www.ijarp.com ISSN 2456-9992 Page: 01-24

International Journal Advanced Research Publications

Research Article

Volume: 02
Issue: 01

URBAN RESILIENCE THROUGH THE USE OF GEOSPATIAL DATA TO OPTIMIZE DRAINAGE NETWORK PLANNING AND MANAGEMENT IN OMOKU, RIVERS STATE, NIGERIA

Owukio, Stewart Senibo*[1], Jonah, Iyowuna Benjamin[2], Eke, Stanley Nwaudo[3]

[1]Department of Urban and Regional Planning, Rivers State University Port Harcourt, Nigeria.

[2]Department of Surveying and Geomatics, Rivers State University Port Harcourt, Nigeria.

[3]Department of Surveying and Geomatics, Rivers State University Port Harcourt, Nigeria.

Article Received: 05 December 2025, Article Revised: 25 December 2025, Published on: 13 January 2026

***Corresponding Author: Owukio, Stewart Senibo**

Department of Urban and Regional Planning, Rivers State University Port Harcourt, Nigeria.

DOI: https://doi-doi.org/101555/ijarp.4297

ABSTRACT

Urban flooding poses a significant threat to public infrastructure, human health, and sustainable development in Nigeria, particularly in mid-sized but rapidly urbanising towns such as Omoku, Rivers State. This study leverages geospatial technologies, hydrological modelling, and field-based survey data to assess the drainage landscape and propose an optimised network for improved flood resilience. High-resolution satellite imagery (Landsat 8 and Sentinel-2) and a 30-metre Shuttle Radar Topography Mission (SRTM) DEM were integrated in a GIS environment to derive land use/land cover (LULC) classification, slope gradients, and flow direction. GNSS data collected using SinoGNSS T30 and differential levelling were used to validate DEM outputs and drainage flow assumptions. The classified LULC showed that impervious surfaces and bare soil accounted for 90% of the urban surface (Figure 4.1), while vegetation and water bodies collectively covered only 10%, indicating minimal natural absorption capacity. Rainfall analysis over a 23-year period (2000–2022) revealed that peak precipitation occurs between June and September, with September recording the highest mean monthly rainfall of 169.3 mm (Figure 4.2). Flow direction modelling (Figure 4.6) and stream order analysis revealed that several existing drainage alignments opposed natural terrain slopes, particularly along Market Road, Jaja Street, Ogwu Street, and Ubeta-Obiomoku Road, contributing to frequent flood events. A proposed drainage reconfiguration, derived from DEM hydrology tools and GNSS field data, was overlaid on the terrain (Figure 4.7), improving alignment with natural flow paths. The study

concluded that, a combined approach of remote sensing, and ground-truthing offered an improved drainage infrastructure.

KEYWORDS: Urban Resilience, Drainage Network, Planning and Management, Remote sensing and Geographic Information Science (GIS) for solving Urban flooding, land use /land cover.

1.1. INTRODUCTION

Flooding is one of the most pressing environmental and socio-economic challenges in Nigeria, particularly in urban areas where rapid and largely unregulated development has outpaced infrastructure provision. The impacts of flooding are severe and recurring, affecting livelihoods, damaging infrastructure, displacing residents, and increasing the prevalence of waterborne diseases. According to the Nigerian Hydrological Services Agency (NIHSA, 2022), the 2022 flooding season displaced over 2.4 million people, destroyed more than 300,000 homes, and disrupted agricultural and economic activities across 34 of Nigeria's 36 states. Urban flooding in Nigeria is typically caused by a combination of intense rainfall, low-lying terrain, impervious surfaces from urban sprawl, blocked drainage channels, and a lack of integrated stormwater infrastructure (Douglas et al., 2008; Okonkwo et al., 2015). In most Nigerian cities, natural drainage routes have been encroached upon by buildings, roads, and other developments. Solid waste often clogs existing drains, while poor enforcement of building codes allows for indiscriminate development in flood-prone areas (Adelekan, 2010; Ede, 2014). These patterns are consistent across cities like Lagos, Port Harcourt, Aba, and Onitsha, and are also evident in smaller but rapidly growing towns such as Omoku. As noted by Nkwunonwo, Whitworth, and Baily (2020), flood risk in Nigeria is intensified by the failure of institutional planning frameworks to incorporate data-driven approaches in urban development and disaster risk reduction.

Urban resilience, defined as the capacity of cities to absorb and recover from shocks such as flooding while maintaining critical functions, has become a central objective in the face of climate change and urbanisation. Resilient cities are those that anticipate hazards and invest in infrastructure that mitigates risk. Drainage systems play a crucial role in achieving this resilience. When properly planned and maintained, drainage networks reduce surface runoff, prevent property damage, and ensure that economic and social activities continue uninterrupted during extreme weather events (Satterthwaite et al., 2020). However, many

Nigerian towns and cities have drainage systems that are reactive, fragmented, and designed without regard to topography or hydrology.

Geospatial technologies offer an effective means of overcoming these planning deficiencies. Remote sensing and Geographic Information Systems (GIS) allow for accurate mapping and analysis of elevation, slope, land use, and water flow patterns. These tools can be used to design drainage systems that reflect the physical reality of the terrain and the dynamics of stormwater movement (Ahiablame et al., 2012; Melesse et al., 2007). In a study conducted in Lagos, Ajayi, Adeniyi, and Iyiola (2021) used high-resolution satellite imagery and GIS modelling to identify drainage bottlenecks and propose system upgrades. Similar approaches have been applied in Ilorin (Olanrewaju et al., 2020), Enugu (Ishaya and Ifatimehin, 2008), and Lokoja (Abaje et al., 2014), with positive results. Omoku, a town located in Ogba/Egbema/Ndoni Local Government Area of Rivers State, exemplifies the risks associated with unplanned urban expansion in flood-prone regions. Omoku's strategic importance in the Niger Delta has led to significant population growth and development due to its proximity to oil and gas operations. However, this growth has been accompanied by informal settlements, poorly constructed roads, and a lack of comprehensive stormwater infrastructure. The town is situated on flat terrain with clayey soils and experiences an annual average rainfall exceeding 2,500 millimetres, making it particularly vulnerable to surface water accumulation during the rainy season (Igbokwe et al., 2008). Despite these risks, Omoku lacks a coordinated drainage network and flood management strategy. Many areas are not serviced by any formal drainage channels, and where drains exist, they are often shallow, narrow, and blocked by waste. New developments frequently occur without site grading or flood risk assessments, and there is no centralised database of hydrological or planning data. These conditions have led to repeated flooding events that damage homes, disrupt business activities, and increase the risk of cholera and other waterborne diseases (Akukwe and Ogbodo, 2015; Efe, 2017).

The recurring floods in Omoku are not simply natural hazards but reflect a failure of planning and governance. Infrastructure is developed in the absence of critical spatial data, resulting in ineffective stormwater management. As noted by Douglas et al. (2008), the most vulnerable urban areas in sub-Saharan Africa are those that expand rapidly without integrating environmental data into development decisions. In Omoku, the absence of digital elevation models, land use plans, and flood risk maps has led to drainage solutions that are either inadequate or entirely missing.

