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A. O. Ayeni^{abc}, E. Kapangaziwiri^b, A. S. O. Soneye^a & F. A Engelbrecht^c

^a Department of Geography, University of Lagos, Lagos, Nigeria

^b HydroSciences Research Group, Natural Resources and the Environment, CSIR Pretoria, South Africa

^c Global Change & Ecosystem Dynamics Group, Natural Resources and the Environment, CSIR Pretoria, South Africa

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Assessing the impact of global changes on the surface water resources of Southwestern Nigeria

A. O. Ayeni^{1,2,3*}, E. Kapangaziwiri², A. S. O. Soneye¹ and F. A. Engelbrecht³

¹Department of Geography, University of Lagos, Lagos, Nigeria

²HydroSciences Research Group, Natural Resources and the Environment, CSIR Pretoria, South Africa

³Global Change & Ecosystem Dynamics Group, Natural Resources and the Environment, CSIR Pretoria, South Africa

aayeni@unilag.edu.ng, ayeniaio2000@yahoo.com

Abstract

Understanding the relative impact of land use, land cover and climate change (LULCC) on basin runoff is necessary in assessing basin water stress. This assessment requires long-term observed rainfall time series and land-use/land-cover (LULC) spatial data. However, there are challenges with the availability of spatio-temporal data, particularly limited range of available historical hydro-meteorological measurements. In order to assess the likely water stress, the study used long-term (1961–2007) rainfall data to drive the Pitman monthly rainfall-runoff model to assess changes to the water resources of three selected basins in Nigeria—Asa, Ogun, and Owena. Three CGCMs—CSIRO Mark3.5, MIROC3.2-medres and UKMO-HadCM3 dynamically downscaled to a 60km by 60km grid using the Conformal-Cubic Atmospheric Model (C-CAM)—are used to simulate impacts of future climate changes on water resources. These 3 models were found suitable for simulating rainfall-runoff based on the insignificant differences of models' mean with mean of observed rainfall and temperature for pre-2010 data compared to other downscaled C-CAM models (GFDL-CM2.0, GFDL-CM2.1, and ECHAM5/MPI-Ocean model). The model results show increases in the runoff coefficient with decreases in forest cover between 1981 and 2007 with average runoff coefficients of 5.3%, 12.0% and 6.4% for Asa, Ogun and Owena basins respectively. Based on CSIRO, MIROC, and UKMO predicted annual reduction in rainfall trend, the future scenarios revealed a low runoff coefficient for the three basins—Asa (CSIRO 6.0%, MIROC 6.0%, and UKMO 5.9%), Ogun (CSIRO 14.6%, MIROC 14.6%, and UKMO 14.4%), and Owena (CSIRO 8.5%, MIROC 8.7%, and UKMO 8.9%). In all scenarios Asa basin has lower runoff coefficient when compared to Ogun and Owena basins, indicating that future water stress in Asa basin would be much higher.

Key words hydrological modeling; water stress; Nigeria; climate change; land-use/land-cover; parameter estimation

1 INTRODUCTION

Humans have exerted large-scale changes on the terrestrial biosphere, primarily through land use – land cover (LULC) and climate changes. Optimal and sustainable water resource management requires an understanding of the impacts of LULC and climate changes on the hydrologic cycle and water balance (Scanlon *et al.* 2005). Impacts of land use – land cover changes (LULCC) on land and atmospheric components of the hydrologic cycle at regional and global climate levels are increasingly recognized, but impacts on subsurface components of the hydrologic cycle are poorly understood (Pielke *et al.* 1998; Pitman *et al.* 2004; Batra *et al.* 2007). LULCC impacts on the hydrological cycle may surpass those of climate change (CC) if human-induced LULCCs are not addressed and remedial action is taken (Scanlon *et al.* 2005). LULCC, CC and climate variability may significantly modify the hydrological regime of watersheds, affecting regional environment, ecosystems and water resources, in particular river flow regimes. In some places, they induce a temporal (and

often destructive) increase of surface flows resulting in floods or at other places reducing, or even eliminating, flows during devastating drought conditions (Batra *et al.* 2007).

The above challenges coupled with complex and rapidly changing geography of water supply and use make the future adequacy of water resources, especially surface water, difficult to assess. Data on climate change, socioeconomic studies, river runoff, and numerical evidence on global fresh water availability have revealed that a large proportion (about two thirds) of the global population are currently experiencing water stress (Vorosmarty *et al.* 2000; OCHA 2010). A common explanation is that even though there is a lot of water on earth, only about 2.5% is fresh, and since a large proportion of this fresh water is stored as glaciers or deep groundwater, only a small proportion is easily accessible for increasing human use (Oki 2005; Oki and Kanae 2006). However, human interference on the water cycle has also been important in explaining water stress situations in many places, especially in the developing world. In order to 'increase' the small proportion of available water, sustainability assessments should be carried out based on river flow regimes (Oki and Kanae 2006).

Climate variability, CC and LULCC remain the major drivers of the earth's water balance. LULCC has extensively altered the earth's surface through conversion from one land use class to another (e.g. from forest to cultivation or through urbanization processes), with impacts including low flows, flooding, erosion, and water quality degradation (Foley *et al.* 2005, Vimal *et al.* 2010). Thereby, intensifying water scarcity and stress in many regions (Oki and Kanae 2006). Water control structures (dams & reservoirs) designed to relieve water stress may exacerbate the problem as upstream users with limited knowledge on hydrological processes of the catchment may influence when, how much, and what quality of water downstream users receive (Padowski and Jawitz 2009).

Scenario analyses help to understand the hydrological system and processes and provide insight into the future catchment system state as well. These analyses use a model-based approach to identify the key factors in environmental change/variability, for example, climate models are used to project future changes in climate under different emission scenarios.. In the quest to understand the complex human-environment relationships, scenario study is gaining widespread acceptance among research scientists and policy makers as a practical tool for describing the uncertainties associated with the changing attributes of aspects such as floods, runoff and drought (Light *et al.* 2013). The scenario development process provides the ability to project, assess and explore the potential risks, benefits, and management options of the conceived extremes (Kepner *et al.* 2008).

Long-term rainfall and temperature play important roles in water resources and hydrology. The amount of basin runoff considerably depends on the spatio-temporal variability of rainfall (Webb *et al.* 2004; Kumar and

Duffy 2009). In addition to climate, the basin's anthropogenic and physiographic (particularly the edaphic and LULC characteristics) are also of significance in generating and explaining monthly runoff patterns (Kumar and Duffy 2009; Peel 2009; Potter *et al.* 2010; Davidson *et al.* 2012; Ayeni *et al.* 2013a). Presently, hydrological simulations still face various challenges in many countries of the world where hydrological data are scarce and/or difficult to access (Kumar and Duffy 2009). The Fourth Assessment Report of the IPCC predicts an intensification of the global hydrological cycle due to climate change and concluded that the negative impacts of climate change on freshwater systems may significantly outweigh its benefits, with runoff projected to decline in most streams and rivers. Groundwater recharge is also projected to decrease (IPCC 2007). River basins may therefore experience severe water stress under climate change for different reasons. For example, in low-flow periods induced by climate change, high water consumption may increase the pressure on both water quality and quantity (Amber and Matlock 2011).

In order to address the the potential impacts of climate change on southwestern Nigeria, a series of studies have been carried out on climate change and water resource assessment in the region. However, extended research making use of the projections of Coupled General Circulation Models (CGCMs) and Regional Climate Models (RCMs) is needed to assess future water stress over the region in more detail. For the generation of river flow time series data for this study, observed rainfall data, basin physiographic (soil properties, land-use factors etc.) and detailed projections of changing rainfall and temperature patterns over southwestern Nigeria were used to force a hydrological model, in order to generate both present and future scenarios of runoff. The result of LULCC generated from remotely sensed datasets were also used to parameterise the model, to generate more realistic river flows and predict the likely future change implications on water stress.

