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Architectural Strategies and Risk of Perennial Pluvial Flooding in Port-Harcourt Metropolis

Okey-Ejiowhor, Caleb H. & Akani, Chioma B.

Department of Architecture
Faculty of Environmental Sciences,
Rivers State University, Port Harcourt, Nigeria

ABSTRACT

The study examined Architectural Strategies and Risk of Perennial Pluvial Flooding in Port-Harcourt Metropolis**.** The methodology integrates both primary and secondary data sources. With a population of 1,416, a sample frame of 708, and a sample size of 512 determined using the Taro Yamane method, the study employed field observations, surveys, and statistical analysis, including descriptive statistics. The study revealed that nearly all respondents (99.2%) use elevated damp proof courses (DPC), and 98.6% apply waterproof coatings and sealants. Most buildings (93.6%) floodproof essential systems like HVAC, plumbing, and electrical equipment. Water pumping machines are universally used (100%), and permanent flood barriers (99.8%) are common. Additionally, 90% collect rainwater to reduce runoff, while 96.5% use permeable surfaces and 90% construct retention ponds. However, community resistance is less of a concern, as 71.1% of respondents indicated minimal opposition to flood mitigation efforts. These results highlight the urgent need for increased financial resources, enhanced infrastructure, and more effective regulatory frameworks to overcome barriers and improve flood management in the metropolis. Addressing these challenges is essential for implementing sustainable and effective flood mitigation strategies. Findings on the Primary Goals of Flood Mitigation Strategies in Alignment with Architectural Objectives show unanimous alignment between flood mitigation strategies and architectural objectives in Port Harcourt, with 100% of respondents agreeing on key priorities. The integration of these objectives indicates a well-rounded strategy for managing flood impacts in the metropolis. Finding on the best ways community involvement can be enhanced to ensure success of flood mitigation measures in Port Harcourt metropolis shows that all respondents (100%) agreed on the importance of community engagement programs, collaborative planning sessions, and public awareness campaigns to boost participation. Additionally, educational workshops were universally supported (100%) as an essential means to raise awareness and provide vital knowledge to the community. We recommend that Constructing levees, floodwalls, and embankments to protect urban areas from riverine and coastal flooding. Developing advanced storm water drainage systems, such as underground tunnels, retention basins, and green infrastructure (e.g., permeable pavements and green roofs) to improve water absorption and reduce surface runoff and Integrating flood-resilient designs in urban planning, including raised buildings, flood-proof basements, and the creation of flood plains and green belts.

Keywords: Architectural Strategies, Risk, Perennial, Pluvial Flooding, Port-Harcourt Metropolis

INTRODUCTION

One of the most prevalent natural disasters in Nigeria is perennial flooding. Many states are increasingly experiencing annual flooding during the rainy season, and a growing body of evidence links these events to climate change. Climate change refers to the periodic modification of Earth's climate brought about by atmospheric changes and interactions with various geologic, chemical, biological, and geographic factors within the Earth system (Intergovernmental Panel on Climate Change [IPCC], 2021; Jackson, 2021). Natural phenomena such as intense rainfall, storm surges, and rapid snowmelt, combined with environmental conditions like soil moisture retention, groundwater levels, and impervious surface coverage, significantly contribute to flooding hazards (Burabari, Ajenifujah- & Joseph, 2024). Globally, heightened rainfall is a primary cause of flooding, occurring when soil and vegetation become oversaturated, causing water bodies to overflow. In Port Harcourt, heavy rainfall is a major factor leading to flooding (Abaye et al., 2012). Effective flood management requires infrastructural design solutions and a re-evaluation of urban planning policies. Sustainable adaptation strategies, including green infrastructure and flood-resilient designs, are essential for enhancing flood resilience in Port Harcourt. Examples from other cities, such as green roofs and permeable pavements, provide valuable insights. Strong governance frameworks and community involvement are crucial for sustainable flood management, flooding impacts on critical infrastructure such as housing and transportation, highlighting the importance of flood adaptation and resilience. The concept of 'living with floods' emphasizes building tolerance to prevent deaths and injuries during flood events (Chen et al., 2020). Effective urban planning and architectural solutions are necessary to mitigate flood risks and enhance resilience in rapidly urbanizing environments like Port Harcourt

Urban flooding in Nigeria is a growing concern, affecting approximately 20% of the population annually (Terence, Ayodele, & Samuel, 2020). Flood sources include rivers, canals, overwhelmed drainage systems, and excessive rainfall. Flooding occurs when water overflows its normal boundaries, inundating land that is usually dry (Subir, Amlan, & Priyanka, 2019). Perennial floods refer to the recurring overflow of water over dry land, often linked to climatic and environmental factors. Recent flooding events, such as the 2010 Sokoto flood, 2011 Ibadan flood, and widespread 2012 flooding, underscore the severe environmental challenges Nigeria faces (National Emergency Management Agency [NEMA], 2021). Furthermore, the three primary types of floods are coastal (storm surge), fluvial (river), and pluvial (surface). Coastal floods, resulting from extreme tidal conditions and storm surges, are the leading causes of flooding in low-lying coastal areas (Andrew, Samuel, & Caitlyn, 2020). Fluvial or river floods occur when excessive rainfall or snowmelt causes rivers to overflow, with severity depending on factors such as precipitation, soil saturation, and terrain (Andrew, Samuel & Caitlyn, 2020). Pluvial floods occur when intense rainfall overwhelms urban drainage systems or flows over impervious surfaces, causing water accumulation in urban areas, even those above coastal and river floodplains (Terence, Ayodele & Samuel, 2020).

One of the major problems in urbanised areas which greatly contribute to the risk of flooding during heavy rainfall is the design of urban drainage systems and other issues associated with drainage sanitation. Port Harcourt has an inadequate drainage infrastructure that fails to handle the excessive water, leading to widespread flooding in the event of heavy rainfall. Inadequate urban drainage systems are a major contributor to flooding during heavy rainfall. Port Harcourt's drainage infrastructure fails to handle excessive water, leading to widespread flooding. Oliveira et al. (2022) highlighted the significance of preserving water spaces to address urban flooding. Poor maintenance of drainage systems exacerbates aesthetic and environmental degradation. Urbanization significantly impacts flooding events. The development of flood-prone areas is influenced by benefits such as waterfront views and commercial proximity. However, this development leads to alterations in the natural environment, increasing vulnerability to natural hazards. In Nigeria, rapid city expansion and environmental issues constrain sustainability efforts as observed by Ishaya et al., (2016) Ogundele and Jegede (2011) argued that the lack of effective urban planning and poor drainage system coordination are major causes of flooding in Port Harcourt. Research has identified several causative factors for the frequent flooding in Port Harcourt, including the lack of proper environmental planning and urban management. Effective flood management

requires collaboration between local communities, non-governmental organizations (NGOs), voluntary groups, and international donor organizations. Despite the global prevalence of urban floods, management practices vary significantly among countries, influenced by existing technologies, infrastructure, and levels of urban planning.

Poor urban planning is linked to flooding (Cirella & Iyalomhe, 2018; Dabi & Kporha, 2015). Urban planners are at the forefront of formulating and implementing planning policies and controls. However, little has been done to engage urban planning professionals themselves in research. This is important because their expertise and insight can help to better understand areas of failure and how to address them. More research on flooding and the influence of plans and planning in Nigeria would help to better understand and control this problem. This paper engages with planners in Port Harcourt on the flooding issue. The findings are presented across three sections: (a) effects of poor urban planning in Port Harcourt; (b) flooding and waste management in Port Harcourt; and (c) addressing the flooding: urban planners' perspectives. From the above, this study examined Architectural Strategies and Risk of Perennial Pluvial Flooding in Port-Harcourt Metropolis.

LITERATURE REVIEW

Pluvial (Surface) Floods

Pluvial or surface water flooding occurs when intense rainfall overwhelms the natural or man-made drainage systems, causing water to accumulate on the surface rather than flowing into rivers or other water bodies. This form of flooding is typically independent of overflowing water bodies and is often associated with extreme precipitation events, which have been increasingly recognized as a growing hazard in many urban areas (Kundzewicz, Hoozemans & Svensson, 2022). Unlike traditional flood risks, pluvial flooding can impact even elevated areas that are not directly near rivers or coastal zones, challenging the common misconception that flood risks are limited to proximity to water bodies (Maddox, 2021).

There are two primary types of pluvial flooding:

1. Saturated Drainage Systems: In urban environments, heavy rainfall can exceed the capacity of drainage systems, causing water to overflow onto streets and properties. This is most common in areas where rainfall intensity surpasses the designed capacity of urban stormwater systems, leading to localized flooding (Núñez, Fernandez & Gómez, 2021).
2. Runoff from Impermeable Surfaces: When rain falls on hard, impermeable surfaces like asphalt or concrete, water cannot be absorbed into the ground. This runoff can quickly accumulate, leading to surface flooding, particularly in densely built-up areas (Piroozfar, Sarlak & Erdem, 2020).

