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Simulating the Impact of Climate Change and Land use on Groundwater Percolation Rate

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***Abstract:* -** This study produced a background methodology used to model the impact of climate change/land use on groundwater percolation rate on Kaduna River. The model was first calibrated to obtain the most sensitive parameters used in the analysis to determine which parameter have the greatest impact on the model results, rainfall and soil-water content were identified as the most sensitive. The magnitude of the percolation rates was reduce significantly from 2 ARI through to 100 ARI resulting in a practical upper limit and a lower limit of the percolation rates considered under observed and climate change conditions. The changecan be adduced to be based on the antecedent moisture conditions

***Keywords:* -** *Simulation, groundwater, infiltration, percolation, climate change, land use*

I. INTRODUCTION

Groundwater is one of the most important resources that are available to man, occupying about 0.6% by volume, it is the third most important resources in the hydrologic circle. In many countries of the world, the uses of groundwater resources for public water supply constitute the central pillar of drinking water supply. (Hiwot 2008) observed that quantitative understanding of the process of groundwater research is fundamental to the sustainable management of groundwater resources. (Hiwot 2008) further demonstrated that the recharge magnitude directly affects the amount of water that can be extracted from an aquifer.(Jyrkama et al 2002) observed that groundwater flow models are used for numerous hydrologic investigation purposes such as vulnerability assessment, remediation design and water quality and quantity estimations. Groundwater recharge according to (Jyrkama et al 2002) is influence by many parameters including climate, land use/cover and hydraulic properties of the underlying soils.

In estimating groundwater recharge using soil moisture balance approach, (Kumar 1993) presented a methodology involving step by step procedure of estimating groundwater recharge based on soil moisture balance approach. In the approach, the theory of Soil Conservation Service (SCS) number method of finding the storage index was incorporated. In predicting the climate change impact on sub- surface hydrology, (Garba et al 2013) applied the use of a stochastic weather generator to simulate the impact of climate on sub-surface hydrological response of Kaduna River as a basis for sustainable groundwater resources development plan. Land use and land cover data sets are important for watershed assessment and runoff modeling. Accurate land use and land cover data sets are use to parametize the physical system being simulated.

Approaches to simulating the impact of climate on groundwater resources using the application of a simple linear function including temperature and rainfall to simulate recharge was considered by (Hsu et al 2001).

II. MATERIALS AND METHODS

The Study Area.

Kaduna River 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).

Data used

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). The data are totals on monthly basis spanning the calibration period. 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 (Nandala) 2010).

$$Q = ICA \qquad (1)$$

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.

In determining the moisture content at saturation, soil samples were obtained at four different locations along the river bank representing four land use pattern. 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 under observed, and climate change condition, while simulations at completely unsaturated condition (0%) moisture serves as control by adjusting the most sensitive parameters of rainfall and soil- water content.

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)

III. GROUND WATER MODELING SYSTEM

The impact of climate change on the ground water system is simulated by applying the hydrognomon rainfall-runoff, recharge- discharge lumped based distributed hydrological model. The forecasted future climate variable parameters of rainfall for 2, 5,10,20,50 and 100 yearly time step was applied a forcing into the ground water recharge for 100×130 mm model cell in the watershed. Prior to the simulation process, the intensity measurement of gauge level at Kaduna South Water works was used for scaling the flow to watershed volume.

IV. FORECASTED FUTURE CLIMATE VARIABLES

The procedure for estimating variables of rainfall and temperature on the hydrological behavior of Kaduna River catchment consist of the following steps as applied by Gleik (1986); first parameters of the hydrological model were calibrated by Garba et al (2013) (fig 3), secondly, monthly historical time series of rainfall and temperature for the hydrological year 2010 were perturb according change scenario by using the expression below.

$$\sum(R,T) - T(\max) = \{2,5,10,20,50,100\}Y$$

Where $\sum(R,T)$ is summation of all the rainfall or temperature data under consideration, T(max) is the maximum return period, and Y is the expected value of the forecasted variable.

V. RESULTS AND DISCUSSIONS

The influence of climate change was used to correlate between physical parameters at catchment scale level to process parameters for continuity of flow. In developing the rainfall-runoff relationship used in the SCS method Mackus (1972) observed that infiltration occurring after runoff begins is control by the rate of infiltration at the soil surface or by the rate of transmission in the soul profile or by water storage capacity of the profile served as a limiting factor. However succession of storms reduces the magnitude of percolation rate because the limiting factor does not have the chances to recover its rate or capacity through weathering, evapotranspiration or drainage. Mackus (1972) further observed that in such a situation, the magnitude of the percolation rate remains virtually the same as the period progresses even if the rains are large resulting in a practical view point, a lower limit of percolation rate for a particular soil cover complex and a similar practical upper limit of percolation rate also depending on the soil cover complex. From this hypothesis by (Mackus 1972), it can be adduced from table 1 that the magnitude of the percolation rate have reduced significantly from the 2 years ARI through to 100 years ARI. Also, the practical upper limit of percolation rate under observed condition was 1365.00m^3/s and a practical lower limit of 859.95m^3/s while under climate change conditions, the practical upper limit was 906.30m^3/s and the practical lower limit of 900.90m^3/s. This change in magnitude of percolation rate is based on the antecedent moisture condition.