2 STUDY AREA

Derived Savanna of SW Nigeria is located in the southern corridor of the River Niger. It cuts across five basins vis-à-vis Ogun, Oshun, Ose, Kampe, and part of Niger.. The sub-basins within these five major basins are many and include Asa, Apoje, Opeki, Ofiki, Ose, Osun, and Owena. Three basins are selected for this study – one major basin Ogun and two sub-basins – Asa and Owena (Fig. 1).

2.1 General characteristics of the basins

The region is located primarily within the lowland humid tropics. As a result the mean temperature ranges between 32⁰C in the northern part around Asa sub-basin and 26⁰C in the southern part of Ogun basin and Owena sub-basin. The annual rainfall ranges between 1000mm and 1800mm from the north (Asa and northern

part of Ogun basin) to south (southern parts of Ogun and Owena). The whole area has two distinguishable seasons—a wet season between April and October and a dry season from November to March. In the region, potential evaporation decreases towards the south due to higher air humidity .

The geology of the whole area is dominated by the Precambrian Basement complex, mainly granite, schist, gneisses, meta-sediment and older granite rocks (Adekunle *et al.* 2007; Ayeni 2012). These rocks by their nature are impervious with limited storage capacity unless where they are weathered in situ over long periods of time when they result in deep weathered saprolite capable of holding substantial amounts of water. Ogun and Owena soils are classified as Ferric Acrisols with relatively higher cation profiles (Jaji *et al.* 2007; Nwackokor and Uzu 2008; Ayeni *et al.* 2011). Asa basin, located on relatively flat to undulating landscape with interspersed hills and valleys, is characterized by ferruginous tropical soils of crystalline acid rocks. The vegetation cover of the area is a derived secondary forest with trees, grasses, fern and bush (Fasona *et al.* 2007 and Alo *et al.* 2008).

3 MATERIALS AND METHODS

This study assessed the impact of LULCC and CC on water stress using long-term observed and future projected rainfall data to generate monthly runoff information through hydrological simulation (Fig. 2).

Given the paucity of observed stream flow data, basin hydro-meteorological and physiographic characteristics data were used to directly estimate the parameters of the model (Kapangaziwiri and Hughes, 2008; Kapangaziwiri, 2011). The conceptual Pitman monthly rainfall-runoff model (Hughes *et al.*, 2006) was chosen for the generation of monthly time series of flow.

The Pitman model has found favour for water resource assessment purposes in the southern Africa region because of its relatively simple and flexible structure. The relatively low data demands (monthly rainfall totals and estimates of evaporation demand are used to drive the model) could generally be met in the study area. For this study, the revised semi-distributed version of the model that incorporates surface and ground water interactions (Hughes 2004; Hughes *et al.* 2006) was used. The choice of a coarse-scale Pitman model is premised on the understanding that in water resources studies where medium to long-term resource estimation and planning based on monthly data are the primary target, a monthly input model is quite adequate (Pitman 1978). Besides, there are very few sub-basins in the study area to provide adequate data for input to any model requiring inputs of fine time resolution.

Long-term observed rainfall and temperature data, obtained from eight different weather stations across the study area were used to characterize the climate of the region and to drive the model to simulate streamflows. The observed rainfall and discharge data for the 3 selected basins—Asa, Ogun, and Owena—were collected

from Lower Niger Basin Authority at Ilorin, Ogun-Osun Basin Authority at Abeokuta, and Benin-Owena at Benin respectively. The monthly rainfall records of 50 years' length (1960 – 2010) for Asa and Owena basins, and 30 years' length (1980–2010) for Ogun basin were available for the study. As a result of challenges in accessing historical observed river flow data in the area, only limited monthly data for 7 hydrological years (1966–1973) for Asa and 9 water years (1990 – 1999) for Owena were available. No discharge data were available for Ogun. While these two periods are too short for any meaningful conclusions about the success of a model's application, especially at the monthly time scale, they are the only data available and parameterizing these sub-basins (to simulate representative flows) was essential for the modelling exercise. They were thus used merely to guide the modeling to evaluate the applicability of the model. Given that the model application is based on direct parameter estimation using basin physical property data, and not calibration, this use of the available data could be instructional and adequate (see Bergstrom 1991; Uhlenbrook and Seibert 2005; Seibert and Beven 2009). The data on estimates of evapotranspiration demand used as input into the model were obtained from the International Water Management Institute (IWMI) database.

For the assessment of CC impacts projected climate data (rainfall and temperature) up to the year 2050 from three (3) of the six (6) A2 scenarios Coupled General Circulation Models (CGCMs) forced with SST and sea ice were used. The CGCMs were dynamically downscaled to a 60km by 60km grid over Africa region, using the Conformal-Cubic Atmospheric Model (C-CAM). The 3 CGCMs used in this study are:

- i. CSIRO Mark3.5 (The version 3.5 CGCM of the Commonwealth Scientific and Industrial Research Organisation in Australia)
- ii. MIROC3.2-medres (Model for Interdisciplinary Research on Climate 3.2, medium resolution version, of the Japanese Agency for Marine-Earth Science and Technology), and
- iii. UKMO-HadCM3 (The Met Office Third Hadley Centre Coupled Ocean–Atmosphere GCM—United Kingdom)

The details of these models can be found in McGregor (2005), Engelbrecht *et al.* (2009 and 2011) and Malherbe *et al.* (2012). C-CAM model was adopted because it employs a wide range of physical parameterizations of CSIRO mass-flux cumulus convection scheme, which includes downdrafts and the evaporation of rainfall (Engelbrecht *et al.* 2009). The model which also function as a Regional Climate Model (RCM) was applied in stretched-grid mode (Engelbrecht *et al.* 2009), uses lower boundary forcing in the form of SSTs and sea-ice and was specified from a transient (1871–2100) simulation from the host model {the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Mk3.0 Coupled Global Circulation Model (CGCM)} (Engelbrecht *et al.* 2009 and 2012). Greenhouse gas forcing in the CGCM and C-CAM

simulations was specified according to the A2 emission scenario of the Special Report on Emission Scenarios (SRES). In addition, its configuration had a resolution of about 60 km over the area of interest which amounted to about 30 grid points and these capture all the selected basins at uniform resolution. The experimental design, description of the numerical settings, and physical parameterizations of C-CAM are detailed in the study of Engelbrecht *et al.* (2009 and 2011).

This study was not designed to focus on climate models comparison, nonetheless, since C-CAM has the ability to simulate both yearly and intra-annual rainfall totals, the validation of C-CAM over the study area was based on ensemble of CSIRO Mark3.5, MIROC3.2-medres, and UKMO-HadCM3 and qualitatively verified against observed data from 8 synoptic stations in the study area before the simulation of rainfall-runoff projection. The validation of the 3 models ensemble and the observed data expressed reasonable results for rainfall and temperature. On average, the results show that between 1961 and 2008, their ensemble have deviations of -24.6 mm (CSIRO – 25.6mm; MIRO – 23.0m, and UKMO – 25.2mm) and 2.1°C (CSIRO – 2.0°C, MIRO – 2.1°C, and UKMO – 2.2°C) from observed data for mean annual rainfall and temperature respectively. These differences are insignificant and give a well representation for rainfall and temperature compared to GFDL-CM2.0, GFDL-CM2.1, and MPI with deviation of 2.4°C and 26.7mm.

Both historical observed and C-CAM simulated future climate data were input into the rainfall-runoff model to generate probable time series of river flows that were used to evaluate the impacts of LULCC and CC on the water resources of the basins and assess conditions of water stress. For study validation, regional features of the observed rainfall and temperature patterns over the study area were used. These include the south–north gradient in rainfall totals over Nigerian derived Savanna and the band of relatively low rainfall that stretches from northwest of Ogun basin to north east of Owena basin; and the increase in the intensity of temperature towards the northern part of the region.

