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A HYDROLOGICAL MODELLING APPROACH IN IDENTIFYING RAINWATER POTENTIAL FOR LONG-TERM WATER AND FOOD RESOURCE MANAGEMENT IN SEVERE CLIMATIC SCENARIOS: A CASE STUDY OF SOUTHERN KADUNA

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ABSTRACT

The unavailability of freshwater in the Sahel region of Africa is one of the hindrances to meeting sustainable development goals. This, coupled with an increasing population, makes irrigation demand unmet. The SWAT hydrological model was used alongside the Water Evaluation and Planning Tool (WEAP) to analyse the current and future conditions under different climatic scenarios. The study found the impact due to urban expansion and climatic change to be severe in the irrigation sector, with an unmet demand of 258 Mm3. The unmet total future demand due to climate variation between 2006 to 2030 is observed to be 30 Mm3,273Mm3,370Mm3,368Mm3 for the climatic scenarios as considered in the study. The SWAT hydrological model produced a Nash-Sutcliffe of 0.837 and 0.75 during calibration and validation, respectively. studies considering water quality are recommended for future studies with also an evaluation of the sustainability of aquatic organisms within the catchment.

Keywords: Food management, water resource management, Hydrological Modelling, Unmet Demand

INTRODUCTION

The food-energy-water nexus is a relatively new emerging field that strives to work at the urban and rural levels for integrated governance of resources. The field has received widespread interest over the past decade due to its ability to harness a triple-win situation by simultaneously meeting sustainable natural resource governance goals. Most attention has been directed at achieving cross-sectoral benefits that could be addressed with nexus components through an interdisciplinary approach (Yaun et al.,2022). According to the United Nations World Water Development Report 2018, there will only be enough clean water for approximately 6 billion people by 2050.

Due to rapid population growth, climate change, and economic expansion, there is a growing need for more water, a stoppage of the depletion of available water supplies, and a decrease in water pollution (Yaun et al.,2022).

Rainwater harvesting systems (RWHS) have a substantial impact on both urban and rural sustainability. These systems offer various additional advantages, such as improved storm-water management, in addition to their more obvious ones (such as the capacity to offer water in a distributed mode and enhance local water security)(De Sa et al.,2022).

People who live in areas with extreme rainfall fluctuations and unpredictable droughts or floods frequently experience acute water scarcity and unstable economic conditions. Because there are insufficient systems in place to collect rainfall that runs off as runoff, there is a severe water deficit in many areas.By increasing groundwater and surface water supplies, rainwater harvesting (RWH) functions as an efficient technology to overcome the gap between water demand and availability under climate change conditions(Pareta et al.,2021).

A well-known method for managing water resources and planning is model scenario simulation, particularly when there are conflicting needs from several users. According to Yates et.al., (2005) the Water Evaluation and Planning Tool (WEAP) has also been widely used over time. Additionally, (Roogers et.al.,2014) confirmed the utility of the WEAP model in alternative methods for managing and developing the hydrological system. Additionally, it should be mentioned that WEAP is an international model that has been successfully tested on many different continents(Roogers et.al., 2014;Haji et.al., 2011;Mulungu et.al., 2012;Van et.al., 2006;Mohd et.al., 2021) This paper applies hydrological and climatic modelling to assess surface water potential for rainwater harvesting.

MATERIALS AND METHODS

The Kaduna watershed

The Kaduna Watershed network is a sizable river basin that separates its geographical area into northern and southern sides, it is located in northwest Nigeria. The Kaduna watershed originates on Kujama Hill in Plateau State and streams for 210 km into Kaduna town. It is a tributary of the River Niger. The study area is located at latitude 10 31' 23'' north and longitude 7 26' 50'' east (Jerome., 2022)

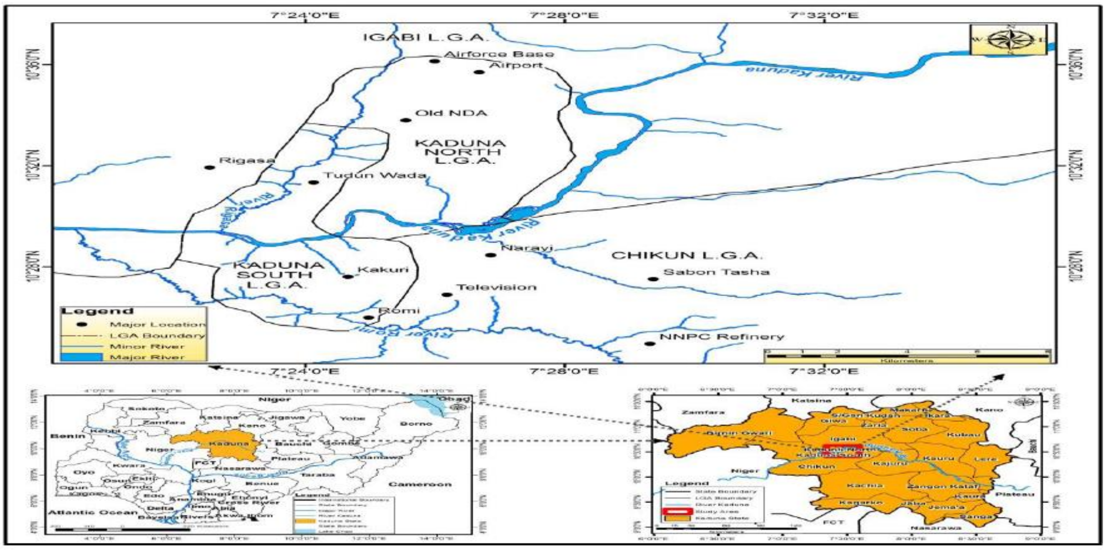

Figure 1: showing the river-basin of Kaduna (ogbozie. Et al., 2017)

Datasets and their Sources

Meteorological data used in this research included rainfall and temperature data, which was obtained from the period of 1990 to 2020 from Nigeria meteorological agency, who is responsible for meteorological datas in then catchment. The soil map adopted was that approved by the food and agricultural organization(FAO). The Landsat data was collected from USGS. The demographic data was obtained from the country census board. The datasets are as illustrated below in table 1, showing sources in which data used for the research were obtained from and the duration, the datasets covers.