Pluvial flooding frequently interacts with other forms of flooding, such as coastal and riverine floods, exacerbating the overall flood risk. Although pluvial floods are typically shallow, even a few centimeters of water can cause significant damage to property and disrupt daily life. While this type of flooding is distinct from flash flooding often caused by rapid runoff from a river or stream both types share similar causes in terms of high-intensity rainfall (Falconer, Smith & Jones, 2022). In particular, the frequency of these rainfall events appears to be rising, which may be linked to broader climate change patterns, leading to more frequent and severe flood events in urban centers (World Bank, 2023). The Niger Delta region, including Port Harcourt Metropolis, is particularly vulnerable to pluvial flooding due to its low-lying topography, intense rainfall, and urbanization. Various studies have highlighted that a combination of environmental factors, such as land-use changes, deforestation, and urban sprawl, contribute to the severity of pluvial floods in this region (Kenny, Booth & Austin, 2021). Notably, while rainfall is a key driver of these floods, it is often the result of a complex interplay of topographical and anthropogenic factors that exacerbate the flood risk.

In response to these recurring flood events, Nigeria has taken steps to address disaster management through the National Emergency Management Agency (NEMA), established by the NEMA Act (12 as amended by Act 50 of 1999). NEMA is tasked with disaster response, policy formulation, risk assessment, and providing relief efforts. The agency's focus extends to areas at risk of pluvial flooding, working alongside state-level entities such as the Rivers State Emergency Management Agency (SEMA)

to mitigate flood-related hazards (Ogu & Adekola, 2022). Understanding flood-prone areas is essential to creating effective prevention and mitigation strategies, a task which requires collaboration between government bodies and local communities.

Figure 1: Depiction of Surface Water Floods (Pluvial Floods). Source: Hlushko, (2021).

Causes and Impacts of Perennial Pluvial Floods in Port Harcourt Metropolis

Several studies have identified the causes of perennial pluvial flooding in Port Harcourt Metropolis and have attributed it to one or all of the following; topography, soil/vegetation/river alteration, increased heavy rainfall, uncontrolled waste dumping, land use change, and unplanned urbanization (Oriola, 1994; Onokerhoraye, 1995; Parker, 1999; Folorunsho and Awosika 2001; Ologunorisa, 2004; Ogba and Utang, 2008; Adeloye and Rustum, 2011). Perennial pluvial flooding in Port Harcourt Metropolis can be attributed to a combination of these factors. Based on available literature and data, the causes of perennial pluvial flooding in Port Harcourt Metropolis include:

Heavy Rainfall and Climate Change: Because of climate change, rainfall variation is projected to continue to increase. Precipitation in southern areas is expected to rise and rising sea levels are expected to exacerbate flooding and submersion of coastal lands (Beyioku, 2016). Port Harcourt Metropolis experiences high levels of rainfall throughout the year, with particularly intense rainfall during the wet season. Heavy and prolonged rainfall events overwhelm the drainage systems, leading to water accumulation and subsequent flooding. Climate change exacerbates the situation, with changing rainfall patterns and an increased frequency of extreme weather events contributing to more intense and frequent floods.

Inadequate Drainage Infrastructure: The city's drainage infrastructure has not kept pace with rapid urbanization and population growth. The existing drainage systems often lack sufficient capacity and are unable to efficiently manage the volume of water during heavy rainfall. Additionally, inadequate maintenance and the dumping of solid waste into drains contribute to blockages and hinder the flow of water (Chiadikobi et al., 2011).

Encroachment on Waterways and Floodplains: Uncontrolled urban expansion and improper land use practices, such as construction on floodplains and encroachment on natural waterways, disrupt the natural

flow paths of water (Oriola, 1994). This reduces the storage capacity for excess water and increases the risk of flooding. The loss of natural buffers, such as wetlands and floodplains, further exacerbates the impacts of flooding.

Deforestation and Soil Erosion: Unregulated deforestation, particularly in upstream areas, leads to increased surface runoff and soil erosion (Adeloye & Rustum, 2011). The removal of vegetation reduces the ability of the land to absorb water, resulting in enhanced runoff and sediment transport. Deforestation also contributes to the clogging of drains and water channels with sediment, further impeding drainage systems (Ogba & Utang, 2008).

Inefficient Waste Management: Improper waste disposal practices, including the dumping of solid waste into drains and water bodies, obstruct the flow of water and exacerbate drainage issues (Folorunsho & Awosika, 2001). Blocked drains and water channels reduce the capacity of the drainage systems, leading to increased flood risks.

Lack of Urban Planning and Regulation: Inadequate urban planning and zoning regulations have contributed to haphazard development, particularly in flood-prone areas. The absence of strict regulations on land use and construction standards has allowed for the encroachment on floodplains and the development of infrastructure that is not resilient to flooding (Oriola, 1994).

Floods: Some Major Flood Events in Nigeria

By studying the past, we learn about the present and are able to plan for the future (Angelakis et al., n.d.). Since 2012, Nigeria has experienced numerous significant flood events that have caused substantial damage, loss of life, and disruption to communities and economies. These events highlight the critical need for improved flood management, infrastructure, and preparedness strategies. The major flood events featured the different types of floods. But for this study, the focus was on the part of pluvial floods. This detailed review, therefore, delved into the major flood events of 2017 and 2021, examining their causes, impacts, and the lessons learned to better prepare for future occurrences.

The 2017 Floods

The 2017 floods in Nigeria were a devastating natural disaster that impacted several regions of the country, resulting in about 18 deaths, displacement of communities, and widespread damage to property and infrastructure. These floods were primarily triggered by intense and prolonged rainfall, which overwhelmed rivers, reservoirs, and drainage systems, leading to severe inundation across many states.

Causes of the 2017 Floods

The primary cause of the 2017 Nigerian floods was heavy and sustained rainfall during the rainy season. Nigeria's geographical location and climatic conditions make it prone to seasonal flooding, especially during the peak months of the rainy season from June to September. In 2017, the intensity of the rains was unusually high, exacerbated by climate change factors, which contributed to the extreme weather patterns observed. Another contributing factor was poor urban planning and inadequate drainage infrastructure in many cities and towns. Rapid urbanization without corresponding improvements in infrastructure led to clogged drainage systems, which could not handle the volume of water. This situation was further aggravated by deforestation and land degradation, which reduced the land's natural ability to absorb and manage rainfall (Sullivan, 2022).

Impact on Affected Regions

The floods of 2017 affected numerous states across Nigeria, with particularly severe impacts in Benue, Kogi, Niger, and Lagos States.

Benue State: One of the worst-hit areas, Benue State, experienced severe flooding that displaced over 100,000 people. The flooding was so severe that it submerged entire communities, destroying homes, farmlands, and critical infrastructure. The state capital, Makurdi, saw significant portions underwater, leading to the displacement of thousands of residents who sought refuge in temporary camps and shelters (Olujobi, 2024).

Kogi State: Kogi State, located along the confluence of the Niger and Benue rivers, also experienced catastrophic flooding. The rise in water levels of both rivers led to widespread inundation, displacing thousands and causing extensive damage to property and agricultural lands. The flooding disrupted transportation and communication networks, hampering relief efforts.

Niger State: In Niger State, the floods resulted in the displacement of many communities, particularly those situated along riverbanks. The swollen rivers led to the destruction of homes and farmlands, severely impacting the livelihoods of residents who rely on agriculture.

Lagos State: As Nigeria's economic hub, Lagos was not spared from the flooding. Urban areas in Lagos experienced significant waterlogging, leading to traffic congestion, property damage, and disruptions to business activities. The city's drainage systems were overwhelmed, highlighting the urgent need for infrastructural improvements to mitigate future flood risks.

Rivers State: Residents of Port Harcourt, the capital city of Rivers State, reported that they were counting their losses after three days of continuous rainfall which started in the early hours of 22nd July 2024. The 2017 floods caused widespread flooding and destruction of property. According to reports, three people lost their lives in various parts of the city due to the flooding. Areas such as D-Line, Diobu, Elekahia, and Ada-George were identified as being the hardest hit. Besides the loss of property, many victims were temporarily displaced from their homes. (TVC News, 2017).

Humanitarian Response and Relief Efforts

The scale of the disaster prompted a swift response from both the Nigerian government and international organizations. The Federal Government, through the National Emergency Management Agency (NEMA), coordinated relief efforts, providing emergency assistance to affected populations. This included the distribution of food, clean water, medical supplies, and temporary shelters to those displaced by the floods. International humanitarian organizations and local NGOs also played a critical role in the response. They assisted in conducting needs assessments, delivering aid, and supporting the establishment of temporary camps for displaced persons. These efforts were crucial in alleviating the immediate suffering of those affected and preventing further health crises due to waterborne diseases and poor sanitary conditions.

