resource base. The implications are more clearly analysed below.

Nigeria appears to have serious population problem with a population estimate of 120 million and a growth rate of 28 per thousand in 2001. The population projections described earlier have serious implications for the condition of cities, health of people, employment, pressure for cropland in farming and food security. As regards the condition of cities in Nigeria, most of the population increase will occur in urban areas, evidence of the attempt of people to escape from the poverty in rural areas. It must be noted that human impact on the environment is a function of population size, per capita consumption and the nature of technology used in production. Contemporarily, land has been degraded through oil spillage, the flaring of massive quantities of natural gas as well as soil and coastal erosion. The water supply is heavily polluted, resulting in the frequent incidence of disease and death. In the context of the future, given the inadequate and poor infrastructure facilities in Nigeria, the projected population will intensify environmental and health threats. Problems of refuse collection and overcrowding will grow worse. Water contamination by faeces will pose problem of disease epidemics in the cities. Smoky indoor air from cooking and heating due to overcrowding will contribute to respiratory infections. In respect of farming, most of the land that can be used for growing food is already being used. Farmers will need to find more resource-efficient and less toxic farming methods to raise more food on the same extent of land. If Nigeria plans to buy food to feed the expected population, it means that resources may have to be diverted from social and economic development to consumption.

The Nigerian economy is predominantly driven by oil revenue and heavily dependent on imports to meet the demand of the teeming population. The price of crude oil is externally determined and the prices of imported manufactured goods are also influenced by conditions of countries of origin. This has subjected the economy to serious external shocks and loss of production multiplier effects of our consumption goods to other nations of the world. There are also the effects of the volatile exchange rates of the naira and its negative impact on the balance of payment position. Thus, an economy of this nature is usually termed as weak (Obadan, 1997).

With the consciousness of the need for diversification by government and the existing under utilized potential in the real sector i.e. manufacturing and agriculture, it appears that oil will eventually cease from being the main driver of the Nigerian economy. If the current effort at repositioning the private sector as an engine of growth succeeds, and a favourable business environment is created, the potential for improved contribution by real sector to GDP is quite high. Besides, if efforts to improve and make adequate, electricity power supply succeed, if transport infrastructures and other social services are improved, and multiple tax structure on private sector activities, harmonized, the economic structure will most likely be diversified. This is because cost of doing business will fall. The wasting underutilized capacity in the manufacturing sector will be fully used up, implying increased domestic supply of manufactured goods which will reduce imports dependency. It also carries high employment benefit for the teeming projected population of Nigeria.

The possibility of the envisaged structural transformation of the economy away from absolute dependence on oil in the future appears more real given the growing acceptance of democratic system of governance. It is hoped that the elected government would demonstrate sufficient understanding of the nation's economic and social problems. Also, that within the framework of good governance, government will adopt strategies and policies that will directly address many of the nagging economic challenges.

3.6 Future Of Crop Production

The main focus of the study remains the relationship between crop production and climate. The question of how the socio-economic milieu moderates the relationship contemporaneously and potentially in the future is the objective in this part of the study. We have data on Nigeria's crop production covering the period from 1970 to 2003.The crops concerned include the major cash and staple food crops as well as a variety of minor crops. The trends in production were analyzed using line graphs. The trends identified were interpreted in terms of the relevant socio economic factors prevailing during the period of analysis

3.6.1 Food crop production 1970 – 1995

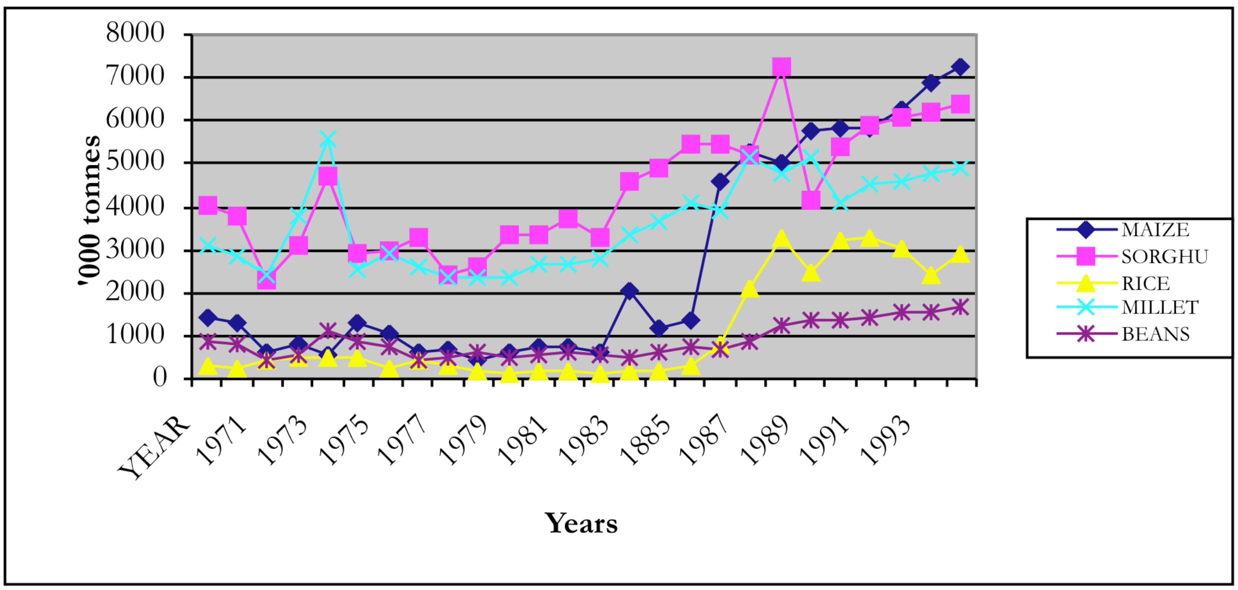


Fig. 3.2: Trends in the production of the major grain crops 1970 - 1995

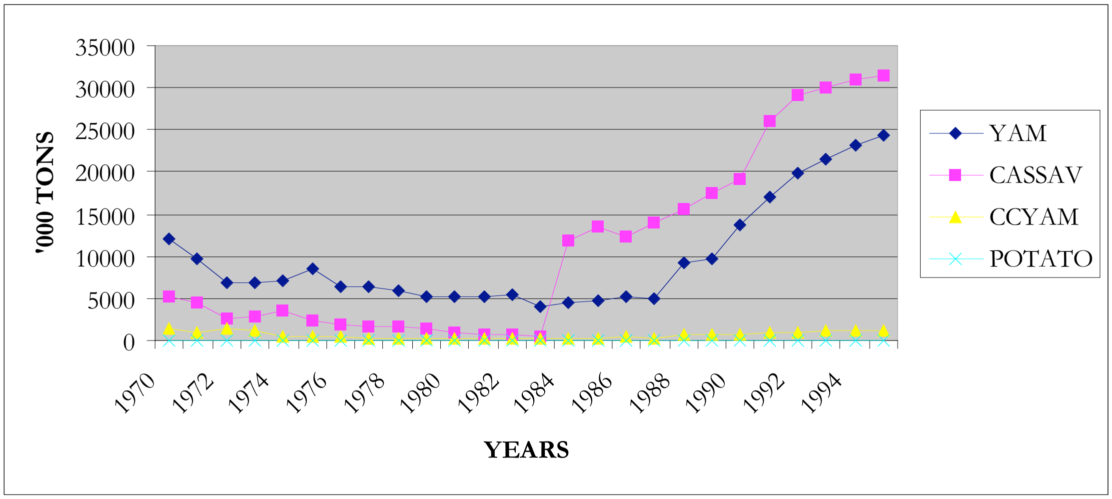


Fig. 3.3: Trends in the production of major tuber crops 1970-1995 (CCYAM = cocoyam)

Considering production during the 26-year period (1970-1995), there has been considerable variability in annual output. As depicted in Figures 3.2 and 3.3, most of the variability is explained by a general upward trend in production. It could be easily noticed from Figs 3.2 and 3.3 that the upward trend did not characterize the whole period from 1970 to 1995. In fact, there was a general decline in production of some of the major crops from 1970 to 1983. For yam, cassava, millet, sorghum, rice and maize negative to minimal growth in production was discernible. The phenomenal growths in the outputs of yam, cassava, maize and rice were not significant until after 1987. Yam production which stood at 12 million tonnes in 1970, declined to less than 5 million tonnes in 1987 before picking up and rising steeply to 24 million tonnes in 1995. Similarly the output of cassava, which was only 5 million tonnes in 1970 subsequently declined to 513,000 tonnes in 1983. After 1983, there was consistent, rapid growth that reached the 32 million tonnes level in 1995. Rice production for the year 1970 was only 280,000 tonnes. Production climbed up to more than half a million tonnes in 1974 but subsequently fell to 105,000 tonnes in 1980. Production of rice was still at a level less than 200,000 tonnes in 1985 after which there was a steep rise to 800,000 tonnes in 1987 and to over 3 million tonnes eleven years later. The output of sorghum which was over 4 million tonnes in 1970 declined to about 2.6 million tonnes in 1979, climbed to the 1970 level in 1985 before rising to 8.4 million tonnes in 1998. Maize production in 1970 was a modest 1.4 million tonnes. The level of production declined to half a million tonnes in 1983 after which it rose to 7.2 million tonnes in 1995.

Another aspect of the developments in food production between 1970 and 1995 was the changes in the relative contributions of the various crops. In 1970, with an output of over 12 million tonnes, yam was well ahead of cassava, which could only contribute about 5 million tonnes. In 1984 cassava production exceeded yam production for the first time. By 1990, while the production of cassava had climbed to 19 million tonnes, that of yam was still below the 1970 level, at about 9 million tonnes. A similar readjustment appears to have taken place between maize and sorghum. In 1970, the production of sorghum was three times that of maize. By 1984, sorghum production was six times that of maize. It was in 1988 that maize production first exceeded sorghum production. Outputs of the two crops have since remained at the same level.

3.6.2 Socio-economic determinants of trends in crop production

Contemporary changes represent the only useful basis for projecting crop production into the 21st century. As shown in the foregoing reviews, four main elements could be discerned as changes in the patterns of crop production in Nigeria between 1970 and 1995. These include:

1. Substantial increases in crop output over the 26-year period
2. Relative stagnation in output from 1970 to 1984

3. A sharp upward turn in output between 1984 and 1988
4. Relatively high rates of increases in output after 1988
5. Changes in the relative significance of the contribution of each crop

The increases in crop output over the 26-year period were probably in response to the growth in population. Increasing population affects growth in crop production in two related ways. In the first place, it creates increasing demand which farmers respond to by increasing output. In the second place, increasing population invariably involves a corresponding growth in the number of farmers and consequently an increase in the labour available for production.

The similarity in the trend of production is quite spectacular and calls for an explanation based on the environment of agriculture rather than on factors affecting the cultivation of each crop plant. The stagnation or decline during the earlier part of the period of interest needs to be considered apart from the phenomenal growth during the second half of the period. In the case of maize rice and cassava, and speaking of the period of phenomenal growth in production in the later half of the 1980s, one of the more plausible explanations is the development and supply of improved cultivars and the introduction of intensive and labour saving systems of cultivation. Hybrid maize is now well known to every farmer planting this crop for profit. New varieties are being developed by the IITA (1986a) in collaboration with government agricultural research institutes. Similar efforts have been mounted with regard to rice (IITA, 1986 b). Simultaneously, efforts were geared towards the distribution of some of the newly developed varieties among peasant farmers all over the country with considerable impacts. Some of the newly developed varieties are high yielding while others are drought or pest resistant. Spectacular gains in output have also come out of the development of new varieties of cassava. Some of the varieties are high yielding while others are less toxic and therefore more generally acceptable as food materials over an ever-expanding range of territory.

Also contributing to the higher levels of production in recent years were improved methods of production involving the application of organic and inorganic fertilizer, pesticides, insecticides, herbicides and credit. However, it is only in the case of fertilizer that such contributions are significant. In 1995, as much as 32 percent of the farming households used chemical fertilizers. During the same growing season, the respective percentages of the households using fertilizers in Kaduna, Katsina, Plateau and Bauchi states were 87, 64, 53, and 50 respectively(FOS, 1996c).

It is noteworthy that this approach to agricultural intensification is more widespread in the northern, drier zones than in the south. Half of those who did not use fertilizer considered the cost too high, a little less than a quarter did not know where to obtain fertilizer, 8 percent found the distance to the source too far, while 12 percent felt they did not need fertilizers. What this implies is that there is considerable scope for expansion of the application of fertilizers if the costs could be reduced by providing subsidies. Contributions to increased productivity through the applications of pesticides, insecticides and credit were relatively modest according to the available statistics. Only 10 percent of farming households throughout the country used either pesticides or insecticides. However, in the case of Katsina State as much as 77 percent of the households applied pesticides and insecticides in 1995. Among those not using, 58 percent either felt the cost was too high or did not know where to get them. Thus, 52 percent of the farming households could be considered as potential users (FOS, 1996c).

Three elements in the trends described earlier could not be explained in terms of internal developments in the sector. First, there is the decline in productivity during the 1970s. Second is the rather sharp change from stagnation to a steep rise in productivity between 1984 and 1987. Third is the fact that crops not characterized by the adoption of improved cultivars and agronomic practices had similar curves of production. Examples among the latter food crops are yam, groundnuts, beans, millet, melon and cocoyam. Also having similar production curves were all the components of export production including cotton, rubber, palm kernel, cocoa and coffee.

One plausible explanation for the observed pattern of growth in agricultural production in Nigeria from 1970 to 1995 is macro-economic and concerns the value of the Naira (local currency) relative to the world's trading currencies. This decline corresponded to the assumption of pre-eminence by the oil producing sector and the unrealistic dollar value that this gave to the local currency. The phenomenal growth in the price of crude petroleum during the 1970s resulted in a value of the naira not related to the local economy. This favoured importation of goods including agricultural products at apparently low costs. At the same time Nigeria agricultural products entered the world market at prices too low to pay for the costs of local inputs. The result was the decline in agricultural production and a phenomenal rise in food importation. The agricultural sector was at the point of collapsing by the middle of the 1980s when rice from South East Asia and wheat from Canada, the USA and Europe came in as substitutes for local production, not only of cereals, but also of tuber crops. The price paid for export crops could not pay the costs of weeding and harvesting of such crops as cocoa, rubber and the oil palm. The adoption of S.A.P (Structural Adjustment Programme) during fiscal year 1985 – 86 in the wake of ineffective earlier fiscal measures to shore-up the economy paved the way for rapid decline in the value of the naira relative to the dollar. Importation bills payable in the local currency rose phenomenally to provide the necessary incentive for the recovery of the agricultural sector. With the imposition, first, of a program of import restriction, followed by massive devaluation of the currency, the trend was reversed and the 1970 levels of production were restored almost immediately. This explains the positive point of inflection on the graph of crop production between 1984 and 1987. By 1995, output of yam had climbed to 24 million tonnes while that of cassava attained 31 million tonnes.

The foregoing analysis provides an answer to the question as to whether the agricultural system is sensitive to policy initiatives at the macro-economic level. Thus, the wrong monetary policies can completely derail domestic food production and render all other factors, including biophysical and socio-economic, irrelevant. The lesson, which could be learnt from this, is that monetary policies could decisively influence agricultural productivity and could be used to enhance resilience in the agricultural sector against the negative impacts of climate variability or climate change.

3.7 Nigeria in the Year 2050

3.7.1 The population

Going by the foregoing analysis of contemporary changes, what Vision 2050 promises is a completely new world for Nigeria. The outlines of this new world lie within the range of reasonable conjecture. A national population of between 400 million and 600 million will determine the nature of the environment, the political economy, and the totality of human security. Targets of population control meant for 2010 would have by the year 2050 started to have the desired impact. Significant decreases in the rate of growth will put the population on a course towards stabilisation and ultimate decline.

3.7.2 Land use

By 2050 the country would have exhausted all its options of increasing agricultural production through the expansion of cultivated land and through the shortening of the fallow period. Areas used for continuous food crop production would dominate the landscape. Especially in the semi arid zones, systems of mixed farming will dominate agricultural practice and the use of organic and inorganic fertilizers will be the order. Forests will be confined to the reserves and the mangrove and fresh water swamp forest ecological zones.

3.7.3 Political economy

After fifty years of democratic dispensation, the bogey of disintegration which protects corruption at the highest levels of government would have been finally put to rest. By the year 2050, the national economy will be in transition, not by choice but as a reaction to the deterioration in human insecurity. The country would have been forced out of the colonial economy syndrome. Earnings from the oil and gas sector would have become grossly inadequate to meet the basic needs of governance. Earlier on, infrastructural development, based on earnings from the huge reserves of crude oil and natural gas, especially in power and transportation sectors, would have laid a solid foundation for industrial take-off. Capacity utilisation of existing industrial plants which stood at less than 30 percent in 1997, would have improved considerably, paving the way for reduction in importation of consumer goods. All these notwithstanding, problems of unemployment, under employment, poverty and food insecurity will remain even if the proportion of the population affected changes. The proportion of the poor in the general population would have declined considerably. However, the poor will still be around in greater numbers.

Unemployment, poverty and food insecurity could be compounded by the negative consequences of a changed regional climate unless the necessary steps are taken to forestall them.

3.7.4 Crop production

With respect to the crop production sector, there are sufficient grounds to believe that a number of developments would have taken place that would prepare the country to meet the challenges of a changed climate later in the century. Among such potential developments are the following:

The application of irrigation in drier zones, especially in the Sokoto Rima Basin has considerably reduced the costs of production of such crops as onions, tomatoes and beans. As a result the products can be transported over long distances to displace local production. Especially during the dry season, much of the food needs of the population in the forest zones are met from such sources. Application of fertilizers has similarly helped to boost the production of such crops as rice in the producing areas with the result that erstwhile predominantly subsistence production has become predominantly commercial. It is envisaged that developments such as these will accelerate as the present century progresses.

Improved inter-regional road networks have led to the introduction of long distance haulage by trucks and trailers of food products. As a result, a higher proportion of the food needs of the coastal and southern urban centres are now met from production in the Middle Belt and northern zones. Such perishable products as fresh yams and plantains are delivered to markets over one thousand kilometres within a few days of harvesting. This is also a development that could enhance the status of food security by the year 2050.

The cultivation and production of maize, rice and cassava have benefited in no small measure from the results of research and development. In particular, the introduction of high yielding varieties of these crops has resulted in the doubling of production since the mid 1980s. Though not particularly successful, the recent introduction of wheat cultivation in the Chad Basin is a product of such government encouragement.

Changes in consumer preferences will lead to the replacement of the traditional staple food crops by relatively new ones. For example, rice ranks very high among the salary earning urban dwellers compared with the more than 70 percent of the population living in the rural areas. The growth in the production of the crop is therefore likely to increase as the proportion of urban population increases. Preference for wheat products has grown phenomenally in recent years and with it the import bill for the items concerned. The response of government to this development is the wheat development program designed to introduce tropical varieties of the crop to the northernmost parts of Nigeria. The use of tomatoes in food preparation has grown to substantially exceed the requirements of traditional food preparations. It is this development that is encouraging the commercial production of the crop for long distance transportation to consumers. Cassava food items are definitely not among the better ones with respect to taste or nutrition. However, after processing the tuber into *gari,* it becomes an item that could most easily turn to food by simply soaking in cold or hot water. This is probably the basis of its preference by working class urban dwellers. Wheat and rice products are preferred partly because of their prestige value. One of the notable recent developments in agricultural production is the intensification of poultry. This has resulted in increased demand for grain products including maize, sorghum and millet

In relation to the current operating socio economic factors, three issues need to be considered. These are: commercialization of staple food crop production; the response of the agricultural system to operative market forces at local, regional and national scales; and the sensitivity of the cropping system to macro-economic levers such as interest rates on bank loans and the values of the local currencies in dollars.

Whether the cropping system is basically subsistence or commercial will determine the extent to which government policy interventions could be effectively utilized to solve national or regional food security problems. Purely subsistence production lies outside the economic system and is largely unaffected by market forces and government policy initiatives. On the other hand, commercial agriculture is sensitive to market forces and is controlled by a strong underlying current of profit motivation. These characteristics can serve as linkages for action and reaction between government and the farming communities, and in the process, promote resiliency in the crop production systems in the face of variable or changing climates.

There is an age-long misconception that in Tropical Africa, food crop production is largely for subsistence. This is a product of Africa's traditional past. A recent study of cassava concludes that the crop is important, not just as a subsistence or food security crop for the households producing it, but essentially as a cash crop (Nweke, 1997). Analysis of data collected in countries within our project area yielded insights to the effect that the crop is produced with relevant purchased inputs, and that the inputs have positive effects on field area expansion and yield. The inputs include hired labour, rented land and purchased inorganic fertilizer. Apart from this, the study reveals that a large proportion of the crop is planted purposely for sale. The crop, on the whole, generates income for a larger number of households than the staple cereal crops. The study also shows that the adoption of high yielding varieties spread rapidly, and access to improved processing technology translated quickly into substantial cash incomes. The foregoing observations in respect of cassava are also true of yams. More than 100 varieties of yams have been described (Waite, 1965). Based on properties such as taste, tolerance of poorer soils, tolerance of adverse weather conditions, some varieties are becoming widely cultivated without the intervention of scientists or extension officers.

The world's food equation is based on grain crop production (Fischer et al, 1996). To the extent that the dominant staple food of Humid Tropical Africa is derived from tuber crops, the equation is not applicable to Africa. Yam is described as the fundamental food crop of West Africa (Johnston, 1958). It is, in fact, the most preferred food item. Its range of distribution is co-extensive with Humid Tropical Africa. Our project area is responsible for about 90 percent of the yam produced worldwide. Nigeria's output, which amounted to 25 million tons in 1995, is responsible for nearly half of the global total production (FAO, 2,001). Our project area produces 80 million tons of cassava annually (Nweke, 1997). This translates to an estimated average of more than 200 calories per person, per day, for over 200 million people. Bringing tuber crops to the food equation will enhance the status of food security in the study area.

Hitherto, attention has been directed at the Sahel and other arid regions of Africa in highlighting the hunger situation in Africa. Little attention has been directed to the humid areas of the Guineo-Congolian ecological zones, which are less prone to extremes of weather and are less vulnerable to food insecurity. As the population of Africa rises to 1.2 billion in 2020 and 2.2 billion in 2060 (United Nations, 1992), it is conceivable that the state of food security in sub-Saharan Africa becomes more and more dependent on the status of tuber production agriculture. It has therefore become a matter of global concern for effective root crop production practices and strategies to be put in place in Humid Tropical Africa. Food security in the project area, achieved in the form of enhanced tuber crop productivity, will definitely reduce the growing tendency in the area to import (Brass et al, 1996; Downing, 1992; Kates et al, 1988)

4 Impacts of Climate Variability

4.1 Introduction

In this chapter, the subject of “Impacts of climate variability on crop yield” is addressed in three studies. The first study is the assessment of the sensitivity of crop yield to inter-annual changes in climate. In the second study, the sensitivity of crop yield to intra-annual changes in climate is assessed. The third study undertakes an assessment of the variable significance of the impact of the weather of each year on crop yield.

The first study, in essence seeks to establish linear relationships between crop yield and inter-annual changes in climate and derive models with which crop yield could be predicted using seasonal weather forecasts. The main predictors are disaggregates of seasonal rainfall. With the second study, it is demonstrated that within the same year, changing the planting dates could result in significantly different levels of yield. Apart from its implications in formulating adaptation strategies, this study throws into relief the relative significance of factors other than rainfall that determine crop productivity. The other factors include temperature, solar radiation and relative humidity. Although these factors are not significant in terms of inter-annual climate variability, they form the basis of the climate change projections outlined earlier. Thus they afford us the analogies for climate change impacts within contemporary, observable crop-climate relations. The third theme examines the issue of the variable significance of the impacts of climate on crop yield from one year to another. This involves an indexing procedure by which measures of significance are attached to the observed annual crop yield anomalies as surrogates of the impacts of climate. It is recognized that there are non climate factors that contribute to the determination of yield. However, there is no doubting the fact that the climatic factors are the ones that have an annual time resolution and therefore more likely to be responsible for the varying significance of the anomalies. It is recognized that when climatic conditions do not exceed the limits of tolerance of the crop plants, crop yield sensitivity to climate could be weak. However, when the conditions approach the limits of tolerance, sensitivity increases rapidly and with it, the impacts of climate indicated by significant yield anomalies.

4.2 Activities Conducted

4.2.1 Sourcing the climate data

The climate data used in characterizing current climate and in projecting future climate in Chapter Two are also employed here in the assessment of impacts. Locally observed climate data were employed in the assessment of impacts of climate variability. On the other hand, observed and model generated data sourced from IPCC Data Distribution Centre were used in the assessment of the impacts of climate change. The data used in the assessment of the effects of intra-annual climate variability were collected on the Teaching and Research Farm of the Obafemi Awolowo University. Rainfall data were obtained with a manual rain gauge. Temperature and potential evaporation data were obtained from mercury thermometers and a shielded Piche evaporimeter, respectively. Data on relative humidity were collected using a hygrometer. The thermometers, the evaporimeter and the hygrometer were kept in a Stevenson’s screen of standard height. Weather records were taken twice daily at 1000 and 1600 hrs local time; that is, 1 hr ahead of GMT. In addition, data were collected on sunshine hours with a Campbell Stokes Sunshine Recorder. In 1981, total solar radiation in the 0.4 to 1.2 μm spectral region was obtained for the total growing season period using a LI-COR LI-200SB pyranometer sensor connected to an LI-1776 solar monitor programmed to integrate and store electronically solar radiation for a 24-hour period. The sensor had a very low response at 0.4 μm, increasing nearly linearly to a maximum at about 0.95 μm before decreasing to a cut-off at 1.2 μm. Maize variety TZPB (FARZ 27) was planted annually from 1978 to 1990 in a field about 100 m from the Meteorological Station. Planting dates and grain yield obtained each year were recorded.

The social and economic data came from the National Integrated Survey of Households (NISH). This is probably the main preoccupation of the Federal Office of Statistics, which is the central data generating organization in the country. It is designed to provide data on areas not covered by the various ministerial and non-ministerial departments. NISH is an on-going programme of household surveys probing various aspects of households including: housing, health, education, employment, etc. The core module of the programme is the General Household Survey (GHS). GHS, which is designed to collect basic data on households, runs from year to year. There are supplemental modules each of which concentrates on a specific aspect, elaborating on it beyond what is covered in the GHS. Two of the supplemental modules are the National Agricultural Sample Survey (NASS) and the National Consumer Survey (NCS)

In view of the importance of agriculture to the economy, the module on agriculture is also designed to run on an annual basis; but the scope is restricted to traditional agriculture. The other important module of NISH is the National Consumer Survey, which has now gone through four rounds: 1980/81, 1985/86, 1992/93, and 1996/97. Basically, the surveys were designed to generate data for assessing income and expenditure pattern of Nigerian Households, computing weights for consumer price indices (CPI) and for preparing aspects of the national accounts. However, the most important use for which we have found this survey is in the assessment of the poverty situation in the country. Data were collected on household income from various sources and their expenditure on various goods and services. The household income covered cash income, income-in-kind, consumption from own production and imputed rent. Their expenditure covered food and non-food items which were grouped into twelve commodities: food, accommodation, fuel and light, drinks and tobacco, household goods, transport, other purchases, clothing, other services, monetary transactions, as well as income-in-kind, imputed rent and consumption of own production. The data on observed crop yield used in this study came from the agricultural sample survey while the data on poverty came from the NCS. The data on the other attributes of the household came from the GHS.

4.3 Description of Scientific Methods

4.3.1 Study of sensitivity of crop yield to contemporary inter-annual climate variability

The study is based on two states, Bornu and Yobe, in the Arid Zone of Nigeria (Figure 4.1). The scientific methods employed in the sensitivity analyses were informed by the study objectives, which include:

- Identification of the climate variables that accounted for the variability in crop yield;
- Estimation of the relative contributions of each climate independent variable in determining the variability of crop yield;
- Estimation of the proportion of annual changes in crop yield that could be ascribed to climate variability;
- Estimation of predictive linear models that could be used to estimate crop productivity and crop production when reliable weather forecasts are available.

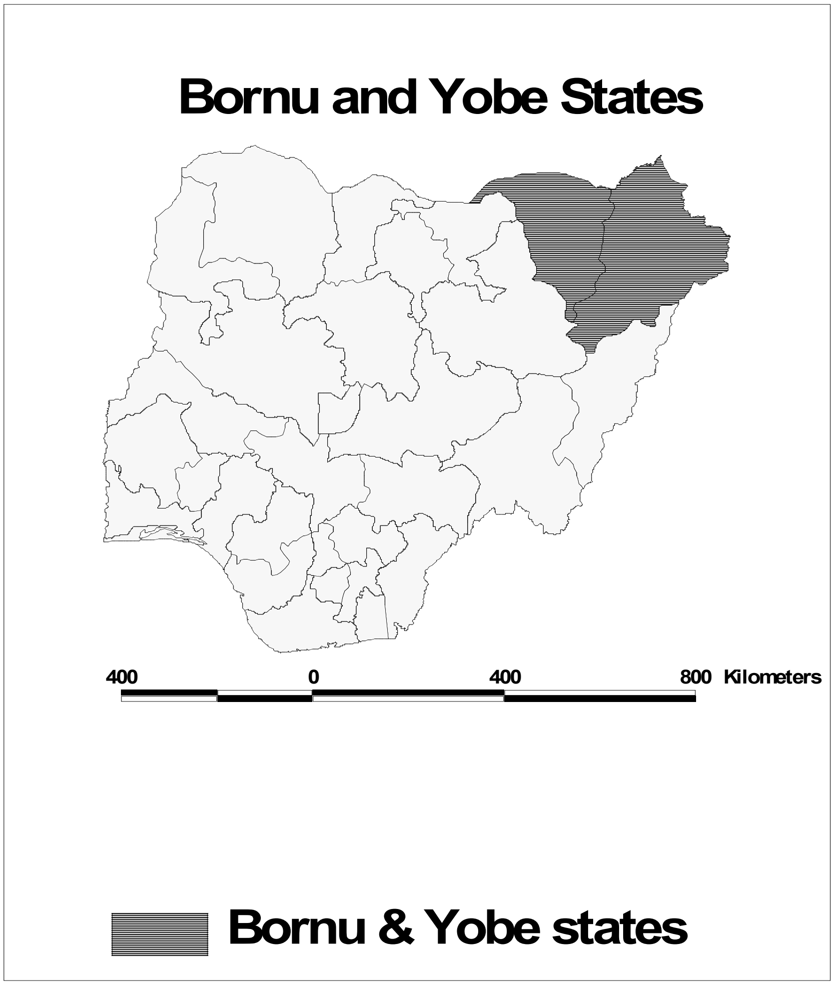


Fig. 4.1: Bornu and Yobe states in the arid zone

Bivariate correlation analysis was used to derive the coefficients of correlation and determination respectively (*r and* r^2) where climate was considered as a single variable. The output of the bivariate correlation indicated the level of significance. Multiple correlation analysis was used to derive the coefficients of correlation and determination respectively (R and R^2) where the climate factor was presented as a multiplicity of variables. R (*r*) was interpreted as measures of the sensitivity of crop yield to climate variation. On the other hand, R^2 (r^2) was interpreted as estimates of the proportion of the variability in the dependent variable that was explained by the independent climate variable or variables.

