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Geographic Information System (GIS) Assessment of the Impact of Flooding on Residential Buildings in Akure, Nigeria

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ABSTRACT: *Flooding has caused the deaths of people, collapse of buildings, destruction of properties, and a lot of worries to occupants in Nigeria. In spite of persistent incident of flooding in many areas, the researches that are aimed at lessening the impacts of flooding, especially on residential buildings close to riverbanks are few. The study assessed the influence of flooding on residential buildings in Ajeromi Community of Ondo State, Nigeria using Geographic Information System (GIS). A triangulation research approach involving structured questionnaire, personal observation and the application of Geographic Information System (GIS) were used. Data were collected from the occupants of buildings and GIS was used to collect information on the geo-referencing of affected buildings showing river channels, contours, and the topography of the area. From the result, the major effects of flooding were; paint defects, present of rot and mould, damage to the finishes of buildings, wall dampness, and cracking of ground floor due to uplift pressure. The major reason for vulnerability of these residential buildings to flooding were heavy rainfalls and climate changes, construction of buildings closes to waterways, and poor physical planning of the community. Flood resilience measures for residential occupants in the areas includes adequate channelization of waterbodies and avoidance of waterways when constructing buildings. All the results correlated with the findings of results from physical assessment and GIS geo-referencing. Based on the findings, GIS can be used to assess residential buildings to prevent flooding and enhance flood resilience.*

KEYWORDS: flooding, GIS, impact, Nigeria, residential buildings.

INTRODUCTION

An overflow of water onto normally dryland is called flood which are normally caused by heavy rainfalls, rapid snowmelt or an overflow of a dam (Iyeshim, 2023; Ousset *et al.* (2023); Ghosh *et al.*, 2024; Das, 2024). The continuous process of this overflow for a long period of time is called flooding. According to Odunsi *et al*. (2024) and Adebayo and Ogunlela (2024), flooding is one of Nigeria's most common natural disasters. It has a devastating effect on the impoverished and vulnerable populations that reside along river courses and depend on the ecosystem's productivity and the fertile floodplains for their livelihoods (Animashaun *et al*., 2020; Utsev *et al*., 2024; Brendan et al., 2024; Agbonaye & Izinyon, 2024). Over the years, the Federal Government of the Republic of Nigeria has been implementing corrective and emergency flood control measures such as emergency evacuation and provision of relieve materials that have shown not to be successful. (Adekola *et al*., 2020; Adefisoye & Arum, 2021; Odunsi *et al*., 2024). However, one of the major obstacles to the nation's current sustainable growth is increasing resistance to flood catastrophes (Agbonaye & Izinyon, 2024; Obinna & Mathew, 2024; Obi *et al*., 2021; Enwin & Ikiriko 2024;). According to National Emergency Management Agency [NEMA] (2012), Over 2.6 trillion Naira in economic damage was inflicted by floods with large-scale transboundary floods being mostly responsible for this harm (Ijigah & Akinyemi, 2015). In 1999, approximately 126 deaths, over 48,000 displaced persons, and millions of Naira worth of property destruction were reported nationwide in 2019 (NEMA, 2020). In 2023, flooding in Nigeria affected ten States, recorded five deaths, seventy-five injuries, seven thousand displaced persons, damaged over eight hundred hectares of farmland and affected over thirty- three thousand households (Odiji *et al*., 2024; Alfa *et al*., 2024; Daniel *et al*., 2024). The effect of flooding on residential building in Nigeria is high therefore preventive measures to reduce the impact of flooding on households is motivated.