Long-Term Implications and Lessons Learned

The 2017 floods underscored the urgent need for comprehensive flood management and mitigation strategies in Nigeria. The disaster highlighted the vulnerabilities of urban and rural communities to extreme weather events and the consequences of inadequate infrastructure and poor environmental management. In response to the floods, there were calls for improved urban planning, investment in resilient infrastructure, and the implementation of early warning systems to better prepare for and respond to future flood events. Enhancing community awareness and preparedness through education and training programs was also recognized as a critical component in reducing the impact of such disasters. The floods also emphasized the importance of addressing broader environmental issues, such as deforestation and land degradation, which contribute to increased flood risks. Reforestation and sustainable land management practices were identified as necessary measures to enhance the natural resilience of the environment to heavy rainfall and flooding.

Figure 2: **Flooding of Federal Road Safety Commission Port Harcourt Office along Aba Road. Source**: Echendu, (2021)

The 2021 Floods in Port Harcourt

Residents reported that on 21st September 2021, the capital city of Rivers State, Port Harcourt, experienced severe flooding due to torrential rains. Among the most impacted were the Federal Road Safety Corps (FRSC) office and the Port Harcourt Shopping Mall (SPAR). The rains, which began at dawn and continued for several hours, overwhelmed the FRSC's Port Harcourt Zonal Office on Aba Road. Business operations at SPAR were heavily disrupted as staff scrambled to protect merchandise from floodwater that submerged the ground floor of the mall on Azikiwe Road. Numerous cars were also submerged on major roads throughout the city, leaving many commuters stranded and residents facing significant property losses. Several respondents and victims blamed the flooding on inadequate drainage systems in the city. Additionally, some criticized the Rivers State Government for the rapid and concurrent construction of road projects concentrated in the capital city and the reclamation of waterways that previously absorbed floodwater. The most affected areas included Station Road, Abali Motor Park, Rivers State Judiciary Complex, Ikwerre Road, Ada George, and Sanni Abacha Road. One resident highlighted that the government's unrestrained land reclamation on waterways that used to absorb floodwater had exacerbated the situation. They remarked, the water will always find its level. The result is what we are seeing now. The affected areas may have been prone to flooding in the past, but the experience today is unprecedented (Vanguard, 2021). Ultimately, the consensus among many was that urbanization and the indiscriminate construction over natural waterways were the primary causes of the severe flooding in Port Harcourt.

Plate 3 Flooding of Port Harcourt Mall Flood along Azikiwe Road.
Source: Vanguard Newspaper, (2021)

Nature-Based Mitigation and adaptation Strategies for Flooding

Flooding is a recurring and devastating natural disaster that affects communities worldwide. As the frequency and severity of floods continue to increase due to climate change, urbanization, and land use changes, there is a growing need for effective mitigation and adaptation strategies (Intergovernmental

Panel on Climate Change [IPCC], 2019). Nature-based solutions, which utilize natural ecosystems and processes to mitigate the impacts of flooding, are gaining recognition as a valuable approach to reducing flood risk (United Nations Office for Disaster Risk Reduction [UNDRR], 2019).

Definition and Types of Nature-Based Mitigation and Adaptation Strategies

Nature-based mitigation and adaptation strategies for flooding involve the use of natural ecosystems, such as wetlands, forests, and floodplains, to reduce the risk and impacts of flooding (World Bank, 2019). These strategies can be divided into two main categories: mitigation and adaptation.

Mitigation strategies: this aim to reduce the likelihood and severity of flooding by restoring or preserving natural ecosystems that can absorb and filter floodwaters (European Commission, 2019).

Examples of mitigation strategies include:

I. Wetland restoration: Restoring wetlands can help to absorb and filter floodwaters, reducing the risk of flooding downstream (Mitsch & Gosselink, 2015).
II. Floodplain management: Allowing floodplains to flood naturally can help to reduce the risk of flooding in nearby communities (Tockner & Stanford, 2002).
III. Green infrastructure: Incorporating green infrastructure, such as green roofs and permeable pavements, into urban design can help to reduce stormwater runoff and alleviate flooding (Fletcher et al., 2015).

Adaptation strategies: These strategies focus on reducing the vulnerability of communities to flooding by promoting sustainable land use practices, improving flood forecasting and warning systems, and enhancing community resilience (International Union for Conservation of Nature [IUCN], 2019).

Examples of adaptation strategies include:

I. Ecosystem-based adaptation: This approach involves restoring and preserving natural ecosystems, such as mangroves and coral reefs, to provide natural barriers against flooding and storm surges (Adger et al., 2005).
II. Flood-resilient agriculture: Implementing flood-resilient agricultural practices, such as agroforestry and conservation agriculture, can help to reduce the vulnerability of agricultural communities to flooding (Ziervogel et al., 2016).

Benefits of Nature-Based Mitigation and Adaptation Strategies

Nature-based mitigation and adaptation strategies for flooding offer numerous benefits, including:

I. Reduced flood risk: By restoring and preserving natural ecosystems, these strategies can help to reduce the likelihood and severity of flooding (World Bank, 2019).
II. Improved water quality: Natural ecosystems can help to filter and purify floodwaters, improving water quality and reducing the risk of waterborne diseases (Mitsch & Gosselink, 2015).
III. Enhanced biodiversity: Nature-based strategies can help to preserve and restore natural habitats, promoting biodiversity and ecosystem services (IUCN, 2019).
IV. Increased community resilience: By promoting sustainable land use practices and enhancing community awareness and preparedness, nature-based strategies can help to increase community resilience to flooding (UNDRR, 2019).
V. Cost-effective: Nature-based strategies can be more cost-effective than traditional engineering approaches, which often require significant investment in infrastructure (European Commission, 2019).

Challenges and Limitations

While nature-based mitigation and adaptation strategies for flooding offer numerous benefits, there are also challenges and limitations to consider, including:

I. Land availability: Restoring and preserving natural ecosystems often requires significant land areas, which can be a challenge in densely populated urban areas (Fletcher et al., 2015).
II. Community engagement: Nature-based strategies often require community engagement and participation, which can be time-consuming and challenging to achieve (IUCN, 2019).
III. Funding: Implementing nature-based strategies can require significant funding, which can be a challenge for communities with limited resources (World Bank, 2019).

IV. Policy and regulatory frameworks: Nature-based strategies often require supportive policy and regulatory frameworks, which can be lacking in some countries (European Commission, 2019).

Nature-based mitigation and adaptation strategies for flooding offer a valuable approach to reducing flood risk and promoting community resilience. By restoring and preserving natural ecosystems, these strategies can help to reduce the likelihood and severity of flooding, improve water quality, and enhance biodiversity. While there are challenges and limitations to consider, the benefits of nature-based strategies make them an important tool in the fight against flooding.

Floods: Sponge City Concept

The Sponge City Concept is a innovative approach to urban flood management that has gained significant attention in recent years (Fletcher et al., 2015). The concept involves designing cities to absorb and filter rainwater, reducing the burden on drainage systems and minimizing the risk of flooding (Li et al., 2019). This report provides an overview of the Sponge City Concept, its benefits, and examples of its implementation in cities around the world. The Sponge City Concept is a holistic approach that integrates urban planning, architecture, and engineering to create sustainable and resilient cities (Wuhan Municipal Government, 2019). The concept has been recognized as a key strategy for mitigating the impacts of urbanization on flood risk (Fletcher et al., 2015).

Sponge City: Definition

A sponge city is an urban area designed to absorb and filter rainwater, reducing the burden on drainage systems and minimizing the risk of flooding (Fletcher et al., 2015). The concept is inspired by the natural water cycle, where rainwater is absorbed by the soil, filtered by vegetation, and slowly released into waterways (Mitsch & Gosselink, 2015). Sponge cities aim to replicate this process through the use of green infrastructure, such as parks, green roofs, and permeable pavements (Li et al., 2019). Green infrastructure is a key component of sponge cities, as it provides a range of ecosystem services, including stormwater management, air quality improvement, and habitat creation (Benedict & McMahon, 2006). The use of green infrastructure in sponge cities can also help to mitigate the urban heat island effect, improve air quality, and enhance biodiversity (Taha, 1997). The concept of sponge cities is not new, but it has gained significant attention in recent years due to its potential to mitigate the impacts of urbanization on flood risk (Fletcher et al., 2015). The concept has been implemented in several cities around the world, including Chicago, Rotterdam, Singapore, Copenhagen, and Wuhan (City of Chicago, 2019; City of Rotterdam, 2019; Urban Redevelopment Authority of Singapore, 2019; City of Copenhagen, 2019; Wuhan Municipal Government, 2019). These cities have implemented a range of green infrastructure initiatives, including green roofs, rain gardens, permeable pavements, and urban parks, to reduce stormwater runoff and improve water quality.

