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Water Resources Development Optimization in a Climate Change Scenario: Case Study of Benin-Owena Basin, Nigeria

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ABSTRACT

Understanding the basin-scale hydrologic potentials in managing water resources require the optimization of relevant model. Therefore, this study described the efficiency of CHyM4 model in optimizing water resource planning in a climate change scenario using daily rainfall and discharge data in Benin/Owena river basin, Nigeria. The model produced daily series rainfall and discharge data at a resolution of 1 km across small catchments. Rainfall and discharge scenarios such as average monthly flow discharge, flow direction, drained surface and accumulated time series (onset, peak and offset of rain) were generated from the observed and simulated for the basin between January and December, 2004. The model simulated results were compared with the basin observed data result. Observations show a wide variation in the monthly simulation in the area with precipitation decreasing slowly Northward over the period. Observed rainfall depths/discharge trends and CHyM4 simulation have similar results as shown from the comparison between the simulated and observed rainfall and discharge output. The observed result was used to examine the optimal efficiency of the basin for water resources planning and management based on the projected result. This is essential in order to sustainably manage available water resources within the basin.

Key words: Water resources, simulation, basin, climate change, Nigeria

INTRODUCTION

Human beings have always struggled to cope with climate variability. In recent times, climate variability has increased the number of floods and droughts. Added to that, climate change has emerged as one of the key environmental issues of concern over the next 50-100 years (World Water Week, 2003). However, there are still many uncertainties relating to the effects of climate variability, including the impact of climate change, which the society is not really ready to handle. There are various elements working together to form the totality of weather and climate in which clouds and precipitation, along with temperature and wind are the most striking elements which are liable to change very rapidly with time and space (Adejuwon, 2004).

Precipitation however, has been known to be in various forms of which the most frequent in Nigeria is rain and it play an important role in sustaining not only the climate, but also life within the climate (Adeyemi, 2000a; Adejuwon, 2004). It is observed that, if the total annual precipitation could be evenly distributed, every region in the world would receive 86 cm of precipitation (Olaniran, 1990). But annual distribution range from 25 cm to more than 245 cm over various regions of the world. In the recent time, examination of various precipitation data has all indicates a run of dry years for the sub Sahara region dating back to the 1940s (Bryson, 1973; Lamb, 1985; Olaniran, 1990; Adejuwon, 2004). In particular, Lamb (1985) noted that the years 1942, 1949 and 1968-1983 are drier than normal in the sub-Sahara region. South of Sub-Sahara Region, dry periods of varying intensity and magnitudes have been observed (Adeyemi, 2000b). In Nigeria, large rainfall fluctuations are inherent characteristics of climate and such fluctuations have had diverse effects such as drought and flood. For instance, availability of surface water sources or shallow groundwater depends on the seasonal stream flow which is a function of precipitation (EEA, 2007; Bates *et al*., 2008).

Water resources management study at the basin/catchment has been studied at different time and spatial scales. Such studies include global water resources: vulnerability from climate change and population growth (Vörösmarty *et al*., 2000), climate change and global water resources: SRES emissions and socio-economi scenarios (Arnell, 2004), implementation of holistic water resources-economic optimization models for basin management-reflective experiences (Cai, 2008) and among others. Understanding the basin-scale hydrologic potentials in managing water resources require the optimization of relevant model. Modeling watershed/river basin is crucial in the developing countries. Nevertheless, it is very difficult to transformed simulated precipitation response into a realistic hydrologic benefit in non inclined research countries.