3. 1 Brief description of the Pitman rainfall-runoff model used

The main purpose of the modeling component of this study was to set up both the hydrological baseline and projection of the study area. Given the paucity of historical observed data (both in quantity and quality) for model calibration in the study area, the application of the model used the physically-based parameter estimation routines described in Kapangaziwiri and Hughes (2008) and Kapangaziwiri (2011).

The Pitman model includes explicit routines to simulate interception, infiltration excess surface runoff, soil moisture (or unsaturated zone) runoff, groundwater recharge and drainage to stream flow, evaporative losses from the unsaturated zone as well as the groundwater storage (in the vicinity of the river channel). The model therefore has a relatively large number of parameters and it is typically impossible to establish parameter sets

that generate unique results through conventional calibration approaches. However, the potential advantage of the model is that the different contributions to stream flow can be determined and should be sensitive to changes that occur within sub-basins. These changes may involve climate, land use and land cover or different types of abstractions and water use. Table 1 contains a list of the main model parameters that influence volumes of runoff generation as well as a brief summary of the estimation approaches that are followed to quantify them. The biggest challenge was the availability of groundwater recharge data to condition the groundwater parameters of the model. These parameters were thus calibrated guided by available general global data on groundwater recharge based on Struckmeier et al. (2006) and Doll and Fiedler (2008). The parameters relating to the main runoff generation and water accounting parameters were all estimated from the available basin physical property data.

The parameter estimation routines used in this study are based on conceptual hydrology interpretations of the model parameters at the model application scale (typically 50 – 10 000 km²) and use basin physical property data to directly estimate parameter values. The information required includes soil depth, soil texture (which is then translated into soil hydraulic properties), topographic slope and sub-surface geological conditions of the sub-basins being modelled. The global FAO maps (FAO 2003) provided a baseline indication of the general soil types and were used in conjunction with the available national maps. However, the information on critical soil attributes such as soil depth and texture is not available on these maps and these were inferred from dominant soils map of Nigeria and literature (Sonneveld 1996; Aregheore 2009).

The model parameters derived from the estimation process and all other available relevant information on water use was then input into the model to generate time series data of the hydrology of the sub-basins. Where there were limited observed runoff data (i.e. for some parts of the Asa and Ogun basins), these were used to guide the model simulations. However, the period covered by these flow records and the quality of the data made them highly uncertain. In addition, water use in the basins is either poorly quantified or unavailable, which makes the representativeness of the available flow records of the natural hydrology of the basins dubious. In spite of these limitations in the available data, the simulations were deemed acceptable based on comparisons of the observed and simulated flows for the period between January 1990 and December 2000 at the outlet of Owena sub-basin (Fig. 3 and 4). For a monthly time step model this length of the observed data is not adequate to make firm conclusions. However, the reasonable success of the model in reproducing the available flows for this basin is encouraging. The measure of the performance of the model is based on six objective functions: coefficient of determination (R^2), coefficient of efficiency (CE, Nash-Sutcliffe 1970) and

the percentage error in the simulated mean monthly flow relative to the observed value (% Error), all based on untransformed and natural log transformed values. The results for Owena are given in Table 2.

While the model managed to reproduce the general water-balance of the basin, it can be noted in Fig. 3 that the low flows were generally a challenge. This could be a result of poor rainfall representation as there were a limited number of gauges used to estimate catchment average rainfall and they were all far from the flow gauging station and could not represent the local conditions properly, and also the poor water use data for the basins, especially dry season abstractions that affect low flows. While the poor quality rainfall and runoff data may not have had a significant impact on the parameter estimation of the model (given that parameters were estimated directly from available basin physical data), there are still uncertainties related to parameter estimation process (Kapangaziwiri *et al.* 2012) and the resulting predicted hydrology for the basin. However, the success of the simulations in this (poorly) gauged basin provided the confidence to apply parameter estimation approach in the ungauged parts of the basins for this study. It is prudent to state here that for the analysis of the impacts of climate and landuse/landcover changes the parameters of the Pitman Model were dynamically adjusted in relation to expected changes in surface vegetation cover, rainfall magnitudes and number of rain days, storm duration, etc inferred from the modelled LULC and future projected climate information.

3.2 Analysis of impacts of climate change

For the assessment of future water resources of the basins, most of the estimated parameters were assumed constant except for the rainfall and evapotranspiration inputs that were changed based on the projections from the regional climate model and the surface absorption parameters based on the LULC analysis. This was a necessary assumption given that information on projected future basin characteristics could only, at best, be guesswork. For the C-CAM projected future rainfall data to be comparable to the historical observed rainfall data, some form of standardization was required given that, for the same baseline period, there were substantial differences between them. The approach adapted by the Institute for Water Research (IWR) at Rhodes University for correction of GCM data was used in this study. The method is based on correcting the main statistical distribution characteristics of the GCM baseline data to the historical data and then applying the same correction to the future data to remove bias in both means and standard deviations (Hughes *et al.* 2011).

The method used to remove this bias from the projected future rainfall estimates expresses the projected monthly rainfall as standard deviates of the baseline monthly distributions (using log values) and to scale the standard deviates with the monthly distribution statistics of the historical rainfall data as follows (Hughes *et al.* 2011):

$$FRC_{ijk} = \text{EXP} (LWRM_j + LWRSD_j * (LFR_{ijk} - LBRM_{jk}) / LBRSD_{jk}) \quad (1)$$

Where:

- FRC_i = Future rainfall after correction for month i and calendar month j in the time series of GCM k.
- LFR_i = Logarithm of future rainfall for month i and calendar month j in the time series of GCM k.
- LBRM_j = Mean of the logarithms of baseline rainfalls for GCM k and calendar month j.

LBRSD_j = Standard deviation of the logarithms of base line rainfalls for GCM k and calendar month j.
LWRM_j = Mean of the logarithms of observed rainfalls for calendar month j.
LWRSD_j = Standard deviation of the logarithms of observed rainfalls for calendar month j.

The transformation removes the bias in the monthly means and variations between the historical and GCM baseline estimates, while preserving the differences between the GCM baseline and the projected future scenarios.

3.3 Landuse/ landcover analysis method/s

The LULCC analysis was based on spatio-temporal orthorectified Landsat imagery data sets for the period between 1972 and 2007. The datasets were sourced from Global Land Survey (GLS) portal (<http://glovis.usgs.gov/>) and include the following scenes: the Multispectral Scanner (MSS) in the 1970s, the Thematic Mapper (TM) in 1990, the Enhanced Thematic Mapper Plus (ETM+) in 2000 and 2006. The paths and rows images for each time T year was downloaded and processed within the ENvironment for Visualizing Images (ENVI) software using the maximum likelihood (MLH) classification technique. ENVI software, commonly used for remote sensing and image analysis, is a state-of-the-art image processing system application designed to process and analyse geospatial imagery. For this study, four (4) major land uses were identified and classified—built up, forest (the study target), cultivation/others and water-bodies. The images were subjected to LULCC classification analysis and interpretation within the ENVI environment. The classified images were later imported into ArcGIS where LULCC maps were produced for visual interpretation of the spatio-temporal changes over time.

4 RESULTS AND DISCUSSION

4.1 LULCC

LULCC analysis shown in Fig. 5 and Table 3 and revealed that forested areas have reduced significantly and cultivation and built-up areas have increased within the derived savanna from 1972 to 2006.

In 1972, forest covered almost 42,819km² (76.4%) out of the total land cover of 56,072km². This was followed by cultivation/others which occupied an area of 13,144km² (23%) while built-up and water-bodies together represent only 109.3km² i.e. 0.25% of the total area. In 2000/2002 massive increase had occurred in cultivation/others (67.4%) with slight increases in built-up (1.4%) and water-bodies (0.3%) as forest landcover continue to decrease in spatial extent (28.8%). The trend continues till 2007 as forest loses more area to built-up, cultivation/other and water-bodies (See also Ayeni *et al.* 2013b). Deforestation has the potential to influence rates of runoff and thereby increase risks of flooding and evaporation (Amber and Matlock 2011). In such cases, more deforested areas experience higher runoff and evaporation whereas cultivated areas are susceptible to more infiltration and less surface flow.

