RESILIENT AFFORDABLE HOUSING FOR FLOOD RISK REDUCTION: A REVIEW OF INTERVENTIONS IN FOUR CITIES IN EAST AFRICA

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Introduction

East African countries are highly susceptible to floods caused by extreme weather events and sea-level rise. In December 2019, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) reported that intensive floods caused by extreme weather events affected a total population of around 2.8 million people in East Africa.[1] Further, OCHA recently reported that as of March 2020, roughly 1.3 million people were already affected by heavy rainfall, causing displacements, flooding, and landslides. And, institutions tracking weather patterns recorded the "highest amounts of rainfall in 40 years."[2] Both historical precedents and recent events of widespread flooding and climate change related risks accelerate the need to implement disaster risk reduction strategies. The need is urgent especially in low-income settlements placed in flood-prone urban areas around Lake Victoria and cities on the coast of the Indian Ocean. These population is expected to rapidly increase in the next three decades[3] in these regions, which are considered to be at high-risk for flooding and sea-level rise.[4]

In a collaboration between Pennsylvania State University and Engineering for Change, two Fellows reviewed and identified existing strategies and solutions for risk reduction within low-income settlements in critical flood-prone areas in four cities: Kisumu, Nairobi, and Mombasa in Kenya, and Dar es Salaam in Tanzania. A combination of desk research and expert interviews were synthesized to identify solutions, drivers, and contextual factors that enhance or discourage housing resilience (at the design and building materials level) in settlements located in flood-prone areas in these East African cities. Two questions guided the investigation:

1. What are the current technologies/strategies/actions implemented to reduce the physical vulnerability of housing in settlements affected by floods in these cities? In answering this question, the research team was able to identify different temporary or more lasting measures adopted at the individual and institutional level to cope with either riverine or wetland-type flood events.

2. What are the barriers and diffusion drivers that enhance or discourage the implementation of identified technologies/strategies/actions? These barriers and drivers will help understand what are the main challenges faced by households and local authorities and opportunities arising to improve housing resilience.

The work methodology consisted of desk research of academic publications, reports, and policy documents among other valuable documents related to flood events in these cities. To further substantiate desk research, the research team also interviewed eight experts working in different fields/sectors such as human settlement transformation and analysis, urban studies, urban planning, architecture, and climate change impact on coastal cities in East Africa.

This report presents an overview of the four cities selected for the study highlighting key geographic features, current socio economic situation, and present challenges related to flood-impact in urban areas. Furthermore, researchers present and describe a list of different solutions/measures found to addressing the physical vulnerability of houses to floods. These actions are organized by intervention level including strategies applied by households to build more resistant houses or to repair their houses after floods, building materials characteristics, and other more enduring solutions such as public infrastructure provision and relocation. The

[1] OCHA, Eastern Africa: Floods impact 2.5 million, 2019
[2] OCHA, Eastern Africa Region. Floods and Locust Outbreak Snapshot, 2020
[3] CLUVA, Climate change and vulnerability of African cities. Research briefs for Dar es Salaam,Tanzania, 2012
[4] Dawson, R., Khan, M., Gornitz, V., Lemos, M., Atkinson, L., Pullen, J., . . . Usher, L. (2018). Urban Areas in Coastal Zones. In C. Rosenzweig, W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, & S. Ali Ibrahim (Eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network (pp. 319-362). Cambridge: Cambridge University Press. doi:10.1017/9781316563878.016

report concludes highlighting systemic challenges and different issues faced at the building materials level, urban design and housing design level, planning and policy.

Overview of the Context: Four East African Cities

Within East Africa, four cities were selected to understand flood issues from multiple perspectives and geographies within the region. These cities are facing recurring flooding, which becomes less predictable but more destructive due to accelerating climate change,[5] requiring urgent attention from various stakeholders. The flood resilience solutions within these cities relies on different social, technical, and environmental factors including precipitation, geographical, public infrastructure, socioeconomic-distribution, and housing. A description of the key characteristics of each city and their current and future climate risks is presented below.

