Quantifying the Impact of Topography and Land Cover Dynamics on Groundwater and Evapotranspiration in Ile-Ife, Southwestern Nigeria

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ABSTRACT

This study quantified the impact of topography and Land Use/Land Cover (LULC) dynamics on groundwater and evapotranspiration in Ile-Ife, Southwestern Nigeria, from 2015 to 2020. Addressing a gap in localized hydrological analysis for Southwestern Nigeria, the research employed the Soil and Water Assessment Tool (SWAT) integrated with Landsat imagery for LULC mapping, Shuttle Radar Topography Mission (SRTM) data for Digital Elevation Model (DEM) acquisition, and satellite-based products for precipitation and soil data.

Key findings revealed a significant spatial correlation between topography and groundwater levels in Ile-Ife, with higher elevations exhibiting lower groundwater, aligning with established principles of increased runoff. Over the study period, LULC analysis indicated a 1.17% decrease in forest cover and a 0.653% increase in urban areas. Model simulations demonstrated a declining trend in groundwater recharge, specifically from a range of 0 to 92.15 mm in 2015 to 0 to 86.41 mm in 2020. Concurrently, mean annual actual evapotranspiration (ET) decreased from 1117.20 mm to 1058.30 mm, suggesting hydrological impacts of deforestation. Temporal variations in surface runoff were also observed. This research provides crucial, localized insights into the hydrological consequences of land cover changes in a tropical urbanizing catchment. The findings underscore the vulnerability of groundwater resources and emphasize the urgent need for informed, sustainable land and water management practices in Ile-Ife and similar regions to ensure long-term water security.

(Keywords: hydrological modeling, land use, land change, groundwater, evapotranspiration, SWAT model, Ile-Ife)

INTRODUCTION

The accelerating pace of global environmental change driven by land use transitions, urbanization, and climate variability continues to exert critical pressure on freshwater systems [1, 2]. In particular, groundwater levels and evapotranspiration (ET) dynamics are profoundly influenced by shifts in land use/land cover (LULC), with consequences for ecosystem health, agricultural productivity, and water security [3, 4, 5]. Understanding these impacts is crucial for developing effective water resource management strategies, particularly in regions vulnerable to environmental change.

Groundwater, a vital yet often over-exploited freshwater reservoir, is directly replenished through infiltration, a process demonstrably sensitive to surface characteristics [1]. A growing body of research has consistently shown that increasing impervious surfaces, often linked to urban expansion, reduce infiltration and groundwater recharge while accelerating surface runoff [6, 7, 8].

Studies from diverse geographical contexts, including northwestern Bangladesh [3] and India [6], demonstrate that the expansion of impervious built-up areas significantly reduces groundwater infiltration. Furthermore, the conversion of vegetation-covered land to non-vegetation-covered land can hamper the groundwater absorption system, leading to reduced storage [7]. Conversely, the presence of natural vegetation generally promotes higher

groundwater recharge rates, with ample natural cover showing increased wet season recharge in basins like Makutupora [5]. However, agricultural expansion, while increasing cultivated land, can paradoxically reduce groundwater recharge if associated with increased runoff and decreased infiltration efficiency, as noted in studies such as the Doce River Basin in Brazil [4]. While a general trend of reduced recharge with increased imperviousness prevails, a nuanced view suggests that urbanization could, in some contexts, increase groundwater recharge due to a greater reduction in ET than infiltration [9, 3], highlighting the importance of local biophysical context. Moreover, land use changes, often compounded by climate warming, have been observed to decrease groundwater recharge [10], and localized pumping can have regional impacts on water availability and quality [1].

Evapotranspiration, the aggregate transfer of water from the land surface to the atmosphere, is intrinsically linked to vegetation type, canopy structure, and available soil moisture [1]. Increased forest land has been observed to correlate with increased ET in various watersheds, including the Shalamulun River in China [11] and the Bilate catchment in Ethiopia (12]. Conversely, the conversion of natural vegetation to agricultural or urban areas can alter ET dynamics, with studies documenting decreased ET following mixed forest loss [7] and increased total annual ET corresponding to LULC changes [13]. The compounded effect of declining groundwater reserves and perturbed ET regimes presents a formidable challenge, particularly in climatically sensitive, rapidly developing regions [1]. Surface runoff, often inversely linked to groundwater recharge, consistently increases with urbanization and conversion to impervious surfaces [1]. Farmland and urban areas typically produce more surface runoff than natural covers [8], while changes in LULC can lead to a decrease in blue water (runoff) and an increase in green water (ET) [11].

Precise quantification of these complex hydrological responses demands advanced analytical frameworks [1]. Geographic Information Systems (GIS) and remote sensing (RS) technologies have become indispensable tools for mapping and monitoring LULC dynamics over expansive spatial and temporal scales, providing critical inputs for hydrological modeling [14]. The integration of these spatial data with physically-based hydrological models, such as the Soil and Water Assessment Tool (SWAT), has revolutionized our capacity to simulate intricate water partitioning processes. These models leverage spatially distributed inputs, including LULC maps, meteorological forcings, and fundamental Digital Elevation Models (DEMs), to provide comprehensive hydrological assessments ([14]).

The Digital Elevation Model (DEM) serves as a foundational input for hydrological analysis, enabling the precise delineation of watersheds, computation of surface slopes, and characterization of drainage networks—all critical parameters governing water movement and partitioning [15, 16]. The resolution of a DEM significantly influences the accuracy of hydrological derivatives and, consequently, the reliability of model outputs [15]. Studies have extensively discussed how DEM accuracy and uncertainties propagate into hydrological derivatives [15] and how DEM cell size variations significantly affect topographical characteristics [17]. However, the choice of DEM resolution involves a trade-off, as finer resolutions, while enhancing accuracy, entail significantly increased computational loads [17].