Since one of our primary objectives was also to estimate the relative contributions of each climate independent variable in determining the variability of crop yield, we opted for the backward selection procedures for the regression analysis. The method begins with the regression of yield on all explanatory variables. The procedure goes on to determine the highest values of R and R^2 that the entire group of explanatory variables could be responsible for. It then eliminates all those variables that are not required in estimating the highest values of R and R^2. The method proceeds by removing a single explanatory variable at each cycle of regression, creating in the process a predictive model with decreasing R^2, decreasing number of variables, and increasing level of significance. The optimum model is the one with the highest R^2 and significance at or higher than the confidence limits set for the analysis (0.05 %). The selected optimum model comes with its own intercept, predictors, predictor-multipliers, R and R^2, model confidence limits as well as predictor confidence limits. All of these go into determining the acceptability or otherwise of the model as a predictor of crop yield.

The climate variables used in the various linear model analyses include not only the annual and seasonal totals, but also the rainfall of each month during the growing season. Thus, while the dependent variables consisted of the yields of the various crops, the independent variables were disaggregates of seasonal rainfall at the two meteorological stations, Maiduguri and Potiskum, in the area where the yield was measured. JUNM (June Maiduguri) is June rainfall for Maiduguri while SEPTP (September rainfall for Potiskum) is September rainfall for Potiskum. The use of rainfall disaggregates at the sub seasonal time resolutions was informed by the realization that optimum crop yield is determined, not by the adequacy of seasonal totals, but by the adequacy of rainfall for each phase in the growth and development of the crop plant from planting date to harvest date.

4.3.2 Study of crop yield sensitivity to intra-annual climate variability

Although our main concern in the exercise reported here is with inter-annual climate variability, it is necessary to bear in mind the fact that factors whose effects are not thrown into relief by inter-annual climate variability contribute to the level of yield recorded. To demonstrate the effects of these other factors, farm level data on maize crop yield and climate elements collected at the Research Farm of the Obafemi Awolowo University in the Rain Forest Belt were analysed. The data were in respect of the period from 1978 to 1990. For this period there were data for planting dates, crop yield, and rainfall, number of rain days, drought probability and maximum temperature in degrees Celsius. For the three years including 1978, 1980 and 1981, the list of climate elements measured was longer, including: total rainfall, maximum temperature, minimum temperature, mean temperature, sunshine hours, potential evapo-transpiration, maximum relative humidity, minimum relative humidity, mean relative humidity, heat units, and effective rainfall. Because during these three years, maize was planted on 25 different dates, we were able to increase the number of observations from three to 25. The time from each planting date to the corresponding harvesting date was recognized as a crop growing period and, therefore, as a separate observation period.

The data were subjected to bivariate correlation and stepwise multiple regression analyses with crop yield as dependent and climatic elements as independent variables. The output included: correlation coefficients (r and R), partial regression coefficients (b-values), coefficients of determination (r^2 and R^2), linear equations and trend lines.

4.3.3 Indexing variable annual impacts

The study outlined in the following paragraphs was conducted in the same area in which the study of crop yield sensitivity to contemporary climate variability was undertaken, that is in the semi arid zone of Nigeria. The data used were for Bornu and Yobe states.

The correlation and regression approaches have given us measures of the sensitivity of crop yield to climate variability. In addition, they have been used in constructing models for the forecast of crop yield from climate. However, the linear approach failed to address two main issues. First is the issue of the magnitude of the impact. Neither correlation nor regression analysis resulted in the derivation of measures of the impacts of the climate as they vary from one year to another. R^2 gave a measure of the total impact over the entire period of study not for the individual years. The second issue is that of the significance of the impact. It is not every change in crop yield that could be described as impact. There should be a way of making distinction between impact and mere sensitivity.

Inter-annual changes in crop yield are usually interpreted as consequences of the corresponding inter-annual changes in climate. There is a basic assumption of a state of normality in the system of concern from which there is a departure that is interpreted as the consequence of the changes in the environment factor. It is not every change in yield that could be interpreted as a significant departure from normality. One could index the varying significance of annual effects of climate on crop yield with a z transformation of the annual yield anomaly data (Norcliffe, 1977; Walford, 1995). The transformation is achieved with:

$$Z = \frac{X - \bar{X}}{SD};$$

i. e. annual yield minus mean annual yield divided by the standard deviation. This produced a Z-distribution array with values varying from approximately –3 to approximately + 3. Values < –1.6 or > + 1.6 indicate anomalies that are significant at 95 percent confidence levels. Higher confidence limits could be set. For example values < –2.3 and > 2.3 define anomalies that are significant at 99 percent. The interpretation is that the yields observed during the years with significant anomalies lie outside the normal range. To be specific, what we have done in assessing the impact of climate variability is as follows: (i) ddetermine the magnitude of annual anomalies in crop yield, (ii) assign negative and positive signs to the anomalies as may be appropriate, (iii) ddetermine which anomalies could be considered as significant or insignificant in the statistical sense,

4.4 Results: Sensitivity of Crop Yield to Climate Variability

4.4.1 The determinants of inter-annual changes in crop yield

The study area for the sensitivity and impact analyses is coterminous with the present Bornu and Yobe states in Nigeria. It covers an area of about 70,000 square km lying between latitudes 10 ^{o} N and 13 ^{o} N and between longitudes 12^{o} E and 15 ^{o} E in the north eastern corner of the country. It is part of the Arid Zone of Nigeria, which consists of the Sudan Savannah and the Sahel Savannah ecological zones. The Sahelian area lies to the north, with an east-west alignment. It occupies about 40 percent of the study area. The Sudan area occupies the southern 60 percent. The climatic data used for the analyses were from the records of the two meteorological stations within the area of study, namely: Maiduguri and Potiskum. The crop yield and climate data covered the 17-year period from 1983 to 1999. The major food crops included in the analyses were maize, sorghum, rice, millet, cowpeas and groundnut.

Bivariate correlation between crop yield and total seasonal rainfall (JJASP) for Maiduguri was not significant at the 0.05. The same was true for the correlation with the three-monthly totals (JJAM and JASM), the two-monthly totals (JJM, JAM, and ASM) as well as the monthly totals (JUNM, JULM, AUGM, and SEPTM). This situation was however somewhat different with respect to the relationship between crop yield and the monthly total rainfall for Potiskum Table 4.1). Some of the components of rainfall were significantly correlated with crop yield. For instance, there was positive and significant relationship between cowpea yield and total seasonal rainfall (JJASP), June and July total rainfall (JJP), June rainfall (JP). The relationship between groundnut yield and June rainfall (JP) was indicated by positive and significant correlation. The relationship between millet yield and September rainfall was negative and significant.

	Maize	Sorghum	G/Nut	Cowpea	Rice	Millet
JJAS	0.27	0.05	0.16	0.54*	0.07	0.42
JJA	0.16	-0.12	0.17	0.44	0.06	0.25
JAS	0.22	-0.004	-0.01	0.42	-0.02	0.03
JJ	-0.13	0.04	0.39	0.55*	-0.07	0.35
JA	0.96	-0.20	-0.03	0.31	-0.04	0.14
AS	0.32	0.11	-0.07	0.27	0.05	0.36
JUN	0.23	0.20	0.59*	0.49*	0.29	0.36
JUL	-0.10	-0.21	0.10	0.49*	-0.13	0.10
AUG	0.19	-0.12	-0.10	0.08	0.03	0.12
SEP	0.34	0.42	0.03	0.40	0.04	0.52*

** Correlation is significant at the 0.05 level (2-tailed)*

*** Correlation is significant at the 0.01 level (2-tailed)*

Table 4.1: Potiskum correlation between components of rainfall and crop yield

4.4.2 Differential effects of two weather stations

The observation that crop yields in the area of study were in general, not particularly affected by the components of rainfall variation in Maiduguri is confirmed by the results of the multiple correlation analysis depicted in Table 4.2. In the table, fourteen out of the 16 most powerful determinants of crop yield were derived from Potiskum rainfall compared with two derived from Maiduguri rainfall. The interpretation one could give to this result is that the rainfall data of Potiskum were more representative of the crop producing areas of the areas of the two states. This is quite understandable because Maiduguri is located in the drier, Sahelian parts of the area while Postikum is located in the wetter Sudan areas. It is conceivable that more of the outputs from the farms would be derived from the Sudan than from the Sahelian areas. Such a pattern would tend to make the total farm output to correlate more with Potiskum than with Maiduguri rainfall.

Crops	Variables	Multipliers	Level of significance
MAIZE	JUNP	8.443	0.012
	JJP	-8.247	0.018
	SEPTP	3.024	0.037
	JULP	5.879	0.055
SORGHUM	SEPTP	1.655	0.081
	JULP	-3.32	0.031
	SEPTM	1.469	0.134
	JJP	1.632	0.185
GNUT	JUNP	4.462	0.013
	SEPTM	2.026	0.089
	JUNM	-2.094	0.152
	JJP	-1.026	0.485
COWPEA	JUNP	3.947	0.006
	JULP	2.972	0.020
	SEPTP	1.271	0.025
	JJP	-2.446	0.066
RICE	JUNP	5.247	0,114
	AUGM	2.907	0.200
	JJP	-2.976	0.20.3
	JULM	2.306	0.281
MILLET	SEPTP	1.507	0.014
	JUNP	1.451	0.050
	JULM	0.886	0.115
	JULP	-0.359	0.518

Table 4.2: The most powerful determinants of Yield

4.4.3 Differential effects of rainfall on the six crops

The results of the multiple correlation analysis are depicted in Table 4.3. The coefficients of correlation are significant only with respect to four crops, namely: maize, groundnut, cowpea and millet. Going by the magnitude of the coefficients, cowpea is the most sensitive to climate variability with an R of 0.872. The other relationships indicated with significant RS were with millet (0.739), maize (0.714) and groundnut (0.697). R^2 values show that as much as three quarters of the variability in the yield of cowpea was determined by rainfall variability. For the other three crops, the proportion of the variability in yield determined by rainfall variability is around 50 percent. We can now offer some explanation for the relatively weak sensitivity of the yields of rice and sorghum to rainfall variability. In the case of rice, a substantial proportion of the crop is produced at fadama sites. These are poorly drained to swampy valley bottom locations where soil water is available for plant growth for a period much longer than the rainy season. Irrigation is also practiced, based on water stored in shallow hand dug pits, especially where an impermeable, clayey sub-surface soil layer is present. Such practices as these are likely to reduce significantly the dependence of crop yield on seasonal rainfall. In the case of sorghum, the low sensitivity may be connected with the drought tolerance of the crop plant. Adaptation of sorghum to the very harsh agronomic situations characteristics of the semi arid regions of West Africa is based largely on its ability to withstand very high temperatures and to remain dormant through prolonged dry spells and then resume growth as soon as there is some rain (Johnston, 1958). This may result in low sensitivity of the crop to rainfall variability especially at the lower ends where the departures from the mean are small.

Crop	**R**	**R^2**	**Sig. Level**	**Sig at 0.05**
Maize	0.714	0.510	0.053	Yes
Sorghum	0.681	0.463	0.09	No
Groundnut	0.697	0.486	0.030	Yes
Cowpeas	0.872	0.760	0.027	Yes
Rice	0.433	0.188	0.082	No
Millet	0.739	0.546	0.037	Yes

Table 4.3: Multiple correlation analysis: rainfall and crop yield

4.4.4 Yield predictors

Judging by the number of entries and especially the significance attached to its multipliers in Table 4.2, June rainfall is a more powerful predictor of crop yield than any of the other monthly rainfall variables. This is explained by the fact that June is the month of the onset of the rainy season. Low or insufficient June rainfall implies a delayed onset and a rainy season not long enough for the needs of most crops. In the respective cases of each of the four crops in the table, September rainfall also serves as a powerful predictor of yield. September is the month of cessation of the rainy season. Low or inadequate rain in September is evidence that the season is truncated before it could provide adequate moisture for crops during the critical phases of grain filling.

4.4.5 Prediction models significant at 0.05 levels

1. Maize yield = 533+ 8.443 JUNP – 8.247 JJP + 3.024 SEPTP + 5.879 JULP -------------- (1)

   R = 0.714 R^2=0.510 SIG=0.053
2. Groundnut yield = 686 + 4.462 JUNP + 2.026 SEPTM – 2.094 JUNM – 1.026 JJP --------------- (2)

   R = 0.697 R^2=0.486 SIG=0.030
3. Cowpeas yield = 144 + 3.947 JUNP + 2.972 JULP + 1.271 SEPTP – 2.44 JJP + 0.564 JULM – 0.201 AUGP – 0.339 AUGM ------------------------- (3)

   R = 0.872 R^2=0.760 SIG=0.027
4. Millet yield = 534 + 1.507 SEPTP + 1.451 JUNP + 0.866 JULM –0.359 JULP ------------- (4)

   R = 0.739 R^2=0.546 SIG=0.037

4.5 Sensitivity of Yield to Intra-Annual Climate Variability

This study is based on just one crop, maize, for which data were available at the Obafemi Awolowo University Research Farm. The data covered the period from 1978 to 1990. It is believed that the findings can be extrapolated to other parts of Nigeria and West Africa. The findings can also apply to the other cereal crops, especially, sorghum (Olaniran and Babatolu, 1987).

Results of the study revealed that RH (relative humidity) generally showed negative correlation with yield (Table 4.4), presumably because of overcast skies and/or heavy rainfall associated, especially since sunshine hours showed a consistent positive relationship with yield.

Climate Variable	**Correlation coefficient**	**Coefficient of determination**
Total rainfall	-0.28	0.08
Max Temperature	0.81**	0.65
Min Temperature	-0.05	0.0025
Mean Temperature	0.61**	0.37
Sunshine hours	0.81**	0.65
Potential evaporation	0.65**	0.42
Max RH	-0.90**	0.81
Min RH	-0.88	0.77
Mean RH	-0.90**	0.81
Heat Units	-0.33	0.11
Effective rainfall	-0.46*	0.21

** Significant at 0.05*

*** Significant at 0.01 level of probability*

Table 4.4: Correlation analysis: maize yield and climate variables

Stepwise multiple regression of the combined data (Table 4.5) showed that maximum RH was the most important climatic variable influencing yield, with a highly significant negative correlation (r = -0.90**).

Climatic variable	**b-value**	**R^2**	**ΔR^2**
Max. RH	-0.28	0.81**	0.81
Min. RH	-0.18	0.83**	0.02
Potential evaporation	-0.16	0.86**	0.03
Mean temperature	0.38	0.88**	0.02

** Significant at 0.05 level*

*** Significant at 0.01 level.*

Table 4.5: Partial regression coefficients (b-values), coefficients of determination (R^2) and R^2 change (ΔR^2) from the stepwise multiple regression of yield on climatic variable for maize.

Simple linear regression of grain yield on max RH showed that yield decreased by 431 kg/ha for every unit increase in max RH, as determined by the linear equation:

$$\hat{Y} = 38.511 - 0.431X;\ r^2 = 0.81^{**} \text{ ------------------------------------ } (5)$$

Sunshine hours had significant large, positive correlation with yield (Table 4.4). When used as the independent variable in a regression with yield, the following equation was obtained:

$$\hat{Y} = -2.325 + 0.01X;\ r^2 = 0.65^{**} \text{ ---------------------------------- } (6)$$

It would seem, therefore, that a constant value of maximum RH, increases in sunshine hours, maximum temperature and potential evaporation would be expected to increase yield moderately. For example, multiple regression of yield on maximum RH (X_1) and sunshine hours (X_2) produced the prediction equation:

$$\hat{Y} = 34.53 - 0.3901X_1 + 0.0012X_2; R^2 = 0.81 \text{ ---------------------- } (7)$$

Using this equation to predict grain yield for combinations of these two variables showed clearly that at a constant rate of maximum RH, plus increased sunshine hours resulted only in modest increases in grain yield. On the other hand, at a constant value of sunshine hours, increased maximum RH rapidly decreased yield. In contrast, potential evaporation demonstrated large negative direct effect and indirect effects via maximum temperature and sunshine hours, and large positive effects through maximum and minimum RH. Its indirect effects through minimum temperature and heat units were moderate.

4.6 Variable Significance of Annual Impacts of Climate

Anomalies of crop yield are depicted in Table 4.6. Out of the 102 anomaly records, only 7 were significant, that is with a magnitude of 1.66 or higher. Six of these anomalies were significant at 95 percent confidence limits and only one significant at the 99 percent level. Three negative anomalies, significant at the 95 percent limit were recorded for 1990. One negative anomaly, significant at 95 percent level was recorded for 1988. One positive anomaly, significant at the 99 percent level was recorded for 1993. Two other anomalies, significant at 95 percent level were recorded for 1994 and 1997 respectively. It thus appears that 1988 and 1990 were the years with negative anomalies while 1993, 1994 and 1997 were the years with positive anomalies of crop yield.

For rice, there was no year with significant anomaly of crop yield. The yield recorded for maize in 1990 represented a significant negative anomaly while that for 1993 represented a significant positive anomaly. Two significant anomalies were also recorded for millet: one negative, 1990, and the other positive, 1994. For sorghum, the only significant anomaly was negative and was recorded for 1990. Also only one significant negative anomaly was recorded for cow peas and that was for 1988. Groundnuts yields also rose significantly higher than the normal in 1997. It thus appears that the worst year for crop yield was 1990 during which significantly low levels of crop yields were recorded for the three major cereal crops: maize sorghum and millet.

For a great majority of the years, departures from the mean were not significant and what could be described as normal yield levels were the order. The years during which negative yield anomalies were observed varied from one crop to the other. For example, it was only in 1990 that negative anomalies were recorded for all the crops. However, the anomalies were significant with respect to only three of the crops. In 1988, the negative cowpea yield was also significant. Positive anomalies were recorded in 1993, 1995 and 1997, respectively for maize, millet and groundnut. In the other years crop yield anomalies did not attain the levels at which they could be considered as significant. The years during which negative yield anomalies were recorded for just one crop did not correspond to any discernible unfavourable weather. However, when significant negative anomalies were recorded for all or most of the crops corresponded to the year with unfavourable weather. For example, in 1990 negative yield anomalies were recorded for all the crops. The anomalies were significant with respect to three crops, namely: maize, sorghum and millet. The weather for that year in Potiskum was abnormally dry. In 1988, the negative cowpea yield anomaly was significant at 95 percent confidence limit even though there was no discernible negative weather anomaly. Based on these results and the fact that climate is the only factor in the crop environment that is characterized by an annual time resolution, one may conclude that the impact of climate on crop yield is significant in certain years and not significant in others. 1990 was the year during which one can say there was an unmistakable impact of climate on crop yield in the study area.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Maize	-0.69	-1.33	1.03	0.17	0.82	-0.56	-0.34	-1.75*	-0.02	0.29	2.45**	0.34	0.22	0.76	-0.62	-0.46	-0.32
Sorghum	0.19	1.16	0.68	-0.77	-1.25	-1.2	-0.94	-1.66*	-0.57	0.03	-0.65	1.2	1.56	0.51	0.51	0.69	0.55
G/Nut	1.46	-1.25	0.27	0	-0.49	-1.16	-0.89	-1.06	-0.92	-0.4	-0.71	0.12	0.37	0.91	1.87*	0.94	0.94
Cowpea	0.54	-1	0.15	1.3	-1	-1.76*	-0.88	-1.43	-0.82	-0.37	0.77	0.57	0.65	0.68	1.07	1.05	0.47
Rice	-1	-0.52	-0.29	0.19	1.62	-1.35	-0.97	-1.36	-1.05	0.53	-0.57	1.52	1.09	0.53	0.53	0.58	0.52
Millet	-1.25	0.68	0.19	1.16	-0.77	-1.51	-0.86	-1.73*	-0.47	-0.12	-0.06	1.68*	0.51	0.64	0.64	0.68	0.6

** Anomaly significant at the 0.05 level*
*** Anomaly significant at the 0.01 level*

Table 4.6: Anomalies of crop yield from 1983-1999

4.6.1 The impact of the 1990 drought on crop yield

In 1990, with the exception of cowpeas, all the crops recorded their highest negative yield anomalies for the period from 1983 to 1999. Cowpeas also recorded yield anomaly that was the second highest for the period. The daily rainfall patterns for the months of April to November for Potiskum in 1990 are depicted in Table 4.7. First, the year recorded the lowest growing season rainfall from 1983 to 1999. This amounted to 319 mm for the four months, June, July, August, and September compared with an average of 748 for the 1983 to 1999 period. Given the fact that daily rainfall of at least 3 to 5 mm is required to balance evaporation and transpiration (Garnier, 1961), the 25 mm rainfall of June was grossly inadequate to wet the fields in preparation for tilling the soil and planting the crops. For this, June could be counted out of the 1990 growing season. Another observation is that, rain stopped abruptly in September. There was no rain during the first two weeks of the month when cereal crops planted in the middle of July would be at the stage of grain filling. The 19.3 mm of rain for that month fell in two ineffective showers of 12 mm and 7 mm respectively. One could therefore also disregard September as part of the growing season. Thus the growing season in that year lasted only two months. With this pattern of rainfall, 1990 was an example of a drought year. The widespread drought of 1973–74 was remembered in our study area (Participatory Rapid Appraisal Survey (PRA) described in Chapter 6). However, the droughts observed in 1983 and 1987 in other parts of the Nigerian Arid Zone did not have any significant impact, according to the data available. The people could recall bad harvests in 1973, which resulted from early cessation of the rains. It was not only crops that were affected by droughts. Animals also suffered when the grass dried up for prolonged periods. Apart from this particular year, their recollection is of good harvests during the past thirty years. According to the farmers in this area, the drought of 1990 was not as severe as that of 1973-74. It appears that there were major droughts, which were widespread in occurrence and local droughts such as the one observed in Potiskum in 1990. According to the peasant householders in responding to our questionnaire, the drought of 1973-74 caused more damage than the drought of 1990. Most droughts are local and could occur in different years in different places (Adejuwon, et al, 1990).

4.7 Summary and Conclusions

4.7.1 Methodology of impact assessment

Some of the main findings in this study are related to the methodology of the assessment of the impacts of climate variability on crop yield. In the study, we were first led to adopt a definition conceiving impacts as a measure of crop yield responses to inter annual changes in climate. In this context, we considered it sufficient to apply the usually reliable tools of linear models. Bivariate correlations were used as a means of providing the required measures. Thus the magnitude of the coefficients of correlation (*r*) was adopted as a first approximation of the impacts. In applying the bivariate correlation model, a problem arose from the inability of the total seasonal rainfall to capture the essence of the association between climate variability and crop yield. The resulting coefficients of correlation were not significant at the acceptable levels. Better results were achieved by adopting disaggregates of seasonal rainfall such as monthly rainfall within the growing season as independent variables. This was justified on the grounds that the impacts on crop yield were summations of the multiplicity of impacts on the processes of crop growth, development, flowering, seed production and maturity. The totality of the impacts was achieved cumulatively from a dynamic climate pattern. In other words, what the methodology had to contend with was not a single variable but a multiplicity of rainfall variables. The time-dependent succession of impacts could however not be added up at the level of the '*r*'s. Multivariate correlation and regression analyses provided us with a methodology for adding up the impact components into a single seasonal climate impact.

Days	April	May	June	July	Aug	Sept	Oct	Nov
1				17.3			50.0	
2				8.9				
3								
4					7.0	Tr		
5		4.1						
6								
7				40.9				
8					8.0			
9		3.1				Tr		
10							27.4	
11						Tr		
12		4.7		22.8				
13		Tr			7.0			
14		Tr		8.6		12.5		
15								
16		0.9						
17				26.9	26.6			
18			2.6					
19				29.0	5.2			
20								
21								
22				3.3				
23						6.8		
24			Tr					
25			1.3		14.9			
26				21.8				
27			11.5					
28								
29			9.6	7.5				
30				2.8				
31	xxxx		xxxx		16.9	xxxx		xxxx
Total		12.8	25.0	189.8	85.6	19.3	77.4	0.0

Table 4.7: Daily rainfall, April to October, Potiskum, 1990

Our indexing of variable impacts using crop yield anomalies is an innovation in the methodology of climate impact assessment. The essence of this approach is to convert crop yield arrays into anomalies of crop yield which could be interpreted as impacts of climate. The signs of the anomalies were adopted as signs of the impacts. The signs, magnitude and significant levels of the impacts were used to divide the yields into those representing negative impacts, positive impacts and a broad band of insignificant departures from normality. The basic assumption of this approach was that the observed crop yield anomalies were consequences of inter-annual climate variability. This assumption could be justified by the fact that, among the crop ecological factors, climate is the one with a pronounced and consistent annual time resolution.

The exercise of assessing impacts of climate variability over a 17-year period suffered from inadequacy of data. For one thing, the time span appeared to be rather short. Also it must be remembered that the crop yield data were collected using a sample of farming households. Such data are usually characterized by a multiplicity of errors; including sampling in addition to other human errors. The climate data were those collected from the two standard meteorological stations within the area of study, Potiskum and Maiduguri. Thus, there was the question of whether they were sufficiently representative of an area covering about 70,000 sq. km. The fact that the levels of the correlations of each of the two data sets with crop yields varied is sufficient proof that the data sets may not be as representative as assumed.

One basic requirement of linear models is that both the independent and the dependent variables must be continuous and continuously associated (Dunteman, 1984). However, even where both the dependent and the independent data are separately continuous, the relationship might not be continuous. For example the relationship between the variability of crop yield and the variability of the weather or climate is not always continuous. The sensitivity of crop yield to moisture and rainfall will be more easily observed when moisture supply is approaching the critical minimum (Odum, 1971). Whenever moisture supply is adequate, change in crop yield will cease to depend on this variable, which is no longer the limiting factor. For example, if rainfall were adequate for optimum crop yield for our crops of interest over a period of thirty years, whatever may be the moisture variability over those thirty years will not be related to, and will have no impacts on changes in crop yield. The reciprocal is that over the thirty years, whatever may be the variability in crop yield observed could not be explained in terms of changes in moisture supply or rainfall. It should, therefore, be appreciated that impact is discontinuous. It is recorded when external perturbation exceeds a threshold and a significant change occurs in the exposure unit. Between one impact recording year and the next, there are other years during which normality prevails. This is the explanation for the fact that for a majority of the years of analysis, variability of rainfall is not translated into variability of crop yield. This could go a long way to dilute the linear relationship, reduce the magnitude of the coefficients of correlation and frustrate the development of measures of impact based on linear models.

4.7.2 Importance of the study of impacts of intra-annual climate variability

One of the justifications of the study of impacts of climate variability is the expectation that it could form a template for the assessment of climate change impacts. Since there is no observed data, on which to base a direct assessment of the impacts of climate change, it was considered reasonable to expect that findings based on climate variability studies could be used as surrogates for potential impacts of climate change. However, in our study area, while the significant elements of inter-annual climate variability are limited to rainfall and moisture-related parameters, the most significant elements of climate change are based in temperature. This limits the extent to which our understanding of inter annual climate variability impacts could be used to gain an insight into the impacts of projected climate change. Our study of impacts of intra-annual climate variability has been very useful in this regard. Sensitivity of maize yield to temperature and the other factors that do not vary significantly at the inter-annual scale were observed to be significant at the intra annual resolution. This has provided a much needed validation of our findings, later to be reported, on climate change impacts.

4.7.3 Variable impacts on different crops

Impacts of climate variability differ from one crop to the other. Thus, in the same year that maize records a crop failure, cow peas may record normal yield levels. This is probably due to the fact that the length of the period from planting to harvesting varies considerably. Moreover, the calendar time of panting also vary from crop to crop. While the major cereals are planted as soon as the first rains arrive, cow peas and ground nuts are planted later in the season. In general, climate impacts were observed to be least on the yield of rice among the six crops considered in the Arid Zone study. This was evident from the values of the coefficients of correlation. It was also evident from the low magnitudes of the yield anomalies over the 17-year period. This could be due to the fact that rice is more likely to be irrigated than the other crops. The crop whose yield is most likely to be impacted by climate variability turned out to be cow peas. The next is maize followed by millet. Negative impacts of climate are more likely to result from inadequate rainfall in June, September or both months. Cowpeas and other late season crops are particularly susceptible to the vagaries of September rainfall.

At the present, climate forecasts in West Africa are for the total seasonal rainfall. This is definitely not sufficient for forecasting crop yields or the impacts of climate. There is thus an urgent need for forecasts of onset and termination of the growing season. With a mind to the relatively low skill levels of the existing capacity for extended range weather forecasting in the sub-continent, the request for sub-seasonal level weather forecasts will be an additional burden on the extended range weather forecasting community. The Nigerian Central Forecasting Office is the only organization with the capacity for making such forecasts (Adejuwon and Odekunle, 2004). There is thus the need to strengthen such national forecasting organizations.

5 Impact of Climate Change on Crop Productivity

5.1 Introduction

The chapter is organized into 5 main sections including this introduction. In section 2, we provide the details of the activities conducted to address the issue of the impacts of climate change on food crop production. These activities led to the choices of approaches for characterizing the impacts of climate change on crop yield. First is the choice of climate change scenarios for the assessment, and second is the choice of a crop model for the simulation of crop yield. In section 3, we describe the scientific methods used in the assessment. Section 4 gives the details of the results of experiments designed to highlight the impacts of individual climatic elements based on arbitrary incremental scenarios. In section 5, the details of crop yield simulations for various time slices between 1961 and 2100 are demonstrated. The results are discussed in section 6.

5.2 Activities Conducted

5.2.1 Climate change scenarios

For the purpose of characterizing the impacts of climate change on the yield of crops, two separate approaches were borrowed from the recommendations of the US Country Studies Program (1994:5-3). In one approach, we adopted arbitrary incremental scenarios to assess the sensitivity of crop yield to changes in the various elements of climate. Using EPIC Crop Model, we conducted sensitivity tests to demonstrate crop yield responses to changes in CO_2 concentration, temperature, rainfall, relative humidity and solar radiation. Thus, the approach afforded us the opportunity to demonstrate the impacts of each climate element separately. The value of one element was altered incrementally while holding down the values of the others. In the second approach, we adopted scenarios based on GCM (General Circulation Models) to estimate potential future changes in crop yield. Specifically, we made use of the scenario earlier presented in Chapter Two which covered the period from 1961 to 2099 and which specified the climate of four time slices, including: 1961–1990; 2010–2039; 2040–2069; 2070–2099. The scenario was one of the outputs of experiments conducted with Hadley M2 General Circulation Model assuming cumulative increases of 1% per annum in atmospheric concentration of carbon dioxide. It is a "worst case" because it falls into a group including: IS92e, IS92f, SRES A1F1 and SRES A2, each of which is projected to result in the highest concentrations of greenhouse gases and highest radiative forcing of climate change by the end of the 21st century (IPCC, 1995, 2000). The control (best case) scenario is one based on an annual increase of 0.5% per annum, which falls into the group of low emission scenarios including: IS92d, SRES B1 and SRES A1T. An increase of 0.5 percent per annum will result in a concentration of 560 ppm by the year 2100. The results of the simulations with the control scenario indicate changes that are less spectacular than those described in this chapter.