Table 1: Data used and their sources.

	Data Type	Unit	Period Covered	Time Step	Source
1	Meteorological data	Rainfall (mm) Temperature (C)	1990-2020	Daily	NIMET
2	Stream-flow	M3/s	1991-2004	Daily	Kaduna state water work/board
3	Demographic data	Population	2006		Census board website, relevant literature
4	Remote sensing data	DEM, Landsat		30m x30m	USGS.gov.org Earth explorer
5	Soil map				HWSD, FAO

Climatic variations and datasets in the Research area

The climatic datasets were processed using excel to ascertain the variations of climate variables in the study region , from the period 1981 to 2020 with MAX temperature having the highest value in 1999 and precipitation with maximum values in 2019. figures 1 to 4 below shows the graphical variation of several climatic variables with time in the catchment.

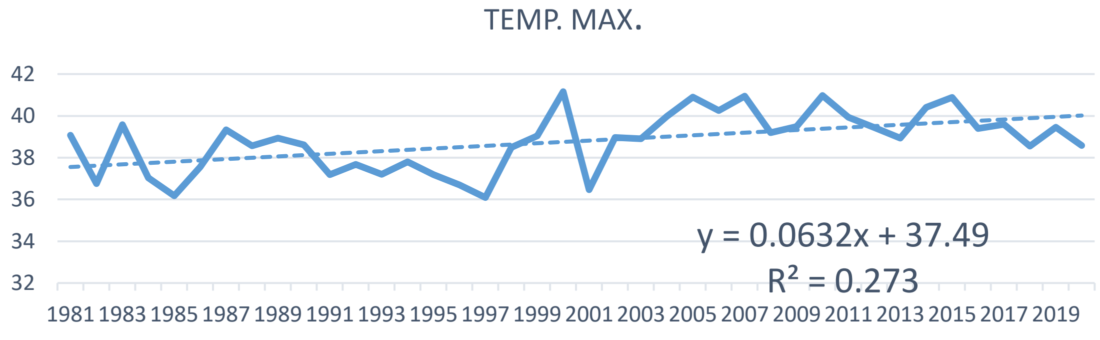

Figure 2: showing the maximum temperature of study area

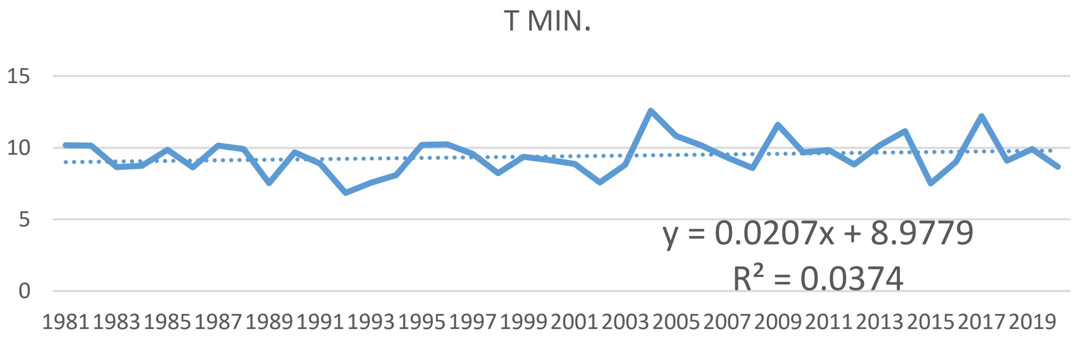

Figure 3: showing the minimum temperature

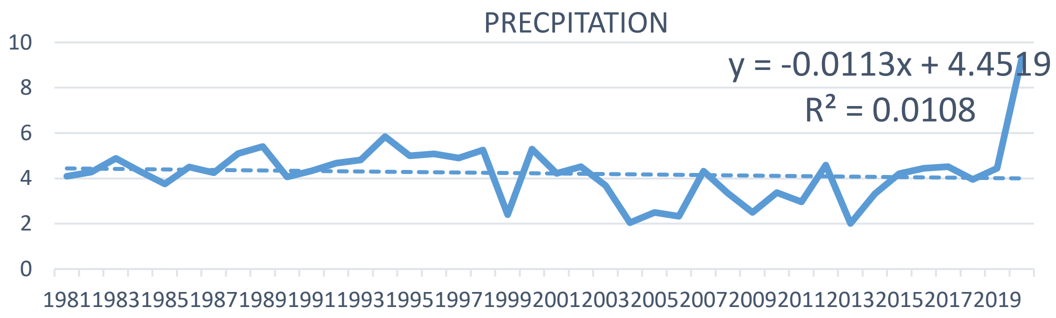

Figure 4: precipitation variations in the study area

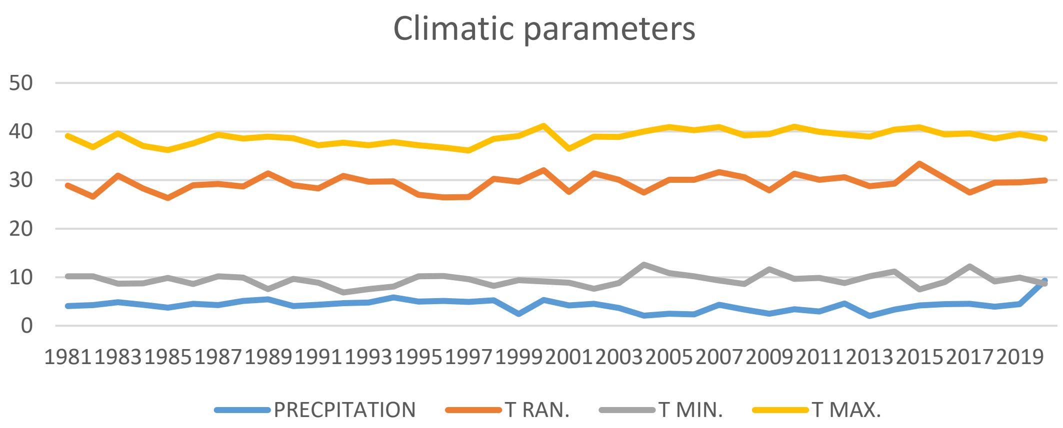

Figure 5: variation of climatic parameters in Kaduna

SWAT Hydrological Model
The soils and water assessment tool (SWAT) makes use of the formula shown in below The surface runoff from daily rainfall is estimated using a modified SCS curve number.

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{R_{day} - I_s + S} \qquad \textbf{(1)}$$

Where I is initial parameter, S is the relation parameter and CN is the curve Number. The model is run as illustrated in fig3.3 as a plugin application on Qgis. QSWAT, which is a SWAT plugin on QGIS was used for this research with the process as illustrated below.

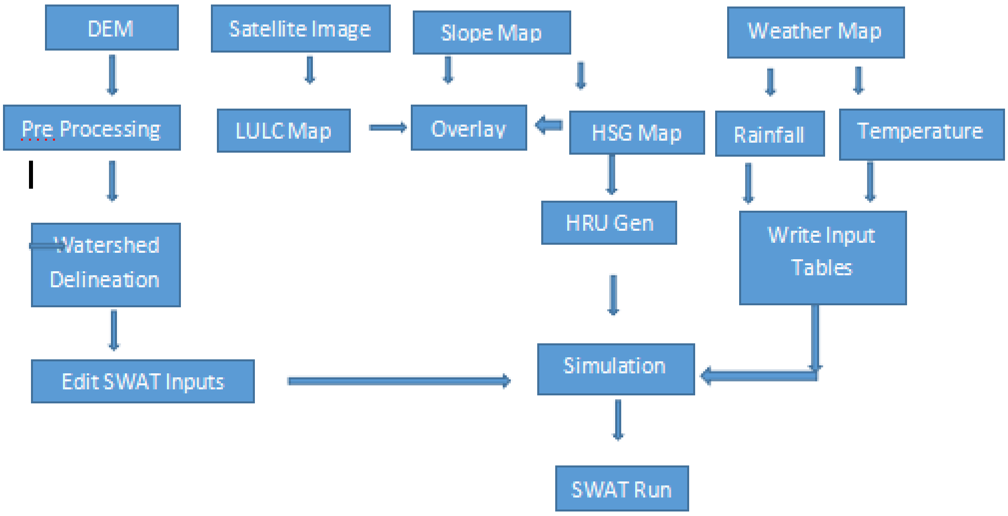

Figure 6: Flow chart showing procedure/methodology for running SWAT. source:

Calibration and Validation

The SUFI-2 tool is used for the calibration and validation of stream-flow. It uses an inverse optimization technique that operates by global search algorithm and the Latin hypercube sampling methodology to assess the activities of objective functions. It is an improved modular calibration strategy, because it allows for any goal function while obtaining good results of model calibration. This method is related to the SWAT's calibration kit contained in the SWAT-CUP[12]. The performance of the model which is measured by Nash sutcliffe coefficient is as illustrated below

The R^2 Coefficient of determination formulae

$$R^2 = \left\{\frac{\sum_{j=1}^{n}(O_j-\bar{O})(S_j-\bar{S})}{\left[\sum_{j=1}^{n}(O_j-\bar{O})\right]^{0.5}\left[\sum_{j=1}^{n}(S_j-\bar{S})\right]^{0.5}}\right\}^2 \qquad (2)$$

The Nash-Sutcliffe coefficient

$$NS = 1 - \frac{\sum_{j=1}^{n}(O_j-S_j)^2}{\sum_{j=1}^{n}(O_j-\bar{O}_j)^2} \qquad (3)$$

Sensitivity Analysis

Latin hypercube-generated parameters are regressed against the objective function after multiple regression to evaluate the parameters' sensitivity. T-statistics and p-value were used as statistical measures. The ratio of a parameter's coefficient to its standard error is known as a t-statistic. It is a scale that indicates how accurately the regression coefficient is measured. Consequently, the parameter is sensitive when the coefficient exceeds the standard error.(Malik, 2021)

Water Demand, Allocation under climatic Scenarios

Water allocation to the various demand sites, primarily home and agricultural, was done using the Water Evaluation and Planning (WEAP) program. The water year approach was used to simulate the large population and climatic variability scenarios, utilizing the output stream flow data from the SWAT model as the input head flow in WEAP.The figure below shows the interface of WEAP.