Sponge City: Benefits

Sponge cities offer numerous benefits, including reduced flood risk, improved water quality, enhanced biodiversity, mitigated urban heat island effect, and improved public health (Li et al., 2019). The use of green infrastructure in sponge cities can also help to improve air quality, reduce noise pollution, and enhance aesthetic value (Benedict & McMahon, 2006). Additionally, sponge cities can provide opportunities for physical activity, social interaction, and community engagement, which can help to improve public health and well-being (Sallis et al., 2016).

Sponge City: Examples

As cities around the world face increasing challenges related to urbanization, climate change, and water management, the concept of the "sponge city" has gained significant attention (Li et al., 2019). A sponge city is an urban area that is designed to absorb and filter rainwater, reducing the risk of flooding and improving water quality. Here are five examples of cities that are implementing sponge city initiatives:

Chicago, USA: Chicago's Green Infrastructure Plan aims to reduce stormwater runoff and improve water quality through the use of green roofs, rain gardens, and permeable pavements (ProQuest, n.d.). The plan, which was launched in 2014, includes a range of initiatives, such as the creation of green infrastructure in public spaces, the implementation of green roofs on private buildings, and the use of permeable pavements in urban areas (City of Chicago, 2014). According to a study by the University of Illinois,

Chicago's green infrastructure plan has the potential to reduce stormwater runoff by up to 70% (University of Illinois, 2018).

Figure 4: One Central Park, Chicago Source: Cook, (2014)

Rotterdam, Netherlands: The Netherlands, literally translating to "low-lands," is famously situated below sea level. To cope with this unique challenge, the country has developed and implemented numerous innovative strategies to coexist with water, minimizing the risk of flooding over the years (Jonkman & Kelman, 2005). Rotterdam's Water Management Plan includes the creation of green roofs, urban parks, and flood-resistant construction to reduce the risk of flooding (City of Rotterdam, 2019). The plan, which was launched in 2013, aims to make Rotterdam a "water-resilient" city by 2025 (City of Rotterdam, 2013). According to a study by the Delft University of Technology, Rotterdam's water management plan has reduced the risk of flooding in the city by up to 50% (Delft University of Technology, 2019).

The Water Square Benthemplein in Rotterdam, Netherlands, is a pioneering example of urban design that combines public space and stormwater storage (Salinas et al., 2014). This innovative square holds a twofold strategy, serving as both a public space and a stormwater storage facility. By integrating these two functions, the square provides a unique solution to urban flooding and climate change resilience. As part of Rotterdam's strategy to increase climate resilience through adaptive measures, the Water Square Benthemplein showcases a new approach to urban design (City of Rotterdam, 2019). The square's design allows it to store excess rainwater during heavy rainfall events, reducing the burden on the city's drainage system and minimizing the risk of flooding. In addition to its functional benefits, the Water Square Benthemplein also demonstrates a new model for funding high-quality public spaces. The square was largely financed by water management departments and innovation subsidies, highlighting the potential for collaborative funding approaches to support urban design initiatives (Zevenbergen et al., 2018).

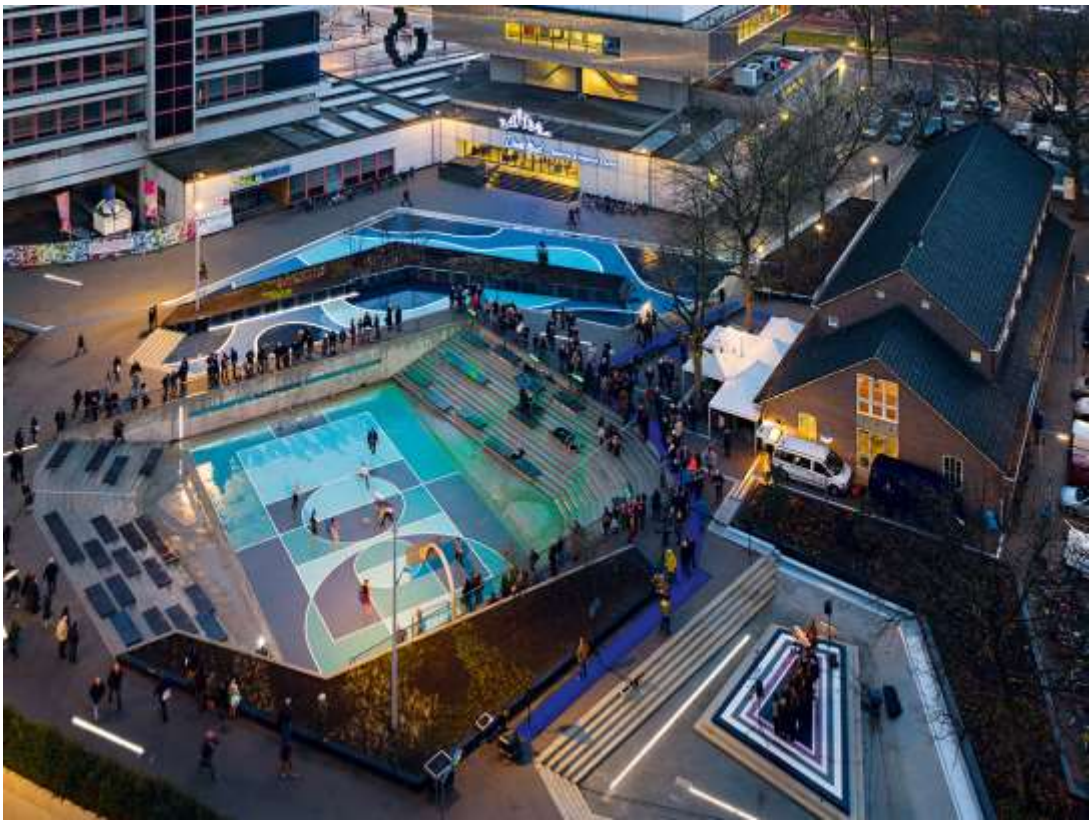

Figure 5: Benthemplein Water Square, Rotterdam.Source: Salinas et al, (2014)

Singapore: Singapore's Urban Redevelopment Authority has implemented a range of green infrastructure initiatives, including green roofs, rain gardens, and permeable pavements, to reduce stormwater runoff and improve water quality (Urban Redevelopment Authority of Singapore, 2019). The initiatives, which were launched in 2014, aim to make Singapore a "City in a Garden" by 2030 (Urban Redevelopment Authority of Singapore, 2014). According to a study by the National University of Singapore, Singapore's green infrastructure initiatives have reduced stormwater runoff by up to 30% (National University of Singapore, 2020). The Singapore Green Plan 2030 is an ambitious initiative launched on February 10, 2021, with the goal of advancing Singapore's national agenda on sustainable development (Zheng, 2021). The plan is built around five key pillars: City in Nature, Sustainable Living, Energy Reset, Green Economy, and Resilient Future. Under the City in Nature pillar, the plan aims to add 1,000 hectares of green spaces by 2035 and double the annual tree planting rate (Zheng, 2021).

Figure 6: Singapore Green Plan 2030: 1,000ha more green spaces & tripling cycling paths to 1,320km Source: Zheng, (2021)

Copenhagen, Denmark: Copenhagen's Cloudburst Management Plan includes the creation of green roofs, urban parks, and flood-resistant construction to reduce the risk of flooding (City of Copenhagen, 2019). The plan, which was launched in 2012, aims to make Copenhagen a "cloudburst-resilient" city by 2030 (City of Copenhagen, 2012). According to a study by the Technical University of Denmark, Copenhagen's cloudburst management plan has reduced the risk of flooding in the city by up to 40% (Technical University of Denmark, 2020).

Figure 7: Copenhagen Cloudburst Management Plan Source: Tauhid, (2021)

Wuhan, China: Wuhan's Sponge City Initiative aims to reduce flood risk and improve water quality through the use of green infrastructure, including green roofs, rain gardens, and permeable pavements (Wuhan Municipal Government, 2019). The initiative, which was launched in 2016, aims to make Wuhan a "sponge city" by 2030 (Wuhan Municipal Government, 2016). According to a study by the Wuhan University, Wuhan's sponge city initiative has reduced flood risk by up to 20% (Wuhan University, 2020).

The Wuhan Xinyuexie Park plays a vital role in the east eco-corridor of the Optics Valley Center Area, connecting Jiufeng Forest Park with Baoxie Lake (Tauhid, 2018). As the primary recreational space in the new Optics Valley CBD area, the park must incorporate several key functions:

I. Provide recreational space for various user groups, promoting an active lifestyle.
II. Preserve and enhance the natural stormwater corridor by integrating the Sponge City concept (Tauhid, 2018).
III. Offer opportunities for public access and environmental education, consistent with restored habitat areas.
IV. Establish connections between existing and restored hills and water bodies.