4.2 Climate change

The CC trends were analyzed to evaluate its influence on water resources and to assess water stress conditions in the derived savanna of Southwest Nigeria. The present day climate and the model predicted future climatic changes, in connection with the anthropogenic, LULCC can be used to provide vital information on the evolution of fresh water dynamics in the study area.

4.2.1 Trends in Rainfall and Temperature

This study uses trend analysis for rainfall and temperature to smooth out events that may be extreme, but quite rare. If a model can correctly predict trends from a starting point somewhere in the past, it is expected to predict with reasonable accuracy of what might happen in the future. Rainfall and temperature anomalies were generated using both observed, CSIRO Mk 3.5, MIROC, and UKMO simulated datasets, and prepared as an input for the Pitman model to simulate the runoff. The seasonal average rainfall for CSIRO Mk 3.5, MIROC, and UKMO from 1961 to the year 2010 showed a decrease inter-annual variability (Fig. 6a through 6d). This inter-annual variability is more obvious for the high rainfall seasons of March-April-May (MAM) and June-July-August (JJA). By analyzing the post-2010 period, CSIRO Mk 3.5, MIROC, and UKMO simulated reductions of 3.1%, 5.7%, and 5.0% respectively in the region future rainfall scenarios.

The temperature anomaly time-series clearly presented an increasing trend for all the seasons except for the December-January-February (DJF) averaged observed temperature (Fig. 7a through 7d).

The temperature is almost 1°C warmer than the 40 years mean in 2010. The future scenarios predictions vary among the 3 models. CSIRO prediction is highest for DJF with more than 3°C increase in 2050 (Fig. 7a); slightly more than 2°C increase for MAM (Fig. 7b), and more than 1°C but less 2°C increase for JJA and SON (Fig. 7c & 7d). MIROC only predicted more than 2°C increase for DJF (Fig. 7a) while other seasons less than 2°C (Fig. 7a, 7b, & 7c). On the other hand, UKMO predicted less than 1°C increase for DJF and SON (Fig. 7a & 7d) while MAM and JJA will experience a more than 1°C increase in 2050 (Fig. 7b & 7c). The post-2010 temperature analysis for CSIRO Mk 3.5, MIROC, and UKMO revealed increases of 2.2°C, 1.7°C, and 0.8°C respectively in the year 2050 future scenarios over the region.

These results imply that the area will be at more risk of water stress in 2050 since increase in temperature and continuous deforestation may result to high rate of evaporation particularly over the central part of Ogun basin and the entire Asa basin where forest cover is continuously disappearing. For instance, based on analysis of mean temperatures in Africa that have risen by 1°C between 1900 and 2000, IPCC study predicted increase of 3°C by 2050 (IPCC 2007). In addition, Boko *et al.* (2007) predicted a decrease in mean annual rainfall by up to 20 percent along the Mediterranean coast and the northern Sahara compared to a 7 percent increase in

tropical and eastern Africa. 2006. According to IPCC (2007), these predictions imply that there will be an increase in the number of people experiencing water stress in Africa.

4.3 Runoff

The three basins demonstrated spatial-temporal variability in their simulated mean annual runoff (MAR). As at 2008 MAR was 146.5 Mil.m³, 433.2 Mil.m³, and 150.3 Mil.m³ for Asa, Ogun, and Owena basins respectively (Table 4). As observed from Fig. 3, the runoff coefficient showed average increases commensurate with decreases in forest cover between 1981 and 2000 (Fig. 5a & b). Since the magnitude of runoff cannot be predicted with certainty at any point in the future, the model prediction results only suggest probable changes in runoff (Peel, 2009). On average, the model results indicate that between 1981 and 2008, Asa, Ogun, and Owena basins had runoff coefficients of 15.6%, 20.3%, and 11.6% respectively. The decadal time series analysis for 1981/1990 and 1991/2000 depicted increase in the runoff coefficient for the three basins while only Asa experienced an increase for 1991/ 2000 and 2001/2008 (Table 4). One of the most important concerns regarding these was that the period experiences relatively continuous deforestation, and rapid urbanization between 1986/1987 and 2000/2002 (Table 3).

Although, the simulations do not exhibit consistent changes in runoff for the three basins as well as for the whole period (i.e. 1981 – 2008), nevertheless, there were conspicuous changes in runoff which, in the absence of proper trend analyses, could be loosely inferred to reflect changes in climate and LULC (Fig. 3). Increases in runoff coefficient predominantly occur within the 2 basins (Asa & Ogun) that have over 50% of deforested areas. The PITMAN model parameters used for 2010 simulation were assumed unchanged for future scenarios. Based on this, the 40yrs (2011–2050) model predictions based on CSIRO, MIROC, and UKMO predicted reduction in annual rainfall, the future scenarios resulted in a low runoff coefficient for the 3 models (Table 5). CSIRO generates runoff coefficient of 6.04%, 14.58% and 8.54%; MIROC generates 5.98%, 14.57% and 8.70% while UKMO simulates 5.87%, 14.43% and 8.87% for Asa, Ogun and Owena basins respectively.

The analyses shown significant difference in runoff coefficient for the three river basins in the 2011-2050 scenarios when compared with the observed. CSIRO decreased by 61.3%, 61.7% and 62.4% for Asa, Ogun, and Owena respectively; MIROC decreased by 28.3%, 28.3%, and 29.0% for Asa, Ogun, and Owena respectively, while UKMO decreased by 26.2%, 24.8%, and 23.3%” for Asa, Ogun, and Owena respectively. . On the average, the runoff coefficients of all models decreased in the order of 61.8%, 28.6%, and 24.8% for Asa, Ogun, and Owena basins respectively. In all scenarios Asa basin has lower runoff coefficient when compared to Ogun and Owena basins. This could indicate serious water stress in Asa basin in the future based

on Falkenmark (1989) indicator which expressed water stress as the fraction of the total annual runoff available for human use. This would imply that in the future, the productive time of women and children living around Asa basin will be jeopardized in the search for domestic water while farming activities may also suffer water requirement for growth.

The basins runoff coefficient resulting from hydrologic responses to LULC and climate changes were evaluated using Pitman rainfall-runoff model baseline information. This study revealed that increased deforestation and built-up between 1980–2002 correlates with a reduction in the decadal flows between 1981 and 2000 in the three basins. This is an indication that the selected basins' hydrology is sensitive to LULCC (Ncube and Taigbenu 2005), with a general pattern of increasing transformation and unregulated changes from forest to cultivations and built-up as well as decreasing transpiration. This result is consistent with Thanapakpawin (2006) findings that deforestation and extensive cultivations may alter the stream flow pattern.

6 HYDRO-CLIMATE SCENARIOS: UNCERTAINTIES AND CHALLENGES IN WEST AFRICA REGION

Globally, availability and interpretation of appropriate hydro-climate information form the basis of adequate assessment of the impacts and risks associated with climate change and water resources assessment as well as effective adaptation strategies. Although, disparities between hydro-climate datasets have posed challenges in West Africa region particularly Nigeria where direct measurements are sparse. As a result, basins' spatio-temporal rainfall distribution datasets and soil property information remain the dominant uncertainties for water resources assessment (Bormann *et al.* 2005; Pedinotti *et al.* 2012). Other uncertainties that also influence West Africa region hydro-climate datasets include socio-economic assumptions, emissions scenarios, GHG concentrations, global climate response to radiative forcing (i.e. choice of GCM, model configuration and parameters, natural climate variability), climate change information (choice of best RCM and driving GCM, model configuration and parameters, climate variability observation, downscaling methods – dynamical or statistical), and climate change impacts (Giorgi 2008 and MacKellar, *et al.* 2010). These make research capacity in the region to some degree problematic. In West Africa, generally sparse spatial distribution and poor quality of observed hydroclimatic datasets have made climate research difficult to provide valid result (Giertz, 2004; Bormann *et al.* 2005).

