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Research Article

Physical Vulnerability of Buildings to Flooding in Lilongwe City, Malawi

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ABSTRACT

Research on flood vulnerability mainly has focused on social, economic and human vulnerability. Not much research has been conducted on the equally important subject of physical vulnerability of buildings which are an important aspect of all human activities. The study investigated the physical vulnerability of buildings to flooding in low-income settlements of Biwi and Kawale1 in Malawi's capital city, Lilongwe. Geographical information system (GIS) Ordinary Least Square (OLS) regression tool and statistical package for social sciences (SPSS) 20 were used to correlate exposure factors and physical vulnerability of buildings. The study found that exposure factors variably influenced the physical vulnerability of individual building types and that building typology and foundation height were also important factors. Irrespective of their location, buildings constructed using fired bricks with cement mortar walls and cement floors had low vulnerability while buildings constructed using fired bricks in mud mortar walls and cement floors had high vulnerability. OLS regression showed that the physical vulnerability was influenced by building typologies and floodwater level with significance value .001($p<.001$) and .004($p<.005$) respectively. Rather than urban planners and disaster management officials emphasising stream reserves as a preventive measure, advocating the construction of buildings using flood-resistant materials and with high enough foundations in flood-prone areas, should be considered central to urban flood risk reduction. Flood vulnerability studies should be conducted in other flood-prone cities of Malawi to support effective citywide urban planning and disaster risk management.

Key concepts: ***Physical vulnerability, flooding, exposure factors, elements at risk, Lilongwe, Malawi***

1.0 Introduction

Cities in Sub-Saharan Africa experience recurring floods in recent years (Ramiaramanana and Teller, 2021). Tiepolo (2014: p.25) reports that "the flooding has a direct impact on the population, buildings, livestock, crops, and goods, as well as an indirect impact on human, economic, social, financial, political, and institutional terms." The rapid increase of urban populations exacerbates exposure to flooding as high housing demand forces many low-income earners to settle in flood-prone areas (Ramiaramanana and Teller, 2021) where the quality of building is too poor to withstand flooding (Douglas et al., 2008; De Risi et al., 2013). Urban Malawi also experiences climate change-related extreme weather events such as floods (Ngwira, 2016); mainly flash floods and river flooding or fluvial flooding (Salami et al., 2017). The most recent was Tropical Cyclone Freddy induced floods and landslides that caused: 679 deaths, 537 people missing, 2178 people injured, and 882,989 people had their houses damaged (Department of Disaster Management Affairs (DoDMA, 2023) mostly in the south of Malawi and several urban centres including Blantyre city. In Mzuzu city similar floods have also been reported (Kita, 2017; Bwanali and Manda, 2023). In Lilongwe City, river floods were reported in 2012, 2015, 2017, 2018, 2019 and 2020 causing death, damage to buildings and displacement of households (Médecins Sans Frontiers, 2017; Regional Office for Southern Africa (ROSA), 2012; Lilongwe City Council, 2017). However, as most studies on flood vulnerability in Malawi focus on social and economic vulnerability, data on vulnerability of buildings to floods is scarce. This is despite that buildings are an essential component of the social, economic and human activities (Marvi, 2020). The study assessed the physical vulnerability of buildings to floods in low-income areas of Biwi and Kawale in Lilongwe City. Specific focus was on key elements at risk of floods, building exposure and vulnerability and effectiveness of household building protection measures. The rest of the paper is structured as follows: The next section reviews literature related to flooding and building vulnerability which is followed by an outline of the methods used to collect and analyse the data. The fourth section presents the study results followed by a discussion of the results while the final section presents a conclusion.

