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Hydrological Modelling of Runoff and Sediment Yield Dynamics Upstream of Eleyele Lake, Oyo State, Nigeria

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ABSTRACT: Water is a critical natural resource, comprising approximately 60% of human body weight and playing a vital role in all physiological processes. However, water quality has deteriorated in recent years due to the presence of harmful contaminants, posing potential health risks. Hence, the objective of this paper is to assess the modelling runoff and sediment yield dynamics of the Upstream of Eleyele Lake Watershed, Oyo State, Nigeria using Geographic Information Systems (GIS) alongside the Soil and Water Assessment Tool (SWAT). The model's predictions indicated an annual surface runoff of 122.56 m^3/s and a sediment yield of 26.02 t/ha within the study area. These levels suggest a significant risk of flooding and heightened susceptibility to soil erosion. Consequently, it is recommended that further modeling efforts be employed to identify erosion-prone zones with greater precision across the watershed, enabling the development of effective management strategies to mitigate these risks.

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Water is an indispensable resource for human existence, covering approximately 50 to 60% of body weight and playing a critical role in supporting all vital physical processes. In recent years, though, the chemical quality of drinking water has significantly degenerated due to the presence of toxic elements, which even in trace amounts pose serious health risks. In an ideal world, water should be free from pathogens and harmful contaminants, yet natural water sources are often compromised. In Nigeria, contamination from fecal matter, domestic and industrial sewage, as well as agricultural and pasture runoff, worsens this issue, leading to a heightened risk of disease transmission. Ensuring access to safe, uncontaminated water remains a priority to protect public health and promote sustainable development. The market is inundated with a large number of brands of bottled water (Mohapatra and Singh, 2012). Many countries have established drinking water standards to regulate the maximum permissible levels of various constituents to ensure public safety. In Nigeria, the rising demand and consumption of bottled water have heightened concerns about the quality of these products. Recent reports have highlighted an increase in substandard water quality, including concerns about well water contamination (Dalvie *et al.,* 2005), prompting the need for stringent quality control measures to safeguard public health. Accurate

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forecasting of water demand across short-term, medium-term, and long-term time horizons is essential for effective capacity planning and operational efficiency within water supply systems. Such forecasts facilitate scheduling of maintenance, future financial planning, rate adjustments, and optimization of water system operations. Moreover, well-informed demand forecasts serve as a foundation for strategic decision-making regarding the selection of future water sources, the upgrading of existing water infrastructure, and the design of management options to address future water demand. This proactive approach ensures sustainable utilization of water resources and equitable access for competing users, ultimately safeguarding this vital resource for future generations in Nigeria. The time series approach offers a direct method for forecasting water consumption without the need to predict the various factors that influence it (Rasifaghihi *et al.,* 2019). Soil erosion and siltation present significant challenges globally, with developing countries like Nigeria experiencing more severe impacts due to intensive agricultural