The Nigerian Meteorological Agency is highly stressed to cope with world standard maintenance of climate measuring stations while the method of collecting and archiving data are not well organized.

For instance, limited rain gauge stations in the country particularly the Southwestern, Nigeria are at irregular intervals and underlie with frequent malfunctions. As a result data on the simulation results revealed an increasing in uncertainty in river discharge information. In many West Africa countries, meteorological stations still operate manually, with measurements being recorded by hand and available to end user in paper format. In some region, data dissemination is still very difficult since the information are not in digital form and where they have them in digital format, stations may not have internet connection and / or where available may be marred with poor internet connections.

Furthermore, bureaucracy and cost of accessing data implemented by meteorological agencies or government to supplement income for the meteorological services hamper the dissemination of observed hydroclimatic datasets in some countries/ regions downscaling of large-scale hydro dataset, CGCM/RCM for hydro-climate model data are mostly restricted from these internet domains and hamper spatial representation of the downscaling materials. The availability of projections of climate change at relevant spatial scales is also problematic. GCMs simulations are widely available, but, they are most at coarse resolution and not appropriate for most applications related to impacts and adaptation, although, this can be overcome by dynamical downscaling of CGCM data to RCMs multimodal climate scenarios for stations in the region.

Reliable data (statistical/dynamical) particularly river flow for validation also poses challenges in the region. Historical data are not available or where available they are discontinuous and therefore could not be used to validate the performance of climate models. Nonetheless, full spatial coverage of global gridded datasets (CRU, GRDC, GPCC, and satellite observations e.g Tropical Rainfall Measuring Mission—TRMM) based on interpolated station observations are available for validations but their quality is questionable in regions where the station density is sparse and not uniform (Giertz 2004; Bormann *et al.* 2005; MacKellar *et al.* 2010).

In order to address the problem, it is therefore necessary for West Africa researchers/modelers to come up with west Africa region based model to address the uncertainties problem. Partners (hydro-climate institutes) in developed nations should be further encouraged to assist in producing West Africa based regional model scenarios that can be used to address the question of uncertainty in the region (MacKellar, et al 2010). In addition, there should be more coordinated modeling activities and

input from multiple institutes and models in the region. Although there are institutes in the region that are producing quality work in the area of hydro-climate research, nonetheless, researchers' efforts to adequately address critical issues and communicate effectively with decision makers to ensure that policy on climate adaptation is relevant and well-informed (MacKellar *et al.* 2010).

7 CONCLUSIONS AND RECOMMENDATIONS

Based on the findings from this study, it was observed that the changes in LULC and CC influenced the hydrology of the three selected basins. The pitman rainfall–runoff simulation results indicate that LULCC and CC have significant impacts in the basins' runoff. Deforestation and urbanization and increasing cultivation were commensurate with significant changes of runoff coefficient over the three selected basins. As a result, continuous deforestation, urbanization and increase in cultivation could possibly increase evaporation over the three basins, and therefore, significantly sustained decrease in coefficient of runoff in future. Thus, the results suggested all water user stakeholders in the area should adopt various options for increasing water supply schemes and capacity as well as reducing LULC and climate changes trigger activities e.g. excessive logging and deforestation around river catchment. For future adaptation, communities in the water stress basins should embrace community water development and management strategies through the under-listed recommendations.

- Government should forefront environmental education, raise awareness campaign on climate change and adaptation in rural areas using appropriate communication tools such as meetings, local radio, framing messages, drama, flyers, posters, workshops, video amongst others. Awareness and strong inter-community cooperation is also required to avoid resource access and use conflicts (Fasona *et al.* 2013). Ecosystems management should be seen as important adaptation measure to prevent future extreme by communities and individual particularly in the northern and central parts of the region.
- Government should encourage communities to adopt improved land clearing methods and embrace re-forestation around surface water stream, springs, ponds, rivers, reservoir, and lakes since recharge process is mainly governed by physical characteristics of the surface and drainage system underneath. Farmers should cultivate land without completely depleting soil resources and resorting to more land protected and canopy-like crops. Some shrubs and small trees should be allowed to grow together with the crops in the farm to facilitate the re-growth of vegetation and also reduce high rate of evaporation (Sahel and West Africa Club/OECD 2009). For surface water catchments conservation in the rural communities, trees such as cashew, banana, kolanut, cocoa, almond, mango, and other rain forest trees are recommended for re-forestation due to their densely canopy and highly adaptation with tropical

environment (Buijs 2009; Tran *et al.* 2010), and their economic values. Communities should also take into account a careful selection of local vegetation for a developmental purpose and the concept that the improvement of inhabitants' livelihood is the most important long-term objective in efforts to enhance natural resources management (Merrey *et al.* 2005; Combest-Friedman *et al.* 2012). Grazing reserves should be established in respective domains to reduce excessive grazing and as well combat climate change induced grazing conflicts.

- Finally, Government should encourage scenario modelling using finer spatial resolution to ascertain future climate changes and incorporating the resultant information into decision making processes with fundamental goals to improve environmental security and ecosystems management in the rural development plans and programmes (Fasona *et al.* 2013). The results can be used to quantify future impacts for water availability and adaptation options. The adaptation should encapsulate a wide variety of related development activities (environmental and health education and programmes) that moderate climate change associated risk to potential benefits and processes of reducing vulnerability and water shortage stresses. Therefore, the study suggested the development of climate models with finer spatial resolution than the commonly used dynamically downscaled CGCMs

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Tables and figures

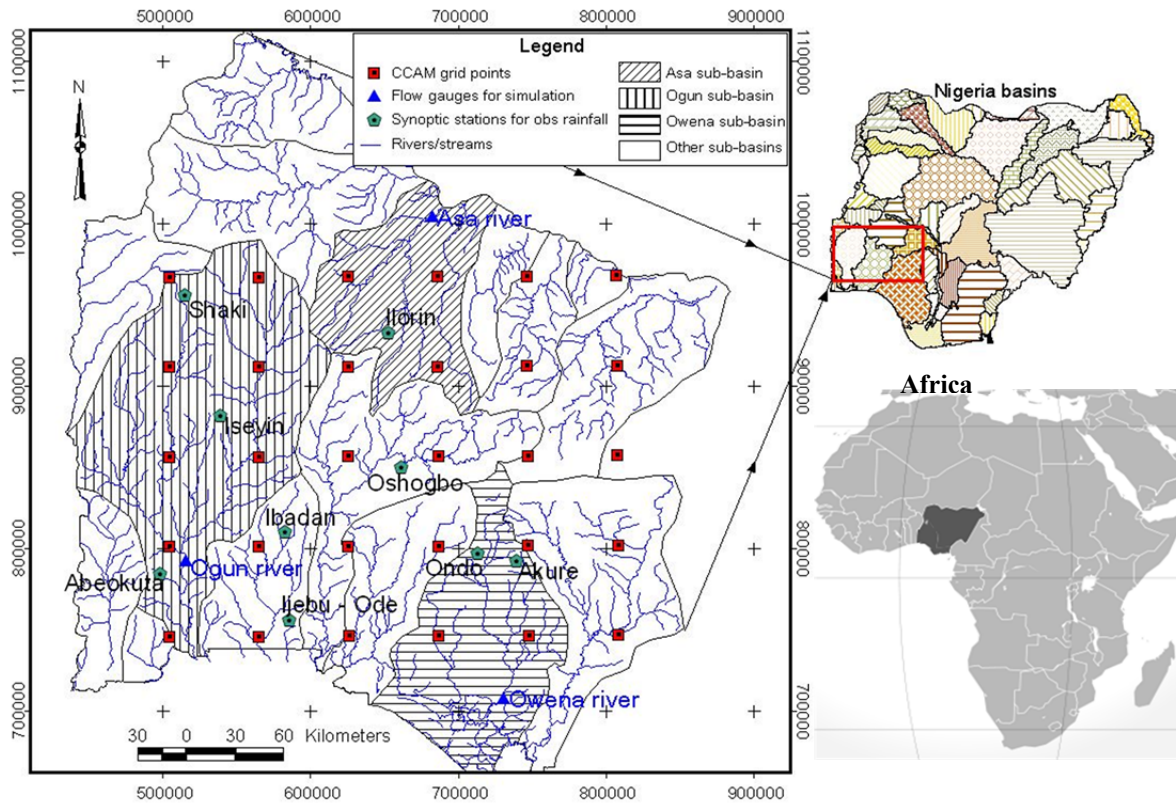


Fig. 1: A map showing the location of the study area.