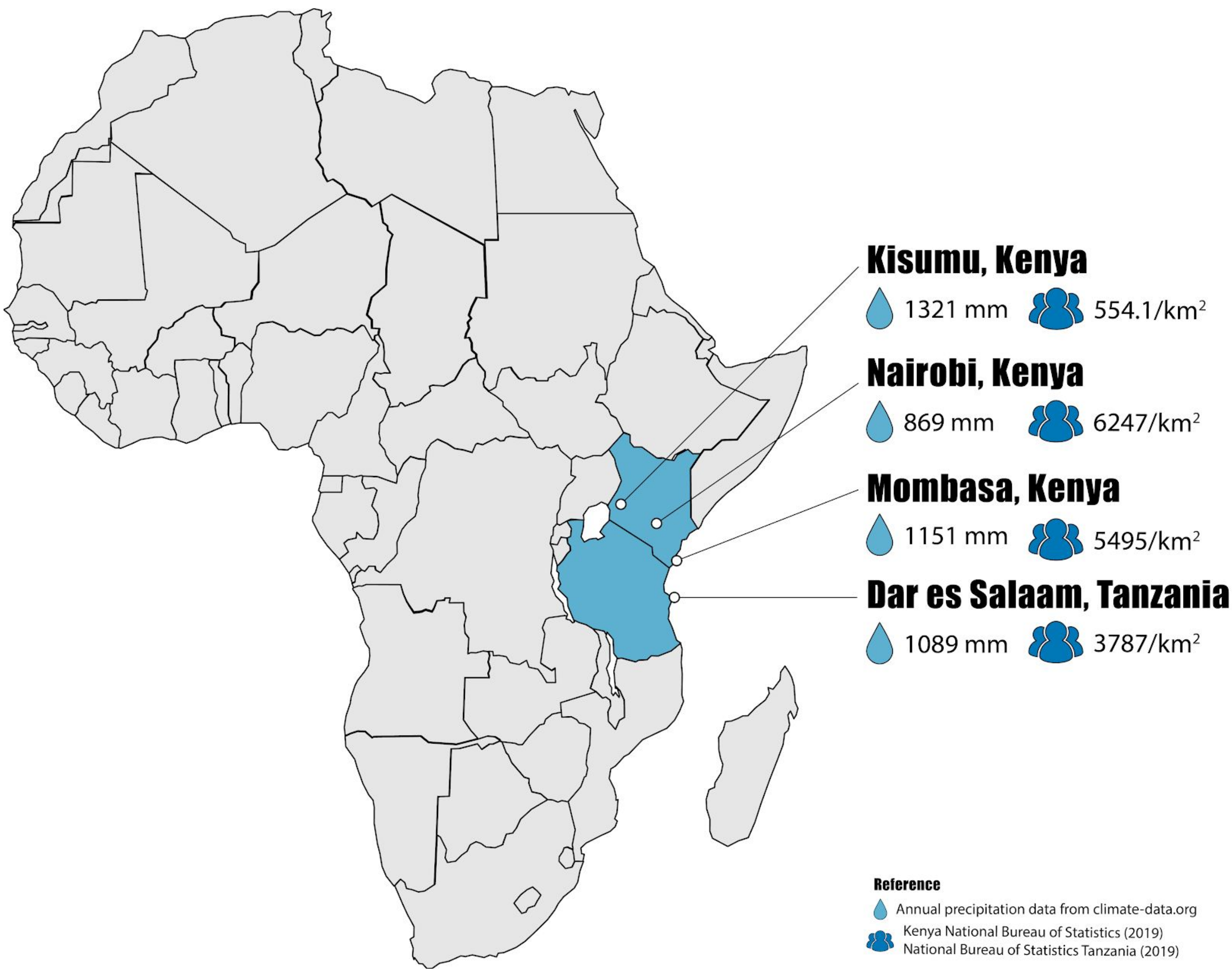

Figure 1. Geographic representation of selected East African cities. Two inland cities: Kisumu Nairobi in Kenya. Two coastal cities: Mombasa in Kenya and Dar es Salaam in Tanzania.

[5] Orindi, V. A., & Murray, L. A. (2005). Adapting to climate change in East Africa: a strategic approach (No. 117). International Institute for Environment and Development.

Dar es Salaam, Tanzania

Dar es Salaam is one of the fastest growing cities in the continent and the largest city in East Africa[6] and sits at the lower and lower-middle basin of the Msimbazi River. This proximity to the mouth of the river in the Indian Ocean increases the city's vulnerability to riverine and wetland severe flood-type risk both caused by seasonal rains and climate change effects. For example, the Tanzania Urban Resilience Program (TURP) estimated around 2 million people (~39% of the population) were affected by floods in the city in 2019 alone.[7] Increasing urbanization obstructs natural water discharge and impacts negatively (directly or indirectly) on the permeability of the urban environment.

Another factor that elevates Dar es Salaam need for a call to action to address flood-risk is related to its urban density increase.[8] Close to 30% of the city's population lives in the Msimbazi Basin and, according to recent studies by the World Bank,[9] the lower and lower-middle basins are mostly urbanized with "little room for further densification." It is also estimated that around 70% of the population lives in highly densified informal settlements. Many of the settlements characterized by lack of basic public infrastructure (e.g., roads, storm water drainage and sanitation, water and solid waste disposal, and public space) and overcrowded housing are located in flood-prone areas.

Mombasa, Kenya

The coastal city of Mombasa is the second largest city in Kenya and has suffered a history of flooding nearly every year.[10] The city district is geographically organized in five divisions that are separated by tidal creeks and channels. This geographical feature makes the city a very confined space separated by water bodies and connected by ferries and bridges. In Mombasa Island, one of the most populated divisions, the geographic situation is illustrative of the city's vulnerability to floods with roughly 94% of the island located within low-lying coastal zones, representing a high risk of flooding.[11]

Mombasa's population growth during the last decade has been driven by migration from the countryside to the city, the existence of vital infrastructure networks, and job opportunities.[12] Migration has also increased Mombasa's informal settlements population[13] and, consequently, the number of people under flood-risk impact. Current programs such as the Kenya Informal Settlement Improvement Programme (KISIP) have implemented living standards improvement projects in several informal settlements. One of the main issues addressed by this initiative (in addition to other infrastructure works) is the housing deficit which according to local officials reaches a total of 380,000 units.[14]

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[6] Dar es Salaam currently has a population of approximately 6.7 million and it is estimated it will grow at around 13.4 million by 2035. Source: Populationstat, Population in Urban Area, 2019

[7] World Bank, Tanzania Urban Resilience Program 2019 Annual Report, 2019

[8] Kigogo in the Kinondoni District in Dar es Salaam has a density of 30,164 inhabitants per km^2 surpassing Manhattan's density of 27,544 inhabitants per km^2. 48% of the district is located in flood-prone areas. Source: Dar Ramani Huria Project, Ramani Huria: The Atlas of Flood Resilience in Dar es Salaam, 2016

[9] The World Bank, The Msimbazi Opportunity. Transforming the simbazi Basic into a Beacon of Urban Resilience (Executive Summary), 2019

[10] Mombasa currently has a population of approximately 1.3 million and it is expected to grow up to around 2.3 million by 2035. Source: Populationstat, Population in Urban Area, 2019

[11] Kebede, A. S., Nicholls, R. J., Hanson, S., & Mokrech, M. (2012). Impacts of climate change and sea-level rise: a preliminary case study of Mombasa, Kenya. *Journal of Coastal Research*, *28*(1A), 8-19.

[12] UN Habitat, Financing for Resilient and Green Urban Solutions in Mombasa, Kenya, 2020

[13] The estimated number of informal settlements in Mombasa reaches 70,000. Source: Mombasa County, Land, housing and physical planning, 2018

[14] Ibid., 7

Kisumu, Kenya

Kisumu county is located in the western region of Kenya, on the eastern gulf of Lake Victoria. On the northern border, the city is adjacent to Nandi county, located 2000 meters above sea level, and on the southern border, adjacent to Kericho county, located 1140 meters above sea level.[15] Kisumu county has an area of approximately 417 km^2, where 71.2% is dry land and 28.8% is under water. Kisumu typically has long and short rainy seasons during March-June and October-November, resulting in an annual rainfall of 1245 mm. The major rivers neighboring Kisumu are Kibos, Nyamasaria, Luado and Lielango in the eastern parts and Nyangori, Muguruk, Kisian to the western part.[16] Due to those geographical factors combined with abundant rainfall, the water table, the upper boundary of saturated groundwater flow,[17] is generally high in Kisumu county, leading to flood risk.

