

Original Scientific paper
Originalni naučni rad
10.5937/POLJTEH2602026F

IMPACT OF LAND USE AND CLIMATE CHANGE ON SOIL PARAMETERS IN SOME SELECTED LGA IN SOUTH EASTERN NIGERIA USING SWAT MODEL

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Abstract: The increasing impacts of climate change and land-use alteration have emerged as major environmental challenges affecting soil water quality, agricultural productivity, and ecosystem resilience, particularly in tropical regions. In recent decades, rising global temperatures, irregular precipitation patterns, and unsustainable human activities such as deforestation and intensive cultivation have disrupted the natural hydrological balance, leading to soil degradation, reduced groundwater recharge, and declining water quality.

This study focuses on assessing the effects of climate and land-use changes on soil water content and quality within selected local government areas in southeastern Nigeria using the Soil and Water Assessment Tool (SWAT).

The model was employed to simulate the hydrological responses of different land-use and climatic scenarios on soil moisture, surface runoff, and river discharge within the study area.

This study involved the acquisition and integration of spatial data such as Digital Elevation Model (DEM), soil classification maps, land-use data from Landsat imagery, and climatic data (rainfall, temperature, humidity, and wind speed). These datasets were processed and input into the SWAT model, which was calibrated and validated using observed hydrological data from 2013 to 2023. Calibration and sensitivity analysis identified key parameters influencing the hydrological response, including soil texture, infiltration rate, evapotranspiration, and precipitation intensity.

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Model validation produced acceptable statistical results, demonstrating a satisfactory correlation between simulated and observed values, thereby confirming the reliability of the simulation for predictive analysis. Scenario simulations were conducted to examine the impacts of varying rainfall and temperature levels, as well as different land-use patterns such as partial and complete deforestation, agricultural expansion, and reforestation.

Results from the analysis revealed that increased temperature coupled with reduced rainfall significantly decreases soil moisture, groundwater recharge, and river discharge. Conversely, afforestation and proper land management practices enhance soil water retention, minimize erosion, and stabilize hydrological cycles.

The findings indicated results for absolute values and percentage distributions between 2013 and 2023: Thick Forest 48128.76 (39.712%), Farmland 35001.54 (28.881%), Built-Up/Bare Surface 35237.07 (29.075%), and Water 2826.45 (2.332%). For 2023: Thick Forest 29273.57 (24.237%), Farmland 32031.00 (26.430%), Built-Up/Bare Surface 57268.08 (47.253%), and Water 2521.17 (2.080%).

This research demonstrates the strong interdependence between climate dynamics, land-use patterns, and soil-water systems. The study emphasizes the necessity for integrated watershed management, climate-smart agriculture, and adaptive land-use planning as sustainable strategies for mitigating the adverse effects of climate change.

Key words: SWAT, Digital Elevation Model, Land Use Hydrology, Ecosystems

INTRODUCTION

The impact of climate change on hydrology, ecology and meteorology along with their economic and social relevance is very important in managing water resources, agricultural activities and the ecosystem. Just as there is abundant rainfall leading to abundant surface water, so there is limited rainfall leading to drought, desertification and scarce availability of water resources. The approach to creating a balance between these two extremes is very important [1, 2].

Water is one of the essential commodities on earth that is widely tapped and utilized by man to meet his various needs. Water is an indispensable resource for the welfare of man, animals and plants.

The world is gradually descending into a critical state where water supply is rapidly diminishing and struggles to meet the demand of the increasing population as a result of climate change impact on hydrological processes. Since the last century, the world's population alongside urbanization, industrialization and agricultural production have multiplied exponentially.

This invariably means that the demand for water has drastically increased over the years and the quality of water resources is fast depleting as a result of increased human activities in various sectors [3].

These changes have given room to a wide range of water exploration; both surface water and groundwater. This has created a lot of adverse consequences across different countries in the world. Climate change can cause significant impacts on water resources by influencing the hydrological cycle.

These notable changes in temperature and variations in precipitation have different effects on the quantity and quality of evapotranspiration and runoff components. In other words, the state of water balance can be greatly influenced by climate change resulting in a massive decline in agricultural production, industrialization and urban development [4].

