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Integrating geospatial mapping and stakeholders' perception on sustainable flood solutions in a typical coastal megacity of Nigeria: a SWOT-AHP approach

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The study involved the identification of urban flood-prone areas, followed by surface inundation mapping and the development of strategic flood solutions using an integrated approach. Digital elevation modeling of the satellite images and Sentinel-2 data, along with spatial rainfall data, was integrated for assessing spatial flood vulnerability using a Geographic Information System (GIS) approach. In addition, questionnaires were administered to participants on 40 elements outlined in the SWOT survey instrumentation, and responses were analyzed. The findings revealed high flood vulnerability in the study area, particularly the densely populated metropolitan areas with inadequate drainage infrastructure. Rainfall patterns during the June–July–August (JJA) and September–October–November (SON) periods were linked to flood frequency and high surface inundation, highlighting the need for early warning systems and drainage improvements. The Strengths, Weaknesses, Opportunities, and Threats-Analytic Hierarchy Process (SWOT-AHP) framework highlighted flood strategies across four thematic pillars: environment (0.45), legal and institutional (0.22), socio-economic (0.16), and urban engineering (0.16). Strategic alternatives were ranked based on global weight values and categorized into short-term strategies focused on critical infrastructure and evacuation planning. Mid-term priorities included green infrastructure and smart monitoring systems, while long-term strategies emphasized sustainable urban planning and regulatory enforcement. The findings also underscore the need for a more integrated policy implementation, community engagement, and improved investment on adaptive infrastructure to reduce flood risk. The structured decision-support tool suggested proactive, sustainable, and inclusive flood resilience strategies for stakeholders.

KEYWORDS

SWOT-AHP analysis, urban flooding, vulnerability mapping, early warning system, strategic planning, urban infrastructure

1 Introduction

Among natural hazards, floods account for nearly 90% of water-related disasters, affecting billions of people and costing hundreds of billions in damages ([United Nations International Strategy for Disaster Reduction, 2022](#)). The situation is particularly dire in developing nations, where rapid urbanization, inadequate infrastructure, and climate change exacerbate flood risks ([Nigeria Hydrological Service Agency, 2024](#)). According to the [United Nations Environment Program \(2022\)](#), over 592,000 individuals across at least 10 countries in the West African sub-region were impacted by floods in 2021. Meanwhile, unaccounted costs of flood disaster

on human capital resources remain a challenge in the global south (United Nations Office for Disaster Reduction, 2023).

Lagos, Africa's largest coastal megacity, faces acute flood vulnerability due to its low-lying geography, rapid population growth, and insufficient drainage systems (Ibeabuchi, 2023). Annual floods disrupt livelihoods (Oguntola, 2022), damage property, and spread waterborne diseases (Abdel-Karim et al., 2020). The 2022 floods alone displaced over 100,000 residents and caused estimated economic losses exceeding \$4 billion (Lawanson et al., 2023). Poor urban planning has compounded these challenges (Aliyu et al., 2023), with many informal settlements infringing natural flood buffers, which have been degraded by human activity (Kasim et al., 2022).

Sustainable flood risk management is a key element in broader water resource utilization and disaster risk reduction effort in Africa (Ndimele et al., 2024). Perception knowledge system related to flood controls focus solely on structural measures, including drainage system adequacy, flood planning, and immediate mitigation or infrastructure development (Odunsi et al., 2024). A paradigm shift toward integrated flood risk management is required (Ogato et al., 2020; Aliyu et al., 2023; Nghiningwa et al., 2025), which will combine urban infrastructure solutions with community-based approaches and spatial knowledge of urban flood dynamics in the coastal settlement of Lagos State, Nigeria.

This study elucidates integrated methods that focus on participatory flood risk management using local knowledge and technical expertise to offer sustainable flood solutions. Studies in similar coastal cities demonstrated that involving residents in flood mapping and early warning systems improves preparedness and reduces vulnerability (Gregory and Gerald, 2020; Faccini et al., 2021). However, developing countries encounter serious challenges in flood vulnerability monitoring and sustainable solutions (Orimogunje et al., 2016; Adelekan and Asiyambi, 2016; Anifowose and Rollason, 2024). In fact, the adoption of traditional top-down flood risk management has failed in the coastal or riverine city of Lokoja-Benue trough of Nigeria (Osayomi et al., 2022). Ghorbani et al. (2022) highlighted the relevance of the SWOT framework combined with AHP to prioritize community-informed flood adaptation strategies (Ezugwu and Okpoko, 2025). Previous studies explored the SWOT technique to analyze coordinated development of water diversion projects (Long et al., 2021), evaluated irrigation systems to meet social and environmental demands (Katirtzidou et al., 2023), and assessed the productivity strategies of an industrial company (Popescu and Gasparotti, 2022). Data inadequacies were encountered during the monitoring of the disastrous impact of rainfalls and river floods (Tramblay et al., 2020), necessitating local perspectives and knowledge systems for flood risk management planning. This study examines sustainable flood solutions by integrating Participatory Geographic Information Systems (PGIS) into Perception Knowledge System (PKS) through a combined SWOT-AHP analytical framework, addressing urban flood vulnerability and resilience in Lagos, a megacity in Nigeria.

Developing a robust flood solution requires a more in-depth analysis, emphasizing an inclusive perception of sustainable flood management and the importance of a participatory approach that embraces diverse viewpoints (Das, 2020). This method, however, has not been fully explored in previous attempts or remains underutilized in urban flood resilience and disaster reduction efforts in many African flood-prone cities. The adoption of the AHP, a multicriteria

decision-making tool, aims to improve the SWOT model and quantify stakeholder preferences through weighted criteria ranking. This study is novel in that it integrates PGIS, PKS, and SWOT-AHP to create context-specific urban flood solutions. It takes into account the recurring urban flooding and the challenges posed by existing flood control measures in the coastal megacity of Lagos State, Nigeria. This study addresses these gaps by investigating the following:

- (a) How can PGIS effectively identify flood-prone areas, facilitating local knowledge on appropriate flood mitigation?
- (b) How can flood inundation mapping contribute to community knowledge levels, enhancing urban flood preparations for all stakeholders?
- (c) How can the SWOT-AHP framework help evaluate, prioritize, and improve flood resilience options for sustainable flood solutions?

The study was tailored keeping in mind the following specific objectives:

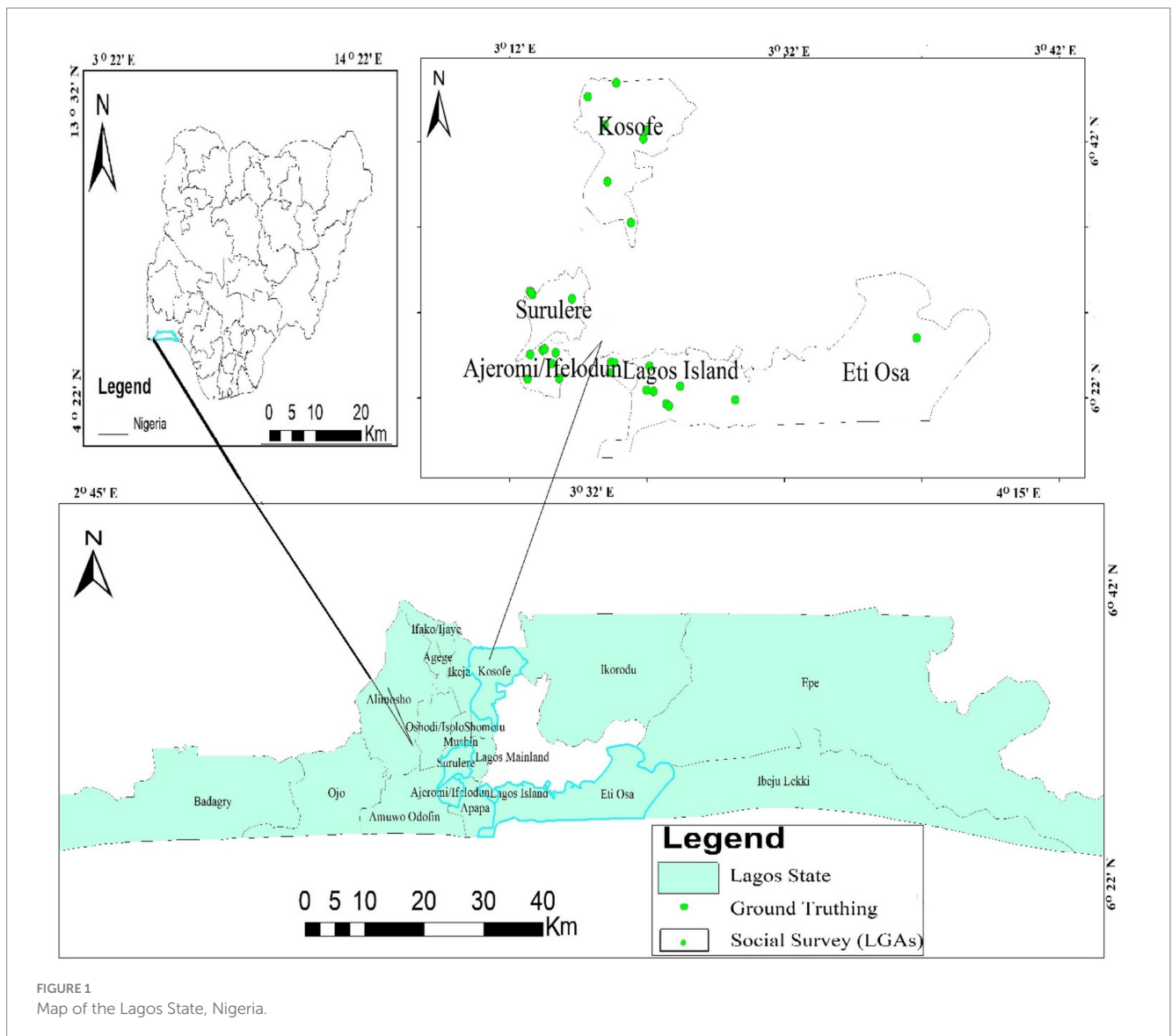
- i To apply PGIS in identifying flood-prone areas and gathering community knowledge for context-relevant flood mitigation strategies.
- ii To generate and analyze flood inundation maps that enhance community awareness, preparedness, and stakeholder engagement in urban flood resilience planning.
- iii To integrate the SWOT-AHP framework in evaluating and prioritizing flood resilience options, thereby developing sustainable, data-driven, and locally appropriate solutions.