Partly due to the materials used for housing Kisumu county, flood damage represents a financial burden for residents. In the Nyando River Basin, an example of a highly saturated groundwater area, which covers an area of 3500 km^2 in the county, more than 5,000 residents are affected during the two rainy reasons, causing annual damage of USD 850,000. The flood damage in the area can be categorized into the following: 1) loss of productive assets including house and livestock, 2) loss of household items, 3) financial loss by not having income-generating activities, 4) transport difficulties including increased transportation fare and damaged roads, and 5) destruction of agriculture, which can lead to food scarcity.[18] Regarding the housing materials in Kisumu county, it was reported in a 2005 UN report that the majority of the houses in Nyalenda are made of mud and wattle with iron sheet roofs. Such a housing type is a carry-over from rural housing and uses tin roofs, plastered/un-plastered floors, and occasional plastered mud walls. Housing rent depends on the building material type ranging from USD 2.77 (mud walled with GCI roof) to 9.23 (cement wall/floor with power). Due to high construction costs, basic amenities including toilets, power, water and security are not always fully serviceable in those rental homes.[19]

Nairobi, Kenya

Nairobi is the capital city of Kenya, and 60 to 80% of urban residents are estimated to live in slum or slum-like conditions. In the city, 73% of slum residents fell below the poverty line of USD 38 per month per adult excluding the rent.[20] Flooding is a major problem, particularly in settlements within Nairobi, where the flood risk is disseminating via the use of weak and inadequate building materials. The rapid population increase has resulted in an increase of homes built close to rivers, exposing residents to higher flood risk. The residents in slum areas have been exposed to unpredictable flood risk mainly due to climate change and local activities. For example, slums such as Mabatini in Mathare now encounter the flood risk in the places where the flood occurrence was rather infrequent two decades ago.[21]

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[15] Laji, A., Ayonga, F. D. J., & Mireri, C. (2017). The dual pathways in the process of urban development and their influence on flood damage in Kisumu City, Kenya. International Journal of Scientific and Research Publications, 7(10), 232-241.
[16] Mireri, C., Atekyereza, P., Kyessi, A., & Mushi, N. (2007). Environmental risks of urban agriculture in the Lake Victoria drainage basin: A case of Kisumu municipality, Kenya. Habitat International, 31(3-4), 375-386.
[17] Gillham, R. W. (1984). The capillary fringe and its effect on water-table response. Journal of Hydrology, 67(1-4), 307-324.
[18] Masese, A., Neyole, E., & Ombachi, N. (2016). Loss and Damage from Flooding in Lower Nyando Basin, Kisumu County, Kenya. *International Journal of Social Science and Humanities Research*, *4*(3), 9-22.
[19] Habitat, U. N. (2005). Situation analysis of informal settlements in Kisumu. Nairobi: UN Habitat.
[20] Amendah, D. D., Buigut, S., & Mohamed, S. (2014). Coping strategies among urban poor: Evidence from Nairobi, Kenya. *PloS one*, *9*(1), e83428.
[21] Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., & Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. Environment and urbanization, 20(1), 187-205.

The flood risk in Nairobi cannot be fully comprehended without considering Kibera, which is the largest slum in Kenya and considered to be the most dense slum in East Africa.[22] Kibera is about 5 km away from the central business district of Nairobi, neighboring to the Ngong River and covering 2.25 km.[2,23] Due to its high poverty level (USD 39 per person per month), the basic infrastructure and services including stormwater drainage, waste collection, water and electricity supply are lacking.[24]