2.0 Literature Review

Physical vulnerability originated from the hazard and impact approach from climate change-related studies and is thus seen as a function of hazard, exposure, and sensitivity (Brooks, 2003) of infrastructures, populations, or activities, and the resulting or potential impacts (Lankao and Quin, 2011). According to van Westen (2011, p. 5-4), "physical vulnerability means the potential for physical impacts on the physical environment, which can be expressed as elements-at-risk, resulting from the occurrence of a natural phenomenon of a given magnitude and is "expressed on a scale from 0 (no damage) to 1 (total damage)". Köhle et al (2012) observed that in many studies on physical vulnerability, vulnerability is perceived as "the degree of loss to a given element, or set of elements within the area affected by the hazard." The emphasis is on the role of hazard and their physical impact (Ciurean et al. 2013: p.14) on the exposed and susceptible systems. More so, physical vulnerability is a functional relationship between process magnitude, the impacts on the structural element at risk, and exposed values (Guillard-Gonçalves, 2016). For example, the physical vulnerability of the built environment is related to the fragility of physical structures and the expected degree of loss or damage resulting from the impact of a certain hazard event on the elements at risk (Guillard-Gonçalves, 2016). The impact on physical structures can only happen to structures that are present at the location where hazard events (such as floods) can occur (Huq and Hossain, 2015). Messner and Meyer (2005) note that elements at risk of being harmed become vulnerable if exposed to a hazard and so (flood) vulnerability analysis needs information concerning factors that are specified as elements of at-risk, and susceptibility indicators.

Studies on the assessment of physical vulnerability to natural hazards are few in developing countries (Sagala, 2006). Fatemi et al. (2020) study in the peri-urban areas of Dhaka, Bangladesh examined physical vulnerability of residential buildings, flood damages, and local physical response to flood in which buildings' typology was classified based on the roof, walls, and floor materials. The results showed that buildings constructed from durable materials experienced low damage while those constructed with temporary and natural materials suffered high damage, while older (than 20 years) and those that were lower than the plinth level had high damage rate. Balasbaneh et al. (2020) study on vulnerability of building materials by examining the degree of damage for each structure in Malaysia (based on five types of wall materials: brick, concrete block, steel wall panels, wooden walls and precast concrete framing) found that wooden walls were the most vulnerable while concrete block and precast concrete framing were the least vulnerable. Shrestha et al. (2021) investigated flood impact on residential buildings and household assets in Bago region, Myanmar by correlating a flood event with buildings characteristics (construction materials, number of stories and plinth height level from the ground) and household assets using flood damage functions (depth-damage curves). The study found that increase in elevation of the plinth level and additional storey of the building significantly reduced the damage of buildings and assets.

In Malawi research on physical vulnerability of building to flooding has only started to emerge. For instance, Gortzak (2021) conducted research in Karonga to predict the most vulnerable areas to floods. Buildings were classified through Machine Learning algorithms model based on wall, roof and floor materials collected from Unmanned Air Vehicles (UAV), Street view (Mapillary) and validated by Open

Street Map and household surveys. The building classification followed the National Statistical Office (NSO) 2008 classification criteria (permanent, semi-permanent and traditional /thatched buildings). The physical vulnerability results show that there was high correlation between flood depth and damage of buildings. The expected damaged of traditional, semi-permanent and permanent buildings at the inundation depth of 1.5metres was expected to be l 100%, 60% and 35% damage respectively. Another study was conducted by Mwalwimba et al. (2024) also in Karonga District to obtain base line data for quantifying vulnerability of households to flood risk with buildings being classified based on the weakness or strength of the construction materials (weak, strong and very strong). Building typology and age were used to determine the households' protected-ness and resilience from flooding. The study found that building type had significant correlation with households' vulnerability to floods.

The foregoing studies suggest that different countries use different construction materials making buildings' vulnerability analysis difficult to compare. It is noteworthy all the same, that the use of models has the disadvantage of predictions that have uncertainties resulting in compromised accuracy (Papathoma-Köhle et al., 2012).