This study is crucial for developing a structural methodology that enhances flood resilience through inclusive, appropriate urban planning and the use of sustainable resilience frameworks. The study contributes to the growing discourse on participatory environmental governance by demonstrating the value of bottom-up approaches in addressing complex urban flood challenges. This approach allows vulnerable community members and stakeholders to directly engage in mapping, problem-solving, analyzing unique flood experiences, and implementing appropriate coping strategies with timely solutions. The participatory spatial data and perception knowledge become contextualized, addressing urban flood dynamics, which is often lacking in formal planning processes. The study particularly examines how these approaches can contribute to achieving Sustainable Development Goals (SDGs) in Nigeria's vulnerable coastal regions.

2 Method

2.1 The study area: Lagos State

Lagos State, a coastal megacity, is situated on the shallow floodplain of the Bight of Benin in southwestern Nigeria (Figure 1) and is bordered on the south by the Atlantic Ocean. It occupies a geographic area between latitudes 6° 22' to 6° 42' N and longitude 2° 42' to 4° 22' E. Lagos has experienced rapid population growth over the years, with its population expanding from 305,000 inhabitants in



1950 to 9.1 million in 2006, according to the [National Population Commission \(2006\)](#). The United Nations World Urbanization Prospects projected a staggering 26 million people by 2025. Remarkably, a significant proportion of this population resides within the boundaries of the water basins, particularly in the central and eastern mainland areas. Similarly, the bulk of the population density is clustered within the Lagos Metropolitan Area of the 16 Local Government Areas (LGAs), while Epe, Ibeju-Lekki, Badagry, and Ikorodu are considered suburban ([Aliu and Ajala, 2014](#)). Meanwhile, a significant proportion of the urban dwellers resides within the boundaries of the water basins and the Atlantic Ocean coastline. These vulnerable areas are mostly affected by severe flooding, posing a risk to both people and infrastructure ([Oladipo, 2023](#)). The landscape of Lagos is typically flat, with certain locations within Lagos State, such as the entire Lagos southern area, exhibiting a varying lowest altitude of around 23 meters, with the highest elevation point of 73 meters above sea level in Ifako-Ijaiye, west of Lagos State ([Adeaga et al., 2020](#)).

The Nigeria Hydrological Services Agency (NIHSA) presented its Annual Flood Outlook (AFO) for 2024, noting that 148 LGAs

in 31 states of the federation fall within the high flood risk areas, while 249 LGAs fall within the moderate flood risk areas. Major parts of Lagos State were classified under the high-risk area, including Agege, Alimosho, Ikorodu, Lagos Island, Ikeja, and Eti-Osa, while other LGAs were classified under moderate flood risk.

2.2 Survey design

The study assessed the knowledge of residents in communities on early warning systems and flood control through a SWOT-AHP experiment. Initially, participants were introduced to the four key aspects of the SWOT model to enhance existing flood solution strategies. They were also educated on the causes, frequency, and severity of floods due to climate change. Furthermore, it was noted that the rainfall pattern in the megacity has intensified, and the existing urban drainage systems are insufficient to address current challenges. Lastly, discussions were held on how to mitigate future

floods and reduce damages through an integrated resilience approach that includes immediate, mid-term, and long-term goals.

The study utilized mixed methodologies, incorporating a structured questionnaire for both respondents and key informants. Copies of questionnaires were administered in person as well as offline, using Open Data Kit (ODK). [Purbasari et al. \(2021\)](#) described ODK as a modern open tool compatible with smartphones, which has proven useful in qualitative and quantitative studies. The SWOT assessment on sustainable flood solutions consisted of 40 statements, with 10 statements each under “strengths, weaknesses, opportunities, and threats.” Participants ranked their responses on a scale of 1 to 5, indicating the weakest to strongest agreement metric. The SWOT elements provided insights into existing flood resilience strategies and areas requiring improvement.

2.3 Sampling method

The study identified five highly vulnerable flood zones in Lagos State ([Lagos State Emergency Management Agency, 2023](#)) based on factors such as spatial flood vulnerability, population density, and socio-economic status. The study selected five LGAs (Ajeromi/Ifelodun, Eti-Osa, Kosofe, Lagos Island, and Surulere) that met the highlighted criteria. Participants were drawn from vulnerable communities identified in reports by [Lagos State Emergency Management Agency \(2023\)](#) and the [Nigeria Hydrological Service Agency \(2024\)](#). Systematic intervals were used to select streets and vulnerable houses in the flood zones, while systematic random sampling was employed to administer copies of the questionnaire to respondents in the selected communities. Key informant officials (KIO), including local community leaders and government officials, were also engaged with for questionnaire administration either online or through physical contact.

A total of 400 out of 1,597 households in the selected flood communities were surveyed, representing 25% of the vulnerable households in the area. The study used the [Yamane \(1967\)](#) formula to calculate the sample size at a confidence level of 0.05. A total of 398 copies of questionnaires were successfully retrieved from the residents at a response rate of 99.5%. As represented in the formula expressed in [Equation 1](#).

$$n = \frac{N}{1 + N(e)} \quad (1)$$

Similarly, 15 key informant interview (KII) participants were contacted, including 6 executive officers from the Ministry of Environment and Water Resources, 5 community leaders from the selected LGAs, and 2 senior officers of the State Emergency Management Agency, as well as 1 representative each from the Waste Management Agency and Lagos Resilience Strategy Agency. Geographic coordinates of the observed urban flooding were collected using a handheld-GPS (Garmin 64 s) for ground-truthing purposes.

2.4 Spatial rainfall mapping and flood inundation knowledge

This study aimed to gather information on the spatial pattern of urban vulnerability and rainfall-related flood issues through

GIS-mapping of Lagos megacity. The objectives were to map rainfall during transitional seasons for flood warning systems and simulate surface inundation through floodwater recession duration in urban impervious areas. Satellite imagery from the Shuttle Radar Topographic Mission-Digital Elevation Model (SRTM-DEM), obtained from the United States Geological Survey (USGS) was used for spatial vulnerability analysis. The boundary of the study area and features were overlaid on the DEM imagery to mark the study area extent using the ArcGIS Spatial Analyst tool.

Similarly, drainage basin and flow accumulation patterns were generated for the surface flood scenarios, and impacts were assessed. The DEM was used to create basin and sub-basin using the hydrological tool in ArcMap 10.8 software, extracting the flow direction grid, flow accumulation, stream order, and basin delineation. The DEM image was processed with sink filling to derive flow direction and accumulation. Basin delineation and sub-basins were generated for the watershed.

Sentinel-2 imagery data were used to classify the extent of land coverage, including vegetation, waterbodies, and built-up structures within the study area. The mosaic function was applied to merge multiple imagery scenes into a seamless raster layer covering the entire study area. The study followed the standard method described by [Jensen \(1996\)](#) to classify Land Use Land Cover (LULC), aiming to understand the urbanization trend through the assessment of spatial flood dynamics of vegetated versus non-vegetated areas. The Maximum Likelihood Classification (MLC) algorithm was employed in ArcGIS, given its widespread use and effectiveness in satellite image classification ([Gowtham and Dhanapriya, 2025](#)). Surface inundation zones were derived using the DEM, and the raster was overlaid on the delineated urban area to extract vulnerable regions, while different flood run-off times were simulated.