5.2.2 Creation of EPIC crop model data files

The simulation of crop yield, which formed the basis for the assessment of the impacts of climate change, required the creation of EPIC8120 Crop Model data files. EPIC consists of a main data file created for each farm level site of interest. In the main part, the data file includes; program control codes, general site data, water erosion data, climate data, wind erosion data, soil data, management information operations codes and management information operation variables. The main data file requires 446 items of input data three hundred of which are the climatic characteristics of each modelled site. As downloaded from the web <www.brc.tamus.edu.epic>, the crop model includes such characteristics for all possible selected sites for continental United States. For Nigeria however, each item of datum had to be computed using data covering at least 30 years. In the process of creating the file for each site, the summary of the climatic records of the station was entered. A total of 112 EPIC data files were created, four for each of the 28 synoptic weather stations. Each of the four files was based on the mean climate characteristics of one out of four time slices, namely: 1961–1990; 2010–2039; 2040–2069; and 207–2099, used for the assessment of the impacts of climate change. To run the model, three other files (daily weather, soil and operations schedule) were created. One daily weather file was created for each year and one soil file for each soil series represented at the site. An operations schedule file was created for each crop, giving details of farm operations and the dates of their execution... For each run, the appropriate combination of files was loaded into EPIC.

We have assessed the suitability of EPIC Crop Model for the study of the impacts of climate variability and climate change in West Africa (Adejuwon, 2005). Our conclusion is that the crop model could be satisfactorily applied to impact and adaptation studies. For the estimation of production and vulnerability assessment, supplementary field validation is required.

5.2.3 The case studies

The assessment of the impacts of climate change on crop productivity was undertaken in ten case studies. Five of the studies adopted incremental scenarios and were designed to demonstrate the relative effects of individual climate elements on crop yield. Using EPIC Crop Model, the elements investigated include: rainfall, relative humidity, temperature, solar radiation and carbon dioxide. EPIC data file for Ilorin, in the southern Guinea Savannah ecological zone was used in the rainfall and relative humidity study. The data file for Jos, representing high altitude ecology was used for the studies of the relative sensitivities to changes in temperature, CO_2 and solar radiation. The other five case studies adopted GCM scenarios. Each of the studies in this group was designed to demonstrate changes in simulated yield of a particular crop, from the baseline of 1961-1990 through three other time slices including: 2010-2039; 2040-2069 and 2070-2099. Only five crops including: maize, millet, sorghum, rice and cassava were investigated. The other major crops, yam, and cocoyam were not in the crop list of EPIC. The output of the model runs included, not just the yield of the crops, but also the numbers of days of water stress, nitrogen stress, phosphorus stress, temperature stress and aeration stress. Stress occurs on such days when the specific needs of the crop plants are presented in such amounts that lie outside the limits of tolerance. To cause stress, temperature may be too low or too high. Also, water presented in amounts less than the minimum or more than the maximum that could be tolerated results in stress. There is aeration stress when too much water in the soil fills all the spaces between soil particles.

5.3 Description Of Scientific Methods

In the case of the study of sensitivity to changing seasonal rainfall at Ilorin, the strategy was to modify the EPIC data file created with 1961-90 data, by increasing the values entered for the monthly rainfall by 5%, 10% and 15%. This results in an artificial scenario with four members including the original file. EPIC runs were conducted with the data files with the outputs demonstrating the changes that could occur in the yield of maize if the climate becomes generally wetter. The same strategy was adopted to assess the possible effects of changing relative humidity (RH) on maize yield, also using an initial data file created for Ilorin.

To assess the effects of changing temperature on crop yield, the main EPIC data file created for Jos, located at an altitude of 1200 metres in the sub-humid belt, with the observed data for the period, 1961 to 1990 was used. The Operations Schedule file was created for planting maize. Changing the values for monthly minimum and maximum temperatures created three other data files. To create one file, 1^{o} C was added to the values of the monthly maximum temperature, and at the same time, 2^{o} C was added to the values of the minimum temperature. For another file, 2^{o} C was added to the values of both minimum and maximum temperatures. For the third file 2^{o} C was added to the values of the maximum temperatures and 3^{o} C to the values of the minimum temperatures. The outputs from the runs of these files generated the yield scenarios that were analysed to demonstrate the impacts of changing temperature.

For the assessment of the impacts of changing solar radiation and carbon dioxide concentration, EPIC file created also for Jos, using 1961-90, data represented the baseline climate. The artificial scenario for solar radiation included three other files with the values of solar radiation increased by 5% in succession. For the CO_2 concentration levels, the scenario consisted of data files with concentrations of 350, 370, 500 and 650 parts per million respectively.

5.3.1 Assessing climate change impacts with GCM outputs

The climate change scenario described in Chapter Two was used in creating EPIC data files for six sites and four time slices. The time slices were, respectively: 1961-90, 2010-39, 2040-69, and 2070-2099. The sites represent six ecological zones which, respectively were: Rain Forest, Southern Guinea Savannah, Northern Guinea Savannah, Jos Plateau, Sudan Savannah and Sahel Savannah. The five crops involved in the assessment included: maize, rice, sorghum, millet and cassava. The files were used to simulate crop yield to demonstrate changes corresponding to the potential changes in climate during the 21st century. The data were analysed, using bar graphs for each crop and each zone.

5.4 Crop Yield Sensitivity To Climatic Elements

5.4.1 Sensitivity to seasonal rainfall

Table 5.1 depicts crop yield responses to changing rainfall component of climate. Four crops, including maize, sorghum, millet and rice were included in the experiment. From the results of crop yield simulations, it could be observed that only marginal increases were realized with the increases in rainfall. Rainfall increases of up to 20 percent resulted in yield increases of 2% for maize, 6.6 % for sorghum, 6.6% for millet and 7% for rice. The increases in yield seemed to have been determined largely by the lower levels of water stress resulting from the higher growing season precipitation. There were also constraining influences in the form of increased aeration stress associated also with the increased rainfall. Such influences were, however, not able to nullify the positive impacts of increased rainfall. There were also little or no changes in neither temperature stress, nitrogen stress nor phosphorus stress.

Climate Scenario	**Maize Yield in Tonnes/ha**	**Sorghum Yield in Tonnes/ha**	**Millet Yield in Tonnes/ha**	**Rice Yield in Tonnes/ha**
Climate I Baseline*	4.34	3.02	1.01	2.34
Climate II Baseline Precipitation + 5%	4.34	3.07	1.03	2.40
Climate III Baseline Precipitation + 10%	4.36	3.12	1.04	2.44
Climate IV Baseline Precipitation + 20%	4.44	3.22	1.07	2.52

*Table 5.1: Crop yield sensitivity to changing rainfall (*Baseline is mean for 1961-1990)*

5.4.2 Sensitivity of crop yield to changing relative humidity

The responses to changes in relative humidity arbitrarily introduced are depicted in Table 5.2, in terms of changes in yield. Increases in yield resulting from increased relative humidity appear to be of a much higher magnitude than those resulting from similar percentage changes in precipitation. Compared with increases of only 2% when increases of 20% in rainfall was arbitrarily introduced, maize yield increased by 40% when a similar percentage change was effected with respect to relative humidity. Under similar conditions, sorghum, millet and rice yields increased by 33, 40 and 37 percent. As should be expected, the increases in relative humidity were converted to lower levels of water stress for the benefit of improved crop productivity. In the case of maize, the level of water stress was reduced from 21 to 10 days. For sorghum, increased relative humidity of 20% was translated into a decrease in water stress of ten days. Under similar climate change scenarios, the number of water stress days for millet was reduced by 13 days while that for rice was reduced by 8 days. For rice, maize and sorghum, there were no significant changes in aeration stress that could depress crop yield. However, in the case of millet, aeration stress increased by as much as three days. Even with this, as much as 40% increases in yield was realized.

Climate Scenario	**Maize Yield in Tonnes/ha**	**Sorghum Yield in Tonnes/ha**	**Millet Yield in Tonnes/ha**	**Rice Yield in Tonnes/ha**
Climate I Baseline	4.34	3.02	1.01	2.34
Climate II Baseline RH+ 5%	4.68	3.30	1.12	2.58
Climate III Baseline RH + 10%	4.98	3.56	1.21	2.83
Climate IV Baseline RH + 20%	6.01	4.03	1.41	3.20

**Baseline is mean for 1961-1990*

Table 5.2: Crop yield sensitivity to changing relative humidity

5.4.3 Crop yield sensitivity to changing temperature

In Table 5.3, the yields for the baseline situation as well as for three scenarios of increased temperature are depicted. The results indicate an increase in the simulated yield corresponding to the increases in temperature. These increases are substantial, amounting to more than 80 percent in the case of scenario D in which the minimum temperature was increased by 3^o C while the maximum temperature was increase4d by 2^o C. At this high altitude site, maximum temperature during the growing season varies between 26.20^o C in June and 24.30^o C in August. Minimum temperature also varies between 15.50^o C in June and 15.90^o C in August. Thus the average temperature for Jos is 20^o C. This is about 5^o C less than the optimum for maize, which is given as 25 ^{o} C (Johnston, 1958). Thus there could be room for increased temperature to promote increased yield of maize before the maximum temperature begins to constrain yield. It is conceivable that, an initial increase in temperature will bring about an increase in yield. However, as temperature rises to higher levels, a decrease in yield may set in. But before that the increases in yield will slow down. As depicted in the table, increases in yield seem to be maintained with increasing temperature.

Temperature	Yield: Tonnes/ha.	Cumulative Increase in Yield	Increase %
A	2.207	-	-
B	3.998	1.391	53.3
C	4.384	1.777	68.2
D	4.865	2.258	86.6

A = mean minimum and mean maximum temperature 1970-99

B = A, maximum temperature +1°C; minimum temperature +2°C

C = A, maximum temperature +2°C; minimum temperature +2°C

D = A, maximum temperature +2°C; minimum temperature +3°C

Table 5.3: Crop yield (maize) sensitivity to changing temperature

5.4.4 Crop yield sensitivity to changing amounts of solar radiation

Table 5.4 depicts the pattern of response of maize to different levels of solar radiation, according to the EPIC simulations at a site corresponding to the weather station in Jos, north central Nigeria. The increases in solar radiation were introduced into the EPIC model while retaining the values of the other climatic parameters at the levels of the 1970-95 means. The resulting increases in yield were continuous, regular and considerable, and more or less at the same percentage levels as the increases in solar radiation. The potential yield in the EPIC model is determined primarily by the amount of solar radiation received. The other climatic determining factors play a constraining role, in reducing the potential yields. This conforms to our observations in an earlier study to the effect that lower amounts of solar radiation characterising the main growing season months in Nigeria tend to depress the yield of maize (Adejuwon, 2002). Maize planted at the onset of the rainy season in April when the cloud cover is relatively low, produced significantly higher yields than maize planted in May or June, when the rainy season is well under way. It is therefore not surprising as depicted in the table, that there were increases in yield in response to increases in solar radiation. It is conceivable that the levels of solar radiation at the experiment site, during the growing season for the 1961-90 period, were sub-optimal for maize production. If changes in climate turn out to be as they are currently being projected (IPCC, 2001a), West Africa may experience substantial increases in the yields of cereal crops, not as a result of increases in moisture supply or temperature, but in response to higher levels of solar radiation.

Solar Radiation Levels	Yields: Tonnes/ha	Cumulative Increase in Yield	Increase %
A = mean 1961-90	2.607		
B = A + 5 percent	2.759	0.152	5.8
C = B + 5 percent	2.904	0.297	11.4
D = C + 5 percent	3.062	0.456	17.5

Table 5.4: Sensitivity of crop (maize) yield to changes in solar radiation

5.4.5 Crop yield sensitivity to changing concentrations of atmospheric carbon dioxide

Carbon dioxide in the atmosphere and water are the main feed stocks for the processes of primary production, that is, photosynthesis, upon which life on the earth's surface ultimately depends. One would expect an enhanced level of carbon dioxide concentration in the atmosphere to increase the gradient between the external air and the air spaces inside the leaves, thus promoting higher levels of diffusive transfer and absorption of carbon dioxide into the chloroplasts and higher levels of photosynthesis and of biological productivity. Higher concentrations of atmospheric carbon dioxide should also induce plants to be more economical in the use of water. With higher concentrations of carbon dioxide, crops should be less subject to water stress in areas normally considered marginal with respect to precipitation. The sensitivity of maize to changes in the atmospheric concentration of carbon dioxide at Jos in Central Nigeria confirmed this (Table 5.5). The 20-ppm change in carbon dioxide concentration (from 350 ppm to 370 ppm) resulted in yield increases of 80 kg per hectare, while the much greater 150-ppm change in carbon dioxide concentration (from 500 ppm to 650 ppm) resulted in further yield increases of only 36 kg per hectare. The model, confirmed the progressively smaller response of maize to higher carbon dioxide concentrations. This should be expected because maize is a *C4 plant* (Fischer *et al*., 1996).

CO_2 Concentrations	Yields in Tonnes/ha.	Increase over baseline	Increase %
350 ppm	2.607	-	-
370 ppm	2.687	0.08	3.06
500 ppm	2,835	0.228	8.71
650 ppm	2.871	0.264	10.10

Table 5.5: Crop (maize) yield sensitivity to changing carbon dioxide concentration

5.5 Crop Yield Sensitivity to Climate Change

The output of the model runs included, not just the yield of the crops, but also the numbers of days of water stress, nitrogen stress, phosphorus stress, temperature stress and aeration stress. Stress occurs on such days when the specific needs of the crop plants are presented in such amounts that lie outside the limits of tolerance. To cause stress, temperature may be too low or too high. Also, water presented in amounts less than the minimum or more than the maximum that could be tolerated results in stress. There is aeration stress when too much water in the soil fills all the spaces between soil particles. Crop yield simulated for each time slice were used to characterize changes in crop yield from 1961-1990 to 2070-2099. In explaining the patterns of changes in crop yield, the climate- related stresses were first considered. In addition changes in the elements of climate as outlined earlier in the climate change scenario were also considered.

5.5.1 Maize: 1961 to 2099

The general pattern, in the changes in the yield of maize, as depicted in Figure 5.1, is an initial increase from time slice one to time slice two, followed by a decline towards the end of the 21st Century, that is from time slice three to time slice four. The exception is at Jos, representing high altitude ecology.

The lowest yield for Jos was recorded for the 1961-1990-time slice. Increase in yield, which started during the second time slice, early in the 21st century continued till the end of the century. Yield increased from less than 3 tonnes per hectare during the first time slice to over 6 tonnes per hectare during the 2070-2099 time slice. For Kano, representing the Sudan Savannah ecology, Maiduguri representing the Sahelian ecology, Kaduna, representing Northern Guinean ecology and Port Harcourt, representing the Forest Zone ecology, peak yields were recorded for the third time slice that is 2040-2069. For Ilorin, representing the Southern Guinean ecology, peak yield was recorded for the second time slice that is 2010-2039. The yield recorded for the 4th time slice was lower than the yield recorded for the first. This means that over the 140- year period, a net decrease in the yield of maize is projected.

The steady increase in yield at the high altitude location corresponds to a steady decline in water stress from 47 days during the 1961-90-time slice, to 15 days during the 4th time slice that is 2070-2099. Temperature stress also declined from 2.6 days to 0.5 days. Since the high altitude site also experienced the general warming trend, one could only conclude that the current temperature levels are sub-optimal and that the warmer days ahead would provide environmental conditions for enhanced yield of maize (Johnston, 1958). However, it seems clear that the steady and significant increases in the yield of maize was related to increased rainfall and not increased temperature.

In Maiduguri, which falls into the Sahelian ecological zone, the increases in yield from 1961 to 2069 correspond to a decline in the level of water stress from 46 to 28 days. However, the further decline to 25 days during the 4th time slice seems not to be reflected in continued increase in crop yield. It appears that by the time of the 4th time slice, the rising temperature will take over as the limiting factor. In other words, the decline in crop yield from 2.75 tonnes per hectare to 2.31 tonnes per hectare could be ascribed to the increase in temperature stress from 8 to 11 days. One should note here, that across the country and across the four time slices, the experiments did not show any stress related to nitrogen, phosphorus and aeration. In selecting the soil with which to create the soil file used we adopted the more commonly cultivated soil series, which in most cases were of moderate productivity.

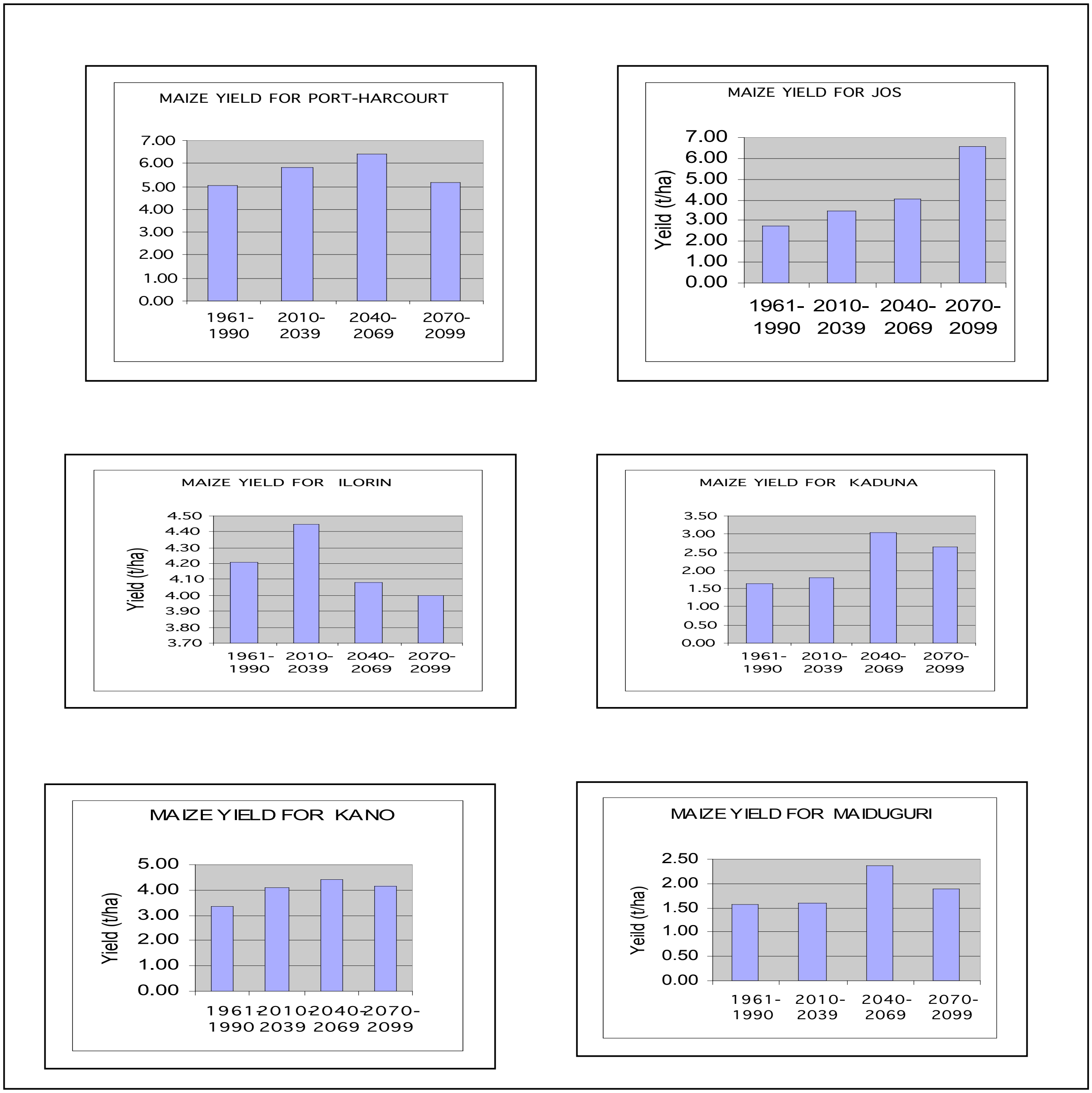


Fig. 5.1: Maize yield projections to year 2100

5.5.2 Rice yield: 1961-2099

Rice demonstrated a mixed pattern of reactions to climate change across the ecological zones as portrayed in Figure 5.2. The most common pattern is an increase up to the third time slice, 2040-2069, followed by a levelling up or a slight decrease in yield during the 4th time slice. This pattern was observed for Maiduguri (Sahel), Kano (Sudan), Kaduna (Northern Guinea) and Port Harcourt (Forest). For Jos, representing high altitude ecology, increases were steady and consistent from the first to the 4th time slice. During the 1961-1990-time slice, yield was at the level of about 1 tonne per hectare. By 2099, yield had increased to 2.5 tonnes per hectare. For Ilorin, (Southern Guinea) yield peaked during the second time slice after a sharp early increase. Subsequently, yield declined sharply to about the 1961-90 level during the third and the 4th time slices.

For Port Harcourt (Forest) the pattern of crop yield changes could be explained by declining water stress. Increases in temperature stress were not reflected in the yield. It could be noted that increases in precipitation was projected for the coastal areas in the climate change scenario outlined in Chapter Two. At the drier end of the climatic cross section in the Sahelian ecological zone that is in Maiduguri, increase from the first to the third time slice, corresponded to a steady decline in water stress. The slight decline in yield from the third to the fourth time slice seems to be determined by limits imposed by the increasing temperature. In other words, temperature did approach and probably surpassed the higher limits of tolerance and caused yield to decline sharply. It should be noted that even though total annual precipitation declined, the growing season rainfall did not according to the climate change projections outlined in Chapter Three. Moreover, the levels of rainy season temperature were still relatively low during the first two time slices. At the high altitude location, changes in both water stress and temperature stress favoured increases in yield. The steady and consistent increases in yield corresponded to the steady decreases in water stress resulting from increasing rainfall. With respect to temperature stress, there was a decline from 4 days to one day from the first to the 2nd time slice. Subsequently there was an increase. However, the level of temperature stress remained lower than what it was during the first time slice. It should be noted that temperature stress could occur as a result of temperature lower or higher than the range of tolerance. It appeared that as a result of temperature lower or higher than the range of tolerance. It appeared that temperature was lower than the minimum temperature tolerated during the first time slice. The general rise in temperature therefore resulted in the removal of the stress.

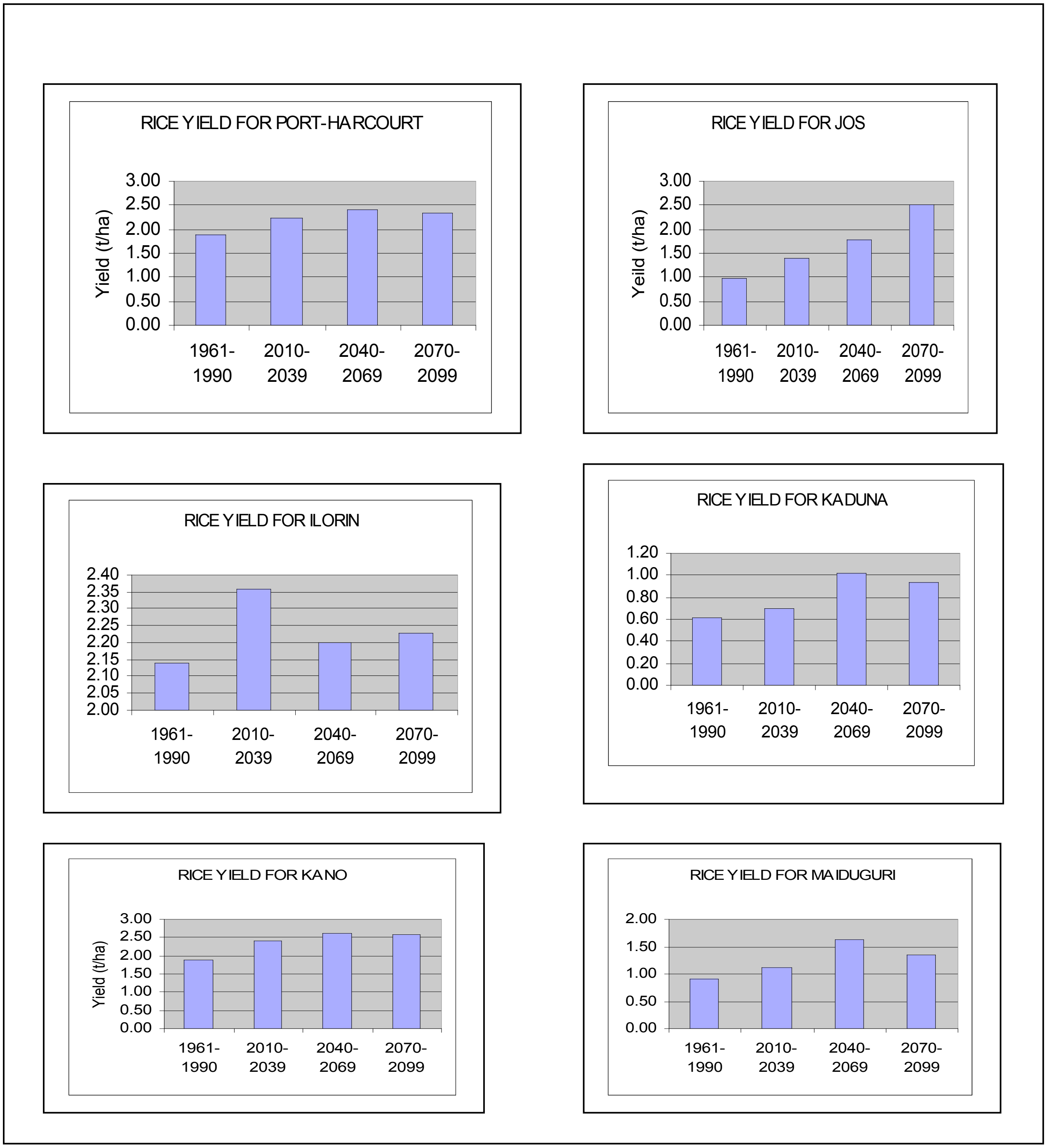


Fig. 5.2: Rice yield projections to year 2100

5.5.3 Sorghum yield: 1961-2099

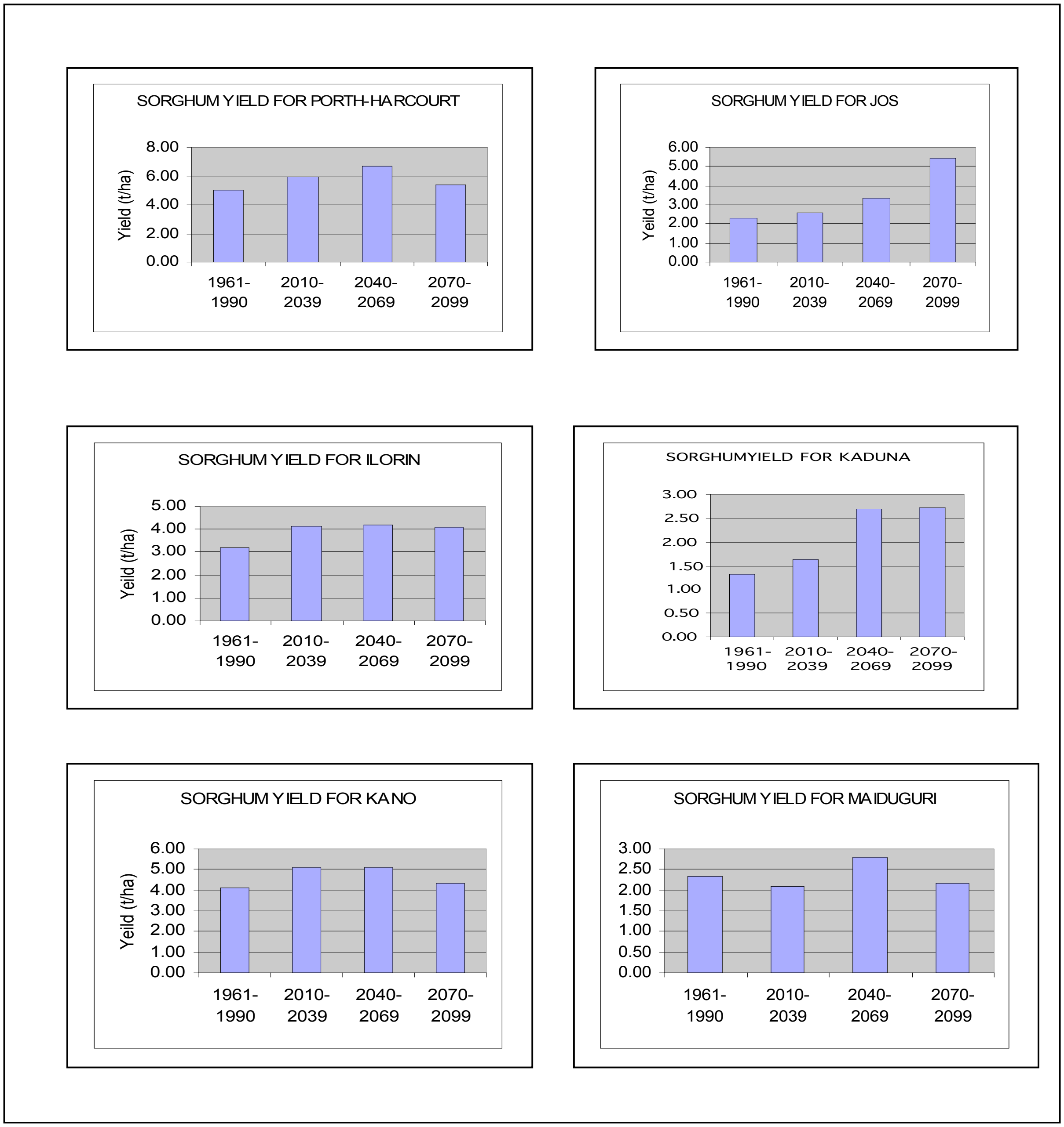


Fig. 5.3: Sorghum yield projections to 2100

Changes in sorghum yield followed three patterns as depicted in Figure 5.3. First, at some sites, there was continuous increase in yield from time slice one to four. This is the pattern observed in Jos, Kaduna and Maiduguri. However, it was only in Jos, the high altitude location, that the increases were evenly distributed from time slice one to four. For Maiduguri and Kaduna, increases in yield tended to slow down after the first time slice in the manner of the upper end of a sigmoid curve. For Ilorin, Port Harcourt and Kano, yield peaked mid-century, time slice 3, after an initial increase and subsequently declined. In Jos, the high altitude site, temperature, moisture and nitrogen became progressively more favourable with climate changing from time slice one to time slice four. At Port Harcourt (Forest Zone) the initial increase in yield from time slice one to two seemed to have been a result of the decrease in water stress. The decline in yield from time slice three to four seemed to have resulted from the continued increases in temperature. As a result, temperature stress increased from less than one day to four days.

5.5.4 Millet yield: 1961-2099

Millet, like sorghum, demonstrated three patterns of yield change over the 140-year period of study as depicted in Fig 5.4. One pattern characterized Jos, Ilorin and Kaduna representing the sub-humid Middle Belt of the country. In this pattern, there was consistent straight-line increase from time slice one to four. The second pattern characterized the forest-based location of Port Harcourt and the semi-arid ecology of Kano. After early, significant increase from time slice one to time slice two, the level of yield remained high until time slice four when there was a notable decline in yield. In Port Harcourt, peak yield occurred in time slice three, while in Kano, the peak was in the second time slice that is 2010-2039. The case of Maiduguri, representing the Sahelian ecology was unique. There was an early decrease in yield from the first to the second time slice. This was followed by an increase to peak yield in time slice three to be followed by another decrease in the fourth time slice.