Impact of climate variability on hydrology and related fields such as water resources planning and management practice require data for both the current climate and a range of future possible scenarios (Kilsby *et al*., 2007). These series must be consistent, both between variables and with a range of observed and projected scenario in order to account for extremes e.g. floods and droughts and seasonality. Therefore, this study aims to establish the efficiency of models in water resources planning and management optimization in Benin-Owena Basin, Nigeria with following objectives;

- To simulate monthly average flow discharge, flow direction, drained surface and accumulated rain for onset, peak and offset of rain
- To compare the simulated result with observed data result

MATERIALS AND METHODS

The study area: Benin-Owena catchment lies between longitude 5°01' and 5°45'E and latitude 7°17' and 8°15'N. The basin area is about 51,400 km^2 and covers 3 states of southwestern-Nigeria vis-à-vis Ondo, Edo and Delta (Fig. 1). The major river in the basin is River Benin with River Owena as main tributary and many other short course tributaries.

Model structure: The CHyM4 model scenarios are based on integrations of factors taken from ARSSA, IDROGRAFICO, Satellite data, ECMWF forecast and RegCM to basin simulation (Fig. 2). ARSSA and ECMWF are meterological centres which are situated in Italy or have collaboration with Italy. ARSSA: Agenzia Regionale per I Servizi di Sviluppo Agricolo (Regional Agency for

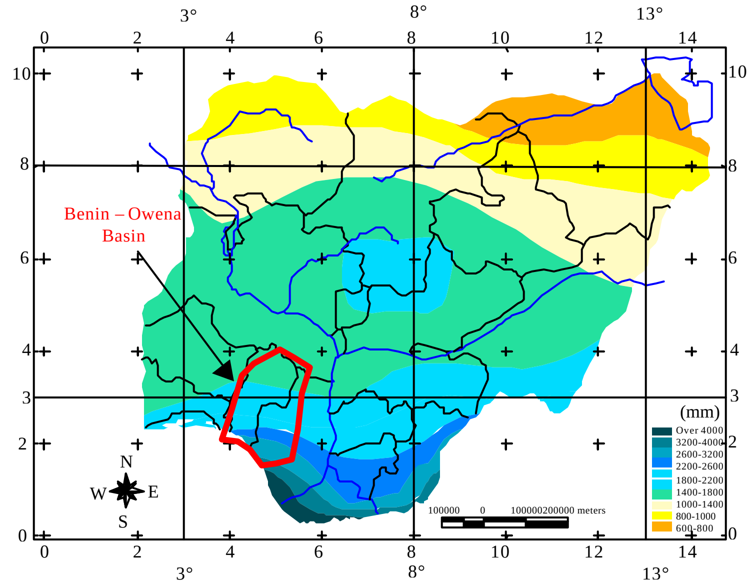

Fig. 1: Nigeria rainfall map showing the study area

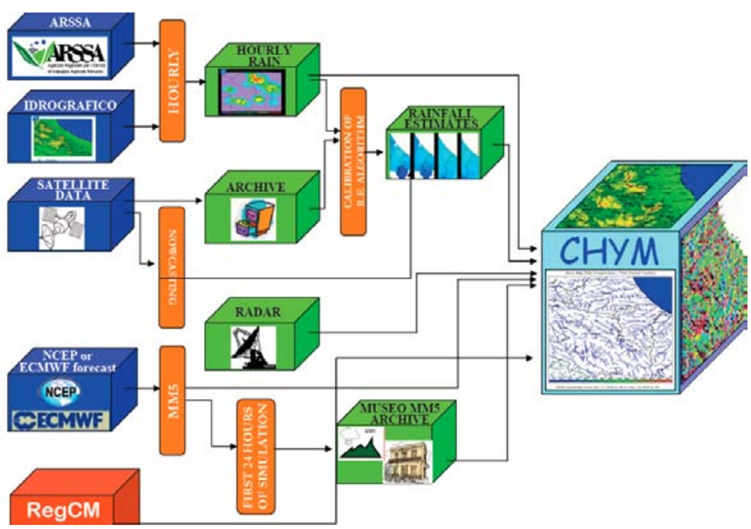

Fig. 2: Model structure (Coppola *et al*., 2007)

Agricultural Development Services). IDROGRAFICO means Basin. RegCM: Regional Climate Modeling. ECMWF: European Centre for Medium-Range Weather Forecasts-is an independent international organisation supported by 31 States. Its Member States includes Italy, it provides meteorological services to the member states.