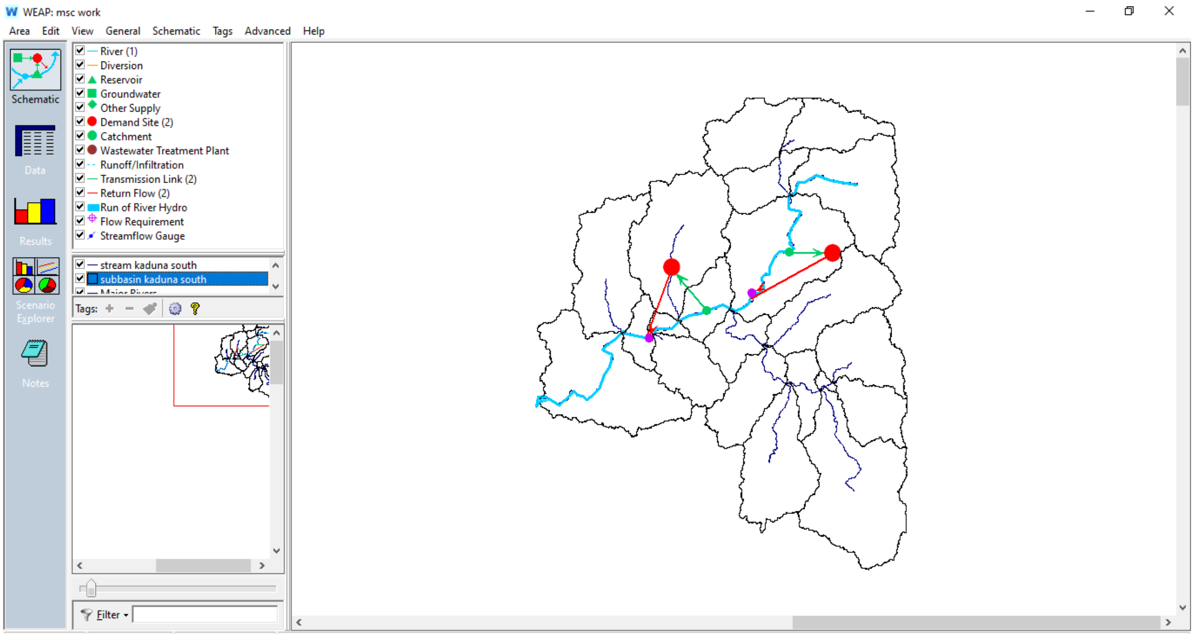

Figure 7: Showing schematic of the WEAP interface

Based on current population data and prospective irrigable lands, the existing, future water demand and also unmet demand were projected.

Analysis of different climatic scenarios

The relationship between climate parameters (precipitation and rainfall) and Water demand in the study area the data was analyzed using excel in other to determine the trend in relation to various situations.

The climatic scenarios were analyzed with respect to the various observed scenarios below.

i. 1-degree increase in temp.
ii. 1degree increase in temp. and a 10% increase in precipitation
iii. 1-degree increase in temp. 10% decrease in precipitation
iv. 1-degree decrease in temp. and 10% decrease in precipitation

Data input and processing

Digital Elevation Model

The Digital Elevation model of the study area as depicted below was delineated using the ArcMap software , the 30m x 30m raster resolution DEM was obtained from USGS .

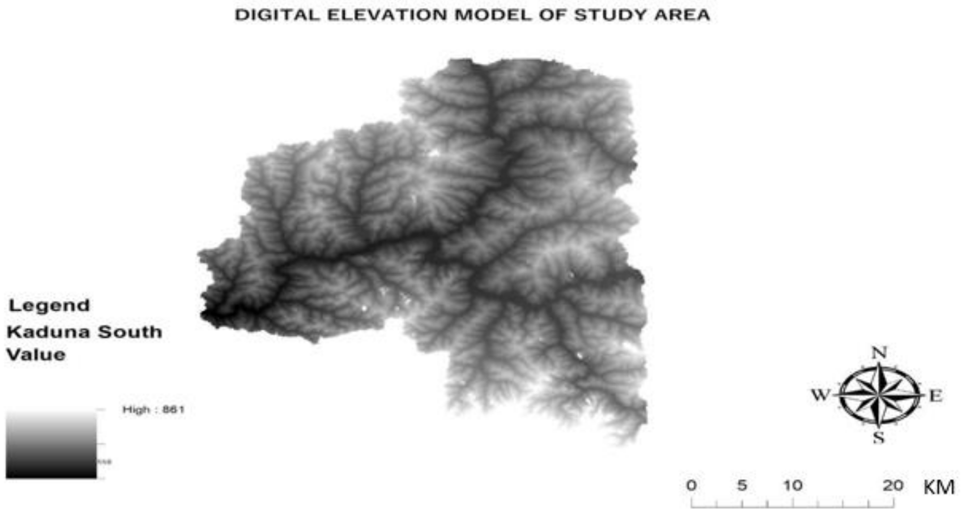

Figure 8: Digital Elevation Model of Study area

Soil Map

Pareta (2021) described soil as one of the most influential parameters in selecting sites for harvesting rainwater. Pareta said this considering the texture of the soil, permeability and aquifer recharge.The soil Map of the area was obtained from Food and Agricultural organization, it showed that 5% of the study area, was made up of loamy soil, 15% from sandy loam and 80% from sandy loam as depicted below, this shows that 5% of the catchment has a higher tendency for Storage of water, with the majority part consisting of fair conditions for storage