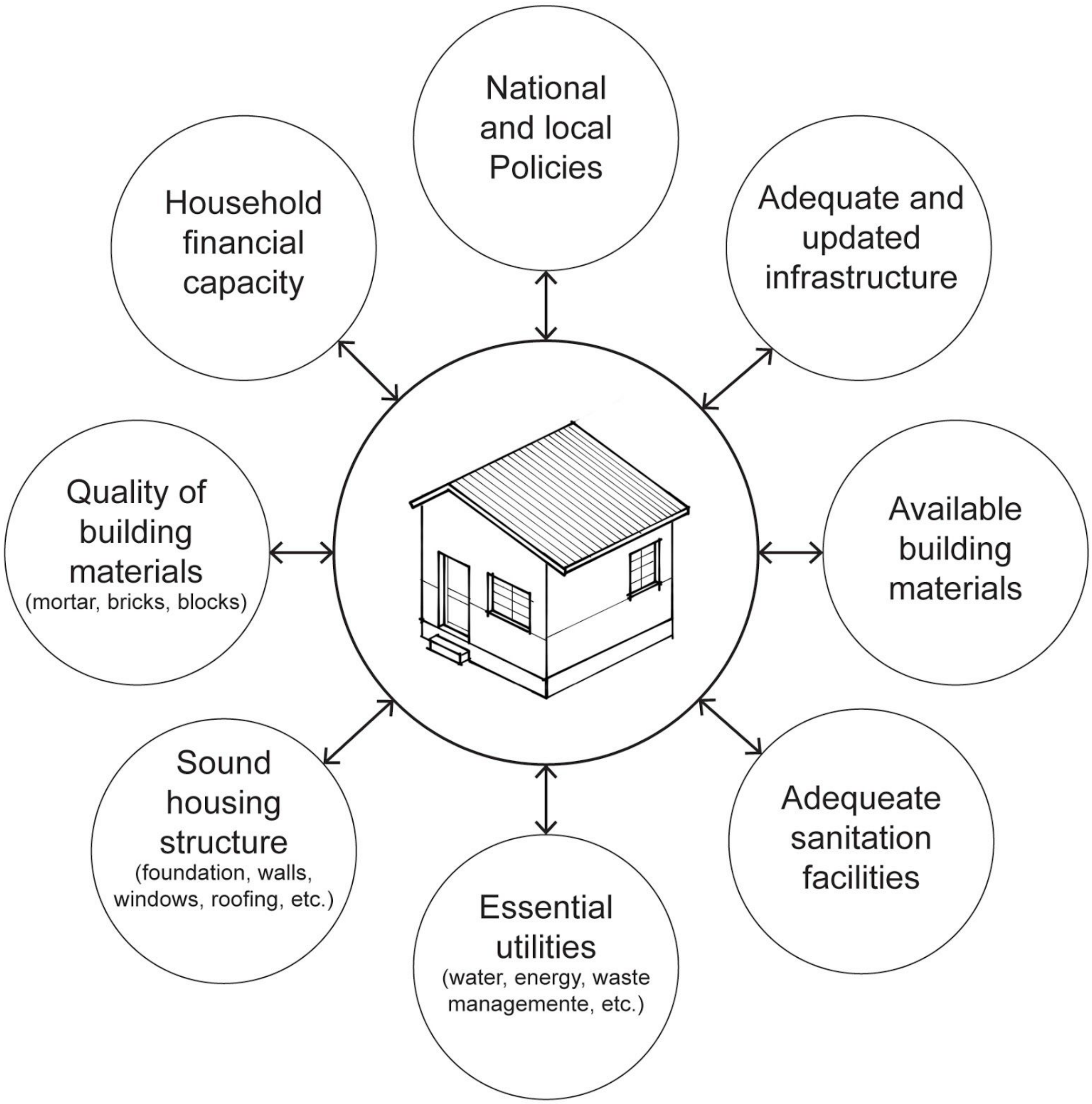

Figure 2. Factors affecting housing resilience in flood-prone areas.

[22] Skilling, L., & Rogers, C. (2017). Crime prevention and coping mechanisms in neighbourhoods: insights from Kibera, Nairobi. Crime prevention and community safety, 19(2), 103-121.
[23] Royo, M. G., Parikh, P., Mutwiri, F., Harper, J., Bukachi, V., & Mulligan, J. (2018). Using Future Scenario Planning as a tool for informed decision making on infrastructure interventions in Kibera, Nairobi in Kenya. Habitat International, 79, 30-41.
[24] Cronin, V., & Guthrie, P. (2011). Alternative approaches to slum upgrading in Kibera, Nairobi. Proceedings of the Institution of Civil Engineers-Urban Design and Planning, 164(2), 129-139.

Housing flood risk

Low-income settlements in flood-prone areas in these cities face systemic issues at different levels. Generally, rapid migration of people from rural to urban areas and lack of affordable housing forces people to settle in marginal and flood-prone areas. Prior work by a multidisciplinary and multi-level team working on Msimbazi Basin Project for Dar es Salaam, for example, highlighted that urban flood risk is driven by urbanization and deforestation, erosion and sedimentation, lack of infrastructure, inefficient urban waste dumping, and climate change effects.[25] From the housing perspective, resilience to floods relies on policy, planning, infrastructure provision, urban design, and physical structure of houses.

Planning, urban design, and infrastructure

While policy initiatives to address housing issues have been enacted, more enabling policies are needed. Tanzania, for example, enacted the Human Settlements Development Policy in 2000. Although this policy stated that the government should facilitate and provide access to housing to people who need it (including land tenure); there is an urgent need for a national housing policy that guides the development of low-income housing initiatives for urban areas, especially for Dar es Salaam.

Low-income settlements often develop organically and quickly in flood-risk areas, consequently lack of guidelines or planning often result in settlements without public space, basic infrastructure, and services elevating the risk of populations living to diseases, displacement, and economic hardship. The overall response of interviewed experts was a critical need of basic infrastructure in these settlements. Critical infrastructure in these contexts includes roads, storm water drainage, sanitation, and water and solid waste disposal. The lack of this infrastructure or the inefficiency of the existing one affect people's adaptive capacity to floods.

Although this general concern is urgent and evident, infrastructure provision seems to be a priority of national and local authorities and occupies many of the current formal and large-scale actions being implemented in these cities. The Tanzania Urban Resilience Program in Dar es Salaam and the Kenya Informal Settlement Improvement Programme are examples of this type of initiative.

Physical structure of houses

Housing resilience depends on both housing typology (layout organization) and building materials quality (e.g., permanent, semi-permanent, or temporary). Other important factors influencing housing resilience are the type of toilet (pit latrine and flash toilet, mainly), drinking water source (bore-hole, vendors, pite water, or shallow wells), solid/water waste disposal method, and housing drainage system.[26]

According to experts and academic research, houses built on plinths above flood levels, constructed using good quality building materials (e.g., concrete blocks instead or soil-cement blocks), and implemented appropriate building methods (houses built with foundations and reinforced concrete structure) are more resilient. However, there is evidence that despite these improvements, these houses are not completely safe for long-term living due to the increasing impact of floods and climate change.[27]

At the building materials level, the materials used for building houses in low-income settlements are commonly substandard and not prepared to face recurrent floods. A recurrent example found in existing research highlights sand-cement blocks made with rammed soil from the area have high porosity and do not have enough strength to endure floods, or concrete bricks or blocks that cannot withstand increasing salinity of the water.

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[25] Ibid., 6
[26] Ibid., 25
[27] Ibid., 26, 54

According to research on building materials in Tanzania, sand-cement blocks and concrete bricks or blocks are the most common building materials used in Dar es Salaam for housing construction by either low-income and high-income households.[28] One of the main challenges regarding these building materials is to maintain a certain quality that will allow them to withstand both structural loads and flooding. However, access to good quality building materials relies on income level and current socio economic levels of low-income people living in flood-prone areas forces them to build with what they can afford (re: substandard building materials that use less cement to save money or inefficient compaction methods because they cannot afford renting or buying appropriate machines).

In Dar es Salaam, housing structures that are more resistant to recurrent floods are those with elevated foundation to approximately 80 cm above ground level, and houses that include protection of walls to direct contact with water.[29] Although these are considered as effective mitigation strategies, none of them can guarantee long-term strength.

Solutions Addressing Physical Vulnerability of Houses to Flooding

The methods for addressing physical vulnerability of houses to flooding depends on different factors. Solutions and preventive measures vary widely depending on the implementing organization and the scope and scale of the intervention. The following information is a synthesis of desk research and expert interviews that organizes solutions and preventive measures at three scales. The first corresponds to housing infrastructure and superstructure describing the main components of housing construction. The second scale is building materials and describes common building elements used in housing construction emphasizing fabrication issues and durability. The third scale includes actions implemented at the urban/territory level and includes forecasting and mapping, public infrastructures, and relocation actions.