This study aims to enhance urban resilience in Omoku by leveraging geospatial data for the optimal planning and management of drainage networks. The specific objectives of the study are to analyse the spatial characteristics of Omoku's topography, land use, and hydrological patterns; assess the condition of existing drainage systems; identify flood-prone areas using GIS-based techniques; propose an optimised drainage network design; and recommend strategies for integrating spatial data into planning decisions.

The study focuses on stormwater drainage infrastructure within the administrative boundary of Omoku. It involves the use of satellite imagery, digital elevation models, rainfall data, and field observations to develop and validate a drainage network model. Limitations include the resolution and availability of spatial datasets, the accuracy of local maps, and the time constraints of field data collection. Nonetheless, the study provides a replicable framework for improving urban drainage planning in other flood-prone Nigerian towns.

1.2. Study Area

Omoku, located in Ogba/Egbema/Ndoni Local Government Area of Rivers State, is a low-lying town in Nigeria's Niger Delta, with elevations ranging from 15 to 25 metres above sea level (Igbokwe et al., 2008). It experiences a tropical monsoon climate characterised by high humidity and intense rainfall, especially between June and September, with annual precipitation often exceeding 2,300 mm (Nigerian Meteorological Agency, 2020). These climatic and topographic conditions contribute to the town's frequent surface flooding and drainage problems.

Urban expansion in Omoku has increased significantly due to its strategic role in Nigeria's oil and gas sector. This has led to extensive conversion of vegetated land and wetlands into built-up areas, increasing impervious surfaces and decreasing the land's natural infiltration capacity (Alimi et al., 2023). This unregulated growth, often without environmental considerations, has heightened flood vulnerability across the town.

Socioeconomically, Omoku has witnessed rapid growth driven by oil-related activities, attracting people and infrastructure, but urban planning has not kept pace (National Population Commission, 2021). Informal settlements have developed in flood-prone zones, and waste disposal practices have further compromised natural and manmade drainage systems (Akukwe & Ogbodo, 2015). Most of the existing drainage infrastructure is either undersized, unconnected, or blocked, and there is no integrated drainage master plan or geospatial inventory of assets to guide interventions (Etuonovbe, 2011).

Consequently, Omoku represents a clear case of urban vulnerability where frequent flooding disrupts livelihoods and infrastructure. This underscores the urgent need for a comprehensive, data-driven approach using GIS, surveying, and hydrological modelling to redesign the town's drainage system and build long-term resilience.

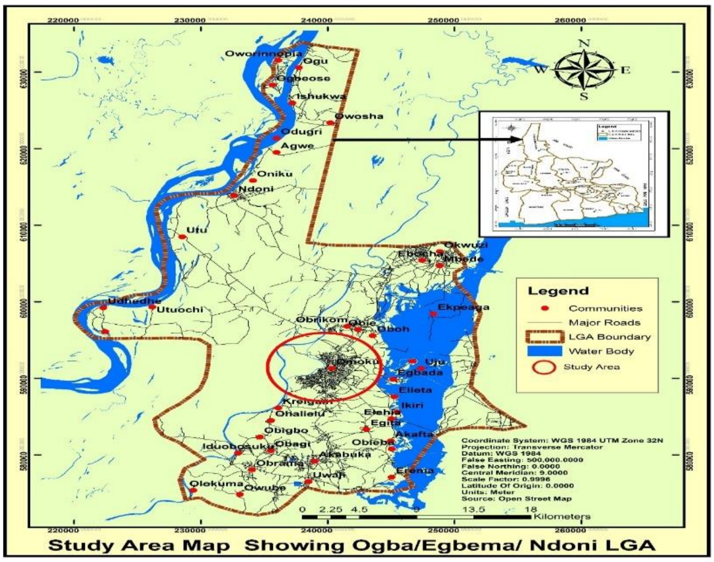

Figure 1.1: Map of Ogb/Egbeme/Ndoni LGA Showing Omoku Town

2.0 Literature Review

2.1. Urban Resilience in Flood-Prone Areas

Urban resilience has become a central theme in the pursuit of sustainable urban development, particularly in cities and towns exposed to climate-related hazards such as flooding. The concept refers to the ability of urban systems including infrastructure, governance, and communities to anticipate, absorb, adapt to, and recover from adverse events while continuing to function effectively (Satterthwaite et al., 2020). It is not merely about survival but about maintaining a capacity for transformation and growth in the face of shocks and long-term stresses.

Flood-prone cities, especially in low- and middle-income countries, are increasingly vulnerable due to a convergence of factors, including uncontrolled urban sprawl, poor land use practices, ageing infrastructure, and climate change. The Intergovernmental Panel on Climate Change (IPCC, 2022) has projected a rise in extreme weather events across Africa, including more intense and erratic rainfall patterns. These changes are expected to increase both the frequency and intensity of urban flooding, particularly in informal and underserved settlements.

In the Nigerian context, urban resilience is often compromised by infrastructural deficits, institutional inefficiencies, and socio-economic disparities. Many urban areas have experienced rapid population growth without corresponding investments in stormwater drainage, solid waste management, or land use regulation. Unregulated development has encroached upon natural water retention areas such as wetlands, floodplains, and riverbanks, thereby increasing flood risk. For instance, Adelekan (2010) found that informal settlements in coastal Lagos are particularly exposed to flood hazards due to a combination of topographic vulnerability and lack of drainage infrastructure.

Douglas et al. (2008) further explained that urban flooding in African cities is a manifestation of environmental injustice, as it disproportionately affects the urban poor who often reside in high-risk, marginal lands. These populations typically have limited access to insurance, social safety nets, and political representation, making recovery from flooding slower and more difficult. Without deliberate planning interventions, these risks are likely to escalate as urban growth continues unchecked.

Building resilience in flood-prone urban areas requires an integrated and forward-looking approach that combines physical infrastructure, institutional reform, and community engagement. Key infrastructure, particularly drainage networks, plays a pivotal role in flood mitigation by managing runoff and directing excess water away from built-up areas. However, resilience extends beyond engineering. It also involves enhancing the adaptive capacity of communities through awareness, preparedness, and access to resources (Arup, 2016). Moreover, spatial planning must incorporate risk-informed decision-making. This means that development controls should be based on accurate hazard maps, hydrological modelling, and projections of climate variability. As noted by Parnell, Pieterse, and Watson (2009), resilience-building also demands a multilevel governance approach, where local authorities, civil society, and national governments collaborate in designing and implementing urban risk reduction strategies.