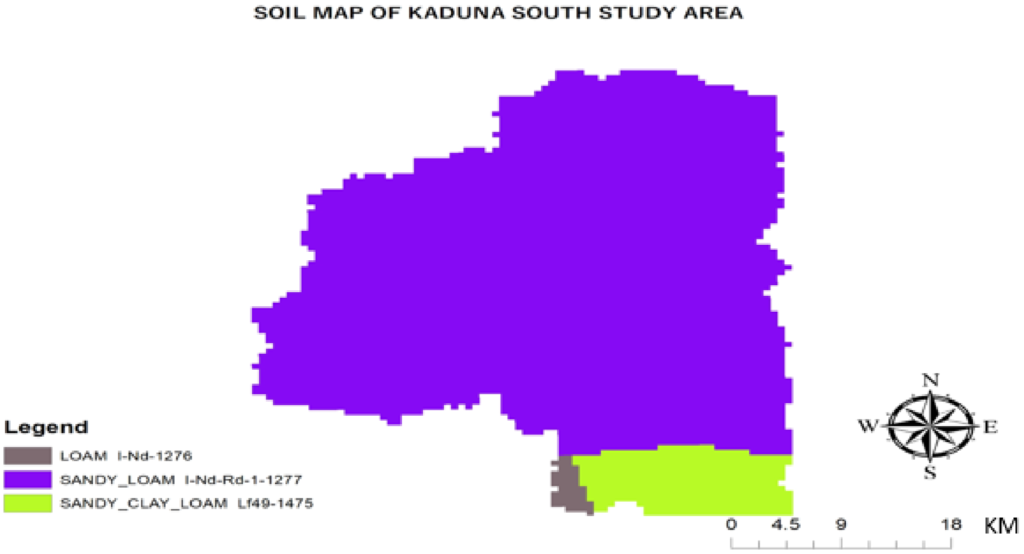

Figure 9: Digitized Soil Map of the study area

Land Use and Land Classification analysis

Landsat data were obtained from USGS, processing was done using ENVIv5.3 and ARCMAP , supervised classification method was chosen to produce the various land-use as classified below.

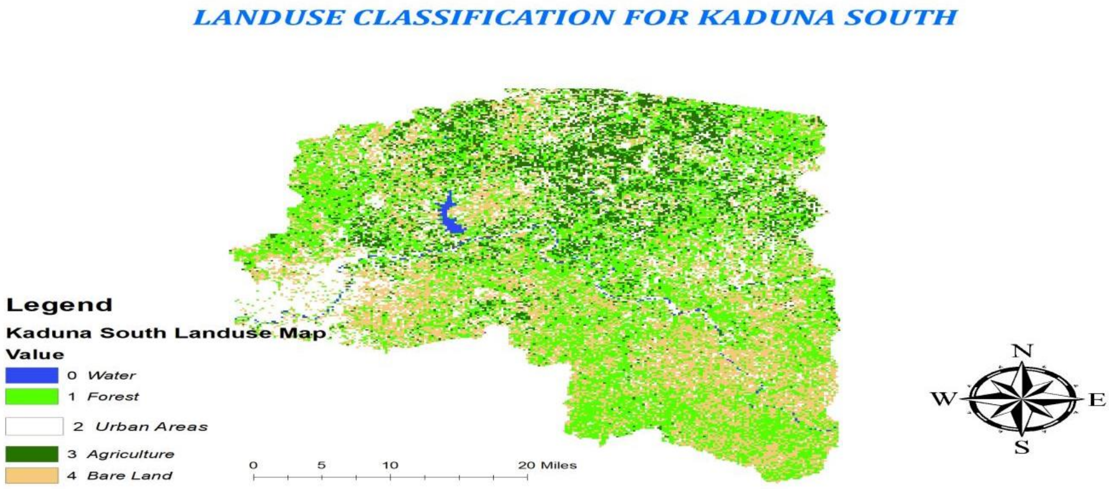

Figure 10: Land-use map of the area

RESULTS AND DISCUSSION

Hydrological Modelling

Water balance Ratio: Modelling of the hydrological processes being performed in the catchment as shown below , depicts recharge to deep aquifer of 36.92 which appears to be within low limits, with most (738.5 going to shallow aquifer).

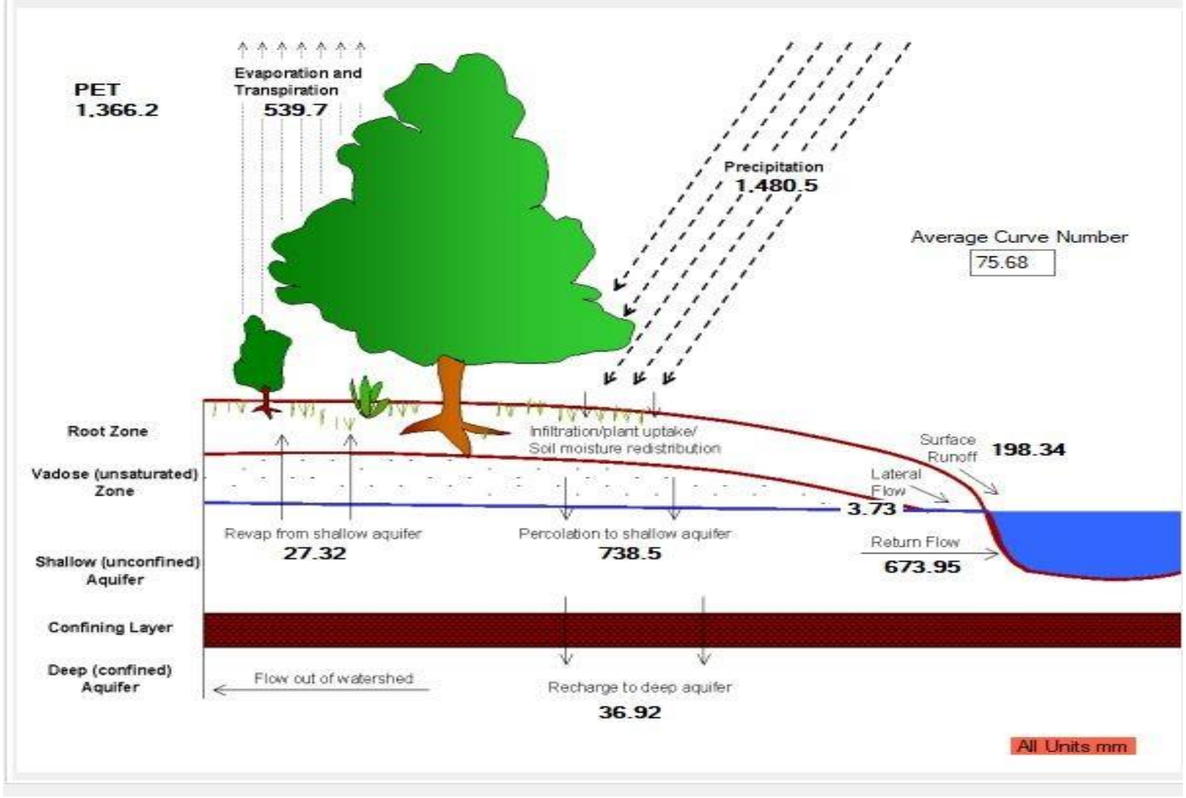

Figure 11: showing the water balance ratio of the Model. source: S.W.A.T output

Below is the illustration of the water balance parameters of the model with a surface runoff of height of 198 mm, and evapotranspiration of 539.7mm.