By serving these purposes, the park can fulfill the city's needs beyond merely improving its image and value (Tauhid, 2018). Upon completion, the park will be well-integrated into the Optics Valley city context, serving communities and user groups while improving local conditions (OBERMEYER Engineering Consulting, n.d.).

Figure 8: Wuhan Sponge City Initiative Source: OBERMEYER, (n.d.)

Resilience Theory

Resilience Theory, introduced by Holling (1973), explores the capacity of systems to absorb disturbances and reorganize while undergoing change to retain essential functions. This theory has evolved to include urban resilience, particularly in the context of climate change and natural hazards (Meerow & Newell, 2019).

In urban flooding scenarios, resilience involves three critical dimensions: resistance, recovery, and transformation. Resistance focuses on minimizing flood impacts through proactive measures like flood-proof architectural designs. Recovery emphasizes quick restoration of functionality after flood events, while transformation involves long-term adaptability to changing climatic conditions.

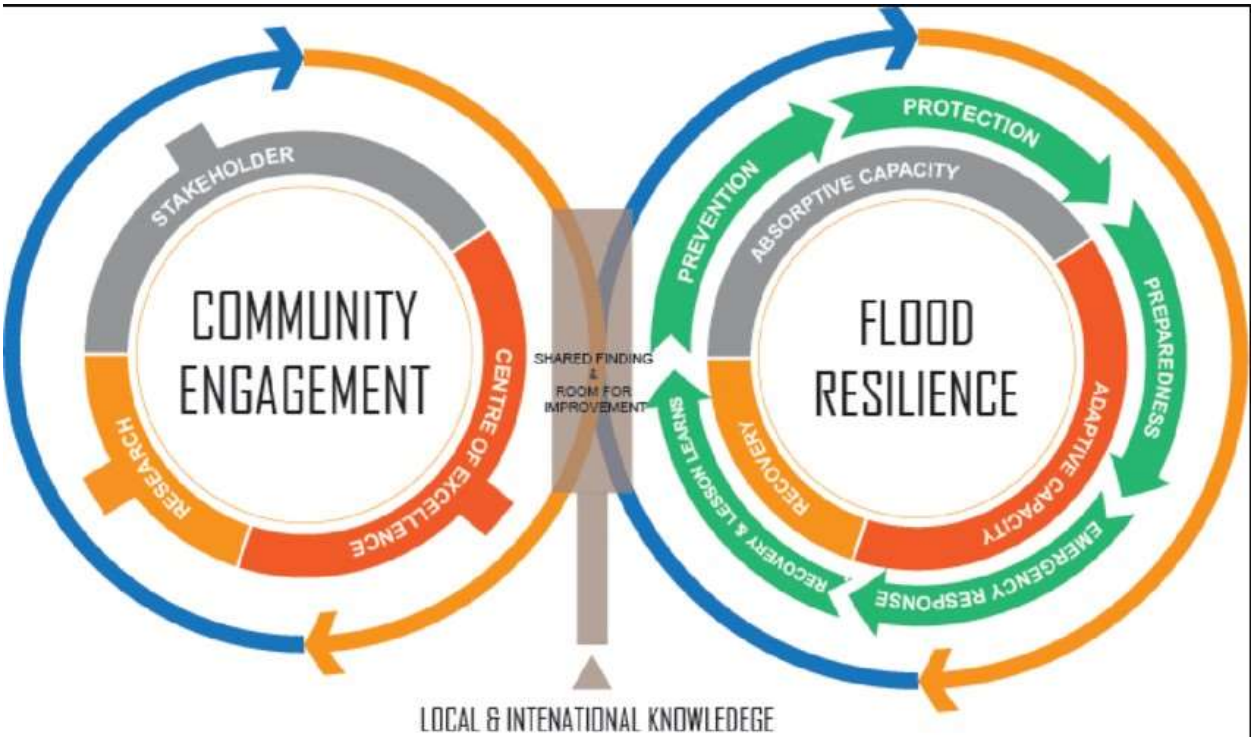

Figure 9: Relationships between Flood Resilience and Community Engagement. (Source: Roslan, Jamaludin & Mohamad, 2015**).**

Architectural Adaptation Strategies

To mitigate the impacts of perennial pluvial flooding in Port Harcourt Metropolis, researchers have proposed various architectural adaptation strategies that are largely Structural measures. Permeable pavements, for example, have been identified as an effective strategy for reducing surface runoff and increasing infiltration (Efe and Opoko, 2020). Blue roofs have also been proposed as a way of reducing runoff, increasing evapotranspiration, and improving thermal performance (Sarai and Oloke, 2021). Other strategies include the use of rain gardens, retention basins, and elevated buildings. Rain gardens are vegetated depressions that collect and filter runoff from impervious surfaces, while retention basins are designed to temporarily store and release stormwater runoff (Enaruvbe et al., 2021). Elevated buildings are designed to raise the ground floor of buildings above flood levels, reducing the exposure of buildings to floodwaters (Akande et al., 2020).

Architecture in general can be adapted to some degree, as buildings can always be modified manually in some manner. Brand's book How Buildings Learn provides insight into the different levels of adaptation that can be expected and how they apply over various periods (Brand, 1994). Therefore, the term Adaptive Architecture must be considered in this broader context, and the distinction between adaptable and adaptive architecture is as follows: Adaptive Architecture refers to buildings that are purposefully designed to adapt, whether automatically or through human intervention, to their environment, occupants, and objects within them (Schnadelbach, 2010).

To manage potential climate hazards, such as extreme storms and flooding, that could impact water quality, infrastructure, and safety, the Environmental Resilience Institute in Indiana suggests adaptation strategies. These strategies include the use of green infrastructure techniques to mitigate recurrent flooding. One or more methods may be employed for adaptation purposes (Environmental Resilience Institute, Indiana).

Use of Bioretention to Collect Stormwater Runoff

Bioretention is a form of landscape feature that is specially designed to collect, store, and allow the infiltration of stormwater runoff on-site (Davis et al., 2012). When it rains, water falling on surfaces like rooftops, driveways, or parking lots is directed towards a shallow depression, which enables runoff to

pool before slowly infiltrating the ground (Dietz, 2007). This depression, which is filled with a filter bed, is typically planted with vegetation that can withstand water-tolerant conditions (Hunt et al., 2017). As stormwater runoff accumulates, it will gradually travel through the filter bed, where it will either be absorbed into the ground or discharged via an underdrain (Davis et al., 2012). This method is commonly used in both residential and commercial areas as it is a cost-effective and efficient way of managing stormwater (EPA, 2017). Bioretention can be used to help reduce the volume and peak flow rate of stormwater runoff, which can help prevent downstream flooding and erosion (Hunt et al., 2017). The use of vegetation within the bioretention area can help improve the quality of the runoff by removing pollutants and nutrients (Dietz, 2007). Small-scale bioretention areas, also known as rain gardens, are often found in residential settings (EPA, 2017). These features are typically designed to manage stormwater runoff from rooftops or other small impervious surfaces (Hunt et al., 2017). They are often planted with native vegetation that is adapted to the local climate and soil conditions, which can help reduce maintenance needs and enhance biodiversity in the area (Dietz, 2007).

Figure 10: Bioretention Pond in a Residential Property (**Source:** mixnew15.bitbucket.io, 2023)

Use of Blue Roof to hold Precipitation

One of the strategies that can be used to manage stormwater runoff is the installation of a blue roof. A blue roof is a roof explicitly designed to capture and slowly release rainwater, in order to slow the rate of runoff and reduce the potential for related flooding (BKSK Architects, n.d.). According to Wong (2017), a blue roof is designed to retain and manage stormwater by temporarily holding it on the roof surface or in engineered trays. The roof can hold up to eight inches of precipitation, and it functions similarly to a vegetated roof, but without the need for soil or vegetation (Carter & Fowler, 2009). The stored water is then slowly released at a controlled rate to the drainage system after the storm event, reducing the peak discharge rate of runoff and allowing for evaporation (Wong, 2017). This process is regulated through a flow restriction device that is located around the roof drain, which controls the discharge rate of water and ensures that the water is slowly released into the drainage system (Carter & Fowler, 2009). Blue roofs can be used in various settings, including commercial, industrial, and residential buildings, to manage stormwater effectively (Wong, 2017). They are particularly useful in areas where there is limited space for other green infrastructure practices, such as bioretention areas or rain gardens (EPA, 2017). In addition to managing stormwater, blue roofs offer other benefits, such as reducing the urban heat island

effect by reflecting sunlight and reducing the need for air conditioning during the summer months (Taha, 2017).