VI. CONCLUSIONS

As a basis for groundwater resources development, the influence of climate change and land use was applied to simulate the percolation rate of groundwater storage of Kaduna River. It was observed that the magnitude of the percolation rates reduces from 2 ARI to 100 ARI. This reduction could lead to reduction in soil moisture storage throughout the summer and autumn months for the chatchment.This assessment conform to (Conor and Charlton 2006) that the lower the capacity of a catchment to store water the greater the sensitivity to climate change.

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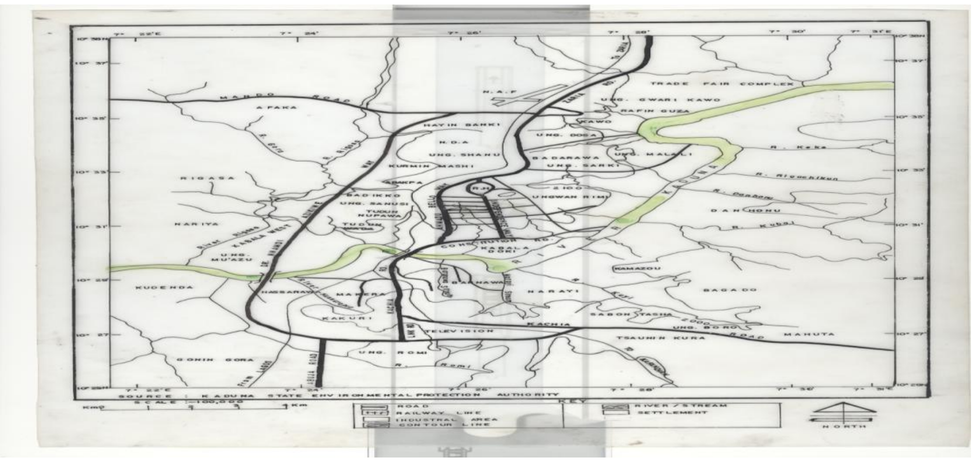

Fig 1 Drainage map of Kaduna River

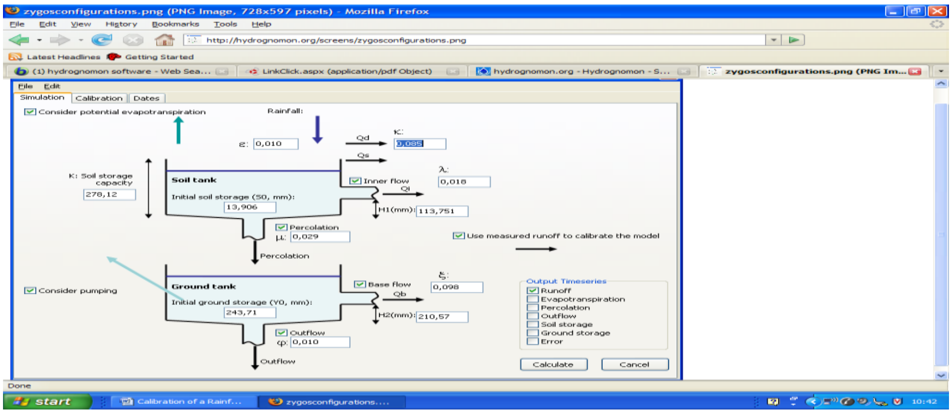

Fig 2 Sructure of simulation module

Fig 3 Predicted and simulated monthly flow of Kaduna River

Table 1 Monthly discharge percolation rate of Kaduna River

ARI (Years)	2		5		10		20		50		100	
Climate scenario	Observed (m^3/s)	Climate change (m^3/s)	Observed (m^3/s)	Climate change (m^3/s)	Observed (m^3/s)	Climate change (m^3/s)	Observed (m^3/s)	Climate change (m^3/s)	Observed (m^3/s)	Climate Change (m^3/s)	Observed (m^3/s)	Climate change (m^3/s)
1	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
2	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
3	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
4	1356.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
5	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
6	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
7	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
8	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
9	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
10	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
11	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90
12	1365.00	900.90	863.65	900.90	859.95	900.90	859.95	904.30	859.95	900.90	859.95	900.90