Housing infrastructure and superstructure

This category refers to solutions implemented on the physical structure of the houses below (infrastructure) and above ground level (superstructure), which includes foundations, walls, floor, roof, and the immediate surrounding of the house. Immediate surroundings include, for example, detached facilities such as toilets or pit latrines or in the yard (on the front, side, or back of the house). Measures applied on the infrastructure and superstructure of houses are commonly implemented at the household level, and depending on income level, with or without technical assistance from master builders.

Raising foundations

People living in low-income areas affected by floods in Dar es Salaam adopt different building methods to elevate their houses and alleviate flood impact. Strategies include using wood piles, building a plinth using stone or sand-cement block walls, or landfilling with rubble. While these solutions can be an effective way to mitigate flood risk, their implementation requires advance planning (e.g., the plinth is built prior to the house) and investing substantial financial resources to access both building materials and specialized labor.

As an alternative, Kikwasi and Mbuya observed that some households in Dar es Salaam prioritized raising the foundations of toilets or pit latrines first in Swahilli houses.[30] In this housing typology, toilets or pit latrines are detached from the main house and have a small area, requiring less investment. According to researchers, this

[28] Interview with Elinorata Mbuya, Dar es Salaam City Lab, September 2020, Ibid 14, 16
[29] Ibid., 3
[30] Kikwasi, G., & Mbuya, E. (2019). Vulnerability analysis of building structures to floods. International Journal of Building Pathology and Adaptation.

measure helps to avoid overflow and can allow continued use of this essential service even during floods. Potential toilet or pit latrine overflow can also have a negative impact on sanitary and environmental conditions of the house and health-vulnerability of households, motivating the implementation of this measure.[31]

Improved building techniques for foundations and walls

Housing infrastructure and superstructure affected by recurrent floods require continual repairs and structural reinforcement. Local researchers from Dar es Salaam have raised concerns about the need to improve certain building practices that might affect resistance and durability of building materials and building components in the long-term.[32] Some of these documented malpractices include the lack of proper housing foundations and lack of building materials quality control during fabrication.

According to researchers, the lack of proper foundations might have to do with the popular misconception that Dar es Salaam has "good soil conditions."[32] Consequently, houses built with foundations made of only sand-cement blocks instead of reinforced concrete suffer structural failures that drive households to implement palliative measures such as building wall buttresses to contain failures. The absence of guidelines for quality control of building materials, on the other hand, affects the way builders prepare soil-cement blocks and the outcome relies on the experience of the builder and household budget. The incorrect preparation of dosages to produce soil-cement blocks can decrease the load bearing capacity of building materials and their resistance to water, therefore making them more flood prone.

Exterior walls reinforcement and/or protection

As a consequence of both flood impact and low-quality building materials, households in Dar es Salaam are forced to build buttressing walls to reinforce existing structures. Although this measure can be efficient and cost-effective, as it requires minimal building materials, the lack of technical knowledge on how to properly build buttressing walls limits the effectiveness of this solution. For example, Mbuya documented cases of buttressing walls that failed due to improper anchorage to existing structure.[33]

Another measure adopted by households to protect exterior walls from floods includes covering the exterior side of the plinth and/or walls of the house with waterproofed materials. Materials can include corrugated tin panels used for roofing or plastering. Plastering is apparently a common technique for protecting sand-cement block walls with high porosity. However, the lack of technical knowledge for correct preparation and application of plaster leads to constant failures, according to references consulted.[34]

Building an exterior barrier around the house to protect entrance or elevate door entrance

Constructing an exterior barrier, mentioned by experts from Dar es Salaam[35] and also mentioned in a World Bank report on Mombasa,[36] may be more economically and technically accessible in the short-term than elevating the house. However, some experts pointed out that if overflow happens, this measure can create a barrier for draining water from the interior of the house when flood passes.

[31] Okaka, F. O., & Odhiambo, B. D. (2019). Health vulnerability to flood-induced risks of households in flood-prone informal settlements in the Coastal City of Mombasa, Kenya. *Natural Hazards*, *99*(2), 1007-1029.

[32] Mbuya, E., Jean-Baptiste, N., & Kyessi, A. G. (2018). Climate adaptation practices in building constructions: Progress and limitations in Dar es Salaam, Tanzania. In *Theory and Practice of Climate Adaptation* (pp. 507-520). Springer, Cham.

[33] Ibid., 1

[34] Ibid., 1, 2; Impact Human, Displacement in Dar es Salaam, 2016

[35] Ibid., 2, Interview with Priscila Izar, Dar es Salaam City Lab, August 2020; Interview with Abiy Kebede, Brunel University, 2020; Interview with Alphonce Kyessi, Ardhi University, August 2020; Mbuya 2016; Mbuya et al. 2018; Impact Human, Displacement in Dar es Salaam, 2016

[36] Ibid., 15

Another measure in this category includes piling sandbags or three logs around the house to reduce flash flood impact. According to Mbuya, if properly placed around the house, sandbags can protect the building adequately. A potential barrier for the application of this solution is access to sandbags and sand.

Pumping water outside of the property

Pumping water is an emergency and temporary measure to reduce the impact of flooding, but requires access to a reliable source of energy and the purchase of equipment, diesel, and maintenance. A local expert in Dar es Salaam has pointed out electric companies in the city might cut off energy when floods happen to avoid accidents, limiting options to diesel pumps.

Filling the soil around the house with rubble or concrete

Soil filling is implemented to control water infiltration to the walls of the house as it seals the surrounding area around the house. It works by placing rubble on the soil surface and compacting it using manual or mechanical means. The affordability of this measure can vary depending on access to raw materials and tools (rubble and tools for compaction) and it can be a costly solution if soil is covered with concrete.[37] Figure 2 illustrates a traditional Swahilli House commonly found in Dar es Salaam. The figure highlights building materials and solutions implemented by households in this type of houses.