A residential building is a kind of construction that is mostly made to accomodate people, especially single people and families (El-Hanandeh, 2015). Residential buildings are made up of walls and roofs that are placed on land intended for residential usage in both urban and rural locations (Daneshyar, 2024). Buoyancy, hydrostatic force, and hydrodynamic force are the three basic processes that can affect any residential building strained by flooding (Paduano *et al*., 2024; Zuo, *et al*., 2024). Buoyancy or Archimedes force results when a building has propensity to float due to the potential weight of water in its volume (Ameh *et al*., 2024). Hydrostatic force is as a result of the volume of water in close proximity to the residential structure (Huang & Wu, 2024). The building's walls, pillars, and other vertical features are affected by the isotropic material, which is often directed perpendicular to the contact surface when acted upon by hydrolic force (Bignami *et al.*, 2019). The third force, hydrodynamic force and water movement affects the upstream surface of the structure directly facing the flow of water (Yuan *et al*., 2024). Due to local whirling winds and negative pressure on the structure's downstream surface, hydrodynamic force has the tendency to scour the foundations and draw the structure into the direction of its flow (Bignami *et al.*, 2019). All these forces make residential building and its occupants close to flooding zones prone to risks and can be forecasted with Geographic Information System (GIS).

Geographic Information System (GIS) is a scientific tool for spatial analysis of data related to positions on the earth surface (Quinta-Nova & Ferreira, 2024; Charles *et al*., 2024). GIS helps in understanding and solving problems related to residential land use (Maryani et al., 2024), environmental conservation (Quinta-Nova & Ferreira, 2024), Agriculture (Raihan, 2024), urban planning (An *et al*., 2024), transport (Widodo *et al*., 2024), and tourism (Quinta-Nova & Ferreira, 2024). Several studies have been conducted on the application on GIS in determining the level of vulnerability in flood-prone areas ((Mourato *et al*., 2023), and hazard risk assessment in other areas (Abdelkareem & Mansour, 2023). Also similar studies have been conducted by El-Hanandeh (2015) in Jordan, Assiah *et al*. (2024) in Togo, Owusu *et al*. (2024) in Accra, Mwenje and Kumar (2024) in Rwanda and Kalita *et al*. (2024) in India. These studies were conducted in locations other than Riverine Community of Ajeromi, Akure, Ondo State, Nigeria. The use of GIS to assess the effect of flooding of residential buildings were not tested in their study. Bakare *et al*. (2015), revealed how human interference with nature has increased, leading to large-scale landscape modification with disastrous consequences that frequently exacerbate flood disasters. These changes have occurred in land uses along the floodplain, river setback, and flood-prone areas. There is an increasing need for the application of GIS in assessing the long term effects of floods on residential areas. The focus of this study is to assess the impact of flood in Ajeromi Community using GIS with a view to propose flood resilience measures in future design and construction of residential buildings.

LITERATURE REVIEW

The assessment of community susceptibility to flooding is an indispensable element of efficient disaster management (Wang *et al*., 2024). The integration of Geographic Information Systems (GIS) within this procedure has notably enhanced comprehension and recognition of vulnerable populations and residential buildings in areas prone to floods (Maryani *et al*. 2024; Kalita *et al*., 2024). Recent researches have utilized GIS methods to scrutinize and assess the social, economic, and physical factors that contribute to vulnerability (Majumder *et al*., 2023). By conducting vulnerability assessment and impact analysis using GIS, decision-makers can pinpoint the areas and populations most prone to risks, necessitating prompt attention towards preparedness, response, and recovery measures. This data holds utmost significance in formulating all-encompassing plans and policies for flood disaster management, tailored to cater to the distinct needs and vulnerabilities of communities residing in flood-prone areas. Flood risk communication entails the dissemination of precise and vital information concerning flood occurrences, potential consequences, and suitable actions to be taken by vulnerable communities (Meléndez-Landaverde *et al*., 2024; Shah *et al*., 2024). The utilization of GIS has fundamentally transformed this procedure by furnishing a spatial framework for the arrangement and presentation of flood-related data. Through the integration of diverse datasets such as flood maps, population distribution, infrastructure positioning, and vulnerability assessments, GIS facilitates a holistic comprehension of the flood impact. Utilizing Geographic Information Systems (GIS), scholars and professionals have successfully devised real-time flood notification systems that effectively inform communities about impending flood occurrences. These systems leverage GIS technology to continuously monitor precipitation patterns, river water levels, and meteorological forecasts, thereby facilitating prompt identification of flood-prone situations. As soon as a predetermined flood threshold is surpassed, the GIS-driven system promptly initiates automated alerts to relevant environmental, disaster and planning authorities and community members, guaranteeing swift evacuation and immediate emergency response (Duru & Ndujiuba, 2023).