The approach relies on deriving factors of change for various statistics from control to future scenarios and applying these to observed statistics, rather than using the RCM's rainfall climatology directly as it does not reproduce the spatial patterns of mean rainfall or seasonality accurately.

Observed data: Observed daily rainfall and discharge data on Benin-Owena catchment for year 2004 were obtained from the Benin-Owena Basin Authority, Benin-Nigeria. The collected daily rainfall and discharge were expressed as a function of the monthly data for every month in year 2004 using simple arithmetic mean formulae:

$$Mx = \Sigma\ (n_i \ldots .n_j)/N$$

Where:

Mx	=	Mean rainfall and discharge for each month
Σ	=	Summation
n	=	Rainfall and discharge values for each day
N	=	No. of days in each month
Subscript i....j	=	Day 1 to the last day in each month

The collected daily rainfall and discharge for each day were added together and divided by the total numbers of days in each month. The rainfall and discharge records were normalized and plotted for comparison for the studied year using the climatic index formulae:

$$Xn = (x\text{-}X)/\delta$$

Where:

Xn = Normalized value
x = Daily value
X = Mean of all daily value
δ = Standard deviation

RESULTS AND DISCUSSION

Model scenario and results: The system produces time series at a daily resolution using two stochastic models in series. Scenarios are generated by fitting the models to observations that have been perturbed by application of change factors derived from changes in the climatic variable from climate models. As new scenarios and simulations from different climate models become available for Benin-Owena basin, therefore, the months of March, July and November were simulated for onset, peak and offset raining season, respectively for scenario observation and update.

Figure 3 a and b show simulated drainage network and DEM for the basin as generated from the satellite Isoline (Contours) feed in the model (Coppola *et al.*, 2007). The basin elevation ranges between 18 and 618 m above sea level.

Figure 4a-c show that the mean discharge ($m^3\ sec^{-1}$) simulation from 01 March (23:00 GMT) to 31 March 2004 (23:00 GMT) ranges between 63 and 946 $m^3\ sec^{-1}$. Discharge simulation for 01 July (23:00 GMT) to 31 July 2004 (23:00 GMT) ranges between 108 and 2049 $m^3\ sec^{-1}$ while 01 November 2004 (23:00 GMT) to 31 November 2004 (23:00 GMT) ranges between 63 and 1198 $m^3\ sec^{-1}$. These represent simulated change in onset, peak and offset of raining season over the basin (Arnell, 2004). Across the basin, different in discharge were noted at mouths of each adjoining river to the higher order (Adeaga *et al.*, 2006).

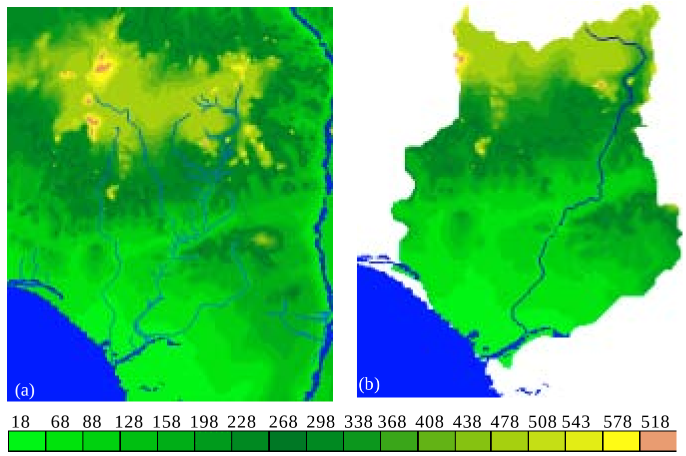

Fig. 3: Digital Elevation Model (DEM) of Benin-Owena Basin. (a) Drainage network and (b) DEM