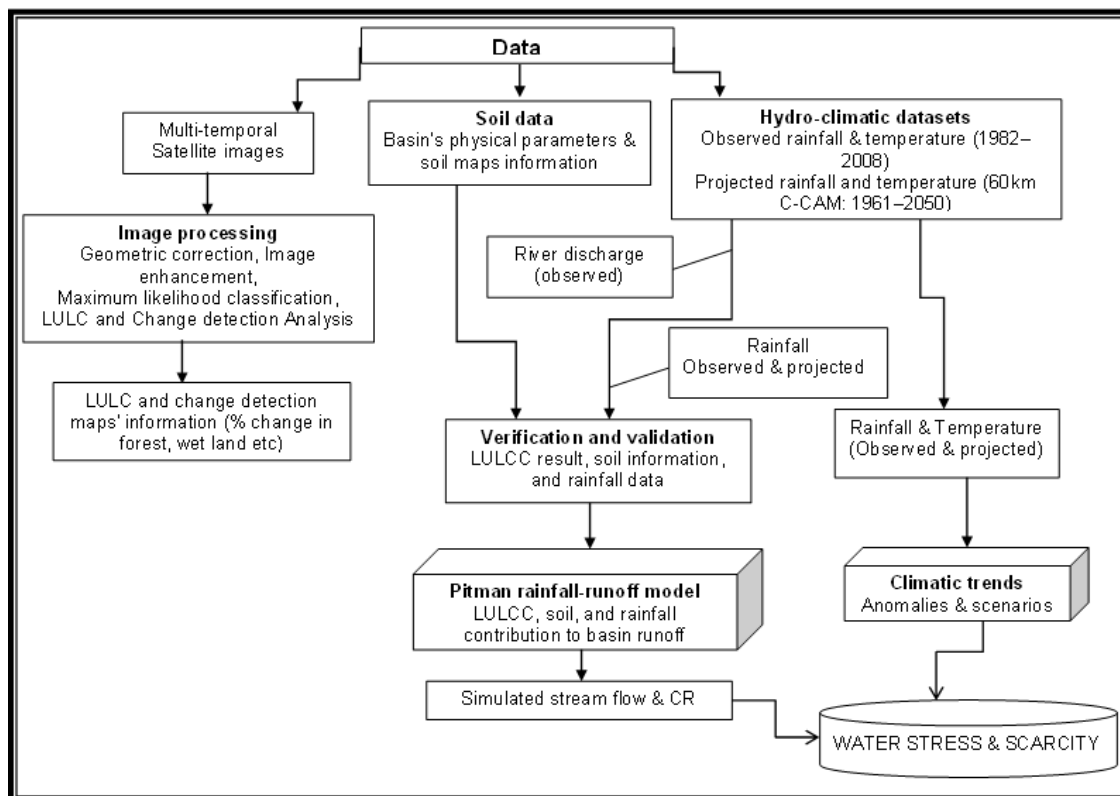


Fig. 2: A flow chart of the methodology followed to assess the water stress and scarcity for this study

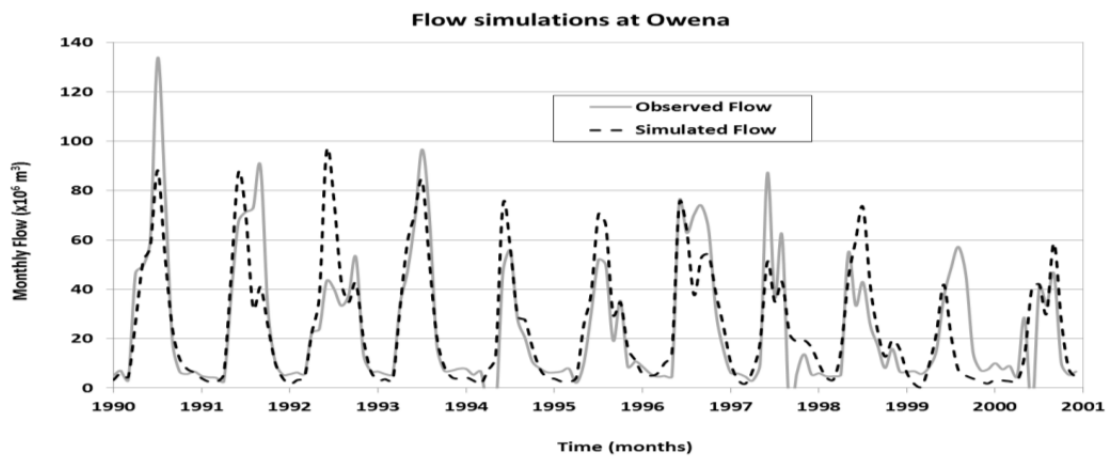


Fig. 3: Time series plots of the observed and simulated monthly flows for Owena sub-basin

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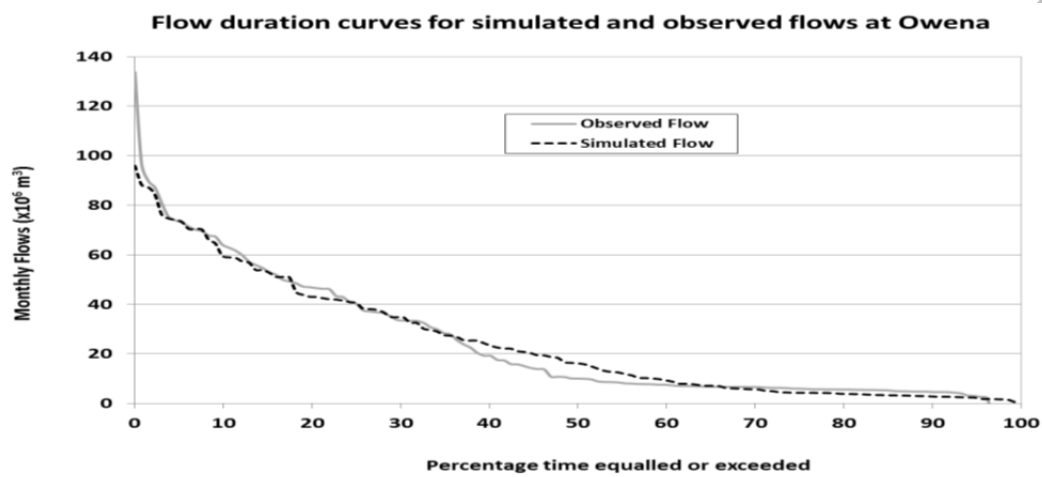


