The Implications of Physical and Technical Conditions on Flood Resilience in Self-build Housing in Tropical Wet and Dry Nigeria

Bobuchi Ken-Opurum, Ph.D. Candidate with the School of Architecture/Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, USA (phone: 407-965-9064; bkenopur@andrew.cmu.edu).

Erica Cochran Hameen, Ph.D., Assistant Professor and Co-Director with the Center for Building Performance and Diagnostics, Carnegie Mellon University, Pittsburgh, PA 15213, USA (e-mail: ericac@andrew.cmu.edu).

Joshua D. Lee, Ph.D., Assistant Professor in the School of Architecture, Carnegie Mellon University, Pittsburgh, PA 15213, USA (e-mail: jdlee2@andrew.cmu.edu).

Jared Cohon, PhD., President Emeritus and Professor in the Department of Civil/Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, USA (email: jaredcohon@cmu.edu).

Waku Ken-Opurum, MS Candidate with the School of Professional Studies, Columbia University in the City of New York, New York, NY, 10027, USA (e-mail: waku.k@columbia.edu).

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ABSTRACT

Floods claim numerous lives and generate significant direct and indirect losses to urban dwellers in Nigeria every year. Climate change will exacerbate flood risks within cities in Nigeria and contribute to these losses. Hence, adapting to climate vulnerabilities especially for the urban poor, elderly, children, and people with disabilities, has become an important part of the development agenda for Nigeria. Governments and urban planners provide top-down, reactive approaches such as flood management infrastructure, evacuation and disaster and emergency communication. While they address large-scale infrastructure and public services, they are not always able to address the immediate and critical day-to-day needs of poor and vulnerable populations. Fortunately, a systematic meta-analysis of over 40 peer reviewed papers published in the last two decades shows the growing evidence that individuals and households have developed and utilized bottom-up solutions including raising plinths and sand-filling for flood resilience in housing. However, some of these design solutions have either mixed outcomes or short-lived successes. It is important to determine the factors and conditions that contribute to long-term success of these design solutions to successfully increase resilience of households in Nigerian mega cities such as Port-Harcourt and Lagos. Using a pilot survey, this research collected data from residents of flood-prone cities in tropical wet and dry regions to investigate the collection and the combinations of factors that impact the long-term success of flood resilience bottom-up solutions in housing. Findings from the pilot survey indicated the physical and technical conditions that were associated with the effectiveness of these solutions. Furthermore, the findings indicated that the most effective way to reduce flooding was to utilize multiple design solutions. These findings will provide decision makers with an improved understanding of flood risk management and resilience in different housing contexts within megacities globally, especially in Nigeria.

1 INTRODUCTION

Climate change is amplifying the impacts of floods and water-based disasters on urban dwellers in megacities within the Global South, especially as climate conditions are becoming more unpredictable. Deforestation, uncontrolled land encroachment, ineffective drainage infrastructure, poor urban planning, and increased development of hard surfaces are just some of the anthropogenic activities that increase exposure and sensitivity of urban dwellers to floods (Chakraborty et al., 2019; Aliyu & Amadu, 2017; Wahab & Falola, 2018). Vulnerability to climatic stressors, especially flooding from sea-level rise, torrential rainfall, and tidal inundation, increases public health risks, loss of lives, and destruction of livelihoods and homes of urban dwellers (Chakraborty et al., 2019; Wahab & Falola, 2018).

Nigeria is one the countries in the global south widely recognized as having increased vulnerability to floods. Annual floods in the country claim hundreds to thousands of lives and displace several thousands (Adelekan & Asinyabi, 2016). Fatalities are especially high in cities with over a million residents, such as Lagos, Port-Harcourt, Benin City, and Ibadan. It was reported that floods that occurred in 2011 in Ibadan, Lagos, and the Niger Delta, which includes Port-Harcourt, resulted in a "tremendous number of casualties" (Olarenwaju et al., 2019).

In addition to high casualties, floods have major financial implications on households and governments due to damages and associated redevelopment costs. In the 2011 floods that affected Ibadan, over 25% of households lost their livelihoods (Olanrewaju et al, 2019). According to Guha-Sapir et al. (2016), the single flood event in 2012, which the World Health Organization (WHO) recognized as "the worst flood to have hit the country in the past 50 years" (Olanrewaju et al, 2019), generated over 500 million dollars in damages. Furthermore, based on a report by Ezeokoli et al. (2019), extreme flood events in the city of Anambra have generated billions of Naira worth of damages.

Beyond direct losses, floods disrupt normal life and inflict long-term physical and mental health problems on individuals, especially on groups that are intrinsically more disadvantaged, including the urban poor, elderly, children and people with disabilities (Adelekan, 2010; Odemerho, 2014; Adebimpe et al., 2018; Adegun & Ayoola, 2019; Ezeokoli et al., 2019; Bello et al., 2017). Literature including Tempark et al. (2013), Bich et al. (2011), Bandino et al., 2015 and Olanrewaju et al. (2019) have reported health implications from prolonged and persistent floods and flooding consequences, which are significant in megacities because of the poor quality of water, sanitation, and hygiene facilities and systems (WASH). For example, the papers by Tempark et al. (2013), Bich et al. (2011), and Bandino et al., (2015) describe the psychological disorders including trauma, immersion injuries, and cutaneous and percutaneous diseases, that are consequences of minimal and extreme flooding events. In Nigeria especially, waterborne diseases such as cholera and typhoid fever, and bacillary dysentery, which are exacerbated by floods, are estimated to cause the deaths of over 860,000 children annually (Olanrewaju et al, 2019).