The study utilized gridded climate data and a base map of Lagos State for interpolation processing operations. Spatial rainfall data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) was obtained to monitor the spatial rainfall-flood relationship. These high-resolution gridded data were multivariate, time-series with variations in rainfall patterns covering the transitional seasons of rainfall in the study area. CHIRPS data was opted for due to its advantages for the study area, including high resolution (~5 km) and long-term record (1981 to near-present), and incorporation of station data to improve accuracy over other satellite-only products like Global Precipitation Measurement (GPM) or Tropical Rainfall Measuring Mission (TRMM), which are typically shorter in duration. In addition, CHIRP data is widely considered one of the best rainfall datasets for climate and flood studies, especially in regions such as Nigeria, where gauge networks are sparse or inconsistent. Hence, CHIRPS rainfall data for specific high rainfall years between January 1981 and December 2023 were collected for hydroclimatic analysis.

However, the rainfall pattern in Lagos State has phases: rainfall onset from April to July, break in August, and the second rainfall peak from September to October. This periodic transitional season reflected 3-month rainfall data acquired for spatial rainfall interpolation. Before analysis, preprocessing operations were conducted to convert spatial rainfall data into a common Geographic Tagged Image File Format (GeoTIFF), and it was georeferenced to a common resolution of WGS-UTM zone 31 using the ArcMap 10.8 software. The Nearest Neighbor resampling technique was used for spatial grids, while Inverse Distance Weight (IDW) interpolation was utilized as a spatial

analyst tool. Results on spatial rainfall data were generated for the periodic transitional season of rainfall-related flood occurrence in the study area.

2.5 Ethical statement and informed consent

This study was conducted according to ethical standards and approved protocols. Ethical approval was obtained from the Departmental Review Board of Post-Graduate Studies, Obafemi Awolowo University Research Ethics Committee, as part of the propositional seminar. Informed consent was obtained from human participants before their participation in the study, as outlined in the administered questionnaires. The study adhered to all relevant national and institutional guidelines for studies involving human participants and field survey processes. Data collection was conducted by the authors over 6 months (June 2024–December 2024) in the study area. [Figure 2](#) presents the conceptual methods and details of the data used in the study.

3 Data analysis

3.1 Demographic analysis of respondents

The data collected through the questionnaires on flood solutions were analyzed using descriptive statistics. The demographic and socio-economic characteristics of the community residents are shown in [Table 1](#). Most of the respondents were male (57.7%), while 42.3% were

female. Respondents aged between 31 and 45 years accounted for 34.8% and approximately 47% of respondents were between the ages of 46 and 59 years, making up a larger portion of the total respondents. In terms of marital status, the majority of respondents identified themselves as married (62.5%). A significant proportion of the well-educated respondents (74.8%) had tertiary education, while 21.9% possessed postgraduate education. Approximately 84% were employed, which reflected the income status of the respondents. The majority (38.4%) of respondents had resided within their local communities for 11–15 years, while 33.2% had lived in their communities for about 16–20 years.

Most respondents (67.8%) resided in flats in blocks, and the others lived in semidetached houses (9.8%), houses made of traditional materials (4.3%), commercial buildings (10.8%), and office buildings (7.3%). The age of the buildings was distributed as follows: less than 5 years (1.0%), 5 to 10 years (19.4%), 11 to 20 years (28%), 21 to 30 years (34%), and 31 years and above (17.6%). When considering disability status, the majority (88.9%) had no disability while 11.1% reported various levels of disability. Respondents demonstrated good knowledge of urban flooding, providing valuable responses on flood impacts, mitigating measures, and intervention schemes. The significant sociodemographic attributes indicated that the majority of respondents were mature, adult, well-educated men.

3.2 SWOT analysis

The SWOT analysis serves as an analytical tool to determine the strengths, weaknesses, opportunities, and threats of urban flood solutions. This study developed a distinct method similar to the

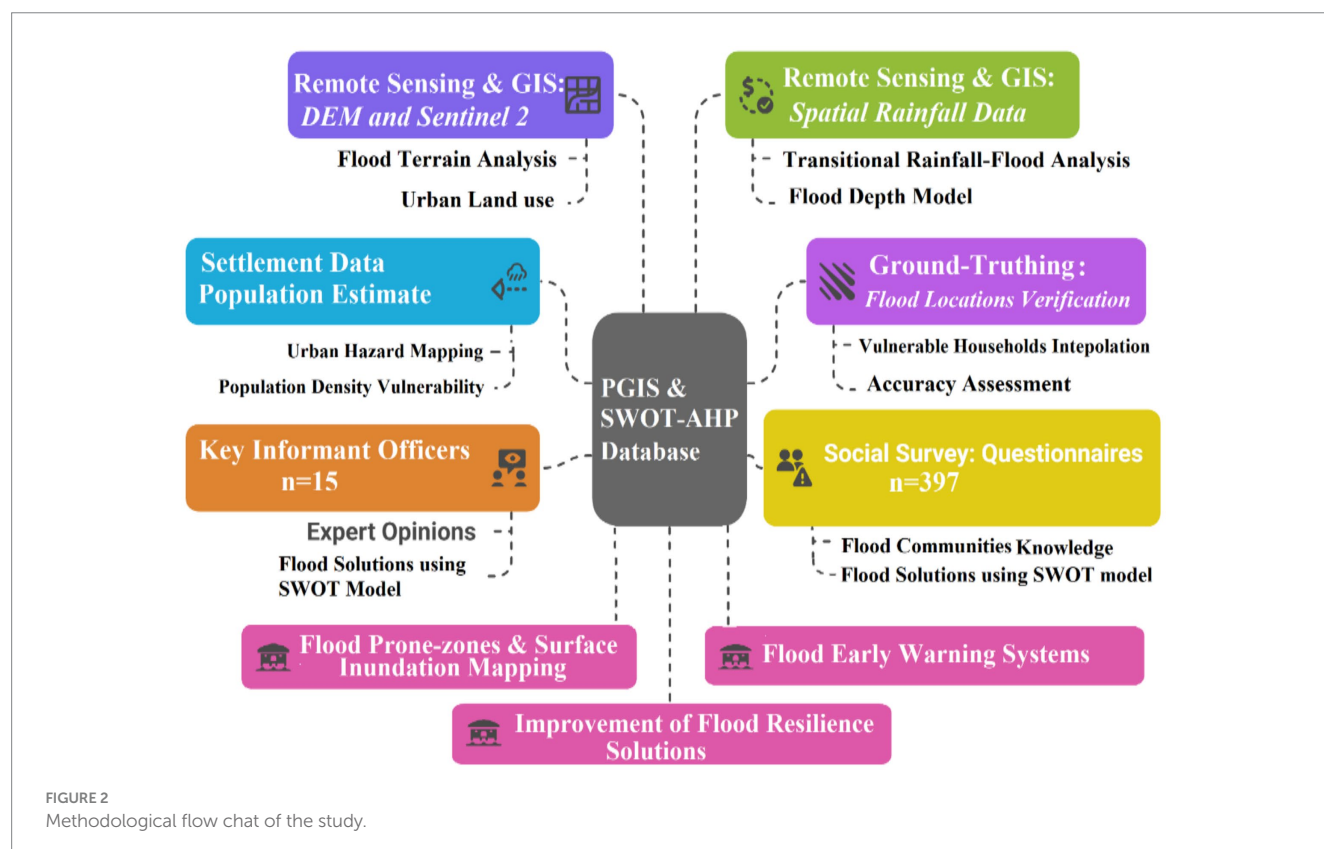


TABLE 1 Social and demographic characteristics of community residents.