As water demand continues to rise with a potential likelihood where available supply may not meet the demand, it has become very important that adequate management plans be sought and implemented to effectively manage the likelihood of such occurrence. Finding water balance in the ecosystem is an important step in addressing the issue of water resource sustainability. Therefore, the prediction of water balance components is very useful in ensuring food security, preventing land degradation and estimating water availability.

Water resource decision-making has been based traditionally on observed historical events on water availability indicators like river flow volumes, groundwater levels, drought, desertification, etc. and on assumptions of a repetitive future occurrence. That is, the probability distribution of relevant hydro-climatic variables is time-invariant. This argument has since been debated and found to be ineffective in handling issues of water resource management regarding climate change [5].

The World Resources Institute (WRI) projects that by 2025, close to half of the world's population estimated at 3.5 billion could experience water scarcity. The severity of such an occurrence puts the world in a critical state. Africa is a continent of vast land and given to a wide range of climate regimes at varying magnitudes. As the average population continues to increase across the continent, there is a corresponding rise in demand for water as well. According to reports from IPCC [1], the impact of climate change is expected to have varied socioeconomic effects across various countries.

It is projected that most developing countries, especially in Africa will find it very difficult to keep up with its impacts. For example, the recent events of flooding, drought and urban water shortages as well as water pollution – oil spillage and saltwater intrusions in Nigeria clearly highlight the impacts that most of these African countries stand to face and underline the need for a rapid response and rational planning towards mitigating these impacts and consequently ensuring water resources sustainability.

The challenge of uncertainties surrounding climate conditions and the need to identify effective mitigating and adaptive measures have created room for the introduction of various approaches. Hydrological modelling is very critical in nearly every element of water resource management, water quality, climate risk management and advanced detection of hazardous events. Irrespective of these problems that hydrological models try to solve, the issue of forecasting remains a difficult task [6, 7].

Recent years have seen the advancement of hydrological models and the introduction of machine learning techniques to improve the process.

Machine learning programs like adaptive neuro-fuzzy inference systems (ANFIS), support vector regressions (SVR), artificial neural networks (ANN) and genetic programming have been widely adopted in hydrological processes and have shown to be very effective in predicting hydrological processes [8].

Constructing strategies and policies for limiting the effect of climate change on water resources and the environment requires both quantitative and qualitative approaches to effectively implement a hydrological process. Water resource management cannot be treated as a separate entity from the ecosystem.

It is essential to consider the entirety of the system taking into consideration factors like land use management practices, quality and quantity of groundwater and surface water, crop productivity, etc [9].

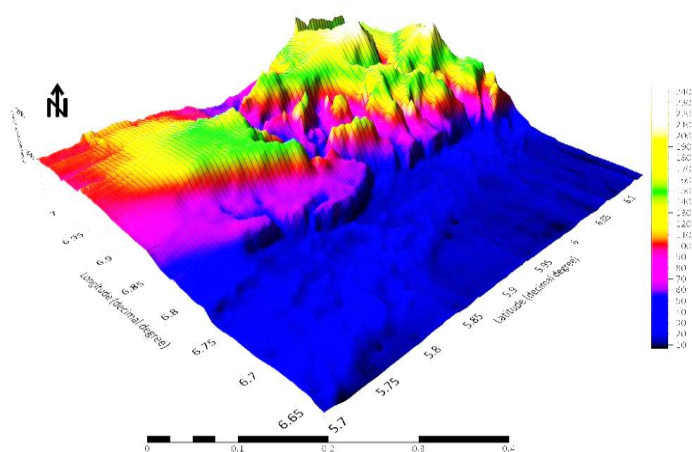
There are several hydrological models fitted to suit specific study objectives. Hydrological models seek to reveal hydrological processes within a catchment and beyond. Soil and Water Assessment Tool (SWAT) models are eco-hydrological models very efficient in assessing hydrological processes as well as simulating crop production and growth within a catchment. Hydrological impacts of climate change are a likely danger to human societal activities as they frequently have serious ramifications for people living near water bodies, agriculture, ecosystems and hydropower production [10].