Consequently, flood risk management is paramount for Nigerian mega cities, especially the cities located in low-elevation coastal zones (LECZ's) because of the large concentration of people building on sites with increased exposure to flooding. This paper focuses on flood resilience design solutions for two Nigerian mega cities in the South, i.e. Port-Harcourt and Lagos. Lagos with approximately 10 million residents is the second largest city in Africa (Adelekan & Asinyabi, 2016). There are also estimates that the population is northward of 15 million due to its annual growth rate of 5.8% (Idris & Fagbenro, 2019; United Nations, 2016; Aliyu & Amadu, 2017). Port-Harcourt has a population of approximately 1,382,592 residents and serves over 13 metropolitan zones (Azuonwu et al., 2017; Akukwe and Ogbodo, 2015). Both Lagos and Port-Harcourt are capital cities, spurring heavy commerce and economic activity within their respective regions, which attracts increased migration. Lagos has evolved over the years to become a major economic hub and West Africa's "most important" coastal city, while Port Harcourt has established itself as the oil and gas hub of Nigeria (Adelekan and Asinyabi, 2016; Owolabi, 2020).

As megacities with large populations, the dangers of flooding events and other climate disasters impedes the safety and well-being of millions of inhabitants as more people are prone to suffer such damages. Both Lagos and Port Harcourt have tropical climates, with the former being a tropical savanna climate and the latter a tropical monsoon climate (Oluleye and Akinbobola, 2010; Abhulimen et al, 2020). As coastal cities, they face fluvial flood risks combined with pluvial flood risks such as riverine floods, flash floods, urban floods, and coastal floods (Lamond et al, 2019; Olanrewaju et al, 2019). The rainy season in Nigeria occurs between the months of April and October, and during this time, many parts of Lagos are extremely vulnerable to flooding due to houses being built on flood plains, poor drainage systems, lack of maintenance of existing drainage systems, and higher risks of runoff (Olanrewaju et al, 2019). Port Harcourt is also at risk due to its low-lying topography combined with heavy rainfall (Akukwe and Ogbodo, 2015). According to Akukwe and Ogbodo (2015), in 2006, Port Harcourt experienced unprecedented flooding which submerged houses, paralyzed economic activities, and rendered some people internally displaced in some zones.

According to Haque et al. (2014), managing the consequences of climate change in urban areas requires a range of responses and strengthening the capacity of agents at the micro-level to respond to climate variability. Research was conducted on flood risk management in Nigeria, and many weak spots were discovered including, weak infrastructure, inadequate drainage networks, lack of an integrated flood risk management system, and poverty (Olanrewaju et al, 2019). Many local governments had only focused on infrastructural and institutional measures such as drainage and waterway construction, post-disaster relief and raising of awareness to discourage dumping of solid waste in the drainage channels (Adelekan and Asinyabi, 2016). Notwithstanding, starting from 2008, considerable actions were taken to raise public engagement on flood management in Lagos such as campaigns, an annual climate change summit and other initiatives (Adelekan and Asinyabi, 2016). Although it may seem as though progress was being made towards better flood management, awareness has been limited and noticeably not directed at the larger population and vulnerable residents who need it (Adelekan and Asinyabi, 2016). Additionally, Adelekan and Asinyabi (2016) explain that flood risk management in the country has not considered useful scientific and social science knowledge that could be gleaned from risk assessments.

These conversations are now in place as research studies have started investigating how individuals, households, and communities from the bottom-up, cope with floods, and the efforts taken to mitigate the risks and recover. Research at the grassroots level has produced emerging principles from localized solutions that have been successful in flood management, such as raising building foundations and cash-for-work systems (Wahab & Falola, 2018). Using a systematic meta-analysis method, this research investigated the design solutions and grassroots initiatives such as those used in informal settlements and other types of self-build housing that are successful in coping and adapting to floods in tropical wet and dry climates.

The process included a review of over 300 conference and journal papers, reports, and white papers focused on the global south retrieved from eleven main databases, literature trails, ‘citation chasing’, and a broad search of google. Through the systematic process, forty-one papers published between the years 2000 and 2020 by authors including Karki (2016), Taiwo et al., (2012), Adelekan (2010), Jabeen et al (2010) Jabeen (2019), and Dobson et al. (2015) culminated in a catalog of flood resilient design solutions applicable for Lagos and Port-Harcourt. These solutions were primarily self-built by households. Self-building is the mainstream housing delivery process practiced in Nigeria and many countries within the global south including Bangladesh and Ghana, and in informal settlements (Alagbe & Opoko, 2013; Emiedafe, 2015; Ahadzie & Badu, 2011).