Furthermore, LULC map quality, particularly its resolution, can be more influential than DEM resolution on hydrological model outputs, especially for runoff simulations, due to its direct impact on parameters like the Curve Number (CN) [17]. Model calibration and validation, crucial for ensuring reliability, typically involve adjusting parameters to match simulated outputs with observed hydrological data, with remotely sensed ET products notably used for calibration in data-scarce environments [18].

Previous scholarly efforts have extensively elucidated LULC-induced hydrological shifts across diverse global contexts [14]. These studies consistently highlight the sensitivity of hydrological processes to land cover transformations and underscore the utility of integrated geospatial modeling [14]. However, a notable lacuna exists in the systematic quantification of these specific impacts—especially the combined influence of DEM and LULC on both groundwater levels and ET—within the unique hydrological context of Southwestern Nigeria. The Ile Ife region, characterized by its distinct geology, tropical climate, and ongoing socio-economic

development, presents a compelling and under-examined geographical domain for such an inquiry.

The proposed study, "Quantifying the Impact of Topography and Land Cover Dynamics on Groundwater and Evapotranspiration in Ile-Ife, Southwestern Nigeria," aligns with established methodologies, leveraging the power of GIS, remote sensing, and hydrological modeling [14]. Its novelty and specific aims include: a detailed analysis of the unique LULC change trajectories and their local impacts on groundwater levels and ET within this specific tropical urbanizing environment; identifying the optimal DEM resolution for hydrological modeling tailored to the particular topographic and climatic conditions of Ile Ife, addressing the accuracy-computational trade-off in a new context; and investigating the synergistic interplay between localized LULC types and DEM-derived parameters in determining water partitioning, specifically influencing groundwater levels and evapotranspiration. By filling this geographical and thematic gap, the study in Ile Ife will not only contribute to the broader scientific understanding of hydrological processes under environmental change but also provide actionable insights for localized water resource management and sustainable development planning within the region. The findings are expected to contribute significantly to the understanding of hydrological dynamics in tropical urbanizing catchments.

MATERIALS AND METHODS

This section details the research design, data sources, and analytical procedures employed to investigate the effects of digital elevation models (DEM) and land use and land cover (LULC) on groundwater level and evapotranspiration in Ile-Ife, Nigeria. The methodologies are described with sufficient specificity to ensure transparency and reproducibility of the study's findings, aligning with the standards for robust scientific inquiry. An integrated geospatial approach, combining remote sensing data with hydrological modeling, was adopted to achieve the study objectives.

Study Area

The historic Yoruba city of Ile-Ife, situated in southwestern Nigeria, serves as the geographical focus of this investigation. According to the 2006 census, Ile-Ife recorded a population of 509,813, making it the most populous city in Osun State and a significant urban center located approximately 218 kilometers northeast of Lagos. The geographical location of Ile-Ife is depicted in Figure 1.

Geographically, the study area is delineated by latitudes 7°28′ N and 7°45′ N and longitudes 4°30′ E and 4°34′ E. This location, within a region characterized by dynamic socio-economic development and associated land-use transformations, provides a compelling setting for analyzing the impacts of LULC on hydrological processes. The terrain of Ile-Ife, part of the Precambrian Basement Complex in Osun State, Nigeria, is characterized by a rugged topography comprising prominent hills and intervening valleys. The highest elevation, Oke-Atapa Hill, reaches 351 meters above sea level. This varied topography is critically relevant to the study's focus on Digital Elevation Models (DEMs), as terrain characteristics directly influence hydrological processes such as surface runoff generation, infiltration pathways, and evapotranspiration rates. The pronounced relief necessitates high-resolution DEMs for accurate watershed delineation, slope gradient computation, and the precise modeling of water flow, elements that are central to understanding groundwater recharge dynamics. The region experiences a tropical savanna climate, marked by consistently warm temperatures year-round, typically averaging between 22°C and 31°C. This climatic regime, characterized by distinct wet and dry seasons, directly impacts precipitation patterns and, consequently, the rates of evapotranspiration and groundwater replenishment. Ile-Ife is drained by a network of rivers and streams, including the prominent Opa River and Ogun River. These water bodies exhibit meandering patterns, indicative of the undulating terrain, and are crucial components of the local hydrological system. The presence of numerous springs further highlights the area's active groundwater system, serving as vital sources of water for domestic and agricultural purposes. The interplay between this climate, the surface water network, and the underlying geology significantly influences both the potential for groundwater recharge and the demands on water resources through evapotranspiration, which are also shaped by the prevailing land use practices.