Increases in the yield of the millet crop from time slice one to four at Jos, Kaduna and Ilorin correspond to decreases in water stress. The interpretation here is that the rising minimum and maximum temperatures were not sufficient to impose a limitation either directly as a result of supra-optimal levels or indirectly as a result of increased rates of evapotranspiration. For the forest-based site, namely Port Harcourt, the early increases in yield from time slice one to two correspond to significant decreases in water stress apparently a consequence of increased precipitation. There were no corresponding increases in water stress, or temperature stress in Port Harcourt that could be adopted as explanation for the decrease in yield from time slice three to four. With respect to Kano, the increase in yield from time slice one to two could be a consequence of the fall in temperature stress from 1.60 to 0.20 days. The decrease in yield from the third to the fourth time slice is apparently a result of increases in aeration stress, which rose from 6.00 to 6.40. Even though the climate of Kano is classified as semi-arid, rainfall during the months of July and August is usually in excess of 250mm per month. This is enough to cause water logging of the surface soil horizon

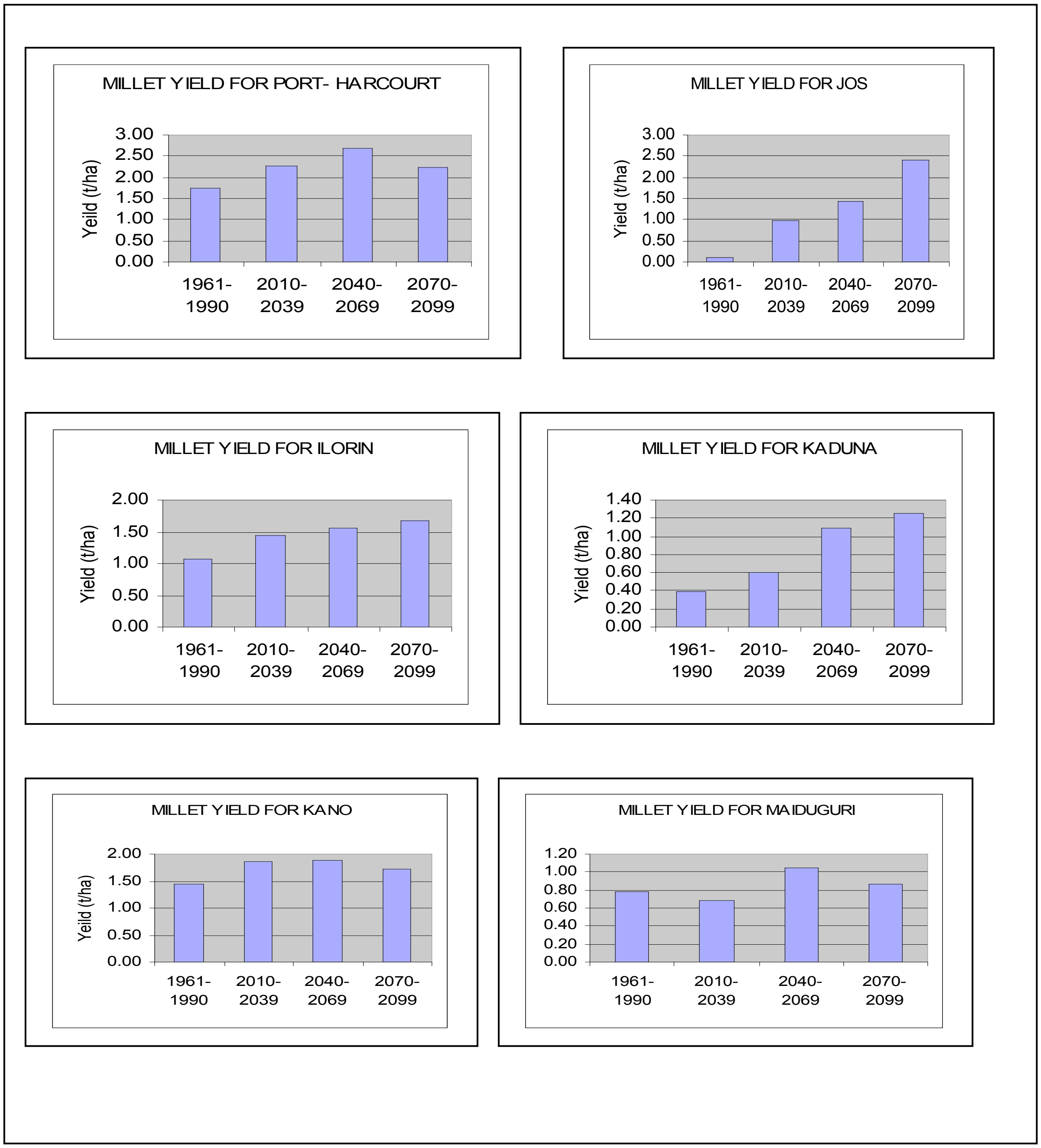


Fig. 5.4: Millet yield projections to 2100

5.5.5 Cassava yield: 1961-209

Projections based on the outputs of the simulation exercises indicate significant increases in the yield of cassava from the first to the fourth time slice in all the semi-arid and sub-humid northern ecological zones. The increases are from insignificant levels of less than 300kg per hectare obtaining at the beginning of the century to over 3 tonnes per hectare towards the end. In Port Harcourt, Forest Zone, the indications are a slight increase from 8 tonnes during the first time slice to 10 tonnes during the third. The pattern in Ilorin is projected to consist of an initial modest increase followed by a substantial decrease to much lower levels. However, it should be noted that baseline yield is relatively low compared with what obtains in the southern forest zone. In fact the yields coming out of model runs are in essence theoretical because these areas lie outside the current cassava-producing zone. For example, while the yield for Jos during the first time slice was only 300kg/ha that for Port Hacourt was as high as 8 tonnes per hectare. The increases being projected for the northern, more arid zones are indicative that the crop may extend northwards its range of occurrence. Such an extension could be based on increased temperature on the high altitude sites and higher rainfall in the other areas. As a confirmation of this, water stress in Kaduna ran as high as 114 to 175 days compared with less than 20 for Port Harcourt.

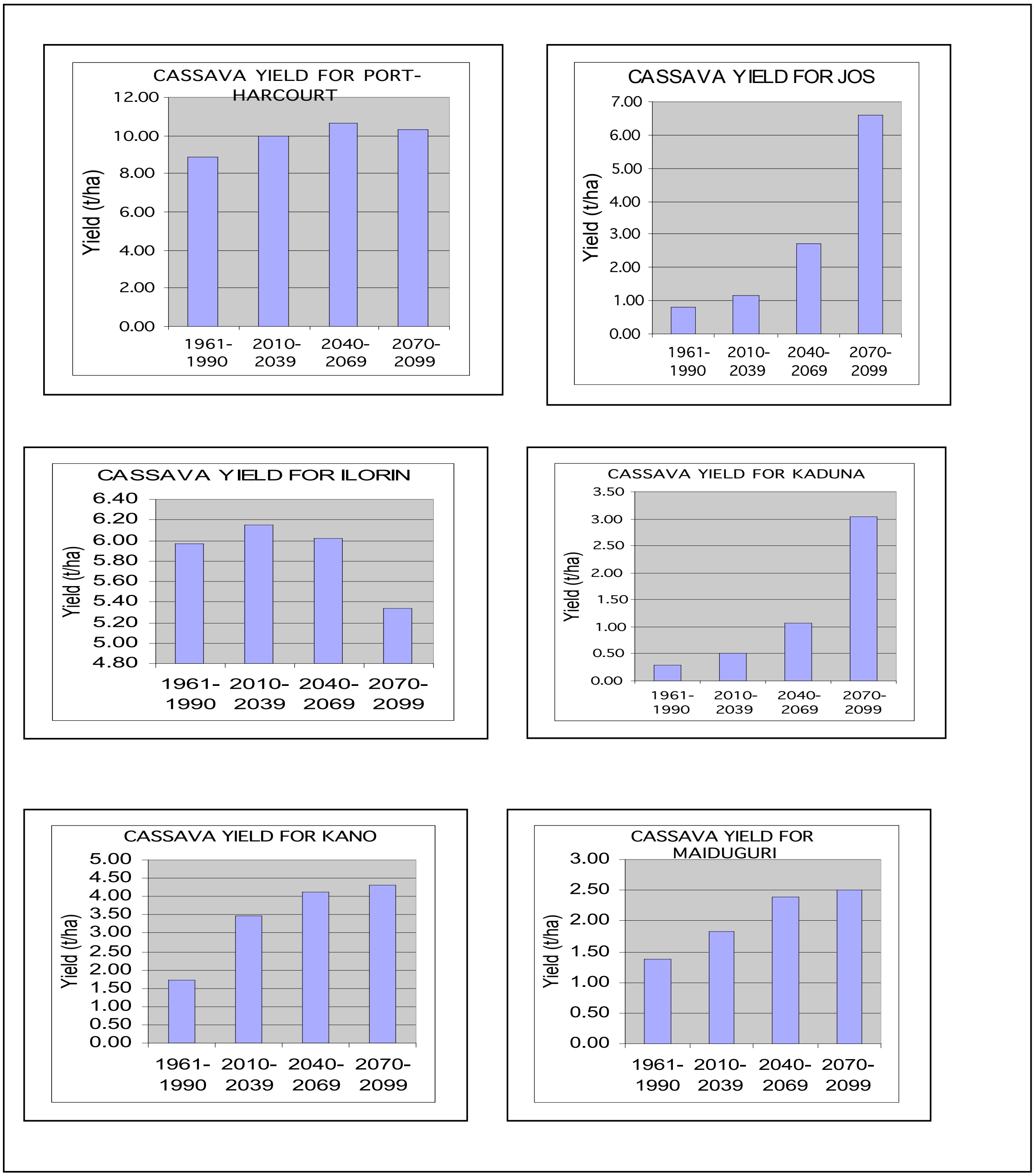


Fig. 5.5: Cassava yield projections to 2100

5.6 Discussion Of Results

EPIC Crop Model was developed by scientists of the USA Department of Agriculture and it has been successfully employed in that country for the study of crop growth and production. However, the model is yet to be introduced for serious research purposes in other countries or regions. Subject to a number of limitations, it has been confirmed that the model is suitable for the study of the impacts of climate variability and climate change on crop yield in West Africa (Adejuwon, 2005). This conclusion was based on the fact that the data used for model testing at locations within the territorial limits of Nigeria cover the climate and ecological zones from the coastal, rain forest belt, through the sub-humid Guinea Savannah, and the semi-arid, Sudan and Sahel zones to the southern margins of the Sahara Desert. These zones extend westwards to cover the entire West African sub-continent, and also replicated in all the major regions of Sub-Saharan tropical Africa, excepting, perhaps, the high altitude locations in East Africa. Although not with the same intensity, the range of occurrence of most West African crops invariably extends to Central, East Africa and Southern Africa.

In the present study, EPIC was used in the assessment of the impacts of climate change on the yield of maize, sorghum, rice, millet and cassava. Yam, which is also listed among the major food crops in Nigeria, was not included in the study because it is not on the crop list of EPIC. In the study, the sensitivity of the various crops to changes in climate elements was successfully demonstrated. The model was used to show crop yield response to changes in rainfall, solar radiation, temperature, relative humidity and carbon dioxide.

The indications are that, in general, there will be increases in crop yield across all ecological zones as the climate changes during the 21st century. In most cases, the increases will continue until mid-century. However, towards the end of the century, the rate of increase will slow down. In other words, lower yields will be realized during the last quarter of the century, compared with the third quarter, although yields will still be higher than what they were at the beginning of the century. As should be expected, there will be significant differences between the various ecological zones. For example, there will be substantial increases in the yield of cassava in the drier areas compared with the rain forest zone where there may be a net decrease in yield. The implication of this is that the cassava-growing region will extend northwards. Yield in the wetter forest areas will however still remain much higher than yield in the north. Another exception to the general trend is that yield of all the crops will continue to increase right to the end of the century on the high altitude Jos Plateau.

The increases in crop yield during the first half of the century are probably related to lower water stress as a result of increased rainfall, higher levels of incident solar radiation resulting from less cloud cover and higher levels of greenhouse gas concentration resulting from unmitigated increases in carbon dioxide emissions. The reduction in the yields towards the end of the century could be ascribed to the attainment of supra-optimum levels of temperature and carbon dioxide concentration.

It should be noted that the climate change scenario used for the assessment of the impacts assumed 1% per annual increases in the concentration of atmospheric carbon dioxide. The assumption is based on failure to put into practice the prescriptions of the Kyoto Protocol to the UNFCC, little progress in developing alternative sources of energy to fossil fuels and continued high rates of increase in human population. In other words, we have adopted a worst case climate change scenario. Ironically, the worst-case climate change scenario appears to be producing the best-case food production scenario. There are, other equally plausible climate change scenarios based on lower rates of increases in the concentration of atmospheric greenhouse gases. If any of these should turn out to be closer to the course of the real world changes in global climate, the impacts on crop yield may be substantially different from what has been outlined above. While the direction of change may be the same, the magnitude of change may be quite different. It may take up to 100 years to attain what the foregoing assessment suggested would be realized in fifty years. In other words, we might not have reached the stage of declining crop yield by 2100, and crop yield changes may remain positive until, the end of the century.

6 Vulnerability of the Peasant Household

6.1 Introduction

Downing et al (2001) contend that "the locus of vulnerability is the individual human being related to social structures of household, community, and society and world system". Therefore, in this study of Climate Variability, Climate Change and Food Security, we have adopted the Nigerian Peasant Household as the primary locus of vulnerability. By definition, a peasant household depends on agriculture and related activities for whatever livelihood he is able to eke out of his environment. In turn, agriculture depends on climate. Thus the vulnerability of the crop production systems easily translates into vulnerability of the dependent human livelihood group. This is probably the reasoning behind the contention that "one major cause of vulnerability to climate change is dependence of the exposure unit on sectors such as agriculture, forestry and fishery that are sensitive to changes in climate" (Sperling, 2003). The logic of this view point is quite easy to appreciate. Crop production, on which the peasant householder depends for his livelihood is sensitive to climate variability and climate change. Whatever climate affects crop production affects the peasant household. In essence, sensitivity of crop production to climate is a good measure of the sensitivity of the peasant household to climate variability and climate change.

The objective in this chapter is to analyze the vulnerability of the Nigerian peasant household to the changes in climate projected for the 21st Century. A household could be defined as a group of related persons, living in a dwelling unit or its equivalent, eating from the same pot and sharing a common house keeping arrangement. The word peasant may sound pejorative, but there is no alternative terminology to capture not only the small scale of farming operations, but also the diseconomy which it connotes. In the present report, vulnerability is conceived simply as a function of exposure, sensitivity and adaptive capacity. V = f (exposure, sensitivity, adaptive capacity). In the glossary of IPCC (2001a), exposure is defined as the nature and degree to which a system is exposed to significant climatic changes. Sensitivity, on the other hand, is the degree to which a system is affected, either adversely, or beneficially, directly or indirectly by climate related stimuli. Adaptive capacity is defined as the ability of a system to adjust to climate change (including variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Neither exposure, nor sensitivity, nor adaptive capacity by itself can be used to determine vulnerability.

Because of his dependence on agriculture, a sector that is by itself exposed and sensitive to climate, the peasant householder's livelihood, including his food and nutrition, is indirectly exposed to the projected climate change. Droughts with decadal frequencies and temperatures that are supra optimum for most of the major crops are the drivers of the potential risks to crop producing households. Vulnerability of the Nigerian peasant household to changes in climate will also be determined by a number of existent characteristics which imposes limits on its adaptive capacity. Among these, the most significant is existent poverty which signifies lack of resources necessary for adapting to climate change. In addition, relatively low levels of educational attainment could also constrain the ability to acquire the technological capacity for combating the negative consequences of climate change. The rates of population increase which at present stand at 28 per thousand could increase the rates of child dependency burden, increase pressure on social infrastructure, and also constrain the capacity to adapt to possible negative impacts of climate change. Based on the analysis, it could be observed that considerable contrasts in vulnerability to climate change exist between the various regions of the country. It appears that the northern parts where the risks posed by projected changes in climate are the highest are the same areas where peasant households' adaptive capacity is least and consequently the most vulnerable.

The chapter is organized into nine sections including this introduction. In Section 2, activities conducted are described. The details of the scientific methods are provided in section3. Section 4 describes the profile of a typical Nigerian Household in the Sudan ecological zone. In section 5, the indirect exposure and sensitivity of the peasant household to climate change, through its dependence on agriculture, a sector that is itself sensitive to climate, is described. Risks and beneficial effects of climate variability and climate change are outlined in section 6. Adaptive capacity is the subject matter of section 7. By limiting adaptive capacity, poverty is considered a major cause of vulnerability to climate change. Other existent characteristics of the peasant household do limit its adaptive capacity. For example, current demographic trends, including the explosive growth of the population, are set to constrain the capacity to adapt to climate change by their contributions to pressure on socio-economic infrastructure and increases in child dependency burden. The extent to which inadequate education statuses impose limitations on adaptive capacity is also considered. Attributes indicating: sensitivity to climate variability, sensitivity to climate change, and inherent capacity or lack of capacity to respond to, in the sense of cope with, recover from, or adapt to climate change are adopted and used to derive a summary index of vulnerability in section 8. The summary and conclusions are presented in section 9.

6.2 Activities Conducted

The data used in this chapter are in the main those already described for the preceding three chapters. These include climate data acquired from the Nigerian Meteorological Agency and IPCC Data Distribution Centre. They also include data from serialised and occasional statistical publications of the Nigerian Federal Office of Statistics. The only source of data yet to be described is our own field surveys which were conducted using the Participatory Rapid Appraisal (PRA) approach. Data from the surveys were used in this report to describe the profile of the peasant household. PRA involved interacting with all available farmers at the study sites both at home and on the fields. Field assistants used a questionnaire package, to guide responses from the farmer respondents. The PRA package was designed to investigate the historical profile of the study sites. Among the information collected were: the date of founding, the political, economic and social practices, as well as the social and economic infrastructure. Questions were asked about the major and minor crops grown under various agronomic practices, and the nature of the climate and the farming calendar. Sources and types of seeds, seedlings and cuttings were supplied in response to the questions. The farmers also gave the reasons for their choice of crops and cultivars.

6.3 Scientific methods

6.3.1 Assessing household adaptive capacity

The extent to which adaptive capacity is constrained by existent household characteristics was derived as the proportion of the households affected. Thus, in the case of poverty, the first question addressed was: "how poor is the poor household". The second question pertains to what proportion of the households was poor. This proportion was adopted as a measure of the adaptive capacity of householders within each social structure, including: household, community, society, nation and world system. The data available permit us to compare householders at the state (Figure 2.1) and at the six regional levels. The six geopolitical zones consist of North West, North East, North Central, South West, South East and South-South.

6.3.2 Index of vulnerability

As intimated earlier, everyone is vulnerable, what varies from person to person is the degree of vulnerability. Vulnerability of the peasant households is assessed at the level of the component states of the Nigerian Federation. Index of vulnerability was derived from measures of the drivers of sensitivity of crop yield to climate, and measures of adaptive capacity. For example, it was established earlier in the report that the severe drought of 1990 resulted in the lowest yields of crops between 1983 and 1999 in the Bornu-Yobe Arid Zone (Chapter Four). The probability of drought occurrence is related to the variability of the climate. Highly variable climate is more likely to produce severe droughts than less variable climates. The rainfall variability indices for the mean annual total, computed for the climatic stations were adopted as indicators of drought occurrence and therefore of the driver of risks related to climate variability. Each of the 30 states was assigned the value for the meteorological station either located within it or closest to it. With respect to sensitivity to climate change, high temperatures projected for the later parts of the century has been demonstrated to cause reductions in yield (chapter 5). The temperatures projected for the 2070 t0 2099 period were for this reason adopted as one measure of the drivers of the risks of climate change. It was demonstrated that poverty limits adaptive capacity. The proportion of the population in each state of the country falling into the extremely poor category was used as one of the attributes indicating lack of adaptive capacity in each state. Other attributes affecting adaptive capacity include: child dependency burden, literacy rate, enrolment at higher institutions of education and infant mortality rate. The various values attached to each of the 30 states with respect to the drivers and the factors constraining or enhancing adaptive capacity, or their surrogates, were used to rank them. The ranks were subsequently added across the indicators and used to derive a single vulnerability index for each state. It must be admitted that data availability rather than any objective criteria determined which indicators were included and which were left out. However all those included are judged to be relevant to exposure, sensitivity or adaptive capacity.

6.4 Profiling the Nigerian Peasant Household

Household sizes varied from one person to over 20 persons in some cases. Nearly one-quarter of the households consisted of more than six persons. Households with more than 10 persons accounted for more than 3.7 percent of the households, while households with more than 15 persons constituted only 0.4 percent. One-person households made up only 12.2 percent of the households, while households with 2 or 3 persons constituted about 25 percent (FOS, 1996b). On the average, the Nigerian household consisted of 4.75 persons. Using the 30-state structure, the average size of the Nigerian household per state varied from 3.2 persons in Ogun state in the south-west, to as high as 5.6 persons in Plateau state. The states with the lower average household sizes (less than 4 persons), were all to be found in the south western parts of the country, while all the states with average household sizes of over 5 persons were in the north of the country. This implies that the size of the household is, in part, determined by ethnicity (FOS, 1996b).

6.4.1 A real-world case study: The Drambi household of Giwa Higgi community

In profiling the Nigerian peasant household, the case of Drambi household of Giwa Higgi community of Askira Local Government Area of Bornu State is presented in addition to the statistical summary provided above. The profile is one of the outcomes of field surveys in the Arid Zone of Nigeria.

The household headed by Mr Drambi consists of six persons; Mr Drambi, his wife and four children. He is the village head of Giwa Higgi, a community founded in 1905 by his father. The name Giwa Higgi is derived from the name of the tribe of the founding population. 'Giwa Higgi' simply translates in their language as the 'community of Higgi tribe'. There is one primary school called Giwa Higgi primary School, no good roads, no clean water, no electricity, and no health facilities within the community land area. Members of the community go to Lassa General Hospital, which is more than 10 km to receive medical attention. Drambi is a farmer practising mixed farming, and mixed cropping. The major crops are guinea corn, maize, millet, beans, g/nuts, and cassava. The minor crops include: okro, tomatoes, and vegetables. The Drambi household and other community members also engage in animal husbandry; keeping animals such as cattle, sheep, goats, horses and donkeys. They engage in fishing during the dry season in the Yadzeram River that flows across the area. There are, in addition to the farmers, nomadic herdsmen who take care of community herds. Each nomadic family controls a herd of up to a hundred assorted animals, which have been contributed by owners within the community including Drambi. Mr Drambi could recall bad harvests in 1973, which resulted from early cessation of the rains. It was not only crops that were affected by droughts. Animals also suffered when the grass dried up for prolonged periods. Apart from those two years, their recollection is of good harvests during the past thirty years. The total population of the community in 1991 census was about two thousand five hundred.

As is often the case in the areas outside the homeland of the major ethnic groups in the north, people of different ethnic backgrounds mix. Even though members of the Higgi tribe are in the majority, members of other tribes are present, not as strangers but as indigenes within the community. People who profess to be Christians are in the majority and churches outnumber mosques. The people associate on the basis of family, religious, economic and social affinities. Thus in Giwa Higgi there is a football or sports club, farmers associations, thrift societies, many age grade associations, many clan associations, Boy's and Girl's Brigades, Church Choir etc. By national standards, the home and environment infrastructure are grossly inadequate. There is generally no pipe-borne water. The main source of water is shallow wells augmented by stream and river sources. Health facilities are few, usually at the level of dispensaries.

The people are quite conscious of the weather factor in their lives. According to Mr Drambi, when the seasonal rains are early, they come in May and crop performance is high. When seasonal rain onset is delayed until July however, crop yield is low. This is because unless cessation of rain is delayed, the growing season is shortened and there is insufficient time for crops to mature. Rain coming in June is judged to be favourable and is associated with good yields of crops. Most crop failures were however, associated with premature cessation of the rainy season. There could also be low yield of crops when there are prolonged dry spells within the growing season. Very few years can really be described as having rainfall patterns that are altogether unsuitable.

The main recurring community problem is the unpredictable delay in the onset of the rainy season. In the past, goats, rams and cows were slaughtered as sacrifices to appease or secure favour with the tribal gods, who they believed could cause rain to fall in good time. However, in 1967, the community adopted the Christian religion and the practice was discontinued. However, the belief persists, that it is only by divine intervention that the problems of variable dates of arrival of the life giving monsoon rains could be solved. Thus, intercessory prayers in the churches replaced sacrifices to tribal gods.

6.5 Dependence on Agriculture for Livelihood

By definition, a peasant household depends on agriculture and related activities for whatever livelihood he is able to eke out of his environment. It is the view in certain quarters that "one major cause of vulnerability to climate change is dependence of the exposure unit on sectors such as agriculture, forestry and fishery that are sensitive to changes in climate" (Sperling, 2003). The logic of this view point is quite easy to appreciate. Crop production, on which the peasant householder depends for his livelihood is sensitive to climate variability and climate change. Whatever climate affects crop production affects the peasant household. In essence, sensitivity of crop production to climate is a good measure of the sensitivity of the peasant household to climate variability and climate change.

The National Agricultural Sample Survey (NASS) (FOS, 1998) indicated that 94 percent of agricultural holdings were involved in crop farming, 68 percent in livestock farming, and only two percent in fishing and one percent in forestry activities. (The figures do not add up to 100 because of multiple activities e.g. many holdings have both crops and livestock). With the exception of Lagos State, over 25 percent of the holdings within each state were involved in crop farming during the 1993/94 season. The figure for Lagos was 5 %. With respect to livestock farming, while some states like Katsina and Jigawa at the northernmost extremity of the country, recorded over 90 percent, Delta and Ogun, along the coastline, recorded 15% and 27% respectively. For fish farming, only three states recorded significant figures, Delta (11%), Rivers (11%) and Ondo (7%). The other states recorded less than 2%. The major crops grown by the households include: maize, guinea corn and cassava. During the 1993/94-crop season maize was the most widely cultivated (FOS, 1998). The crop was grown on 54 percent of the holdings. On the other hand, guinea corn (sorghum) was cultivated on 48 percent and cassava on 47 percent of the household holdings. Most of the states of the Nigerian Federation recorded high percentages for maize. The exceptions were the states of Jigawa, Sokoto and Yobe, located in the Sudan and Sahel, which recorded percentages less than 10 respectively. Guinea corn (sorghum) cultivation was concentrated in the same Sudan and Sahel zones, where more than 90 percent of the households cultivated the crop. In the Guinean, (Middle Belt) zones, from 60 t0 70 percent of the households cultivated guinea corn, whereas, in the southern forest zones less than 10 percent of the households was engaged in cultivating the crop. The core of high intensity cultivation of cassava was in the south, eastern states of Anambra, Imo, Enugu, Akwa Ibom and Abia. The areas of intensive cultivation of cassava extended westwards into Delta, Edo and Oyo states, all lying outside the main Cocoa Belt. Intensity of cultivation of cassava decreased northwards. The Sudan and Sahel zones could be considered as lying outside the proper cassava growing areas. What all these imply is that any disaster overtaking maize, sorghum, or cassava cultivation as a result of climate variability or climate change is also a disaster for the Nigerian Peasant Household. Beans, millet, yam and groundnuts are also regionally important crops, cultivated by between 30 and 40 percent of the households during the 1993/94 growing season. Yam cultivation is intensive in the South East and the Middle Belt, while beans and millet are important crops in the Far North.

A good measure of the extent of dependence on agriculture is the percentage of employed persons in the sector. For the country as a whole, the percentage of employed persons in the agricultural sector for 1993 was 65 (FOS, 1997). The data for 1993 also indicated that the percentage was above 50 in 20 out of the 30 states constituting the Federation. Figure 6.1 depicts the spatial pattern of dependence on agriculture. In general, the proportion of employed persons in agriculture tended to be higher in the northern, drier parts of the country than in the wetter south. It shows that the degree of dependence on agriculture for employment is highest among the states at the northern boundary with Niger Republic. In Kebbi and Sokoto states, in the extreme north-west, the percentage for 1993 was 93 and 92 respectively. All the states with boundary with Niger Republic had over 85 percent of their employed persons in agriculture. By contrast, dependence on agriculture for employment was lowest in the south-west where the percentage was generally less than 50. In Lagos, consisting essentially of the city, the percentage was 2.37, while in Ogun, Oyo and Osun, the percentage was 20.66, 23.52 and 25.60 respectively.

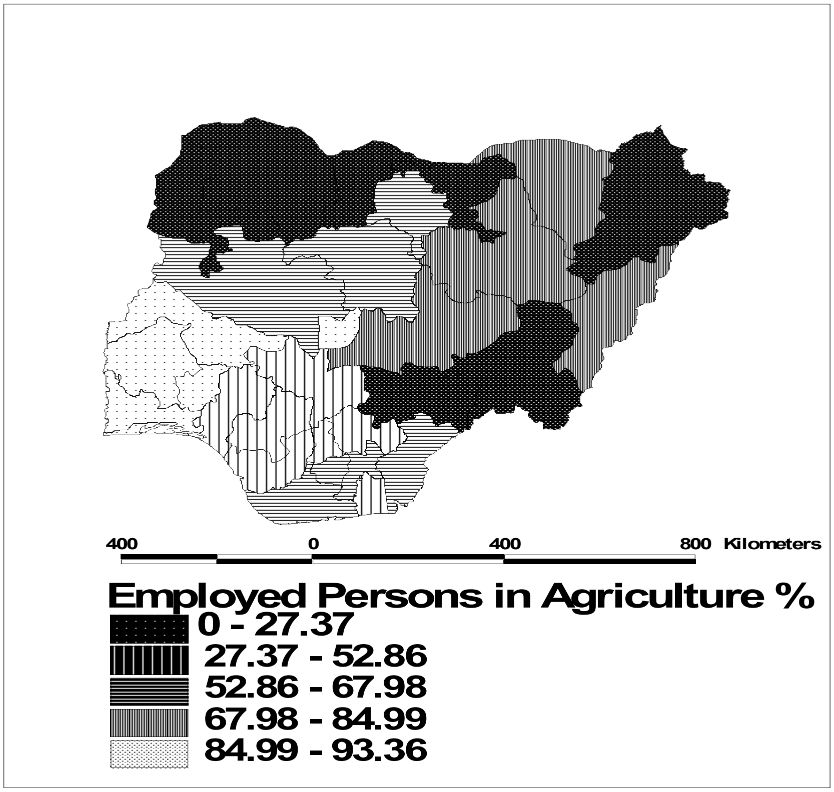


Fig. 6.1: Percentage of employed persons in agriculture

6.6 Climate Driven Risks and Benefits

6.6.1 Risks

According to Downing et al, (2001) risks are the expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. From the foregoing analysis, the risks to the livelihood of peasant households are related to reductions in the yields of their crops. The risks vary from widespread crop failure affecting all crops in the arid zone or some of the crops throughout the country, to regional, local and individual farm-level crop failures affecting the more sensitive crops. Depending on its severity, crop failure could result in food inadequacy and famine, loss of livelihood and long distance emigration from the arid zone to the rain forest belt. Usually, it is the able-bodied young men that emigrate. A large proportion of those left behind, especially the women and the children could be made to pay with their lives.