In Nigeria, policy frameworks such as the National Urban Development Policy and the Nigerian Building Code acknowledge the importance of resilience but are often poorly enforced at the local level (Ede, 2014). Resource constraints, limited technical capacity, and bureaucratic fragmentation hinder the translation of policy into action. Consequently, flood risk continues to escalate, particularly in cities and towns with little or no drainage master plans or flood early warning systems. Despite these challenges, urban resilience is not unattainable (Ede, 2014). It can be strengthened through improved urban governance, strategic infrastructure investment, and the mainstreaming of climate adaptation into urban planning processes. The use of geospatial tools and data-driven approaches, as explored in this study, offers a promising pathway toward building more resilient urban environments in flood-prone settings such as Omoku.

2.2. The Role of Geospatial Data in Urban Planning

Geospatial data has become an indispensable tool in modern urban planning, particularly in addressing challenges related to flood risk and drainage management. Technologies such as Geographic Information Systems (GIS), remote sensing, and Digital Elevation Models (DEMs) enable urban planners and environmental engineers to visualize terrain, model hydrological patterns, and identify flood-prone areas with greater precision. These tools facilitate informed decision-making, allowing for the development of resilient infrastructure and sustainable urban environments.

In regions where ground-based data is limited or outdated, geospatial technologies offer significant advantages. For instance, Melesse, Shih, and Wang (2007) demonstrated the application of GIS-based hydrological models in simulating wetland restoration and flood mitigation strategies. By integrating various spatial layers such as land use, rainfall intensity, soil type, and elevation GIS platforms can produce comprehensive flood risk maps that inform urban development controls and infrastructure placement.

In the Nigerian context, the adoption of geospatial tools has shown promising results. Ajayi, Adeniyi, and Iyiola (2021) utilized GIS techniques to assess the adequacy of existing drainage networks in Lagos, revealing misalignments with natural water flow paths and recommending restructuring to reflect actual topographical and hydrological conditions. Similarly, Olanrewaju, Yusuf, and Ajayi (2020) employed GIS tools to evaluate drainage conditions in Ilorin, identifying high-risk flood areas and suggesting interventions such as channel widening and improved maintenance routines.

Beyond Nigeria, other sub-Saharan African countries have also leveraged geospatial data for urban planning. In Dar es Salaam, Tanzania, the Ramani Huria project exemplifies community-driven mapping initiatives. This project trained local community members and university students to create accurate maps of flood-prone areas using OpenStreetMap, enhancing flood response strategies and resilience in vulnerable neighborhoods (Ramani Huria, 2023).

Despite these advancements, challenges persist in the widespread adoption of geospatial technologies. High costs, technical barriers, and limited institutional capacity can hinder the integration of these tools into urban planning processes. However, the decreasing cost of geospatial technologies and the increasing availability of open-source platforms are gradually mitigating these obstacles, allowing for broader application even in resource-constrained contexts (Ahiablame, Shakya, & Chaubey, 2012).

2.3 Existing Studies on Drainage Network Modelling and Management

In recent years, the adoption of drainage network modelling and geospatial technologies has become increasingly relevant in addressing the persistent challenge of urban flooding in Nigeria. Urban centres such as Lagos, Port Harcourt, Ilorin, and Ibadan frequently experience flood events due to a combination of factors, including unregulated urban expansion, climate variability, increased impervious surfaces, and inadequate or poorly maintained drainage systems (Nkwunonwo, Whitworth, & Baily, 2020; Douglas et al., 2008). As population growth outpaces infrastructure development, rainfall events now pose more severe consequences, particularly in low-lying or topographically disadvantaged areas (Adelekan et al., 2015; Alimi et al., 2023).

Drainage modelling defined as the simulation and spatial analysis of surface water movement through natural and artificial channels has emerged as an essential method for flood mitigation planning. These models, particularly when integrated with tools such as Geographic Information Systems (GIS), Digital Elevation Models (DEMs), and remote sensing, provide a robust, evidence-based foundation for identifying flood-prone areas, evaluating infrastructure capacity, and designing optimised drainage networks (Ajayi, Adeniyi, & Iyiola, 2021; Komolafe et al., 2020).

Historically, drainage planning in Nigeria has relied heavily on manual surveys, static cadastral maps, and empirical estimations, which often lack the resolution and accuracy needed for dynamic urban environments. However, the use of advanced tools such as HEC-HMS and SWMM, coupled with terrain analysis from DEMs, has introduced a paradigm shift. These tools allow for the simulation of runoff behaviour, stormwater volume, and the impact of structural and non-structural interventions across various rainfall scenarios (Melesse, Shih, & Wang, 2007; Oladokun, Odesola, & Akinwale, 2017).

Ajayi et al. (2021) showcased this capability in Lagos, where GIS-based analysis was used to evaluate existing drainage networks against terrain flow paths. Their findings indicated that many drains were misaligned with natural slope directions, resulting in frequent overflows and urban flooding. The authors recommended a redesign based on slope, flow direction, and accumulation models to improve system efficiency.

In Ilorin, Olanrewaju, Yusuf, and Ajayi (2020) adopted a similar approach using terrain modelling and land use overlays. Their work identified high-risk zones with either undersized or absent drainage infrastructure and recommended the integration of buffer systems such as detention basins to moderate flood peaks.

Further strengthening the use of simulation tools, Oladokun et al. (2017) applied SWMM in Ibadan to model stormwater discharge under various rainfall return periods. The results revealed critical deficiencies in the city's drainage capacity, prompting recommendations for proactive infrastructure expansion and the incorporation of low-impact development (LID) features, such as vegetated swales and permeable pavements.

A more advanced and terrain-specific technique was presented by Komolafe et al. (2020), who used a multi-criteria evaluation framework integrated with the Height Above Nearest Drainage (HAND) model to map flood susceptibility in the Ogun River Basin. This high-resolution approach enabled targeted identification of at-risk areas and provided regional planners with actionable insights, especially in resource-constrained environments.

Beyond Nigeria, the importance of stream order analysis and DEM-based hydrological modelling was exemplified by Raju, Raju, and Rajasekhar (2020). In their study of the Mandavi River Basin in southern India, the authors detailed a sequential GIS workflow for drainage network extraction including DEM filling, flow direction, flow accumulation, and stream order classification. Their approach demonstrates how automated terrain-based modelling, supported by high-resolution DEMs, can generate accurate drainage maps and inform comprehensive hydrological assessments. The stream order analysis, in particular, enabled a clearer understanding of watershed hierarchy and drainage density, tools essential for designing scalable and efficient stormwater infrastructure.

Despite the methodological advances and increasing academic contributions, the practical implementation of drainage modelling remains limited across many Nigerian towns and cities. Drainage interventions often follow damaging flood events rather than preceding them. This reactive planning cycle is compounded by institutional fragmentation, low investment in technical tools, and a disconnect between research outputs and policy application (Nkwunonwo et al., 2020; Adelekan, 2010).

To address these shortcomings, there is an urgent need to integrate modelling outputs into urban planning decisions. This includes developing local capacity to operate GIS platforms, updating and sharing hydrological datasets through open-access platforms, and enforcing drainage master plans that are informed by real-time and predictive flood data. Surveying should also play a greater role, as accurate topographic and drainage mapping relies heavily on field-validated terrain data, especially in regions where satellite-derived DEMs may have resolution limitations.