3.0 Methodology

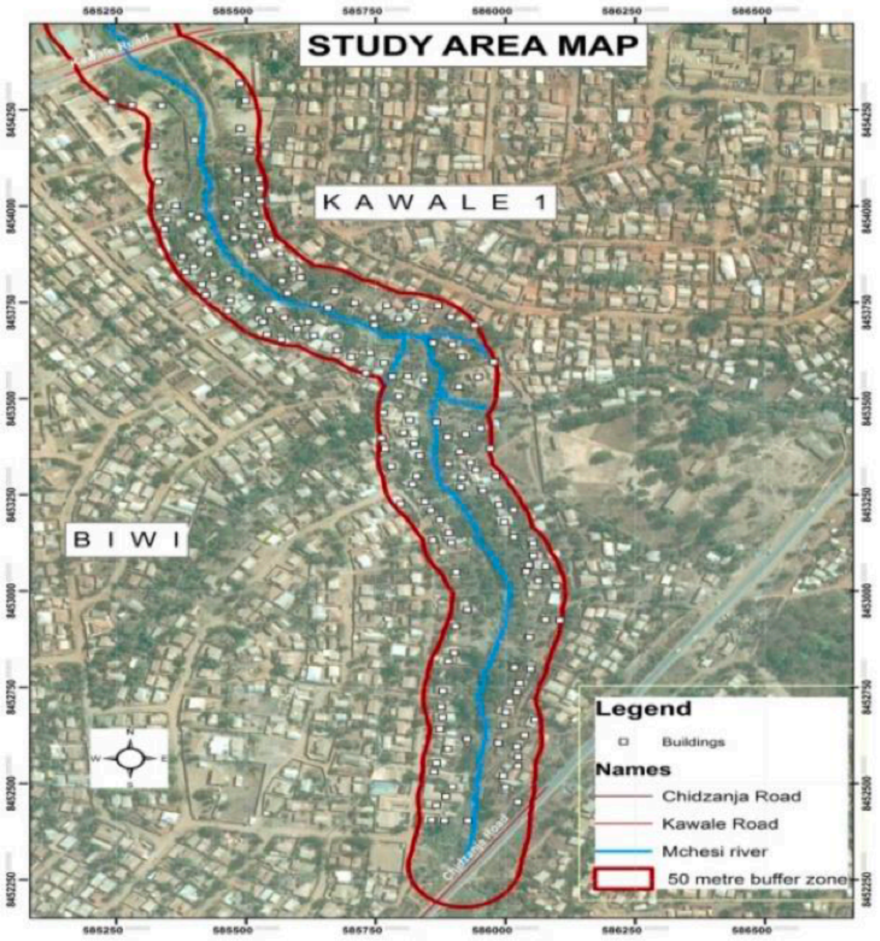
The study adopted a mixed method approach where both qualitative and quantitative methods were used to collect and analyse data. A building inventory and household interviews were main data sources.

3.1 Description of the Study site

The study was conducted in Lilongwe City (figure 1), which has, based on 2018 census, a population of 989,318 rising at 3.8% per year from 674,448 in 2008 (NSO, 2019). The study targeted two low-income settlements of Biwi and Kawale-1 and focussed on buildings within a 50-metre buffer zone along the Mchesi river, between Chidzanja and Kawale bridges (Figure 2). Stream reserves are prescribed by government departments such as the Department of Physical Planning which recommends 15 to 30m on either side of a river according its size (GoM,2014). This study used a 50 m river reserve to assess if buildings beyond the official zoning would be vulnerable to flooding. Mchesi river acts as a physical boundary between Kawale and Biwi Townships. The number of people settling on river banks such as that of Mchesi and other river reserves since the return to multi-party democracy in 1994 has been increasing (Manda 2005, p.15). The two settlements experience near annual flood events; the recent ones occurring in December 2017 and January 2019.

Figure 1: Map of Lilongwe Showing study sites (inset)

Figure 2: Biwi and Kawale1 study sites



3.2 Data Collection and Analysis

This study used building inventory, household survey, field observations and technical measurements to collect data on building characteristics, flood damage and exposure factors. The population size of buildings for the study area was not available, therefore a high resolution (0.60m resolution) Quick bird satellite image of 2016, the latest available at the time of the study, was used to digitise buildings and a total of 200 buildings were digitised for the building inventory. To account for buildings constructed after 2016 and before the 2017 flood event a physical count was also conducted and 130 buildings were identified from the 50-metre river buffer zone between Chidzanja and Kawale1 bridges. The sample sizes for building inventory and household interviews were computed using Israel's (2012) formula for infinite population size: $n = \frac{N}{1+N(e)^2}$ (where: n is the sample size; N is the population size; E is the level of precision set at 5% or 0.05). Thereafter, the calculated sample sizes were adjusted for finite population sample sizes to increase the power of statistical tests by Hoyle's (2018) formula: $na = \frac{n}{1+\frac{n-1}{N}}$ where na is the adjusted sample size, n is the sample size for infinite population size and N is the population size. Therefore, the adjusted sample sizes for building inventory and household interviews were 80 buildings and 56 households respectively. The selection criteria for the sample elements were based on Glen (2015) where the K^{th} element was computed by dividing the population by sample size (N/n) which gave an interval of 3, thus, a total of 52 interviews were conducted.