The use of GIS has been instrumental in the development of tools for planning evacuation routes (Akallouch *et al*., 2024; Wibowo *et al*., 2024). By incorporating GIS data on road networks, topography, and flood-prone areas, the optimization of evacuation routes to steer clear of flood-affected zones is made possible. The utilization of GIS in the planning of evacuation routes takes into account factors such as traffic flow, distance to secure areas, and the capability of alternative routes. This method ensures a smooth and secure evacuation process, minimizing congestion and potential risks to evacuees (Karna *et al*., 2023). Furthermore, the integration of mobile technologies and social media platforms has considerably bolstered the efficacy of flood risk communication and early warning systems. The development of mobile applications and Short Messaging Service-based alert systems ensures prompt delivery of real-time flood alerts directly to individuals' smartphones, granting immediate access to vital information. These applications make use of GIS capabilities to provide location-specific alerts, enabling users to comprehend their personal flood risk and take appropriate measures (Majumder *et al*., 2023). In addition, social media platforms have emerged as invaluable tools for flood risk communication. By incorporating GIS-enabled platforms, users can access real-time flood information and interactive maps, allowing for the visualization and sharing of flood-related data. This fosters crowd-sourced information gathering and dissemination, empowering communities to actively engage in flood risk management. Moreover, social media platforms serve as avenues for community involvement, enabling residents to report flooding incidents, share experiences, and offer support during and after flood events (Majumder *et al*., 2023). Flood destruction to residential buildings and its assets greatly depends on flooding speed and depth, although other factors like flow velocity, flood duration, and sediment concentration may also impact the extent of damage in residential areas (Adefisoye & Arum, 2021; Kalita *et al*., 2024)

As stated by Huttenlau *et al*. (2015) and Wu *et al*. (2024), flood damage functions can be categorized as either one or more parameters types or approaches. These parameter includes assessment of the building exposed elements, spatial distributions, and damage of building functions. The most commonly utilized approach for estimating direct flood damage to residential areas remains the use of single parameter depth-damage functions (Wu *et al*., 2024). But in addition, the utilization of GIS-based flood risk modeling plays a significant role in bolstering community resilience through facilitating well-informed decision-making and proactive flood management. This empowers authorities to identify areas highly susceptible to flooding and enact tailored interventions to mitigate vulnerability and strengthen preparedness. By comprehending the potential repercussions of flooding, stakeholders can devise appropriate response plans, allocate resources efficiently, and implement measures to safeguard critical infrastructure and minimize the socio-economic impacts of flood events (Majumder *et al*., 2023; Abdelkareem & Mansour, 2023; Obinna & Mathew, 2024).

METHODOLOGY

Ajeromi community is located in Akure, Ondo State. Its coordinates are 7.2252447 Northing and 5.1435911 Easting. The location is such that it connects with the King's market also known as *Oja Oba* in Yoruba language. These study sites were considered for this study because they experienced flooding regularly. A triangulation research approach involving structured questionnaire, personal observation and the application of Geographic Information System (GIS) were used. The respondents to this study are residents in the study sites who have experienced the flood. Ajeromi community was visited and the building were observed and counted physically. Owners and occupants of buildings in Ajeromi community in Akure, Ondo State. The population of this study is 259, which is the total number of buildings around the area of Akure; which are Ajeromi community in Eyin Ala-Ayedun and Isikan. Data collection was done through structured questionnaires, photographs from observation of study area and GIS application in the geo-referencing of affected buildings on the globe, showing river channels, contours and topography. Due to the impracticability of sampling every building in the study population, a manageable number of samples that is capable of representing the entire population, known as Sample Size, was adopted for the data collection. The total number of buildings in the flood prone areas is 259. A sample size of one hundred and fifty-seven (157) was drawn from the total number of buildings that falls within the selected flood prone areas of Akure, using Yamane's formula (Oluwatoyin, 2024). One hundred and fifty-seven (157) questionnaires were administered representing of the total population and all the questionnaire were retrieved (100%) as represented in Table 1. The study area was also visited by the research team and the coordinates of residential buildings that are frequently affected by flooding were collected using a GPS-satellite camera. The coordinates were then used to geo-reference these buildings on the globe. Descriptive statistical method was employed for analysis. It involves tabulation and description of various data collected, using Mean score, Percentages, and Relative Index.