Contemporaneously, the crop production systems are constrained by poor soils, disease and pest infestation and chronic peasant production diseconomies. These serve as amplifiers of the climate factor as the chief driver of the risks.

6.6.2 Climate variability-driven risks

The drivers of crop failure are droughts, that is, inadequate growing season rainfall. Droughts have always been a common, though irregular feature of the arid region of Nigeria, The areas most exposed to the incidence of disastrous droughts are the Sudan and Sahel ecological zones which respectively cover about 240,900 km^2 and 20,700 km^2 and thus constitute about 26.6 percent of the country's land area. These areas are characterized by a mean annual rainfall averaging 600 mm to 800 mm and a short, rainy period of 100 to 120 days. From the records, five major drought periods with resultant human deprivation were documented in the Nigerian arid zone during the 20th Century. These were the 1913-14, 1931-32, 1942-43, 1972-73, and 1983-84 droughts (Mijindadi and Adegbesin, 1991). Recurring drought periods were not limited to the 20th Century. Oladipo (1988) traced the occurrence of periodic droughts in Africa from before the birth of Christ up to the 20th Century.

The farmers in the arid zones are quite conscious of the weather factor in their lives. According to the farmers interviewed during field work, when the seasonal rains are early, they come in May and crop performance is high. When seasonal rain onset is delayed until July however, crop yield is low. This is because unless cessation of rain is delayed, the growing season is shortened and there is insufficient time for crops to mature. Rain coming in June is judged to be favourable and is associated with good yields of crops. Most crop failures are, however, associated with premature cessation of the rainy season. There could also be low yield of crops when there are prolonged dry spells within the growing season. However, the significant negative impacts of climate on crop production are delivered by extreme events such as season-long droughts with decadal frequencies of occurrence. Disaster usually comes in the form of a late arrival and/or a premature termination of the growing season. In the broad band of years that could be described as normal, noticeable rather than significant responses of crops to changes in climate could be observed. The responses reflect changes in the environmental drivers from one locality to another. Thus for the impacts to be noticeable at the sub-regional scale, at which data are usually summarised, the type of weather described for Potiskum in Table 4.6, must occur over wide areas.

6.6.3 Climate change-driven risks

For the rest of the current century, the risks outlined above will remain with the Nigerian peasant household. However, the severity, the reference period, spatial and temporal resolutions will differ as the century progresses. Instead of oscillating or periodic timing, the risks will tend to gather momentum as the century progresses. Instead of cellular occurrence, the risks will tend to affect the entire sub-continent of West Africa with comparable severity. The risks will be least during the first half of the century during which crop yields increase in response to higher levels of solar radiation, atmospheric humidity, rainfall and carbon dioxide. Also the risks will be driven by a new set of climatic factors. The current moisture-based drivers will be replaced by temperature-based factors. In the context of ecological factor interaction, the negative impacts of supra-optimum temperatures will tend to mask the positive impacts of increased solar radiation, moisture and carbon dioxide during the second half of the century.

6.7 Constraints to Adaptive Capacity

Adaptive capacity is the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or cope with the consequences. Resources, including: social, financial, natural, physical and human capital, are required for planning, preparing for, facilitating and implementing adaptation measures. Among the factors imposing limitations on adaptive capacity, the most significant is existent poverty which signifies lack of the resources necessary for adapting to climate change (Sperling, 2003). In addition, there are disabilities such as poor health that could undermine labour availability for the farming activities both in quality and in quantity. Relatively low levels of educational attainment could also constrain the ability to acquire the technological capacity for combating the negative consequences climate change. The rates of population increase which at present stands at 28 per thousand could increase the rates of child dependency, increase pressure on social infrastructure, and constrain the capacity to cope with the negative impacts of climate change.

6.7.1 Poverty and adaptive capacity

Widespread poverty has been cited as the main cause of a low capacity to adapt to climate change in Africa (IPCC, 2001a). Poor persons, poor communities and, poor nations do not have enough of these resources, hence their low adaptive capacity. A low capacity to adapt to climate change automatically implies vulnerability. Hence, existent or pre-impact poverty connotes vulnerability. Summary of the latest results from the National Integrated Survey of Households 1995 (FOS, 1996c) showed that practices that could have boosted the adaptive capacity of the peasant households were still being constrained by lack of funds at the individual household level. With respect to livestock production, 99 % were not using vaccine, 96 % were not using drugs, while 95 % were not using supplementary feeds. With respect to crop production, the use of pesticides and insecticides was limited to 4 %, the use of improved seeds was limited to 11 %, while the use of chemical fertilizers was limited to 32 % of the peasant holdings. Among those who did not use fertilizer, 51 % considered the cost too high, 8 % found the distance to the source to be too far, 23 % did not know where to obtain fertilizer, while 12 % felt they did not need fertilizers. Of those who were not using pesticides and insecticides, 36 % felt the cost was too high, 24 % felt no need for them and 22 % did not know where to obtain them. All these boil down to inadequate financial resources and ignorance, which are the hallmarks of the poor. 94 % of the holders had no credit for their farm work. Only 1 % had credit through formal banking and cooperative society system. Informal credit system accounted for only 2.6 %. Friends and relatives were the source of credit for 2% of households while 0.4 % obtained credit from money lenders (FOS, 1996c p 37)

The current, official poverty line for Nigeria was defined in a study to assess the poverty trend in the country between 1980 and 1996. The study, conducted by the World Bank in collaboration with the Federal Office of Statistics, used data generated by the National Consumer Expenditure Survey, and adopted two-thirds of the mean household expenditure as the poverty line. The approach used in the report titled: *Poverty Profile for Nigeria 1980-1996* (FOS, 1999a) is based on the classification of the poor and non-poor households in relation to their total expenditure (food and non-food). This involves setting two lines relative to the standard of living in Nigeria:

1. A moderate poverty line equivalent to two-thirds of the mean per capita expenditure
2. A core poverty line, equivalent to one-third of the mean per capita expenditure.

Households are classified into one of three mutually exclusive groups, separated by the lines specified either as core poor, moderately poor, or non-poor.

There is significant difference in the incidence of poverty between households engaged in agriculture and households with occupation in the other sectors. With the dominant role played by agriculture in the provision of employment, it is not surprising that most of the poor were found on the farmlands, in the rural areas. About 77 percent of farming households were poor, while 48 percent fell into the core poor category. Male farmers were poorer than female farmers.

Most of the poor live in rural areas (FOS, 1999b). Nigeria's Poverty Assessment Study indicates that 87% in 1985 and 67% in1992, of the core poor were in agriculture and all basically resided in the rural areas. 75 percent of the population of the country live in rural areas. The southern parts of the country suffer less poverty than either the central or the northern parts. This pattern is depicted in Figure 6.2. In 1980, the core poor constituted 11.8 percent of the population of the states in the North East, 8.3 percent of the population of the states in the North West and 5.7 percent of the population of the states in the North Central zone. By comparison, 2.1 percent of the population in the South West, 2.4 percent of the population in the South East, and 3.3 percent of the population in the South-South were classified as core poor (FOS, 1996a).

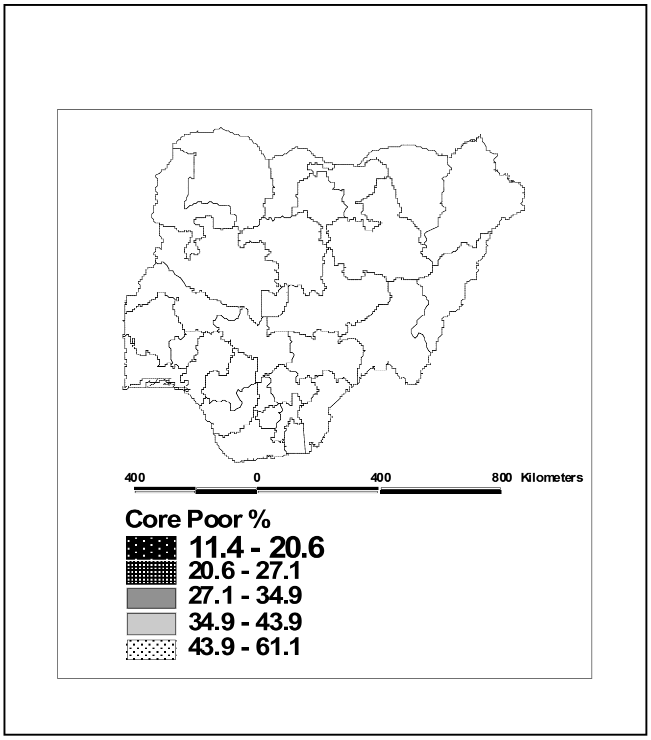


Fig. 6.2: Distribution of core poor

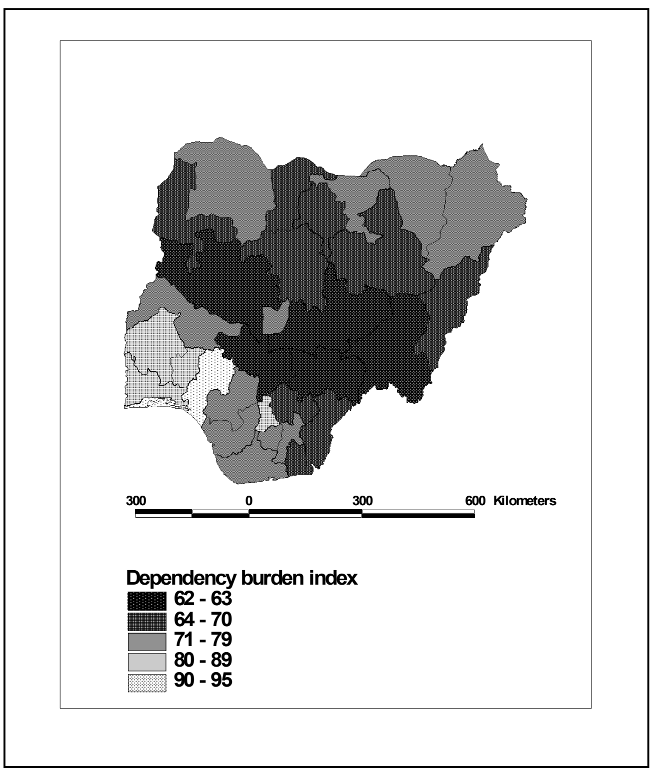


Fig. 6.3: Dependency burden

6.7.2 Demography induced constraints

From the most recent statistics, Table 6.1, it could be observed that Nigeria has a youthful population. In youthful populations, high proportions of the members are children. Going by the estimates for 1995, children under the age of 15 years constituted 44.0 percent of the population. Also, the youthful age structure creates a built-in momentum for future population growth. Even if it were possible to reduce the growth rate to replacement level, births would outstrip deaths and the population would continue to increase until the very large number of young females had passed through their reproductive years. The percentage of the female population that is in the reproductive age brackets, after declining between 1980 and 1990, increased from 1990 to 1995, giving indications that the growth rate might be accelerating. In 1981/82, 1990, 1993/94 and1995, women in the reproductive age brackets constituted 44.3%, 36.8% 46.6% and 46.0% of the female population respectively (FOS, 1996a). (It should be noted that these were results of different surveys). With such high percentages within the reproductive age range coupled with the youthful nature of the population, policies aimed at reducing fertility may not produce the desired results within a short time. In the short run, the population of children would remain high relative to total population even if the fertility rate declined.

Age	**Male**				**Female**			
	1981/82	**1990**	**1993/4**	**1995**	**1981/2**	**1990**	**1993/4**	**1995**
0-14	50.2	48.2	46.8	45.5	45.7	47.7	42.4	42.0
15-29	20.8	21.2	21.4	21.2	28.2	22.5	27.1	27.1
30-44	14.9	14.1	15.8	15.6	16.3	14.6	19.5	18.8
45-59	8.5	8.3	10.5	10.8	7.2	9.9	7.7	8.0
60 +	5.6	8.2	5.5	6.8	2.6	5.3	3.3	4.1
All ages	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources 1981/2 data: National Population Bureau (1984) The Nigeria Fertility Survey, Vol. 1, p 34.

1990 data: F.O.S. (1992) Nigeria Demographic and Health Survey, p. 9.

1993/4 data: F.O.S. (1995) National Agricultural Sample Census, 1993/4.

1995 data: F.O.S. (1995) Multiple Indicator Cluster Survey.

Table 6.1: Age-sex distribution of Nigeria's population; 1981/82, 1990, 1993/94 and 1995

Nigeria is thus characterized by a high and stable birth rate, which has varied between 5.6 and 7 percent since 1960. Also the death rate has been declining as a result of improvements in medical and community health facilities. The balance between the stable high birth rates and the steadily declining death rates has produced a steady annual growth rate of about 28 per thousand.

The importance of a vigorous and effective population policy was noted in the 1988 National Policy for Development, Unity, Progress and Self Reliance. The policy adopted specific demographic objectives and called for the extension of family planning services to half of all women of child- bearing age by 1995 and to 80% by the year 2000 (FOS, 1994). Neither the general nor the specific objectives spelt out in the policy statement have been achieved. The main problem has to do with entrenched cultural and religious practices. The use of modern methods of contraception remains very low in spite of significant increases between 1982 and 1984 and between 1993 and 1995 (FOS, 1996b).

It is therefore, not surprising that the Nigerian population remains youthful; that the percentage of the population in the age range 0-15years is above 40 and that the rate of population increase remains very high. All these result in problems that may rank higher on the priority lists of governments at all levels than the need to combat the consequences of climate change. At the very least, these problems will compete for attention with those that are consequent upon climate change and hence contribute to the vulnerability of the household to climate change. Among such problems are: inadequate social infrastructure and child dependency burden.

6.7.2.1 Inadequate social and economic infrastructure

The rapidly expanding population is exerting increasing pressure on the social and economic infrastructure of the country. Schools, hospitals, and houses become inadequate almost as soon as they are completed. Similarly, electricity, water and waste disposal facilities designed for a given population are being made to serve much more than that population on the day they are commissioned. Existing facilities are being put to a higher rate of usage than they were designed for. This is resulting in a high rate of infrastructure deterioration. There is the possibility that these inadequacies will tend to command greater attention from policy makers and draw away funds from pro-acting to the consequences of a potential climate change.

6.7.2.2 Child dependency burden

The youthfulness of the population is directly responsible for the high rate of child dependency burden in the country. Child dependency burden, calculated as the population of children below the age of 15 divided by the population of working adults aged from 15 to 59, is depicted in Figure 6.3 for the year 1993. The South West has the least burden followed by the South East and the North West. The main consequence of this at the household level is that each pair of hands has to strive to provide for many more persons than it can conveniently cater for. In countries with such high proportions of children, relative to the proportions of the working age population, high percentages of national income is expended on consumable goods for these children. The higher the percentage of income expended on these consumables, the lower the percentage of income left for savings and investments. The capacity to cope with any additional stress in the form of negative consequences of climate change will also be lower in situations with high dependency burden because the first inclination would be to care for children rather than to prepare for a future under a changed climate.

6.7.3 Educational statuses and adaptive capacity

Education will definitely enhance personal, community and national capacity to respond to external stresses placed on human livelihood and well-being. Therefore, inadequate or substandard education is a measure of the vulnerability of human exposure units to expected negative impacts of climate change. It is easy to appreciate the fact that education is one of the means for achieving the goals of better health, higher labour productivity and more rapid GDP growth; all of which are required as the need arises to anticipate, manage or adapt to a worsening climatic factor (Hulme, 1996; WMO, 2000). The higher levels of education are especially called for to enable individuals and countries understand and participate more fully in the technological and administrative processes of the modern global economy. Since achieving independence from colonial rule in 1960, a considerable proportion of the national income has been invested in raising the standard of education. Because of this, enrolment ratios have been on the upward trend. However, there are considerable differences between the component regions in this regard.The northern, semi-arid zones, where the impacts of climate variability are most severe, and the potential consequences of climate change are expected to be most damaging, are the same regions least prepared in terms of education capacities to meet the challenges of climate variability and potential climate change.

The national adult literacy rate averaged 25 percent in 1970 (FOS, 1996a). By 1995, it had climbed up to 49 percent. The1995 statistics showed a gender disparity with the female rate at 41 percent while the male rate was 58 percent (UNDP, 1995; FOS, 1996a; and National Population Commission, 1984). Regional disparities were also well marked. Literacy rates among male adults varied from a low of 19 percent in Jigawa state located in the far north, to a high of over 93 percent in Lagos state, located in the humid forest zone. Lagos is dominated by the city of Lagos and this may explain its high rate of adult literacy. However, in the predominantly rural states in the forest zone, such as Abia, Akwa Ibom, Cross River, Rivers, Imo, and Delta, the rate was over 80 percent. Regional disparities were also indicated in the female adult literacy rate. For example, the rate in such northern states as Kebbi, Sokoto, Jigawa and Yobe were respectively less than 10 percent. For all the forest zone states, the rate of female adult literacy was over 50 percent and was in fact more than 70 percent in Abia, Anambra, Edo and Rivers states. Intermediate values were recorded for the sub humid Middle Belt. Figure 6.4 depicts the pattern of adult literacy rate based on 1995 statistics.

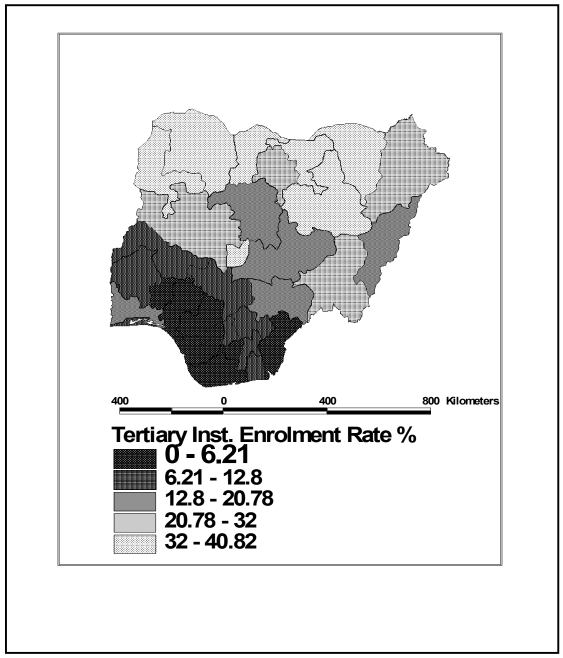


Fig. 6.4: Adult literacy rate

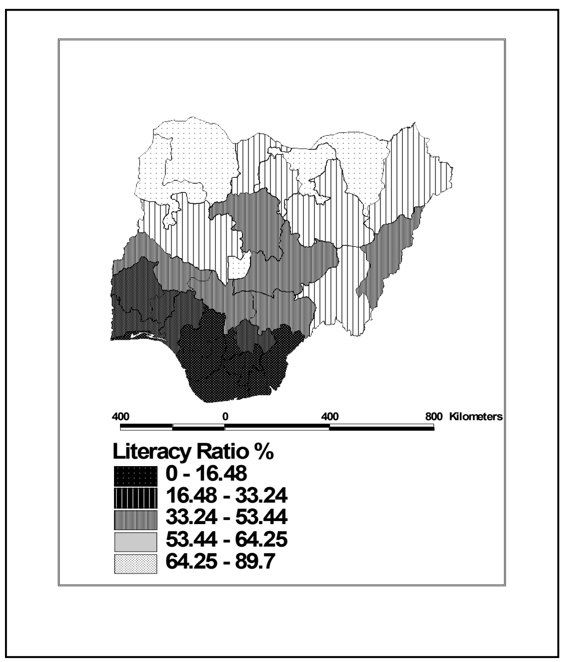


Fig. 6.5: Tertiary institution rates

Primary school enrolment stagnated at about 3 million in the 1960s. By 1975, primary school enrolment was still less than 5 million (FOS, 1996a). Thereafter, increases became more consistent, reaching 16 million in 1994. The regional disparities observed with respect to adult literacy were also observable with respect to primary school enrolment. In every state based in the humid forest zone, the most recent statistics (1994) indicated primary school enrolment of over 90 percent with little or no difference between the sexes. In the far northern states, the rate was generally less than 40 percent for male and less than 30 percent for female. Similar patterns were repeated for enrolments in secondary schools and tertiary educational institutions. Secondary school enrolments in all the forest-based states exceeded 80 percent, compared with less than 30 percent for male and less than 10 percent for female in Sokoto state in the Sudan Zone. In 1993/94, tertiary institution enrolment depicted in Figure 6.5, ranged from 2.0 percent in Sokoto state, in the arid zone, to 41.0 percent in Ondo state, in the forest zone.

6.7.4 Health and adaptive capacity

The view has been expressed that climate change impact on human health would increase vulnerability and reduce opportunities by interfering with education and the ability to work (Sperling, 2003). In the absence of mechanisation and other forms of modernisation, the main input to crop and animal production in Nigeria is labour. Most of the labour used on peasant farms is supplied by members of the household. In households headed by women, hired labour could be employed for the more strenuous activities such as tilling in preparation for planting. Households engaged in cash crop production use more hired labour than households engaged in food crop production. During the harvest season, the households cooperate to ensure that farm output is brought in as soon as possible. There is always limited time available for harvests as delay may expose the output to pests, diseases and destruction by the weather. Thus sufficient and timely availability of labour is crucial to the level of yield realised. The effect of the HIV/AIDS epidemic in limiting farm productivity is common knowledge. Hands that could have been employed in production are either lost though death or immobilised by sickness. Statistics on morbidity and mortality due to HIV/AIDS are not yet in the public domain. Estimates supplied through the news media are largely unreliable. The rates of losses in man days of farm work due to the disease are probably now as high as those reported for the traditional human ailments. The contributions of the other diseases to morbidity and mortality are depicted in Table 6.2. However, most of the reported cases of death and morbidity are children under the age of 5. Infant mortality rate is depicted in Figure 6.6. This does not seriously reduce the impact on labour supply because the women who have primary responsibility for the care of the children are also the ones that supply a disproportionably higher percentage of agricultural labour (Gallop and Sachs, 2000).

Climate is one of the major factors influencing the incidence of diseases in Nigeria (Adejuwon, 1978). In general, disease agents do better when the temperature is high, under conditions of optimum water supply. The climate has long been identified as the fundamental cause of the low state of human health in the Tropical World. With ample justification, Gourou (1961) contended that: "The steady, high temperatures, the high humidity of the air, the many water surfaces fed by rains, are necessary for the maintenance of pathogenetic complexes in which man insect and a microbe are closely associated"

For instance, heavy rainfall quickly fills small surface depressions and abandoned containers with water in which mosquitoes find suitable conditions for breeding. About forty different types of human diseases are known to be transmissible by mosquitoes (Brown, 1955). The most widespread include malaria, filariasis and yellow fever. Malaria is transmitted by *Anopheles* spp. From 1991 to 1995, cases of malaria reported throughout the country averaged one million annually. These figures make malaria the most widespread disease among Nigerians (FMH, 1994). There is no part of the country free from the disease. In the coastal belt, as a result of high year-round humidity, and abundant water surfaces, continuous transmission of the disease is possible (Brown, 1955). In the rain forest belt, the period of transmission is as long as 9 months, dropping to 7 months in the Guinea savannas and 5 months in the Sudan and Sahel. Projected higher humidity and rainfall are likely to result in higher rates of transmission. Probably because of the association of mosquitoes with wet surfaces, the disease is more prevalent in the wetter parts of the year. From 1965 to 1970, the northernmost states had the lowest rates of incidence. However the figures for 1991 to 1995 indicated no such difference. The most seriously affected states now include Plateau, Sokoto and Kaduna in the north as well as Lagos in the south (FOS, 1996a).

There are other diseases such as measles, chicken pox, small pox, pneumonia and meningitis whose incidences attain epidemic proportions during particular parts of the year. One cannot avoid the conclusion that the occurrences of these diseases are related to the changing seasonal weather. Incidences of measles, chicken pox and small pox tend to be high during the hot and dry seasons. On the other hand, pneumonia, which ranks third after malaria and diarrhoea, with respect to mortality rates, is significantly associated with the middle of the rainy season in Southern Nigeria.

Cerebro-spinal meningitis is a virus killer-disease, well known in the drier, northern parts of the country. It is an endemic disease but incidence mounts to epidemic proportions in certain years during the dry season, that is, from November to March. It is suggested that high temperatures associated with the change of seasons might be the direct predisposing factor (Brown, 1955). If this proves to be the truth, the high temperatures projected for the country could mean a higher rate of incidence of the disease. Cerebro-spinal meningitis quickly spreads through the population as the conditions of the victims quickly deteriorate to an acute state. The mortality rate among affected individuals is probably higher than that of any other common disease including small pox before it was eradicated. This is one disease whose ravages have not abated in recent years notwithstanding the general improvement in medical facilities. Epidemics of serious proportions were reported as far back as 1885, and at intervals of about five years ever since (Brown, 1955). The number of reported cases, which stood at 2,511 in 1964, rose to 7,623 in 1965, declined to 1,879 in 1969, rose again to nearly 10,000 in 1970 and declined rapidly thereafter to 1,719 in 1973. The most recent statistics gave a figure of 7,375 for 1995 indicating another upsurge. From the data on reported cases in recent years, it can be observed that the main areas of occurrence are in the northernmost states of Sokoto, Kebbi, Zamfara, Katsina, Kano, Jigawa, Yobe, Bornu, Bauchi and Plateau.

Notifiable Diseases	Rates of Morbidity per 100,000 Population			Rates of Mortality per 100,000 Population		
	1991	**1992**	**1993**	**1991**	**1992**	**1993**
Malaria	1027.7	1337.4	1045.7	2.2	1.2	0.77
Dysentry	523.1	609.0	519.0	1.8	0.7	0.59
Pneumonia	154.8	152.3	171.3	1.0	0.5	0.28
Measles	49.7	94.3	58.3	0.4	0.9	0.34
Gonorrhoea	49.4	54.3	35.5	-	-	-
Wh.Cough	21.1	24.3	25.3	0.1	-	0.06
Filariasis	8.0	14.1	17.9	-	-	-
Leprosy	15.4	16.3	15.5	-	-	-
Chicken Pox	9.9	19.4	14.1	-	-	-
Schistosomiasis	15.2	18.7	12.8	-	-	-
Typhoid	9.9	20.8	12.7	0.3	0.1	0.04
Tuberculosis	22.2	16.2	12.4	0.6	0.3	0.20
Food poisoning	9.4	11.0	12.3	-	-	-
Hepatitis	10.1	9.1	6.7	0.1	0.1	0.04
Guinea worm	6.2	7.4	5.7	-	-	-
Meningitis	7.9	7.0	4.5	0.8	0.6	0.39
Cholera	69.6	9.5	4.3	0.8	0.7	0.22
Trachomia	7.9	6.0	4.2	-	-	-
Opthalmia	4.0	3.8	4.2	-	-	-
Influenza	4.0	5.6	4.1	-	-	-
STD	20.5	21.7	17.6	-	-	-
Relapsing fever	5.8	9.5	2.5	-	-	-

Source: Federal Ministry of Health (1994) Nigeria Health Profile 1992/93

Table 6.2: Reported rates of morbidity and mortality from diseases for 1991 - 93

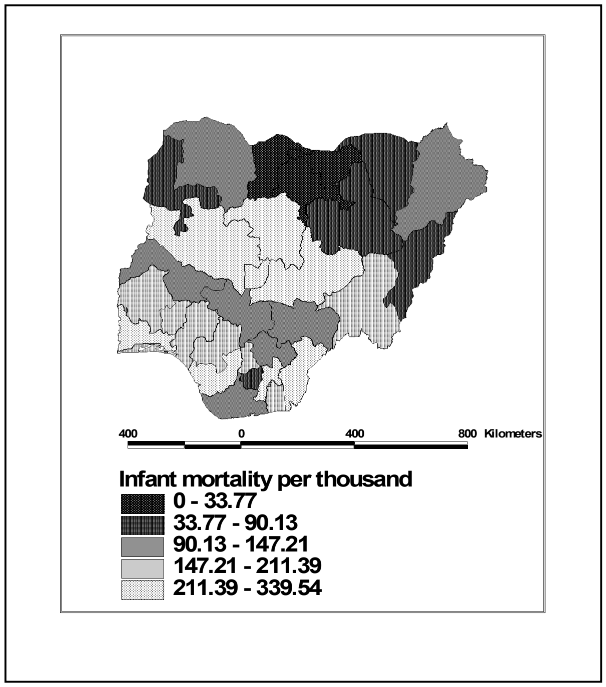


Fig. 6.6: Infant mortality rate

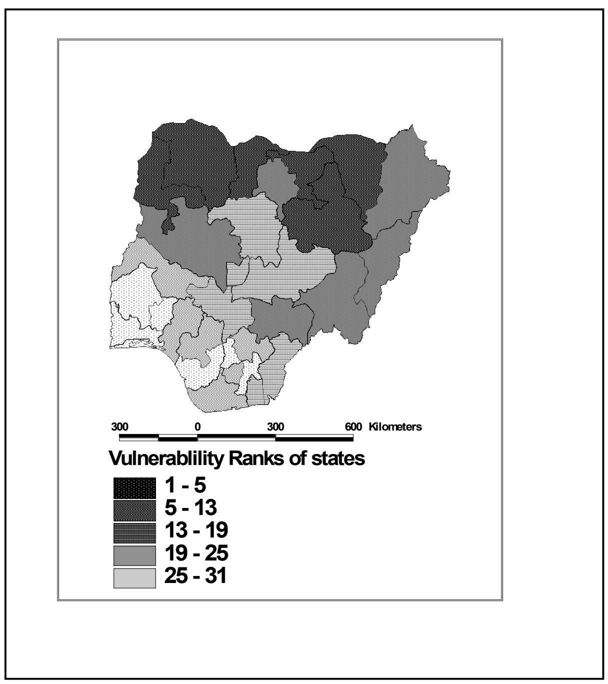


Fig. 6.7: State vulnerability ranks

6.8 Indicators of Vulnerability

Figure 6.7 is a map depicting the spatial pattern of vulnerability in the country based on the 30-state structure and attributes indicating: sensitivity to climate variability, sensitivity to climate change, and inherent capacity or lack of capacity to respond to, in the sense of cope with, recover from, or adapt to climate change. The attribute representing climate variability is the index of variability of total annual rainfall between 1961 and 1990. The attribute representing climate change is the projected average temperature for the growing season for the 2070–2099- period. The attribute connecting the peasant household through agriculture to climate is the percentage of the households employed in agriculture. The attributes indicating adaptive capacity include economic, health, education and demographic conditions of the households. The economic attributes at household level include poverty head count and access to electricity. Internally generated revenue is adopted as a measure of poverty at state level. The environment attribute included was access to potable water. Among the health attributes are population per medical personnel and under-five mortality. Education-related attributes include adult literacy, primary school enrolment, secondary school enrolment and tertiary institution enrolment. Demographic attributes included are child dependency burden ratio and the use of modern contraceptive methods. Each state was assigned a rank for each attribute depending on their positive indication of adaptive capacity. The ranks were added and the results used to determine a composite value of relative vulnerability to each state. These were the data used in preparing the map. The mean rankings show clearly that the peasant households in the southern states are the least vulnerable to climate change, followed by those in the Middle Belt, while the households in the extreme northern states were the most vulnerable.