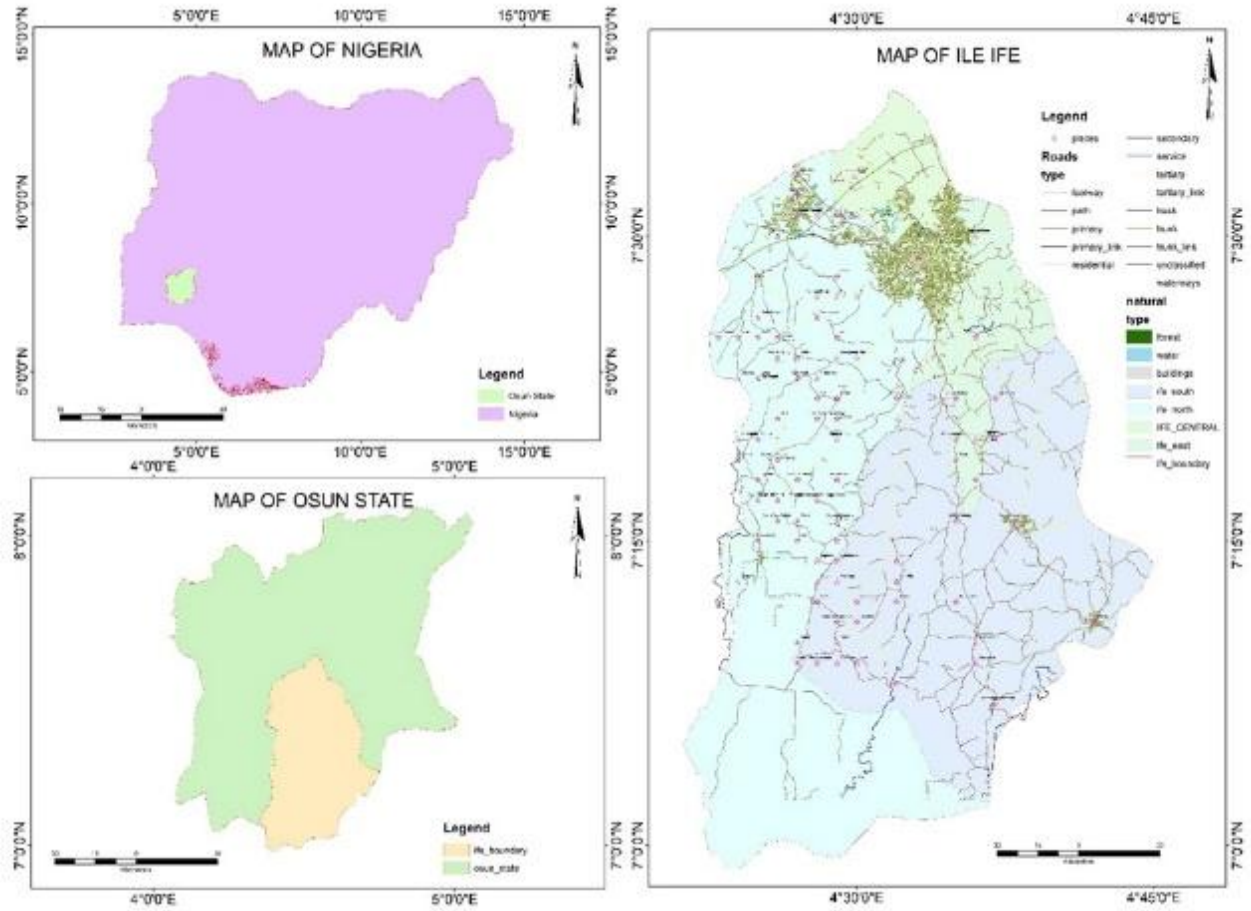


Figure 1: Study Area Map of Ile-Ife.

Data Sources

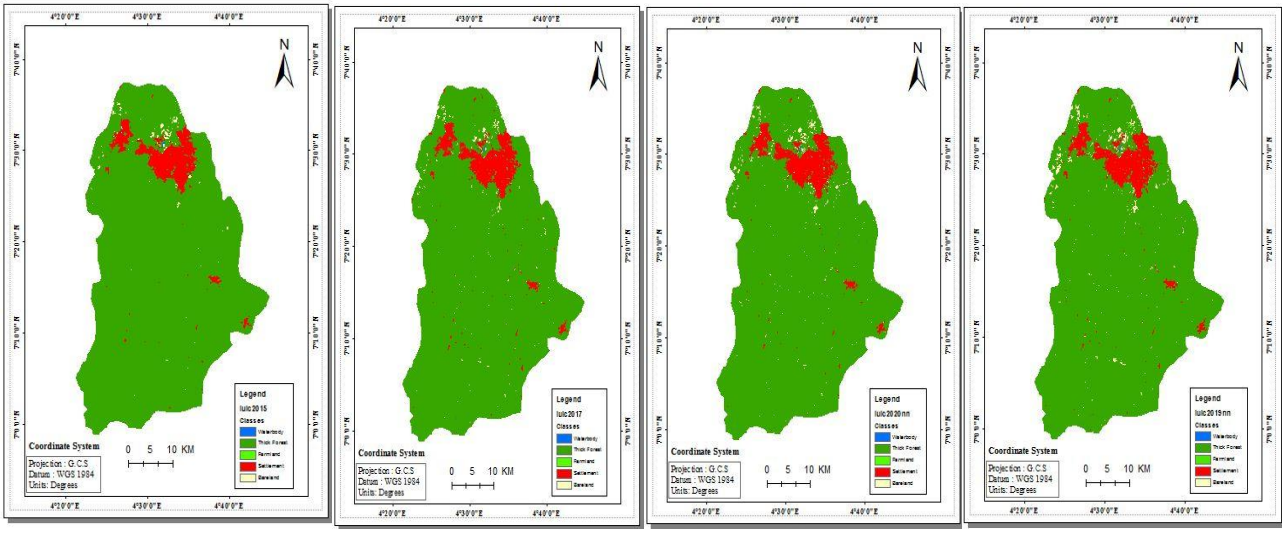
To achieve the objectives of this study, a variety of data sources were utilized, as detailed in Table 1.

Data Type	Data Source	Relevance
LULC	Satellite Imagery	To determine land use land cover
SRTM	Remote Sensing data	To determine the digital elevation model
Precipitation	Remote Sensing data	To produce precipitation data for analysis
Soil	Remote Sensing data	To produce soil data for analysis

Table 1: Data Sources and Relevance.

