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Hydrological Modeling of the Impact Of Climate Change On A Tropical Perennial River Flooding

By

[1]Haruna Garba [2]Dr Abubakar Ismail [1]Abdullahi Ibrahim [1]Saminu Ahmed [1]Bayang Faustinus

1 Department Of Civil Engineering, Nigerian Defence Academy Kaduna Nigeria. E-Mail
2 Department Of Water Resources And Environmental Engineering, Ahmadu Bello University Zaria Nigeria

ABSTRACT: This paper applied the use of a stochastic weather generator at the site of a hydrological model to simulate the impact of climate change on a Tropical River flooding, aimed at developing a quantitative understanding of the changing behavior of hydrological systems under climate change. Prior to the simulation, the model was calibrated and validated with historical data, to obtain process parameters. Simulations with the model indicates an increase in the magnitude and frequency of flooding events associated with higher return periods

KEYWORDS; Hydrological, Climate change, Flood, Statistical, Frequency distribution

I. INTRODUCTION

One of the major challenges facing the hydrological science today is to develop a holistic and quantitative understanding of the changing behavior of hydrological systems [1]. Prediction of hydrological responses of a river basin needs to allow for adoptive temporal evolution of soil, vegetation and climate. The main challenges however emerge when extrapolating model predictions to unmeasured conditions. Two major concerns of climate change and land use have being identified by [1]. Hydrological variable such as rainfall are statistical quantities that can be estimated from a given probability of occurrences. Traditional hydrological frequency analysis was anchored on the presumption that climate is stationary, meaning that statistical properties of hydrological variables in the future will be similar to the past. This assumption of stationarity is criticized by academic articles i.e. [2] and [3].

However, The Intergovernmental Panel on Climate Change [4] observed that global climate changes induced by increase in temperature, may change precipitation patterns and probably raise the frequency of extreme events such as flood and drought. These changes may have serious impacts on the society especially river basins because of both sea level rise and an increases in the occurrences of flooding events [5]. [6] Observed that flood estimation with climate change cannot be done on a purely statistical basis because extreme value distributions may change in the future, He therefore proposed a physical based approach which incorporates meteorological and hydrological information. The approach can be carried out with the analytical method or the Monte Carlo Simulation. In the analytical approach, the use of simple analytical solvable equations such as Intensity-Duration- Frequency (IDF) curves have being used i.e. [7].

The Monte Carlo Simulation involves the generation of synthetic meteorological time series as inputs into the rainfall-runoff model to derived discharge series i.e. [3]. An extreme value distribution function can then be fitted to the discharge. Although,[8] identified two draw backs when applying the analytical method; the spatial heterogeneity of inputs and processes is not incorporated and the interaction of the different flood generation mechanism is not contained. The reason for this is that equqtions cannot be too complex because they should be solved analytically. The Monte Carlo Simulation on the other hand does not have this requirement and can be used in climate change situations [9], moreover, with this approach an uncertainty assessment can be done to evaluate the validity of the estimated floods with climate change. Hydrological models according to [1] are important for a wide for a wide range of applications which includes; water resources planning, development and management, flood prediction and design and coupled system modeling such as water quality, hydro ecology and climate. Hydrological model applications have a variety of objectives depending on the problem that needs to be investigated. [10] summarized the different aim of hydrological modeling which includes the following; extrapolation of point measurement in both time and space, improving the fundamental understanding of existing hydrological systems and assessing the impact of climate change on water resources and developing new models or improving old models for management decisions on current future catchment hydrology.

II. MATERIALS AND METHOD

2.1 The Study Area

Kaduna River (fig 1) is the main tributary of Niger River in central Nigeria. It rises on the Jos plateau south west of Jos town in a North West direction to the north east of Kaduna town. It then adopts a south westerly and southerly course before completing its flow to the Niger River at Mureji. Most of its course passes through open savanna woodlands but its lower section cut several gorges including the granite ravine at Shiroro above its entrance into the extensive Niger flood plains.