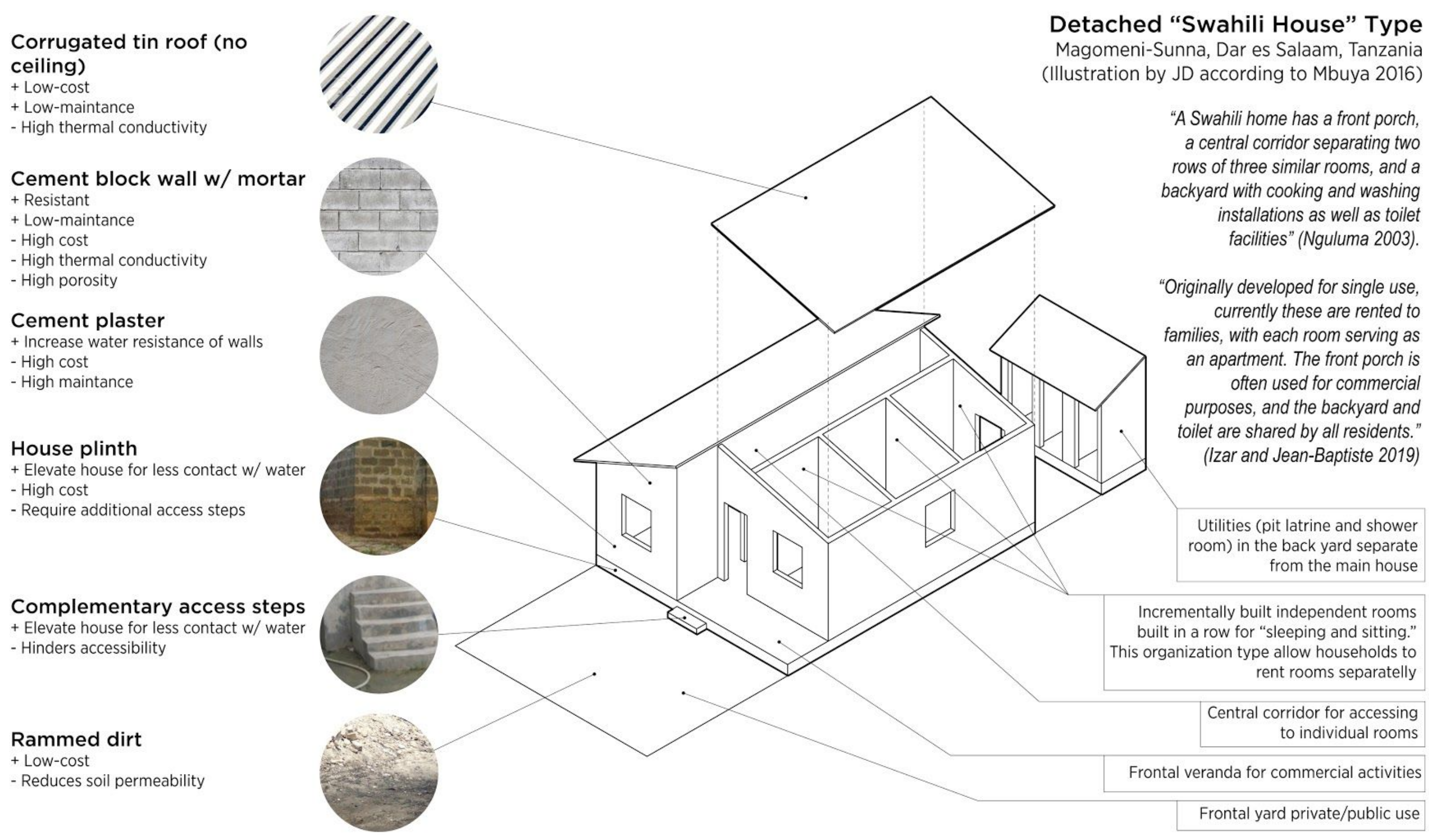

Figure 2. Adaptive measures implemented to improve the physical structure of a typical "Swahilli" house typology in Dar es Salaam, Tanzania. Illustration inspired by data from Mbuya 2016

[37] Ibid., 3

Building materials technology

Common building materials and construction technologies used in flood-prone areas include blocks made with a mix of soil-cement and water that is compacted using a press machine, soil-cement tiles, tiles made with plastic moulds, concrete door and window frames, and concrete bricks and blocks.

Soil-cement interlocking blocks made with manual press machine

Block manual press machines have been used since the late 1950 as a lower-cost method as compared to using standard building material. The National Housing and Building Research Agency (NHBRA) in Tanzania has experimented with the use of manual press machines similar to the CINVA-RAM invented in 1957 to help communities in Latin America.[38] Cited advantages of this technology includes portability, usability, and cost effectiveness, as it has an interlocking system that reduces the use of mortar therefore cement, and low-maintenance, as the machine is commonly fabricated from durable steel plates and therefore requires minimal maintenance such as cleaning and application of grease or motor oil on the gears.

The fabrication process of soil-cement interlocking blocks requires the machine,[39] cement (in smaller quantities than in conventional blocks), soil, water, workspace, and training. NHBRA has implemented the application of this technology for social housing development and educational buildings in different parts of Tanzania including Dar es Salaam.[40]

Other alternative materials explored by NHBRA in Tanzania also made with soil-cement are roofing tiles produced with vibrating-machines, roofing tiles made with synthetic fibre molds produced with recycled plastics, and door and window frames made with reinforced concrete. The first utilizes an electric machine for vibrating the mix of sand-cement and the second is made of recycled plastic that can be repurposed. The concrete door and window frame replaces wood or metal frames.[41]

Concrete bricks and blocks

The main difference between soil-cement and concrete blocks is in the aggregates, dosages, and equipment used. Concrete bricks and blocks utilize a major concentration of cement in the mix and also includes aggregates. Cement companies advise to use high-strength cement, and aggregates such as river or pit sand, coarse sand or stones of certain size, and water.[42] The mix is poured on moulding machines that produce one block at a time or several blocks at a time. Blocks production requires labor for fabrication and land for the drying process. To reduce the cost of production, the ratio of cement in the dosage can be reduced, the concrete can be mixed manually and individual molds can be used for casting blocks. One limitation in reducing the cement ratio is that it will decrease the resistance of the block. Concrete bricks and blocks are more resistant and durable than soil-cement blocks, however, the system requires more investment.