Thus, the need to provide the necessary information on potential future changes in the hydrological cycle becomes pertinent to enable decision makers to develop possible mitigation and adaptation strategies. Hydrological models are applied to model the impact of climate change on the water cycle as the event happens in real life, also, to forecast the future hydrological system. To drive such a model, reliable hydro-meteorological data such as temperature, precipitation, evapotranspiration, and river discharge are needed [11].

Nigeria experiences various effects of climate change impacts across the country. Hence, it has become very important that efforts to curb climate change impacts as well as credible reports be readily available to help decision policymakers propose effective measures to mitigate the effects of climate change. The lack of credible data in Nigeria currently makes it difficult to effectively quantify the extent of climate change impact in the country. Hence, this research seeks to implement a hydrological model using SWAT models in evaluating the impact of climate change and land use on soil properties in Michael Okpara University of Agriculture, Umudike.

MATERIAL AND METHODS

Michael Okpara University of Agriculture is situated at latitude 5.48°N (5°28'N to 5°30'N) and longitude 7.55°E to 7.56°E, located southeast of Umuahia.



3D Surface Model of the Study Area [Projection: Perspective; Rotation: 45°; Tilt 30°; Field of View 45°]

Fig.1. 3D Surface Model of the Study Area

The SWAT Minimum and Maximum Normalization

The data collected covered a period of 10 years (2013–2023) and included river discharge (m³/s), rainfall (mm), temperature (°C), and relative humidity (%). These were normalized between the ranges of 0–1 via the min–max method (eq. (1)), to transform the data into a convenient and trainable form before being used for training, testing, and validation for model development.

$$N_k = \frac{R_k - \text{Min}_k}{\text{Max}_k - \text{Min}_k} \quad (1)$$

Where:

- R_k = real value applied to neuron k
- N_k = normalization value calculated for neuron k
- Max_k = maximum number
- Min_k = minimum number
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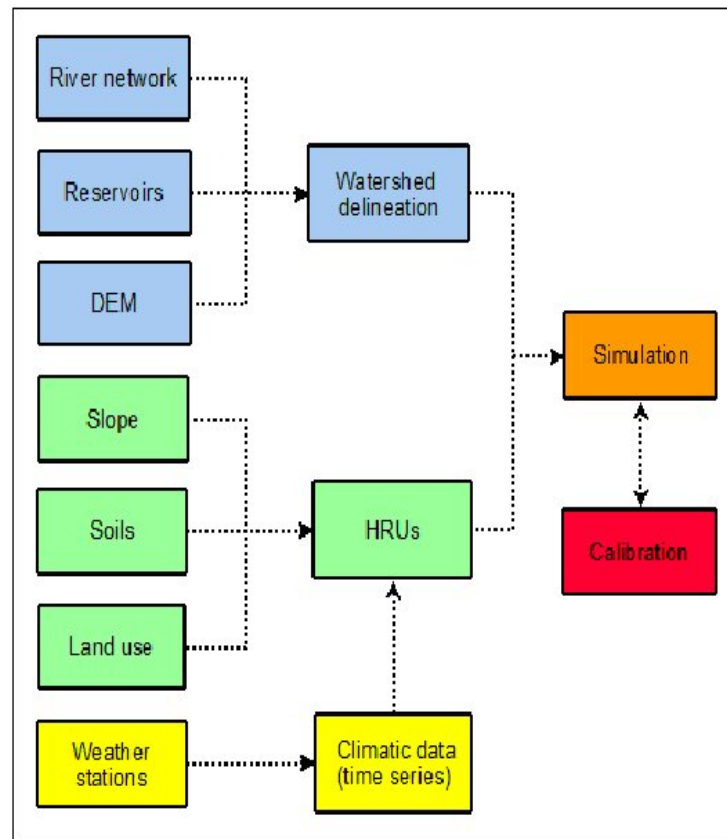


Fig. 2. Classification of SWAT models (Peter et al., 2010)

Indices for the Land Use Cover Characteristics

Table 1. Indices for Land Use/Land Cover Change

S/N	Indices	Definition	Unit of Measurement
1	Water bodies	Areas covered by water, including rivers, oceans, reservoirs, ponds, lakes, streams	Hectare
2	Thick Bush	Land left uncultivated for >5 years; secondary forest	Hectare
3	Cultivated Land	Existing farmland under cultivation	Hectare
4	Fallowed land	Land previously cultivated but left uncultivated for <3 years	Hectare
5	Built Up	Land occupied by buildings/structures	Hectare

The detection of changes provided an understanding of land use/land cover changes occurring in the catchment over years and their possible influence on water flow in the river system.