6.9 Summary and Conclusions

Exposure of crop production to contemporary climate variability, especially to droughts of varying severity is a major source of existent vulnerability of the Nigerian peasant household. Climate change during the 21st Century in Nigeria will be manifested with a higher degree of confidence with regards to temperature than any other climatic element. The higher temperatures projected will be associated with significant increases in atmospheric humidity and significant increases in precipitation. As a result of the increases in precipitation and atmospheric humidity, crop yield will increase substantially during the first half of the century. This will tend to relieve contemporary vulnerability. However, during the second half of the century, whatever benefits are due from the increases in precipitation and atmospheric humidity will be masked by the negative consequences of the higher temperatures. The net result of these is that climate change will pose considerable risks to peasant household health, crop production and food security. The risks will be intensified towards the end of the century. The risks will be greater in the north than in the southern parts of the country. Peasant households in the country will be vulnerable to the potential climate change mainly because they are dependent on agriculture, which will be subject to the negative impacts of the change in the second half of the century. Also if existent poverty is not alleviated, the households will be vulnerable to the changes in climate because they will lack the resources required for coping. Vulnerability will also result from the potential compounding consequences of the changes in climate on some of the current household inadequacies. Such inadequacies include: scarcity of water, food insecurity and poor health. Part of the vulnerability will derive from the predisposition to further damage by some of the current negative attributes including explosive growth in human population, low levels of educational attainment and inadequate social and economic infrastructure. There are indications that the climate projected may present opportunities for improving the quality of human life in the coastal and high altitude regions.

7 Extended Range Weather Forecasting: The Basic Adaptation Strategy

7.1 Introduction

Adaptation is described as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001a). Adaptation could be anticipatory or reactive; private or public, and autonomous or planned. The project was approved for funding under the title: "Extended Range Weather Forecasting as a Strategy for the Enhancement of Crop Productivity". It is clear from this that the central objective of the study as originally conceived was adaptation. The options to be developed were meant to be anticipatory, public and planned. After the change of title to "Climate Variability, Climate Change and Food Security", the Research Team agreed that the adaptation objective should be pursued with three main targets in view. First, adaptation options were to be developed with the target of building resilience into the crop production systems and making them less sensitive to climate variability and climate change. Second, options were to be developed with the target of mitigating the negative consequences of climate variability and climate change. Third, the original central objective was to be developed into an early warning system and a mechanism for anticipating and forestalling the negative impacts of climate variability and climate change.

With respect to the objective of building resilience into the crop production systems, five main lines of activities were outlined. These included: 1) an assessment of current institutional capacities in the area of agricultural extension, 2) a review of the achievements in the development of improved seeds and cultivars, 3) promotion of strategies to neutralize biological constraints including those pertaining to pests and diseases, 4) design of strategies for the management of soil constraints and 5) development of strategies targeted at reducing recognized socio economic constraints. The adaptation measures involved are not new to agricultural practice. They only need to be put into practice by stake holders at the various levels of engagement with food production.

With respect to the objective of developing options targeted at mitigating the negative impacts of climate variability and climate change, emphasis was placed on agronomic practices aimed at specific weather-related risks. Along one line of activities, practices based on modern farming techniques were to be assessed. Along another line of activities, the reactions of farmers to extreme weather events were to be considered with the aim of identifying measures that could be adopted for enhancing crop productivity. The third line of activities was to be directed at making the best use of the growing season as it is presented each year. For example, planting dates could be altered to make use of the more reliable parts of the growing season. The adaptation measures involved are also not new. They could be found in both traditional and modern agricultural practices.

The adoption of extended range weather forecasting for the enhancement of crop productivity is informed by the understanding that a fore-knowledge of the weather of a growing season will enable farmers to plan with greater confidence to forestall its negative consequences and exploit its beneficial opportunities. *Ex ante* decisions relevant to agricultural timing that might be influenced by forecasts of growing season, climatic conditions are in essence adaptation measures. These include among others:

- Choice of planting dates to enable crops benefit maximally from whatever weather is expected;
- Adoption of water conservation practices whenever below normal rainfall is predicted;
- Adoption of early maturing varieties to mitigate shortened growing season;
- Change to drought tolerant crop varieties whenever a drier weather is forecasted;
- Change to high yielding crop varieties to take advantage of unusually favourable weather;
- Change to better adapted crops;
- Application of irrigation practices;
- Adoption of weather compensatory farm operation schedules e.g. higher doses of fertilizer;

- Adoption of multiple cropping to take advantage of unusually long growing seasons;
- Change of site locally e.g. cultivation of *Fadama* soils during year of drought and deep loam soil during years of heavy rainfall; and
- Intensive use of herbicides and pesticides whenever the weather is favourable to weeds and pests.

Thus a well developed early warning system is an invaluable asset in any plan to adapt crop production systems to a variable climate. Since variability will remain a significant element in any future climate, skilful weather forecasting will also remain a valid adaptation strategy in the context of any projected climate change.

The current chapter in the Project Report is designed to highlight the results of the activities targeted at improving extended range weather forecasting as a strategy for enhancing crop productivity. This is justified by the fact that it was the main focus of the proposal approved for funding and on which was based the main deliverables promised. There are three groups of studies being reported in the chapter. These include: 1) assessment of the weather forecasting needs of farmers in the area of study; 2) assessment of the skill levels of the existing weather forecasting capacity; and 3) studies designed to fine-tune the existing weather forecasting capacity in West Africa. The contents of the chapter are organized into seven sections including the introduction. Section 2 is a summary of the weather forecasting needs of farmers in the study area. Section 3 presents the weather forecasting organizations with interests in West Africa and the tools already developed for extended range weather forecasting. Section 4 is the assessment of the skill levels of the existing weather forecasting capacity. In section 5, we present a weather calendar clock work as a strategy for identifying the 'safe' parts of the growing season, during which risks of unfavourable weather are minimal. In Section 6, we develop and test models for forecasting the dates for the onset and cessation of the growing season. In section 7 we develop and test models for forecasting the number of rain days. Section 8 is the summary and conclusions.

7.2 Weather Forecasting Needs

In a typical tropical region like West Africa, rainfall is the principal controlling element of crop productivity (Nieuwolt, 1982, Stern and Coe, 1982). Normally, at elevations below 1000 meters, temperature never falls below levels at which they could be stressful to crop plants. In other words, the growing season lasts thermally, the whole year. Low temperature does not constitute a limiting factor on growth, development or maturity of the crop plants. Thus, it is moisture rather than temperature that influences the abundance of natural life. Life depends entirely on the amount of rainfall received and so interest in climate or the weather naturally centres on the amount, duration and distribution of rainfall. The crop plants are sensitive to the moisture situation both during their growth, development and especially as they reach maturity. This is reflected in a definite soil and atmospheric moisture range in which field preparations are expected to commence; and also in which such farm operations as sowing, thinning; transplanting, weeding, irrigation, insecticide and fertilizer applications as well as harvesting are scheduled to take place. When soils are too wet or too dry, specific farm operations might prove inefficient or harmful to growth and development. Dry spells within the growing season could reduce economic yield considerably, or as it often the case, result in total crop failure. On the other hand, continuous rains could delay the harvest and expose yield to pest damage. Moreover, since most crops require varying periods of time for curing post-harvest, incessant rains could not only slow down this process, but could also create a favourable environment for moulds and fungi which may in turn cause a reduction in the quality of the harvested crops. Thus, the weather forecaster is seldom asked what the temperature will be, but everyone is greatly concerned about whether or not it is going to rain.

From our various field surveys, we gathered evidences indicating that the farmers, wherever they are found, whether in the humid or semi arid zones are quite conscious of the relationship between farm operations and the weather patterns of the growing season. Each year, the farmers use the dry season to prepare the land for cultivation. The bush could be cleared entirely by the use of fire. In most cases, the bush is first cleared by slashing before fire is applied. If the rains come too early, preparation operations could be adversely affected. It is therefore, necessary to know when the rains are going to start. However, the main anxiety about the onset of the rainy season concerns the planting date. Farmers like to sow their crops as early as possible. The earlier the crops are sown, the earlier the food products will be made available to end the annually occurring period of food deficiency. Moreover, farmers who get their crops early to the market are likely to enjoy better prices. Our own studies also show that the yields of crops planted early are higher (Adejuwon, 2002). This is explained by the fact that nitrogen levels in the soil, sourced from farm residues, are higher at the end of the dry season before they are washed away by the rains. This is usually referred to by agronomist as early season nitrogen flush. Also, incident solar radiation levels are highest during this period before the rains come and the clouds reduce the amount of sunlight available for photosynthesis. All these explain why farmers are anxious about when the rains will come. Sometimes, there are false starts of the rainy season and farmers rush to plant their crops. This can result in disaster as the seeds may be completely lost. Replanting could be expensive if the seeds have to be purchased. If replanting seeds are sourced from the farmers' stores, they could deplete food needed by the household during the period of low food supply. The amount of resources wasted in this way could be considerable when the crop concerned is yam. The yam seed is cut from the same tuber used as food, and could be up to 25 percent of production. The farmers would, therefore, benefit considerably from a fore-knowledge of the onset of the rainy season.

A fore knowledge of the cessation of the rainy season is also useful for agricultural timing. Crops such as cow peas or late maize are planted so that they could be ready for harvesting after the rains have ceased. A late cessation of the rains means that the crops would be harvested under wet conditions and much of the crop could be lost to moulds and other pests and diseases. On the other hand, if the rains cease too early, the entire crop could fail due to inadequate moisture. There is a system of yam production usually practised in the Derived Savannah Zone which requires the seeds to be planted at the end of the rainy season, just before the rains cease. The seed remains dormant for the whole period of the dry season. As soon as the rains come during the following year, yam vines shoot up and harvestable tubers are produced two or three months ahead of the normal yam harvest season. New yam produced in this way commands very high prices as they are preferred to the old yam which would by then be losing its taste. The critical weather requirement of this system is that at least one heavy downpour must fall on the planted seeds before the dormancy period. In the absence of this as much as 50 percent of the crop could be lost. Thus the farmers can also benefit considerably from a fore knowledge of when the rains would cease.

The length of the rainy season, the amount of rain that falls during the peak rainfall period is also watched with anxiety by farmers. Palm fruits are harvested by climbing the tree to cut the fruit. This is a very hazardous operation especially during the rainy season when the trunks are slippery. Fewer climbers are available during the rainy season, and for this reason palm products such as palm oil are in short supply and expensive. The fruits are left to waste during the rainy season, and the longer the season the greater the loss. Also during the rainy season, rural roads become impassable and crops like cassava are unable to reach the market. Heavy tropical rainstorms can make all the difference between a good harvest and crop failure. Farmers complain that such storms could cause a heavy loss to flowers before they become fruits. Cowpea is an example of crops that could be damaged in this way. Heavy rainfall reduces the number of pods per stand of cocoa, while it increases the degree of infestation by the black pod disease (Thoroid, 1952; Adejuwon, 1962). Years with heavy rainfall therefore usually correspond to years with low yields of the crop. Moreover, cocoa harvested at the height of the rainy season has low grades and may not be able to make the export market. This is due to the prevailing heavy clouds and the little sunlight available for drying the seeds. A prolonged little dry season mid way into the rainy season is a blessing to cocoa farmers.

A minimum amount of rainfall during the dry season is needed for the establishment phase of cocoa. Cocoa is usually planted as seeds or seedlings during the rainy season. The new crop plants will die during the first dry season if no rain falls. Thus in the forest zone farmers meet with varying successes in developing a new plot to the crop depending on how much rain falls during the first dry season after planting (Adejuwon, 1962). Farmers' needs from the weather forecaster, includes statements on whether or not the dry season will be completely dry.

Thus the weather forecasting needs of farmers include, not just the total annual or seasonal rainfall, but also the rainfall of the component months and recognizable sub seasons. The tendency for forecasters especially those based outside West Africa is to leave the stake holders with forecasts of only the total seasonal rainfall. No wonder the end consumers of the forecast are not interested in these products!

7.3 Existing Weather Forecasting Capacity

7.3.1 The approaches to weather forecasting

There are three main approaches to extended range weather forecasting. These could be described as statistical, synoptic and dynamic. Statistical models fall into two main groups, including linear regression and linear discriminant models. The candidate predictors in either of the two models almost always now include SSTA (sea surface temperature anomaly) variables observed during the spring preceding the main rainy season. The analyses are carried out on seasonally averaged data for a training period of at least 30 years. The resulting forecast represents a choice of one out of three or five broad weather categories. The linear regression output consists of deterministic 'best estimate' forecasts. The predictors have been selected through principal component and stepwise regression analyses. The results give category boundaries as percentages of mean rainfall for the training period. In the case of the Linear Discriminant Model, the probability of the coming seasonal weather falling into any one of the weather categories boundaries are determined by separate linear discriminant equations (Folland, et al, 1986).

The basic assumption in synoptic weather forecasting is that each composite weather situation develops after certain predisposing conditions have been met. Such conditions could relate to the earth's surface or to any of the identifiable layers in the atmosphere. What later becomes a weather system is initiated at specific locations over specific time spans. Then it takes time to develop and mature before "breaking out" as a recognizable weather type that could be experienced and observed. The same weather system, while moving across land and ocean surfaces in characteristic pathways, is often experienced at different locations in succession. Along its path, the weather system could be modified as it persists for shorter or longer spans of time at the various locations it affects. In the final phase of its life cycle, the weather system and its characteristic weather disintegrate and fade, to be replaced by other systems and the next generation of weather types. Thus, each weather system is characterized by a set of time and space antecedents that herald its eventual "break out" or arrival. Such antecedents represent the scientific basis for forecasting and anticipating particular weather events. The synoptic approach is the main tool for shorter range forecasting. However, there are synoptic systems in West Africa, which persist for periods long enough, and follow predictable paths, that they could be used for extended range weather forecasting. Such systems are indicated by the presence of the Inter-tropical Convergence Zone or either of the two air masses converging on the zone. For each season, the onset or cessation of the rainy period could be predicted by monitoring the movements of these weather indicators.

Dynamic models are in essence mathematical representations of the earth-atmosphere-ocean system. They individually consist of a set of simultaneous equations written in the language of differential calculus. The equations are statements that are consistent with the laws of classical physics, (specifically, those of fluid dynamics} which apply to a continuous moving fluid around a spherical object. Among such laws are those pertaining to thermodynamics, motion and gases. The fundamental variables that appear in the equations are referenced at grid points describing the atmosphere in its vertical and horizontal dimensions. Each grid point is a member of a network representing a layer in the atmosphere. As many as 19 such layers extending from the earth's surface to the middle stratosphere constitute the HADAM 3 Version of the UK Met Office's atmospheric general circulation model. Apart from truly representing changing temperatures, air densities and moisture at various points in the atmosphere, a GCM could produce clouds and calculate yields of precipitation.

GCM models can incorporate external input either from space or from the earth's surface. For example, variations in solar heating with latitude, season and time of day, as well as rotation of the earth, the effect of friction of the earth's surface and other major effects of mountains are reflected in changes in model variables. The land surface and the atmosphere exchange moisture, which, in turn, translate into heat exchange. At each model grid node, feedback between soil and the atmosphere takes place and is reflected in the model as precipitation, evaporation, sublimation and runoff changes. Similar exchanges of heat and moisture are observed between ocean surfaces and the atmosphere. Each GCM primarily models the earth planet and could be used to forecast the weather or future climate of any part of the earth's surface. However, there is always the need to fine-tune each model before application to specific regions.

7.3.2 Weather forecasting organizations

The forecasts assessed in this study have been prepared by various meteorological organizations including: Met Office (United Kingdom Meteorological Office), C.N.R.S (Centre de Recherchede climatologie, 21000 Dijon – FRANCE), NOAA (USA National Oceanic and Atmospheric Administration) and the Nigerian Central Forecasting Office. The forecasts of the International Organizations have been obtained from articles published in Experimental Long-Lead Forecasts Bulletin. The forecasts of the Nigerian Central Forecasting Office were obtained directly from their offices in Lagos, Nigeria

The Met Office has been engaged in experimental forecasts of seasonal rainfall in the Sahel (region 1) since 1986. Since 1992, the organization has extended the coverage of its forecasts to a slightly re-defined Sahel (region 2, 15^0 W to 37.5^0 E and 12.5^0 N to 17.5^0 N). The new areas covered also include an area south of the Sahel (region 3, 7.5^0W to 33.75^0E, 10^0N to 12.5^0N) and another area extending to the coast of the Gulf of Guinea (region 4, approximately 7.5^0W to 7.5^0E, 5^0N to 10^0N). The forecasts are based on ocean and atmospheric information available in early May. The statistical forecasting methods used are the multiple linear regression and discriminant analysis. Predictors include indices of March and April sea surface temperature anomaly patterns which are represented by eigenvectors. The predictors for regions 1, 2 and 3 include a global SSTA pattern showing opposing signs north and south of the equator, a global pattern with strong weights in the tropical South Atlantic, and a global pattern showing ENSO related variability and regional patterns for South Atlantic. The one predictor used for the Guinea Coastal region (region 4) is a South Atlantic pattern with strong weights in the Gulf of Guinea (Colman et al, 2000).

Both the Stepwise Linear Regression and the Linear Discriminant techniques are based on Folland et al (1991). The analyses were carried out on seasonally averaged 10^0 x 10^0 square SSTA data and the mean seasonal rainfall for a training period of at least 30 years. The results, given for the four regions defined by longitude and latitude mainly, give boundaries for five rainfall predictand categories as percentages of mean rainfall for the training period. In the case of the Linear Discriminant Model, the predictands also consist of five categories. Using archival data, the category boundaries are defined so that each category, known at quint, is equiprobable in the training period (Folland, et al, 1986). The candidate predictors were continuous SSTA variables being the time coefficients of unrotated and rotated principal components, observed during the spring preceding the main rainy season. A 95% significance level was used to select predictors in a stepwise, regression fashion. Only two out of eleven prospective predictors were retained in the model used. The forecasts are given, relative to the mean of the training period as very dry, dry, average, wet and very wet. Attempts are now being made to forecast seasonal weather using multiple model configurations (Graham and Clark, 2000). It is expected that a higher skill level would be attained with a combination of dynamic models than with single model forecasts.

The Centre de Recherche de Climatologie of France applies two complementary statistical tools in forecasting rainfall in West Africa (Philippon and Fontaine, 2000). The tools, consisting of the Multiple Linear Regression Analysis (MLR) and the Linear Discriminant Analysis (LDA) have been adapted from Folland et al (1991). However, the predictor composition is quite different. Also different is the procedure for their computation and selection. In order to make the forecasts available before the beginning of the growing season, only information available by the end of April is employed. The predictands (June to September cumulated rainfall) refer to the entire West African sub continent (17.5^0N - 5^0N; 17.5^0W - 17.5^0E) and utilizes 2.5^0 latitude and 3.75^0longitude grid box rainfall database. The predictands also consist, on the one hand, of a regional Sahel index computed over the zone extending from 10^0N to 17.5^0N and from 15^0W to 15^0E. On the other hand, they consist of 41 local indexes covering the whole of West Africa. Thus each block in the 2.5 x 3.75 grid has its own forecast results. The data utilized include a set of 27 potential and tropical (30^0N - 30^0S) SST indices analyzed on a 5 x 5 degrees grid. There is also another set of data of 50 potential regional (25^0W - 15^0E; 25^0N - 5^0S) atmospheric indexes describing near surface humidity, moist static energy and geo potential values.

The National Oceanic and Atmospheric Administration USA has established an African Desk at the Climate Prediction Center Springs, Maryland. The 'Desk' has been experimenting with African seasonal forecasting in collaboration with the CPC (Thiaw and Barnston, 1999). Efforts have so far been limited to statistical methods. In 1998 and 1999 Canonical Correlation Analysis (CCA) was employed to produce experimental forecasts for rainfall anomalies for July, August and September in the Sahel. The latter has been defined as lying within 10^0N - 25^0N and 20^0W - 45^0E.

The forecasts issued from the *Nigerian Central Forecasting Office* ahead of each cropping season are primarily based on statistical forecasts by regional West African organizations. The latter are downscaled and supplemented with local synoptic observations. The forecasts are presented first in terms of broad zones including the Far North, the Middle Belt and the Southern Forest Zone. Further details are then given in respect of the main weather observing stations spread across the country. One of the West African Regional Organizations is PRESAO (First West African Forum on Climate Variability and Its Applications in Early Warning Systems for Food Security). The PRESAO forecast map is meant to be downscaled by national meteorological services to better serve the need of users. While making its own local forecasts, CFO makes use of SSTA data of 2^o x 2^o resolution (Tourre, 2000), compared with SSTA data on a resolution of 5^o x 5^o employed by CNRS (Philippon and Fontaine, 2000) and the 10^o x 10^o grid SSTA data used by the Met Office (Andrew et. al, 2000). CFO makes additional use of the current trend of weather, pressure systems and the position of the Inter- Tropical Convergence Zone (ITCZ).

7.4 Skill Assessment of the Existing Capacity

7.4.1 Assessment of forecast skills

The stations selected to test the forecasting skills of the various tools include Benin City, Lagos, Ibadan, Ilorin, Enugu, Minna, Jos, Kaduna, Lokoja, Maiduguri and Kano; all located within Nigeria (Figure 2.1). The stations have been selected to represent the various climatic and ecological zones between the Gulf of Guinea in the South and Sahara Desert in the north. Their selection is also based on the availability of rainfall data from 1961 to 2000. The forecasts assessed were for the five years from 1996 to 2000.

Skilful forecasts are those that were subsequently confirmed by observations. High skills are demonstrated when forecasts are very close to observations while low skills are recorded when the two are substantially different. One practical problem in assessing the skills is the fact that observations and forecasts are not presented in the same units of measurement. Observations are usually presented on an interval scale with the amounts of rainfall given in millimetres. On the other hand, forecasts are stated using ordinal categories. The most common are quint categories varying from very wet, to wet, average, dry, and very wet. Determination of what is very wet, wet, etc in this exercise is based on the records from 1961 to 1995. Rainfall values for each year, whether annual, seasonal or monthly, were arranged in descending order of magnitude and divided into five groups. The resulting highest quint consists of the values for the seven wettest years and the lowest those of the seven driest years. The years with rainfall values falling within the range in the highest quint are classified as very wet while years with values falling within the range of rainfall in the lowest quint are classified as very dry. Other years are similarly classified as wet, average or dry (Adejuwon and Odekunle, 2004).

Stations	Climate zones	Mean jas (rainfall in mm)	Rainfall quint category limits (in mm)				
			V. Wet	Wet	Average	Dry	V. Dry
Maiduguri	Sahel	402	680-597	437-479	363-436	277-362	206-276
Kano	Sudan	518	609-857	561-608	475-560	353-474	283-352
Kaduna	N. Guinea	765	866-1052	834-865	750-833	626-749	438-625
Minna	N. Guinea	705	803-994	744-802	659-743	575-658	477-574
Jos	Plateau	735	788-840	733-787	729-772	698-728	552-697
Ilorin	S. Guinea	493	611-753	551-610	485-550	359-484	130-358
Lokoja	Derived Savannah	575	689-955	636-688	520-635	431-519	321-430
Ibadan	Dry Forest	487	582-1168	498-581	338-497	291-337	132-290
Enugu	Dry Forest	816	1003-1185	836-1002	745-835	638-744	572-637
Ikeja	Rain Forest	508	729-935	512-728	447-511	286-446	147-285
Benin	Rain Forest	979	1171-1465	1032-1170	860-1031	841-859	471-840

Table 7.1a: Definition of quint forecast categories for July, August and September

Stations	Climate zones	Mean jas (rainfall in mm)	Rainfall tercile category limits (in mm)		
			Above Normal	Near Normal	Below Normal
Maiduguri	Sahel	402	471-597	356-470	206-355
Kano	Sudan	597	597-857	442-596	283-441
Kaduna	N. Guinea	765	849-1052	734-848	434-733
Minna	N. Guinea	706	762-994	639-761	477-638
Jos	Plateau	735	780-840	709-779	552-708
Ilorin	S. Guinea	493	585-753	455-584	130-454
Lokoja	Derived Savannah	575	645-955	489-644	321-488
Ibadan	Dry Forest	487	526-1168	432-525	132-431
Enugu	Dry Forest	816	914-1185	712-913	572-711
Lagos	Rain Forest	508	675-935	408-674	147-407
Benin	Rain Forest	979	1124-1465	938-1123	471-937

Table 7.1b: Definition of tercile forecast categories for July, August and September

Sometimes, tercile categories are used, by simply forecasting near normal, above normal or below normal. Determination of what is above normal, near normal or below normal was also based on the records from 1961 to 1995. Rainfall values for each year, whether annual, seasonal or monthly were arranged in descending order of magnitude and divided into three groups. The resulting highest tercile (above normal) consists of the twelve wettest years and the lowest (below normal) those of twelve driest years. The eleven middle years define the near normal range. The quint and the tercile limits provide the framework for converting both observations and forecasts to the same units of measurement. Such a scheme is demonstrated in tables 7.1a-c, which have been compiled with rainfall records for the period 1961-1995 (Adejuwon and Odekunle, 2004).

Stations	Climate zones	Mean jas (rainfall in mm)	Rainfall tercile category limits (in mm)		
			Above Normal	Near Normal	Below Normal
Maiduguri	Sahel	474	571-733	408-570	253-407
Kano	Sudan	625	737-1005	517-736	408-516
Kaduna	N. Guinea	935	1020-1236	876-1019	609-875
Minna	N. Guinea	855	940-1132	825-939	561-824
Jos	Plateau	929	779-1084	910-978	677-909
Ilorin	S. Guinea	665	749-936	593-748	232-592
Lokoja	Derived Savannah	734	795-1110	658-794	447-657
Ibadan	Dry Forest	663	750-1368	578-749	310-577

Table 7.1c: Definition of tercile forecast categories for June, July, August and September

7.4.2 Results and discussion

The results rank NOAA and CFO ahead of CNRS and MO in weather forecasting skill over West Africa, Table 7.2. A careful look at the background of the methods of data collection and analysis appears to explain the relative successes of the forecasting organizations. Virtually, all the forecasting organizations made use of the sea surface temperature anomalies as a predictor among others. However, a noticeable difference in the nature of the sea surface temperature data used by various organizations is in respect of the spatial resolution. While CFO and NOAA made use of SSTA data of 2^o x 2^o resolution (Tourre, 2000), CNRS employed seasonally averaged 5^o x 5^o grid SSTA data (Philippon and Fontaine, 2000) and UKMO employed seasonally averaged 10^o x 10^o square SSTA data (Colman et al, 2000). It thus appears that the finer the SSTA resolution, the better the forecasting skill. It is evident in the results obtained in this study that the forecasting skill varies directly as the spatial resolution of the grid used for the collection of SSTA data.

Forecasting organization	Percentage contribution of each skill category		
	Skill High	Skill Moderate	Skill Low
MO (all)	2 1%	44%	35%
NOAA	56%	22%	22%
CNRS	18%	55%	27%
CFO	20%	70%	10%

Table 7.2: Organizational skill performance assessment

The number of predictor variables used in the forecast models also seems to have played a role in determining the level of skill. While MO whose tools seem to be less skilful than the others, made use of SSTA data alone in the construction of their prediction models, other forecasting centres made use of additional rainfall-formation-related factors. For instance, CFO which came first, on the basis of having the least `low skill' score, made additional use of synoptic data including current weather, pressure systems, equivalent potential temperature and the position of the inter-tropical Convergence Zone (ITCZ). NOAA that, came first, on the basis of the highest `high skill' score made additional use of upper air geopotential heat, tropical low level wind and outgoing long-wave radiation (Thiaw and Barnston, 1999). CNRS, which came third employed additional factors such as geopotential indexes describing near surface humidity and moist static energy values (Philippon and Fontaine, 2000). Note that ITCZ is one major factor not used by CNRS in the construction of their prediction model. This study thus shows that the more predictor variables employed in the construction of a forecast model the better the skill of forecast attained.

The study clearly demonstrates regional disparities in the skills of the forecasting tools Table 7.3. The prediction skill is generally higher for southern coastal locations than for the northern continental locations. It is well known that the Atlantic Ocean is the major if not the only source of moisture into the West Africa sub continent. The moisture is brought to the land areas by the south westerly winds moving in after the northward migrating ITCZ. The characteristics of the south westerly winds, which bring the moisture to the land mass are in turn determined by the nature of the sea surface temperature of the Gulf of Guinea (Adedokun, 1978). It is thus logical that the conditions of the south westerly winds as determined by the SSTA and its associated ITCZ would be least modified near the coast. As the ITCZ advances and the southerly winds progress further inland, their thermodynamic transformations become more pronounced. The changes in the nature of south westerly winds and other rainfall-associated factors are thus a function of space and time. Thus, the space connection between rainfall over the land and the activities over the Atlantic Ocean weakens with distance between a location over the land and the sea. It is, therefore, not surprising that a prediction model based on sea surface temperature anomalies is more skilful in the south, near the ocean, than in the interior of the continent.

Stations		**Percentage contribution of each skill category**		
		Skill High	**Skill Moderate**	**Skill Low**
Maiduguri	Sahel	17%	33%	50%
Kano	Sudan	17%	17%	66%
Kaduna	N. Guinea	20 %	60%	20%
Minna	S. Guinea	25%	25%	50%
Jos	Plateau	17%	50%	33%
Ilorin	S. Guinea	17%	83 %	0%
Lokoja	D. Savannah	50%	25%	25%
Ibadan	Dry Forest	29%	71%	0%
Enugu	Dry Forest	33%	33%	34%
Ikeja	Rain Forest	29%	57%	14%
Benin	Rain Forest	33	6 7	0%

Table 7.3: Regional disparities in the forecasting skill

7.4.3 Inadequacies in the existing capacity

The skill level attained by the existing capacity for weather forecasting is not sufficiently high and there is no evidence to the effect that it improved between 1996 and 2000 (Adejuwon and Odekunle, 2004) This suggests that the predictors are yet to be fully understood by the forecasting organizations and underlies the need to develop improved forecasting tools. As noted in the preceding section, the forecasting organizations that are more skilful are those that made use of more predictor variables. It appears that the more predictor variables employed in the construction of a forecast model, the better the skill of forecast attained. Also, it appears that the finer the SSTA resolution, the better the forecasting skill. To improve the rainfall forecasting skills of the extended-range forecasting in West Africa therefore, higher resolution sea-surface temperature anomaly data and more predictor variables, especially those of a synoptic nature should be employed in the construction of forecast model.