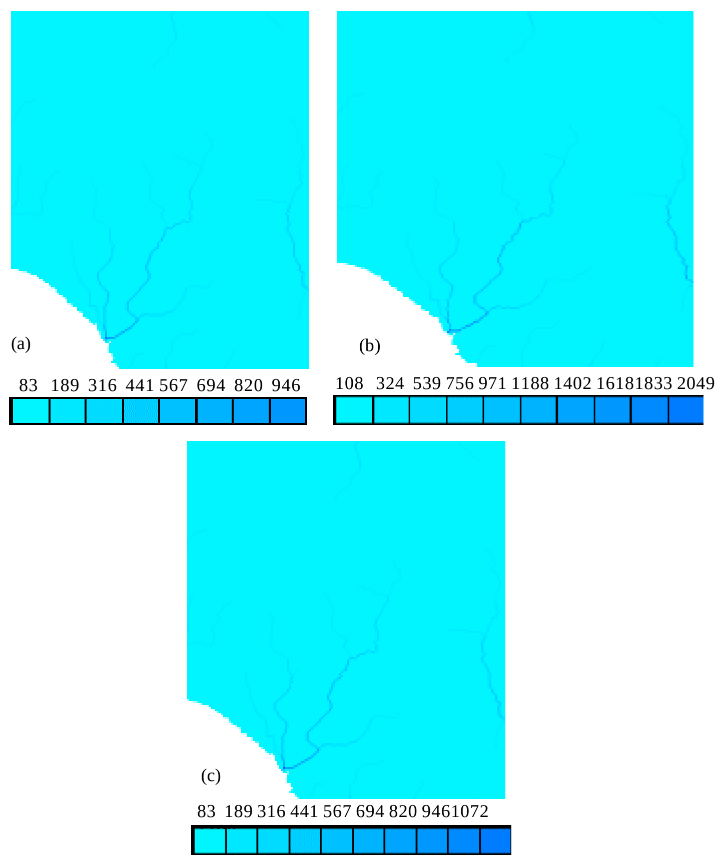

Fig. 4: Mean discharge (m^3 sec^{-1}) simulation for March, July and December. (a) Onset, (b) peak and (c) offset

The scenarios show that only 20% of the total rains were drained at the onset, 46.7% at peak and 6.7% at offset raining season (Fig. 5a-c). These indicate that during the peak period surface were

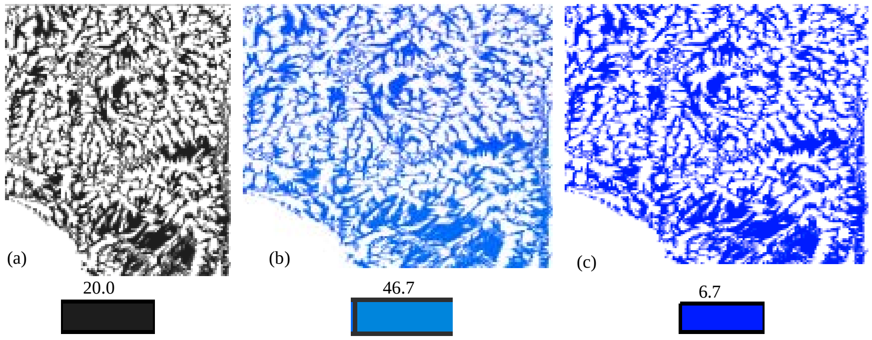

Fig. 5: Total drained rain/total drained surface (Alarm). (a) Onset, (b) peak and (c) offset