practices, overgrazing, and escalating population pressures (Laflen *et al.,* 2004). These phenomena lead to two primary consequences for water resources: onsite and offsite effects. Among the key offsite effects is the reduction of reservoir capacity, which poses substantial challenges for the sustainable management of reservoirs throughout their intended design lifespan due to the accelerated rates of siltation. Addressing these issues is critical to ensuring the long-term viability of water resources in Nigeria. Webster and Wilson (2010) considered the influences of accelerated soil erosion on reservoir capacity loss at a faster rate and suggested catchment management, sediment flushing, and sediment routing as general mitigation measures. However, (Young, 2010) identified that land and water management play a significant role to combat life storage depletion and sustaining dams to their useful life in the highlands of the Ethiopian watershed. Reservoir sedimentation rates varied across reservoir size, watershed management interventions, and physiographic and climate conditions, but worldwide, more than 1% of reservoir total capacity is lost annually. The study by (Soil and Water Conservation Society, 1993) on the Gereb reservoir in Northern Ethiopia using a bathymetric approach revealed annual reservoir capacity loss rate due to sedimentation is higher than 3.0%. Conversely, onsite impacts are primarily characterized by soil erosion and deposition processes. Quantifying these processes and identifying hotspot areas within the watershed are crucial efforts for mitigating soil erosion and reducing its overall impact. By focusing on these specific areas, targeted interventions can be developed to enhance soil conservation practices, improve land management, and ultimately safeguard water quality and availability within the watershed. Such initiatives are essential for promoting sustainable agricultural practices and ensuring the long-term health of Nigeria's water resources. (Kaey, 2010). Water erosion significantly contributes to land degradation, leading to a decline in agricultural productivity, particularly in areas with steep slopes and high population density. This situation necessitates intervention from government bodies and environmental institutions. (Benik *et al.,*2003) noted that such land degradation can be effectively mitigated through active farmer participation in constructing soil and water conservation structures, such as bunds, to combat erosion. However, implementing these erosion control measures at the watershed level can be prohibitively expensive, underscoring the need to identify hotspot areas for targeted watershed management and soil conservation initiatives. Various methods have been developed to spatially assess soil erosion and sediment yield rates, which can be broadly classified into three main approaches. These approaches provide essential frameworks for prioritizing conservation efforts and optimizing resource allocation in Nigeria's vulnerable landscapes. The first approach to assessing soil erosion involves quantifying erosion through experimental measurements obtained from erosion plots (Soil Survey Staff, 1990). The second approach entails mapping erosion features by conducting erosion surveys or by utilizing visual interpretation of satellite imagery and aerial photographs. The third and most widely employed method involves integrating spatial data on erosion factors through the application of erosion models (Egharevba, 2004). Each of these approaches provides valuable insights into the dynamics of soil erosion, facilitating targeted interventions for effective soil and water conservation in Nigeria's diverse agricultural landscapes. Hence, the objective of this paper is to assess the modelling runoff and sediment yield dynamics of the Upstream of Eleyele Lake Watershed, Oyo State, Nigeria.

