FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

SPATIAL ANALYSIS OF URBANIZATION IMPACTS ON WATER RESOURCES USING GEOGRAPHIC INFORMATION SYSTEM IN KANO CITY

Ajibade, F. O.

Department of Civil and Environmental Engineering, Federal University of Technology, Akure, PMB 704, Nigeria

Correspondence: foajibade@futa.edu.ng

Ajibade, F. O. (2025): Spatial Analysis of Urbanization Impacts on Water Resources Using Geographic Information System in Kano City. *FUTA Journal of Engineering and Engineering Technology /19(1),* 143-154

Received Date: 12.4.25 **Accepted Date: 09.6.25**

Abstract
Urbanization is a global phenomenon, with over half the world's population now residing in urban areas. Rapid urban expansion, particularly in developing regions like Africa and Asia, exerts immense pressure on natural resources, especially water. This study employs Geographic Information System (GIS) and remote sensing techniques to assess the spatial impacts of urbanization on water resources in Kano, Nigeria. Using high-resolution Landsat TM, ETM+, and OLI satellite imagery, land-use changes, groundwater levels, and surface water distribution from 1994 to 2024 were analyzed. The Modified Normalized Difference Water Index (MNDWI) reveals a decline in groundwater abundance as built-up areas expanded from 38.4 km² to 40.1 km², driven by intensive urbanization and agricultural activities. While groundwater stress remains minimal in Kano's original urban core, newly developed metropolitan areas experienced significant depletion between 2014 and 2024. Projections suggest continued groundwater reduction if urbanization persists. These findings underscore profound transformations in Kano's hydrological cycle, marked by disparities in water availability across urban zones. The study provides critical insights for policymakers and water resource managers, emphasizing the need for sustainable urban planning to mitigate water scarcity in fast-growing cities like Kano.

Keywords: *Urbanization, water resources, geographic information system (GIS), groundwater depletion, sustainable urban planning*

Introduction

Water is a fundamental resource essential for human survival, economic development, and environmental sustainability. However, the availability of freshwater is critically limited, constituting only 2.5–2.75% of the total water on earth, with the remaining majority being saline and largely unsuitable for direct human consumption (Sridhar and Sathyanathan, 2020). Groundwater, which accounts for nearly 99% of all liquid freshwater, serves as a primary source for domestic, agricultural, and industrial uses worldwide. However, multiple factors, including climate change, geographical features, groundwater depletion, and, most notably, urbanization, threaten the sustainability and quality of this vital resource (Kiflay *et al.,* 2025). Given the rapid growth of urban areas, sustainable water resource management faces significant challenges. Currently, over 55% of the world's population resides in urban centers, with projections indicating an increase to 68% by 2050 (United Nations, 2018). This unprecedented urban expansion contributes to groundwater depletion, increased pollution, and reduced natural water infiltration due to surface sealing (Ajibade *et al.,* 2019; 2020; 2021a). In Nigeria, uncontrolled urban sprawl has led to unregulated groundwater extraction, pollution from industrial effluents, and improper sewage disposal. Additionally, the alteration of natural stream channels and the expansion of impervious surfaces disrupt groundwater recharge mechanisms, leading to declining water tables and increased flood risks. Given these challenges, it is crucial to understand how urbanization has affected groundwater recharge patterns over time and to determine the extent of urban expansion and its correlation with groundwater depletion.

Urbanization, defined as the expansion of built environments to accommodate growing populations, has accelerated significantly in recent decades, particularly in developing regions such as Africa and Asia (United Nations, 2018). While urbanization drives economic growth and infrastructure development, it simultaneously exerts severe pressure on water resources through increased demand, pollution, and modifications to natural hydrological systems (Ajibade *et al.,* 2021b, c;

Ayodele and Olubaju, 2024). Groundwater, a vital component of the earth's hydrological cycle, serves as a significant source of freshwater for human consumption, agriculture, and various industrial processes (Bierkens and Wada, 2019; Moeck *et al.,* 2020). However, the rapid conversion of natural landscapes into urban areas significantly modifies the hydrological dynamics of affected regions (Ongaga *et al.,* 2024). One of the most prominent effects of urbanization is the alteration of groundwater quantity and quality (Schirmer *et al.,* 2013; Vázquez-Suñé *et al.,* 2005), primarily due to excessive water consumption, wastewater discharge, and infiltration of emerging contaminants into aquifers (Vystavna *et al.,* 2019; Burri *et al.,* 2019; La Vigna, 2022). The dynamic interactions between urbanization, hydrological systems, and groundwater quality create significant challenges for sustainable water management. While some studies suggest that urban expansion leads to reduced groundwater recharge due to increased impervious surfaces (Siddik *et al.,* 2022), others argue that urban groundwater recharge can increase due to water infrastructure leaks and reduced evapotranspiration (Abdelaziz *et al.,* 2020; Wakode *et al.,* 2018). These findings highlight the complexity of urban groundwater dynamics and emphasize the need for localized studies that account for diverse urban settings. In regions where urban expansion is poorly regulated, as in Kano, groundwater sustainability remains a pressing concern.

Despite the growing body of research on urbanization and water resource management, a critical gap remains in spatially explicit analyses that integrate Geographic Information Systems (GIS) and remote sensing. These technologies offer advanced tools for mapping, monitoring, and predicting changes in water resources due to urban expansion. However, their application in African cities, including Kano, remains limited, necessitating further investigation into how urbanization influences groundwater quality and sustainability in Kano City and how GIS and remote sensing technologies can be leveraged to assess groundwater sustainability. Unlike other natural resources, water has no substitute, making its sustainable management a priority in urban planning. As a rapidly growing city in Sub-Saharan Africa, Kano is experiencing severe pressure on its groundwater resources due to rapid urbanization. The necessity for sustainable urban water management in Kano cannot be overstated, given its critical role in socio-economic development and environmental stability. Previous studies have examined the environmental impacts of urbanization globally (Ramachandra *et al.,* 2013; Unah and Okopi, 2021); however, limited research has explored the specific effects of urban expansion on groundwater dynamics in Kano. By employing GIS and remote sensing technologies, this study provides spatially detailed insights into the extent of urban-induced groundwater stress. These findings support policymakers, urban planners, and environmental managers in devising sustainable strategies for water conservation and land-use planning. Moreover, the study aligns with the United Nations Sustainable Development Goal 6 (SDG 6), which advocates universal access to clean water and sustainable water management practices.