Table 1. Number of Buildings in the Flood-prone Area of Ajeromi Community of Akure

Flood-prone areas	**Number of Buildings**	**Number of Questionnaire Distributed**	**Number of Questionnaire Retrieved**
Ala community	147	89	89
Isikan community	112	68	68
Total	259	157	157

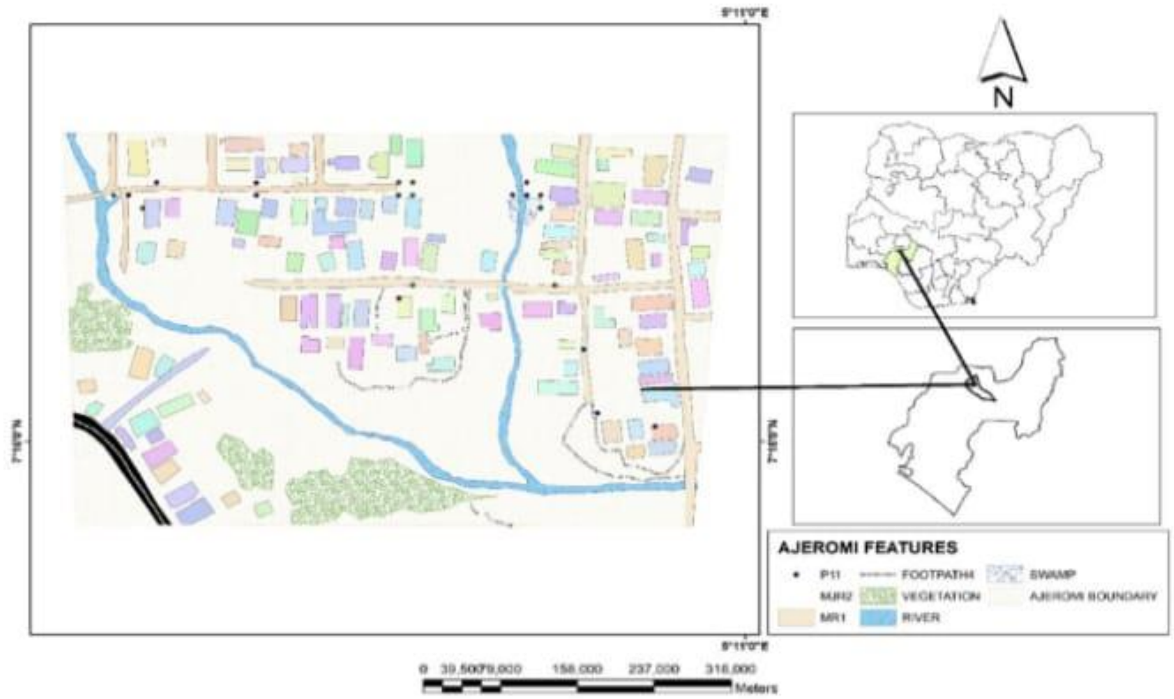

Figure 1. Map Showing Ajeromi Community
Source: Ondo State Ministry of Physical Planning and Urban Development (2024)