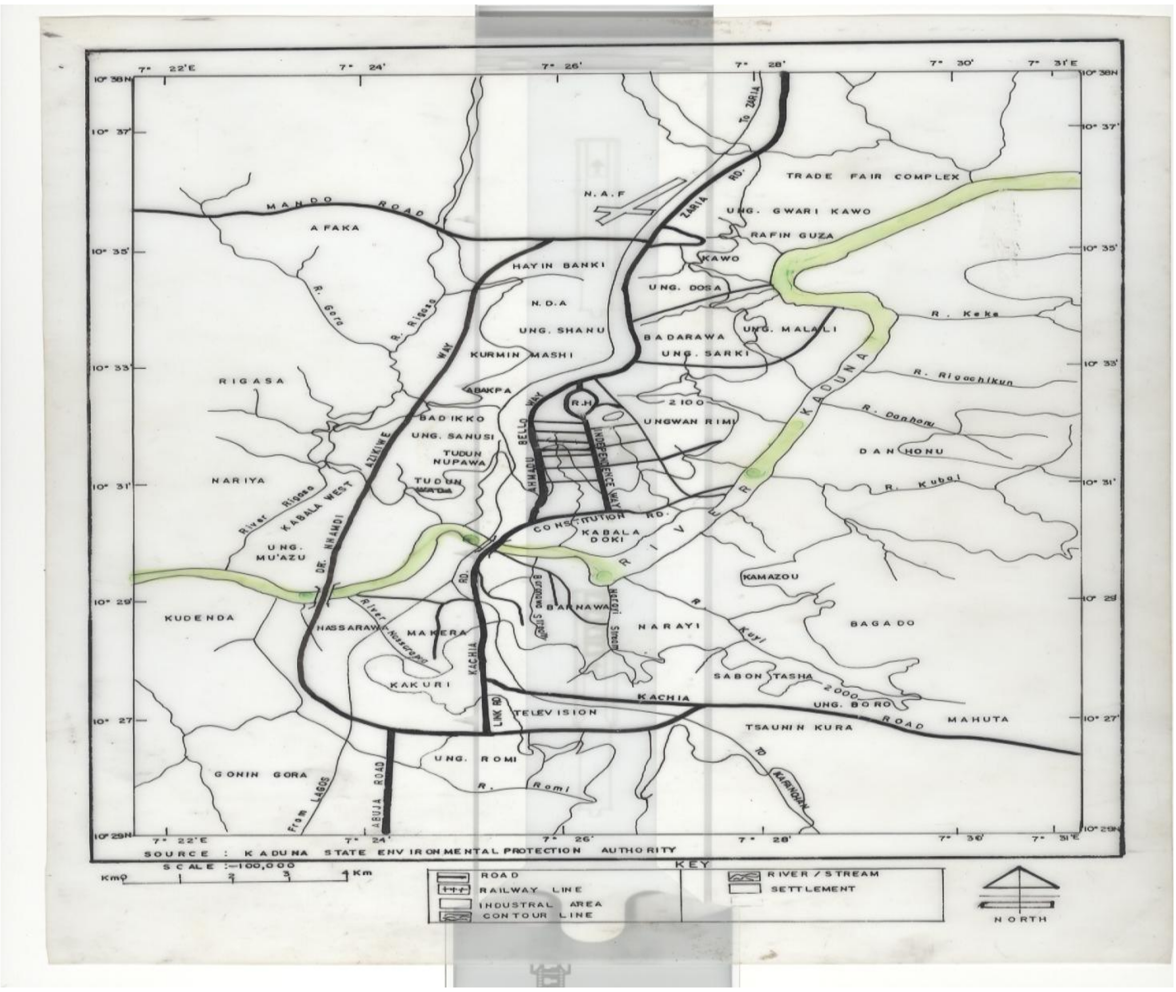

fig 1 drainage map of Kaduna River

2.2 The modeling tool

Hydrognomon is an open sources software tool used for the processing of hydrological data. Data are usually imported through standard text files, spread sheets or by typing. The available processing techniques for the tool includes time step aggregation and regularization, interpolation, regression analysis and infilling of missing values, consistency test, data filtering, graphical and tabular visualization of time series. Hydrognomon support several time step from the finest minutes scales up to decades. The programme also include common hydrological application such as evapotranspiration modeling, stage discharge analysis, homogeneity test, areal integration of point data series, processing of hydrometric data as well as lumped hydrological modeling with automatic calibration facilities (fig 2)