MATERIALS AND METHOD

Description of the Study Area: Eleyele is situated in North-west of Ibadan, Oyo State, Nigeria at an altitude of 125 m above sea-level and between7°25'00' and 7°26'30'N latitudes and 3°51'00' and 3°52'30'E longitudes. The Lake is located between latitude 7 25'0" to 7 26'15" N and longitude 3 50'45" to 3 52'15" E. The study area has a tropical savanna climate with a distinct rainy season from March to October, where rainfall averages between 1,200 to 1,500 mm annually, and temperatures range from 24°C to 27°C. The dry season, from November to February, brings lower humidity, warm days, and cooler nights. Originally part of the tropical rainforest zone, Ibadan's vegetation is now a mix of secondary forest, grasslands, and farmlands due to urbanization and agriculture. The soil is predominantly ferruginous tropical soil, typically red to reddish-brown with sandy loam or loamy textures, supporting a range of crops such as maize, cassava, and yams. The study area location map is depicted in Figure 1.

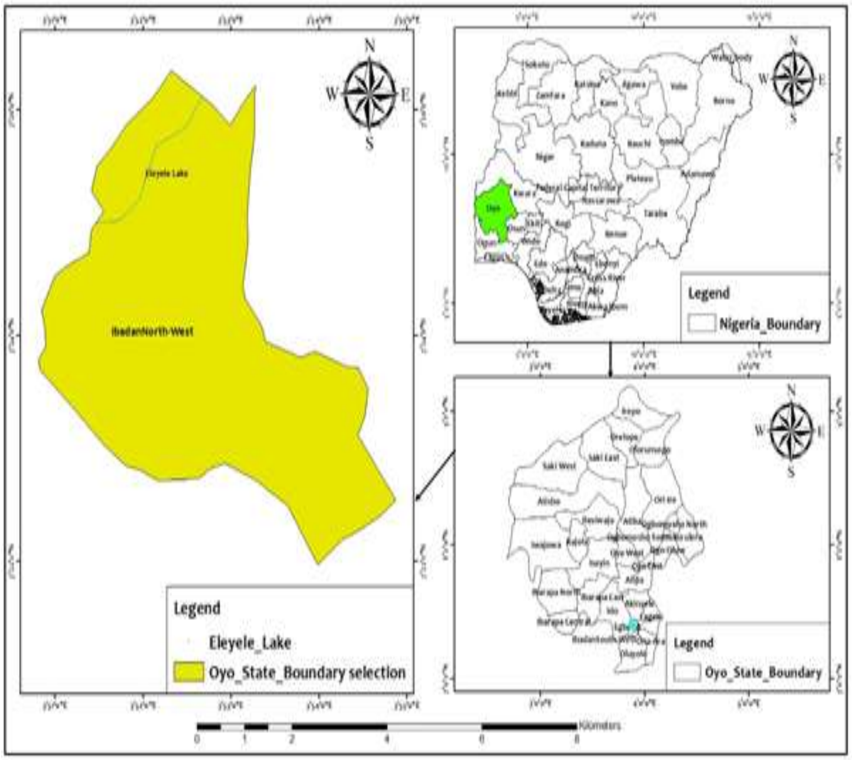

Fig. 1: Study Area Location Map

Data Collection

Temporal Data: The daily meteorological data rainfall, minimum and maximum air temperature, relative humidity, wind, and solar radiation data were collected from Nigeria Metrological Agency (NIMET). The datasets were collected for the period of 30 years from January 1982 to December, 2022.

Spatial Data

Soil Data: A soil map is a geographical representation displaying a variety of soil types and/or soil properties such as the soil pH, texture of the soil, organic matter, depth of horizon, etc in an area of interest. The Digital Soil map used in this study was obtained from the United States Geological Survey (USGS) website. Figure 2 shows the soil map of the area.

Landuse Data: The landuse data was extracted from the Global Land Cover Characterization (GLCC). Landuse maps are used for the sustainable management of natural resources. Landuse results from the interactions between humans and their environment. The Landuse map of the watershed is shown in Figure 3.

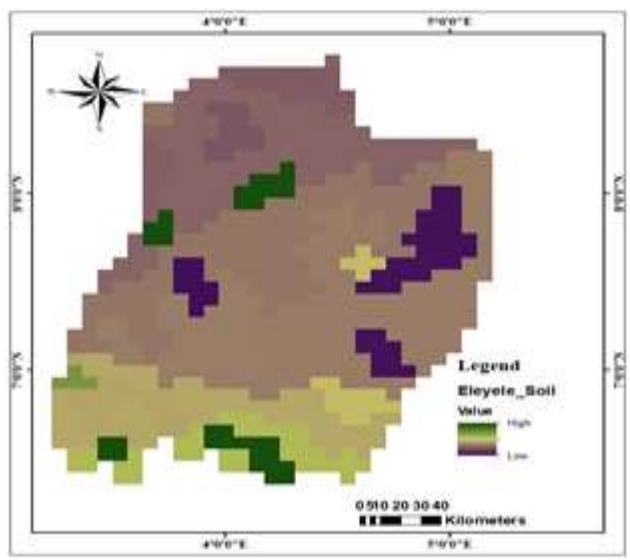

Fig. 2: Soil Map of Eleyele Lake

Digital Elevation Model: The Digital Elevation Model (DEM) data for this investigation came from the final version of the Shuttle Radar Topography Mission (SRTM) (CGIAR, 2012). DEM is defined as the topography that describes the elevation of any point in a given area at a specific spatial resolution and shows the terrain parameters such as slope gradient and slope length, and stream network characteristics such as channel slope, length and width when used as an input in the SWAT model. Figure 4 shows the DEM of the area.