However, the findings from the systematic approach to the literature review had gaps in relation to the outcomes of some of the determined design solutions. The study also revealed inconsistencies in the outcomes that were reported due to households applying the design solutions in the wrong context. Households, though knowledgeable of their flood risks and the solutions that could be used to reduce these risks, were unaware that the decision to use one option over another requires deeper analysis and considerations of many factors and conditions to prevent failure and reduce risk of maladaptation.

Therefore, to increase the likelihood of a design solution being effective in the long-run in both Lagos and Port-Harcourt, it is important to investigate the conditions, factors and combination of both that may have implications on long-term success for different contexts. This paper aims to add to the body of literature on design solutions utilized for flood resilience in tropical wet and dry climates and the respective outcomes of the solutions. Furthermore, the paper aims to draw conclusions on conditions and combinations of conditions that may affect the viability of a design solution.

2 METHODS

An online pilot survey was conducted to determine design solutions individuals in tropical climates used for flood resilience in their houses. In addition, the survey was conducted to determine how technical and physical housing conditions played a role in the outcomes of these design solutions.

2.1 Semi-structured Survey

The online pilot survey was conducted via the *Qualtrics* platform between June and August 2020. The survey is part of a PhD research project at Carnegie Mellon University (CMU) which investigates the impacts of flooding on the comfort, health, and safety of households, and the solutions used by households to recover and adjust to these impacts in their homes. An ethics protocol by the institutional review board (IRB) at CMU was followed and approval was granted for the survey. Responses were solicited through email, distribution to contacts and via promotion of the survey on multiple online social media platforms. The pilot survey was distributed to people in the Caribbean, West Africa, East Africa, and South-East Asia, locations within the Global South. Participation in the survey was limited to the following groups of people.

i. People (including owner-occupants and landlords) who have purchased and/or built their homes in countries within the Caribbean, Latin America, South Asia, and Africa that have rainy (wet) and dry (harmattan) seasons.

ii. Homeowners who live in regions with rainy and dry seasons and have made improvements to their homes through either renovation or retrofits.

iii. Renters who live in regions with rainy and dry seasons and have made improvements to their homes either through renovation or retrofits.

The choice to source responses from only people in tropical climatic regions in the global south was due to the location specificity of climate resilience. Research studies such as Karki (2016), Taiwo et al., (2012), and Adelekan (2010) have stated that resilience is region specific. In a bid to get results that are applicable to both Lagos and Port-Harcourt, the research utilized a climate filter. The most vulnerable regions to floods are LECZs and countries within the tropic of cancer, which are described as tropical and subtropical regions. These regions fall within the Koppen Geiger megathermal climate A. The Koppen Geiger classification of megathermal climates are tropical rainforests (Af), tropical monsoon (Am), and tropical wet and dry (Aw/As). It runs adjacent to the north and south of the equator through the Americas, Africa, Asia, and Australia.

Participants for the survey were from over 18 cities in the global south, and responses used for data analysis are from participants of ten reported cities and three unreported cities as shown in Figure

1. The reported cities include Port-Harcourt, Nigeria; Lagos, Nigeria; Mumbai, India; Dharavi, India; Accra, Ghana; Abuja, Nigeria; Benin, Nigeria; Petit Valley, Trinidad, and Tobago; Illesha, Nigeria; and Owerri; Nigeria. The three unreported cities were in Barbados, Grenada and Nigeria.

A total of forty-four responses were received for the survey, which included seven responses that were partially completed and nine responses from houses in the Global North. After excluding the responses in the latter two categories, data analysis was performed on the remaining twenty-eight. Out of the 28 responses analyzed, 17.8% of the respondents were 18-24 years old, 64.3% were 25-34 years old, 7.1% were 35 – 44 , 3.5% were in both the 45 – 54 years old and 55- 64 years old age group, and 3.5% were 65 years or older. Furthermore, 11 of the respondents were female, 15 male, and 1 unknown (preferred not to answer) as shown in Figure 1.

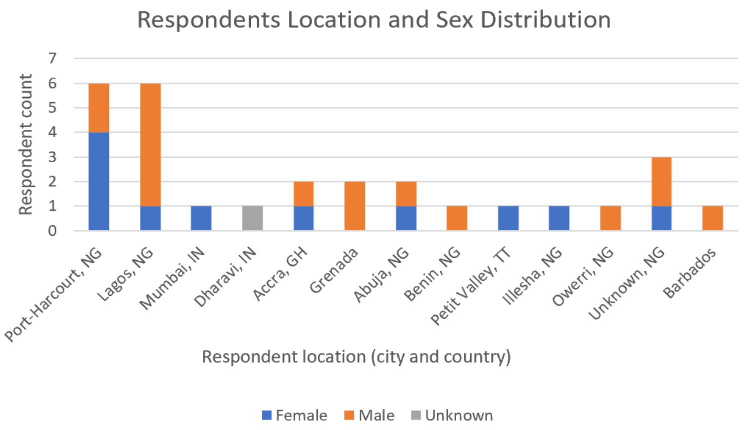

Figure 1. Respondents location of residence and sex distribution

2.2 Structure of Survey Questions

The survey was designed to identify design solutions utilized by respondents to avoid flooding in their houses, and to identify the physical and technical conditions of the site and the surrounding locale of the home. The physical conditions include attributes that are naturally occurring, such as landforms, water bodies and vegetation. Technical conditions include human made or manipulated physical attributes such as infrastructure.