Overall, the body of literature reviewed points to a growing recognition of GIS-based drainage network modelling as a transformative tool. However, the path to resilience lies in bridging the gap between analysis and action through stronger institutions, better data, and sustained investments in capacity building.

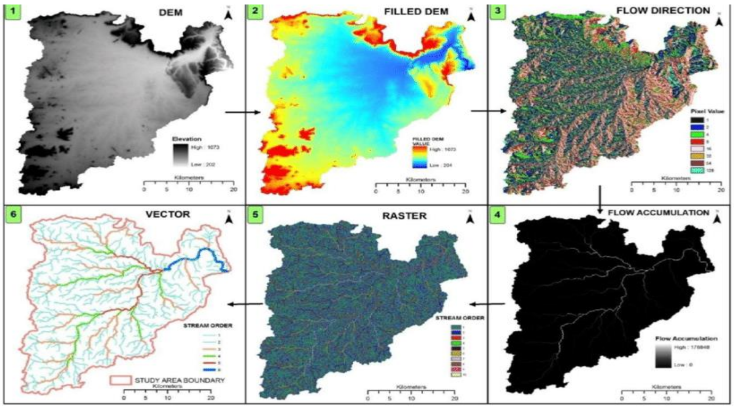

Figure 2.1: Automatic Extraction and Stream Order Classification of Drainage Network from SRTM DEM Using GIS Techniques.

***Source*: Raju, R.S., Raju, G.S., & Rajasekhar, M. (2020). Morphometric analysis of Mandavi River Basin in Rayalaseema region of Andhra Pradesh (South India), using remote sensing and GIS.**

2.4. Case Studies in Nigeria and Sub-Saharan Africa

Beyond major cities like Lagos and Ibadan, several studies across Nigeria and sub-Saharan Africa have demonstrated the effectiveness of geospatial tools in flood risk assessment and drainage planning. In Kaduna State, Ishaya and Ifatimehin (2008) used remote sensing and GIS to delineate flood-prone zones in Jema'a Local Government Area, recommending development restrictions in high-risk floodplains. Similarly, Isma'il and Saanyol (2013) applied GIS and Digital Elevation Models to classify flood zones along River Kaduna, providing a valuable tool for disaster preparedness and land use planning.

In Anambra State, Akukwe and Ogbodo (2015) assessed flood vulnerability in Ogbaru Local Government Area using multiple spatial datasets, identifying high-risk areas and advocating for green infrastructure interventions alongside conventional drainage systems. Their study highlighted the benefits of integrating environmental and socio-economic data into flood planning.

In East Africa, the Ramani Huria project in Dar es Salaam, Tanzania, represents a successful community-based mapping initiative. As documented by Msilanga (2018), the project trained residents and university students to map flood risks in informal settlements using OpenStreetMap and mobile GPS tools. This participatory approach enhanced the accuracy of spatial data, strengthened community engagement, and informed flood preparedness strategies. The project's success shows the value of combining local knowledge with geospatial tools to build resilience in vulnerable urban areas.

Together, these case studies illustrate how GIS and remote sensing, when applied alongside community input, can produce scalable and context-appropriate flood management solutions. They also demonstrate that such tools are adaptable to a range of urban settings, from informal settlements to peri-urban floodplains, making them highly relevant for expanding urban centres like Omoku.

3.0 Methodology

This study adopts an integrated geospatial and field-based methodology to assess and optimise drainage network performance in Omoku, Rivers State. The approach combines Digital Elevation Model (DEM) analysis, stream order classification, supervised land use mapping, Global Navigation Satellite System (GNSS) data collection, and levelling-based elevation verification. These methods are supported by structured field observation to validate spatial outputs and ensure that the resulting drainage plan reflects both natural hydrology and local urban dynamics.

The methodology is structured into four core stages: data acquisition, hydrological and terrain modelling, drainage network extraction and analysis, and validation and accuracy assessment.

3.1 Data Sources

Geospatial Data

- **Satellite Imagery**: Landsat 8 and Sentinel-2 images were used for land use/land cover (LULC) classification. Supervised classification techniques were applied to distinguish between impervious surfaces, vegetation, and bare soil, which are critical for estimating surface runoff characteristics.
- **Digital Elevation Model (DEM)**: A 30-metre resolution Shuttle Radar Topography Mission (SRTM) DEM was sourced from the US Geological Survey (USGS). This provided the foundational terrain data for modelling flow direction, accumulation, and watershed boundaries.
- **Rainfall Data**: Daily and monthly precipitation records from 2000 to 2022 were collected from the Nigerian Meteorological Agency (NiMet) and cross-referenced with satellite-based CHIRPS data. These datasets informed contextual flood risk interpretation and helped estimate potential runoff volumes.

- **Topographic and Infrastructure Maps**: Local Road layouts, administrative boundaries, and informal drainage records were obtained from the Rivers State Ministry of Works.

Field Data Collection

A combination of GNSS measurements, structured field observation, and differential levelling was employed to ground-truth the geospatial data:

- The **SinoGNSS T30 GNSS receiver** was used to collect high-precision coordinate data of existing drainage outlets, culverts, and critical points along flood-prone corridors.
- **Structured observation** was conducted across pre-identified transects to systematically assess physical slope, surface runoff direction, drain blockages, and informal drainage routes. Field teams used observation checklists to ensure consistency across all locations.
- **Levelling** was carried out using a digital level and staff to confirm and correct elevation values to validates elevations from the derived DEM. The **Height of Instrument (HI)** method was applied for calculating reduced levels (RLs) at surveyed points, using the formula:

$$RL_{new} = HI - FS \qquad 1$$

Where,

$$HI = RL_{benchmark} + BS \qquad 2$$

- FS = Fore Sight (staff reading at the new point)
- BS = Back Sight from benchmark
- RL_{new} = Reduced Level at the unknown point

This method provided vertical accuracy and confirmed slope gradients along natural and constructed drainage paths.

3.2 Tools and Techniques

The following tools were employed in data analysis and modelling:

- **ArcGIS Pro (v3.1)**: Used for hydrological modelling (flow direction, accumulation, stream extraction), watershed delineation, slope analysis, and thematic map generation.
- **QGIS (v3.28)**: Applied for land use classification, raster reclassification, and spatial data validation using open-source hydrology plugins.
- **Google Earth Pro**: Supported visual inspection of land use changes and pre-field planning.

- **Microsoft Excel**: Used to organise rainfall data, calculate slope gradients, stream metrics, and cross-validate field measurements.

3.3 Process Workflow

a. Data Acquisition and Preparation

- The DEM was pre-processed using sink-filling to eliminate elevation artefacts.
- Satellite imagery was corrected, classified, and overlaid with topographic data for land use runoff estimation.
- All datasets were projected to a uniform coordinate system and clipped to the Omoku boundary.

b. Hydrological and Terrain Modelling

- Flow direction and flow accumulation rasters were generated from the DEM.
- A flow accumulation threshold was applied to extract a stream network.
- **Strahler's stream order classification** was used to categorise the stream segments, identifying primary (1st order), secondary, and higher-order channels.