The land-cover change in percentage was calculated using the equation adapted from Lambin (2011):

$$\text{Percentage Change} = \frac{OC}{ASC} \times 100 \quad (2)$$

Where:

- OC = observed change
- ASC = absolute sum of change

Annual rate of change was calculated as:

$$\text{Annual Rate Change} = \frac{Y_2 - Y_1}{N} \quad (3)$$

Where:

- N = number of years
- Y_1 = starting year
- Y_2 = ending year

Performance Metrics of the Developed SWAT Model

The SWAT model was assessed via metric indicators such as coefficient of determination (R^2) and mean square error (MSE).

$$R^2 = 1 - \frac{\sum_{i=1}^n (Y_{i,pred} - Y_{i,exp})^2}{\sum_{i=1}^n (Y_{i,pred} - Y_{exp,ave})^2} \quad (4)$$

$$MSE = \frac{\sum_{i=1}^n (Y_{i,exp} - Y_{i,pred})^2}{n} \quad (5)$$

RESULTS AND DISCUSSION

The performance, in terms of regression value (R) and mean square error (MSE), of the SWAT model developed in this study was compared with the performance of the same model in other fields of study such as extraction, energy, economy, biogas production, and more. This comparison with previous studies was done to examine the reliability of the developed SWAT model for predicting/forecasting, as presented in Table 2.

Table 2. Comparative study of the developed SWAT model with previous work in the literature

Predictive Model	Predicted/Forecasting Output	Performance Metric (R, MSE)	Reference
NARX-NN	River discharge	0.9987, 4.30×10^{-5}	Orji et al., 2024
SWAT	Exchange rate	0.9962, 1.98×10^{-5}	Markova, 2019
SWAT	Rainfall quantities	0.9532, 0.00280	Tawfeeq and Arb, 2016

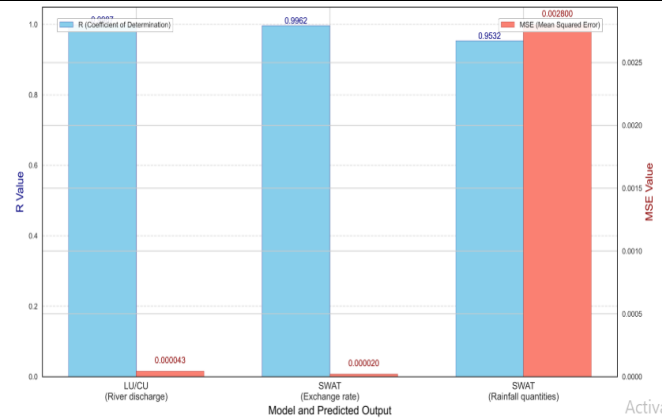


Fig. 3. Performance values for R and MSE of the SWAT model

Impact of Land-Use Characteristics in the Last 10 Years in Response to Climate Change

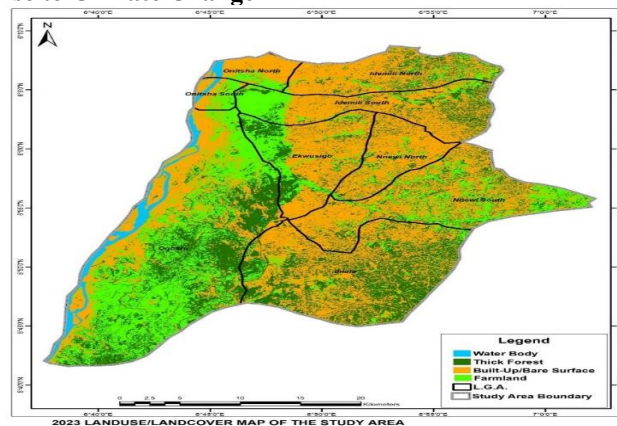


Fig. 4. 2013 Land-Use/Land-Cover Classes (Source: Classified SatelliteImage of Anambra State, 2013)