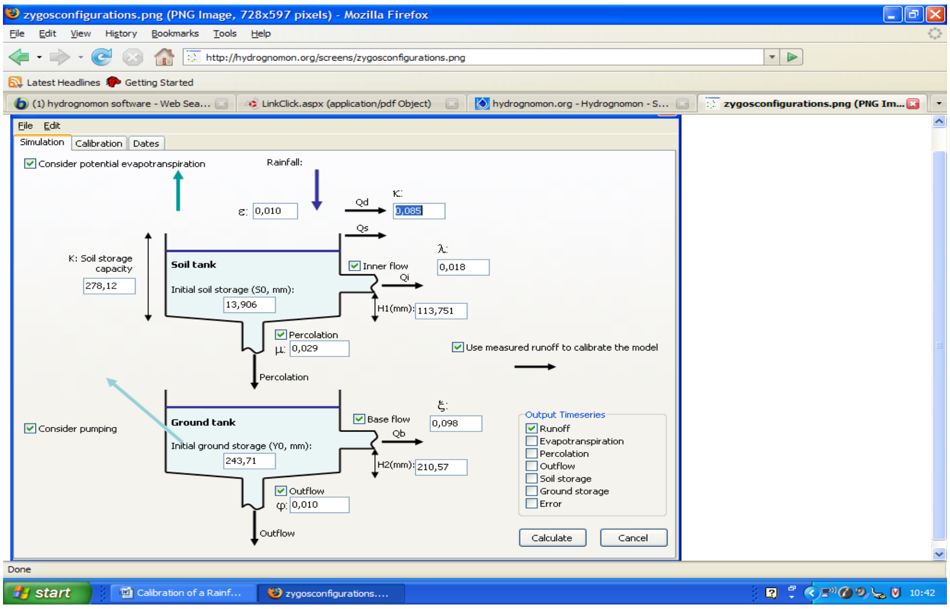

Fig 2 Structure of the Simulation module (http:www.hydrognomon.org)

III. STOCHASTIC MODELING OF FUTURE CLIMATIC VARIATION PARAMETERS

A changing climate according to [1].leads to changes in the frequency, intensity, spatial extends, and duration and timing of extreme weather and climate events, and can results in unprecedented extreme weather and climate events. The character and severity of impact from climate extremes depends not only on the extreme themselves but also on the exposure and vulnerability as observed by [11]. Global climate change is expected to have a strong impact on water resources on local [12] regional [11] and global scales[13]. Changes in the precipitation patterns affect surface and ground water availability and runoff directly while changes in temperature, radiation and humidity have an effect on evapotranapiration [1].

To asses the variability in the hydrological responses due to climate change GCM- forced hydrological model are used [14]. The role of hydrological models as part of global climate models has become imperative. The essential component of global climate models as observed by [1] are; the fluxes of moisture and energy from land to atmosphere and from land to oceans, the impact of soil moisture on plant cover and CO_2 fluxes. These components of GCM are often very sophisticated i.e. dividing the atmosphere into many layers [14]. Global atmospheric general circulation models (GCM) have been developed to simulate the present climate and used to predict future climate change by using regional hydrological models, in assessing the impact of climate change has many attractive characteristics [15]. He Further observed that the land- phase parametization in the coarse GCM do not agree on predictions of most hydrological variables when all atmospheric forcing are identical.

There exist therefore many gaps in the relationship between hydrological modeling and climate modeling as [16]. Recent research development and achievement have been proposed by [16] to handle the problem of mismatch between GCM and hydrological models. The challenging task for both the meteorologist and hydrologist arise from the fact that the meteorologist who work with large complex models are forced through computational limitations to operate on a coarse grid scale whishing to move to finer scale (scale down) while the hydrologist on the other hand are used to modeling at much smaller scale and is having to scale up. To circumvent the problems and narrow the gaps between GCM ability and hydrological models various methodologies have been developed during the past [16]. The approaches are; dynamic downscaling approach for generating high resolution meteorological input, statistical downscaling approach for simulating local scale surface variable based on large scale free atmospheric variable, macro scale hydrological modeling approach and hypothetical scenarios have been used as input into the model to show the sensitivity to climate with reasonable interval.Methods of simple alteration of the present condition proposed by [17] are widely used by hydrologist. In the approach, various hypothetical climate changes have been adopted and climate predictions for double CO_2 conditions have become the standard. The procedure for estimating variables of rainfall and temperature on the hydrological behavior of Kaduna River catchment consist of the following steps derived from[15]; first parameters of the hydrological model were determined by calibrating the model with historic data, secondly, monthly historical time series of rainfall and temperature for the hydrological year 2010 were perturb according change scenario by adding $\Delta T = +1,+2,+4$, for temperature and $1+\Delta P/100$ for rainfall, thirdly, the hydrological characteristics of the catchment were simulated using the calibrated model.

Daily climate variables of temperature and rainfall for the year 2010 was used as a threshold at the site of the model to generate a 2,5,10,20,50,aand a 100 year monthly time series in the future. Frequency graphs for the return periods were constructed.