The **stream order hierarchy** informs hydrological behaviour, where first-order streams originate in the upper catchment and merge to form higher-order streams:

If two streams of order n merge, the resulting stream is of order $n + 1$

- Slope (SSS) was calculated using the standard GIS raster slope function and verified with levelling data:

$$S = \frac{\Delta h}{\Delta x} \qquad 3$$

Where:

- Δh = change in elevation
- Δx = horizontal distance

c. Drainage Network Mapping and Flood Zone Identification

- The extracted stream network was overlaid on LULC and infrastructure maps to identify drainage mismatches, blockages, and high-risk zones.
- Zones with high flow accumulation, low slope (≤2%), and high impervious surface coverage were flagged as flood-prone areas.
- Spatial buffers (15–30 metres) were generated around high-order streams and observed drainage channels to visualise encroachment and prioritise interventions.

d. Data Integration and Spatial Analysis

- A geodatabase was created to store and manage spatial layers.

- Stream attributes (length, slope, order, and drainage density) were computed and analysed for prioritising segments for drainage upgrades or realignment.
- Proposed drainage paths were aligned with natural flow direction and validated with field observations and elevation profiles.

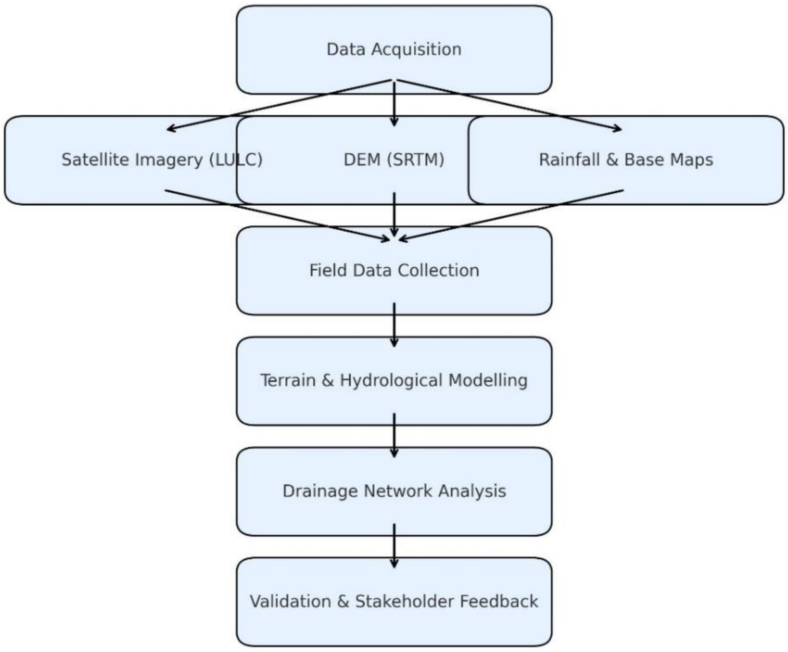

Figure 3.1: Geospatial and Hydrological Analysis Workflow for Drainage Network

Assessment in Omoku

3.4 Validation and Accuracy Assessment

Topographic Validation (Levelling and GNSS)

- Field-measured elevations were compared with DEM-derived elevation values to assess vertical accuracy. Differences exceeding ±1.5 metres were corrected in the spatial model.
- GNSS data were used to validate the locations of drainage inlets, outfalls, and critical convergence points.

Land Use Classification Accuracy

- A confusion matrix was developed using 100 ground-truth points across different land use classes.
- The classification produced an overall accuracy of 88% and a kappa coefficient of 0.81, confirming the suitability of the LULC data for runoff analysis.

Stakeholder Feedback

- Informal interviews and field feedback sessions were held with ONELGA planning officials and community representatives.
- Their input confirmed historical flood zones and informed the refinement of drainage intervention priorities.

4. RESULTS

4.1 Land Use/Land Cover (LULC) Classification

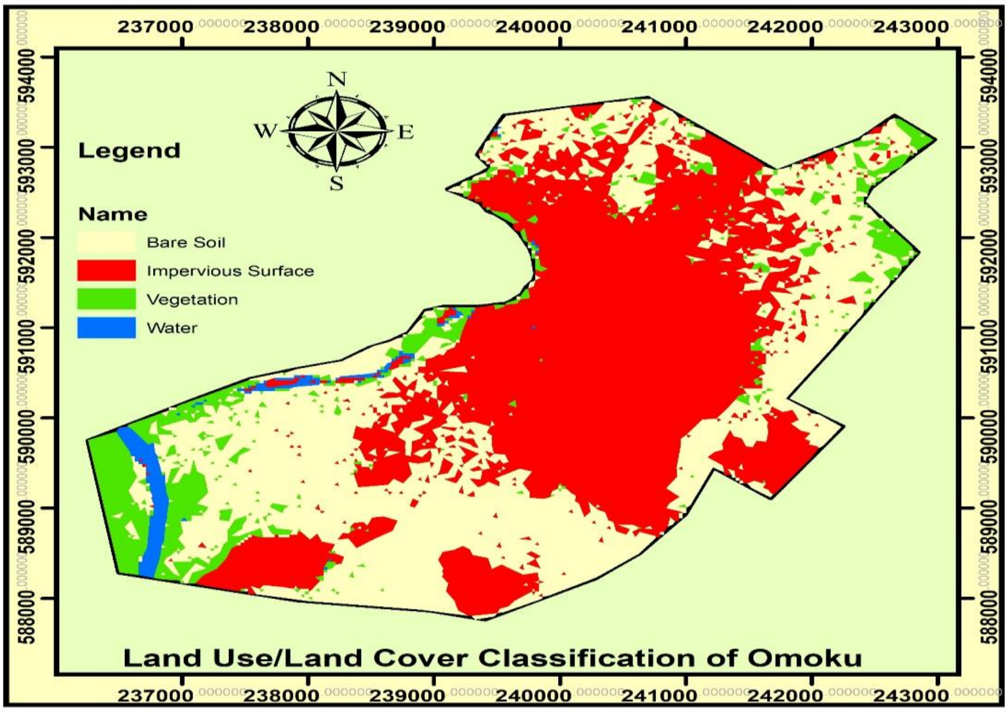

Figure 4.1: Land Use/Land Cover Classification of Omoku.