Gender				
Male		Female		
229 (57.7)		168 (42.3)		
Age group				
18–30 years		31–45 years		46–59 years
14 (3.5)		138 (34.8)		186 (46.9)
Level of education				
Primary		Secondary		Tertiary
02 (0.5)		11 (2.8)		297 (74.8)
Residence duration				
5–10 years		11–15 years		16–20 years
12 (3.0)		153 (38.5)		138 (34.8)
Housing/Building type				
Flat in block		Semi-detached		Traditional materials
269 (67.8)		39 (9.8)		17 (4.3)
				Commercial
				Public/Private office
				29 (7.3)
Disability status				
No		Yes		
353 (88.9)		44 (11.1)		

studies of Ghazinoory et al. (2011) and Nathaniel et al. (2023), where each questionnaire targeted the participants' responses to gain a thorough understanding of the statement in the SWOT questionnaire. The study analyzed the perception of the SWOT Index for each variable obtained by calculating the Summation Weight Value (SWV) for each attribute (variable) using frequency data. As represented in the formula expressed in Equation 2:

$$SWV = \sum_{i=1}^{i=5} PiVi \quad (2)$$

where Total Weighted Value (TWV) is the Summed Weighted Value (SWV) for each of the 10 questions, Pi is the number of respondents choosing a particular rating, and Vi is the weight assigned to rating i . The PSI for each variable was obtained by dividing the SWV by the total number of the respondents to each of the five ratings of a question. As represented in the formula expressed in Equation 3:

$$SWOT_{\text{perception}} = \frac{TWV}{\sum_{i=1}^{i=5} PiVi} \quad (3)$$

where $SWOT_{\text{perception}}$ is the perception index. It must be noted that the closer the $SWOT_{\text{perception}}$ of a question (variable) is to 5, the higher is the assumed significance of the SWOT index. The mean of Pi was also computed with the aim of calculating the mean value of each attribute (variable), their variance and standard deviation (SD). A total of 412 responses were analyzed from participants (community

residents and KIIs) to obtain comprehensive flood knowledge. Table 2 reveals the summation and mean values of the SWOT Index (see Figures 3, 4 for more details on the SWOT elements), and coefficients of variation have also been presented.

3.2.1 SWOT matrix analysis

The study utilized AHP, a popular tool for Multi-Criteria Decision-Making (MCDA). Saaty's (1980) procedures were followed, focusing on the most important alternative, and the preference for all alternatives for each decision-making. The study utilized mean values of SWOT matrix (Nathaniel et al., 2023). The internal factors strategy (IFAS) focused on strengths and weaknesses, while the external factors strategy (EFAS) considered the opportunities and threats.

The study utilized a crosstab contingency matrix (Popescu and Gasparotti, 2022) to identify and formulate the strategic framework for flood solution components. Four criteria (environment, legal and institution, socioeconomic, and urban engineering) and corresponding alternative elements were generated for the pairwise comparison. As per strategic fit theory, recommended by Gresov (1989), coordinated points fall in the quadrants of the Opportunities-Weaknesses (O-W) model (Figure 5). In addition, the geometric mean calculation of the O-W variables was computed, while the normalization matrix was obtained by dividing the sum of column values in each matrix being compared. The weight of each element was determined by calculating the average value of each row of elements in the normalization matrix for the SWOT-AHP.

The SWOT-AHP considered factors and criteria in the systematic evaluation of flood resilience strategies, prioritizing ten (10) formulated in the same pairwise procedures to obtain weighted values as presented in Furthermore, values of Strategic Framework Analysis (SFA) were used to determine the flood solution timeframe in three different categories. The weighted values of criteria and alternatives were used to calculate the final ranking score. Based on the final score, each strategic framework was classified into an aggregate ranking of short-, medium-, and long-term strategies. This is further defined as follows: If the score value $< (SFA/3 + Min)$, it is termed a short-term strategy, while a long-term strategy is when the score value $> (Max - SFAS/3)$. The medium-term strategy is defined as a score value between $(SFAS/3 + Min)$ and $(Max - SFAS/3)$. The SWOT model is efficient for analyzing existing flood resilience structures and specific areas where significant improvement is required. The suggested strategic flood solution, classified and pairwise, generates in-depth insights into immediate actions under sustainable flood solutions in the study area. The integration of SWOT and AHP justified the need to overcome the subjectivity of SWOT and provide a structured, quantitative basis for decision-making (Görener et al., 2012). This hybrid approach is particularly valuable in Lagos, where recurrent flooding, limited data availability, and diverse stakeholder interests demand a robust methodology that is both participatory and analytically comprehensive (see Table 3).

3.2.2 Logical consistency

The study validated the accuracy of calculated weight values using a consistency ratio (CR). AHP principles of quantitative weights using pairwise comparisons helped in ranking flood resilience options, rendering decision-making more transparent and systematic (Saaty and Vargas, 2001). However, major AHP studies require random index (RI) values, as adopted from Saaty (1980), and the CR threshold of 0.10, as suggested by Saaty (1990), was used to determine the acceptability of the

TABLE 2 Summary of SWOT model for flood control strategies.

s/n	SWV	Mean	$(x - \bar{x})$	$(x - \bar{x})^2$
Strengths (S)				
S1	824	2	0.05	0.0025
S2	824	2	0.05	0.0025
S3	1,030	2.5	0.55	0.3025
S4	824	2	0.05	0.0025
S5	618	1.5	−0.45	0.2025
S6	824	2	0.05	0.0025
S7	824	2	0.05	0.0025
S8	1,030	2.5	0.55	0.3025
S9	618	1.5	−0.45	0.2025
S10	618	1.5	−0.45	0.2025
Total (\bar{x})	8,034	19.5 (1.95)		1.22
Weaknesses (W)				
W1	1,442	3.5	−0.3	0.09
W2	1,648	4	0.2	0.04
W3	1,442	3.5	−0.3	0.09
W4	1,442	3.5	−0.3	0.09
W5	1,442	3.5	−0.3	0.09
W6	1,648	4	0.2	0.04
W7	1,648	4	0.2	0.04
W8	1,442	3.5	−0.3	0.09
W9	1,854	4.5	0.7	0.49
W10	1,648	4	0.2	0.04
Total (\bar{x})	15,656	38 (3.8)		1.10
Opportunities (O)				
O1	1,648	4	−0.2	0.04
O2	1,854	4.5	0.3	0.09
O3	1,854	4.5	0.3	0.09
O4	1,648	4	−0.2	0.04
O5	1,442	3.5	−0.7	0.49
O6	1,648	4	−0.2	0.04
O7	2,060	5	0.8	0.64
O8	1,648	4	−0.2	0.04
O9	1,854	4.5	0.3	0.09
O10	1,648	4	−0.2	0.04
Total (\bar{x})	17,304	42 (4.2)		1.60
Threats (T)				
T1	1,854	4.5	0.55	0.30
T2	1,442	3.5	−0.45	0.2025
T3	1,854	4.5	0.55	0.3025
T4	1,648	4	0.05	0.0025
T5	1,442	3.5	−0.45	0.2025
T6	1,236	3	−0.95	0.9025
T7	1,442	3.5	−0.45	0.2025

(Continued)

TABLE 2 (Continued)

T8	1,648	4	0.05	0.0025
T9	1,854	4.5	0.55	0.3025
T10	1,854	4.5	0.55	0.3025
Total (\bar{x})	16,274	39.5 (3.95)		2.73

pairwise comparison matrices. Therefore, the eigenvector value was obtained by multiplying the comparison matrix by the weight of each element as represented in the formula expressed in Equation 4:

$$\begin{matrix} 1 & 0 & 0 & B1 & \lambda 1 \\ 0 & 1 & 0 & \times B2 & \lambda 2 \\ 0 & 0 & 1 & B3 & \lambda 3 \end{matrix} \quad (4)$$

The maximum eigenvector value (λ_{\max}) was calculated by dividing the eigenvector value and the weight of each element to obtain the average score as shown below as represented in the formula expressed in Equation 5:

$$\lambda_{\max} = \frac{((\lambda 1 / B1) + (\lambda 2 / B2) + (\lambda 3 / B3))}{n} \quad (5)$$

where λ_{\max} = maximum eigenvector value and n = order of matrix.

The consistency vector (CV) was calculated by dividing each element of the weighted sum vector by the corresponding element in the weight vector. The average value of the CV is denoted as λ_{\max} . The AHP used the CR for its calculation as represented in the formula expressed in Equation 6:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (6)$$

where CI = consistency index, n = order of matrix.

However, the random index is a predefined value based on the size of the matrix that was used to obtain the average consistency index of randomly generated pairwise comparison matrices. The CR is calculated as follows in Equation 7:

$$CR = \frac{CI}{RI} \quad (7)$$

where CR = consistency ratio, CI = consistency index, and RI = random index.

A CR value of ≤ 0.10 (10%) is regarded as acceptable, indicating a reasonable consistency level. However, if $CR > 0.10$, the pairwise comparisons need to be revisited and improved for better consistency.