The study relies on high-resolution satellite imagery, hydrological datasets, and socio-economic data to construct comprehensive GIS models. However, limitations include the availability and accuracy of secondary data sources, potential inconsistencies in historical land-use records, and challenges in obtaining real-time groundwater monitoring data. Despite these constraints, the study aims to provide a robust, data-driven analysis of urbanization's effects on groundwater resources in Kano by assessing the trend of urbanization in Kano City using GIS and remote sensing techniques, evaluating changes in groundwater levels over time, and analyzing the impact of urbanization on groundwater quality and sustainability. By addressing these objectives, the study aims to bridge existing knowledge gaps and offer actionable insights for sustainable urban and water resource management in Kano and similar rapidly urbanizing regions.

Materials and Methods

Study Area

Kano City (the capital of Kano State, Nigeria) has a history spanning over a thousand years. The city experiences a tropical wet and dry climate (Aw) according to Köppen's classification, characterized by high temperatures reaching up to 43°C (Ibrahim, 2011) and an annual mean rainfall of approximately 80 mm. The region's climate is influenced by both tropical maritime and continental air masses, similar to other parts of the West African savannah. The geology consists primarily of Pre-Cambrian basement complex rocks, including gneisses, amphibolite, marble, and older granites, which make up about 80% of the area. The soils vary from mature types in the plains to immature ones on hill slopes, foot slopes, and valley bottoms. Loamy sand dominates the lower course of the area. Figure 1 presents the map of Kano City.

GIS-Based Methodology

The methodology for this study follows a GIS-based approach, as illustrated in Figure 2. The process includes data acquisition from Landsat TM, ETM+, and OLI satellite imagery, land-use classification, Modified Normalized Difference Water Index (MNDWI) computation, and groundwater stress analysis. This structured methodology is widely recognized for assessing urbanization impacts on

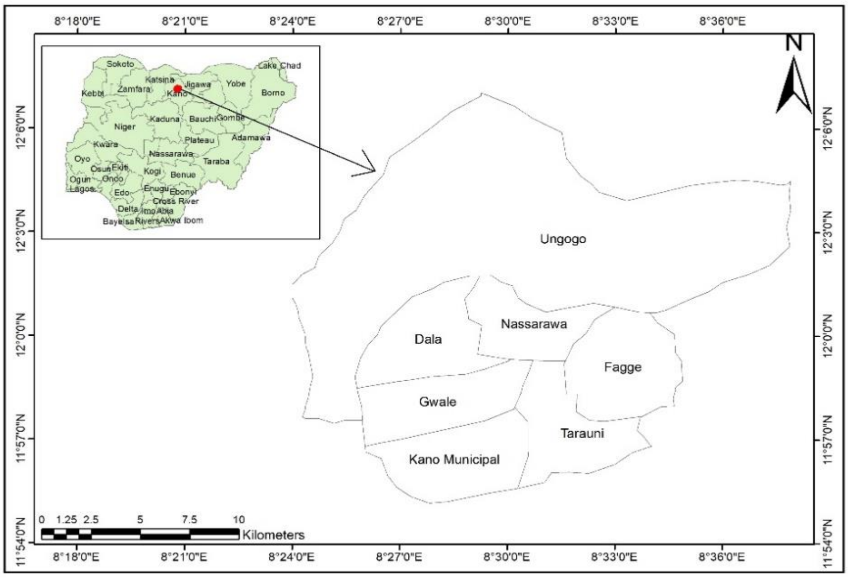

Figure 1: Map of Kano City

water resources (Ahmed *et al.,* 2021; Olabode and Comte, 2024; Chen *et al.,* 2024).

Data Collection
Satellite imagery from Landsat TM, ETM+, and OLI covering Kano City was acquired from the USGS/LANDSAT database. The specifications for each sensor system are as follows:

Landsat thematic mapper (Landsat 4-5)
The TM sensor includes seven spectral bands with a spatial resolution of **30 meters** for most bands and 120 meters for Band 6 (thermal), resampled to 30 meters (Table 1). Each scene covers 170 km (north-south) by 183 km (east-west).

Landsat Enhanced Thematic Mapper Plus (ETM+) (Landsat 7)
The ETM+ sensor provides eight spectral bands with a 30-meter resolution, except for Band 6 (thermal), acquired at 60 meters and resampled to 30 meters, and Band 8 (panchromatic) with 15-meter resolution (Table 2).

Landsat Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (Landsat 8)
Landsat 8 imagery consists of nine spectral bands with a 30-meter resolution, except for Band 8 (panchromatic) at 15 meters and Bands 10–11 (thermal) at 100 meters, resampled to 30 meters (Table 3). The path and row for the study area are p188 r52.

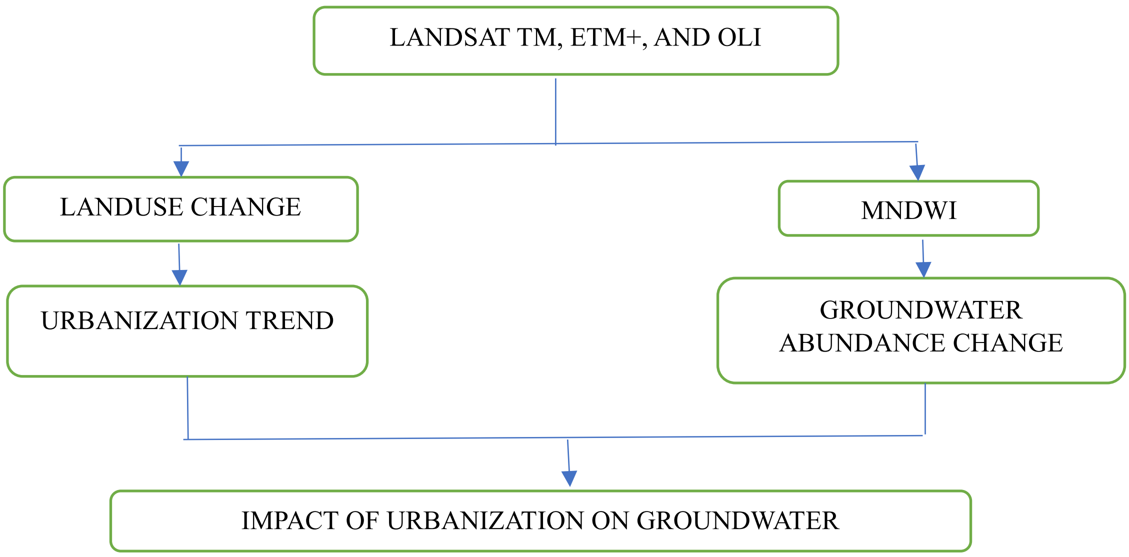

Figure 2: Schematic Representation of GIS Tools Workflow and Final Objective

Table 1: Thematic Mapper

Landsat 4-5	Bands	Wavelength (micrometer)	Resolution (meter)
Thematic Mapper (TM)	Band 1 – Blue	0.45-0.52	30
	Band 2 – Green	0.52-0.60	30
	Band 3 – Red	0.63-0.69	30
	Band 4 – Near Infrared (NIR)	0.76-0.90	30
	Band 5 – Shortwave Infrared	1.55-1.75	30
	(SWIR) 1	10.40-12.50	120*(30)
	Band 6 - Thermal	2.08-2.35	30
	Band 7 – Shortwave Infrared		
	(SWIR) 2		