RESULTS, FINDINGS AND DISCUSSIONS

The results of the socioeconomic characteristics of the respondents in the study area were presented in Table 2. The study exposed the dominance of male household heads in the study area which claimed 58%. The female household heads claimed 42% of the responses. The respondents with undergraduate degree are 9.6%, professional and graduate degrees are 10%, those with vocational training are 31.2% while others claimed a response of 49.0%. Table 2, also presents the results on duration of stay of the respondents in the study area. 8% of the respondents have stayed in Ajeromi community for about 16 to 20 years, while 10.2% have stayed between 6 to 10 years. But, 29.30% of the respondents have only stayed for less than 5 years. Records from Table 2, also shows that 71.1 % of the respondents have experienced flooding more than four times while leaving in the community and only 10.20 % of the respondents have experiencing flood once.

Table 2. Socioeconomic Characteristics of the Respondents

	Respondents	**Freq.**	**Per cent**		**Respondents**	**Freq.**	**Per cent**
Gender	Male	91	58	**Frequency of Flood Experience**	Once	16	10.2
	Female	66	42		Twice	0	0
	Total	**157**	**100**		Thrice	0	0
					Quadruple	31	19.7
Duration of Stay	1 to 5	46	29.3		More than four times	110	70.1
	6 to 10	16	10.2		**Total**	**157**	**100**
	11 to 15	0	0				
	16 to 20	13	8.3	**Academic Qualifications**	Vocational	49	31.2
	Above 20 years	82	52.2		Undergraduate degree	15	9.6
	Total	**157**	**100**		Graduates or Professional degrees	16	10.2
					Others	77	49
					Total	**157**	**100**

Source: Author's Fieldwork (2024)

Table 3. shows the characteristics of the residential buildings examined for flooding at Ajeromi community, Akure. The results indicated that most of the respondents had door plinth level (89.8%), others claimed they do not have, which accounted for (10.2%). Most of the respondents reside in a rooming building type (81.5%), 10 percent of the respondents stay in a flat, while others stay in a storey building, none of the respondents stay in a duplex and 8.2% stays in bungalow. All the buildings enumerated has a blockwork as wall material used for their construction. Lastly, 90.4% of the buildings enumerated do not have a basement, while 9.6% have a basement. Van den Brom *et al*. (2018) reiterated that the quality of building members will determine the coping capacity in the event of flooding.

Table 3. Characteristics of the Residential Buildings Examined for Flooding

Respondents	Frequency	Per cent		Frequency	Per cent
Door plinth level			**Basement Floor**		
Available	141	89.80	Existing	15	9.6
No Available	16	10.20	Not Existing	142	90.4
Total	**157**	**100.00**	**Total**	**157**	**100**
Building Type			**Construction material**		
Rooming	128	81.50	Block work	157	100.00
Flat system	16	10.20			
Storey building	13	8.30			
			Total	**157**	**100.00**

Source: Author's Fieldwork (2024)

Table 4. shows the result of the effect of flooding on residential buildings in Ajeromi community, Akure. Majority of the respondents strongly agreed that paint defects is the highest effect of flooding on residential building in the study area (M = 4.50). The respondents also ranked the presence of rot and mould, damage to internal and external doors and skirting boards, and cracking of ground floor due to uplift pressure as the second effects of flooding on residential buildings (M = 4.40). Exposure of some part of building's foundation and soaking up of base block, damage to foundation, walls and floors, and erosion of the ground surface due to high speed around the building perimeter were all rank. Most of the respondents were neutral about collapse of buildings as an effect of flooding on building (M = 3.06). While most disagree that undercutting of beddings is an effect of flooding on building (M = 2.30). Hanafi *et al.* (2018) claimed that bleaching and flaking of paints is one of the effects of flooding to buildings.