2013 Land-Use/Land-Cover distribution (absolute values):

- Thick Forest: 48,128.76
- Farmland: 35,001.54
- Built-Up/Bare Surface: 35,237.07
- Water: 2,826.45

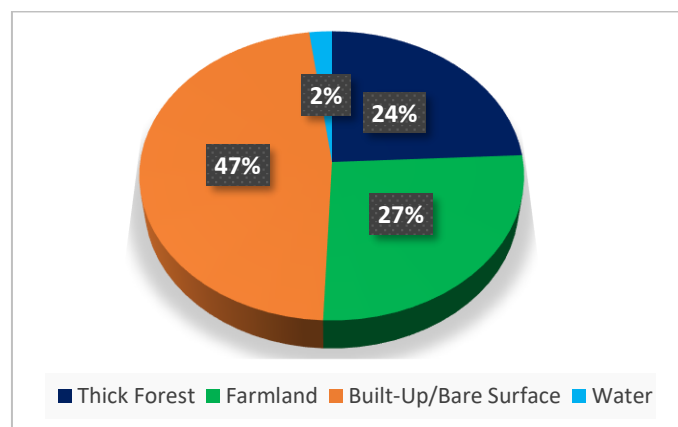


Fig. 5. Pie Chart of 2013 Land-Use/Land-Cover Status
(Source: Digitized data from Satellite Imagery, 2013)

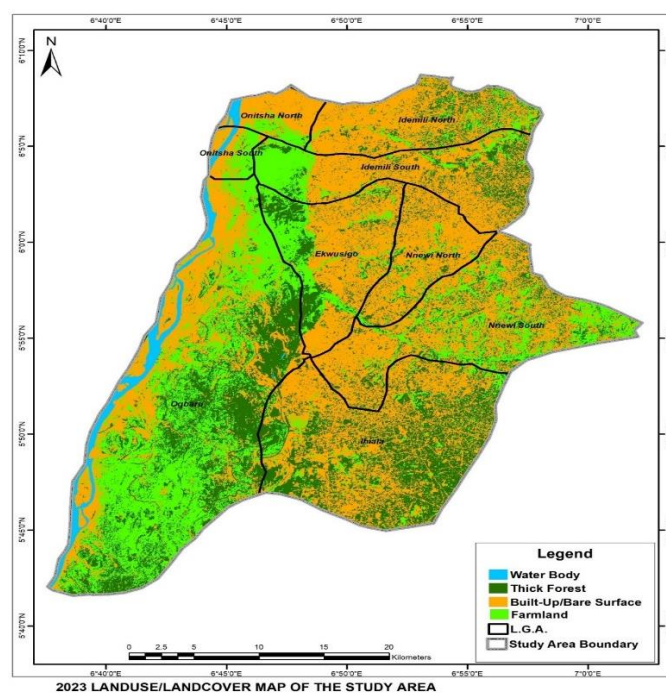


Fig. 6. 2023 Land-Use/Land-Cover Classes
(Source: Classified Satellite Image of Anambra State, 2023)

2023 Land-Use/Land-Cover distribution (absolute values):

- Thick Forest: 29,373.57
- Farmland: 32,031.00
- Built-Up/Bare Surface: 57,268.08
- Water: 2,521.17

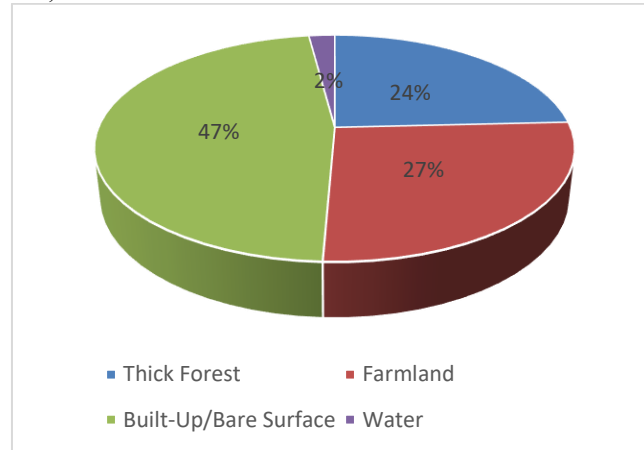


Fig. 7. Pie Chart of 2023 Land-Use/Land-Cover Status
(Source: Digitized data from Satellite Imagery, 2023)