*TM Band 6 was acquired at 120-meter resolution, but products are resampled to 30 meters pixels

Table 2: Enhanced Thematic Mapper (ETM+)

Landsat 7	Bands	Wavelength (micrometer)	Resolution (m)
Enhanced Thematic Mapper Plus (ETM+)	Band 1 – Blue	0.45-0.52	30
	Band 2 – Green	0.52-0.60	30
	Band 3 – Red	0.63-0.69	30
	Band 4 – Near Infrared (NIR)	0.77-0.90	30
	Band 5 – Shortwave Infrared	1.55-1.75	30
	(SWIR) 1	10.40-12.50	60*(30)
	Band 6 - Thermal	2.09-2.35	30
	Band 7 – Shortwave Infrared	52-90	15
	(SWIR) 2		
	Band 8 - Panchromatic		

*ETM+ Band 6 is acquired at 60-meter resolution, but products are resampled to 30-meter pixel

Table 3: Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Landsat 8	Bands	Wavelength (micrometer)	Resolution (m)
Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Band 1 – Ultra Blue	0.43-0.45	30
	Band 2 – Blue	0.45-0.51	30
	Band 3 – Green	0.53-0.59	30
	Band 4 – Red	0.64-0.67	30
	Band 5 – Near Infrared (NIR)	0.85-0.88	30
	Band 6 – Shortwave Infrared (SWIR) 1	1.57-1.65	30
	Band 7 – Shortwave Infrared (SWIR) 2	2.11-2.29	30
	Band 8 – Panchromatic	0.50 – 0.68	15
	Band 9 – Cirrus	1.36 – 1.38	30
	Band 10 – Thermal Infrared (TIRS) 1	10.60–11.19	100 *(30)
	Band 11 – Thermal Infrared (TIRS) 2	11.50-12.51	100 *(30)

*TIRS bands are acquired at 100-meter resolution, but are resampled to 30 meter in delivered data product.

Methods

Supervised Classification

Supervised classification was applied to identify land cover types in the image using training sites. The Maximum Likelihood Classifier (MLC) was employed due to its statistical decision-making approach, assigning pixels to the most probable class. This method, though computationally intensive, is known for its superior accuracy (Eastman, 1995). The resulting land-use and land-cover map was generated based on this classification.

Modified Normalized Difference Water Index

Modified Normalized Difference Water Index (MNDWI) was used to enhance the detection of water bodies while suppressing built-up areas. This method utilizes the visible green (GREEN) and

Table 4: Land use Area in Kano city between 1994 and 2024

Landuse	1994 Area (km^2)	2004 Area (km^2)	2014 Area (km^2)	2024 Area (km^2)
Built Up	38.4	40.1	59.0	124.1
Bare Surface	7.3	16.1	9.1	28.6
Light Vegetation	89.3	139.2	64.5	51.7
Dense Vegetation	4.3	6.6	3.1	13.0
Marshland	191.2	133.1	195.4	103.3
Water Body	1.0	0.4	0.33	10.6

Table 5: MNDWI statistics for Kano city between 1994 and 2024

Year	Maximum MNDWI	Minimum MNDWI	Mean MNDWI
1994	0.1980	-0.5638	-0.1829
2004	0.4224	-0.6776	-0.1276
2014	0.3374	-0.4505	-0.0566
2024	0.2675	-0.5152	-0.1238

shortwave infrared (SWIR1) bands, providing a significant improvement over the traditional Normalized Difference Water Index (NDWI) (Xu, 2006). The index values range between -1 and +1, where higher values indicate greater water content (Tuan *et al.,* 2019). The MNDWI formula is represented in Equation 1.