Use of Permeable Pavement

To manage stormwater runoff effectively, one strategy is to use permeable pavement that allows water to flow through and be temporarily stored before being discharged (Fletcher et al., 2018). Permeable pavement includes pavements and pavers that have void spaces that permit runoff to flow through them (Dietz, 2007). After the runoff flows through the pavement, it is stored in an underground stone base before infiltrating into the ground or discharging from an underdrain (Bean et al., 2007). Permeable pavers are particularly efficient at removing heavy metals, oils, and grease in the runoff (Barrett, 2008). In addition, permeable pavement also helps remove nutrients such as phosphorous and nitrogen (Dietz, 2007). As runoff infiltrates through the porous surface, soil and engineered media filter pollutants (Fletcher et al., 2018). The void spaces in the permeable pavement surface and reservoir layers provide storage capacity for runoff, thereby reducing peak volume (Bean et al., 2007). By implementing permeable pavement systems, we can effectively manage stormwater runoff and mitigate the negative impacts of urbanization on water quality, while also providing a durable and functional pavement surface (Barrett, 2008).

Figure 10: Permeable Concrete Paver (Source: thepavercompany.com, 2022).

Use of Underground Storage Systems

Underground storage systems are an effective way to manage stormwater runoff by detaining it in receptacles located beneath the surface of roadways, parking lots, or athletic fields (EPA, 2017). They can also be used in private compounds (Wong, 2017). These systems have varying designs, including culverts, engineered stormwater detention vaults, or perforated pipes, and they slowly release the detained runoff (Fletcher et al., 2018). Compared to other green infrastructure practices, underground storage has the advantage of not occupying additional surface area, making it particularly useful in areas where space is limited (Dietz, 2007). These systems are usually designed to store large volumes of runoff and can have a significant impact in reducing the risks of flooding and peak discharges (Wong, 2017). By holding back large volumes of water, underground storage systems provide time for water to percolate into the soil or to be slowly released through other green infrastructure practices (EPA, 2017). This helps to minimize the impact of large storm events on downstream areas and protect critical infrastructure (Fletcher et al., 2018). These tanks come in different materials, including polyethylene tanks, fiberglass tanks, and concrete tanks (ASCE, 2014).

Polyethylene Tanks

Polyethylene underground water tanks have gained popularity due to their numerous advantages (Aladenola & Adekitan, 2012). Firstly, these tanks are lightweight, making them easy to transport and install (Khan et al., 2015). They require less labour and equipment during installation, resulting in cost savings (Ariaratnam et al., 2013). Additionally, their flexibility allows them to withstand ground movements, reducing the risk of cracking or damage (Hufenus et al., 2016). On the downside, polyethylene tanks have limitations in terms of capacity (Khan et al., 2015). They are available in smaller sizes, making them more suitable for residential or small-scale applications (Aladenola & Adekitan, 2012). Moreover, they are not as durable as concrete tanks and may be susceptible to punctures or damage from sharp objects (Hufenus et al., 2016). Cost is another consideration, as polyethylene tanks can be relatively more expensive compared to other materials (Ariaratnam et al., 2013). However, their lower installation and maintenance costs may offset this initial investment (Khan et al., 2015).

Figure 11: Polyethylene Underground Rain Tank (Source: rainharvest.co.za, 2013). Fibreglass (GRP) Tanks

GRP (glass reinforced plastic) underground water tanks are lightweight in nature, making them easier to handle and install compared to concrete tanks (Al-Sharif, 2017). Their lightweight construction also reduces transportation costs (Khan et al., 2015). Additionally, fibreglass tanks are highly resistant to corrosion, making them suitable for long-term use without the risk of rust or degradation (Awad et al., 2014). Another advantage is their versatility in terms of shape and size (Al-Sharif, 2017). Fibreglass tanks can be customised to fit specific requirements, allowing for a tight fit in limited spaces. They also have excellent insulation properties, helping to maintain water temperature (Khan et al., 2015). However, fibreglass (GRP) tanks do have some disadvantages to consider as well. They can be more expensive compared to other options such as plastic tanks (Ariaratnam et al., 2013). Also, if they are exposed to UV light, they can degrade over time and weaken the structure (Awad et al., 2014), however, if installed underground, this will minimize the UV rays affecting it (Al-Sharif, 2017).

Concrete Tanks

Concrete underground water tanks can be constructed precast or in situ (Kumar et al., 2017). They have their own set of advantages and disadvantages. One of the major advantages of concrete tanks is their durability (Al-Sharif, 2017). They are known for their strength and longevity, with the ability to withstand harsh weather conditions and external forces (Khan et al., 2015). Concrete tanks also have a larger capacity, making them suitable for commercial or industrial applications (Ariaratnam et al., 2013).

Another advantage of concrete tanks is their thermal properties. They have excellent insulation, which helps to maintain the temperature of the stored water (Kumar et al., 2017). Along with advantages, there are some disadvantages to consider with concrete underground water tanks. Firstly, concrete tanks are heavy and require heavy machinery for installation, resulting in higher installation costs (Al-Sharif, 2017). They also have a longer installation time compared to other options (Khan et al., 2015). Another drawback is the possibility of cracks or leakages over time. Concrete is prone to cracking due to ground movement or settling, which can lead to water loss or contamination (Ariaratnam et al., 2013).

Figure 11: Concrete Underground Rain Tank (Source: Rain Brothers, 2023).

METHODOLOGY

Design

The quantitative component of the study provides objective data to complement the qualitative findings and offer statistical evidence on flood risks and mitigation strategies. Surveys were administered to residents, property owners, and local government officials in flood-prone areas of Port Harcourt Metropolis. The survey gathers data on the level of awareness among residents about pluvial flooding, current flood mitigation measures in place, and their views on various architectural strategies for flood prevention. The survey used a mix of Likert scale questions to measure attitudes and perceptions, along with close-ended questions. This approach allows for the quantification of public knowledge and opinions, as well as the identification of patterns in attitudes towards flood resilience. In addition, spatial analysis and mapping using Geographic Information System (GIS) tools was employed to map stratified flood-prone areas in Port Harcourt Metropolis, and analyze the relationship between urban development patterns, existing infrastructure, and the architectural features that influence flooding. Finally, the study incorporates flood impact data analysis. This was involved doing an urban flood vulnerability assessment of the selected areas in Port Harcourt Metropolis. It is essential for developing effective flood risk reduction and management strategies. Statistical tools will be used to analyze this data and explore the relationship between specific architectural features and the occurrence of flooding.

Population and Sampling

The targeted population for the study on Architectural Adaptation Strategies to Mitigate Perennial Pluvial Floods in Port Harcourt Metropolis includes various stakeholders and groups directly or indirectly involved in addressing pluvial flooding challenges.

Residents of Flood-Prone Areas: Based on the work of Wizor & Mpigi, (2020) on the 25 most-flooded roads in Port Harcourt Metropolis. 13 regions (streets/roads) were chosen from the 25 most-flooded roads/streets in Port Harcourt Metropolis. 4 streets/roads were chosen from low-flooded areas, 5 from moderately-flooded areas, and 4 from high-flooded areas. A total of 13 streets/roads were considered for this research. However, Residents from these 13 selected flood-prone areas in Port Harcourt Metropolis form a key part of the population. These individuals provided valuable insights into local experiences with flooding, awareness of flood risks, and opinions on both existing and potential architectural strategies for flood mitigation. From each of the 13 areas, 20 compounds were selected, with one respondent per compound, resulting in a total of 260 respondents from this group.

Urban Planners and Architects: Professionals such as urban planners and architects are integral to the study, offering expert opinions on design and urban development strategies aimed at reducing flood risks. The research focuses on members of the Nigerian Institute of Town Planners (Rivers State branch), which has 570 members, and the Nigerian Institute of Architects (Rivers State branch), comprising 240 fully registered members. These professionals provide insights into the most effective architectural solutions for mitigating pluvial flooding.

Government Officials: Officials from relevant state ministries in Port Harcourt also form part of the population. These include the Rivers State Ministry of Urban Development and Physical Planning, with 84 staff members, River State Ministry of Housing with 134 staff, and the Rivers State Ministry of Environment, with 102 staff members. Their perspectives on flood management practices, policies, and regulations are crucial for understanding the institutional framework required to implement architectural adaptation strategies.

Community Leaders: Community leaders from the 13 selected flood-prone areas were included to represent the views of the broader community. These leaders play a critical role in advocating for local concerns and influencing decision-making processes related to flood mitigation, two leader or such as street chairman and a member were selected from each flood area, making a total of 26 stakeholders in this category.

Sample Frame

The sample frame for this study, "Architectural Adaptation Strategies to Mitigate Perennial Pluvial Floods in Port Harcourt Metropolis", was thoughtfully developed to include a broad range of stakeholders with diverse roles and experiences related to flood mitigation. The approach ensures a balanced representation of opinions from individuals and institutions who are directly impacted or involved in addressing flooding challenges in the metropolis. The sample was selected by taking 50% of the total population from six key stakeholder groups.