3.3 Integration of AHP weights for geospatial vulnerability mapping

The study identified flood-conditioning factors relevant to Lagos, including elevation, slope, distance to drainage, land use/land cover,

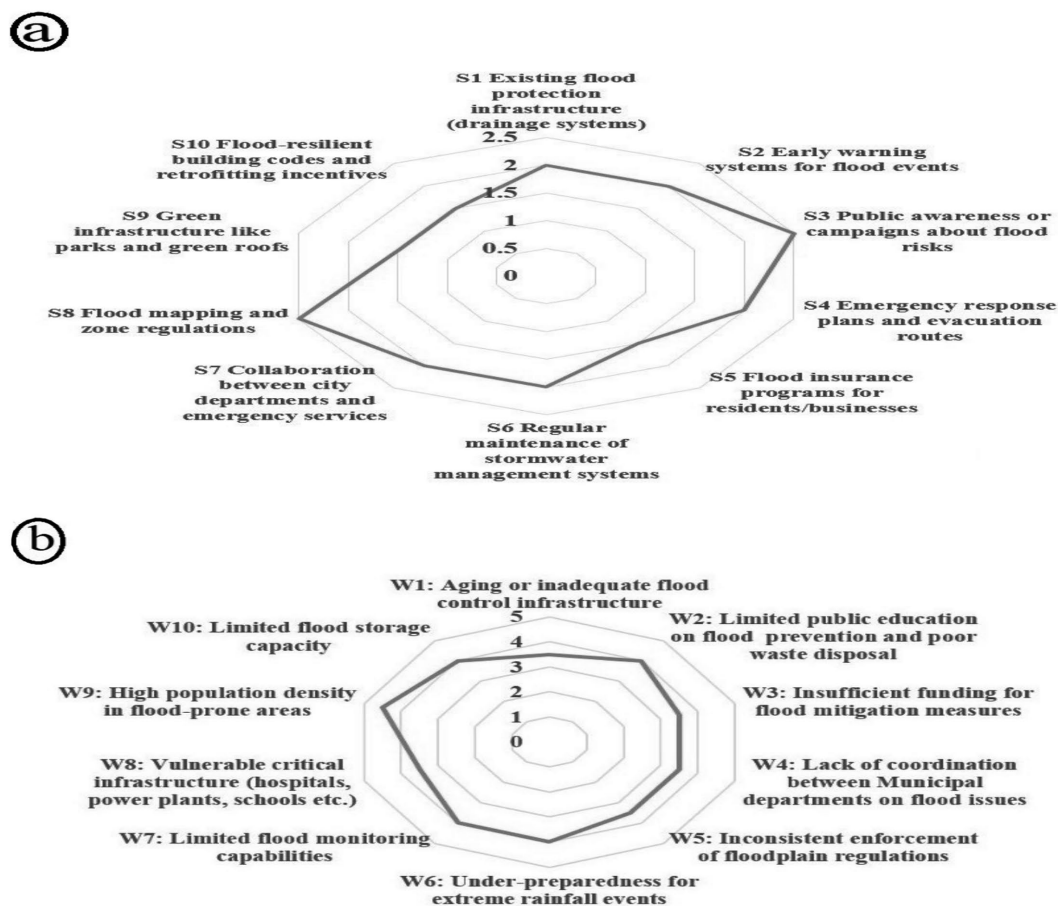


FIGURE 3
Spider charts of internal index of SWOT analysis. (a) Strength Index, (b) Weakness Index.

soil class, rainfall intensity, drainage density, distance to coast, imperviousness, and population exposure. All layers were projected, clipped, and resampled to a common grid and standardized to a 0–1 vulnerability scale using monotonic linear transformations for continuous variables and expert-informed reclassification of categorical variables. Stakeholder elicitation informed AHP pairwise comparisons, and the resulting weight vector ($CR \leq 0.1$) was applied in ArcGIS with the weighted sum tool to generate inundation outputs. The composite vulnerability surface was normalized and classified (Jenks) into six flood run-off categories. The robustness was evaluated via ± 10 –20% weight perturbations and alternative stakeholder scenarios, and the map was validated against independent flood observations in the study area.

4 Results

4.1 Identifying flood-prone areas

The study presents findings on the population and aerial vulnerability mapping of recurring flooding in the 20 LGAs of Lagos State, drawing attention to the vulnerable settlements within the urban metropolis. Figure 6a shows the extremely high population density (>5 million persons/sq.km) in high-exposure flood zones, particularly

areas such as Lagos Island, Mainland, and surrounding LGAs within the Urban Metropolitan Districts (UMD). The areas with moderate vulnerability had a varying density (1 to 5 million persons/sq.km), indicating moderate to poor infrastructure in densely populated areas of the informal settlements.

Figure 6b shows that the extremely vulnerable areas are concentrated in the southern coastal LGAs such as Eti-Osa (8), Lagos Island (14), and Amuwo-Odofin (4), while very high-risk areas extend to inland corridors through LGAs such as Ibeju-Lekki (9), Apapa (5), and Lagos Mainland (15). The lowest flood vulnerability levels were observed mostly in the northern LGAs, including Ifako-Ijaiye (10) and parts of Agege (1), Alimosho (3), and Ikorodu (12). Similarly, flood risk relative to the urban population density was mapped, revealing areas with high vulnerability to floods. The findings revealed a strong spatial overlap between extreme flood zones and densely populated settlements, especially in the southern coastal area and central metropolitan LGAs, noting a high rate of flood recurrence within the identified areas.

4.2 Flood early warning system and surface inundation mapping

Figure 7 presents findings on the need for flood early warning and rainfall-flood awareness during the first and second peaks of rainfall

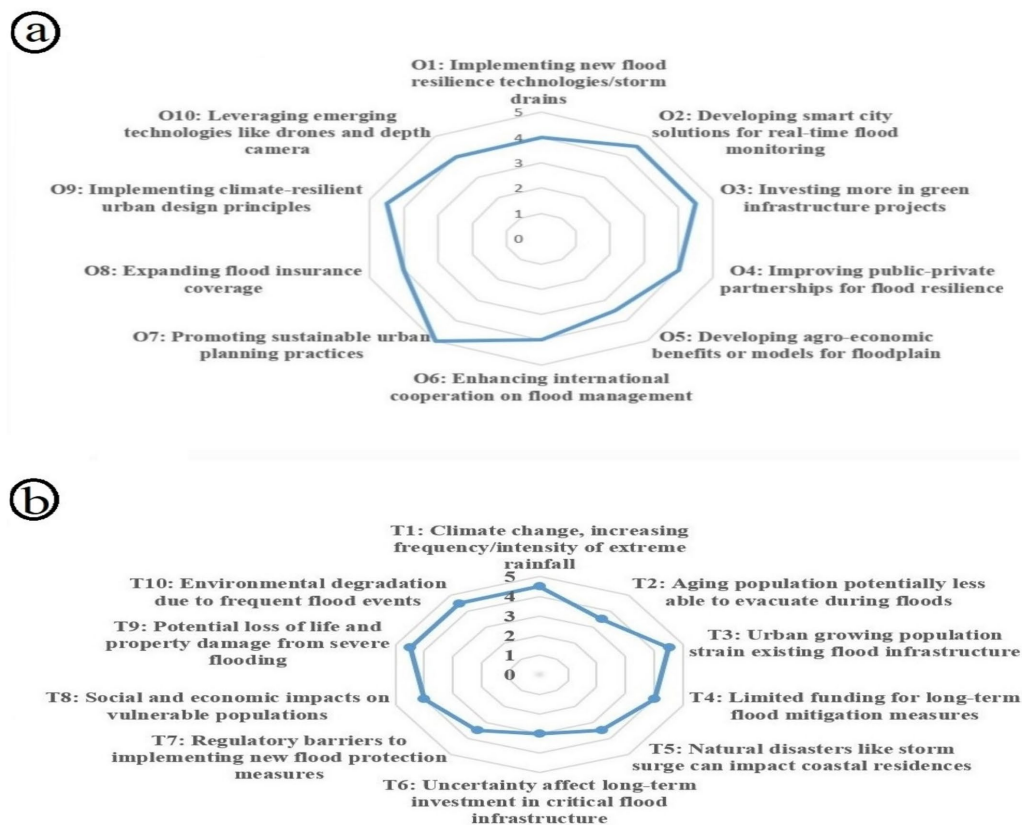


FIGURE 4
Spider charts of external index of SWOT analysis. (a) Opportunity Index, (b) Threat Index.

in Lagos State, addressing the important causes of flooding in the settlements. Therefore, resilience stakeholders should focus on the high rainfall periods across Lagos State in JJA, requiring community engagement on flood mitigation techniques. The second peak in SON, particularly in coastal regions where floods were significantly high, also needs attention. Areas with over 1,900 mm and 1,700–1,900 mm rainfall are most prone to flooding due to high annual rainfall. These zones are extensive across the northern and southern fringes during the peak JJA rainfall, indicating sustained flood risks. However, mid-range rainfall zones (1,300–1,700 mm) are transitional, even though still significant for planning purposes.

Figures 7a,b establishes an understanding of flood warning scenarios under rainfall extremes in JJA, emphasizing the southward shift of higher rainfall zones in the SON transitional rainfall peak. Real-time rainfall monitoring and integrated awareness campaigns should be prioritized in areas where the rainfall threshold is above 1,500 mm, particularly in coastal regions where 1,900 mm of rainfall is consistently received annually. This suggests a larger flood-prone region in JJA compared to SON, which is critical for the flood early warning system and excavation plans in the study area.