Table 4.1: Land Use/Land Cover Distribution in Omoku

Row Labels	**Sum of Area** (Sqkm)	**%**
Bare Soil	8.71814135497	42%
Impervious Surface	9.93854732910	48%
Vegetation	1.74935014827	8%
Water	0.32887905781	2%
Grand Total	**20.73491789015**	100%

4.2 Terrain and Hydrological Analysis

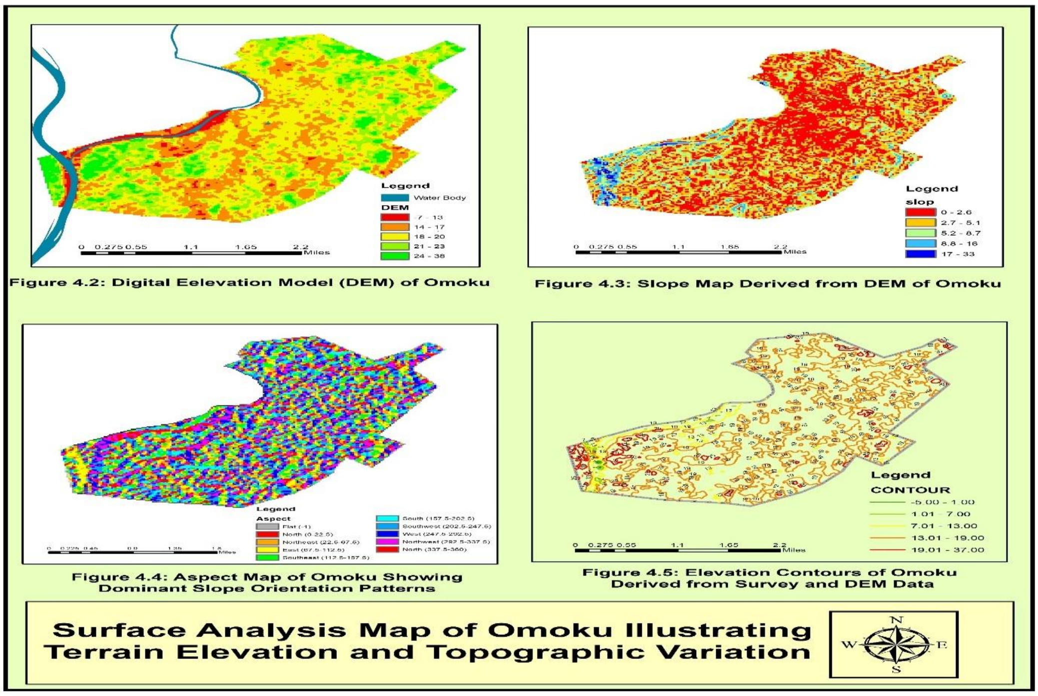

Table 4.2: Validation of Field-Measured Elevation Points with DEM-Derived Values in Omoku.

NAME	UTMX	UTMY	SINO ELEVATION	DEM ELEVATION
P1	239871	588028	13	18
P2	239841	588334	13	18
P3	239825	588882	14	16
P4	239803	589971	14	19
P5	239831	590439	15	16
P6	240077	590827	16	17
P7	240310	591149	16	18
P8	240435	591529	16	17
P9	240386	592054	15	18
P10	240354	592541	15	18
P11	240543	593062	16	17
P12	240807	593492	0	0
P13	240243	593114	15	21
P14	239616	589439	17	18
P15	239651	590797	15	20
P16	239267	590181	15	18
P17	240019	592426	14	13
P18	240545	593365	16	20
P19	240155	592121	15	18
P20	240031	591542	16	19
P21	239564	589009	15	20
P22	239526	588321	14	22
P23	240129	588445	17	22

P24	240372	588992	14	17
P25	240205	589340	16	21
P26	240465	589838	15	20
P27	239974	589626	14	17
P28	240281	590167	14	16
P29	240200	590486	17	19
P 30	240565	590824	14	18
P31	240701	591345	16	19
P32	240784	591812	16	19
P33	240728	592115	15	18
P34	240605	592502	16	21
P35	240964	592998	16	25
P36	240901	593296	17	20
P37	240961	592658	15	21
P38	239978	591121	15	16
P39	238597	589118	14	17
P40	241632	590918	14	21
P41	240643	590333	14	18
P42	240962	589891	14	18
P43	238481	589840	12	11
P45	241432	591260	16	20
P46	241112	591630	16	17
P47	241466	592560	15	17
P48	241887	591721	15	23
P49	239110	590718	16	17
P50	237944	589713	15	22
P51	238712	589393	15	20
P52	239791	590273	16	18
P53	241036	589633	15	20
P54	239993	592857	15	21
P55	239573	592629	16	19
P56	239374	593058	0	0
P57	241394	592968	16	23
P58	241642	592092	16	19
P59	241424	591828	15	22
P60	242078	591413	15	22
P61	241804	591208	17	20
P62	241342	592235	15	22
P63	239049	589208	12	21
P64	239185	589605	14	18
P65	241077	590542	14	19
P66	241425	590571	17	22

Table 4.3: Average Monthly Rainfall in Omoku (2000–2022)

	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
YEAR	46	2000	2022	2011.00	6.707
JAN	46	.00	122.39	10.4974	21.95012

FEB	46	.04	144.60	15.4933	28.49227
MAR	46	.59	154.28	36.8891	45.90817
APR	46	1.18	365.05	69.5602	87.73097
MAY	46	1.41	302.35	96.5350	102.32933
JUN	46	3.42	977.47	145.1578	188.56552
JUL	46	2.18	702.08	133.5741	168.25454
AUG	46	2.69	625.26	131.0137	155.64587
SEP	46	3.81	710.72	169.3220	185.18828
OCT	46	2.29	794.61	130.2828	159.51921
NOV	46	.18	273.36	54.5213	72.84824
DEC	46	.00	99.97	10.0561	19.52387
Valid N (listwise)	46				

SOURCE: Nigerian Meteorological Agency (NiMet). (2024

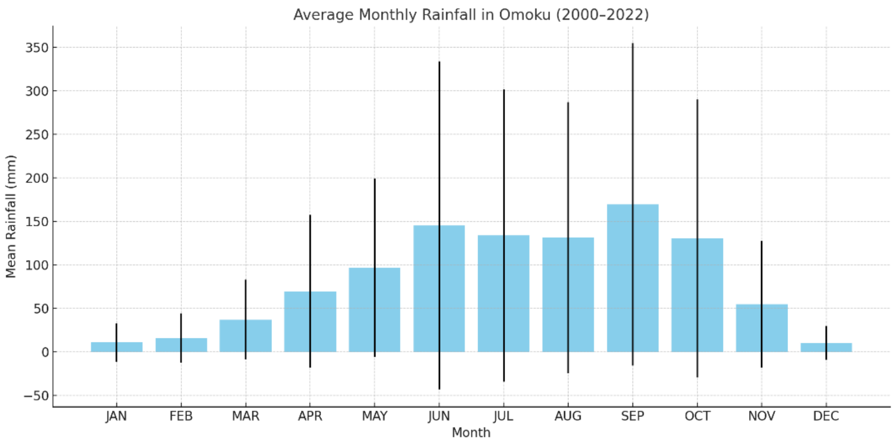

Figure 4.7: Average Monthly Rainfall in Omoku (2000–2022)

SOURCE: Nigerian Meteorological Agency (NiMet). (2024)