Residents of flood-prone areas constitute a significant portion of the sample frame, with 130 participants selected from a population of 260. This group provides firsthand accounts of the flooding issues they face, offering valuable insights into the effectiveness of existing measures and highlighting the areas requiring improvement for better flood resilience.

The Nigerian Institute of Town Planners (Rivers State Branch) represents the largest group in the sample, with 285 participants selected out of 570. Town planners bring critical expertise to the study as they are responsible for urban development and zoning regulations. Their contributions help evaluate how planning practices can mitigate flooding in urban areas.

The Nigerian Institute of Architects also play a crucial role, contributing 120 participants from its total membership of 240. Architects are vital in designing buildings and infrastructure to withstand flooding. Their input focuses on assessing existing designs and recommending solutions tailored to the challenges posed by recurrent pluvial flooding in the region.

Officials from the Rivers State Ministry of Urban Development and Physical Planning are also included, with 42 selected from a population of 84. This group represents government involvement in urban

planning and policy-making, ensuring that the study reflects institutional perspectives and strategies currently in place to manage urban flooding.

The Rivers State Ministry of Environment contributes 51 participants from a population of 102. Their expertise provides an understanding of the environmental dimensions of flooding, including its causes, impacts, and the role of sustainable practices in mitigating its effects.

The Rivers State Ministry of Housing contributes 67 participants from a total population of 134. Their specialized knowledge offers valuable insights into the environmental aspects of flooding, encompassing its underlying causes, consequences, and the importance of sustainable practices in addressing its challenges.

Finally, community leaders from flood-prone areas are represented by 13 individuals from a total of 26. These leaders provide collective insights on how floods affect local communities and the social and cultural dimensions of flood management. Their involvement ensures that community needs and priorities are well-represented in the findings.

In total, the sample frame includes 708 participants, drawn from a population of 1,416 across the seven stakeholder groups. By incorporating inputs from residents, professionals, government agencies, and community leaders, the study ensures a comprehensive understanding of the flooding problem. This diversity strengthens the analysis and helps develop practical, inclusive, and sustainable architectural strategies to address pluvial flooding in Port Harcourt Metropolis.

Sample size

The sample size for the research Architectural Adaptation Strategies to Mitigate Perennial Pluvial Floods in Port Harcourt Metropolis was determined using the Taro Yamane formula. This statistical approach ensures the selection of a representative sample that accurately reflects the target population while minimizing sampling error. The study drew participants from seven key stakeholder groups, resulting in a total sample size of 512 individuals from an initial sample frame of 708. The Formula for Taro Yamane method is statistically given as follows:

$$n = \frac{N}{1+N\,(e)^2}$$

Where n = sample size

N = Population size

e = Level of significance or allowable error

1 = a constant

However, for each stakeholder, the estimated sample size was obtained for the sample frame of the population, for example, using the residents of flood prone area with a sample frame of 130 stakeholder for illustration, the Taro Yamane formula is thus substituted.

$$n = \frac{130}{1 + 130\,(0.05)^2}$$

$$= \frac{130}{1 + 130\,(0.0025)}$$

$$= \frac{130}{1.325} \quad = \quad 98$$

The Residents of Flood-Prone Areas constituted a significant portion of the sample size, with 98 participants selected from a sample frame of 130. The Nigerian Institute of Town Planners, Rivers State Branch had the largest sample frame of 285 members, from which 166 were selected. From the Nigerian Institute of Architects (Full Members), 92 individuals were selected from a sample frame of 120. The Rivers State Ministry of Urban Development and Physical Planning had a sample frame of 42 participants, with 41 selected for the study. The Rivers State Ministry of Environment had a sample size of 45 individuals, drawn from a sample frame of 51. While the Rivers State Ministry of Housing has a sample size of 57 selected from a sample frame of 67. Finally, the Community Leaders of Flood-Prone Areas, representing grassroots stakeholders, had all 13 members included in the sample size. In summary, the total sample size of 512 participants encompassed a diverse range of stakeholders, ensuring

the study benefited from a broad spectrum of expertise, experiences, and perspectives. This approach enhances the reliability of the findings and supports the development of effective architectural adaptation strategies to mitigate pluvial flooding in Port Harcourt Metropolis.

Instrumentation and Data Collection

This section outlines the instrumentation and data collection methods employed in this research, including the design and administration of surveys, interviews, and observational studies. The data collection instruments were carefully developed and validated to ensure that they captured the necessary information to address the research questions and objectives. This chapter provides an overview of the data collection process, including data collection techniques, and instrumentation used to gather both qualitative and quantitative data.

Instrumentation

This research utilized a variety of tools to collect comprehensive data on strategies for architectural adaptation to address recurring urban floods in Port Harcourt Metropolis. The instruments employed included well-structured questionnaires, interviews, and Geographic Information System (GIS) tools, each tailored to extract specific information from relevant stakeholders actively involved in flood management in the city. The structured questionnaire served as the main instrument for data collection, featuring both closed and open-ended questions. Its purpose was to gather diverse insights from key groups such as government officials, urban developers, architects, residents of affected neighborhoods, and community leaders in areas susceptible to flooding. The questionnaire was organized into sections.

Data Collection

This study employed a mixed-methods approach, integrating both qualitative and quantitative methods to gain an understanding of flood risks and mitigation strategies. Field Observations focused on flood-prone areas, examining drainage systems, building elevations, and construction materials, providing a baseline for adaptation strategies. Document Review was conducted using government reports, urban planning documents, and flood management policies to understand the historical and policy context of flood mitigation in Port Harcourt Metropolis. Additionally, Surveys were used to gather both expert and community perspectives. Semi-structured interviews were conducted with professionals, including architects, urban planners, and flood management experts, to gain expert insights into effective architectural strategies. Focus group discussions with community leaders were held to explore local views on current flood mitigation measures and potential solutions. Surveys were distributed to residents, property owners, and local government officials to assess their awareness of pluvial flooding and their opinions on architectural strategies for flood prevention. The surveys combined Likert-scale and close-ended questions, providing statistical data on public knowledge and attitudes.

Analytical Techniques for Data Collected/ / Analysis

The data obtained from the survey and GIS assessments were carefully organized and prepared for analysis. Responses from the structured questionnaire were initially sorted according to the demographic characteristics of respondents and the study's key research objectives. Descriptive statistical techniques, such as frequency distributions, percentages, and graphical representations, were utilized to interpret the responses. These methods facilitated the identification of participants' views on recurrent pluvial flooding in Port Harcourt Metropolis. In addition, spatial data analysis was conducted using ArcGIS. The GIS software was instrumental in visualizing and analyzing specific flood-prone areas within the study region. However, in mapping these vulnerable locations, ArcGIS provided valuable spatial context to the survey findings, enabling an understanding of the challenges and solutions related to pluvial flood mitigation in Port Harcourt Metropolis. The integration of descriptive statistics and GIS analysis ensured that the data was examined from multiple perspectives, contributing to well-rounded insights into strategies for addressing flooding issues in the study area.

Validity and Reliability of Research Instruments

To guarantee the accuracy and dependability of the tools used in this study, a thorough validation process was undertaken. The consistency of the structured questionnaire was evaluated using the test-retest technique. This approach involved administering the same set of questions to a small group of urban planners and other relevant stakeholders within Port Harcourt Metropolis at two different times. This

allowed for an assessment of the uniformity in responses, ensuring the questionnaire effectively captured participants' views and experiences related to pluvial flooding and its mitigation. The variations observed between the two rounds of responses were reviewed, and modifications were made to improve the questionnaire's reliability. Additionally, the GIS tools utilized in this research, particularly ArcGIS, were rigorously tested by a certified GIS specialist before being deployed for data collection. This preliminary evaluation ensured the software's capability to accurately extract and analyze spatial data related to pluvial flooding within the study area. The GIS tools were also assessed to confirm their reliability in providing consistent results throughout the study. This step was critical in verifying that the spatial data collected was both precise and dependable. However, in employing the test-retest method for the questionnaire and subjecting the GIS tools to expert evaluation, the study ensured that all research instruments were both valid and robust. These efforts ensured the collection of high-quality, reliable data that was essential for developing effective architectural strategies to mitigate recurring pluvial flooding in Port Harcourt Metropolis. The combined validation process enhanced the credibility of the research findings and supported the study's objectives.