$$MNDWI = \frac{(G - SWIR1)}{(G + SWIR1)} \quad (1)$$

Where G is green and SWIR1 is shortwave infrared

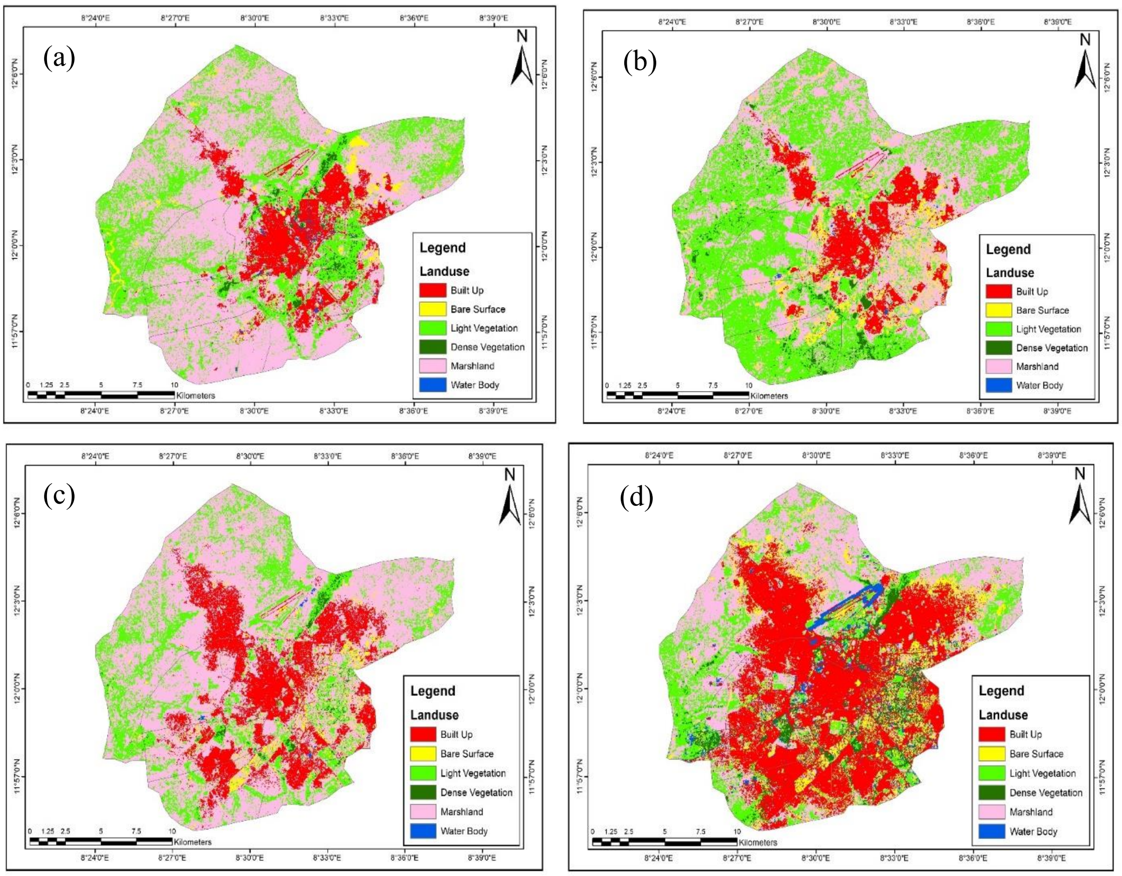

Figure 3: Kano city land use in (a) 1994, (b) 2004, (c) 2014 and (d) 2024

Results and Discussion

Land-use Change in Kano City

Kano City has undergone substantial land-use transformations between 1994 and 2024 due to rapid urbanization. The six identified land-use categories in the study area include built-up areas, bare surfaces, light vegetation, dense vegetation, marshlands, and water bodies (Table 4). Figures 3a–d illustrate the spatial distribution of these land-use types over the years. A significant trend observed is the expansion of built-up areas, which increased from 38.4 km² in 1994 to 124.1 km² in 2024, highlighting continuous urban growth. This expansion has primarily occurred at the expense of marshlands, which declined from 191.2 km² in 1994 to 103.3 km² in 2024, reflecting large-scale land conversion for infrastructure and settlement development. Similarly, light vegetation decreased from 89.3 km² to 51.7 km², and dense vegetation shrank from 4.3 km² to 13.0 km² within the same period. These changes indicate a significant alteration in the city's ecological landscape, with a shift towards impervious surfaces. Water bodies initially covered 1.0 km² in 1994, fluctuated in subsequent years, and later increased to 10.6 km² in 2024. This increase may be attributed to artificial reservoirs, urban water management interventions, or enhanced conservation efforts. Conversely, bare surfaces have exhibited inconsistent trends, reflecting dynamic land-use practices, including temporary land clearing and infrastructure expansion.

The observed changes in land-use patterns have significant hydrological and environmental implications for Kano City. The increase in impervious surfaces, resulting from urban expansion, reduces groundwater recharge rates while simultaneously increasing surface runoff. This is consistent with findings from Chen *et al*. (2024) and Olabode and Comte (2024), which highlight the disruption of natural hydrological cycles due to rapid urbanization. The reduction in vegetative cover further exacerbates these issues, as vegetation plays a critical role in natural filtration processes and soil water retention. Moreover, the conversion of marshlands into urban areas diminishes natural water retention zones, potentially increasing flood risks. The decline in light and dense vegetation suggests that Kano is experiencing a loss of green spaces, which could lead to higher urban heat island effects, reduced biodiversity, and increased soil degradation. The expansion of built-up areas indicates continued population growth and urbanization, which will exert more pressure on existing water resources, potentially leading to groundwater depletion and water scarcity.