The building inventory involved observations and recording construction materials for walls, floors, and roofs; proximity to the river, measurements of foundation heights (above the ground) and geographic location (Coordinates) of buildings. Several pit latrines, kitchens and bath shelters were observed but all were excluded from the inventory for the study. Household interviews using questionnaires comprised of data on geographic location (Coordinates) of buildings, building use/function, floodwater level, flood damages on buildings and contents, and buildings protection measures (coping measures). Building typology was determined based on a combination of the construction materials for walls, floors and roofs (Sagala, 2006; Uwakwe, 2015; Fatemi et al., 2020; Blanco-Vogt and Schanze,2013). This building typology is also used during the national population and housing census (see NSO, 2019 p. 32). The study categorised the buildings based on wall and floor materials as all buildings were observed to have one type of roof material (iron sheets). The damage of building structures was described as Nothing Happened (NH), Half damage/collapse (HC) and Collapsed (C) in the household questionnaires. The description of impacts is presented in Table 1.

Table 1: Descriptions of building damage

Serial No.	Damage	Description
1.	Nothing happened (NH)	If material types of floor, wall, window, and door were not damaged due to a certain level of flood depth
2.	Half Collapse (HC)	If material types of floor, wall, window, and door got damaged from a certain level of floodwater depth and there is a need for repair
3.	Collapse (C)	If the material type of floor, wall, window, and door got completely damaged from a certain level of flood depth and needs to be replaced

Source: Adapted from Sagala (2006)

The damage grades were further assigned scales between 0 to 1, where there was no damage 0 was assigned and 1 was assigned to building collapse. Table 2 shows the description of damage and the vulnerability ratios assigned.

Table 2: Damage and vulnerability ratios

Damage Descriptions	Vulnerability class	Vulnerability Ratios
No damage	No Vulnerability	0
Slight damage	Low Vulnerability	0.01– 0.31
Moderate	Moderate Vulnerability	0.4 - 0.71
Severe/ Collapse	High Vulnerability	0.8- 1

Source: Fieldwork 2018

Figure 3: some of the Building Types in the Study Area


2019-1-11 13:50


2019-1-11 12:42

Source: field work 2019

3.3 Data Analysis Methods

Data was analysed using Descriptive statistics frequencies, Cross-tabulation and Chi-Square in SPSS 2.0 with significance of 5% ($p<0.05$); and Spatial Statistics Ordinary Least Square (OLS) regression and Spatial Analysis tools ArcGIS 10.7.2 software. The analysis was done in four stages. Firstly, descriptive statistics frequencies were applied to construction materials from building inventory and household survey data from 52 households. Secondly, cross-tabulation analysis was conducted for building materials to create building typologies and for exposure analysis. Thirdly, Chi-Square correlation test between exposure factors and flood damage on buildings was conducted; and fourthly, OLS regression analysis between physical vulnerability scales and exposure factors, and relating vulnerability scales to protection measures.

4.0 Study Results

4.1 Key elements are at risk

The results in Table 3 show that the study area was predominantly residential with 96% residential buildings. According to the Lilongwe City plan, the area was developed in line with the designated residential zoning for low-income earners where traditional housing type of buildings are permitted. In such areas households are permitted to build outside kitchen, pit latrines and bathing shelters. Whereas data on one school was unavailable, the other school had up to 165 learners.

Table 1: Building functions

Building function/use	Percentage
Dwelling house	96.2 (50)
School	3.8 (2)
Total	100 (52)

Source: Fieldwork (2018)

It was found from the building inventory and household survey that over half (58% and 50% respectively) of the buildings had fired bricks and cement mortar walls and cement floors (Table 4). This implies that most buildings in the study area were permanent as they had been constructed using durable building materials as defined by the Malawi government (NSO, 2019).

Table 4: Building types

	BI Floor Types		HHI Floor Types	
Wall Type	Cement	Earth	Cement	Earth
Fired bricks & cement mortar	58% (48)	4% (3)	50% (26)	15% (8)
Fired bricks & mud mortar	2% (2)	16% (13)	-	14% (7)
Sun-dried bricks & mud mortar	16% (13)	5% (4)	15% (8)	6% (3)

Source: Fieldwork (2018)

The buildings were categorised into classes for easy referencing. Table 5 shows the building typologies from the household survey data.