In the existing capacity, there is the tendency to concentrate on the total rainfall amount while neglecting other determinants of crop yield. As noted by Odekunle and Gbuyiro (2003),all the recent studies on rainfall predictability in West Africa, including those from the Department of Meteorology, University of Oklahoma, Norman U.S.A. (Bert and Ward, 1998), Nigerian Central Forecasting Office, Oshodi Lagos, (1991), Centre de Recherchede Climatologic, 21000 Dijon-France (Philippon and Fontaine, 2000), UK Meteorological Office, Bracknell, United Kingdom (Colman et al, 2000), Gbuyiro et al (2002) and Wilson (2002), were directed to rainfall amounts only. The number of rain days is hardly ever included in the forecasts notwithstanding its relevance as a determining factor of crop yield. The same total amount of rainfall produced by many rain days is expected to benefit crops more than when it comes in one heavy downpour (Odekunle and Gbuyiuro, 2003). Other important parameters of rainfall that are not considered by the various forecasting organizations for West Africa are the rainfall of onset and retreat periods. These rainfall characteristics appear to be of paramount importance in the sub-region because they affect regional economies (Walter, 1967; Olaniran, 1983; Adejuwon et al, 1990). A failure in early establishment of rainfall onset for example, usually indicates a drought in the early part of the rainy season. Furthermore, as noted by Odekunle et al (2004), the prediction models generated so far by the existing forecasting organizations are regional in approach and general in perspective. Models developed at such spatial scales often fail at individual farm level sites. This appears to be so because of the fact that rainfall characteristics (especially, onset and retreat dates) vary considerably over space. Perhaps this may be part of the reasons why Folland et al (1991), concluded their study by advocating for a separate study of the predictability of rainfall in a few longitudinal subdivisions. In the following sections of the current chapter, additional strategies and skills for fine-tuning the existing weather forecasting capacity are formulated and assessed.

7.5 Calendar Clock Work as Basis for Forecast

Perhaps, the essential beginning of rainfall prediction inter-annually is to identify the relatively stable part of the growing season. Rainfall distribution during such a period in any year should be adequate for agricultural purposes. In other words, no matter how variable the rainfall distribution characteristics of a given region at the onset and cessation periods are, there is a certain period of the year during which it would be adequate for crop germination, establishment, and development in any given year. Such a period would not exhibit significant variation from year to year. This core of the growing season is determined in this study by the use of daily rainfall probability method (Odekunle, 2004).

7.5.1 Description of scientific methods

The data used for the study are the daily rainfall data collected from archival sources, namely the library of the Nigerian Meteorological Services, Oshodi, and Lagos. The rainfall stations selected include; Ondo, Ilorin, and Kano representing humid, sub-humid ands semi-arid climates. Data for all the rainfall stations in this study are available for the period between 1961 and 2000.

A variety of methods have been devised to ensure meaningful probability and reliability values with which to determine rainfall events. In this study, the overall probability of rain is determined and the method chosen is that proposed by Garbutt et al (1981), whereby the probability of rain on any given date can be estimated by the proportion of rainy days on that date. In other words, the process of estimating the probability of rainfall for each day of the year is to express the number of rainy days as a proportion of the total number of days considered for each day of the year. Furthermore, since probability values range between 0 and 1, with success and failure breaking even at 0.50, a day with reliable rainfall may be taken as a day with a probability value that is equal to or greater than 0.50 (Odekunle, 2004).

There is however, a need to define the threshold value of rainfall amount required for a day to be counted as rainy. Several thresholds have been tried by Garbutt et al (1981), and 0.85mm was found appropriate for West African Countries. Therefore, a threshold value of 0.85mm is employed in this study. This implies that any day with a rainfall amount below this threshold value is assumed to be rainless (Odekunle, 2004).

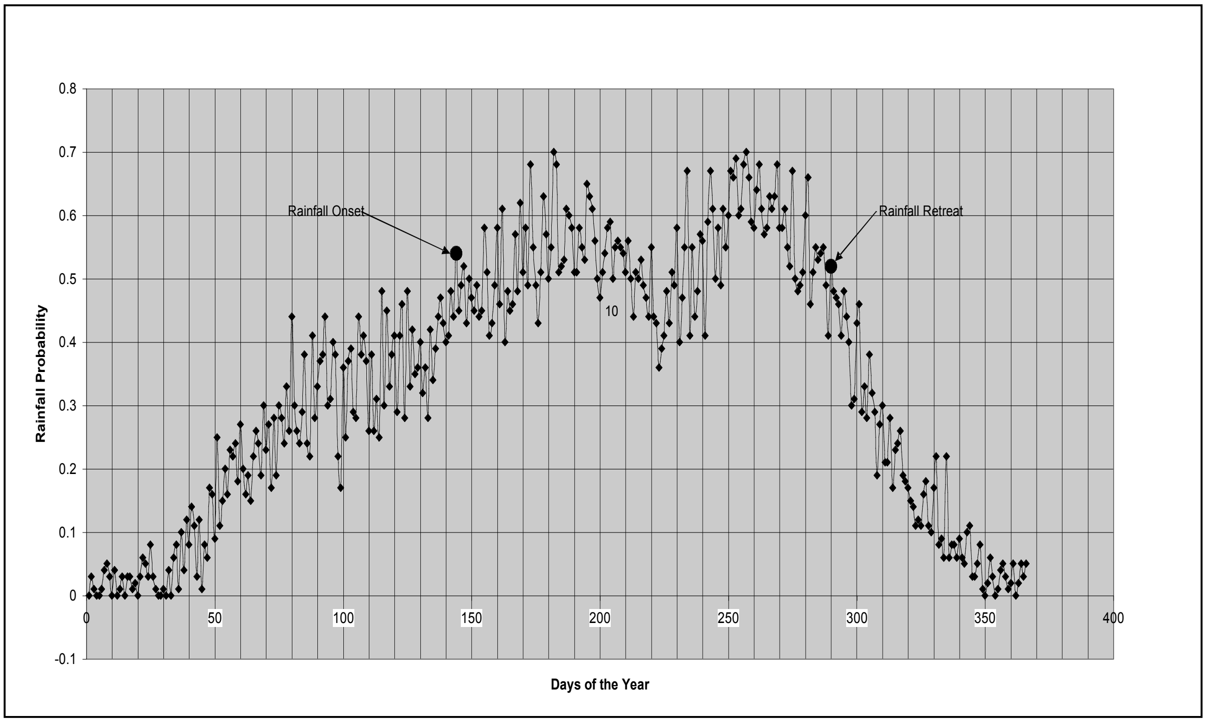


Fig. 7.1a: Rainfall onset, retreat and the length of the growing season in Ondo humid zone (using the rainfall probability/reliability approach)

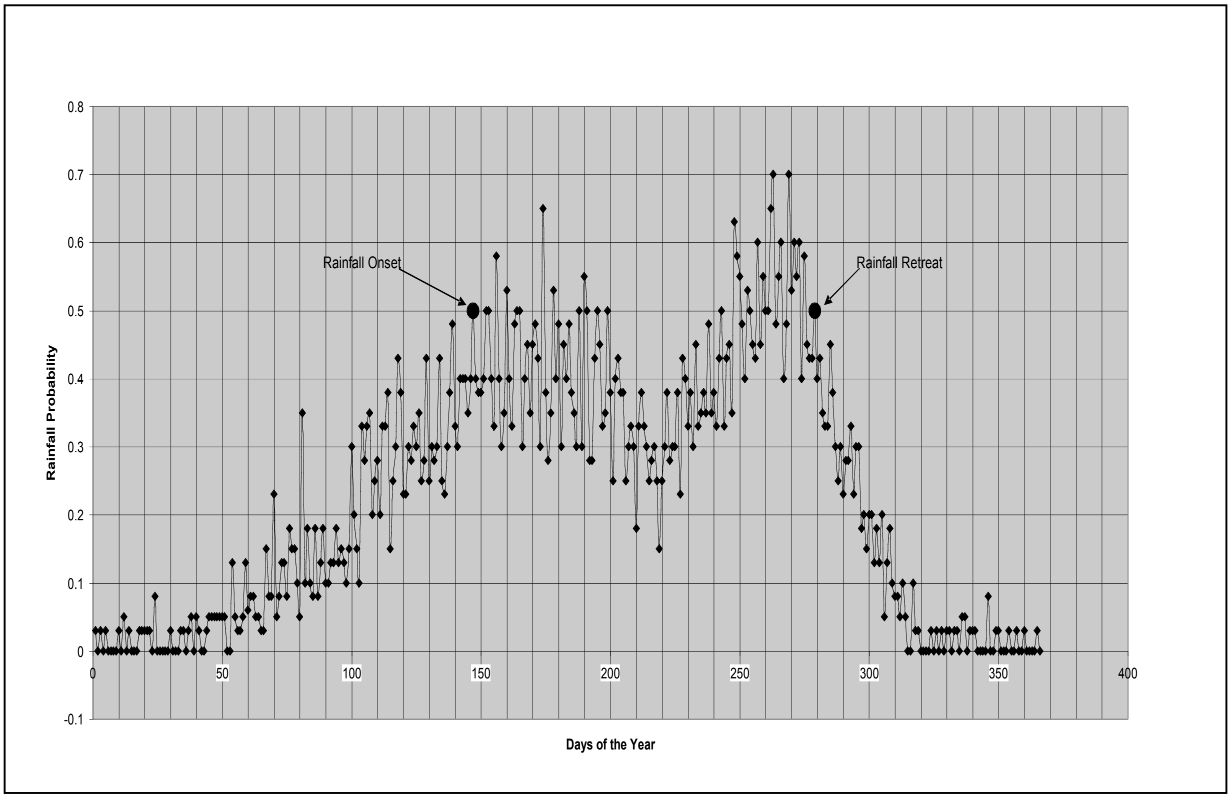


Fig. 7.1b: Rainfall onset, retreat and the length of the growing season in Ilorin sub-humid zone (using the rainfall probability/reliability approach).

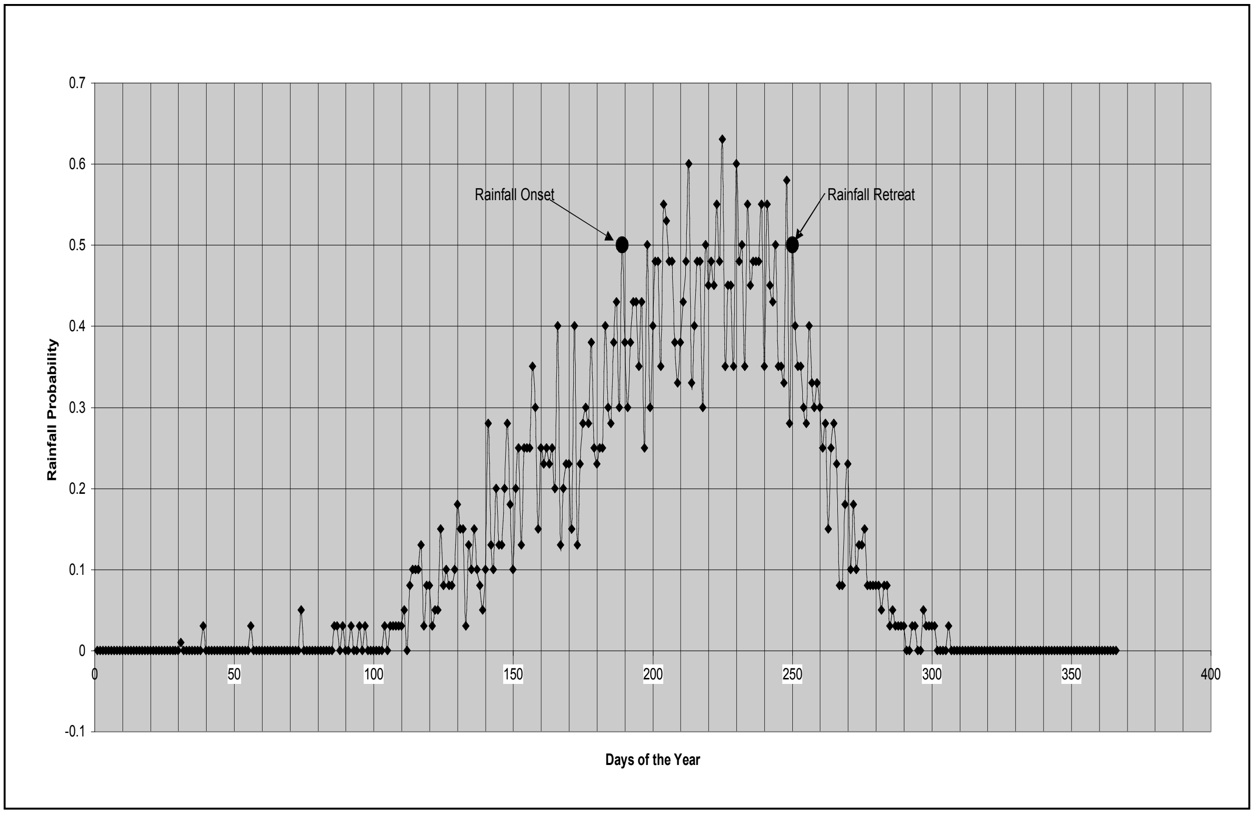


Fig. 7.1c: Rainfall onset, retreat and the length of the growing season in Kano Arid Zone (using the rainfall probability/reliability approach)

7.5.2 Results and discussion

Figures 7.1 a-c respectively shows the rainfall onset and retreat periods and the length of the 'safe' growing season in Ondo, Ilorin and Kano, using the daily rainfall probability/reliability method. The results show that, on average, there are 5 months (early third dekad of May to the end of the second dekad of October) for Ondo, 4 months (mid third dekad of May to the middle of the first deka of October) for Ilorin, and 2 months (end of the first dekad of July to the middle of the first dekad of September) for Kano. During the periods defined in this way, rainfall is reliable. The length of the growing season estimated by rainfall probability method defined the relatively 'safe' core of the growing season, during which crops will thrive well in any given year. Using the methods suggested by Ilesanmi (1972 a and b) the rainy season is already two months old at Ondo, 40 days old at Ilorin and 35 days old at Kano before the 'safe' core is established. This implies that crops planted between the middle of the third dekad of March and early third dekad of May in Ondo, between mid April and mid third dekad of May in Ilorin, and between early June and end of the first dekad in July in Kano are vulnerable to critical dry spells that may adversely affect crop yield. Thus crops that are tolerant to short, dry spells may be planted commencing from the end of May, and early June in Ondo, Ilorin and Kano respectively. However, crops that are less tolerant of drought at the germination and establishment stages should be planted starting from early third dekad of May in Ondo, mid third dekad of May in Ilorin and end of the first dekad of July in Kano. Missing out on the fist two months of the rainy season is however not an option that the farmers will like to consider for the reasons stated earlier. First it has been demonstrated experimentally that maize planted early in the growing season produce much higher yields than maize planted mid way into the rainy season Adejuwon, 2002). Outputs from such late plantings will reach the market when prices offered would be at the lowest level. Moreover bush clearing will be much more difficult when the fields are drenched and there is much difficulty in using fire. Although, the 'safe' period is still long enough for the production of the cereal crops in the humid and sub humid areas, it is definitely not long enough in the semi arid regions. The implication of all these is that the 'unsafe' period needs to be brought profitably into the farm calendar through extended range weather forecasting. However, demarcating the 'safe' period is useful in guiding weather forecasters to the critical early and late season onset and retreat (cessation) periods.

7.6 Predicting Rainfall Onset and Retreat Dates in Nigeria

Rainfall onset can be taken as the period, at the beginning of the rainy season, when rainfall distribution has become adequate for crop development, while rainfall cessation refers to the period, towards the end of the rainy season, when the last series of rains fall.

This study attempts to generate multivariate models that can be used to forecast rainfall onset and retreat dates in Nigeria. The prediction models in this study are based on the combined effect of the SST (from the Gulf of Guinea up to Benguela current region), land/sea thermal contrast between some selected rainfall stations and the selected SST stations, ITCZ and land surface temperature, for individual rainfall stations. Furthermore, the prediction models generated from this study are for individual rainfall stations as opposed to the earlier studies that are regional in approach and general in perspective. This is especially necessary in view of the fact that rainfall onset and retreat dates vary considerably over space.

7.6.1 Description of scientific method

Data on rainfall amount, the monthly surface location of the ITCZ, and the monthly land surface temperature were sourced from the archives of the Nigerian Meteorological Agency, Oshodi, and Lagos. The SST data were sourced from the archives of the Hadley Centre for climatic prediction and research, U.K. Data on the surface location of ITCZ were collected along three longitudinal positions across West Africa, namely: 5ºW, 0º and 5ºE. The data were collected at 0600Z. Data on the SST were collected for twelve locations over the Atlantic Ocean namely, 22.5ºS; 7.5ºE, 22.5ºS 2.5ºE and 22.5ºS; 2.5ºW; in the Benguela current region of the South Atlantic Ocean, 17.5ºS; 2.5ºW and 17.5ºS; 7.5ºW, near St. Helena, 7.5ºS; 2.5ºE and 7.5ºS; 12.5ºW, near Ascension Island and 2.5ºS; 2.5ºE; 2.5ºS; 2.5ºW, 2.5 S, 7.5 W; 2.5ºN; 2.5ºE and 2.5ºN; 2.5ºW to represent the Gulf of Guinea. The resolution of the data set is 5º x 5º. All the data used are for the period 1962-1996. Ten years of the thirty-five year data set (1962-1969; 1995-1996) were utilized in testing the models. The data from the other twenty five years were used to calibrate the models. The 1962-1969 period was used to hind cast, while data for 1995 and 1996 were used to forecast.

The first step in the data analysis was the determination of the mean rainfall onset and retreat dates. The method employed is that proposed by Ilesanmi (1972a, b). The first essential step of this method is to derive the percentage mean annual rainfall that occurs for each 5-day interval. This is followed by accumulating the percentages of the 5-day periods. When the cumulative percentage is plotted against time through the year, the first point of maximum positive curvature corresponds to the effective onset of the rainy season while the first point of maximum negative curvature corresponds to the effective end of the rainy season. Figures 7.2 a-c is for Ikeja, Ilorin and Kano, and is presented here as examples from the humid, the sub-humid and the semi-arid zones respectively. Ilesanmi (1972a) notes that the point of onset on the graph corresponds to the time when an accumulated 7-8% of the annual rainfall totals has been obtained, whereas that of rainfall retreat (cessation) is 90%. The mean proportion constituting the rainfall onset and retreat periods of the various stations were then employed to estimate the rainfall onset and retreat dates of each rainfall station for each year from 1992 to 1996. (Odekunle et al, 2004).

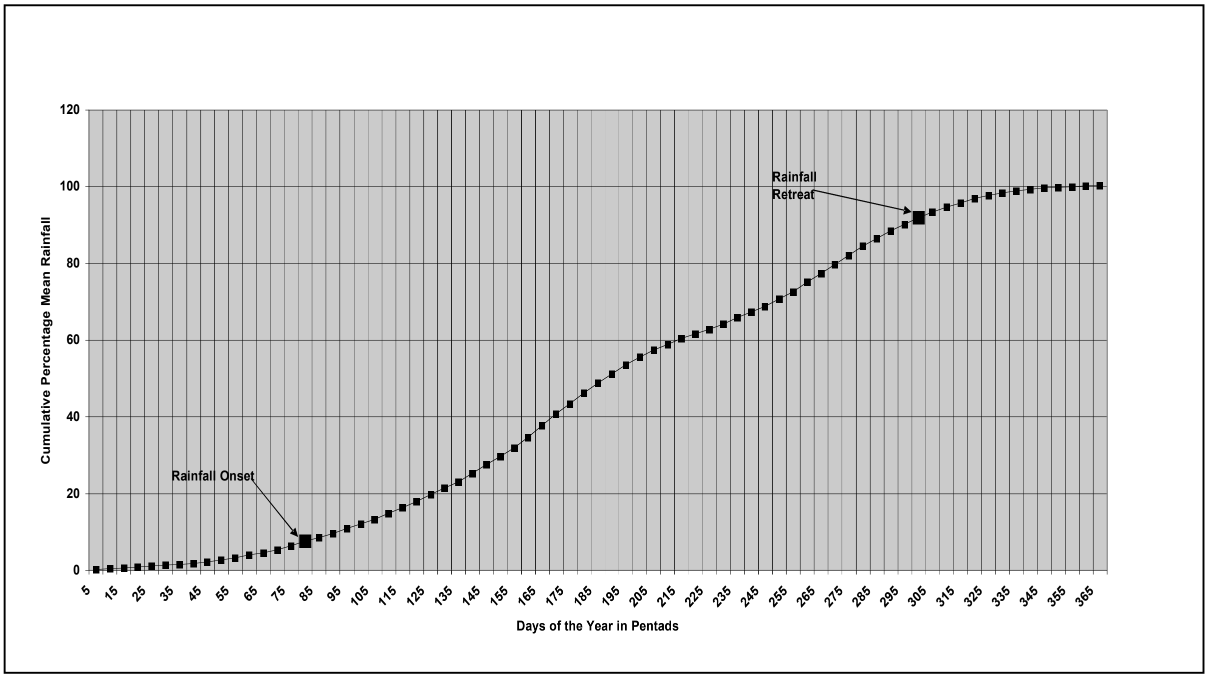


Fig. 7.2a: Rainfall onset, retreat and the length of the growing season in Ikeja (humid zone)

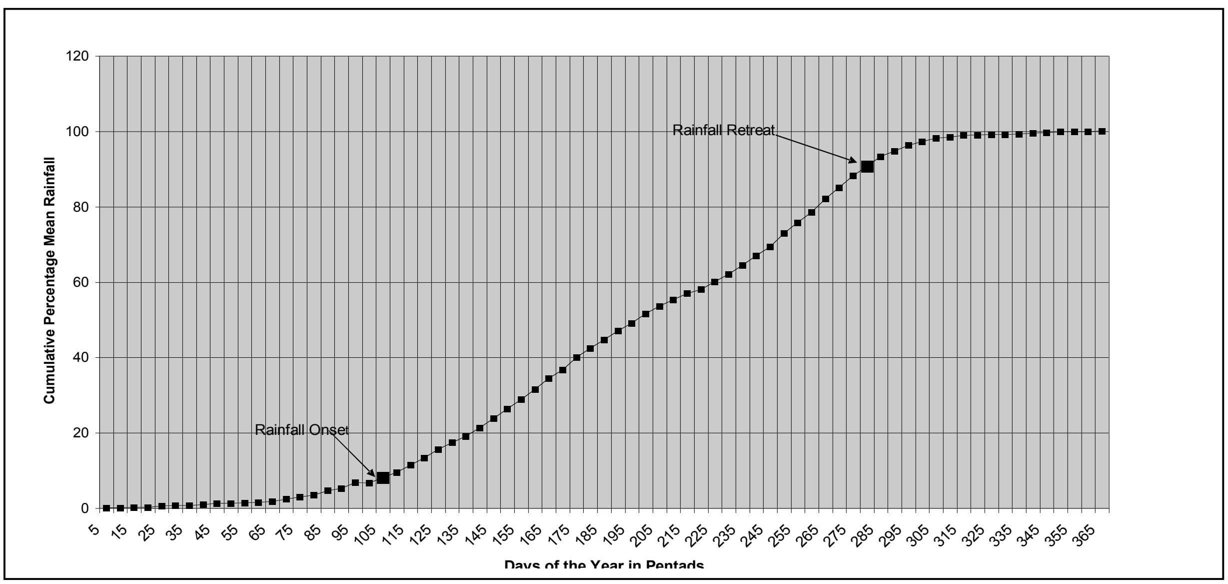


Fig. 7.2 b: Rainfall onset, retreat and the length of the growing season in Ilorin (sub-humid zone)

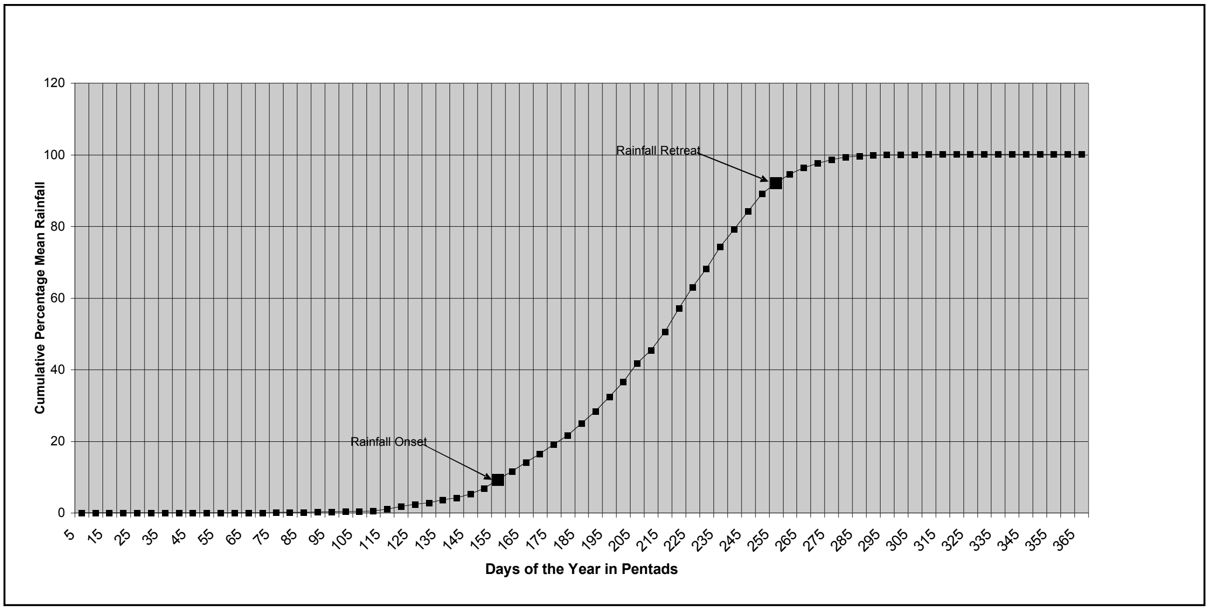


Fig. 7.2 c: Rainfall onset, retreat and the length of the growing season in Kano (arid zone)

Next is the generation of the required prediction model. The stepwise multiple regression algorithm was adopted for the construction of the prediction model. Rainfall onset and retreat dates of the six locations (Ikeja, Benin, Ibadan, Ilorin, Kaduna and Kano) constitute the dependent variables, while SST, ITCZ, land/sea thermal contrast and land surface temperature constitute the explanatory variables. Time (year) was included in the explanatory variables because of the trend that may be present in the explanatory variables, thereby generating misleading results (Grager and Newbolt, 1974). The predictor variables of all months preceding the rainfall onset and retreat months were used.

Finally, we applied the `F' parametric test and coefficient of multiple determination ($R^2$) to assess goodness of fit. These may not be sufficiently efficient for determining `goodness of fit'. Therefore, in addition, a set of data different from those employed in calibrating the model, were used to assess the level of skill that the model were likely to achieve in real time forecasting. Based on the decadal crop-water requirement, the predicted rainfall date is taken as correct if it is within 10 days of the actual date (Omotosho et al, 2000). Thus this study rated the model prediction skill performance on the rainfall onset and retreat dates in three categories. The skill is rated high, moderate and low if it within 10 days, between 10 and 20 days and above or below 20 days of the actual dates respectively.

7.6.2 Results and discussion

The results of the analysis shows that the coefficients of multiple determination (R^2), which represents the variance in the dependent variable explained by the independent variable(s), is above 50% (i.e. $R^2 > 0.50$) in 75% of the regression equations. Also, SST alone constitutes 67% of the total explanatory variables found to be significant in the various equations. Land/sea thermal contrast, ITCZ and land surface temperature constitute 26%, 5% and 2%, respectively. This means that rainfall onset and retreat of Nigeria can be predicted using SST and the land/sea thermal contras alone (the two constituting 93%). The model's actual "goodness of fit" assessment of the prediction equations develop for the rainfall onset and retreat dates of the various rainfall stations are summarized in Tables 7.4 and 7.5. With regards to the rainfall onset dates, the skill is rated high in 42%, moderate in 25% but low in 33% of the cases tested. As for the rainfall retreat dates, the skill is rated high in 48%, moderate in 29% but low in 23% of the cases tested.

Both the statistical "goodness of fit" (using both the R^2 and α values) and the actual "goodness of fit" (by comparing the observed rainfall onset and retreat dates with the expected values using 1962-1969; 1995-1996 data) of the models obtained in this study tend to support the reliability of the models for predicting rainfall onset and retreat dates in Nigeria. The results have also demonstrated that the most important factors affecting inter-annual variability in rainfall onset and retreat dates in Nigeria are the SST of the Atlantic Ocean (from the Gulf of Guinea, through St. Helena and Ascension Island, up to the Benguela region) and the land/sea thermal contrast between the selected stations in the country and the various SST locations.

The pattern of the results obtained is not unexpected because studies have demonstrated that SST anomalies are a significant cause of inter-annual variability in West African rainfall characteristics (Adedokun, 1978; Folland et al, 1991; Colman et al 2000). Also, the land/sea thermal contrast factor, through its effect on both the strength of south westerlies and the frequency of easterly shear, has long been recognized as a prime factor of inter-annual rainfall variability in the sub-region (Carlson, 1969; Adedokun, 1978; Folland et al, 1991). It is the wind shear that promotes frequent squalls, disturbance lines and most convection and overturning that constitute the ITCZ band of rainfall (see for example, Riehl et al, 1974, Moncrieff and Miller, 1976; Nicholson and Chervin, 1983).