The survey had four main parts which included open-ended, multiple choice and Likert scale questions. Part A asked participants demographic questions. Part B asked participants about the physical characteristics of their neighborhood and part C asked about the physical characteristics of participants' houses and building sites. Lastly, part D explored flood prevention design solutions and their outcomes.

In parts B and C, survey participants were asked to summarize the temporary and permanent conditions of their site/yard, and the surrounding locale of their house. The surrounding locale was defined as a radius within 20-minute walking distance of the respondents' house. These conditions were grouped into permanent and temporary conditions. Permanent conditions are considered the state of the site or surrounding locale that cannot be easily manipulated including being changed or removed, while temporary conditions can be manipulated within the site and the surrounding locale.

In part D, participants were asked to select the design solutions they have employed to avoid flooding in their houses from the list of design solutions in Table 1. Each of the 12 suggested design solutions were drawn from this research project's catalog and represented coping and adaptive options for flood avoidance (FAv), flood exclusion (FEx) and flood acceptance (FAc). Each question was structured as an open-ended question to facilitate *other* responses. Solutions that are FAv, prevent water from entering the building by avoiding water discharge. FEx solutions resist, reject and redirect water from the building. Lastly, FAc solutions *facilitate* the flow of water through the building or site, also known as wet proofing.

Table 1. List of design solutions included in the survey questions

Flood Avoidance (FAv)	Flood Exclusion (FEx)	Flood Acceptance (FAc)
Built house on wooden stilts	Installed foundation (footing) drainpipe	Used waterproofing materials
Deconstructed house and moved to a safer site (relocation)	Built walls around house	Used damp proof membrane
Planted trees/built green infrastructure (bioswales, etc.)	Other – used buckets and drums to collect rainwater	Dug a ditch to transport water
Raised entry points of house (plinth and splash apron)		Installed French drain system/mechanical water pump
Built an open ground story (OGS)		
Sand-filled yard		

2.3 Data Analysis

Descriptive statistics were completed in Excel and utilized to determine socioeconomic characteristics of respondents. Each survey response was reviewed for completeness. Surveys that were mostly complete contributed to the findings on houses that do not flood, and the physical home attributes associated with their no flooding outcomes. However, those findings were excluded from this analysis. Only completed surveys were analyzed to identify associations between the existing site conditions, the neighborhood attributes, selection of flood prevention design solutions and flood prevention success.

These surveys were also reviewed to determine the association between selection of a flood prevention design solution and income of the decision maker. Socioeconomic factors such as education and employment were not factored into the analysis, however future research will consider these factors.

3 RESULTS

Flood avoidance design solutions were primarily used by respondents as shown in Table 2. The two most frequently used design solutions were '*dug a ditch to transport water out of the yard'* and '*raising the entry points of the house (e.g. the plinth and splash apron)'*.

Table 2. List of design solutions utilized by survey respondents

Design Solutions	Percent of Total Responses	Tag
Dug a ditch to transport water	20	FEx
Planted trees/built green infrastructure	15	FAv
Raised entry points of house (plinth and splash apron)	15	FAv
Used damp proof membrane	10	FAc
Built walls around house	10	FEx
Sand-filled yard	5	FAv
Used waterproofing	5	FAc
Built an open ground story (OGS)	5	FAv
Installed foundation drainpipe	5	FEx
Other – used buckets and drums to collect rainwater	5	FEx
Did not use any actions	5	N/A

Fifty-eight percent of respondents reported that the outcomes of the design solutions they utilized were very successful (VS) and twenty-one percent reported the outcomes as somewhat successful (SS). Outcomes were considered very successful if they were very successful at preventing water infiltration during site flooding events. Outcomes are considered somewhat successful if solutions worked sometimes or worked every time but only for a short period of time. Unsuccessful (US) outcomes represented solutions that were never successful for avoiding floods. Twenty-one percent reported that the outcome of their design solutions was unknown (UN), and none of the respondents identified the design solutions as having no impact (unsuccessful) on flood reduction in their homes (US). The distribution of the outcomes for each design solution is illustrated in Figure 2.