Table 2: Building typologies from household survey

Building type	Wall type	Floor type
Structure type 1	Fired bricks & cement mortar	Cement
Structure type 2	fired bricks and cement mortar	Earth
Structure type 3	fired bricks and mud mortar	Earth
Structure type 4	Sun-dried bricks and mud mortar	Cement
Structure type 5	Sun-dried bricks and mud mortar	Earth

Source: Fieldwork (2018)

4.2 Building exposure to flooding

The results on the buildings that were exposed to floods show that over 90% of buildings were inundated by one or two flood events regardless of their proximity to the river. Some of the building were those outside the officially designated stream reserve of 30m. The study also found that all buildings that were on flat terrain were flooded by either one or two flood events (Table 6).

Table 3: Exposure of buildings based on their location

		Flood inundation frequency		
Exposure Variables	Description	None	≤2 times	>2 times
Proxy to river	<30m	0% (0)	94% (29)	7% (2)
	31-50m	5% (1)	91% (19)	5% (1)
Elevation type	Flat	0% (0)	100% (14)	0% (0)
	Gentle slope	3% (1)	92% (34)	5% (2)

Source: Fieldwork (2018)

The results also show that over half (54%) of the buildings were inundated by high floodwater of over 60 centimetres (Table 6). Figure 4 shows floodwater level inside and outside of the building. Some of the buildings were damaged partly or had totally collapsed. The high number of buildings with high inundation level inside only shows that many buildings had low foundation levels which allowed floodwater to enter the buildings or protection measures like storm drains, brick fences and vegetation cover were not effective enough in reducing flood risk.

Figure 4a: Flood water level inside and outside a damaged house

Source: Field Work, 2019

Table 4: Floodwater depth inside buildings

Inundation depth	No. of Buildings	Percentage
Low (<30 cm)	11	21

4.3 Vulnerability by Type of buildings

The cross-tabulation of building typologies and the physical vulnerability ratios show that building type2 had a high percentage of buildings with high vulnerability (38%) while building type1 had highest percentage of buildings with low vulnerability (69%). The number of affected buildings in 2018 may surely have been larger.

Table 5: Vulnerability by type of building

Vulnerability Classes	Building typologies				
	type1	type2	type3	type4	type5

Low	69% (18)	50% (4)	57% (4)	63% (5)	33% (1)
Medium	15% (4)	12% (1)	29% (2)	25% (2)	33% (1)
High	15% (4)	38% (3)	14% (1)	13% (1)	33% (1)

Source: Fieldwork (2018)

4.4 Household building protection measures

Building protection and flood prevention measures including structural, non-structural and reforestation of the river reserves (van Westen, 2016) used by households in the area were identified. Structural protection measures also known as flood barricading (du Plessis and Viljoen, 1999) are employed to protect buildings from flood damage. The measures include the choice of building construction materials and foundation elevation (van Westen, 2016). The non-structural measures are applied to protect the building site/area through the blocking of floodwaters, such as drainage improvement or building water retention zones (van Westen, 2016). The non-structural measures were constructing barriers such as brick fences, terraces along the riverside, digging storm drains around the buildings, and laying sand and stone bags along the riverside to keep floodwater from entering the houses (van Westen, 2016).

Field observations also showed that several buildings had both structural and non-structural protection measures and few buildings had all three measures which made it difficult to evaluate the effectiveness of individual non-structural measures in isolation from others. None the less Table 9 shows that 57% of buildings that had employed all protection measures (structural, non-structural measures and reforested the river banks) had low vulnerability and 29% of the buildings with the same protection measures had high vulnerability. Some buildings had both structural and non-structural measures, however, 40% of them had low vulnerability and 23% had high vulnerability.

Table 6: Buildings vulnerability and protection measures

Protection measures	Buildings' Vulnerability		
	Low	Moderate	High
All measures protection measures	57% (4)	14% (1)	29% (2)
Reforestation and non-structural	0% (0)	100% (2)	0% (0)
Structural and Non-structural	40% (14)	37% (13)	23% (8)

Source: Fieldwork (2018)

4.0 Discussion

There are several factors for the vulnerability of buildings to flooding in low-income areas of Lilongwe City including the type of construction materials, their exposure to flooding, characteristics of the terrain of the surroundings of the buildings, and flood characteristics such as flood water levels. Buildings' vulnerability may also due to how they are protected from flood impacts. The analysis focused on characterisation of the elements of at risk, exposure analysis, comparison of individual building's vulnerability and effectiveness of protective measures adopted by households.