Table 2: water balance parameters of the model

Parameter	Mean Value (mm)	%
Precipitation	1480.5	100
Surface runoff	198.34	13.4

Lateral flow	3.73	0.25
Return flow	673.95	45.52
Deep aquifer	36.92	2.49
Shallow aquifer storage	27.32	1.85
Evapotranspiration	539.7	36.45

Calibration and validation: the model was calibrated and validated using the SWATCUP based sufi2 algorithm, the results gave a nash sutcliffe of 0.837 during calibration and 0.737 during validation as illustrated in the table below.

Table 3: showing the performance of the model

Statistic parameter	calibration	validation
Nash Sutcliffe	8.37E-01	7.37E-01
R2	0.84	0.75
Pbias	0.47	0.4

The illustration of the variations involving the 95ppu uncertainty plot is shown below, making comparisons with the observed discharge.

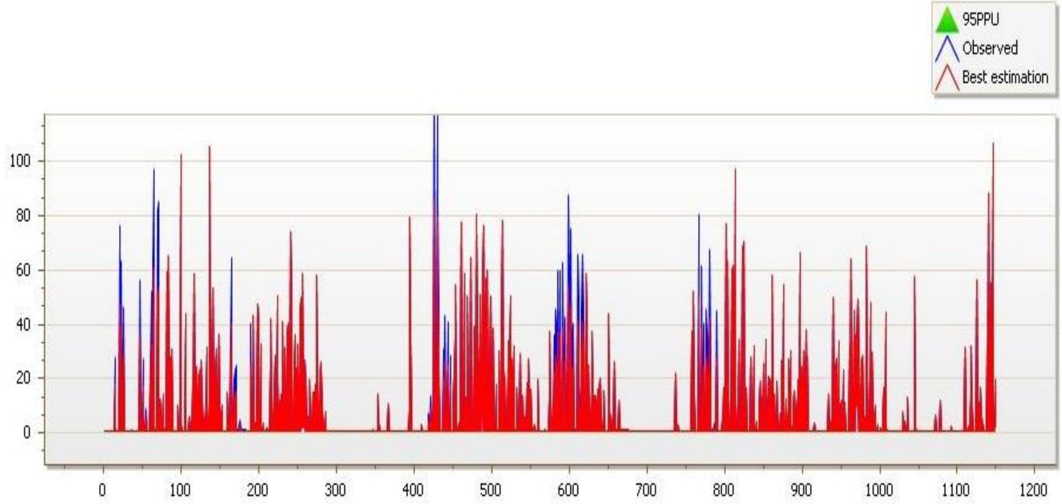

Figure 12: calibration and validation of the hydrological model.

WEAP Modelling

Water demand and allocation under selected scenarios

The model is built on several what-if scenarios which will serve as hypotheses in order to build up a model, the what-if are illustrated below.

Table 4: WEAP model Scenarios

	What if Scenarios
1	High population growth rate
2	Decrease in Agriculture demand
3	Climate variability

One degree increase in temp: the resultant effect of a 1 degree increase in temperature, as shown in the figure below resulted into an unmet demand of 22.0Mm3 in 2019. this shows a steady and slow increase in unmet demand.

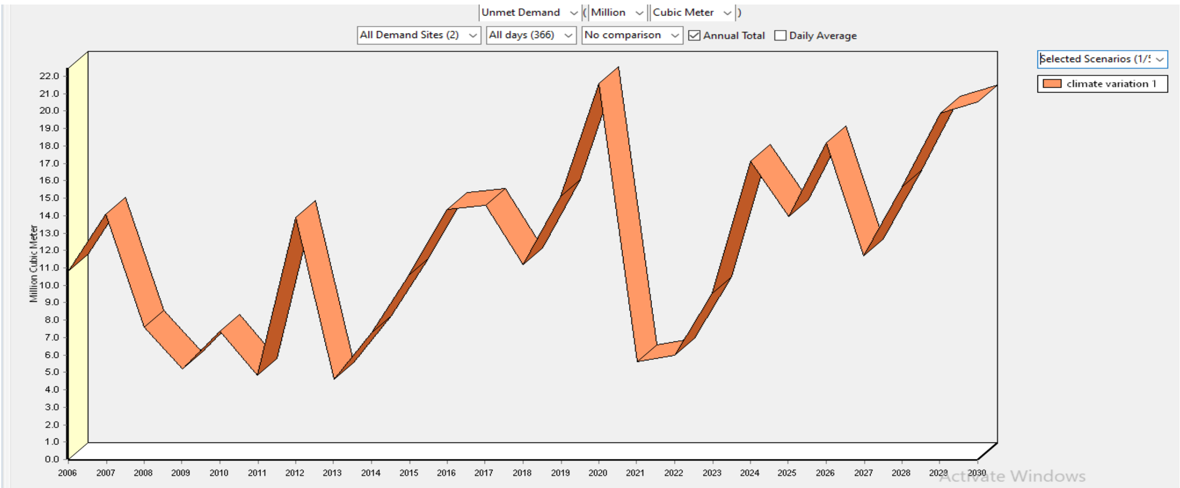

Figure: 12 showing unmet demand for scenario one source: W.E.A.P output

One degree increase in temperature and 10% increase in precipitation: a 10% increase in temperature from scenario 1, shows similarity with not much change as obtained from scenario one, as illustrated in the figure below