	IKEJA				BENIN				IBADAN				ILORIN				KADUNA				KANO			
Year	**Obs rod**	**Pre rod**	**Db. obs Pre**	**Pre_2 SkL**	**Obs rod**	**rre Rod**	**Db. obs pre**	**Pre_2 SkL**	**Obs Rod**	**Pre rod**	**Db. obs pre**	**Pre_2 SkL**	**Obs rod**	**Pre rod**	**Db. obs pre**	**Pre_2 SkL**	**Obs rod**	**Pre rod**	**Db. obs pre**	**Pre_2 SkL**	**Obs rod**	**Pre rod**	**Db. obs pre**	**Pre_2 SkL**
1962	81	61	20	Mod	104	85	19	Mod	81	81	0	High	113	106	7	High	136	130	6	High	122	143	21	Low
1963	86	60	26	Low	93	90	3	High	95	74	21	Low	112	101	11	Mod	150	128	22	Low	144	168	24	Low
1964	60	77	17	Mod	82	105	23	Low	81	81	0	High	112	91	21	Low	135	129	6	High	147	158	11	Mod.
1965	105	57	48	Low	78	105	27	Low	85	80	5	High	68	105	37	Low	144	127	17	Mod	161	168	7	High
1966	82	92	10	High	89	80	9	High	83	79	4	High	115	99	16	Mod	124	128	4	High	143	164	21	Low
1967	112	90	22	Low	94	105	11	Mod	108	84	24	Low	80	94	14	Mod	118	129	11	Mod	141	140	1	High
1968	114	54	60	Low	98	103	5	High	108	82	26	Low	103	106	3	High	113	125	12	Mod	110	146	36	Low
1969	85	63	22	Low	68	76	8	High	84	82	2	High	103	96	7	High	124	135	11	Mod	164	150	14	Mod.
1995	68	64	4	High	79	102	23	Low	90	95	5	High	118	82	36	Low	142	144	2	High	160	171	11	Mod.
1996	46	102	56	Low	82	98	16	Mod	62	66	4	High	111	107	4	High	144	144	0	High	155	163	8	High

Table 7.4: Model's "Goodness of Fit" assessment of rainfall onset dates in Nigeria (1962 1969; 1995 and 1996)

OBS.ROD.OBS.	-	Observed Rainfall Onset Date (in Days of the Year)
PRE_1.ROD.	-	Predicted Rainfall Onset Date (in Days of the Year)
DB.OBS.PRE	-	Difference between the Observed and Predicted (in days)
PRE_2.SKL	-	Prediction Skill Level
Mod.	-	Moderate
High Skill	-	When the difference between the observed and predicted rainfall onset and retreat dates is within 10 days
Moderate Skill	-	When the difference between the observed and predicted rainfall onset and retreat dates is within 10-20 days

	IKEJA				BENIN				IBADAN				ILORIN				KADUNA				KANO			
Year	**Obs rrd**	**Pre_1 rrd**	**Db. obs pre**	**Pre_2 Skl.**	**Obs rrd**	**Pre_1 rrd**	**Db. obs pre**	**Pre_2 Skl.**	**Obs rrd**	**Pre_1 Rrd**	**Db. obs pre**	**Pre_2 Skl.**	**Obs rrd**	**Pre_1 rrd**	**Db. obs pre**	**Pre_2 Skl.**	**Obs rrd**	**Pre_1 rrd**	**Db. obs pre**	**Pre_2 Skl.**	**Obs rrd**	**Pre_1 rrd**	**Db. obs pre**	**Pre_2 Skl.**
1962	314	285	29	Low	315	300	15	Mod	312	298	14	Mod	310	281	29	Low	279	284	5	High	254	245	9	High
1963	304	281	23	Low	298	249	49	Low	295	266	29	Low	279	260	19	Mod	283	280	3	High	246	258	12	Mod
1964	299	292	7	High	318	320	2	High	295	302	7	High	294	291	3	High	264	279	15	Mod	243	242	1	High
1965	288	298	10	High	284	317	33	Low	300	285	15	Mod	293	299	6	High	264	276	12	Mod	244	242	2	High
1966	323	298	25	Low	305	274	31	Low	295	285	10	High	285	242	43	Low	264	282	18	Mod	259	254	5	High
1967	307	302	5	High	337	319	18	Mod	307	276	31	Low	306	300	6	High	266	274	8	High	245	250	5	High
1968	292	287	5	High	288	277	11	Mod	304	287	17	Mod	271	265	6	Low	265	273	8	High	236	261	25	Low
1969	306	306	0	High	306	318	12	Mod	301	285	16	Mod	301	305	4	High	285	264	21	Low	255	247	8	High
1995	310	314	4	High	307	297	10	High	298	290	8	High	299	270	29	Low	264	263	1	High	252	264	12	Mod
1996	287	317	30	Low	276	262	14	Mod	290	303	13	Mod	276	286	10	High	271	288	17	Mod	258	248	10	High

Table 7.5: Model's "Goodness of Fit" assessment of rainfall retreat dates in Nigeria (1962 – 1969; 1995 and 1996}

OBS.RRD.	-	Observed Rainfall Retreat Date (in Days of the Year)
PRE_1.RRD.	-	Predicted Rainfall Retreat Date (in Days of the Year)
DB.OBS.PRE.	-	Difference between the Observed and Predicted (in days)
PRE_2.SKL.	-	Prediction Skill Level
Mod.	-	Moderate
High Skill	-	When the difference between the observed and predicted rainfall onset and retreat dates is within 10
Moderate Skill	-	When the difference between the observed and predicted rainfall onset and retreat dates is within 10-20 days
Low Skill	-	When the difference between the observed and predicted rainfall onset and retreat dates is more than 20 day

7.7 Predicting Number of Rain-Days in Southwestern Nigeria

The aim in this section is to generate models that could be used to predict rain-days in south western Nigeria. The most important rain-day parameters and for which the model is developed include; the number of rain-days of the first two months after the rainfall onset, the rain-days of the last two months to the rainfall retreat period and the total annual rain-days. The rainfall-engendering factors of the sea surface temperature (SST) of Atlantic Ocean from the gulf of Guinea, southwards to the Benguela current region of the South Atlantic Ocean, land/sea thermal contrast between SST locations and rainfall stations in south western Nigeria, surface location of ITD and land surface temperature of rainfall stations in south western Nigeria were used as explanatory variables.

7.7.1 Description of scientific method

The sources of the data sets used in this study are the same as for the other exercises reported in this chapter. The same ITCZ positions and time and SST locations were used. However, the stations used were only four, namely; Ikeja, Benin City, Ibadan and Ilorin. 27 years data (1970-1996) were used for the study. Two years (1995 and 1996) were set aside for testing the scheme, thus left with 25 years for developing the required models for the rain-days predictability of the sub-region.

Studies have been carried out extensively on the onset and retreat of rainfall in Nigeria (Ilesanmi, 1972a; 1972b; Olaniran, 1983; Odekunle, 1997; 2003; 2004). Rain starts in earnest in most stations in south western Nigeria between March ending and early April. Rainfall retreats truly towards the end of October and early November. Thus the months of April and May qualify as the first two months into the rainy season, while the last two months to the end of rainy season in the sub-region are September and October. Therefore, this study determined the rain-days for the months of April, May, September and October and annual totals, for the selected rainfall stations (Ikeja, Benin, Ibadan and Ilorin) in southwestern Nigeria, and generated models for their forecast.

The threshold value of the rainfall amount required for a day to be counted as rainy is as in Section 5 that is under 'Calendar Clockwork as basis for Forecast'. The same procedures described in section 6 for modelling onset and retreat of the rainy season was also adopted in the study reported in the current section. As observed by Folland et al (1991) the use of part of the historical data outside that employed in the construction of the model to verify forecasts, is the best way to assess the level of skill such models were likely to achieve in real time forecasting. This assessment, which can be referred to as the actual "goodness of fit" and thus the reliability of the prediction models was assessed by comparing the predicted values of the rain-days with the observed values using some threshold values. On the basis of this, the relative accuracy of the prediction skill was determined. The skill performance was rated high if the difference between the actual and predicted number of rain-days is within 10% of the mean. Also the skill performance was rated moderate if the difference between the actual and predicted number of rain-days is within 25% of the mean. Where the difference is more than 25%, of the mean, the skill of forecast is rated low (Odekunle and Gbuyiro, 2003).

7.7.2 Results and discussion

The equations generated revealed the order of importance of the various rainfall-engendering factors. It was observed that SST alone was responsible for 57% of the inter annual variation in the number of rain days Land/sea thermal contrast was responsible for 30%, while the land surface temperature and the surface location of the ITCZ were respectively responsible for 6 and 7%. Thus rain-days in the sub-region seems predictable using the SST and land/sea thermal contrast only, as the two factors alone could explain 87% of the variability in the number of rain days, Table 7.6 shows the performance of the prediction models of rain-days in 1995 and 1996. Using the criteria outlined earlier for the actual "goodness of fit" assessment of the rain-days forecast models, the skill is rated high in 47% of the cases tested. The skill is assessed moderate and low in 25% and 28% of the cases respectively. Generally, the model is suitable for forecasting rain-days during the critical periods before rainfall cessation and after rainfall onset in south western Nigeria. This is the period of most variable rainfall during the rainy season.

7.8 Conclusions

Extended - range weather forecasting in West Africa has been recognized as the first basic step for all adaptation studies. This is in view of the fact that no reasonable adaptation plan can be made to forestall the negative consequences of climate variability and climate change without gaining insights into future meteorological conditions of each locality. With this understanding, the skill of the existing capacity for extended – range weather forecasting was assessed. The study noted a number of inadequacies in both the prediction skill and the usefulness of the forecasts to the end users. The prediction skill seems inadequate because of the high percentage of the "moderate skill" and low percentage of the "high skill" categories obtained in its assessment. Inadequacies in terms of the usefulness to the end users include; (a) lack of forecasts on rainfall characteristics such as onset, retreat, length of the growing season and rain-days; (b) lack of forecasts for specific localities instead of extensive zones; and (c) lack of forecasts for coastal and middle belts of West Africa. The series of studies reported here attempted making up for the various inadequacies. Prediction models were generated for the relevant rainfall characteristics including onset, retreat, and rain-days. Also, the models generated represent an improvement on the existing weather forecasting tools as they could be used to make forecasts for specific locations (i.e. towns), and for all the zones from the coast to the Sahel. The study concluded that rainfall characteristics of the region could be reliably predicted, using the rainfall engendering factors of SST and land/sea thermal contrast alone.

YEAR	RAIN-DAY PARAMETERS	IKEJA RAIN-DAYS			BENIN RAIN-DAYS			IBADAN RAIN-DAYS			ILORIN RAIN-DAYS		
		Obs	Pred	Skill Level	Obs	Pred	Skill Level	Obs	Pred	Skill Level	Obs	Pred	Skill Level
1995	Total Annual Rain-Days	119	112	High	149	121	Moderate	93	85	High	94	-	-
1996		87	91	High	136	121	Moderate	98	96	High	69	-	-
1995	April Rain-days	9	6	low	10	10	High	9	3	Low	5	-	-
1996		9	9	High	12	8	low	10	11	High	6	-	-
1995	May Rain-Days	13	13	High	12	14	Moderate	10	9	High	12	12	High
1996		10	11	High	15	7	low	9	7	Moderate	11	10	High
1995	September Rain- Days	14	24	low	20	25	Moderate	10	13	Moderate	14	14	High
1996		7	14	low	23	14	low	15	12	Moderate	12	25	low
1995	October Rain-Days	13	14	High	22	18	Moderate	12	5	Low	11	9	Moderate
1996		7	8	High	11	11	High	10	9	High	5	8	low

Obs: Observed; Pred: Predicted

Table 7.6: Performance of models for forecasting rain days in South Western Nigeria

8 Capacity Building

8.1 Introduction

The project was designed to enhance the capacity for research on the impacts of, and adaptations to, climate change and climate variability in Sub-Saharan West Africa, using Nigeria as the case study. When the project was approved for funding by the AIACC, the country was just emerging from a 15-year period of a most brutal military rule. Within the academic community, morale had sunk to its lowest level ever. The brightest and the best had either emigrated to greener pastures overseas or retired prematurely in order to keep body and soul together. Students who enrolled for a four-year programme in 1998 were not able to graduate until mid 2004 because of almost continuous industrial action by academic and non-academic staff. Avenues for capacity building cooperation between Nigerian and overseas institutions of higher learning had been blocked for ten years or more. It was therefore not surprising that the country was not able to submit its first communication to the UNFCCC until 2004. One way of solving the AF23 share of this problem was to bring in more hands to boost research capacity. The project was approved with only six core research staff apart from the Principal Investigator. By the time of writing this report, more than 15 had participated. Capacity building was therefore accorded the highest priority in the prosecution of the project. Our assessment of the present situation is that resident capacity for research on climate change has increased considerably compared with what obtained three years ago when the project was approved for funding. Contributing to this improved situation were the AIACC- organized workshops; the in-house project seminars; the two-day stakeholders workshop held from September 20 to 21 2004; the stock of equipment including four desk top computers, one lap top computer; and one power-point projector; participation by students, especially at the undergraduate level; the visit of Professor C.G. Knight of Pennsylvania State University; and the study visits of two of our students respectively to the University of Cape Town South Africa and the University of Oxford, United Kingdom. Three solid evidences of our successes in capacity building could be cited. First is the generally high level of performance by the undergraduate students who opted for Climate Change as a speciality. One of them was awarded the third first class honours in the 43-year history of the Department of Geography and has gotten herself admitted to the University of Oxford, pending the completion of her National Youth Service assignment and availability of sponsorship. Second, Dr Adeolu Ayanwale, a member of the Research Team was awarded a START Fellowship based on a proposal which was derived from the AF23 Project and his experience when he attended the AIACC Workshop in Trieste, Italy in 2002. Third, Odeyemi Odekunke who was the most junior member of the research team as approved for funding is the sole author of three of the publications submitted with this report and a joint author of a fourth.

8.2 Contributions of AIACC Workshops Capacity Building

The AIACC organized workshops at UNEP, Nairobi, Kenya; University of East Anglia, United Kingdom; Third World Academy of Sciences, Trieste, Italy; suburban Johannesburg, Republic of South Africa and Darkar, Senegal. Apart from the Principal Investigator, nine members of the research team attended. For at least four of the nine, it was the first opportunity to attend a learned conference outside the country. This by itself represents a measure of capacity building. The intellectual horizon of the persons concerned must have definitely been extended through interactions with participants from the other countries working on similar or related disciplines. As a result of experiences gained during these workshops, the original, objectives, philosophy, conceptualisation and methodology were significantly modified. This was more so with reference to the human dimensions which were developed subsequent to the change of title from “Extended range weather Forecasting as a strategy for the enhancement of crop productivity” to “Climate Variability, Climate Change and Food Security”. Our understanding of vulnerability was considerably facilitated by the “Oxford School” as represented by Thomas Downing. The relationship between exposure, driver, risk and adaptive capacity in the context of vulnerability would not have been as clear as it to us now without the benefit of attendance at these workshops. Our anxieties over the downscaling of GCM outputs was put to rest by Mike Hulme of The University of East Anglia whose view was that the simplicity of the method we had adopted for that purpose was not a mark of inferiority in the situation we found ourselves which is similar to the situation the developed countries were before the development of regional miodels. Our GIS approach to downscaling was developed with a significant technical assistance from members of the Oxford School in Trieste. We have since passed the technique of IDW (Inverse Distance Weighting) interpolation to our students. Although we ended up not using the approach for downscaling, it was an invaluable asset for rasterising meteorological points' data or the simulated yield data derived from them.

8.3 In-House Project Seminars

These started early in 2002 as soon as the award was communicated and before the funds were released. The first set of seminars were held to discuss the proposal as it was approved for funding as well as the comments of the reviewers that were passed on to us. Another set of seminars were held on 'Building Resilience into the agricultural system as an adaptation strategy'. The topics considered included: development of improved seeds and cultivars, removal of socio economic constraints, control of pests and diseases, management of soil resources and the development early warning systems for anticipating the weather of the coming growing season. Some of the papers were on methodological issues such as the applicability of GIS for downscaling, applicability of the EPIC Crop Model for study in a tropical environment, the skill of existing weather forecasting capacity, impacts and vulnerability. Some of the working papers were submitted for publication and have since been published.

8.4 Stake Holders Workshop

The two-day workshop was held on September 20 and 21 2004. The theme was "Climate Change, Crop Productivity and Food Security". Invited participants consisted of stakeholders at local state and national levels. Organizational participants included representatives of the Ministries of Environment and Agriculture at national and state levels. A considerable proportion of the 56 participants came from the Nigerian Meteorological Agency. Universities and Research Institutes from across the country were represented. The workshop was designed primarily as a forum for the discussion of the findings of the AF 23 research team. However, a great majority of the papers discussed were presented by researchers from the participating Research Institutes and Universities. The papers, together with those generated by the in-house seminars are being peer reviewed for publication by the Obafemi Awolowo University Press. The publication is in the final stages of production. Copies will be distributed, not only to the participants at the Workshop, but also to recognized stakeholders across the country. Copies will be submitted as soon as they are ready to START as one of the outputs of the Research Project.

8.5 Student Participation

From the class that graduated in 2004, six undergraduate participated in the sense that the scopes of their respective dissertations were within the general theme of climate variability and climate change'. We offered four among the students vacation employment during which they worked on their individual projects, helped with the extraction and downscaling of GCM data and run EPIC Crop Model. There is a member of the class graduating in 2005 also working on the project under similar conditions. We also support the individual projects with allowances to facilitate travelling to project areas of study for fieldwork. Two doctoral and two masters students have been working on the project for more than three years.

The topics of the projects, dissertations and theses of participating students are as follows:

1. **Undergraduate Projects**
    - Oyo, Adefunke: "Impact of climate variability on pearl millet production"
    - Omotayo, Mary: "Potential Climate Change for Nigeria for the 21st Century" (based On MAGICC-SCENGEN data)
    - Ogunade Idowu: "Crop substitution as an adaptation strategy in Oyo State"
    - Nevo, Augustina: "Impact of climate variability on Sorghum production in Nigeria"
    - Okonji, Angela: Climate Variability and crop production in Bornu and Yobe States

- Adesina, Elizabeth: "Changing planting dates as a strategy for the enhancement of crop productivity in Oyo State"
- Adeyeye, Festus: "Potential changes in Precipitation over West Africa during the 21st Century" (based on AIACC, University of Cape Town, data)

2. Masters Dissertation

- Adelani O.A: "Perception of, and traditional response to climate variability in Kwara state"
- Sanni, Maruf: "The impact of climate change on maize production in Nigeria"
- Ayanlade, Ayansina: "Application of GIS to the study of the spatial patterns of crop productivity in relation to climate change

3. Doctorate Theses

- Odeyemi, Yetunde: "Climate Change and Human Security in the Guinea Savanna Zone of Oyo State, Nigeria"
- Dami, Anthony: "Shrinking Lake Chad: Causes and Consequences"
- Adejuwon, Joseph: "Vulnerability of peasant farmers in the Sokoto-Rima River Basin in the Nigerian Arid Zone to Drought"

8.6 Visit of Professor C.G. Knight

Professor C.G. Knight and his wife, Marieta Stenova of Pennsylvania State University came on a scheduled visit to AF 23 for purposes of capacity building from February 28 to March 12th 2004. Through class room appearances, seminars and public lectures, the pair made considerable impact, not only on the AF 23 research team but also on the entire academic community. Their presentations were mainly on topics related to water resources and climate change. They interacted at individual level with all the members of the AF 23 research team, and all the student associates. They read through drafts of dissertations being prepared for submission in partial fulfilment for the award of bachelor degrees. One of the lectures was public and the Deputy Vice Chancellor (academic) was on hand as the chairman.

8.7 Visits to Universities of Oxford and Cape Town

We were able to secure two supplementary grants totalling US$ 9,000.00 for study visits by two of our younger colleagues respectively to the Stockholm Environment Institute, Oxford, U.K. and the University of Cape Town, South Africa. The main objective of the visit to Oxford was to enable Miss Adefunmike Ojo develop approaches to the development of Socio-economic scenarios and the assessments of the vulnerabilities of cocoa farmers and the cocoa production system to potential climate changes during the 21st Century in South-western Nigeria. Cocoa was the leading foreign exchange earner for Nigeria before crude oil started to dominate the economy during the 1970s. Because of age of the cocoa plantations, and unfavourable international trade practices, there has been a change in fortune for both the crop and the farmers. However, it had been observed that inter annual variability in yield of the crop is significantly higher than that of any other crop (Adejuwon, 1962). Because climate is the only factor in the plant environment with an annual time resolution, it seems reasonable to suggest that climate is part of the contributing factors to inter annual changes in the yield of cocoa. At the same time, it is incontrovertible that trade and demand at the international level and sector competition for attention within the country also have had their effects. The nexus of climate and the economy needs to be considered in projecting the Cocoa Sector deep into the 21st Century. Hence the current interest of Miss Ojo in Cocoa in South Western Nigeria. Miss Ojo, s work will represent one of the outgrowths of the Project AF 23.

The main objective of the study visit to the University of Cape Town was to enable Mr Festus Adeyeye learn the use of the Regional Climate Model produced by AF 07 Research Group for the construction of Climate Change Scenarios. On his return, Mr Adeyeye will help, with the knowledge he gained as a result of the visit, to develop another set of climate change scenarios for the study area of AF 23, which is Nigeria. One of the problems of AF 23 is the absence of data at an appropriate resolution for the projection of Nigerian climate into the 21st Century. Our hopes were initially anchored on the promise of the authors of the MAGICC/SCENGEN model to make available, by May, 2001, a new version of their product that could be used to generate data at the appropriate resolution of 0.5 x 0.5 longitude and latitude for all land areas. The new version was not published until late 2003. Apart from being less user-friendly, it failed to provide the data for our own area of study at the promised resolution. The climate change scenarios we have created and are using for our projections are based on a technique of downscaling from the GCM grid box to the desired higher resolution nesting grid using the change projected by the GCM.

The visit to Oxford was to have taken place during the summer of 2004. The lady concerned was ready but she could not secure the necessary visa in good time. The visit has been rescheduled for the summer of this year, 2005. The visit to the University of Cape Town was undertaken from February to March 2005. The main goals were accomplished.

9 Contributions to National Communications

Nigeria's 'First National Communication', was published in 2003. The P.I. of AIACC Project AF 23, as a member of the National Committee on Climate Change, participated in two workshops respectively in 1997 and 2000 designed to facilitate the preparation of the Communication. As far back as 1996, much had been accomplished in the area of compilation of GHG emissions in the country. For this, many thanks were due to the Centre for Energy Research and Training of the Obafemi Awolowo University, Ile-Ife. During the first half of the year 2002, the P.I. was invited to edit a draft of the Communication. It was quite obvious to him that much still needed to be done before the project could be brought to a successful conclusion. One of the deficiencies in the draft was the absence of a chapter on Climate Change Scenarios, which should serve as the point of departure for any meaningful characterization of Impacts, Vulnerabilities and Adaptations. He was then commissioned by the National Committee to prepare a draft of such a chapter. The draft he submitted was accepted as Chapter 4 of Nigeria's First National Communication, which was submitted in 2004.

In the chapter, we attempted to give an outline of the potential climate change in Nigeria in the aftermath of observed current global warming. The outline has been provided with respect to the ecological zones including: Forest, Southern Guinea, Northern Guinea, Sudan and Sahel. The climatic parameters presented included cloud cover, precipitation, diurnal temperature range, minimum temperature, maximum temperature, average daily temperature and vapour pressure. In the main section projections based on assumption of 1% annual increases in CO_2 concentration was presented. In the second part, uncertainties related to varying GCM outputs and to varying CO_2 concentration scenarios were discussed. Also as part of the discussion on uncertainties, projections based on SRES A2 and SRES B1 Emission Scenarios were outlined.

10 Outputs of the Project

10.1 Narrative

The papers, published and to be published (items i to viii), were efforts directed at seeking early peer review of our research to ensure we did not go too far off the mark. The majority of the papers are on climate or weather forecasting as should be expected given the fact that the original title of the project as approved for funding was “Extended range weather forecasting as a strategy for the enhancement of crop productivity”. EPIC Crop Model was designed for use in continental USA. To import it to Nigeria requires the type of assessment undertaken in item IV, now published in the Singapore Journal of Tropical Geography. The papers represent the fulfilment of our promise in the research proposal to attempt a fine-tuning of existing capacity for extended range weather forecasting in West Africa. The other outputs form part of a data base, being created in the Department of Geography, Obafemi Awolowo University, Ile-Ife, for the benefit of future students. The data base includes other downscaled data from the IPCC Data Distribution Centre and original raw data for all standard meteorological stations from the Nigerian Meteorological Agency.

10.2 Papers Published in Peer Reviewed Journals

- Rainfall and the length of the growing season in Nigeria. International Journal of Climatology, Vol. 24 , 467 - 479 (2004)
- Skill assessment of the existing capacity for extended-range weather forecasting in Nigeria. International Journal of Climatology, Vol. 24,.249 – 1265 (2004)
- On the prediction of rainfall onset and retreat dates in Nigeria. Theoretical and Applied Climatology, 81 (1-2), June 2005: 101-112; DOI 10.1007/s00704-004-0108-x}
- Assessing the suitability of EPIC Crop Model for use in the study of impacts of climate variability and climate change in West Africa. Singapore Journal of Tropical Geography, Vol. 24, 44 – 60, (2005).
- On the use of rainfall amount and rainy days in the determination of rainfall onset and retreat dates in Nigeria. Forthcoming: Theoretical and Applied Climatology.

10.3 Manuscripts being processed for publication

- Variability in the length, the rainfall and the severity of the Little Dry Season in South Western Nigeria. Journal of Climate (Reviewers queries answered; awaiting final letter of acceptance)
- Crop Yield Response to changing and variable climate: A selection of workshop and AF 23 Seminar Papers being processed for publication by the Obafemi Awolowo University Press
- Vulnerability of the Nigerian Peasant Household to Projected Climate Change During the 21st Century. AIACC Vulnerability Synthesis Volume (Undergoing peer review)

10.4 Other Outputs

- Climate Change Projections for the standard Nigerian Meteorological Stations
- Simulations of crop yield using Epic Crop Model and daily weather records of 16 meteorological stations from 1961 to 2000.
- Decision making processes of peasant farmers in Forest and Savannah ecological zones: Field Survey Monographs, Number 1
- Atlas of Food Crop Production in Nigeria: 1984 – 1993 including maps of production crop yield and area harvested, area

11 Policy Implications and Future Directions

11.1 Findings

Inter-annual change in crop yield in response to climate variability in future is a reasonable conjecture. For a majority of the years, near normal levels of crop yield and production of crops will be achieved. As at present, inter-annual changes in crop yield will be a function of how early or late the rainy season comes and go. It is also reasonable to surmise that major disruptions to life and livelihood caused by drought-driven widespread crop failures will be part of the experiences in the rural areas, coming at intervals of more than a few years in the future. However, we do have evidences suggesting that the rainy season could be longer than it was during the concluding decades of the 20th century. The implication of this is that sensitivity of crop yield to inter-annual changes in climate could be much less than at present. This should not be interpreted as a possibility of less frequent drought occurrence or less severe impacts of droughts on crop yield and livelihood. This is because the mechanism producing inter-annual variability (continental incursion of Inter Tropical Convergence Zone) is not the same as the one producing less frequent droughts (Walker Circulation, ENSO) (Adedokun, 1978).

Climate change projections based on an emission scenario of 1% per annum increases in CO_2 concentration indicate that the conditions of crop growth and development are likely to improve during the 21st century for as long as the limiting factor remains moisture supply. Higher rainfall and higher atmospheric humidity are set to produce higher levels of crop yield. There are other aspects of the projected climate change that could be detrimental to crop performance and bring about reduced crop yield. These are the projected substantial increases in both minimum and maximum temperatures. The rate of increases in minimum temperature is projected to be higher than that of maximum temperature. These could change the thermo- period to the detriment of crop yield. There are also evidences to the effect that the higher temperatures projected may be supra optimum for the crop plants and therefore cause a reduction in their respective yields. What all these suggest in the context of factor interaction is that during the first half of the century, improvements in the moisture supply situation could produce higher crop yield levels. However, during the second half of the century, temperature, rather than moisture will serve as the main limiting factor of crop yield. Increasing temperatures will negatively impact on crop yield which will therefore tend to decline.

The livelihood group considered in this study is the Nigerian Peasant Household. The word peasant may sound pejorative, but there is no alternative terminology to capture not only the small scale of farming operations, but also the diseconomy which it connotes. Because of his dependence on agriculture, a sector that is by itself exposed and sensitive to climate, the peasant householder's livelihood, including his food and nutrition, is indirectly exposed to the projected climate change. Droughts with decadal frequencies and temperatures that are supra-optimum for most of the major crops are the drivers of the potential risks to crop producing households. Vulnerability of the Nigerian peasant household to changes in climate will also be determined by a number of existent characteristics which imposes limits on its adaptive capacity. Among these, the most significant is existent poverty which signifies lack of resources necessary for adapting to climate change. In addition, relatively low levels of educational attainment could also constrain the ability to acquire the technological capacity for combating the negative consequences of climate change. The rates of population increase which at present stand at 28 per thousand could increase the magnitude of child dependency burden, increase pressure on social infrastructure, and also constrain the capacity to adapt to possible negative impacts of climate change. Based on the analysis, it could be observed that considerable contrasts in vulnerability to climate change exist between the various regions of the country. It appears that the northern parts where the risks posed by projected changes in climate are the highest are the same areas where peasant households' adaptive capacity is least, and consequently, the most vulnerable.

11.2 Policy Implications

The policy implications are multidimensional both in terms of strategy and in terms of possible stakeholder engagement. Perhaps the most important policy implication is the need to improve the adaptive capacity of the peasant householder in terms of poverty reduction, higher levels of educational attainment, improved public health. These are issues included in the design of the United Nations Millennium Goals to be achieved by the year 2015. They are also included in the mandate of many United Nations Agencies including the UNEP, UNDP, the UNESCO, the WHO etc... Thus, in this respect, one could describe the United Nations as the leading stakeholder. Government at all levels are also engaged in activities designed to improve the capacity of individual citizen to respond to, in the sense of cope with, recover from, or adapt to, any external stress placed on his livelihood and well-being. The roles of the Developed Countries in this regard cannot be underestimated (DFID, 2001).

There is also the need to develop strategies with the aim of building resilience into the crop production systems and make them less sensitive to climate variability and climate change. In this respect, five main lines of activities could be identified. These include: 1) development of institutional capacities in the area of agricultural extension, 2) investment in the development of improved seeds and cultivars, 3) strategies to neutralize biological constraints including those pertaining to pests and diseases, 4) strategies for the management of soil constraints and 5) strategies targeted at reducing recognized socio economic constraints. Agricultural Extension used to be the main pre-occupation of the Department s of Agriculture of the Regional Governments when they existed during and immediately after the end of the colonial administration in Nigeria. The creation of thirty-six states out of the original three regions has considerably weakened the component units of the Federation. One of the victims of this development is the various extension services. The Federal Government of Nigeria through the inauguration of the River Basin Development Authorities and the Agricultural Development Programmes (ADPS) is attempting to redress the situation. Part of the mandate of the United Nations Development Programme also includes aspects of extension. The other four lines of resilience building activities lie within the purview of the mandates delineated for the various Agricultural Research Institutes. The leading stakeholder in this group is the IITA (International Institute for Tropical Agriculture). Policy should continue to provide budgetary allocations to encourage them to meet the needs of the crop producing sector.

Two other sets of strategies need to be developed with the target of mitigating the negative consequences of climate variability and climate change. One set comes from traditional agricultural practices. Some of these were investigated during our (AF 23) Field Surveys and are to be reported in forthcoming publications. In one of such publications, the reactions of farmers to extreme weather events were assessed with the aim of developing strategies that could improve adaptive capacity. Another set of strategies comes from modern farming practices developed on research farms and which are available for dissemination to farmers through agricultural extension channels.

What we now recognize as the core theme of the project was to be developed into an early warning system and a strategy for anticipating and forestalling the negative impacts of climate variability and climate change.

This strategy is dictated by the understanding that a fore-knowledge of the weather of a growing season will enable farmers to plan with greater confidence to forestall its negative consequences and exploit its beneficial opportunities. The logic of this realization is that skilful weather forecasting is an invaluable asset in any plan to adapt crop production systems to a variable climate. Since variability will remain a significant element in any future climate, skilful weather forecasting will also remain a valid adaptation strategy in the context of any projected climate change. The assessment of the skill level of the existing capacity forecasting has been undertaken and published in the *International Journal of Climatology.* Three other papers directed at fine-tuning the existing weather forecasting capacity have similarly been published in reputable international journals. The targets of the fine-tuning exercises were the onset and the cessation of the rainy or growing season. The stake holder engaged in formulating policies that would incorporate this strategy is the Nigerian Meteorological Agency at the local level. There are also regional organizations such as PRESARIO, ACMAD and AGRHYMET. Climate weather and climate modelling organizations include: the U.K. Met Office, Centre de Recherchde Climatologie (CNRS, France) and National Oceanic and Atmospheric Administration (NOAA, USA).

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