4.2.1 Analysis of 3D Flow Direction and Proposed Drainage Pathways

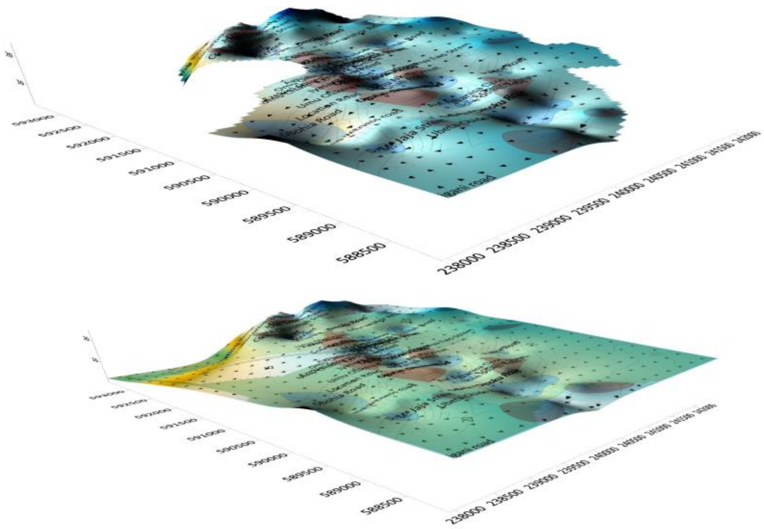

Figure 4.7: 3D Terrain Model of Omoku Showing Natural
Flow Direction and Proposed Drainage Alignments Based on SinoGNSS Survey Data

Discussion of Results and Findings

This study applied an integrated geospatial approach combining land use classification, DEM-based terrain analysis, rainfall data interpretation, GNSS field survey, and flow modelling to assess and optimise drainage planning in Omoku. The findings provide detailed insights into the factors influencing flood vulnerability and propose a technically informed, location-specific drainage strategy.

5.1 Urban Land Use and Runoff Potential

The classified land cover revealed that nearly 90% of Omoku is made up of impervious surfaces (48%) and bare soil (42%), while only 8% is vegetated. This imbalance contributes significantly to reduced infiltration and high runoff generation, particularly during peak rainfall periods. Impervious surfaces accelerate water flow, while bare soils increase sedimentation and clogging in already constrained drain networks.

These results align with studies such as Ajayi et al. (2021) and Adelekan et al. (2015), which emphasized the runoff amplification effects of urban expansion and informal land development. The limited vegetation coverage further reduces the landscape’s ability to buffer rainfall impacts, exacerbating urban flood risks.

5.2 Rainfall Variability and Seasonal Drainage Load

Rainfall data from NiMet (2000–2022) showed a distinct wet season between April and October, with rainfall peaking in September (169.3 mm) and remaining high through June to August. These months also recorded the highest standard deviations, indicating inter-annual variability and potential extreme rainfall events.

This seasonal concentration of rainfall places significant pressure on Omoku’s drainage system. The correlation between flood-prone periods and peak rainfall months supports residents’ reports and validates the need for larger-capacity drains and strategic timing of maintenance during the early wet season. These findings also reinforce the necessity of planning for design storms in line with projected climate patterns.

5.3 Topography and Hydrological Behaviour

Using a 30m SRTM DEM and GIS-based hydrological modelling, the study generated slope, flow direction, and accumulation layers. Results indicated that many existing drainage routes were constructed against the natural flow gradient, a condition confirmed through SinoGNSS field data and levelling. Elevation discrepancies of over ±1.5 metres were observed, requiring correction to ensure slope reliability in modelling.

The stream order analysis, using Strahler's classification, revealed how numerous first-order streams converge into higher-order flow channels in central Omoku. These areas represent natural catchment basins, where water accumulates during rainfall events. Streets located in these low-lying areas, such as Market Road, Ubeta-Obi omoku Road, Jaja Street, and Coca-Cola Road, are at highest risk of urban flooding.

5.4 3D Terrain and Drainage Misalignment

The 3D terrain model provided critical spatial understanding of **elevation-dependent flow behaviour**. Overlaid flow direction arrows showed several areas where road alignments and existing drains either:

- Oppose the natural flow path
- Intercept flow without proper discharge outlets
- Traverse depressions with no elevation gradient

This is most evident along Ogwu Street, Nkpolu Street, and Effere Street, where poor gradient and blocked paths lead to localised waterlogging. Streets such as Location Road and Chief Okoroma Road, by contrast, are better aligned with flow paths and can be leveraged for enhanced drainage design.

5.5 Field Validation and Stakeholder Insight

The integration of GNSS data (SinoGNSS T30), levelling profiles, and stakeholder feedback created a feedback loop that enhanced the reliability of modelled outputs. Ground-truthing confirmed flow paths, elevation patterns, and flood-prone streets. Stakeholders consistently identified problem zones (e.g., Market Road, Coca-Cola Road) that aligned with areas of high flow accumulation in the model.

This validation process underscores the value of combining technical modelling with local knowledge for practical, community-informed planning.

5.6 Implications for Drainage Network Planning

The findings of this study have several implications for future drainage design and urban flood resilience in Omoku:

- **Drainage realignment is essential** in multiple sectors to match flow direction and avoid water stagnation.
- Drainage infrastructure must be **dimensioned to handle peak flows**, especially between **June and September**.
- **Bare soil zones must be stabilised**, as they contribute to sedimentation and channel clogging.

- Priority streets identified for intervention include:
- **Market Road, Jaja Street, Oboni Road, and Ubeta-Obi omoku Road**
- GIS-based planning should become standard in ONELGA's infrastructure development, supported by continuous data updating and open-access mapping systems.

5.7 Summary of Findings

- Urbanisation in Omoku is runoff-intensive due to high imperviousness and bare soil exposure.
- The current drainage system is poorly aligned with terrain, causing inefficiencies and flooding.
- Rainfall peaks align with drainage system failures, especially in known low-lying zones.
- A GNSS-validated, terrain-aligned drainage plan offers a technically sound, cost-effective approach to improving flood resilience.

6.1 CONCLUSION

This study successfully applied geospatial analysis, digital elevation modelling, and GNSS-based field validation to assess and improve drainage network planning in Omoku. Findings revealed that poor alignment of drainage systems with natural terrain, combined with high impervious surface coverage and intense seasonal rainfall, significantly contributes to urban flooding. The integration of terrain data, stream order analysis, and stakeholder feedback provided a robust framework for identifying flood-prone areas and proposing data-driven drainage interventions.

6.2. Recommendations

1. **Realign drainage channels** to follow natural slope and flow direction.
2. **Prioritise flood-prone streets** like Market Road and Jaja Street for drainage upgrades.
3. **Incorporate geospatial tools** such as slope and stream order analysis into local planning.
4. **Design infrastructure** to withstand peak rainfall from June to September.
5. **Promote community awareness** and ensure regular drainage maintenance.
6. **Create a central GIS database** to manage and update drainage and terrain data.
7. **Train local authorities** in GIS and GNSS tools for ongoing planning and monitoring.