Figure 7c represents flood run-off time and response of shorter run-off time (2–3 h) observed in the northern region of the study area, as flooding occurs and recedes normally after the rainfall period. Moderate run-off time (4–5 h) offers more lead time for evacuation or intervention, but the rainfall may result in prolonged flooding due to slow water dissipation. The high-risk areas are mainly in the southern

belt of Lagos State, dominated by a longer run-off time (6 h), which indicates high vulnerability due to slow drainage and accumulation of water. The JJA and SON rain periods necessitate early warning to residents of flood-prone areas in the Lagos metropolis. Similarly, findings emphasize the prolonged surface inundations of 6 h in coastal areas, resulting in significant losses across the rainfall peak season. Flood resilience efforts by appropriate municipal authorities should focus on depopulating coastal residences, channelizing waterways, and relocating vulnerable populations to a safe resettlement base.

4.3 Internal factor index

Figure 3a presents the results of internal factors of strengths and weaknesses in the SWOT model. The Perception Strength Index (PSI) obtained a SWV of 8,034 and a mean value (\bar{x}) of 1.95. Positive deviations were observed in S3 (public awareness campaigns) and S8 (flood mapping and zoning regulations), with scores above 2.5, which suggests they are perceived as more impactful. Similarly, S1, S2, S4, S6, and S7 had individual scores of 2.0, indicating moderate effectiveness. In addition, S5, S9, and S10 each scored 1.5, which is below the PSI mean, showing their perceived weaker PSI.

Results in Figure 3b revealed that the Perception Weaknesses Index (PWI) obtained a SWV of 15,656 and a PWI mean value (\bar{x}) of 3.8. A high positive deviation from the PWI mean was observed in W9 (high population density in flood-prone areas), indicating

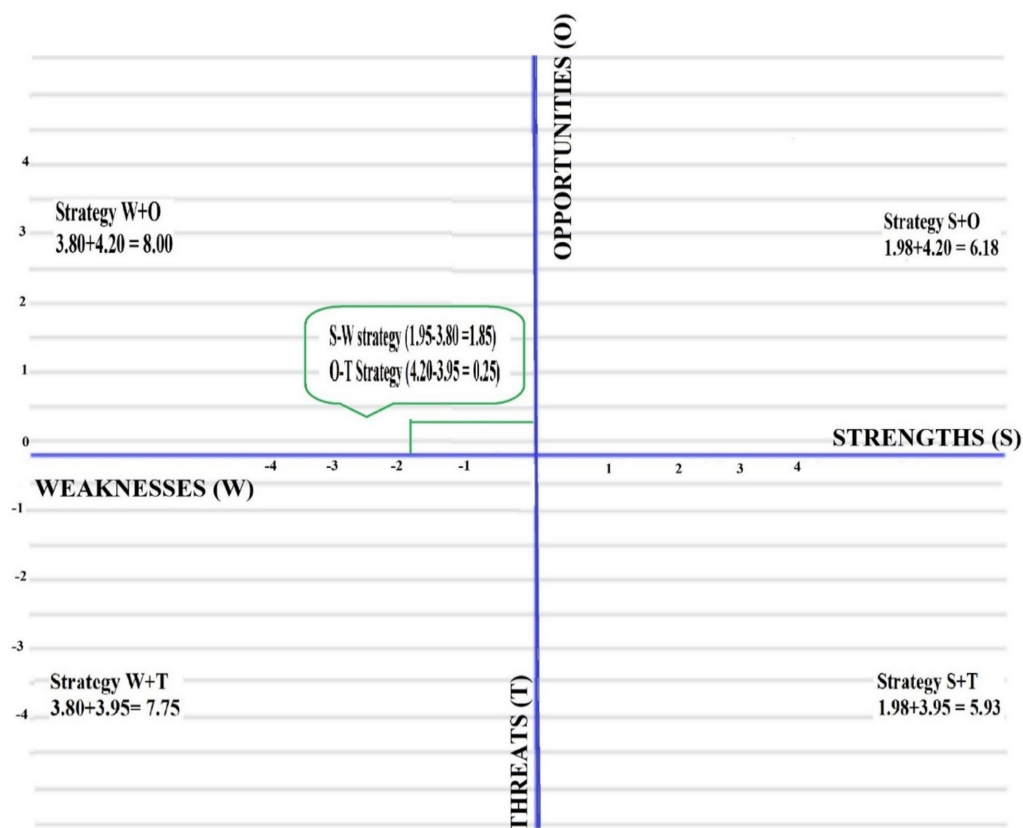


FIGURE 5
Quadrant fit point of the internal and external SWOT flood solutions.

the most significant weakness with the highest deviation (+0.7). Similarly, W2, W6, W7, and W10 maintained scores above the PWI mean, indicating serious weaknesses and critical vulnerabilities. In addition, W1, W3, W4, W5, and W8 had mean scores of 3.5 each, which is below the PWI mean, showing considerable weak priority and relevance. However, the standout score of W9 (4.5) accounts for half of the total variance, showing one dominant weakness in the PWI results. This indicates limited implementation, awareness, or effectiveness, and suggests potential priority areas for improvement.

4.4 External index

Results in Figure 4a revealed that the Perception Opportunities Index (POI) obtained a POI mean value (\bar{x}) of 4.2. Findings show that the topmost opportunity was found in O7 (5.0), while others, such as O2, O3, and O9, had a mean score of 4.5. Moderate opportunities were found in O1, O4, O6, O8, and O10, with a mean score of 4.0, which is considered viable but requires targeted execution. POI obtained the highest SWV of 17,304 with the highest mean score of 4.2 in the SWOT model, establishing a combination of high likelihood, severity, and mitigation of possible impacts of urban flooding through suggested opportunity indices. The high-rated opportunities appear to be proactive, integrated, and formidable strategies for addressing flood challenges and enhancing urban resilience and disaster reduction efforts.

Findings shared in Figure 4b revealed a mean value (\bar{x}) of 3.95, while high-rated Perception Threats Index (PTI) around a mean score of 4.5 was found in T1, T3, T9, and T10. Similarly, T4 and T8, with a mean score of 4.0, aligned with the PTI mean. Negative deviations were observed in T2, T5, and T7, while T6 maintained a lower-scoring threat index. The SWOT model of internal and external factors accounted for variation in SWV, while the opportunities index scored the highest (17,304), signifying the perception of residents and stakeholders on the potential of counterreaction to threats through proactive measures such as green infrastructure (O3) or smart monitoring (O2). Furthermore, the mean scores of TPI (3.95), PWI (3.8), and lower PSI (1.95) indicate the need for urgent actions through TOI (4.2).

4.5 SWOT-AHP strategy for resilience improvement

The strategic factor positions suggested strengthening weaknesses through opportunities for flood resilience improvements in the study area. The SWOT-AHP model helps address the weaknesses and predict and mitigate threats using opportunity strategies. Thus, the formulation of policies to strengthen the strategic flood resilience and regulations can be maximized. Table 4 presents the formulated strategies and their rankings, which were further analyzed using the SWOT-AHP matrix. The weight of each variable was determined through the PI mean values, and criteria and alternatives were assessed

TABLE 3 Strategic factor of SWOT model and consistency index.

Strategic factor					
Flood resilience strategy (FRS) variables	Weight	Consistency vector			
FRS-1	1.28	16.27	(λ_{\max})	101.92/10	10.192
FRS-2	1.04	10.82	CI	10.192–10/10–1	0.192/9
FRS-3	1.03	10.56	CI	0.021	
FRS-4	0.92	8.52	Random index	1.49	
FRS-5	1.03	10.56	Consistency Ratio (CR)	0.021/1.49	
FRS-6	0.91	8.29	Consistency Ratio (CR)	0.014	
FRS-7	0.91	8.29			
FRS-8	0.94	8.75			
FRS-9	1.15	13.12			
FRS-10	0.82	6.77			
Total	10.02	101.92			

Build the pairwise comparison matrix					
Criteria	Environment	Socioeconomic	Legal & institutional	Urban engineering	
Environment	1	2.76	2.09	2.76	
Socioeconomic	0.36	1	0.76	1	
Legal & institutional	0.48	1.31	1	1.31	
Urban engineering	0.36	1	0.76	1	
Normalize pairwise					
Environment	0.455	0.46	0.453	0.455	
Socioeconomic	0.164	0.17	0.165	0.165	
Legal & institutional	0.218	0.22	0.217	0.216	
Urban engineering	0.164	0.17	0.165	0.165	
Consistency check	Wi	CV	Priority		
Environment	0.455	1.86	0.455	λ_{\max}	4.09
Socioeconomic	0.165	0.67	0.165	CI	4.09–4/3
Legal & institutional	0.217	0.89	0.217	CI	0.03
Urban engineering	0.165	0.67	0.165	RI	0.91
				CR	0.03/0.91
Remark: 0.033 is acceptable				CR	0.033

using the AHP. In addition, environment, socioeconomic, legal and institution, and urban engineering had weighted values of 0.45, 0.16, 0.22, and 0.16, respectively. The highest and moderate weight values were assigned to the environment and legal and institution, indicating that focusing on the environment of the Lagos metropolis could result in optimal flood countermeasure strategies. In addition, alternative strategic variables were computed to generate weight values for ranking purposes. The global weight ranking for each strategy was determined based on the level of priority.