RESULTS AND DISCUSSION

Table 1: Architectural Adaptations to Mitigate Flooding

S/N	Reason	Response		
		Yes	**No**	**Total**
1.	Elevate building DPC above the flood level	99.2	0.8	**100**
2.	Apply waterproof coatings, sealants	98.6	1.4	**100**
3.	Raise or floodproof HVAC equipment and mechanical, Plumbing, and electrical system components	93.6	6.4	**100**
4.	Use of water pumping machine	100	0	**100**
5.	Construct permanent barriers (floodwalls)	99.8	0.2	**100**
6.	Collection and storage of rainwater to reduce runoff when it's raining	90.0	10.0	**100**
7.	Permeable ground surfaces to promote water infiltration	96.5	3.5	**100**
8.	Retention ponds	90.0	10.0	**100**

Source: Researcher, 2025

Table 1 presents the list of architectural adaptations that have been effective in mitigating flood-related issues. However, the results show that significant architectural adaptations have been made in Port Harcourt metropolis to reduce flooding risks. Nearly all respondents (99.2%) reported that buildings are designed with elevated damp proof courses (DPC) to prevent water intrusion. Additionally, 98.6% of respondents use waterproof coatings and sealants for enhanced protection, and 93.6% raise or floodproof critical systems like HVAC, plumbing, and electrical equipment. Water pumping machines are universally used (100%), underscoring their importance in flood management. Permanent flood barriers are also common (99.8%), while 90% of respondents collect rainwater to minimize runoff. Furthermore, permeable ground surfaces (96.5%) and retention ponds (90%) are commonly used to manage rainwater effectively. These findings highlight proactive steps taken to address flooding, though better integration with urban planning could further enhance their effectiveness.

Table 2: Challenges Hindering Successful Implementation of Flood Mitigation Measures

S/N	Reason	Response		
		Yes	**No**	**Total**
1.	Insufficient funding	99.8	0.2	**100**
2.	Infrastructure limitations	99.4	0.6	**100**
3.	Community resistance	28.9	71.1	**100**
4.	Regulatory issues	84.8	15.2	**100**

Source: Researcher, 2024

Table 2 presents the challenges hindering successful implementation of flood mitigation measures in the study area. The successful implementation of flood mitigation measures in Port Harcourt metropolis faces

significant challenges, primarily due to insufficient funding and inadequate infrastructure. Nearly all respondents (99.8%) cited a lack of financial resources as a key hindrance, stressing the importance of adequate funding to support flood management projects. Similarly, 99.4% identified limitations in existing infrastructure, suggesting it is not equipped to handle the growing flood risks. Regulatory issues also emerged as a notable challenge, with 84.8% of respondents highlighting difficulties in enforcing effective policies. However, community resistance was less of a concern, as 71.1% felt there was little opposition. These findings underscore the need for better funding, infrastructure improvements, and more effective regulatory measures to address the city's flood challenges.

Table 3: Primary Goals of Flood Mitigation Strategies in Alignment with Architectural Objectives

S/N	Option	Response		
		Yes	**No**	**Total**
1.	Protecting infrastructure	100	0	**100**
2.	Enhancing community safety	100	0	**100**
3.	Preserving architectural heritage	100	0	**100**
4.	Sustainable urban development	100	0	**100**
5.	Human comfort & building sustainability	100	0	**100**

Source: Researcher, 2025

Table 3 presents the Primary Goals of Flood Mitigation Strategies in Alignment with Architectural Objectives. However, the result reveals that flood mitigation strategies in Port Harcourt are fully aligned with key architectural objectives. Every respondent (100%) emphasized the importance of protecting infrastructure, enhancing community safety, preserving architectural heritage, supporting sustainable urban development, and ensuring human comfort and building sustainability. This shows a shared consensus on the necessity of integrating these goals into flood mitigation efforts. The alignment indicates a holistic approach that addresses immediate flooding risks while also focusing on long-term urban sustainability, public safety, and the preservation of both cultural and architectural heritage within the metropolis.

Table 4 How Community Involvement Can Be Enhanced to Ensure the Success of Flood Mitigation Initiatives

S/N	Option	Response		
		Yes	**No**	**Total**
1.	Community engagement programmes	100	0	**100**
2.	Collaborative planning sessions	100	0	**100**
3.	Educational workshops	100	100	**100**
4.	Public awareness campaigns	100	0	**100**

Source: Researcher, 2025

Table 4 presents the best ways community involvement can be enhanced to ensure success of flood mitigation measures in Port Harcourt metropolis. However, the results highlight a strong agreement on the role of community involvement in the success of flood mitigation initiatives in Port Harcourt. Every respondent (100%) emphasized the importance of community engagement programs, collaborative planning sessions, and public awareness campaigns to ensure effective participation. Additionally, educational workshops received full support (100%) as a means of enhancing public understanding and providing essential knowledge. This unanimous agreement underscores the need for an inclusive approach where the community is actively engaged in flood management efforts, ensuring that flood mitigation strategies are more widely accepted and effectively implemented.

Figure 12: Rumuewhara new layout after the flood December 2024 flood (remodeled shops with raised DPC) Source: (Researcher 2025)

DISCUSSION

The paper tried to evaluate the effectiveness of existing architectural and urban planning strategies in mitigating the risks associated with perennial pluvial floods. Findings on the list of architectural adaptations that have been effective in mitigating flood-related issues, indicate that in Port Harcourt metropolis, various architectural adaptations are widely employed to mitigate flooding. Nearly all respondents (99.2%) use elevated damp proof courses (DPC), and 98.6% apply waterproof coatings and sealants. Most buildings (93.6%) floodproof essential systems like HVAC, plumbing, and electrical equipment. Water pumping machines are universally used (100%), and permanent flood barriers (99.8%) are common. Additionally, 90% collect rainwater to reduce runoff, while 96.5% use permeable surfaces and 90% construct retention ponds. These measures show proactive flood mitigation, though their integration with broader urban planning could improve overall effectiveness in managing flood risks. Findings on the challenges hindering successful implementation of flood mitigation measures in the study area indicate that the implementation of flood mitigation measures in Port Harcourt faces challenges due to insufficient funding (99.8%) and inadequate infrastructure (99.4%). Regulatory issues also pose a significant obstacle, with 84.8% of respondents acknowledging difficulties in policy enforcement. However, community resistance is less of a concern, as 71.1% of respondents indicated minimal opposition to flood mitigation efforts. These results highlight the urgent need for increased financial resources, enhanced infrastructure, and more effective regulatory frameworks to overcome barriers and improve flood management in the metropolis. Addressing these challenges is essential for implementing sustainable and effective flood mitigation strategies.

Findings on the Primary Goals of Flood Mitigation Strategies in Alignment with Architectural Objectives show unanimous alignment between flood mitigation strategies and architectural objectives in Port

Harcourt, with 100% of respondents agreeing on key priorities. These include protecting infrastructure, enhancing community safety, preserving architectural heritage, supporting sustainable urban development, and ensuring human comfort and building sustainability. This consensus reflects a comprehensive approach to flood management that not only addresses the immediate risks of flooding but also emphasizes long-term sustainability, public safety, and the preservation of cultural and architectural values. The integration of these objectives indicates a well-rounded strategy for managing flood impacts in the metropolis. Finding on the best ways community involvement can be enhanced to ensure success of flood mitigation measures in Port Harcourt metropolis shows that all respondents (100%) agreed on the importance of community engagement programs, collaborative planning sessions, and public awareness campaigns to boost participation. Additionally, educational workshops were universally supported (100%) as an essential means to raise awareness and provide vital knowledge to the community. These findings highlight the need for an inclusive approach, ensuring that the community actively contributes to the planning and execution of flood mitigation strategies, thereby enhancing their effectiveness and acceptance.

CONCLUSION

The study also analyzed flood mitigation strategies, revealing gaps in awareness and implementation. While 61% of respondents were aware of flood measures like barriers and water pumps, inadequate drainage, poor urban planning, and ineffective early warning systems were significant challenges. Effective adaptations included elevated damp proof courses, flood proofing essential systems, and permeable surfaces, widely used across the metropolis. However, challenges such as insufficient funding, inadequate infrastructure, and policy enforcement hindered broader success. Stakeholder engagement and community-driven approaches, including public awareness campaigns and educational workshops, were identified as essential for enhancing resilience. Finally, a flood-resilient design framework integrating innovative architectural adaptations, stakeholder involvement, and policy recommendations was proposed to address the unique challenges of flooding in Port Harcourt.

RECOMMENDATIONS

i. To enhance the effectiveness of government in flood-prone areas like Port Harcourt, it is essential to incorporate both alternative project locations and structural designs focused on flood mitigation and resilience.
ii. Constructing levees, floodwalls, and embankments to protect urban areas from riverine and coastal flooding
iii. Developing advanced storm water drainage systems, such as underground tunnels, retention basins, and green infrastructure (e.g., permeable pavements and green roofs) to improve water absorption and reduce surface runoff.
iv. Integrating flood-resilient designs in urban planning, including raised buildings, flood-proof basements, and the creation of flood plains and green belts.

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