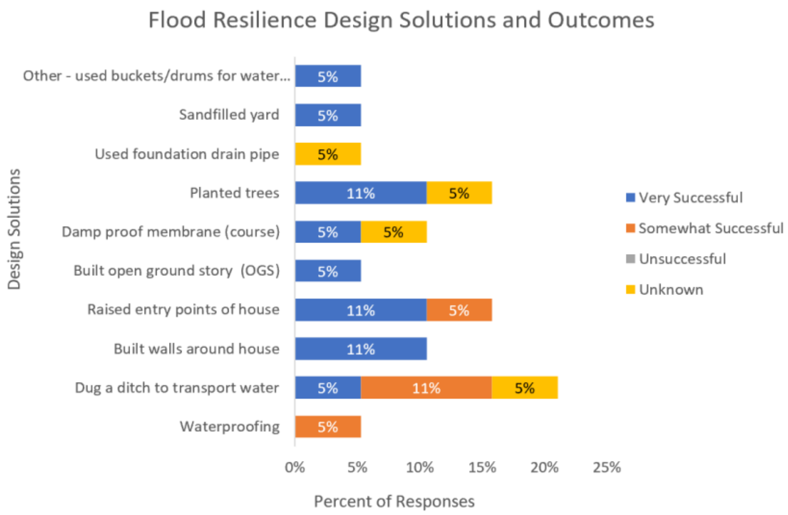

Figure 2. Flood resilience design solutions and distribution of outcomes

Survey responses for the ten design solutions in Table 2, were used to investigate the physical and technical conditions that contributed to successful outcomes. Findings revealed that there were multiple outcomes when '*planted trees*', '*damp proof membrane (course)*', '*raised entry points of house*' and '*dug a ditch to transport water*' design solutions were used. These four solutions were further analyzed to determine the conditions that were associated with very successful outcomes and somewhat successful outcomes.

The following sections discuss the design solutions that were very effective and their associated outcomes. Table 3 highlights three flood design solutions that were very successful (VS) for flood prevention when flood levels were below 0.9 feet (28cm). The table also highlights the permanent and technical conditions that were associated with the effectiveness of these solutions.

Table 3. Individual design solutions associated with effective flood resilience

Design Solution	**Permanent Conditions**		**Temporary Conditions**					
	Site Topography	Terrain	Neighborhood Density	Site Vegetation	Neighborhood Vegetation	Surface Type	Drainage System	Drainage Condition
Built walls around house	Flat	Wetland	High	Some trees	Some trees	Mostly hard surfaces	Open concrete canal	Clogged
	Low-lying/Valley	N/A	Low	Some trees	Forest/Bush	Mostly soft surfaces	Closed concrete, undefined	Clogged
Built an open ground story (OGS)	Flat	N/A	Medium	None	None	Hard and soft surfaces	Closed concrete	Good

Raised entry points of house (plinth and splash apron)	Sloping	Wetland	Low	Some trees	Some trees, Some lawns	Mostly soft surfaces	Vegetated canal	Clogged
	Flat	Swamp	Medium	None	Some trees	Mostly hard surfaces	Closed concrete	Clogged

Findings also indicated that the most effective way to reduce flooding was to utilize multiple design solutions. Table 4 highlights the three combinations of seven designs that were effective for flood prevention for flood levels up to 4 feet (121 cm).

Table 4. Design solution combinations associated with effective flood resilience

Design Solution	Permanent Conditions		Temporary Conditions					
	Site Topography	Terrain	Neighborhood Density	Site Vegetation	Neighborhood Vegetation	Surface Type	Drainage System	Drainage Condition
Built walls around house + Planted trees + Used drums for rainwater collection	Low-lying/Valley	N/A	Low	Some trees	Forest/Bush	Mostly soft surfaces	Closed concrete, undefined	Clogged
Planted trees + Dug a ditch in the yard to transport water	Flat	Swamp	Low	Some trees	Some trees	Mostly hard surfaces	Open concrete ditch	Clogged
Sand-filled site + Used damp proof membrane (course) + Raised entry points of house (plinth and splash apron)	Flat	Swamp	Medium	None	Some trees	Mostly hard surfaces	Closed concrete	Clogged

All solutions in Tables 3 and 4 can be applied in both Lagos and Port-Harcourt contexts. Both tables can serve as a guide for decision makers' selection of design solutions that have an increased likelihood of success for flood prevention. Beyond the conditions highlighted, recognizing the elements of the design solutions and how it can contribute to improved success and prevent maladaptation will further promote flood resilience in housing.

3.1 Tree planting

The findings showed that tree planting was very effective in preventing flood damage. It also indicated that the presence of vegetation at a site or within the neighborhood improved the effectiveness of the design solution. Nonetheless, it is important for decision makers to consider the terrain and topography of their site and surrounding locale, when selecting the species, size, age, and quantity of trees to use for flood resilience. This is especially important in coastal cities such as Lagos and Port-Harcourt, with increased risk of salinization of soils from saltwater intrusion (Adeoti et al., 2010; Oteri and Atolagbe, 2003) and storm surges that can cause diebacks and severely damage trees (Fagherazzi et al, 2019). In addition, heavy storms come with intense wind that can fell trees and which may cause blockages in the path of run-off or drainage systems. Tree damage also has significant implications on maladaptation, as this can exacerbate existing flooding conditions, especially for vulnerable populations.

Furthermore, for cities such as Port-Harcourt that are easily and heavily inundated after precipitation, flood resistant tree species that are native to the region can increase tolerance to prolonged flooding events.

Soil type is another significant consideration when tree planting. Literature has shown that trees are very valuable for flood management, especially if planted in soil with good capillarity. Capillarity takes water to the roots of trees through surface tension, adhesion, and cohesion forces ("Capillary Action and Water", n.d.). Lastly, trees and vegetation are especially beneficial for both flood management and groundwater recharge if located on steep sloping hills. The roots of trees aid the dual purpose by increasing the permeability of the soil (Monteiro et al., 2006).