Land Use Land Cover (LULC) Data

Landsat satellite imagery (specifically Landsat 8 Operational Land Imager - OLI) were acquired for the years 2015, 2017, 2019, and 2020 to map the LULC of the study area. These datasets provide a comprehensive view of the changes in land use patterns over a five-year period, crucial for understanding their impact on hydrological processes. LULC maps were generated using a supervised classification approach within ArcGIS software. Pre-processing steps included atmospheric correction using FLAASH and geometric correction to ensure accurate spatial representation. The classification delineated five distinct classes: Waterbody, Thick Forest, Farmland, Settlement, and Bareland. The spatial distribution of LULC for these years is presented in Figure 2 (a-d).



a. 2015 b. 2017 c. 2019 d. 2020

Figure 2: Land Use/Land Cover (LULC) Maps of Ile-Ife for (a) 2015, (b) 2017, (c) 2019, and (d) 2020, illustrating changes in land cover classes over the study period.

In 2015 (Figure 2a), the majority of the watershed was covered by Thick Forest, while Settlements were concentrated in the central-northern part. By 2017 (Figure 2b), a slight decrease in Thick Forest and a marginal increase in Settlements were observed. This trend continued in 2019 (Figure 2c), with further reduction in forested areas and expansion of Settlement and Farmland. The LULC map for 2020 (Figure 2d) indicated a continued decrease in Thick Forest and a slight increase in other classes, reflecting ongoing land cover changes.

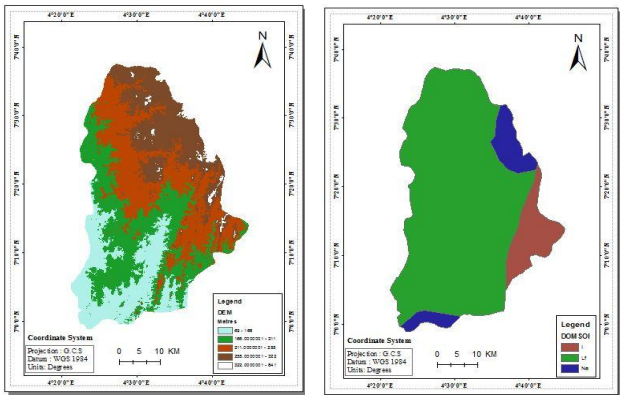
While a formal accuracy assessment (e.g., using ground truth points and confusion matrix) was not explicitly performed due to data limitations, the classification relied on visual interpretation and expert knowledge of the region. The analysis of the Land Use/Land Cover Analysis between 2015-2020 is represented in Table 2.

Table 2: Showing Ile-Ife Land Use/Land Cover Analysis between 2015-2020.

Class	Area (Km^2) 2015	(%) 2015	Area (Km^2) 2017	(%) 2017	Area (Km^2) 2019	(%) 2019	Area (Km^2) 2020	(%) 2020
Waterbody	0.37	0.019	0.46	0.024	0.52	0.027	0.73	0.038
Forest	1829.76	94.10	1813.88	93.29	1801.55	92.65	1806.97	92.93
Farmland	0.061	0.003	0.21	0.01	0.58	0.030	0.12	0.0062
Settlements	104.19	5.36	117.01	6.02	118.23	6.08	116.92	6.013
Bare Surface	10.07	0.52	12.88	0.66	23.56	1.21	19.71	1.013

Digital Elevation Model (DEM)

The Shuttle Radar Topography Mission (SRTM) data (version 3, 1 arc-second global) was utilized to obtain the DEM of Ile-Ife. The DEM, illustrated in Figure 1a, reveals that the northern and northeastern regions of Ile-Ife exhibit higher elevations, ranging from 255 to 361 meters (depicted in shades of brown), while the southern and southwestern areas are characterized by lower elevations, ranging between 100 and 255 meters (shown in shades of green and light blue). This 30-meter resolution DEM provides essential information on the terrain's elevation, influencing groundwater flow, surface runoff, and evapotranspiration rates across the watershed. The digital elevation model map of Ile-Ife is depicted in Figure 3a and the soil map is represented in Figure 3b.



a. DEM map b. Soil map

Figure 3: (a) Digital Elevation Model (DEM) of Ile-Ife, showing elevation variations in meters. (b) Soil Map of Ile-Ife, indicating the dominant soil types.

Precipitation and Soil Data

Precipitation data, crucial for driving the hydrological model, was acquired from satellite-based precipitation products, specifically the Global Precipitation Measurement (GPM) Integrated Multi-satellitE Retrievals for GPM. This near-global, quasi-real-time data was processed to generate monthly or annual precipitation maps for the study area for the years 2015, 2017, 2019, and 2020 (Figure 4 a-d).

These maps illustrate the spatial distribution of rainfall in millimeters. In 2015 (Figure 4a), precipitation ranged from approximately 1537.47 mm (red) in the northern part to 1334.39 mm (blue) in the south. Similar spatial patterns were observed in 2017 (Figure 4b), with precipitation ranging from 1336.64 mm to 1265.73 mm. The precipitation map for 2019 (Figure 4c) showed a range from 2160.52 mm to 2175.62 mm, indicating higher overall rainfall in this year. In 2020 (Figure 4d), precipitation varied from 1633.84 mm to 1712.38 mm.