Fig. 4: Flow duration curves of the simulation results of the Owena sub-basin

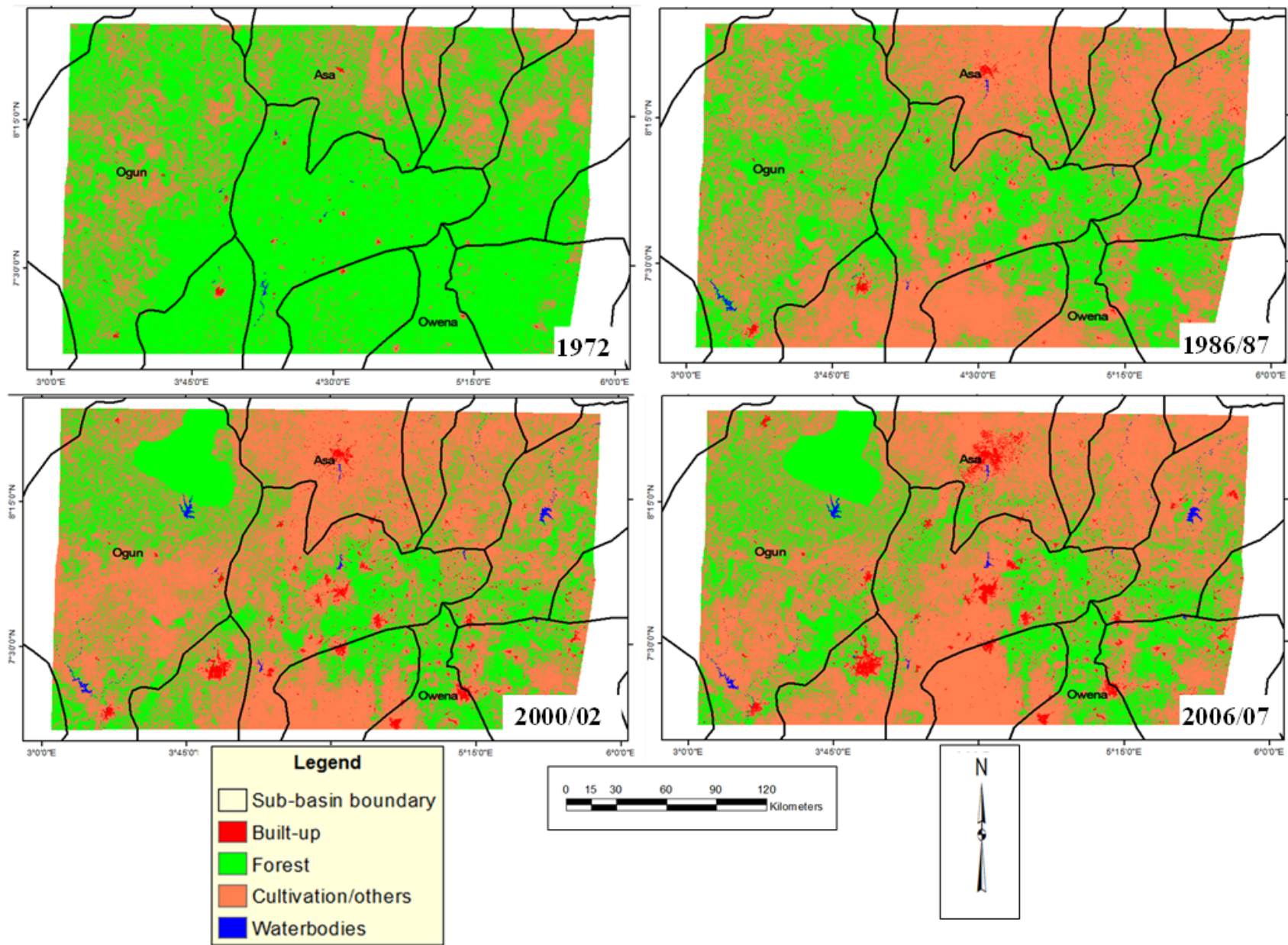


Fig. 5: LULCC over the study area between 1972 and 2007

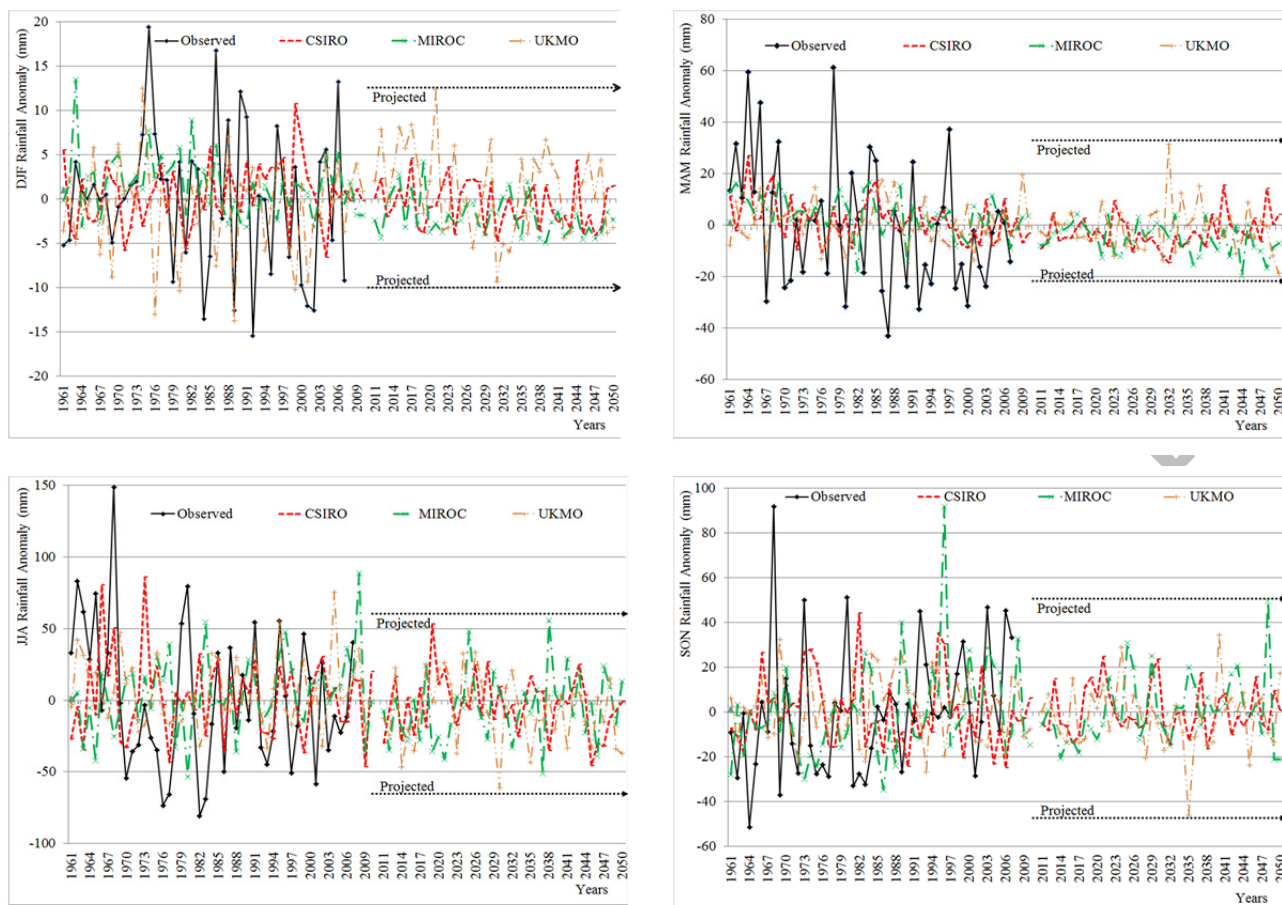


Fig. 6: Rainfall anomalies for Observed and projected C-CAMs over the area (a- DJF, b – MAM, c – JJA, d – SON)