The Modeling Procedure

The modeling procedure consists of three steps; first, the model was calibrated using historical data. The historical data used for the calibration were recorded rainfall and gauge height levels at gauging point (Datum at 582.96 m) located in the study area at Kaduna south water works for 26 years (1975-2000) were used as calibration period. The data are totals on monthly basis spanning the calibration period, [18]. The steps of the data collection process involve the following;

- The daily stream flow was read as gauge height while the daily rainfalls were read for each of the stations.
- The monthly maximum stream flow values and rainfall values were extracted from the daily values.
- The gauged levels measured were used to scale the flow to runoff volume of the watershed by using the expression below [19] in calibrating the model.

$Q = ICA$ (1)

Where

Q =calculated runoff

I = gauged water levels

C = a factor (distribution coefficient) the ratio maximum gauge level at a point to the mean gauge levels of Kaduna river.

A = drainage area of Kaduna river.

Secondly, the hydrology of the river basin was simulated at initial moisture content and at saturated moisture content. In determining the initial moisture content and moisture content at saturation, soil samples were obtained at four different locations along the river bank (fig 3) representing four land use pattern. The four locations represent densely vegetated condition sample location 1 (SL1), sparsely vegetated conditions sample location 2 (SL2), crusted condition sample location 3 (SL3) and bare land conditions sample location 4 (SL4). The method of undisturbed sampling was employed in obtaining the samples for testing. The samples were taken using cylindrical core cutters (100mm by 130mm). The recharge to ground water was simulated at initial moisture content and moisture content at saturation while simulations at completely unsaturated condition (0%) moisture serves as control by adjusting the most sensitive parameters of rainfall and soil- water content.