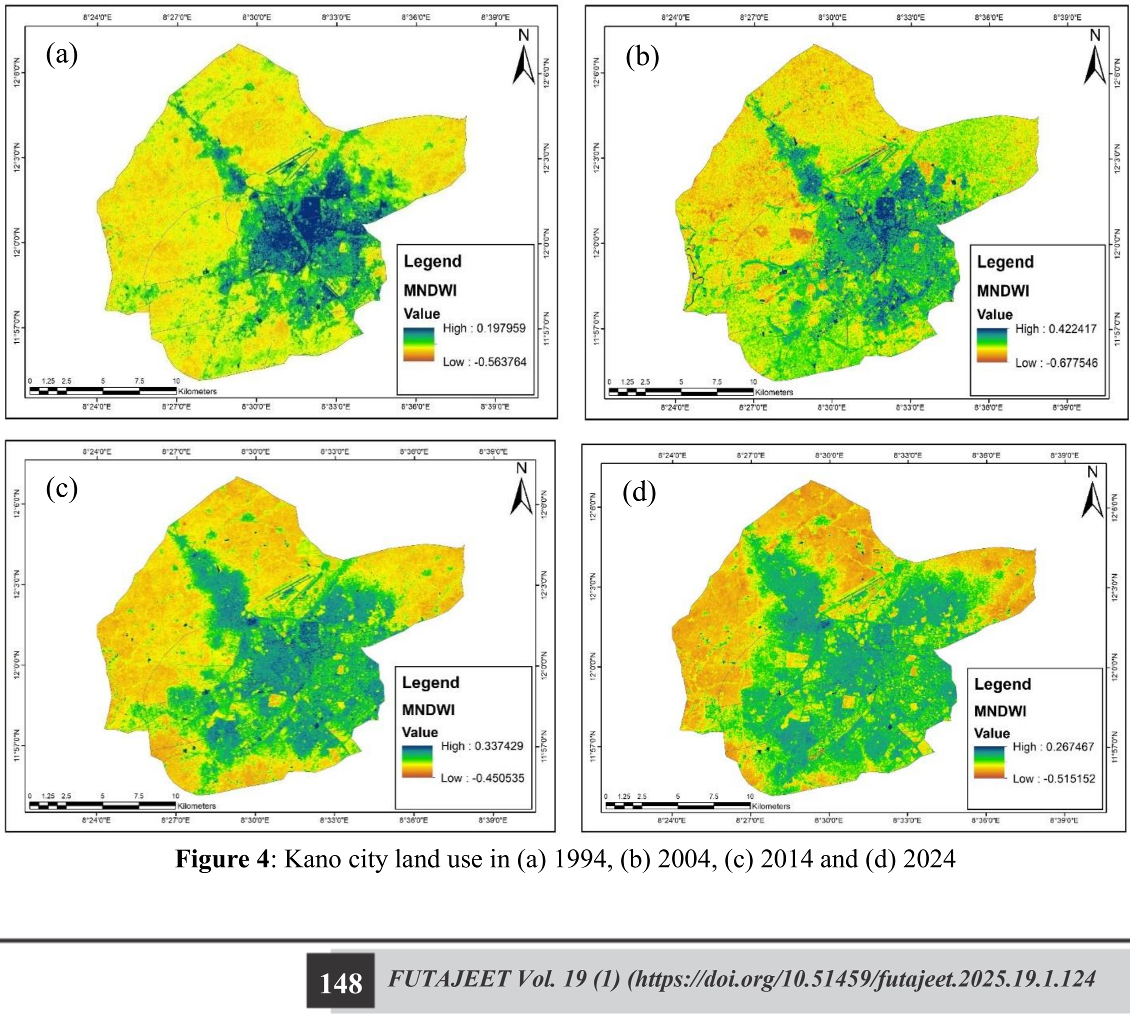

Figure 4: Kano city land use in (a) 1994, (b) 2004, (c) 2014 and (d) 2024

Analysis of MNDWI Results and Urbanization Trends

The Modified Normalized Difference Water Index (MNDWI) results reveal significant variations in groundwater availability over the study period, correlating with the increasing rate of urbanization in Kano State (Figure 4). The MNDWI is commonly used for detecting surface water bodies, with positive values indicating water presence and negative values representing non-water features. However, the threshold for distinguishing water bodies from other land-cover types may vary depending on regional characteristics and environmental conditions. In West Africa, particularly in the Sahel region, MNDWI has been effectively applied to water detection. Chen *et al*. (2024) found that in the Nigerien Sahel, pixels with an MNDWI value above zero were reliably classified as water bodies, efficiently suppressing bare land and built-up areas. Similarly, a study on Lake Chad, which spans multiple West African countries, highlighted the importance of calibrating MNDWI thresholds to minimize errors in water mapping. This underscores the necessity for region-specific threshold adjustments to ensure accurate groundwater assessments.

Table 5 presents the MNDWI values over the study years, showing a fluctuating trend in groundwater availability influenced by rapid land-use changes.

I. 1994: The maximum MNDWI of 0.1980 suggests localized groundwater abundance, while the minimum value of -0.5638 indicates areas with very low water presence. The mean MNDWI (-0.1829) reflects generally low groundwater availability across the region. At this time, the built-up area covered 38.4 km², allowing for natural groundwater recharge with minimal human interference.

II. 2004: The maximum MNDWI increased to 0.4224, indicating improved groundwater retention in certain regions. However, the minimum value dropped to -0.6776, highlighting increased dryness in some areas. The mean MNDWI (-0.1276) suggests a slight overall improvement in groundwater conditions. The built-up area expanded to 40.1 km², a modest increase that had a limited impact on recharge and possibly even facilitated localized groundwater retention due to vegetation growth in urban peripheries.

III. 2014: The maximum MNDWI declined to 0.3374, indicating a reduction in groundwater-abundant areas. The minimum value improved to -0.4505, suggesting a slight reduction in extreme dryness. The mean MNDWI (-0.0566) was the highest recorded, implying a temporary improvement in groundwater availability. However, urbanization significantly accelerated, with the built-up area reaching 59.0 km². This expansion led to increased impervious surfaces, reducing infiltration and causing higher surface runoff.

IV. 2024: The maximum MNDWI further declined to 0.2675, while the minimum value decreased to -0.5152, indicating persistently dry conditions. The mean MNDWI (-0.1238) suggests a marginal decrease in overall groundwater levels. This period saw a dramatic expansion in built-up areas to 124.1 km², more than doubling since 2014. The rapid urbanization significantly reduced natural recharge zones, exacerbating groundwater depletion and increasing water stress across the city.

The observed decline in MNDWI values over time aligns with findings from other rapidly urbanizing regions, where land-use change negatively impacts groundwater recharge. Ahmed et al. (2021) documented similar trends in Indian cities, where extensive urban expansion led to significant groundwater depletion. Chen et al. (2024) also reported that in the Chengdu-Chongqing Urban Agglomeration, impermeable surfaces from urban development disrupted natural hydrological cycles, increasing surface runoff and reducing infiltration rates. In West Africa, Olabode and Comte (2024) found that urban growth in Lagos, Nigeria, exacerbated water stress, particularly in newly developed areas. The findings from Kano City emphasize the need for sustainable urban planning and integrated water resource management to mitigate the adverse effects of urbanization on groundwater availability. Without appropriate measures, continued urban expansion could lead to severe groundwater depletion, increased water scarcity, and heightened flood risks. Implementing green infrastructure, improved water conservation policies, and controlled urban growth strategies will be crucial in preserving groundwater resources for future generations.

Changes in Kano City Groundwater

The analysis of groundwater changes in Kano City from 1994 to 2024 reveals a dynamic relationship between urban expansion and groundwater depletion. The variation in groundwater levels over time, driven by land-use changes, highlights the increasing stress on water resources due to urbanization. Higher change values indicate significant groundwater loss, while lower values suggest minimal reductions over time. The computed changes in groundwater availability across the study years are summarized in Figure 6 and Table 6:

I. 1994–2004: The minimum groundwater change was -0.4595, while the maximum was 0.6707. During this period, urban areas experienced less groundwater stress, whereas farmlands, light vegetation, and marshlands showed higher depletion rates. This indicates that groundwater recharge was still occurring in urban zones, but agricultural land experienced greater extraction and loss.

II. 2004–2014: The groundwater change ranged from a minimum of -0.7625 to a maximum of 0.5547. This period saw a notable decline in groundwater levels, particularly in newly developed urban areas. The expansion of impervious surfaces, such as roads, buildings, and paved areas, likely contributed to reduced infiltration and higher surface runoff, limiting groundwater recharge.

III. 2014–2024: The minimum groundwater change was -0.4492, while the maximum was 0.5184. The depletion of groundwater was most severe in newly urbanized regions, where rapid development further restricted natural recharge processes. Unlike earlier years, older urban areas showed relatively stable groundwater conditions, suggesting that pre-existing urban infrastructure had already reached a steady state of water balance, while newer developments continued to exacerbate groundwater depletion.