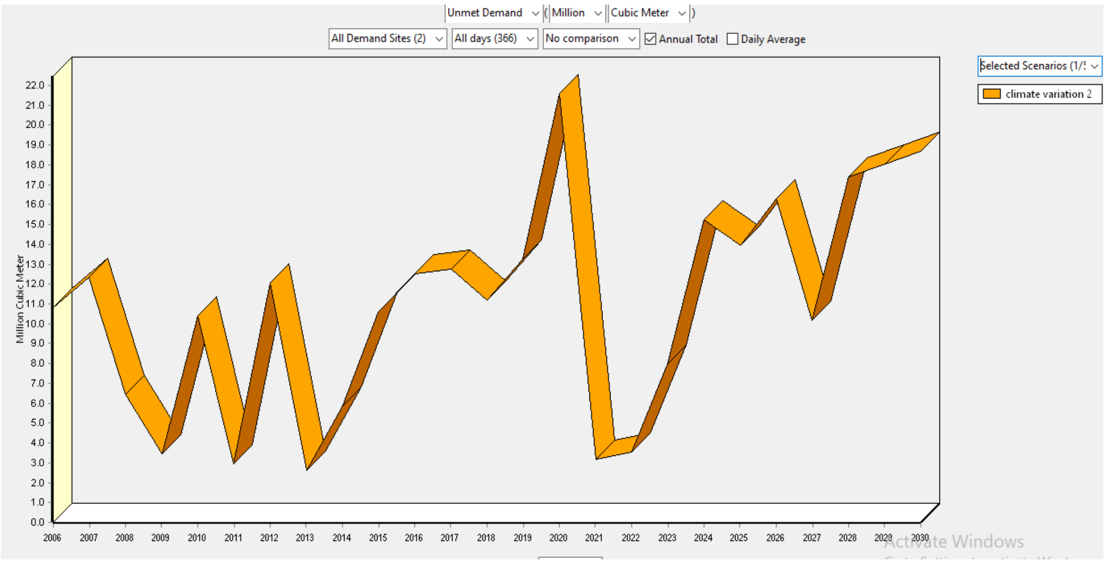

Figure: 13 showing unmet demand for scenario two Source: W.E.A.P output

One degree increase in temperature and a 10% decrease in precipitation: the figure below shows a maximum unmet demand in the year 2029.

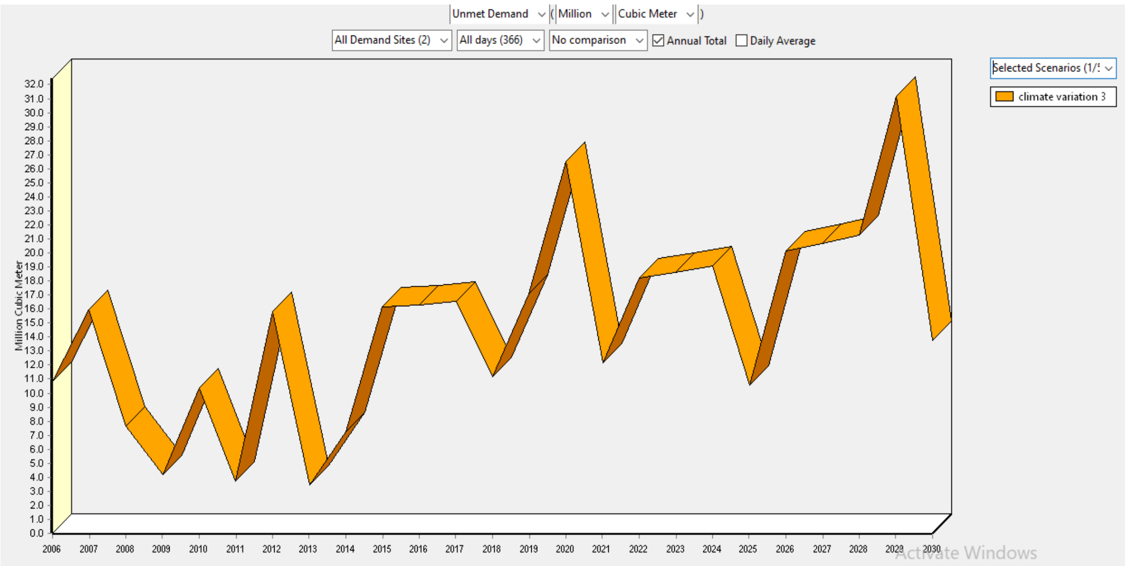

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Figure: 14 showing unmet demand for scenario three Source : W.E.A.P output

One degree decrease in temperature and 10% decrease in precipitation: this results to a steeper and steady increase in unmet demand as depicted in the illustration below.