Soil data, including information on soil type and properties, was obtained from a global soil database, such as the FAO Harmonized World Soil Database (HWSD), to produce soil maps essential for parameterizing the Soil and Water Assessment Tool (SWAT) model. The soil map of the study area, presented in Figure 1b, indicates the dominant soil types classified as DOM SOI: Lf (green), Ls (blue), and Ne (brown). The majority of the watershed is covered by the Lf soil type, with smaller patches of Ls found in the northern and southwestern regions, and Ne in the southeastern part. The specific properties of these soil types (e.g., texture, hydraulic conductivity) were used to inform SWAT parameters.

DATA ANALYSIS

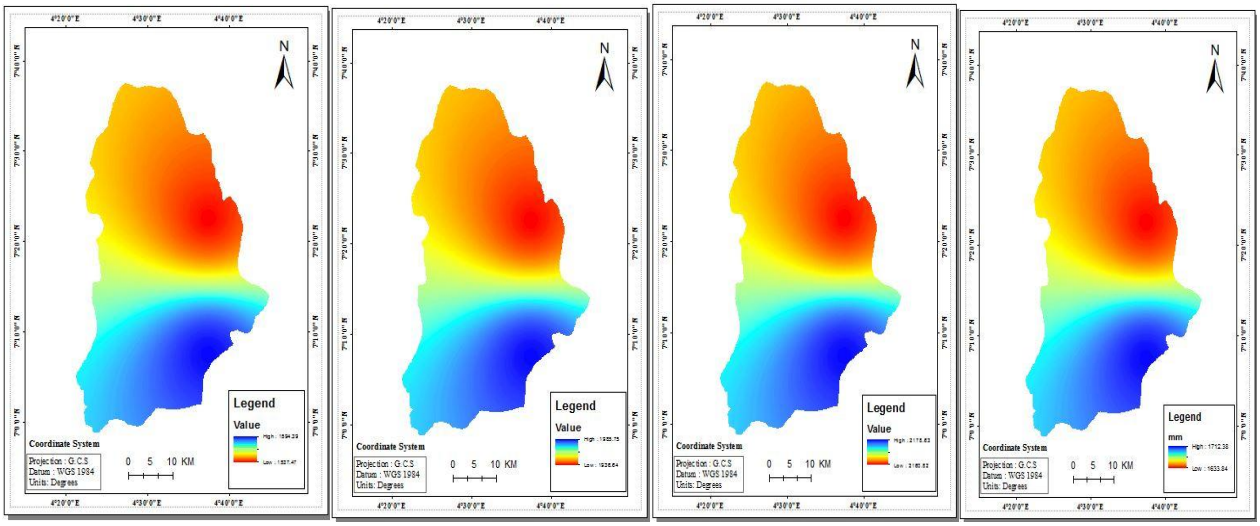
The Soil and Water Assessment Tool (SWAT), a physically-based, open-source model, was in ArcGIS Pro was utilized for model setup and simulation.

SWAT Model Setup

The SWAT model setup involved several key steps:

1. **Model Interface:** The ArcSWAT interface, integrated within ArcGIS software, was used. The SWAT model was downloaded and installed from the Texas A&M AgriLife Research website (https://swat.tamu.edu/).

2. **Watershed Delineation:** The boundary of the study area was defined using a shapefile within the ArcSWAT interface, and the DEM (Figure 1a) was used for watershed and sub-basin delineation.



a. 2015 b. 2017 c. 2019 d. 2020

Figure 4: Precipitation Maps of Ile-Ife for (a) 2015, (b) 2017, (c) 2019, and (d) 2020, showing the spatial distribution of rainfall in millimeters.

3. **Hydrologic Response Unit (HRU) Definition:** HRUs were created based on unique combinations of LULC, soil type, and slope, representing homogeneous land areas within the watershed. Standard thresholds (e.g., 10% for LULC, 20% for soil, and 10% for slope) were applied to define HRUs, ensuring sufficient representation of the watershed's variability.

4. **Input Data Integration:** The LULC data for the years 2015, 2017, 2019, and 2020 (Figure 2 a-d), precipitation data for the corresponding years (Figure 3 a-d), and the soil data (Figure 1b) were meticulously integrated as crucial meteorological and physical parameters.

5. **Model Parameterization:** The SWAT model parameters related to hydrology, soil, and land use were parameterized based on the input data and relevant literature, utilizing default SWAT values where local specifics were unavailable.

6. **Model Calibration:** The ArcSWAT model was calibrated for the watershed. Due to the absence of long-term observed groundwater level data, streamflow data from the region (if available, state source) or regionalized parameters from similar hydro-climatic zones were used for calibration. This involved adjusting model parameters within acceptable ranges to optimize performance, using metrics such as the Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R^2), and Percent Bias (PBIAS) to evaluate the model's ability to simulate the hydrological variables, particularly streamflow.

7. **Scenario Analysis:** Following initial calibration, the model was updated with LULC data for the years 2017, 2019, and 2020 to examine the effect of LULC changes on groundwater levels and evapotranspiration under historical conditions.