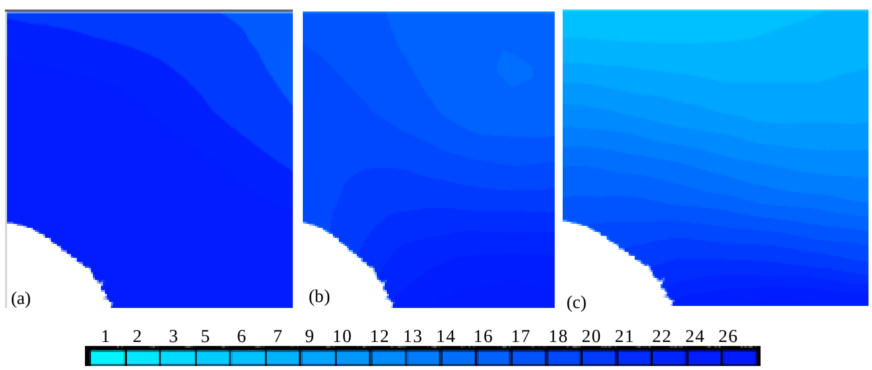

Fig. 6: Accumulated rain (mm). (a) Onset, (b) peak and (c) offset

more saturated hence infiltration capacity reduced (Oyebande and Adeaga, 2006). The result also shows infiltration rate are different at each period of simulation.

Figure 6a-c indicate that accumulated rain increases towards the coast of the basin where River Benin (Main River) discharged its water to Atlantic Ocean (Adeaga *et al*., 2006).

The simulation shows basin flow direction in which majority of stream and overland flow southwards and westwards along the coast of the basin (Akinro and Olanrewaju, 2007; Cai, 2008). According to Fig. 7, the stream and overland flow in the Northern part of the basin flows toward east (Yu *et al*., 1999). Figure 8 shows that the highest and lowest slopes were recorded at 160 and 180 km away from the source of the main river (Marsili-Libelli and Giusti, 2008).

Observed data result: The index of observed data result in Fig. 9 shows that there were low rains between the months of January and March but the rain continues to increase during the month of April up till May the first peak of the simulated year. The rainfall declines in June and July but rises to second peak again in August.

The rain begins to reduce in amount, duration and frequency from August until the offset of November and returned to minima in December (Fig. 9). On the other hand, the discharge data trend Fig. 9 shows that the river discharge rate is much lower during the onset (Akinro and Olanrewaju, 2007). The increase in discharge began in July until it reach the peak in September