Comparative Land-Use/Land-Cover Status (2013 vs. 2023)

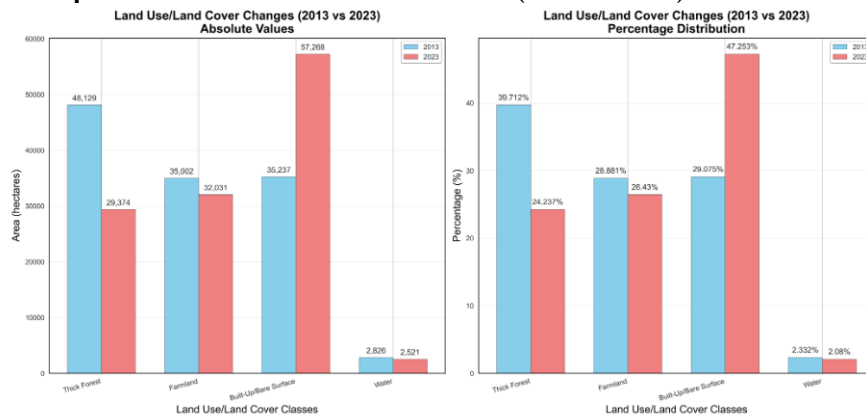


Fig. 8. Bar Chart of 2013 and 2023 Land-Use/Land-Cover Status for absolute values and percentage distribution

SWAT Prediction Pattern on the Soil Properties

The result of the prediction showed that there would be fluctuations in the soil properties as the years go by, which could be attributed to seasonal changes.

Melkamu and Zerihun [16] highlighted that changes in atmospheric temperature alter the amount of rainfall within a geographical location.

From **Fig. 9–10**, the surge in discharge was higher within the first two years (2013), which decreased over the next ten years (2023). Subsequent increases are expected in the coming years. The fluctuation can be attributed to changes in temperature and rainfall levels during the subsequent years.

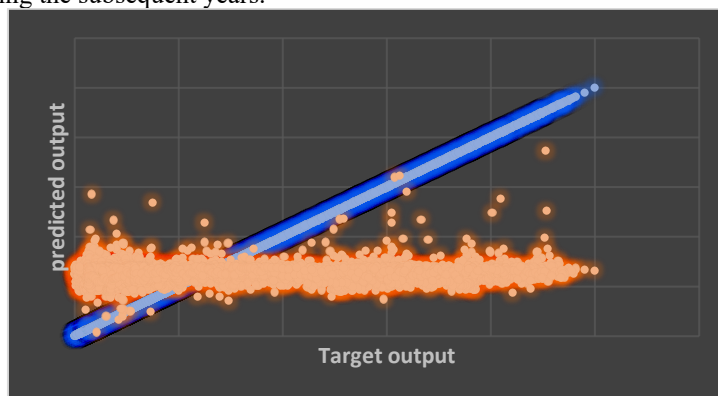


Fig. 9. SWAT prediction pattern of soil properties (2013)

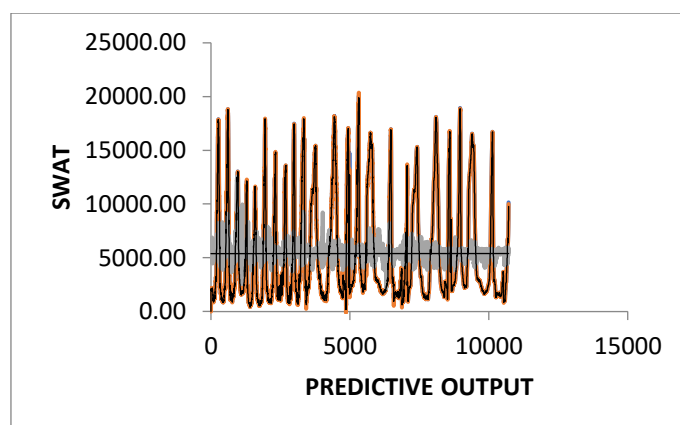


Fig. 10. SWAT prediction pattern of soil properties, (2023).