Analysis of DEM and LULC Effects

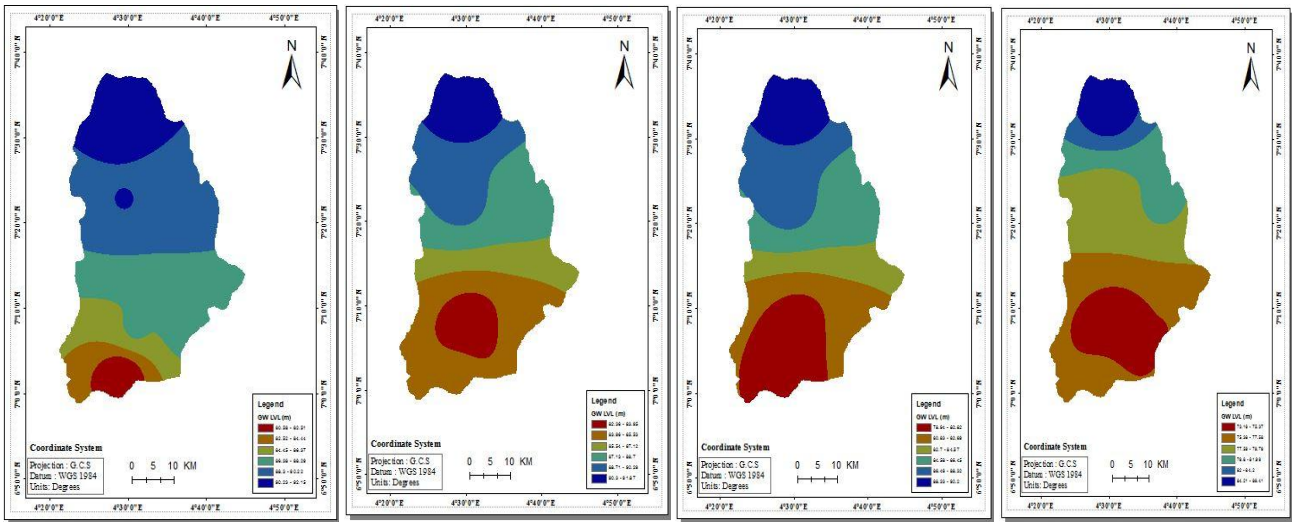
The calibrated SWAT model was run for each of the LULC periods (2015, 2017, 2019, and 2020) to simulate the hydrological responses of the watershed. The model outputs for groundwater level and actual evapotranspiration were analyzed in conjunction with the DEM (Figure

1a) and LULC maps (Figure 2a-d) to determine the spatial and temporal effects of these factors.

The spatial distribution of simulated groundwater levels (GW LVL) for the years 2015, 2017, 2019, and 2020 are shown in Figure 5 (a-d), with groundwater levels ranging from approximately 40.25 m to 92.15 m. In 2015 (Figure 5a), higher groundwater levels (blue and green) were predominantly observed in the southern and southwestern regions, while lower levels (red and brown) were more prevalent in the north and northeast. Similar spatial patterns persisted in 2017 (Figure 5b) and 2019 (Figure 5c), with slight variations. The groundwater level map for 2020 (Figure 5d) indicated a general decrease in higher groundwater level areas.

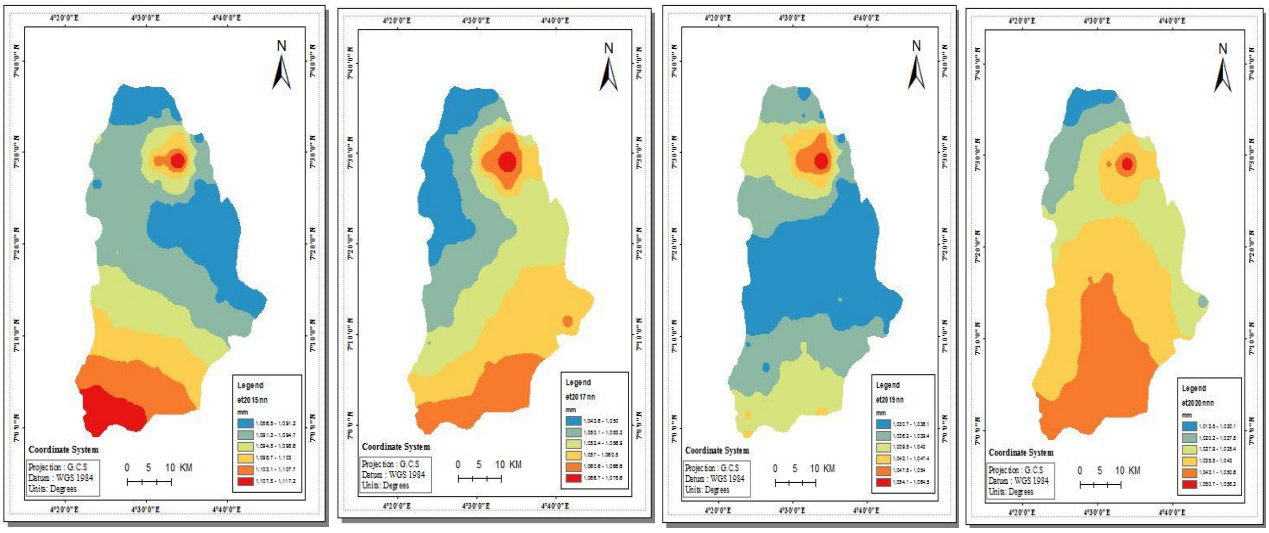
The spatial patterns of simulated actual evapotranspiration (et20) for the years 2015, 2017, 2019, and 2020 are presented in Figure 6 (a-d), with evapotranspiration values ranging from approximately 1012.8 mm to 1117.2 mm. In 2015 (Figure 6a), higher evapotranspiration rates (red and orange) were observed in the central and northern parts of the watershed, while lower rates (blue and light blue) were more common in the south.