3.2 Built walls around house (floodwalls)

Floodwalls are designed to withstand flooding with water levels of at least 4 feet (121 cm) ("Other Flood Protection Measures", n.d.). Findings suggest that the conditions of the drainage system of the surrounding locale will not affect the effectiveness of floodwalls. As floodwalls are designed to resist and redirect water, any increased flooding from clogged and/or broken drainage systems would most likely be resisted by the wall. Findings also indicated that neither the physical nor technical conditions will impact the success of floodwalls for both pluvial and fluvial flooding conditions when the flood level is below 1 feet (30.48 cm).

With its capacity to resist floods levels that are at least 4 feet, the floodwall is considered the most effective design solution utilized by respondents. It is recommended that when using a floodwall, decision makers should be cognizant of the "bathtub effect" within their enclosed site. The *bathtub effect* is a phenomenon that causes floodwater to backup leading to a rise in the flood level, and can lead to significant maladaptation, especially with sites on flood plains (Jessop, 2019). However, this may be alleviated by combining floodwalls with other design solutions such as tree planting, that have an equal or greater-than drainage rate of the flood waters. Furthermore, the respondents reported that trees were present either on the site, within the surrounding locale or in both areas, and this may have contributed to the absence of the effect on outcomes. A more robust survey could provide further details on the association between vegetation and the 'bath-tub' effect.

3.3 Raising entry points of a house

Raising the entry points of a house is important for avoiding floodwaters, however it may become ineffective if the raised height is lower than the flood level. Flood level which may be affected by factors including slope of a site, volume and rate of run-off, neighborhood density, and the absence of vegetation, should be directly proportional to the height of raised entry points to increase the likelihood of a very successful outcome.

The results also indicate that medium - high density neighborhoods coupled with a site on flat land reduces the effectiveness of raising entry points of a house. This finding aligns with literature which shows that compared to sloped sites that improve the flow of water, water will remain stagnant on relatively flat land because of minimal gravity ("Types of Floods and Floodplains", n.d., McFarlane et al., 1985, "Floods and Floodplain Management", n.d.). This is especially exacerbated on wetlands that have a higher degree of waterlogging.

3.4 Dug a ditch to transport water from yard

The findings indicated that density of the surrounding locale reduced the effectiveness of ditches, especially for sites with high risks from fluvial flooding and storm surges. The depth and width of the ditch dictates the volume of water that can be held and conveyed offsite during a flood event ("Chapter 7 – Ditches and Channels", n.d.). The relationship between density and reduced effectiveness of the solution may be a result of the volume of run-off from the surrounding locale, coupled with the volume of precipitation on the site. The findings also suggested that the presence or absence of drainage systems and/or the state of their condition may not be linked to any outcomes for this design solution at the indicated flood level.

Conclusions

In this complex and changing world, there is a growing need for mega cities to increase resilience capacity at the household level. Over the course of the next 100 years, floods are projected to rise because of climate change and global warming. In this same period, millions of people are expected to build homes, especially in LECZs as urbanization increases. With the expectation that houses will be built regardless of dynamic climatic conditions, this paper provides a source of options for city dwellers to build homes that can increase their resilience to flood damages from increased precipitation and rising sea levels. This paper also discusses the physical and technical conditions that may improve or impair the effectiveness of these flood preventing design solutions. Drawn from grassroots experiences of "urban poor", and self-build households and communities coping with extreme weather and reducing their vulnerability to climate change, through literature review and empirical work. The research focuses primarily on megathermal climates, and considers the physical characteristics of the case location, vulnerabilities (sensitivity and exposure), and the relation to outcomes of the associated design solution.

Improving the capacity of households to recover and adapt to flood risks in the long-term requires a range of strategies not solely at the infrastructure and institutional levels. It also requires the provision of climate resilient information to households and individuals. By drawing on lessons from grassroots experiences of "urban poor", and self-build households and communities coping with extreme weather and reducing their vulnerability to climate change, these bottom-up design solutions can provide a pathway towards equitable, economic, and resilient solutions for developing and least developed countries. Increasing resilience capacity at the household level provides a footstool for the development of effective resilient policy in global south cities and will help to improve the lives of people in some of the most vulnerable dwellings in the world.

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References

Abhulimen, E. A., Bonet, M. U., Oyekunle, S. O., Achara, N., & Solomon, W. C. (2020). An inquisition on the combined effects of ambient temperature and relative humidity on the performance of a uniform speed single shaft gas turbine in tropical monsoon climate, using GPAL. *European Journal of Engineering Research and Science (EJERS)*. https://doi.org/10.24018/ejers.2020.5.6.1946

Adebimpe, O., Oladokun, Y., Odedairo, B., & Oladokun, V. (2018). Developing flood resilient buildings in Nigeria: A guide. *Journal of Environment and Earth Science*, 8(3), 143–150. https://pdfs.semanticscholar.org/e2a1/b3739afd23ed463ef3f9a533c44bcc1bf70e.pdf

Adegun, O. B., & Ayoola, H. A. (2019). Adaptation to heat stress within housing estates in Akure, Nigeria. *Covenant Journal of Research in the Built Environment (CJRBE)*, 7(1), 51–62. doi:10.20370/45y0-hs42

Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, 22(2), 433–450. doi:10.1177/0956247810380141