Table 4. Effect of Flooding on Residential Buildings in the Study Area

Effects	N	Mean (M)	Standard deviation	A*N	RII	Rank
Paint defect	157.00	4.50	0.93	785.00	0.90	1
Present of rot and mould	157.00	4.40	1.03	785.00	0.88	2
Damage to internal finishes, such as wall coverings and plaster linings	157.00	4.40	1.29	785.00	0.88	3
Cracking of ground floor due to uplift pressure	157.00	4.40	1.03	785.00	0.88	3
Wall dampness	157.00	4.40	1.03	785.00	0.88	3
Exposure of some part of building foundation and soaking up of base block	157.00	4.30	1.43	785.00	0.86	6
Damage to foundation	157.00	4.30	1.43	785.00	0.86	6
Damage in walls and floors	157.00	4.30	1.20	785.00	0.86	6
Erosion of the ground surface due to high speed around the building perimeter	157.00	4.30	1.20	785.00	0.86	6
Floating of immersed floor insulation and debonding of screeds	157.00	4.10	1.38	785.00	0.82	10
Erosion beneath foundation, instability and settlement	157.00	4.10	1.31	785.00	0.82	10
Timber based material likely to be replaced	157.00	4.00	1.42	785.00	0.81	12
Damage to internal and external doors and skirting boards	157.00	4.00	1.62	785.00	0.80	13
Corrosion of metal and fittings	157.00	3.56	1.56	785.00	0.72	14
Collapse of Building	157.00	3.06	1.58	785.00	0.61	15
Undercutting of buildings	157.00	2.30	1.11	785.00	0.46	16

Source: Author's Fieldwork (2024)

Figures 2-6 show photographs of personal observation carried out in Ajeromi community, Akure. The result in Figure 2. Shows wall dampness of residential buildings in the area. The result is in agreement with the result of the response from structural questionnaires. Figure 3 show a picture of, rot and mould while Figure 4 and 6 is a picture and geo-coordinates of a collapsed perimetre fence. Figure 4 show the pictures and geo-coordinates of an abandoned building by the occupants. Deserting of building and soaking of the building foundation are some of the observed effects of flooding on a building in the study area. The results is in agreement with previous studies, such as Adekola *et al*. (2020); Ormandy *et al.* (2020) and odunsi *et al* (2024) who stated that most prevalent issue in housing in Nigeria has been retention of water in the blockwork of residential buildings due flooding and the use of substandard

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building materials. According to Majumder *et al*., (2023)**,** this leads to noticeable dampness on walls, ceilings, and floors, as well as paint blistering, plaster bulging, sulphate, and deterioration of brickwork. It also leads to the growth of mould on surfaces and fabrics, often accompanied by a stale odour.

Figure 2. Wall dampness on flooded building

Figure 3. Rot and mould

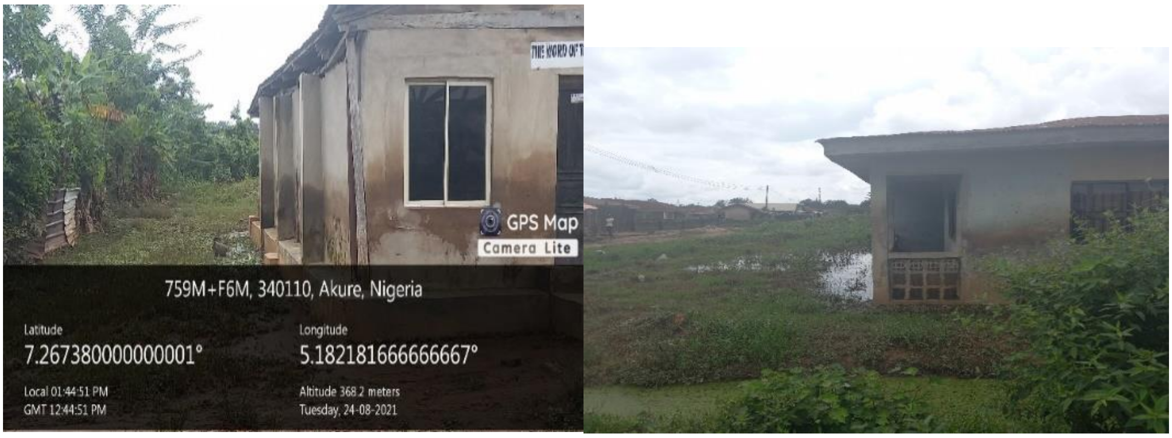

Figure 4. Exposure of some part of building foundation and soaking up of base block