This pattern shifted slightly in 2017 (Figure 6b), 2019 (Figure 6c), and 2020 (Figure 6d), indicating temporal variations in evapotranspiration across the Ile-Ife watershed. Statistical analyses and spatial mapping techniques within ArcGIS were used to identify trends and patterns in groundwater levels and evapotranspiration in relation to elevation and land cover changes.



a. 2015 b. 2017 c. 2019 d. 2020

Figure 5: Simulated Groundwater Level Maps of Ile-Ife for (a) 2015, (b) 2017, (c) 2019, and (d) 2020, depicting the spatial variation in groundwater levels in meters.



a. 2015 b. 2017 c. 2019 d. 2020

Figure 6: Simulated Actual Evapotranspiration Maps of Ile-Ife for (a) 2015, (b) 2017, (c) 2019, and (d) 2020, showing the spatial distribution of evapotranspiration in millimeters.

DISCUSSION

This study provides specific insights into the impact of digital elevation models (DEM) and land use and land cover (LULC) changes on groundwater level and evapotranspiration within the Ile-Ife watershed of Nigeria between 2015 and 2020. Utilizing the SWAT model, our analysis has revealed distinct spatial and temporal patterns directly relevant to the unique characteristics of this region, allowing us to build upon and, in some respects, diverge from existing understanding.

The analysis of the DEM of Ile-Ife revealed a clear spatial pattern in groundwater levels corresponding to elevation. Specifically, the higher northern and northeastern regions (255 to 361 meters) exhibited lower groundwater levels, a finding that aligns with the general understanding that steeper slopes at higher elevations often lead to increased surface runoff and reduced infiltration, limiting groundwater recharge [1]. Conversely, the lower regions (100 to 255 meters) in the south and southwest showed higher groundwater levels, consistent with better recharge conditions [6]. However, the increased evapotranspiration observed in these lower regions suggests a dynamic interplay between recharge and water loss, a factor that requires careful consideration in water resource management, as also highlighted in the study by [19] in a different Ethiopian catchment.

Our assessment of LULC changes between 2015 and 2020 in Ile-Ife indicated a notable decrease in forest cover by 1.17% and an increase in urban/built-up land by 0.653%. Agricultural land also showed a net increase of 0.0032% over this period. These specific land cover changes are consistent with general global trends of urbanization and agricultural expansion [2], and their impacts on hydrological processes are well-documented. For instance, the 0.653% increase in urban areas in Ile-Ife, while seemingly small, contributes to an increase in impervious surfaces, which is known to limit localized infiltration and diminish groundwater recharge, corroborating findings by [3] in northwestern Bangladesh.

The 1.17% loss in forest cover in Ile-Ife likely contributed to the simulated reduction in overall evapotranspiration from forested areas. This finding contrasts with studies such as Liu et al. (2009) in China, where increased forest cover correlated with increased ET, highlighting that the type of forest cover and local climatic context are

crucial. In Ile-Ife, the specific nature of the replaced vegetation or altered microclimates could explain this reduction.

The SWAT model simulations for Ile-Ife estimated a declining trend in groundwater recharge from 0 to 92.15 mm in 2015 to 0 to 86.41 mm in 2020. This specific trend, directly linked to the observed LULC changes, corroborates findings from other studies, such as [10] in Ethiopia, who also reported decreased groundwater recharge with land use changes. The simulated reduction in total mean annual actual evapotranspiration in Ile-Ife from 1117.20 mm in 2015 to 1058.30 mm in 2020 further emphasizes the hydrological impact of these land surface alterations. This reduction in ET, potentially linked to the decrease in forest cover, aligns with the general understanding of the role of vegetation in the water balance [13]. The temporal variation in surface runoff in Ile-Ife, showing an initial increase followed by a decrease in 2020, highlights the complex and potentially non-linear hydrological responses of the watershed to LULC change, a complexity also observed in studies like [2].

Gap Filled by This Research

While previous scholarly efforts have extensively elucidated LULC-induced hydrological shifts across diverse global contexts [14] a notable gap existed in the systematic and quantitative assessment of these specific impacts—especially the combined influence of DEM and LULC on both groundwater levels and ET—within the unique hydrological context of Ile-Ife, Southwestern Nigeria. This research has precisely filled this gap by providing a detailed, model-based analysis using localized data for a five-year period. Unlike broader regional studies or those focused on different climatic or geological settings, our study offers specific, quantified insights into the LULC change trajectories in Ile-Ife and their direct impacts on groundwater levels and evapotranspiration. This localized and quantitative assessment provides a crucial baseline for future water resource management and sustainable development planning tailored to the specific challenges and opportunities of the Ile-Ife watershed.

LIMITATIONS OF THE STUDY

While this study provides valuable insights into the hydrological dynamics of the Ile-Ife watershed, it is important to acknowledge certain limitations that should be considered when interpreting the findings, particularly in the context of existing literature in the field.

Firstly, the accuracy of the SWAT model simulations is inherently dependent on the quality and resolution of the input data. The use of SRTM DEM with a 30-meter spatial resolution, while widely utilized in regional-scale hydrological studies [15], might not fully capture the nuanced micro-topographical variations within the heterogeneous and urbanizing Ile-Ife watershed. This can potentially introduce a degree of uncertainty in fine-scale hydrological flow paths and localized groundwater estimations. Furthermore, as highlighted by [17], the resolution of land cover data can significantly influence hydrological model outputs; thus, potential inaccuracies in the Landsat-derived LULC classification, particularly in distinguishing between subtly different land uses or features, could have propagated uncertainties into the model parameterization. While efforts were made to ensure robust classification, a formal, quantitative accuracy assessment (e.g., using independent ground truth points and a confusion matrix) was beyond the scope of this study, a common challenge in data-scarce regions.