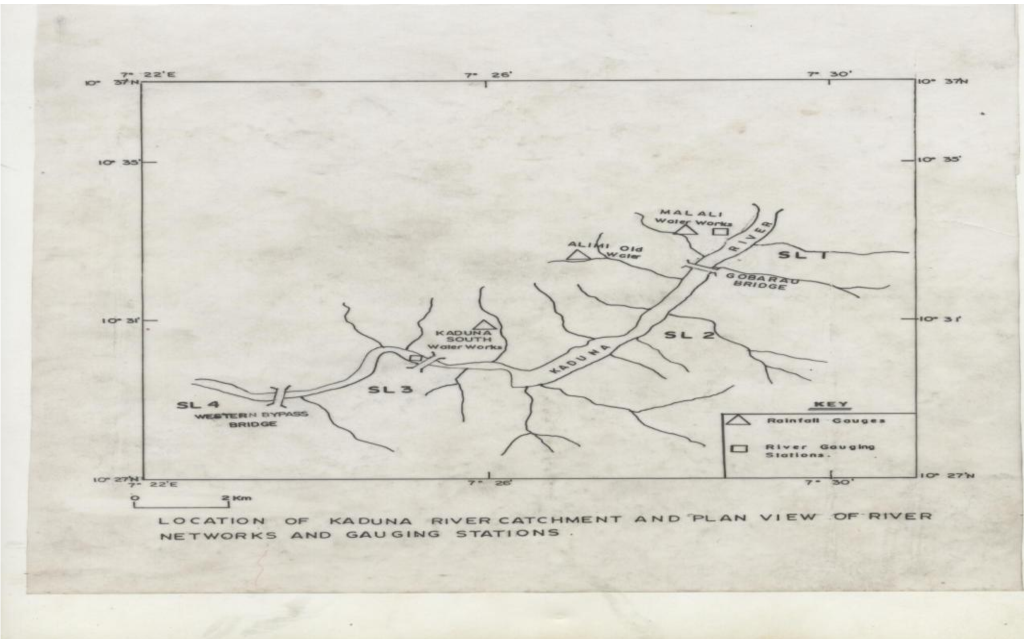

Fig 3 Map of Kaduna River showing the sampling point

IV. RESULTS AND DISCUSSIONS

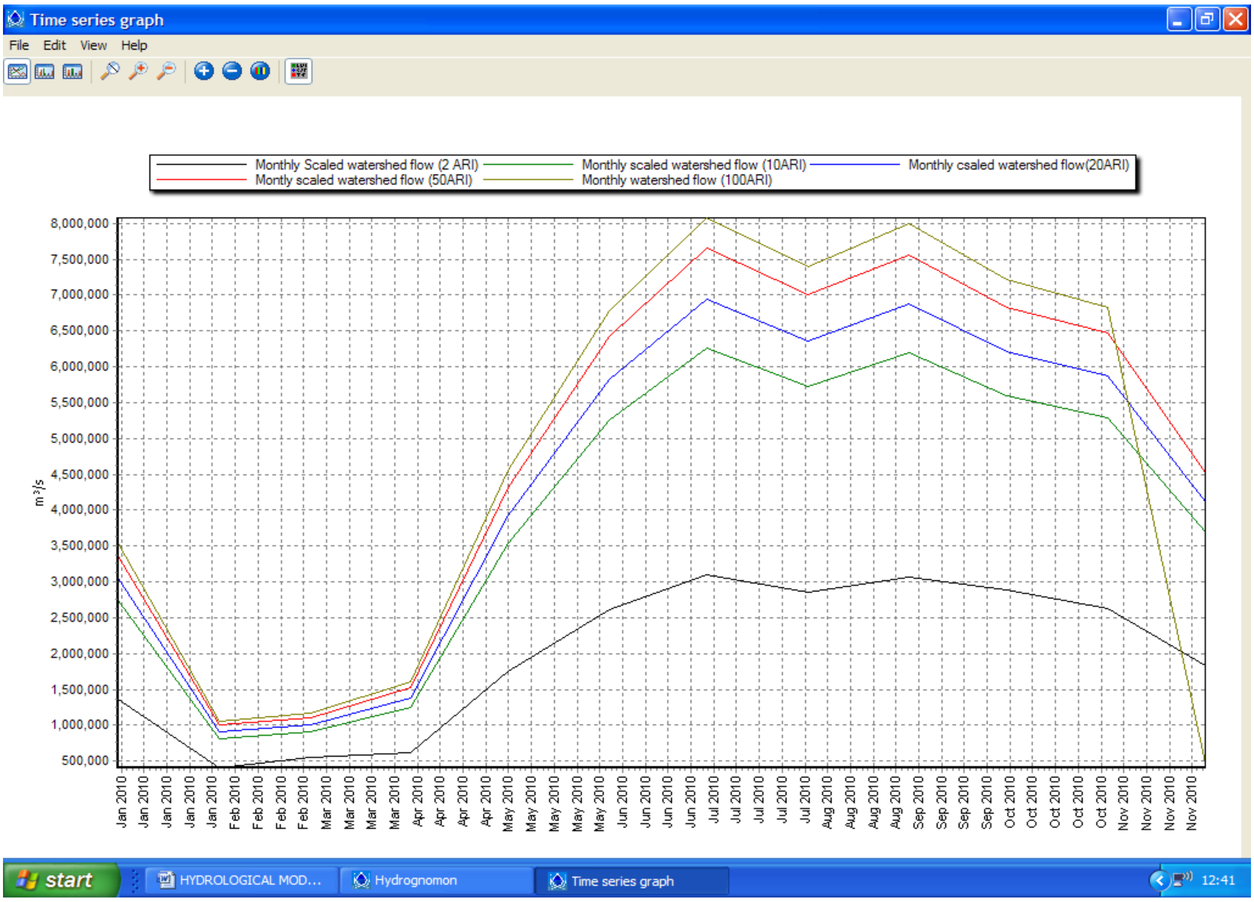

Fig 4 Simulation results

5.1 Results

The discharge of Kaduna River was simulated with the hydrognomon model. The mean ensemble of daily field precipitation and temperature were used as forcing. The river basin was simulated at completely unsaturated, initial or partially saturated as well as completely saturated moisture conditions for 2,5,10.20,50 and 100years return periods as shown in fig 4 above.

5.2.Discussions of Results

The average extreme discharge behavior of Kaduna River simulated at 2,5,10,20,50 and a 100 years return periods is as illustrated in figure 4. The simulation results showed that the average monthly runoff of the river basin increase during the summer months with the peak discharges in the months of June and August. Decrease in the runoff is observed in the autumn months with January-February producing the lowest for all the return periods. At 2 Years return periods the river basin has the lowest runoff, while at 5,10,20,50 and a 100 years there is a corresponding increase in the runoff.

V. CONCLUSION

The use of a stochastic weather generator at the site of a hydrological model was adopted using the daily climate variables of temperature and rainfall for the hydrological year 2010 was used as threshold to generate a 2.5.10.20.50 and a 100 year monthly time series in the future when the CO_2 emission is expected to double the present. Simulation results suggest increase in the magnitude and frequency of flood events associated with floods of higher return periods.

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