Figure 5. Occupants abandon/desert buildings

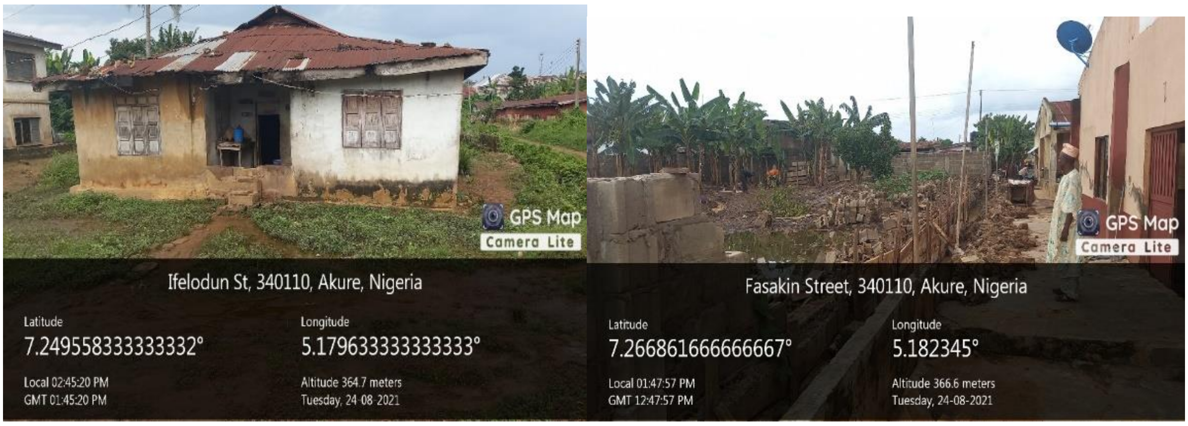

Figure 6. Collapse of fence walls

GIS application to determine the effect of flooding on residential buildings in the study area

Figure 7, 8, and 9 shows the result of GIS application to determine the effect of flooding on residential building in the study area. Figure 7 shows the cutting out of study area Eyin-Ala from Google-Earth in the study area. Figure 8 Identified the affected buildings from Google-Earth, while Figure 9 Identified the affected residential buildings in the Study Area. The Figures show the water channels, rivers, contours, and vegetation in the study area.

Figure 7. Cutting Out of Study Area Eyin-Ala from Google-Earth in the study Area
Source: GIS application and Google-Earth (2021)

Figure 8. Identification of Affected Buildings from Google-Earth in the study Area
Source: GIS application and Google-Earth (2021)

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Figure 9: Identification of Affected Residential Buildings in the Study Area
Source: GIS application and Google-Earth (2021)

Reasons for the vulnerability of buildings to flooding

Table 5. present the result of the reasons for the vulnerability of those residential buildings to flooding. The mean item score of respondents indicated that most respondents strongly agree that climate change and heavy rain is the reason of vulnerability of the residential buildings to flooding (M = 4.80). Most of them also agreed that building design and orientation (M = 3.56), poor or inadequate drainage (M = 3.76), construction methodology (M = 3.56), building setback from river/building along water channel (M = 4.40), poor physical planning (M = 3.76) are all reasons of vulnerability of buildings to flooding. Most of the respondents were indifferent about the absence of drainage (M = 3.26) and poor waste management (mean score = 2.91) as the reasons of vulnerability of building. All the respondents disagreed that type of building material used (M = 1.70) was the reason of vulnerability of residential buildings to flooding. The study is in agreement with Ousset *et al.* (2023) and Ghosh *et al*. (2024) who stated that heavy rainfall can lead to flooding, which can weaken the foundation by destroying pipes, wires and other structures that reinforce the building.