The study established from both building inventory and household survey that key elements at risk for physical vulnerability assessment were five types of residential buildings. The most prominent type were buildings constructed with fired bricks and cement mortar walls and cement floors while the least common type was built using sun-dried bricks with mud mortar and mud floors. It was observed that most of the buildings had multiple building protection measures, which may imply that the inhabitants were aware of the flood risk. Ngoma et al. (2019: p.65) found that "the use of fired bricks and cement mortars is increasing in the urban areas" possibly because of the home owners' awareness. The study revealed that over half of the buildings that had all protection measures (structural, non-structural measures and reforested the river banks) had low vulnerability. The result disagrees with Müller et al. (2011) who found that protection measures, though regarded as important by officials, were not effective in reducing the physical vulnerability of buildings to floods as there was 'no significant relation between the households that have private flood mitigation measures (e.g. walls or water gates) and households that suffered damage' (p.2116).

The study established that all buildings that were on flat terrain were flooded by either one or both flood events. In fact, almost half of the buildings were inundated with high level of floodwater of more than 60 centimetres. Sagala (2006) found that one storey buildings with low level of plinth, such as those under this study, were inundated with high levels of floodwater. This implies that floodwater had easier entry in buildings that were on the flat terrain than those that were on relatively higher ground. Although other factors such as floodwater velocity, depth, incident angle and dynamic pressure causing scouring and erosion of foundations (Postacchini et al 2019; Bignami et al, 2019; Wilk, 2018) may have contributed to the inundation of buildings, it is clear that terrain, rather than stream reserve, is a key factor. It is not surprising that almost all (over 90%) buildings were inundated by one or both flood events irrespective of their proximity to the river. Specifically, all buildings that were located within the 50-metre reserve were exposed to flooding which challenges the Malawi Land Use Planning and Development Management Guidelines and Standards which set the buffer zone (river reserve) of 15 to 30 metres on either side of rivers (GoM, 2014). Nonetheless, that citizens of Lilongwe can build houses in locations restricted by bylaws and regulations points to the difficulties of accessing 'good' land within the city, where political settlement is among key determinants (Brown et al, 2024). Furthermore, even though the study did not collect data on ancillary buildings like pit latrines, it can be mentioned that flooding could pose serious public health problems such as spread of disease like cholera for which Lilongwe is already well known (Manda, 2009; WHO, 202; Chinkaka, et al, 2024).

The comparison of vulnerability of different types of buildings suggests building type1 can be said to have low vulnerability and building type2 high vulnerability. Building type1 and type2 had the same type of walls (fired bricks with cement mortar) but had different floor materials. This would suggest that, either if soaked in water some floor materials can weaken and render the buildings vulnerable, or that there were other factors at play that increased the vulnerability of building type2. According to Kloukinas et al (2020), apart from construction materials, some factors for the high vulnerability of buildings are poor and variable construction practices including lack of skilled labour and lack of building designs suitable for areas prone to disasters triggered by natural hazards such as floods.

5.0 Conclusions

The study assessed the physical vulnerability of buildings to floods in the low-income settlements of Biwi and Kawale1 in Lilongwe City. The study concludes that though many buildings were within the 50 m river buffer zone, due to several factors, not all exposed buildings were vulnerable to flooding and this was irrespective of their locational characteristics. The typology of buildings significantly influenced their vulnerability. Building type2, that is building constructed using fired bricks with cement mortar walls and mud floors had high vulnerability while building type1, those constructed using fired bricks with cement mortar and cement floor had low vulnerability. The use of multiple protection measures such as structural, non-structural and reforestation of river reserves was more effective in reducing vulnerability of buildings to flooding than single measures. In order to reduce building vulnerability to floods, in as far as prescribing buffer zones is an essential policy direction where data availability is lacking, constructing buildings using permanent materials and incorporating protective measures, is more effective and worthy advocacy. For instance, by using flood resistant materials and raising foundations of buildings beyond 60 cm or up to 100cm above the ground can significantly reduce the vulnerability of buildings to flooding. Further research on physical vulnerability of buildings, including key elements at risks like pit latrines and bath shelters in flood prone areas, can be conducted in low-income settlements citywide and countrywide.

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