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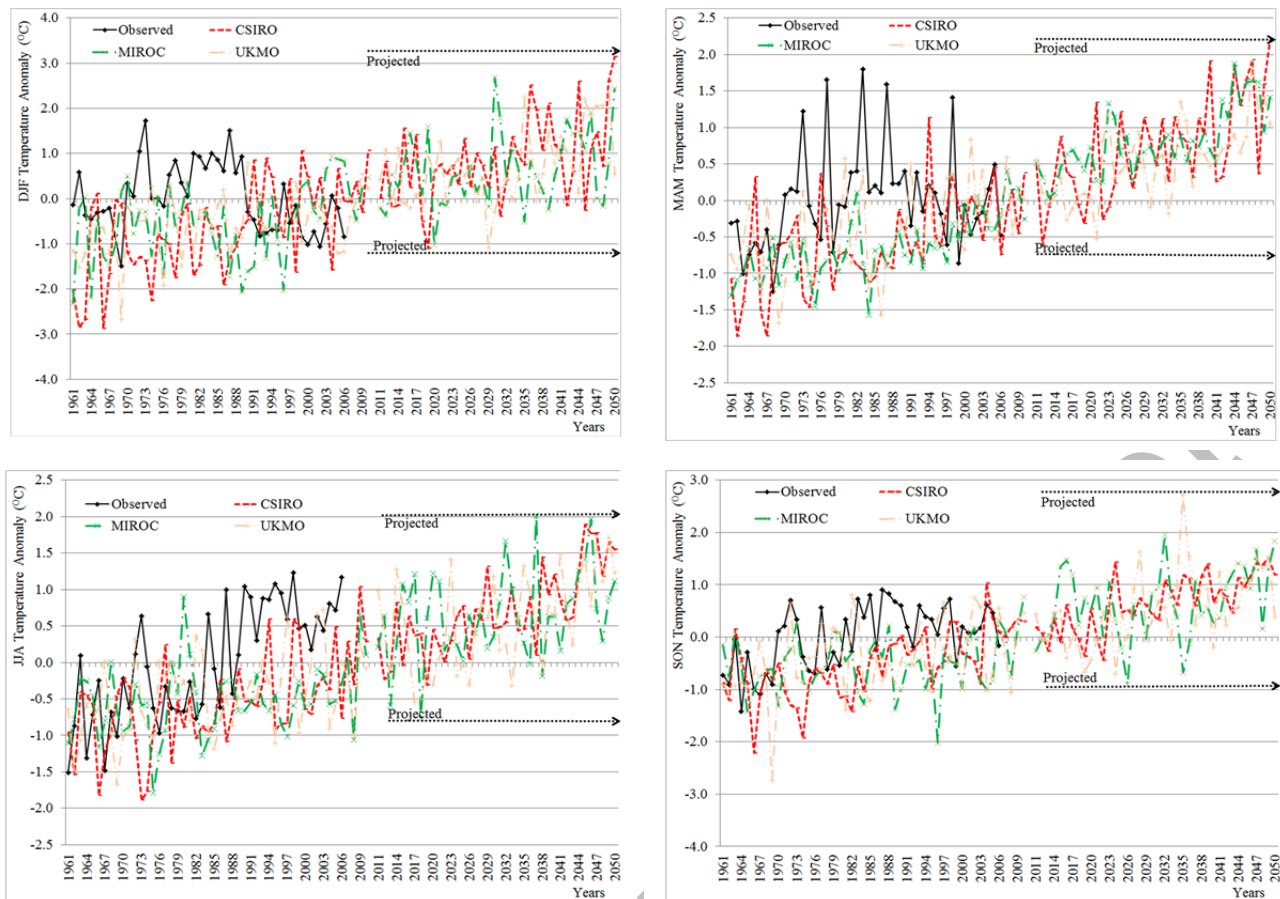


Fig. 7: Temperature anomalies for Observed and projected C-CAMs over the area (a- DJF, b – MAM, c – JJA, d – SON)

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Table 1 Main Pitman model parameters and a summary of the estimation methods (Hughes et al., 2010)

Parameter	Description and estimation approach
ZMIN ZAVE ZMAX	Parameters of the asymmetric triangular distribution of catchment absorption rate (mm month^{-1}). Estimated from the infiltration characteristics of the soil.
ST	Maximum unsaturated zone storage capacity (mm). Estimated from the soil depth and texture characteristics and including storage in the rock above the phreatic level based on fracture density and depth to groundwater.
FT	Maximum unsaturated zone drainage (mm month^{-1}) when storage = ST. Estimated from topographic slope, drainage density, soil depth and texture (translated to permeability). Includes an unsaturated zone contribution based on fracture zone transmissivity and gradient.
POW	Power of the relationship between unsaturated zone drainage and unsaturated zone storage. Estimated from assumptions about the spatial distribution of relative moisture contents for different levels of unsaturated zone storage using topography and soil drainage characteristics.
GW	Maximum groundwater recharge rate (mm month^{-1}) when storage = ST. Difficult to estimate directly and is typically calibrated against estimates of mean annual recharge from available literature.
GPOW	Power of the relationship between groundwater recharge rate and unsaturated zone storage.
Drain. Density	The drainage density of the channel network expected to receive groundwater outflows.
T	Transmissivity ($\text{m}^2 \text{d}^{-1}$) of the groundwater storage zone.
S	Storativity of the groundwater storage zone.
GW Slope	Regional groundwater gradient used to estimate groundwater outflows to downstream sub-basins.
RSF	Riparian strip factor (% of the sub-basin expected to contribute to evaporation from near-surface groundwater in the vicinity of channels).

Table 2 Results of the simulation of the hydrology of Owena basin. $R^2(Q)$, $R^2(\ln(Q))$, $CE(Q)$ and $CE(\ln(Q))$ are the coefficient of efficiency values (Nash and Sutcliffe 1970) based on untransformed and natural log transformed values, respectively. % Error is the percentage error in the simulated mean monthly flow relative to the observed value.

Objective function	Value
$R^2(Q)$	0.691
$R^2(\ln(Q))$	0.700
$CE(Q)$	0.679
$CE(\ln(Q))$	0.578
% Error (Q)	-2.674
% Error ($\ln(Q)$)	-4.107

Table 3 Land-use land-cover change between 1972 and 2007.

	1972	1986/87	2000/02	2006/07
	km^2 (%)	km^2 (%)	km^2 (%)	km^2 (%)
Built-up	82.6 (0.2)	307 (0.6)	803.3 (1.4)	1,133.5 (2.0)
Forest	42,819.3 (76.4)	21,855.7 (39.0)	17,304.6 (30.9)	16,148.3 (28.8)
Cultivations & others	13,143.7 (23.4)	33,838.2 (60.4)	37,801.9 (67.4)	38,616.6 (68.9)
Water-bodies	26.7 (0.05)	71.5 (0.13)	162.3 (0.3)	173.8 (0.3)
Total	56,072.3 (100)	56,072.3 (100)	56,072.1 (100)	56,072.1 (100)

Table 4 Hydroclimatic and Runoff coefficient for the observed data.

	1981–1990			1991–2000			2001–2008		
	Asa	Ogun	Owena	Asa	Ogun	Owena	Asa	Ogun	Owena
Mean flow (hm ³)	121.0	399.9	166.5	138.1	488.7	193.1	146.5	433.2	150.3
Area of sub-basin (km ²)	9600	22000	11000	9600	22000	11000	9600	22000	11000
Mean monthly runoff (mm)	12.6	18.2	15.1	14.4	22.2	17.6	15.3	19.7	13.7
Mean monthly rainfall (mm)	90.9	99.5	132.4	90.7	98.1	142.2	89.	98.1	124.2
Runoff coefficient (%)	13.9	18.3	11.4	15.9	22.6	12.3	17.0	20.1	11.0

Table 5 Hydroclimatic and runoff coefficient for CSIRO, MIROC, and UKMO scenarios.

	CSIRO			MIROC			UKMO		
	Asa	Ogun	Owena	Asa	Ogun	Owena	Asa	Ogun	Owena
Mean flow (hm ³)	46.7	258.6	101.2	46.9	258.9	101.5	45.5	257.4	100.0
Area of sub-basin (km ²)	9600	22000	11000	9600	22000	11000	9600	22000	11000
Mean monthly runoff (mm)	4.87	11.78	9.20	4.90	11.77	9.23	4.74	11.69	9.09
Mean monthly rainfall (mm)	80.57	80.62	107.70	82.68	82.98	112.15	80.72	81.05	102.50
Runoff coefficient (%)	6.04	14.58	8.54	5.98	14.57	8.70	5.87	14.43	8.87

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