Table 5. Reasons for the Vulnerability of Buildings to Flooding

Reasons	N	Mean (M)	Standard Deviation	A*N	RII	Rank
Climate change and heavy rain	157.00	4.80	0.60	785.00	0.96	1
Building setback from river/building along water channel	157.00	4.40	1.29	785.00	0.88	2
Poor physical planning	157.00	3.76	1.47	785.00	0.76	3
Poor or inadequate drainage	157.00	3.76	1.78	785.00	0.76	4
Construction methodology	157.00	3.56	1.68	785.00	0.72	5
The building design and orientation	157.00	3.56	1.68	785.00	0.71	6
No drainage	157.00	3.26	1.67	785.00	0.65	7
Poor waste management	157.00	2.91	1.51	785.00	0.58	8
The type of building materials	157.00	1.70	1.20	785.00	0.34	9

Source: Author's Fieldwork (2024)

Flood resilience measures in the study area

From the result in Table 6, most of the respondents strongly agreed that residential buildings should be located at non-vulnerable sites not prone to flooding (MS = 4.90). Residential building professionals, land regulators and building developers should avoid water ways, swampy areas, and valley lands close to canal. Adequate channelization of drainage system (MS = 4.70) was ranked as the second flood resilience measures carried out in the study area. Most of respondents in the study area agreed that elevated foundation levels, elevated building entrance level (MS = 4.62), excellent waste disposal system (MS = 4.47), column raised building (MS = 4.40), engineered landfills (MS = 4.20), and adequate rain harvesting system or dam construction (MS = 3.67) were all significant flood resilience methods. Most of the respondents disagree that tiled floors and walls (MS = 2.45) is not an adoptable resilience measure.

Table 6. Flood Resilience Measures in the study area

Flood resilience measure	N	Mean Score	Standard Deviation	A*N	RII	Rank
Building should be located at Non-vulnerable site not prone to flood. Building developers should avoid water ways, swampy area, and valley lands close to canal.	157.00	4.90	0.30	785.00	0.98	1
Adequate channelization of drainage system	157.00	4.70	0.46	785.00	0.96	2
High foundation level, high building entrance level	157.00	4.62	0.91	785.00	0.94	3
Excellent waste disposal method	157.00	4.47	1.29	785.00	0.89	4
Column raised building	157.00	4.40	1.03	785.00	0.88	5
Engineered landfill	157.00	4.20	1.41	785.00	0.84	6
Harvesting of the rain water into a storage tank or dam	157.00	3.67	0.90	785.00	0.73	7
Tiled floor and tiled walls	157.00	2.47	1.20	785.00	0.49	8

Source: Author's Fieldwork (2024)

CONCLUSION AND RECOMMENDATIONS

The major effects of flooding on residential buildings in the study area are damage to finishes, wall dampness and cracking of ground floor due to uplift pressure. The buildings are vulnerable to flooding because of heavy rainfalls from climate changes, building design and orientation, poor or inadequate drainage, construction of buildings close to water channels and the poor physical planning of the community. Flood control measures incorporated for this study includes construction of residential buildings at located that are non-vulnerable or prone to flooding. These includes avoidance of water ways, swampy areas and canals during construction of residential buildings. Others includes provision of elevated foundation levels, good waste disposal method to prevent the blockage of drainage and construction of column raised buildings. The result from the questionnaire survey, personal observation and the application of Geographic Information System (GIS) all arrived at the same conclusion on effect of flooding, reasons for the vulnerability of buildings to flooding, and flood resilience measures. This study therefore recommends that GIS should be used to forecast flood-prone area before construction of residential building are permitted by town planning authorities. This study can also be repeated in other flood prone areas like Lokoja, Kaduna and Rivers State Nigeria to give it a national look.

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