The results indicate a progressive trend of groundwater stress, particularly in newly developed urban zones. This aligns with studies in other rapidly urbanizing cities where groundwater availability has declined due to extensive land-use change. Chen *et al.* (2024) and Olabode and Comte (2024) reported similar findings in Chengdu-Chongqing (China) and Lagos (Nigeria) respectively, where rapid urban expansion led to reduced infiltration, increased water stress, and declining groundwater tables. In Kano City, the observed trends suggest that

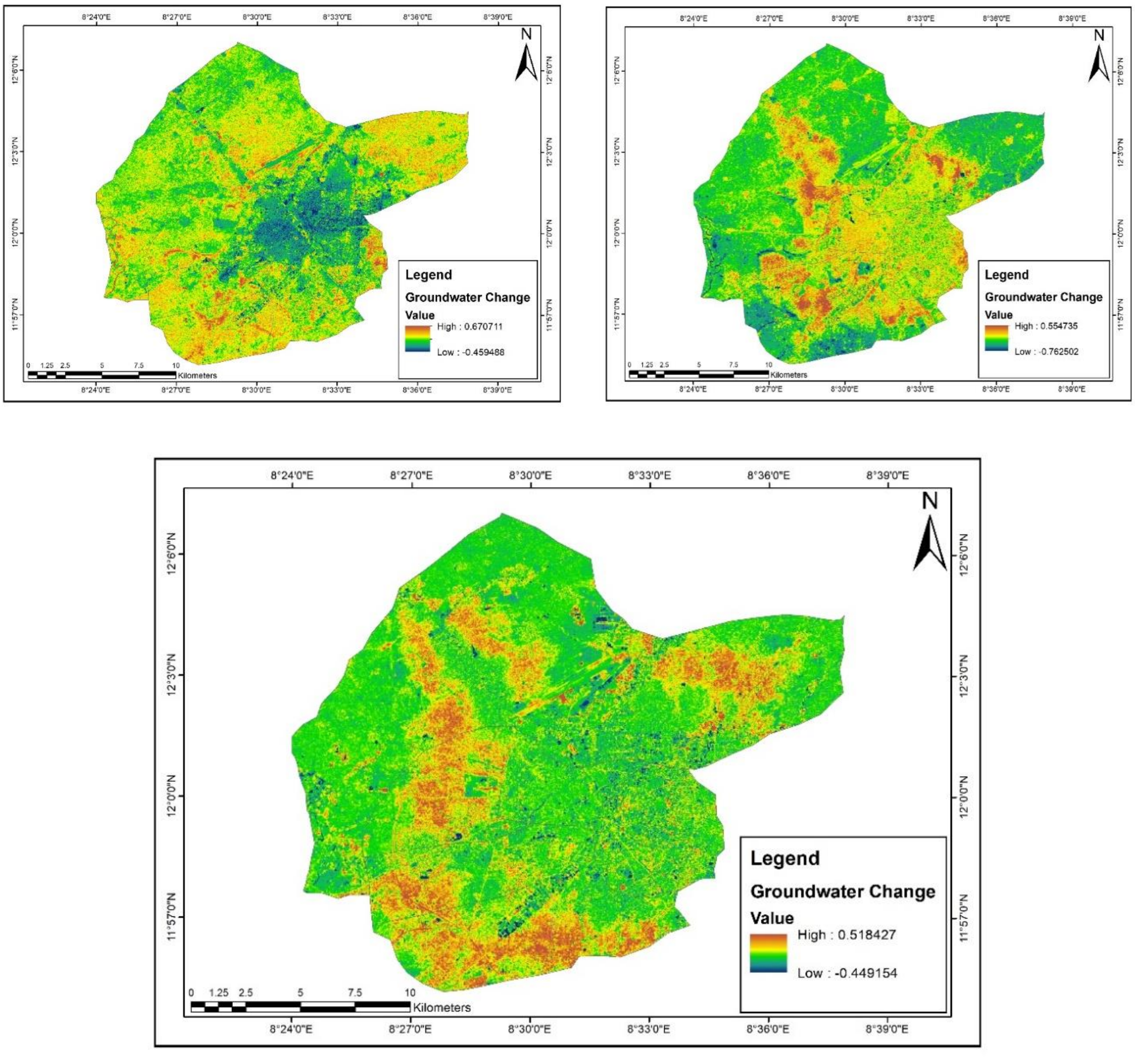

Figure 5: Changes in Kano City groundwater between (a)1994 and 2004, (b) 2004 and 2014, (c) between 2014 and 2024

uncontrolled urban growth without adequate water conservation strategies could lead to severe water shortages in the coming decades.

Impact of Urbanization on Kano City Groundwater

The continuous urban expansion in Kano City has had a significant impact on groundwater availability over the past three decades. The severity of groundwater reduction has varied across different time periods and urban zones, with newly developed areas experiencing higher levels of depletion compared to older, more established urban areas (Figure 3).

3.4.1 Temporal Trends in Groundwater Impact (1994–2024)

I. 1994–2004: The impact of urbanization on groundwater was minimal during this period, as urban expansion was still relatively controlled. The built-up areas did not significantly disrupt natural groundwater recharge, and permeable surfaces allowed for continued infiltration.

II. 2004–2014: This period marked increased groundwater stress, particularly in newly developed built-up areas. The expansion of impervious surfaces, such as roads and buildings, reduced infiltration rates, leading to greater surface runoff and lower groundwater recharge.

III. 2014–2024: Groundwater depletion persisted in built-up areas, but the most severe reduction was observed in newly urbanized zones. Older urban centers showed relatively stable conditions, likely due to the establishment of a new hydrological equilibrium over time.