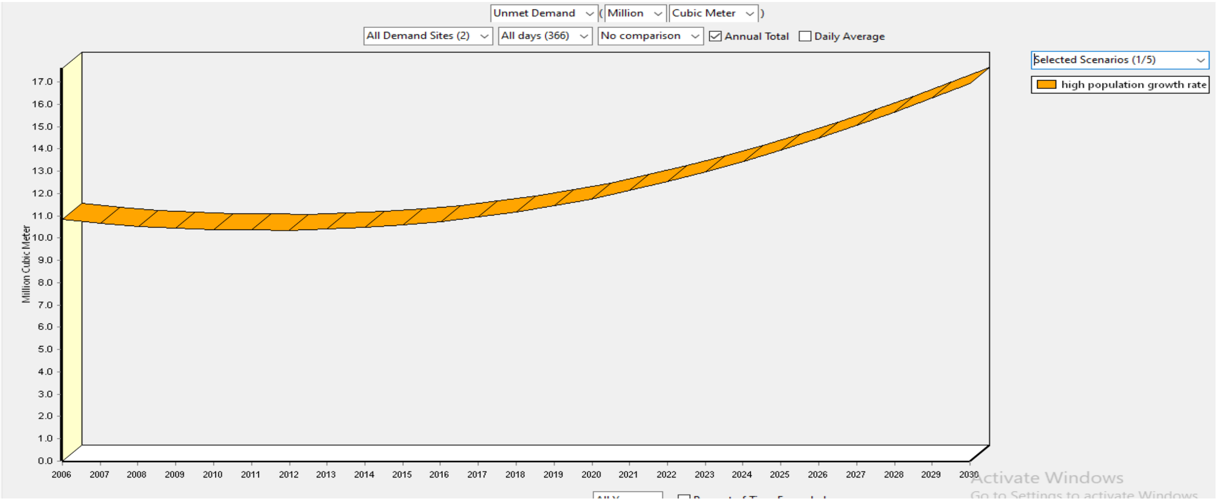

Figure: 15 showing unmet demand for scenario four. Source : WEAP

The scenario of high population growth rate, with a growth rate value of 2.21%, as shown from the results; the total unmet demand observed between the period of 2006 to 2030 is found to be 305Mm3 in which domestic unmet demand is about 70% and the unmet demand for irrigation is 30%.

The unmet total future demand due to climate variation in increasing demand of all sectors between the period of 2006 to 2030 is observed to be 301Mm3, 273Mm3, 370Mm3, 368Mm3 for scenario one, two, three and four respectively. showing that scenario three has the highest unmet demand of 370Mm3.

CONCLUSION

The study reveals that the impact of all future projected demands due to urban expansion and climate change, is expected to be severe in the irrigation sector with unmet demand as well as the domestic water demand which will also not be fully met with an unmet demand of 258Mm3. This reveals that the unmet demand for sustainable Water and food resource management increases with a retarding effect of climate, the study also finds that significant differences are not noticed against one-degree increase in temp versus a scenario of one-degree increase in temp. and a 10% increase in precipitation. For a futuristic scenario of high population growth of about 2.21% within Norther Kaduna, the total unmet demand estimated between the periods between 2006 to 2030 is 305Mm3 in which domestic unmet demand is about 70% and the unmet demand for irrigation is 30% .

REFERENCES

Arranz, R., & McCartney, M. P. (2007). Application of the Water Evaluation and Planning (WEAP) model to assess future water demands and resources in the Olifants Catchment, South Africa (Vol. 116). IWMI.

Baviskar, D., Pareta, K., Goswami, D., Joshi, M., Dhande, H., Mukherjee, A., ... & Luchner, J. (2019). India: Strengthening Climate Change Resilience in Urban India–Strengthening Smart Water Management and Urban Climate Change Resilience in Tamil Nadu (Subproject 1)–Part 5 of 27.

de Sá Silva, A. C. R., Bimbato, A. M., Balestieri, J. A. P., & Vilanova, M. R. N. (2022). Exploring environmental, economic and social aspects of rainwater harvesting systems: A review. Sustainable Cities and Society, 76, 103475.

Fryslân, W., Droogers, P., de Boer, F., & Terink, W. (2014). Water Allocation Models for the Umbeluzi River Basin, Mozambique.

Haji, H. T. (2011). Impact of climate change on surface water availability in the Upper Vaal River Basin (Doctoral dissertation, Tshwane University of Technology).

Jerome, O. D., Sule, A., Abdullahi, Abubakar, I., Samuel, O., & Abdullahi, Y. (2022). Water Demand Assessment under Climate Variability Scenarios Using SWAT and WEAP: A Case Study of Kaduna South Catchment. International Journal of InnovativeResearchandDevelopment,11(2).

Malik, M. A., Dar, A. Q., & Jain, M. K. (2022). Modelling streamflow using the SWAT model and multi-site calibration utilizing SUFI-2 of SWAT-CUP model for high altitude catchments, NW Himalaya's. Modeling Earth Systems and Environment, 8(1), 1203-1213.

Mulungua, D. M., & Taipeb, C. L. R. (2012). 2 WATER EVALUATION AND PLANNING IN THE WAMI RIVER BASIN: APPLICATION OF THE WEAP MODEL. Bioenergy and Food Security, 47.

Skaggs, R., Hibbard, K. A., Janetos, T. C., & Rice, J. S. (2012). Climate and energy-water-land system interactions. Richland, WA, USA.

Van Loon, A., & Droogers, P. (2006). Water Evaluation And Planning System, Kitui-Kenya. Wageningen: WatManSup Research. 69p.

Yates, D., Sieber, J., Purkey, D., Huber-Lee, A., & WEAP21, À. (2005). A demand, priority, and preference driven water planning model: Part 1, model characteristics. Water Int, 30(4), 487-500.

Yuan, M. H., & Lo, S. L. (2022). Principles of food-energy-water nexus governance. Renewable and Sustainable Energy Reviews, 155, 111937.

Walker, A. R., Bouattour, A., Camicas, J. L., Estrada-Peña, A., Horak, I. G., Latif, A. A., Pegram, R. G. and Preston, P. M. (2014). Ticks of domestic animals in Africa: a guide to identification of species. UK: Bioscience Reports, Edinburgh Scotland, U.K. pp: 227

Zhang, R. L. and Zhang, B. (2014). Prospects of using DNA barcoding for species identification and evaluation of the accuracy of sequence databases for ticks (Acari: Ixodida). *Ticks and Tick-borne Diseases*, 5: 352–358.