Secondly, the reliance on remotely sensed precipitation and soil data presents another potential limitation. While satellite-based precipitation products (e.g., GPM IMERG) provide valuable spatial coverage and overcome the scarcity of ground-based gauges, their accuracy might differ from direct, long-term in-situ measurements. Similarly, global soil databases, while comprehensive, might not perfectly represent the local-scale variations in soil properties crucial for precise infiltration and groundwater recharge rates, a factor emphasized by [1] regarding the single resource concept. The absence of a dense network of ground-based rain gauges and detailed local soil surveys for validation limited the direct calibration of these input datasets.

A significant limitation of this study is the lack of readily available, long-term in-situ groundwater level data for direct calibration and validation of the SWAT model's groundwater component. While the model was calibrated using streamflow data parameters from similar hydro-climatic zones, the absence of direct groundwater level measurements increases the uncertainty associated with the absolute values of the simulated groundwater recharge and levels. This challenge is common in hydrological studies, particularly in data-scarce regions [18], where researchers often rely on alternative calibration approaches.

Furthermore, the five-year study period (2015-2020), while providing a snapshot of the hydrological responses to LULC changes, might not be sufficiently long to capture the full spectrum of inter-annual climate variability or long-term trends in groundwater storage and evapotranspiration. Longer-term studies, such as those conducted by [3] over more extended periods in Bangladesh, can provide a more robust understanding of the impacts of LULC change on hydrological regimes, particularly in the context of climate change.

Finally, the SWAT model, like all hydrological models, involves certain assumptions and simplifications of complex real-world processes. While SWAT is a widely used and validated model in numerous studies (e.g., [12, 10]), its representation of processes such as groundwater flow and evapotranspiration might not perfectly reflect the specific subsurface complexities or microclimatic conditions within the Ile-Ife watershed. Efforts were made through careful parameterization to minimize these inherent model limitations.

CONCLUSION

This study successfully provides a comprehensive and localized assessment of the impact of Digital Elevation Models (DEM) and Land Use/Land Cover (LULC) changes on groundwater levels and evapotranspiration within the Ile-Ife watershed, Nigeria, from 2015-2020. By employing the Soil and Water Assessment Tool (SWAT) and integrating remote sensing data, this research quantifies hydrological responses in a region previously under-examined in this specific context, thereby addressing a notable gap in the hydrological literature for Southwestern Nigeria.

The findings revealed a significant spatial correlation between the DEM and simulated groundwater levels in Ile-Ife. Higher elevation regions (255 to 361 meters) consistently exhibited lower groundwater, aligning with established hydrological principles of increased runoff and reduced infiltration often associated with steeper terrains. Conversely, lower elevation areas (100 to 255 meters) showed higher groundwater levels, consistent with better recharge conditions, although accompanied by increased evapotranspiration rates. The analysis of LULC changes between 2015 and 2020 in Ile-Ife indicated a 1.17% decrease in forest cover and a 0.653% increase in urban/built-up land, alongside a net increase of 0.0032% in agricultural land. These specific land cover transformations demonstrably influenced the watershed's hydrology. The simulated decline in groundwater recharge from 0-92.15 mm in 2015 to 0-86.41 mm in 2020 corroborates findings from other developing regions facing similar LULC changes. The reduction in total mean annual actual evapotranspiration from 1117.20 mm to 1058.30 mm, likely linked to the observed deforestation, suggests that local biophysical context is crucial in determining ET responses, as our results presented a nuanced view compared to some studies where increased forest cover led to increased ET. Furthermore, the complex temporal variations in surface runoff, initially increasing then decreasing in 2020, highlight the dynamic interplay of LULC and hydrological processes.

This study's primary contribution lies in its localized and quantitative analysis for Ile-Ife, a geographical and thematic area previously lacking such systematic assessment. It offers precise insights into the unique LULC change trajectories and their quantified impacts on groundwater levels and ET within this specific tropical urbanizing environment. The implications of these findings for Ile-Ife are significant: the observed declining trend in groundwater recharge, exacerbated by deforestation and urbanization, underscores the urgent need for sustainable land management practices to ensure long-term water security. Recommendations include implementing reforestation efforts and integrating green infrastructure into urban planning to enhance infiltration. The potential effectiveness of watershed management practices, hinted at by the observed decrease in surface runoff in later

years, suggests that targeted interventions can foster a more resilient hydrological system.

While providing valuable insights, this study acknowledges limitations such as the reliance on remote sensing data of 30-meter resolution for DEM and LULC, which may not capture all micro-topographical variations or fine-scale LULC changes. The absence of long-term in-situ groundwater level data for direct model validation also presents a limitation, a common challenge in data-scarce regions. Future research should aim to utilize higher-resolution DEM and LULC data, integrate more extensive ground-based hydrological measurements for robust calibration and validation, and incorporate climate change projections to provide a more comprehensive understanding of the long-term water resource security in Ile-Ife. Investigating the socio-economic drivers of the observed LULC changes and engaging stakeholders in the development of sustainable land and water management strategies are also critical next steps.

In conclusion, this study offers a robust, model-based assessment of the hydrological impacts of DEM and LULC changes in the Ile-Ife watershed. The findings highlight the region's vulnerability to ongoing environmental changes and underscore the imperative for informed, sustainable management practices to safeguard water resources and ecological integrity amidst increasing developmental pressures.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the author(s) used GEMINI 2.0 Flash Service in order to improve the readability of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Author Contribution

Caleb Olutayo Oluwadare: Conceptualization, Writing- Review & Editing, Supervision.

John Adeyemi Eyinade: Methodology, Data curation, Visualization.

Micheal Oluwatimileyin Adebayo: Writing- Original draft preparation, Data Interpretation.

Conflicts of Interest

The authors declare no conflicts of interest.

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