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[38] The first block manual press machine was developed by the Chilean engineer Raul Ramirez and developed within the Inter-American Housing and Planning Center in Colombia in 1957. Source: Centro Interamericano de Vivienda y Planeamiento. (1958). EL CINVA-RAM, MAQUINA PORTATIL PARA FABRICAR BLOQUES DE TIERRA ESTABILIZADA. Ekistics, 18-20.

[39] Portable block making machines can be found on sale online from around 500 USD at Alibaba.com

[40] Ministry of Lands, Housing and Human Settlements Developments, National Housing and Building Research Agency, 2016

[41] Ibid., 23

[42] Lafarge Holcim Tanzania, How to make concrete bricks and blocks, 2019

Figure 3. (A) Fabrication of interlocking soil-cement blocks; (B) Finished soil-cement block; (C) Construction made in 2000 by the NHBRA using interlocking soil-cement blocks in Tanzania; and (D) Example of a house built by the NHBRA in Chamazi, Dar es Salam. Source: NHBRA[43]

Materials selection based on flood damage assessment

A study conducted by Balesbaneh et al. in 2018 evaluated five types of typical building materials for a wall such as common brick, concrete block, steel wall panels, wood, and precast concrete framing with respect to different flood conditions[44] . The study defined that flood damage can be categorized based on structural vulnerability ranging from the minimum measure (up to 5% related to cosmetic damage) to maximum measure (up to 30% requiring repair and replacement). The vulnerability function for each material type shows both concrete block and precast concrete framing have the minimum water penetration during the flood, whereas the wooden wall has the maximum susceptibility. Moreover, a full life cycle cost assessment found that both common brick and concrete block systems have a stabilized cost for all non-flood, low-flood, and high-flood conditions. However, the cost of the prefabricated timber structure increases rapidly in the case of a flood due to its high damage susceptibility and high maintenance cost, including the replacement and transportation of new material. This study suggests that building materials have different expected flood risk and cycle cost, and common brick and concrete blocks can be a reasonable selection for raising building material resilience compared to the timber and steel frame.

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[43] National Housing and Building Research Agency, Building Materials Research, 2016

[44] Balasbaneh, A. T., Marsono, A. K. B., & Gohari, A. (2019). Sustainable materials selection based on flood damage assessment for a building using LCA and LCC. Journal of Cleaner Production, 222, 844-855.

Flood forecasting and mapping

In addition to infrastructural flood mitigation measures, flood forecasting and mapping can be implemented for risk reductionThese methods are used to understand the geographic territory affected by floods and augment resiliency through preventive actions. Examples include warning systems used in Kisumu and Kibera in Kenya and community mapping in Dar es Salaam.

Utilizing hydrometric measurements for early warning system

Hydrometric measurements can quantify water elevation and flux.[45] A well-established flood warning system can enable individuals and communities to prepare for the upcoming flood danger and to act accordingly to reduce the upcoming damage. Timely and reliable flood alerts require a systemized communication chain with substitutive measures, which includes the use of mobile and landline phones, radio communication, bells, and megaphones.[46] At Rwambwa bridge in Budalangi, Kisumu, a digital sensor measures the level of water, sends a signal to Kenya Meteorological Department headquarters to identify the possible occurrence of flooding, and then alerts the community about the floor risk via a community radio station.[47] Also, the community space in Kibera has a visual elevation gauge on the river bank, which can be functioned as an early flood warning system in the community.[48]

Community mapping for flood prevention

Mapping the territory is essential for flood prevention and planning in general. For example, the TURP developed the Dar Ramani Huria project in Dar es Salaam to map flood-prone areas in the city.[49] The action involved different stakeholders, including the academy, students, and local communities, to train and map flood-risk locations. Methods implemented in this project to create reliable maps to document the city visually included surveys, open-source mapping software, and diverse equipment types (e.g., smartphones, cameras, motorcycles, and three-wheelers). The open-access maps allow local authorities and community members to estimate the extent of flood events, organize prevention measures as mentioned in the previous subsection, and assess flood impact on the built environment.

As seen in some cases, the tool allows the mapping team to determine the causes of floods. For example, if there is inadequate drainage or improper waste dumping obstructing existing drainage systems, as it could be seen in the case of Dar Ramani in Dar es Salaam after floods in March 2019.[50] Figure 4 shows an example of the maps created by Dar Ramani Huria to evaluate assets and potential threats in Kigogo Kati in Dar es Salaam.

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[45] Mishra, A. K., & Coulibaly, P. (2009). Developments in hydrometric network design: A review. Reviews of Geophysics, 47(2).
[46] Neussner, O., Molen, A., & Fischer, T. (2008, December). Using Geoinformation Technology for the Establishment of a Local Flood Early Warning System. In the second International Conference of Geoinformation Technology for Natural Disaster Management and Rehabilitation (pp. 1-2).
[47] Otieno, S. A. (2016). A comparative study of resilience to flood disasters: a case of Kano in Kisumu county and Budalangi in Busia county (Doctoral dissertation, University of Nairobi).
[48] Interview with Charles Newman, August 6, 2020
[49] Dar Ramani Huria Project, Ramani Huria: The Atlas of Flood Resilience in Dar es Salaam, 2016
[50] Dar Ramani Huria Project, Community Flood Response Mapping and Damage Assessment, March 3rd 2019, 2019