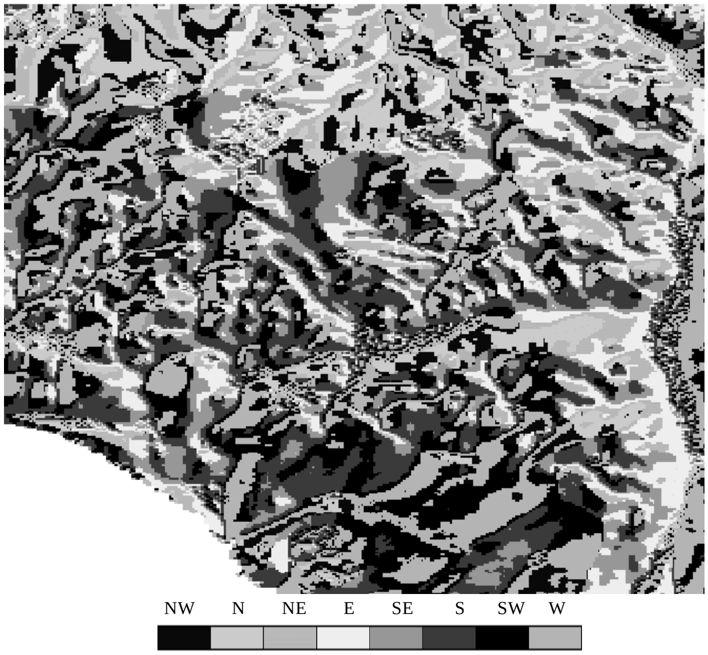

Fig. 7: Basin flow direction

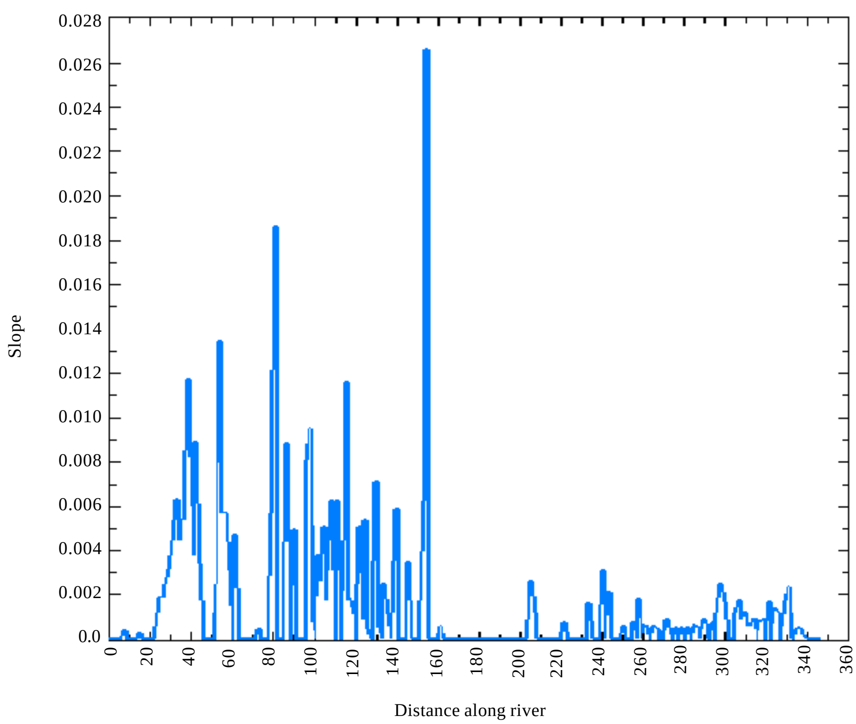

Fig. 8: Slope along the main river in the basin

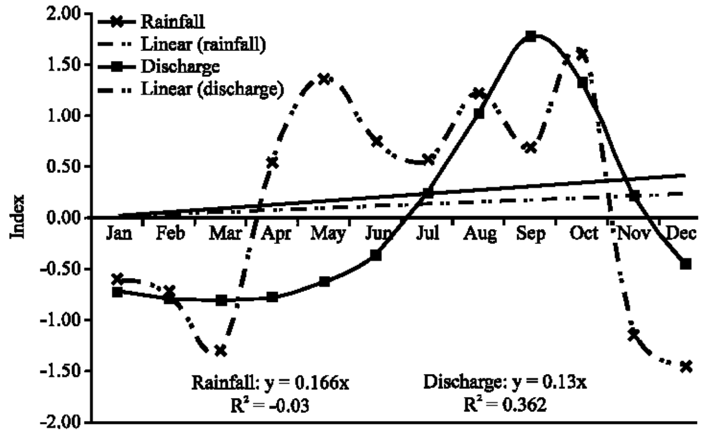

Fig. 9: Index of monthly rainfall (mm) and discharge (m^3 sec^{-1}) for 2004

and started reducing towards the offset of raining period until it reach it minima in December (Adeaga *et al.*, 2006).

CONCLUSION

The monthly simulation of rainfall was performed, starting from 23 h for the off, peak and off raining season of 2004. Observations show a wide variation in the season's simulation in the area. The precipitation decreased slowly northward over the period. It was observed that CHyM4 model simulation captured the rainfall pattern of the basin moderately well and produced similar results with observed rainfall/discharge trends for the year 2004. It is anticipated that effective and efficient optimization of climate and hydrologic models will increase the potentiality of the basin in water resources development in the threatening climate change scenario. In order to increase the reliability of water supply for the increasing population of the basin area, the results of the model can be used in determining the best area suitable for water resources development especially multi-purpose dam. Hence, the downstream of the catchment major river is best suitable for all such development in order to meet water need of the populace in the area.

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