Spatial Distribution of Groundwater Stress

A groundwater stress map was generated for the study period (1994–2024), highlighting areas of severe groundwater reduction risk (Figure 7). The analysis reveals a strong correlation between urban expansion and groundwater depletion, with newly developed zones experiencing the most significant stress. Nassarawa exhibited low to very low groundwater stress, as indicated by the green and blue color zones in Figure 8. This suggests that the area retains better groundwater recharge capacity, possibly due to higher vegetation cover and fewer impervious surfaces. Ungogo experienced very high groundwater stress levels, particularly in densely developed sections, although a few areas showed low stress levels. Gwale, Kano Municipal, and Dala showed consistently high groundwater stress levels, reflecting the long-term impact of urbanization and infrastructure expansion on groundwater resources. Fagge and Tarauni exhibited localized high-stress zones, indicating that some sections have undergone significant depletion, while others retain moderate groundwater availability. The findings highlight the critical impact of urban expansion on groundwater depletion, reinforcing the need for sustainable urban planning and water resource management strategies. The rapid conversion of vegetation and farmlands into built-up areas has significantly reduced groundwater recharge, leading to:

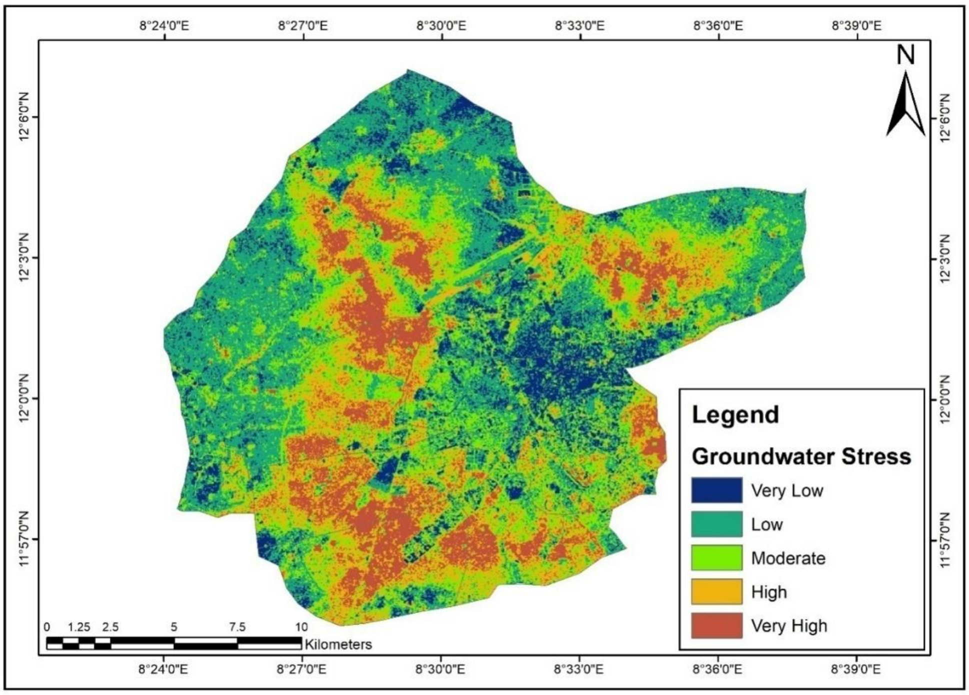

Figure 6: Risk of groundwater stress in Kano city between 1994 and 2024

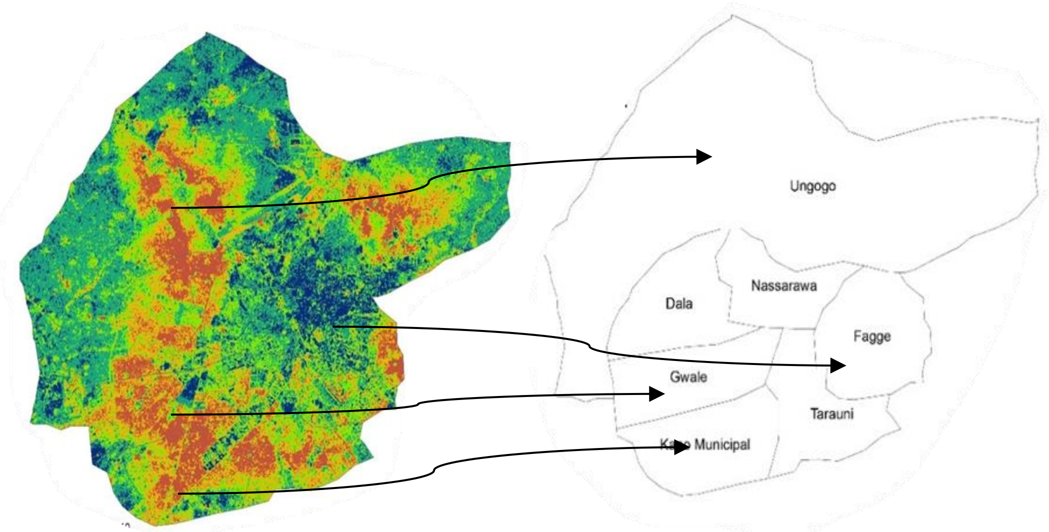

Figure 7: Comparison to show groundwater stress levels at different locations in Kano

i. Increased reliance on alternative water sources, which may not be sustainable in the long term.

ii. Potential water scarcity risks, especially in high-stress areas such as Gwale, Kano Municipal, and Dala.

iii. The need for urban water management policies, including the promotion of green infrastructure and recharge-friendly urban designs to mitigate groundwater loss.

Conclusion

This study demonstrates a continuous increase in urbanization in Kano City from 1994 to 2024, leading to a notable decline in groundwater availability, as indicated by Modified Normalized Difference Water Index (MNDWI) analysis. The primary drivers of this reduction are intensive urban expansion and agricultural activities, which have significantly altered natural groundwater recharge processes. The findings reveal that groundwater stress was minimal in the initial urban core, whereas severe depletion was observed in newly developed urban areas, particularly between 2014 and 2024. Spatial analysis highlights regions such as Gwale, Kano Municipal, and Dala as experiencing very high groundwater stress, primarily due to impermeable surfaces, reduced infiltration, and increased groundwater extraction. If urbanization continues beyond 2024 without effective water management strategies, groundwater depletion is expected to intensify, increasing the risk of water scarcity. Therefore, integrated urban planning, groundwater conservation measures, and sustainable land-use policies are essential to mitigate future groundwater stress and ensure long-term water security in Kano City.

References

Abdelaziz, K.K., Nicaise, Y., Séguis, L., Ouattara, I., Moussa, O., Auguste, K., Kamagaté, B., and Diakaria, K. (2020). Influence of land use land cover change on groundwater recharge in the continental terminal area of Abidjan, Ivory Coast. *Journal of Water Resources and Protection*, 12(5), 431 - 453

Ahmed, S., Kumar, S., and Thakur, J.K. (2021). Remote sensing and GIS-based assessment of groundwater depletion due to urbanization. *Environmental Earth Sciences, 80*(2), 120 - 135.