Adelekan, I. O., & Asiyanbi, A. P. (2016). Flood risk perception in flood-affected communities in Lagos, Nigeria. *Nat Hazards* 80, 445–469.https://doi.org/10.1007/s11069-015-1977-2

Adeoti, L., Alile, O., & Uchegbulam, O. (2010). Geophysical investigation of saline water intrusion into freshwater aquifers: A case study of Oniru, Lagos State. *Scientific Research and Essays*. 5. 248-259. https://www.researchgate.net/publication/228676764_Geophysical_investigation_of_saline_water_intrusion_into_freshwater_aquifers_A_case_study_of_Oniru_Lagos_State

Ahadzie D. K., and Badu E. (2011). Success indicators for selfbuild houses in two Ghanaian cities. *Journal of Science and Technology*, Vol. 31, No. 3, pp 86-96. http://dx.doi.org/10.4314/just.v31i3.10

Akukwe, T. I., & Ogbodo, C. (2015). Spatial analysis of vulnerability to flooding in Port Harcourt metropolis, Nigeria. *SAGE Open*, 5(1), 215824401557555. doi:10.1177/2158244015575558

Alagbe, O. A., & Opoko, A. P. (2013). Housing Nigerian urban poor through self-build housing concept using compressed stabilized laterite bricks. *International Journal of Research in Social Sciences*, 2(4), 13–18. http://ijsk.org/uploads/3/1/1/7/3117743/v2i402_architecture.pdf

Aliyu, A. A., & Amadu, L. (2017). Urbanization, cities, and health: The challenges to Nigeria - A review. *Annals of African medicine*, *16*(4), 149–158. https://doi.org/10.4103/aam.aam_1_17

Azuonwu O., Nnenna I., & Uwuma O. E. (2017) Evaluation of haematological profile of geriatric subjects in Port Harcourt metropolis of Niger Delta of Nigeria. *J Clin Lab Med*. 2(1): doi http://dx.doi.org/10.16966/2572-9578.111

Bandino, J. P., Hang, A., & Norton, S. A. (2015). The infectious and noninfectious dermatological consequences of flooding: A field manual for the responding provider. *American Journal of Clinical Dermatology*, 16(5), 399-424. doi:10.1007/s40257-015-0138-4

Bello, N. A., Durosinmi, W. A., & Abdulharim, R. I. (2017). Assessment of adaptation strategies to flooding impacts in Nigeria - a review. *International Technology & Science*, 135–145. https://www.researchgate.net/publication/322470730_Assessment_of_Adaptation_Strategies_to_Flooding_Impacts_in_Nigeria-A_Review

Bich, T. H., Quang, L. N., Ha, L. T., Hanh, T. T., & Guha-Sapir, D. (2011). Impacts of flood on health: Epidemiologic evidence from Hanoi, Vietnam. *Global Health Action*, 4(1), 6356. doi:10.3402/gha.v4i0.6356

Capillary Action and Water. (n.d.). USGS. https://www.usgs.gov/special-topic/water-science-school/science/capillary-action-and-water?qt-science_center_objects=0#qt-science_center_objects

Chakraborty, T., Hsu, A., Manya, D., and Sheriff, G. Disproportionately higher exposure to urban heat in lower-income neighborhoods: A multi-city perspective. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ab3b99

Chapter 7 – Ditches and Channels. (n.d.). Virginia Department of Transportation. http://www.virginiadot.org/business/resources/LocDes/DrainageManual/chapter7.pdf

Dobson, S., Nyamweru, H., & Dodman, D. (2015). Local and participatory approaches to resilience in informal settlements in Uganda. *Environment & Urbanization*. Vol 27, no. 2: 605 - 620. https://doi.org/10.1177/0956247815598520

Emiedafe, W. (2015, March 27). How to successfully build your own house in Nigeria. http://sapientvendors.com.ng/how-to-successfully-build-your-own-house-in-nigeria/

Ezeokoli, F. O., Okolie, K. C., & Onwuka, S. U. (2019). Flood resilience measures in buildings on the flood-plains of Ogbaru, Anambra State, Nigeria. *Advances in Research*, 1–10. doi: 10.9734/air/2019/v19i430131

Fagherazzi S., Anisfeld S. C., Blum L. K., Long E. V., Feagin R. A., Fernandes A., Kearney W. S., Williams K. (2019). Sea level rise and the dynamics of the marsh-upland boundary. *Frontiers in Environmental Science*, 7(25). https://doi.org/10.3389/fenvs.2019.00025

Floods and Floodplain Management. (n.d.). FEMA. https://www.fema.gov/pdf/floodplain/nfip_sg_unit_1.pdf

Guha-Sapir, D., Hoyois, P., Wallemacq, P., & Below, R. (2016). Annual disaster statistical review 2016: The numbers and trends (pp. 1-81, Rep.). *Centre for Research on the Epidemiology of Disasters (CRED)*. https://www.emdat.be/sites/default/files/adsr_2016.pdf.