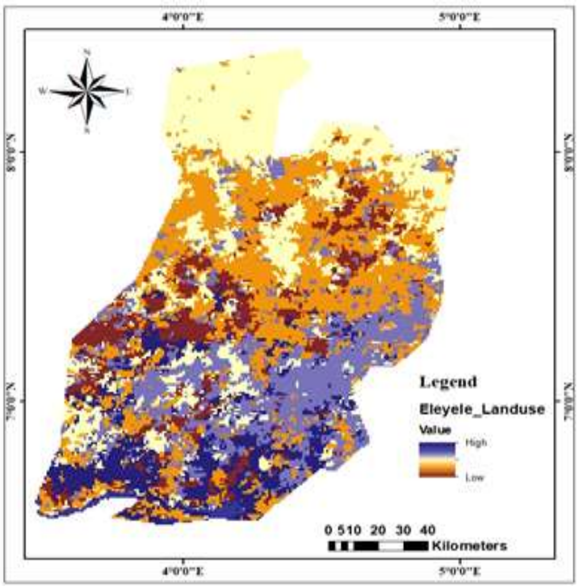

Fig. 3: Landuse Map of Eleyele Lake

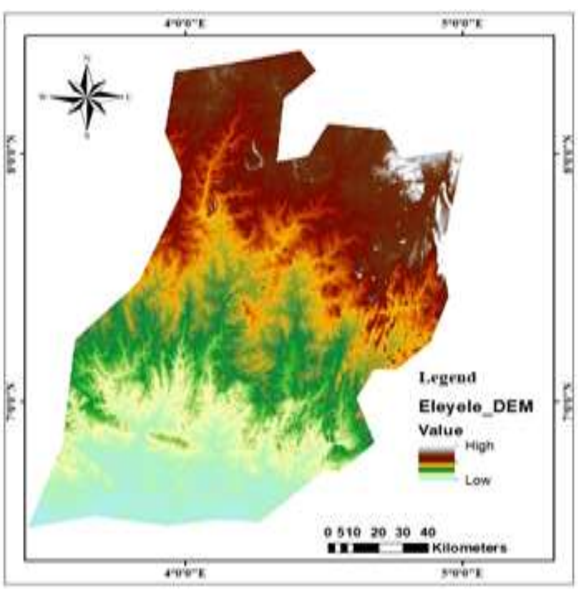

Fig. 4: DEM of Eleyele Lake

Model Setup and Processing

Watershed Delineation: In this stage, the reprojected DEM served as the foundational layer for hydrological analysis, allowing for accurate watershed delineation. Using network delineation tools, the watershed was segmented into sub-watersheds, making the stream networks distinctly visible. An inlet/outlet shapefile was generated for the area, with a specific outlet point strategically selected along the stream network to optimize flow analysis. This setup provided a detailed spatial framework for subsequent hydrological modeling, as illustrated in Figure 5.

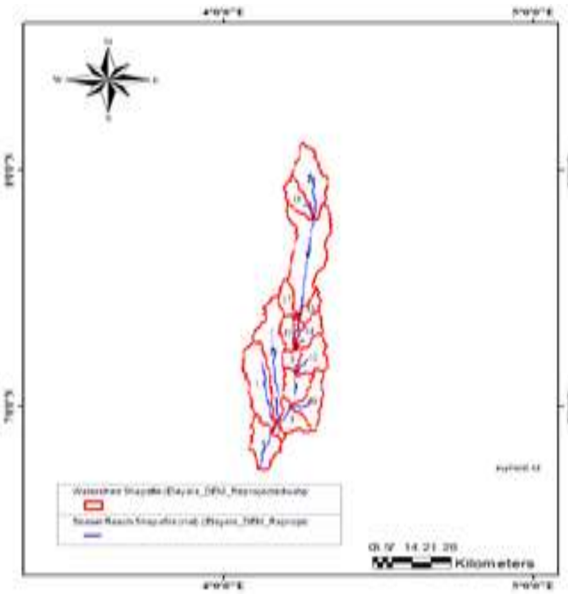

Fig. 5: Delineation of watershed into subbasins

Delineation of Watershed into Hydrological Response Units (HRUs): The reprojected land use and soil maps were integrated as key inputs for hydrological analysis. Sub-watersheds were further subdivided into Hydrological Response Units (HRUs), which represent unique combinations of homogenous soil and land use characteristics within each sub-watershed. This detailed classification yielded 41 HRUs distributed across 19 sub-basins, providing a granular framework for modeling spatial variability in hydrological processes and enhancing the precision of runoff and sediment yield predictions.

SWAT Model Setup and Run: Temporal datasets, including precipitation, temperature, and other relevant climate variables, were imported into the SWAT model as input parameters to capture seasonal and annual variations affecting watershed hydrology. Following the import, model configurations were fine-tuned to accurately reflect the temporal dynamics of the study area. The simulation was initialized and executed, with specific runs selected based on calibration requirements to ensure output accuracy. The selected model run was then saved for further analysis, setting the stage for detailed evaluation of hydrological processes, such as runoff, evapotranspiration, and sediment transport over time, under varying climatic conditions.

RESULTS AND DISCUSSION

Predicted Runoff in the Eleyele Lake: The SWAT model simulation indicated a total annual surface runoff of 122.56 m^3/s for the simulation period. This spatial variation provides insights into hydrological responses within the watershed, identifying sub-regions prone to higher runoff due to factors such as land use, soil properties, and topography. The quantified runoff serves as a critical metric for understanding water movement, informing flood risk assessments, and guiding water resource management. Identifying high-runoff zones enables the development of focused intervention strategies to mitigate potential flood risks and soil erosion, essential for sustaining watershed health and enhancing the resilience of local water infrastructure. Figure 6 presents the spatial distribution of predicted annual surface runoff across the Eleyele watershed, revealing areas with varying runoff intensities.