Ajibade, F.O., Adelodun, B., Lasisi, K.H., Fadare, O.O., Ajibade, T.F., Nwogwu, N.A., Sulaymon, I.D., Ugya, A.Y., Wang, H.C., and Wang, A. (2021a). Environmental Pollution and their Socio-economic Impacts. In: Kumar, A., Singh, V. K., Singh, P. K., and Mishra, V. (eds) *Microbe mediated Remediation of environmental contaminants*, Woodhead Publishing, Elsevier, US., 321-354.

Ajibade, F.O., Olajire, O.O., Ajibade, T.F., Fadugba, O.G., Opafola, O.T., and Adewumi, J.R. (2021b). Groundwater Potential Assessment as a Preliminary Step to Solving Water Scarcity Problem in Ekpoma, Edo State, Nigeria. *Acta Geophysica*, 69, 1367–13816.

Ajibade, F.O., Ajibade, T.F., Idowu, T.E., Nwogwu, N.A., Adelodun, B., Lasisi, K.H., Opafola, O.T., Ajala, O.A., Fadugba, O.G., and Adewumi, J.R. (2021c). Flood-prone area mapping using GIS-based analytical hierarchy frameworks for Ibadan city, Nigeria. *Journal of Multi-Criteria Decision Analysis*. 28(5-6), 283-295.

Ajibade, F.O., Olajire, O.O., Ajibade, T.F., Nwogwu, N.A. Lasisi, K.H., Alo, A.B., Owolabi, T. A., and Adewumi, J.R. (2019). Combining Multicriteria Decision Analysis with GIS for suitably siting landfills in a Nigerian State. *Environmental and Sustainability Indicators* 3-4.

Ajibade, F.O., Nwogwu, N.A., Adelodun, B., Abdulkadir, T.S., Ajibade, T.F., Lasisi, K.H., Fadugba, O.G., Owolabi, T.A., and Olajire, O. O. (2020). Application of RUSLE integrated with GIS and remote sensing techniques to assess soil erosion in Anambra State, South-Eastern Nigeria. *Journal of Water and Climate Change*, 11 (S1): 407–422.

Ayodele, I.V., and Olubaju, A.E. (2024). Geospatial assessment of environmental impact of urban growth in Akure South, Ondo State, Nigeria. *Journal of Environment*, *4*(1), 1 - 23.

Bierkens, M.F., and Wada, Y. (2019). Non-renewable groundwater use and groundwater depletion: a review. *Environmental Research Letters,* 14(6), 063002.

Burri, N.M., Weatherl, R., Moeck, C., and Schirmer, M. (2019). A review of threats to groundwater quality in the Anthropocene. *Science of the Total Environment* 684,136 - 154

Chen, Y., Zhong, S., Liang, X., Li, Y., Cheng, J., and Cao, Y. (2024). The Relationship between Urbanization and the Water Environment in the Chengdu-Chongqing Urban Agglomeration. *Land*, *13*(7), 1054.

Kiflay, E., Schirmer, M., Foppen, J.W., and Moeck, C. (2025). Impact of urbanization on groundwater recharge: altered recharge rates and water cycle dynamics for Arusha, Tanzania. *Hydrogeology Journal*. 33:33–47.

La Vigna, F. (2022). Urban groundwater issues and resource management, and their roles in the resilience of cities. *Hydrogeology Journal* 30(6), 1657 - 1683

Lerner, D.N., and Barrett, M.H. (1996). Urban groundwater issues in the United Kingdom. *Hydrogeology Journal* 4, 80 - 89

Moeck, C., Grech-Cumbo, N., Podgorski, J., Bretzler, A., Gurdak, J.J., Berg, M, Schirmer, M. (2020). A global-scale dataset of direct natural groundwater recharge rates: a review of variables, processes and relationships. *Science of the Total Environment,* 717, 137042.

Olabode, O.F., and Comte, J. (2024). Water scarcity in the fast-growing megacity of Lagos, Nigeria and opportunities for managed aquifer recharge. *Wiley Interdisciplinary Reviews Water*, *11*(5), e1733.

Ongaga, C.O., Makokha, M., Obiero, K., Kipkemoi, I. and Diang'a J. (2024). Urbanization and hydrological dynamics: a 22-year assessment of impervious surface changes and runoff in an urban watershed. *Frontiers in Water*. 6:1455763.

Ramachandra, T.V., Bharath, H.A., and Sowmyashree, M.V. (2013). Analysis of spatial patterns of urbanisation using geoinformatics and spatial metrics. *Theoretical and Empirical Researches in Urban Management,* 8(4), 5-24.

Schirmer, M., Leschik, S., and Musolff, A. (2013). Current research in urban hydrogeology: a review. *Advanced Water Resources* 51, 280 - 291

Siddik, M.S., Tulip, S.S., Rahman, A., Islam, M.N., Haghighi, A.T., Mustafa, S.M.T. (2022). The impact of land use and land cover change on groundwater recharge in northwestern Bangladesh. *Journal of Environmental Management* 315, 115130.

Sridhar, M.B., and Sathyanathan, R. (2020). Assessing the spatial impact of urbanization on surface water bodies using remote sensing and GIS. *IOP Conference Series Materials Science and Engineering*, *912*(6), 062069.

Tuan, V.A., Hang, L.T.T., and Quang, N.H. (2019). Monitoring urban surface water bodies changes using MNDWI estimated from pan-sharpened optical satellite images. *FIG Working Week 2019, Geospatial Information for a Smarter Life and Environmental Resilience*. Hanoi, Vietnam, April 22 - 26.

Unah, N., and Okopi, M. (2021). Urbanization and Sustainable growth of Urban Kano, Nigeria. *IOP Conference Series Earth and Environmental Science*, *665*(1), 012063.

United Nations, Department of Economic and Social Affairs, Population Division. (2018*). World Urbanization Prospects: The 2018 Revision, Online Edition.*

Vázquez-Suñé, E., Sánchez-Vila, X., and Carrera, J. (2005) Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain. *Hydrogeology Journal* 13, 522 - 533

Vystavna, Y., Schmidt, S., Diadin, D., Rossi, P., Vergeles, Y., Erostate, M., Yermakovych, I., Yakovlev, V., Knöller, K., and Vadillo, I. (2019). Multitracing of recharge seasonality and contamination in groundwater: a tool for urban water resource management. *Water Research* 161, 413 - 422

Wakode, H.B., Baier, K., Jha, R., and Azzam, R. (2018). Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad, India. *Int Soil Water Conservation Res* 6(1), 51 - 62

Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27, 3025 - 3033.