The AHP model ranking was used to establish the strategy timeframe with formulated strategic frameworks. The timeframe was categorized into three phases: short-term, mid-term, and long-term plans. The aggregate weight score of all variables was calculated to determine the strategic timeframe for each variable. The SFA

summary within the lower category indicated short-term plans, while mid and upper values defined mid-term and long-term plans, respectively. However, the short-term plans (<5.61) included RS10, attention on critical infrastructure vulnerability (1.02); RS7, focus on aging or inadequate flood drainage infrastructure (3.33); RS6, regulating land use and new flood protection measures (3.33); and RS4, prioritizing evacuation of vulnerable populations before floods (4.48). Mid-term plans ranged from 5.7–10.1, including RS8, provision of funding for flood mitigation measures (5.7); RS5, prediction of storm surge impact on coastal residences (8.61); S3, investing more in green infrastructure projects (8.61); and RS2, developing smart city solutions for real-time flood monitoring (9.92). In addition, the long-term plan (>10.2) consisted of RS9, which includes consistent enforcement of floodplain regulations and setback

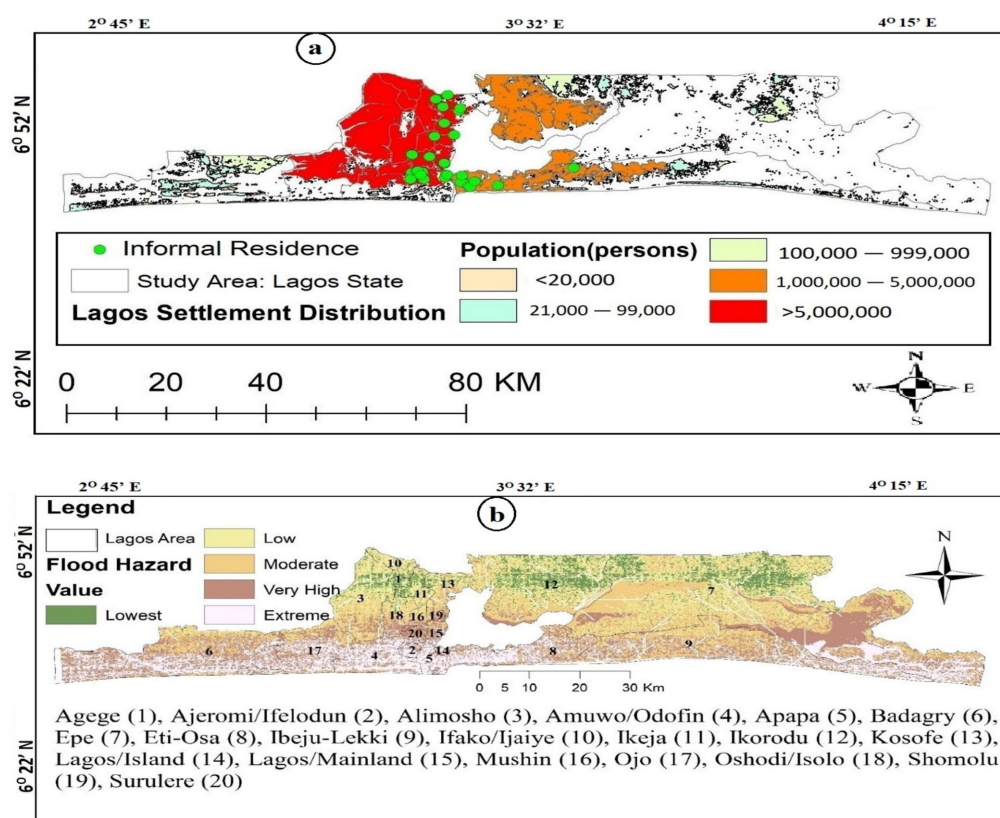


FIGURE 6

(a) Flood hazard mapping of the 20 LGAs of Lagos State. (b) Population density with their vulnerability to flood.

(12.15), and S1, which includes promotion of sustainable urban planning practices (14.8).

5 Discussion and future study

The significance of urban flood solutions is reflected in the assessment of current flood vulnerability and recurrence in Lagos State, using participatory GIS (PGIS) and perception knowledge systems. The findings of the study were in agreement with previous works by Salami and Otokiti (2022), Oladipo (2023), Ndimele et al. (2024), and Oguntokun and Fayomi (2025), which provided robust knowledge on the spatial dynamics of floods, challenges faced by residents, and how improvement can be achieved in sustainable flood risk management of the study area. The assessment quantifies flood vulnerability problems, temporal consequences of surface water inundation, and flood solutions using the advanced SWOT-AHP technique. Oguntola (2022) affirmed that flood likelihood assessment is intertwined with the general condition of low-lying land, proximity to drainage, and massive impervious surfaces, as well as a highly vulnerable population. The results highlighted that low elevation remains a major flood-influencing element promoting flood risk in a larger part of the Lagos coastal environment. The GIS-based spatial assessment revealed flood vulnerability classes of Lagos metropolis, establishing that low-lying coastal areas and densely populated UMDs are highly vulnerable and experience severe flood hazards (Kasim et al., 2022).

However, the observed surface inundation is extremely high due to the inherent nature of land configuration, impervious surfaces, and land utilization patterns in Lagos State, Nigeria. Findings revealed a high occurrence of rainfall-induced floods in JJA, which validated the spatial rainfall mapping of flood susceptibility of urban areas. The study analyzed the influence of transitional rainfall patterns and their effects contributing to urban flood impact in coastal residential areas, helping recreate flood prewarnings (Aliyu et al., 2023). The findings agree with Obiefuna et al. (2021), Osanyintuyi et al. (2022), and Isiaka et al. (2023), affirming the impact of high rainfall-induced flood on the coastal and lagoon settlers, emphasizing spatial rainfall frequency and accompanying flood severity in Makoko, Shomolu, Ojo, Apapa, Ebute-Metta, Obalende, Bariga, and other floating settlements in and around the corridors of Lagos water bodies.

The most significant impact is seen in the densely built-up and poorly planned urban areas, such as Ajeromi/Ifelodun, Surulere, Shomolu, Agege, Lagos Mainland/Island, and Isolo/Oshodi. The effect of surface runoff, backwash flood, and flash flood also aggravates the damage to lives and properties, limits road efficiency, and impacts public infrastructure (Oguntokun and Fayomi, 2025). These floods occur seasonally, aligning with the intensity and frequency of rainfall events, exacerbated by the rate of urbanization and unsustainable human practices (United Nations Development Programme, 2023). The findings of the study highlighted the areas where major flood programs are required, particularly during the first rainfall peak (JJA) and second peak (SON). The coastal residential areas require more

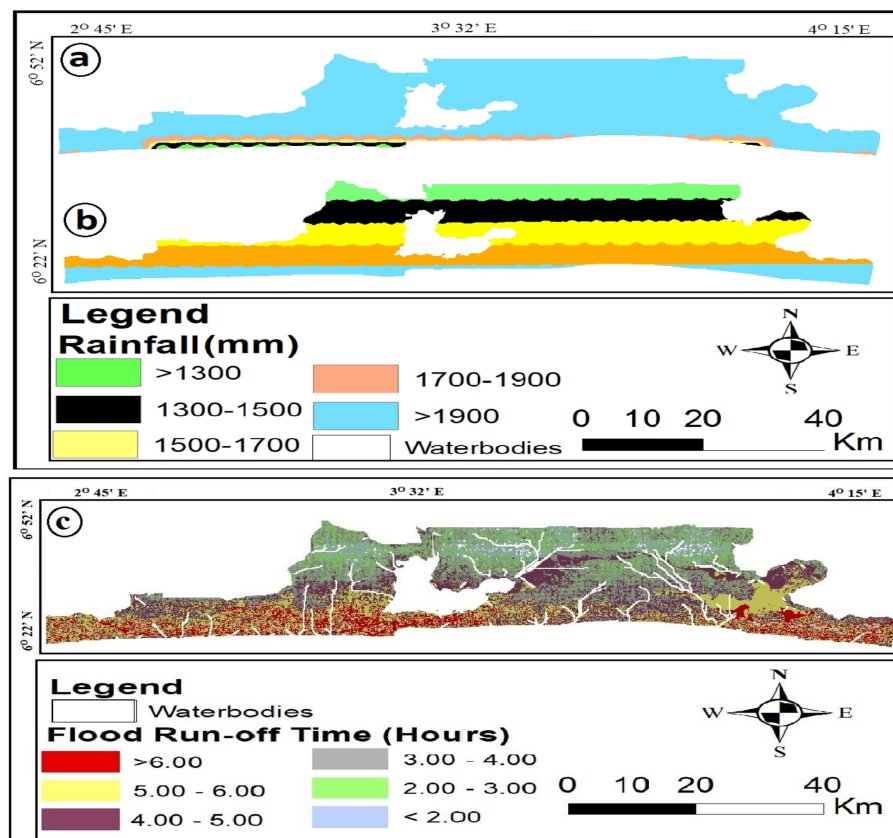


FIGURE 7

(a–c) Rainfall-induced flood awareness and early warning system. (a) First peak in JJA. (b) Second peak in SON. (c) Surface runoff time.