CONCLUSIONS

Excessive discharge, especially during the rainy season, has significant effects on the lives and properties of those within the affected areas. Predictive discharge values are important because they help in enacting laws.

This study provides real-time information on soil properties and their impact on water management, assisting policymakers in making informed decisions to mitigate the effects of climate change and land use for sustainable economic development.

BIBLIOGRAPHY

- [1] Ajala O., Oyelade J., Oke E., Oniya O., Adeoye B. 2023. A nonlinear autoregressive exogenous neural network (NARX-NN) model for the prediction of solvent-based oil extraction from *Hura crepitans* seeds. *Chem. Prod. Process Model*, pp.1–9. <https://doi.org/10.1515/cppm-2022-0032> (doi.org in Bing).
- [2] Akhtar M.K., Corzo G.A., van Andel S.J., Jonoski A. 2009. River flow forecasting with artificial neural networks using satellite observed precipitation pre-processed with flow length and travel time information: case study of the Ganges river basin. *Hydrol. Earth Syst. Sci.* 13. pp.1607–1618.
- [3] Al-Zu'bi Y., Sheta A., Al-Zu'bi J. 2010. Nile river flow forecasting based on Takagi-Sugeno fuzzy model. *J. Appl. Sci.* 10. pp.284–290.
- [4] Anh D.T.L., Aires F. 2019. River discharge estimation based on satellite water extent and topography: an application over the Amazon. *J. Hydrometeorol.* 20. pp.1851–1866. <https://doi.org/10.1175/jhm-d-18-0206.1> (doi.org in Bing).
- [5] Anthony R.E., Aster R.C., Ryan S., Rathburn S., Baker M.G. 2018. Measuring mountain river discharge using seismographs emplaced within the hyporheic zone. *J. Geophys. Res. Earth Surf.* 123:210–228. <https://doi.org/10.1002/2017JF004295> (doi.org in Bing).
- [6] Arnold J.G., Fohrer N. 2005. SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrol. Process.* 19. pp.563–572. <https://doi.org/10.1002/hyp.5611>.
- [7] Ayeleru O., Adeniran J., Ntsaluba S., Fajimi L., Olubambi P. 2023. An economic analysis of energy consumption at student residences in a South African-based academic institution using NARX neural network. *Energies* 16(942). pp. 1–14.
- [8] Orji F.N., Ahaneku I.E., Awa J.I., Cyprain N.T., Ubah J.I. 2024. Effect of artificial neural network transfer function optimization on hydrological modeling. *Umudike Journal of Engineering and Technology (UJET)* 10(1). pp.60–90.
- [9] Burtin A., Bollinger L., Vergne J., Cattin R., Nabelek J.L. 2008. Spectral analysis of seismic noise induced by rivers: a new tool to monitor spatiotemporal changes in stream hydrodynamics. *J. Geophys. Res. Solid Earth* 113: B05301. <https://doi.org/10.1029/2007JB005034> (doi.org in Bing).
- [10] Melkamu M., Zerihun K. 2018. Review on impacts of climate change on watershed hydrology. *J. Environ. Earth Sci.* 8. pp.91–99.
- [11] Markova M. 2019. Foreign exchange rate forecasting by artificial neural networks. *AIP Conference Proceedings* 2164:1–14. doi:10.1063/1.5130812.
- [12] Tawfeeq M., Arb G. 2016. Monthly rainfall quantities forecasting using NARX network. *Journal of Engineering and Sustainable Development* 20(6). pp.103–114.
- [13] Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press.
- [14] Lambin E.F. 2011. Land cover change: Theory and practice. In: *Earth System Science Encyclopedia*, Vol. 4, pp. 345–358. Springer.