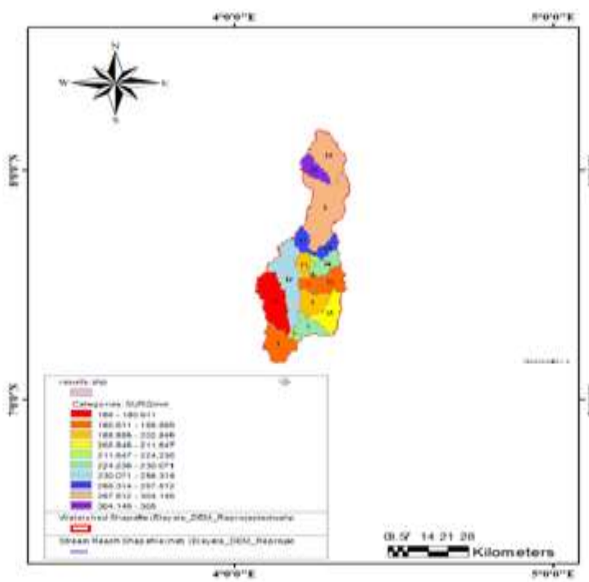

Fig. 6: Spatial Variation of the Predicted Annual Surface Runoff

Predicted Sediment Yield in the Eleyele Lake: The SWAT model simulation estimated an average annual sediment yield of 26.02 t/ha for the study period. This spatial variation reflects the influence of land cover, soil type, slope, and runoff intensity on sediment generation and transport processes within the watershed. High-yield areas identified through the model indicate zones with elevated erosion potential, likely due to factors such as steep gradients or less vegetative cover, which increase soil vulnerability to displacement. Understanding these spatial dynamics is crucial for implementing targeted soil conservation measures, optimizing land use planning, and reducing sediment loads in water bodies, which helps to preserve reservoir capacity and maintain water quality in the Eleyele watershed. Figure 7. Displays the spatial distribution of predicted annual sediment yield within the Eleyele watershed, highlighting areas with varying sediment deposition intensities.

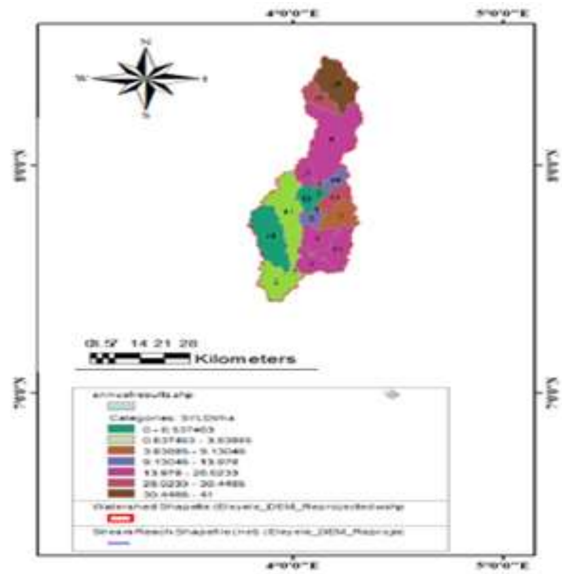

Fig. 7: Spatial Variation of the Predicted Annual Sediment Yield

Conclusion: This research assessed surface runoff and sediment yield in the Eleyele watershed by integrating Geographic Information Systems (GIS) with the Soil and Water Assessment Tool (SWAT), leveraging data from DEM, soil properties, land use, and temporal climate inputs. Results indicated elevated levels of sediment yield and surface runoff, signifying high flood and erosion risks across the watershed. Based on these findings, enhanced modeling efforts are recommended to accurately identify and prioritize erosion-prone areas for targeted intervention. Improved land management practices, combined with the establishment of erosion control measures in critical zones, are suggested to mitigate sediment transport and manage runoff sustainably. Additionally, routine monitoring and calibration of the model with updated spatial and temporal datasets are encouraged to enhance predictive accuracy and adaptive watershed management strategies.

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