TABLE 4 Resilience strategic analysis and their timeframe.

Resilience strategic framework		Weight	Rank	Score	Time
FRS1	Promoting sustainable urban planning practices	1.48	1st	14.8	Long term
FRS9	Consistent enforcement of floodplain regulations and setback	1.35	2nd	12.15	
FRS2	Developing smart city solutions for real-time flood monitoring	1.24	3rd	9.92	Mid term
FRS3	Investing more in green infrastructure projects	1.23	4th	8.61	
FRS5	Predictions of storm surge impact on coastal residences	1.23	4th	8.61	
FRS8	Provision of funding for flood mitigation measures	1.14	5th	5.70	Short term
FRS4	Prioritizing evacuation of vulnerable population before floods	1.12	6th	4.48	
FRS6	Regulating land use and new flood protection measures	1.11	7th	3.33	
FRS7	Focus on aging and inadequate flood drainage infrastructure	1.11	7th	3.33	
FRS10	Attention on critical infrastructure vulnerability	1.02	8th	1.02	
SFAS (maximum-minimum)		13.78			
Lower		>5.60			
Mid-term		5.70–10.10			
Upper		<10.20			

focus because of their high vulnerability across the rainfall transitional periods, a finding that aligns with a study by Gregory and Gerald (2020) on flood risk management in the United States. This study contains useful information on the duration of surface area flooding and the severity of the expected flooding in time and space (Ahmad

and Ma, 2020). Studies by Olowoopejo (2019), Rahman et al. (2021), and Lawanson et al. (2023) projected that coastal and densely populated areas have a prolonged period of flooded conditions due to the impact of climate change, emphasizing the need to undertake aggressive sensitization, awareness campaigns, and urban flood

infrastructure improvement. Similarly, consistent clearing of the waterways and maintenance of drainage structures become essential as these initiatives will speed up runoff and floodwater removal from household premises. In addition, backwash floods in Lagos metropolitan areas are worsened by a poor inland drainage system, and poorer populations often reside in low-income areas with substandard housing conditions. The study validates Onifade et al. (2023) and Yoade et al. (2023) on the interconnected vulnerabilities and compounded flood risks attributed to the simultaneous effects of rainfall and a poor drainage system in a typical developing country. Orimoogunje et al. (2016), Asiedu (2020), Odunsi et al. (2024), and Nghiningwa et al. (2025) reported that many informal residents of most African countries suffer due to inadequate infrastructure, enhancing their vulnerability to flood damage.

However, the localization of strategic flood solutions through the SWOT-AHP approach provides a pathway to achieve flood minimization on short-, medium-, and long-term scales. The SWOT-AHP analysis helps establish robust modalities to achieve flood risk management and urban sustainability, emphasizing the improvement of the current shortcomings of flood reduction practices. Internal and external factors were prioritized using integrated hierarchical principles to address flood problems (Long et al., 2021). The study findings correspond to the results of a study by Tzanou and Skoulikaris (2024), which evaluated the SWOT-AHP framework combining geospatial databases with multicriteria decision-making in mapping flood protection infrastructure of the Strymonas river basin, Greece. Similarly, participatory mapping and community-led resilience studies in coastal cities in Accra, Ghana (Darkwah et al., 2018), present a relevant scientific contribution to the regional and global discourse of community-based flood adaptation.

The study resulted in a 10-point strategic framework that helps tackle urban flooding using a broad scale and time frame. Prioritizing flood recurrences as well as improving critical infrastructure, focusing on aging and vulnerable population groups, improving flood drainage infrastructure, regulating land use, developing new flood protection measures, and promoting urban green infrastructure were some of the required approaches identified through the SWOT-AHP analysis. The SWOT model proved effective (Ghazinoory et al., 2011), as the information obtained from the respondents and key informants significantly impacted the flood strategic framework (Nathaniel et al., 2023). However, the flood solutions framework may not uniformly mitigate floods across all urban landscapes (Ghorbani et al., 2022). The adoption of ideas and appropriate elements in the SWOT-AHP model can enable local flood solutions, suggesting better actions in a specific urban environment. Sustainable flood solutions focused on reducing future risks in line with SDGs (Orimoogunje and Aniramu, 2025), addressing flood challenges through immediate relief or livelihood tools that can foster long-term recovery in African coastal cities.

It was observed that the flood problem in Lagos is linked to environmental factors influenced by local practices of the overpopulated megacity. This study acknowledges the inherent subjectivity of the AHP method and discusses steps taken to mitigate it. However, potential limitations such as data resolution exist, which highlights the need to integrate machine learning with SWOT-AHP for multihazard assessment cascaded by climate impact in Lagos. Future studies should look into this direction and apply the framework to other megacities for comparative analysis.

6 Conclusion

Flooding in Lagos has become pervasive, prompting the need for proactive solutions through community engagement and spatial vulnerability modeling. The disparity in flood-rainfall transitional seasons highlights a critical gap in flood risk management across the Lagos coastal areas. This is a significant concern, as adequate knowledge systems and community-based solutions serve as immediate awareness interventions, reaffirming the role of stakeholders in providing comprehensive flood solutions. The overall grassroots efforts can be effective in solving flood issues if community knowledge is improved and the urban drainage system is effective, because Lagos residents are high taxpayers. Current developments in flood risk management place a strong emphasis on integrating SWOT-AHP frameworks and high-resolution flood inundation mapping through PGIS to improve flood resistance in the Lagos coastal region. As evidenced in Reading, UK, where local knowledge and flood zones were modeled, PGIS has been successful in bridging the gap between technical flood models and community perception to enhance flood risk management. In addition, the SWOT-AHP approach prioritizes flood protection measures, balancing the indices of technical, social, institutional, and environmental criteria. Similarly, GIS-based AHP models have been employed to rank flood mitigation projects, integrating sustainability dimensions, such as economic, ecological, and social, into spatial decision-making. Coupling SWOT with AHP allows quantitative prioritization of measures, effective decision-making, and social equity, representing a critical step in inclusive flood governance. The need for community involvement in improving flood risk assessments and early warning systems is highlighted by the study, emphasizing their relevance in flood disaster reduction in Lagos State, Nigeria, as well as identifying the adaptive framework necessary for flood reduction in megacities across Africa.

The study focused on protecting vulnerable communities and infrastructure links directly to SDG 11.5 (reduce the adverse per capita environmental impact of cities), with special attention to the blockage of waste material in urban drainage systems. The development of early warning systems and resilience strategies advances SDG 13.1 (strengthen resilience and adaptive capacity to climate-related hazards), and community awareness campaigns contribute to SDG 13.3 (improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning).

Targeted actions on high-risk areas can significantly reduce vulnerability, as demonstrated in the geospatial study of the Lagos coastal area. Nigeria can greatly enhance flood resilience and progress toward the 2030 Sustainable Development Agenda by implementing participatory measures that enhance spatial planning to address the human-caused factors contributing to flooding. With more intense floods expected in Nigeria due to climate change, it is crucial that these integrated solutions are implemented promptly and precisely. By combining community knowledge with geospatial precision within a structured decision-making framework, African cities can develop flood solutions that are both technically sound and socially sustainable. This approach will protect vulnerable coastal populations and contribute to the achievement of several SDGs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This study involving human participation was approved during the Propositional Seminar of the Postgraduate Review Committee, Obafemi Awolowo University, Ife Nigeria. Participants were properly inform about the purpose of the study, assuring them of the anonymity and confidentiality of their responses. In addition, consent was obtained before administering the questionnaire survey.

Author contributions

OA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. OO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Supplementary material

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