Haque, A. N., Dodman, D., & Hossain, M. M. (2014). Individual, communal and institutional responses to climate change by low-income households in Khulna, Bangladesh. *Environment and Urbanization*, 26(1), 112–129. doi: 10.1177/0956247813518681

Idris, J., & Fagbenro, A. (2019). Lagos the Mega-City: A Report on How the Metropolis Handled an Outbreak of the Ebola Epidemic. *Socio-cultural Dimensions of Emerging Infectious Diseases in Africa: An Indigenous Response to Deadly Epidemics*, 281–298. https://doi.org/10.1007/978-3-030-17474-3_21

Jabeen, H. (2019). Gendered space and climate resilience in informal settlements in Khulna City, Bangladesh. *Environment and Urbanization*, 1-24. doi:10.1177/0956247819828274

Jessop, S. (2019). *Flooding in the Hawkesbury -Nepean Valley* (Rep.). Retrieved https://www.gtansw.org.au/wp-content/uploads/2019/12/GTA-Bulletin-Vol-51-Issue-4-2019-17-20.pdf

Karki, T. (2016). How capable are local residents and local governments at coping with and adapting to flood disasters in Malaysian cities? *Malaysia Sustainable Cities Program, Working Paper Series*. https://malaysiacities.mit.edu/paperKarki

Lamond, J., Adekola, O., Adelekan, I., Eze, B., & Ujoh, F. (2019). Information for adaptation and response to flooding, multi-stakeholder perspectives in Nigeria. Climate, 7(4), 46. doi:10.3390/cli7040046

McFarlane, D J., Negus, T R., and Cox, J W. (1985). Drainage to control waterlogging. *Journal of the Department of Agriculture, Western Australia*, Series 4: Vol. 26: No. 4, Article 7. https://researchlibrary.agric.wa.gov.au/journal_agriculture4/vol26/iss4/7

Monteiro, E. Z., Moreno, M. M., Pina, S. A. M. G., Labaki, L. C., Kowaltowski, D. C. C. K., Silva, V. G., and Oliveira, M. C. A. (2006). A sense of comfort in open space around owner-built houses: the case of Campinas, Brazil. Conference on Passive and Low Energy Architecture. https://pdfs.semanticscholar.org/eba5/67176098c081d4f46932c92e62950a26849b.pdf?_ga=2.146082608.562532054.1590089599-112854364.1556510428

Odemerho, F. O. (2014). Building climate change resilience through bottom-up adaptation to flood risk in Warri, Nigeria. *Environment and Urbanization*,27(1), 139-160. doi:10.1177/0956247814558194

Olanrewaju, C. C., Chitakira, M., Olanrewaju, O. A., & Louw, E. (2019). Impacts of flood disasters in Nigeria: A critical evaluation of health implications and management. *Jamba (Potchefstroom, South Africa)*, *11*(1), 557. https://doi.org/10.4102/jamba.v11i1.557

Oluleye, A., & Akinbobola, A. (2010). Malaria and pneumonia occurrence in Lagos, Nigeria: Role of temperature and rainfall. *African Journal of Environmental Science and Technology*, *4*(8). https://www.ajol.info/index.php/ajest/article/view/71305

Oteri, A. U., & Atolagbe, F.P. (2003). Saltwater intrusion into coastal aquifers in Nigeria. *The Second International Conference on Saltwater Intrusion and Coastal Aquifers*. https://olemiss.edu/sciencenet/saltnet/swica2/Oteri_ext.pdf

Other Flood Protection Measures. (n.d.). FEMA. https://www.fema.gov/media-library-data/2c435971150193efc6a6ba08f2403863/P-936_sec4_508.pdf

Owolabi, T. (2020). Nigerian oil union suspends industrial action after Exxon Mobil workers freed. Reuters. https://www.reuters.com/article/us-health-coronavirus-nigeria-exxon-mobi/nigerian-oil-union-suspends-industrial-action-after-exxon-mobil-workers-freed-idUSKBN2210HZ

Taiwo, O. J., Olaniran, H. D., & Osayomi, T. (2012). Perceived causes, exposures and adjustments to seasonal heat in different residential areas in Ibadan, Nigeria. *The Environmentalist*, 32(4), 405–414. doi: 10.1007/s10669-012-9403-8

Tempark, T., Lueangarun, S., Chatproedprai, S., & Wananukul, S. (2013). Flood-related skin diseases: A literature review. *International Journal of Dermatology*, 52(10), 1168-1176. doi:10.1111/ijd.12064

Types of Floods and Floodplains. (n.d.). FEMA. https://training.fema.gov/hiedu/docs/fmc/chapter%202%20%20types%20of%20floods%20and%20floodplains.pdf

United Nations. (2016). The world's cities in 2016. https://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf

Wahab, B., & Falola, O. (2018). Vulnerable households and communities' responses to flood disasters in the Ibadan metropolis, Nigeria. *Ibadan Journal of Sociology*, 7, 47–75. https://www.researchgate.net/publication/327366112_Vulnerable_Households_and_Communities'_Responses_to_Flood_Disasters_in_the_Ibadan_Metropolis_Nigeria

Yu, J., Shannon, H., Baumann, A., Schwartz, L., & Bhatt, M. (2016). Slum upgrading programs and disaster resilience: A case study of an Indian 'smart city'. *Procedia Environmental Sciences*, 36, 154-161. doi:10.1016/j.proenv.2016.09.02