REFERENCES

1. Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environment and Urbanization, 22(2), 433–450. https://doi.org/10.1177/0956247810380141
2. Adelekan, I. O., Johnson, C., Manda, M. A., Matyas, D., Mberu, B. U., Parnell, S., and Satterthwaite, D. (2015). Disaster risk and its reduction: An agenda for urban Africa. International Development Planning Review, 37(1), 33–43. https://doi.org/10.3828/idpr.2015.4
3. Abaje, I. B., Ati, O. F., Iguisi, E. O., and Jidauna, G. G. (2014). Droughts in the Sudano-Sahelian ecological zone of Nigeria: Implications for agriculture and water resources development. Weather and Climate Extremes, 5, 7–15. https://doi.org/10.1016/j.wace.2014.05.001
4. Ahiablame, L. M., Shakya, R., and Chaubey, I. (2012). Vulnerability assessment of urban communities to flooding in African cities using GIS. Water, Air, & Soil Pollution, 223, 4253–4273. https://doi.org/10.1007/s11270-012-1189-2
5. Ajayi, O. G., Adeniyi, T. E., and Iyiola, O. (2021). Application of geospatial techniques in drainage network analysis for sustainable flood risk management in Nigeria. Environmental Challenges, 4, 100164. https://doi.org/10.1016/j.envc.2021.100164
6. Akukwe, T. I., and Ogbodo, C. M. (2015). Spatial analysis of flood vulnerability zones in Ogbaru Local Government Area of Anambra State, Nigeria. African Journal of Environmental Science and Technology, 9(7), 592–600. https://doi.org/10.5897/AJEST2015.1881
7. Alimi, O. S., Adebayo, S. B., and Akinluyi, F. O. (2023). GIS-assisted flood-risk potential mapping of Ilorin and its environs. ResearchGate. https://www.researchgate.net/publication/374618152
8. Arup. (2016). City Resilience Framework. The Rockefeller Foundation. https://www.arup.com/perspectives/publications/research/section/city-resilience-framework
9. Douglas, I., Alam, K., Maghenda, M., McDonnell, Y., McLean, L., and Campbell, J. (2008). Unjust waters: Climate change, flooding and the urban poor in Africa. Environment and Urbanization, 20(1), 187–205. https://doi.org/10.1177/0956247808089156

10. Ede, P. N. (2014). Urban flooding in Port Harcourt Metropolis: Causes, effects and possible solutions. International Journal of Science and Engineering Research, 5(7), 104–110.
11. Efe, S. I. (2017). Waste disposal problems and management in Ughelli urban area of Delta State, Nigeria. Journal of Environmental Studies, 4(1), 15–26.
12. Etuonovbe, A. K. (2011). The devastating effects of flooding in Nigeria. In FIG Working Week 2011 (Marrakech, Morocco). https://www.fig.net/resources/proceedings/fig_proceedings/fig2011/papers/ts06j/ts06j_etuonovbe_5002.pdf
13. Igbokwe, J. I., Akinyede, J. O., and Dang, B. (2008). Mapping flood risk zones using satellite remote sensing and GIS: A case study of River Kaduna. African Journal of Environmental Science and Technology, 2(2), 66–70.
14. IPCC. (2022). Climate change 2022: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg2/
15. Ishaya, S., and Ifatimehin, O. O. (2008). Using remote sensing and GIS techniques in the management of flood risk in Jema'a Local Government Area of Kaduna State, Nigeria. Journal of the Environment, 1(1), 15–21.
16. Isma'il, M., and Saanyol, I. O. (2013). Application of remote sensing and GIS in flood vulnerability mapping: Case study of River Kaduna. International Journal of Geomatics and Geosciences, 3(3), 618–625.
17. Komolafe, A. A., Awe, B., Olorunfemi, I. E., and Oguntunde, P. G. (2020). Modelling flood-prone areas and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River Basin, Nigeria. Natural Hazards, 102, 1–24. https://doi.org/10.1007/s11069-020-03962-3
18. Melesse, A. M., Shih, S. F., and Wang, X. (2007). Wetland restoration planning using hydrologic simulation model and GIS: The case of Kissimmee River, Florida. Water Resources Management, 21, 113–134. https://doi.org/10.1007/s11269-006-9010-4
19. Msilanga, G. (2018). Community mapping for flood resilience – The case of Dar es Salaam, Tanzania. AGILE International Conference on Geographic Information Science.
20. National Population Commission (NPC). (2021). Population projections for Nigerian urban centres. Abuja, Nigeria.
21. Nigerian Hydrological Services Agency (NIHSA). (2022). Annual flood outlook report. Abuja, Nigeria.

22. Nigerian Meteorological Agency (NiMet). (2020). Annual climate summary report. Abuja, Nigeria.
23. Nigerian Meteorological Agency (NiMet). (2024). Historical rainfall records for Omoku, Rivers State (2000–2022). Abuja, Nigeria.
24. Nkwunonwo, U. C., Whitworth, M., and Baily, B. (2020). A review of flooding and flood risk reduction in Nigeria. Natural Hazards, 104, 713–740. https://doi.org/10.1007/s11069-020-04195-3
25. Oladokun, V. O., Odesola, I. A., & Akinwale, O. A. (2017). Application of SWMM for flood risk assessment in Ibadan, Nigeria. Journal of Water and Climate Change, 8(4), 650–661. https://doi.org/10.2166/wcc.2017.014
26. Olanrewaju, A. B., Yusuf, R. O., and Ajayi, M. A. (2020). Assessment of drainage condition and flood vulnerability in Ilorin, Nigeria using GIS techniques. Heliyon, 6(10), e05256. https://doi.org/10.1016/j.heliyon.2020.e05256
27. Okonkwo, C. I., Mbajiorgu, C. C., and Ufoegbune, G. C. (2015). Urban flood modelling using HEC-HMS: A case study of Onitsha North LGA, Anambra State. Nigerian Journal of Hydrology, 24(1), 45–58.
28. Parnell, S., Pieterse, E., and Watson, V. (2009). Planning for climate change in African cities. Urban Landmark.
29. Ramani, H. (2023). Community mapping for flood resilience in Dar es Salaam. https://ramanihuria.org/
30. Raju, R. S., Raju, G. S., and Rajasekhar, M. (2020). Morphometric analysis of Mandavi River Basin in Rayalaseema region of Andhra Pradesh (South India), using remote sensing and GIS. ResearchGate. https://www.researchgate.net/figure/Automatic-extraction-process-of-drainage-network-from-SRTM-DEM-through-GIS-software_fig3_339297471
31. Satterthwaite, D., Archer, D., Colenbrander, S., Dodman, D., Hardoy, J., Mitlin, D., and Patel, S. (2020). Building resilience to climate change in informal settlements. One Earth, 2(2), 143–156. https://doi.org/10.1016/j.oneear.2020.02.002