**UTICAJ KORIŠĆENJA ZEMLJIŠTA I KLIMATSKIH PROMENA
NA PARAMETRE ZEMLJIŠTA U NEKIM ODABRANIM LOKALNIM
SAMOUPRAVAMA JUGOISTOČNE NIGERIJE,
PRIMENOM SWAT MODELA**

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Sažetak: Sve veći uticaji klimatskih promena i promena namene zemljišta pojavili su se kao veliki ekološki izazovi koji utiču na kvalitet vode u zemljištu, poljoprivrednu produktivnost i otpornost ekosistema, naročito u tropskim regionima.

Poslednjih decenija, porast globalnih temperatura, neredovne količine padavina i štetne ljudske aktivnosti poput krčenja šuma i intenzivne obrade zemljišta narušili su prirodnu hidrološku ravnotežu, što je dovelo do degradacije zemljišta, smanjenog obnavljanja podzemnih voda i opadanja kvaliteta vode.

Ova studija se fokusira na procenu uticaja klimatskih promena i promena namene zemljišta na sadržaj i kvalitet vode u zemljištu u odabranim lokalnim područjima jugoistočne Nigerije korišćenjem alata Soil and Water Assessment Tool (SWAT).

Model je korišćen za simulaciju hidroloških odgovora različitih scenarija namene zemljišta i klimatskih uslova na vlažnost zemljišta, površinsko oticanje i rečni proticaj u proučavanom području.

Studija je obuhvatila prikupljanje i integraciju prostornih podataka kao što su digitalni model reljefa (DEM), karte klasifikacije zemljišta, podaci o nameni zemljišta iz Landsat satelitskih snimaka, kao i klimatski podaci (padavine, temperatura, vlažnost vazduha i brzina vetra). Ovi skupovi podataka su obrađeni i uneti u SWAT model, koji je kalibrisan i validiran korišćenjem posmatranih hidroloških podataka za period od 2013. do 2023. godine. Kalibracija i analiza osetljivosti identifikovale su ključne parametre koji utiču na hidrološki odgovor, uključujući teksturu zemljišta, stopu infiltracije, evapotranspiraciju i intenzitet padavina.

Validacija modela dala je prihvatljive statističke rezultate, pokazujući zadovoljavajuću korelaciju između simuliranih i posmatranih vrednosti, čime je potvrđena pouzdanost simulacije za prediktivne analize. Izvedene su simulacije scenarija kako bi se ispitali uticaji različitih nivoa padavina i temperature, kao i različitih obrazaca namene zemljišta poput delimične i potpune deforestacije, širenja poljoprivrednih površina i pošumljavanja.

Rezultati analize pokazali su da povećana temperatura uz smanjene padavine značajno umanjuje vlažnost zemljišta, obnavljanje podzemnih voda i rečni proticaj. Nasuprot tome, pošumljavanje i pravilne prakse upravljanja zemljištem poboljšavaju zadržavanje vode u zemljištu, smanjuju eroziju i stabilizuju hidrološke cikluse.

Nalazi su pokazali sledeće apsolutne vrednosti i procentualne raspodele između 2013. i 2023. godine: gusta šuma 48128.76 (39.712%), poljoprivredno zemljište 35001.54 (28.881%), izgrađene/ogoljene površine 35237.07 (29.075%) i voda 2826.45 (2.332%). Za 2023. godinu: gusta šuma 29273.57 (24.237%), poljoprivredno zemljište 32031.00 (26.430%), izgrađene/ogoljene površine 57268.08 (47.253%) i voda 2521.17 (2.080%).

Ovo istraživanje pokazuje snažnu međuzavisnost između klimatske dinamike, obrazaca korišćenja zemljišta i sistema zemljište–voda. Studija naglašava neophodnost integrisanog upravljanja slivovima, klimatski pametne poljoprivrede i adaptivnog planiranja korišćenja zemljišta kao održivih strategija za ublažavanje negativnih posledica klimatskih promena.

Ključne reči: SWAT, digitalni model reljefa, hidrologija korišćenja zemljišta, ekosistemi

Prijavljen:

***Submitted:* 31.01.2026.**

Ispravljen:.

***Revised:* 20.03.2026.**

Prihvaćen:

***Accepted:* 24.04.2026.**