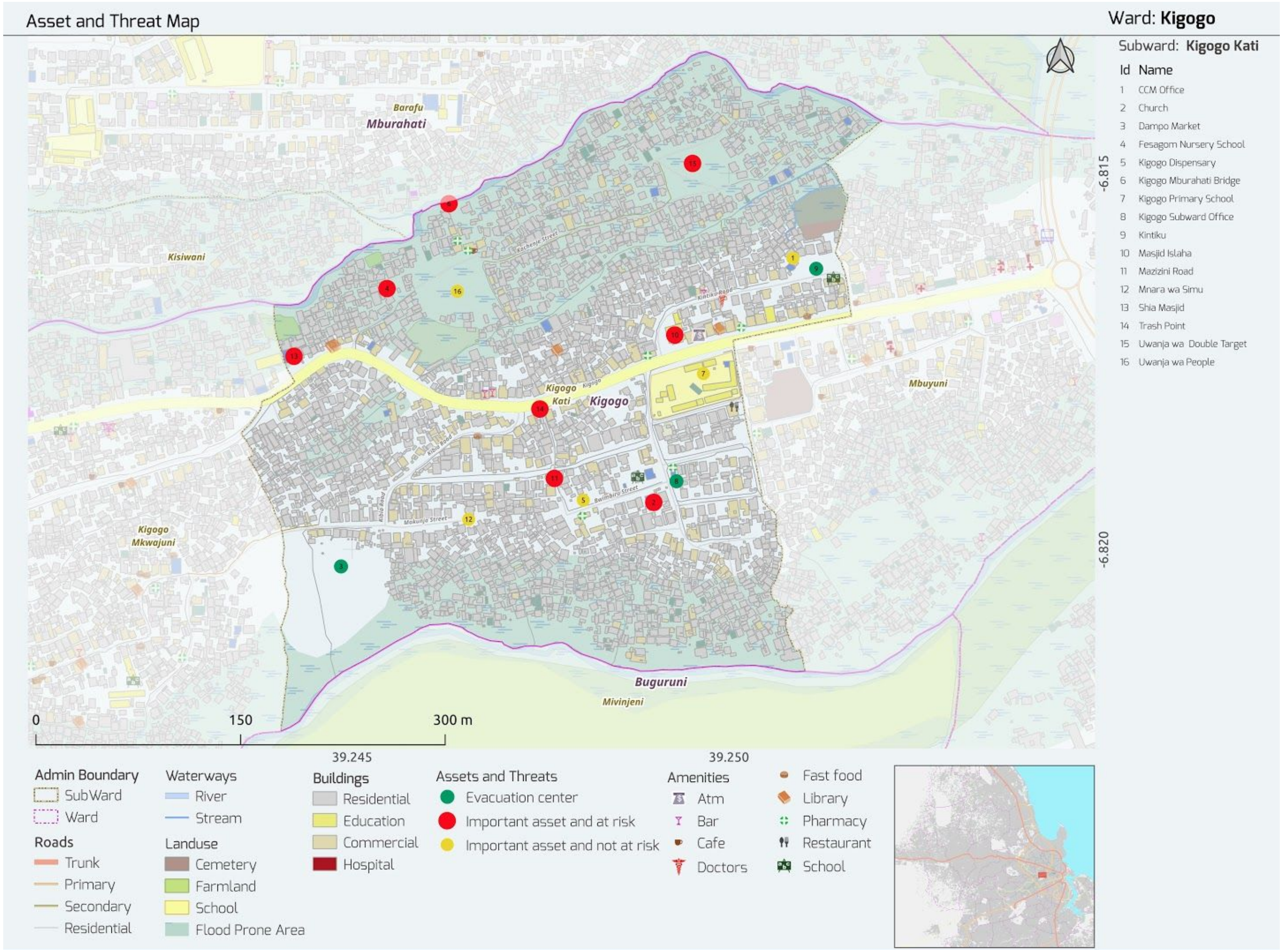


Figure 4. Asset and threat map of Kigogo Kati, part of Kigogo Ward in Dar es Salaam. Map created by Dar Ramani Huria Project. Source: Dar Ramani Huria

Hard and green infrastructure

Hard infrastructure aims to provide basic public services such as drainage systems, sanitation, opening roads, and building bridges. Green infrastructure concerns provision of public parks that can work as floodable areas when it is needed and/or green areas restoration.

Clearing, building, and/or extending water drainage systems

Inadequate infrastructure for water and storm sanitation, lack of solid waste management and infrastructure, and need of roads infrastructure are listed as some of the main drivers of urban flood risk.[51] Therefore, application of these measures can be found as a preventive strategy at the household level (clearing around the house only) or at the city or national level through large-scale plans.

An example of clearing measures as part of community action is the organization of cleaning squads with the support of local authorities in Nairobi as part of KSIP program.[52] One of the main reasons that drive people to

[51] Ibid., 2
[52] The KISIP has promoted the organization of this type of community actions as preventive measures.

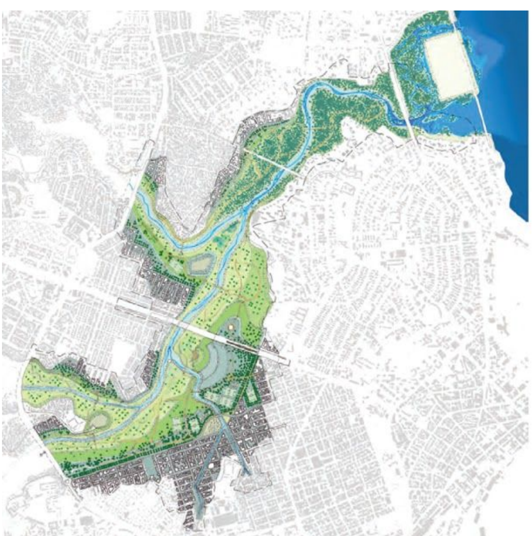
organize these squads to clear the area around their houses is waste contamination of existing drainage systems due to inadequate waste disposal.

Another example of the significance of clearing the existing water drainage system is the amount of daily waste generation. For households in Kibera, approximately 75% of the waste is organic materials, and its daily generation of solid waste ranges from 150 to 200 tonnes, which can be a direct cause that makes the water drainage system fail. However, waste collection service is a challenge in the area because of poor accessibility by vehicle and equipment.[53]

Local and national governments prioritize infrastructure provision, building and/or extending rainfall water drainage systems. This high priority can be seen, for example, in the Msimbazi transformation plan for Dar es Salaam that includes structural solutions for "enhancing water conveyance capacity."[54] These solutions include dredging certain areas and removing obstacles from the floodplain. Similarly, the Mombasa City County Integrated Development Plan prioritizes works aimed to improve water, waste, and sanitation infrastructure.

Natural ecosystem restoration

Fast urbanization processes occurring in these cities have a negative impact on natural systems through deforestation, reducing soil absorption, or by simply occupying the territory of water. Urban sprawl affects natural ecosystems by transforming originally green or low-tide areas into human settlements. Implementing strategies to restore natural areas requires extensive financial investment, technical resources, and time. With this in mind, the Msimbazi transformation plan for Dar es Salaam includes a reforestation and rehabilitation strategy for natural ecosystems with the goal of incrementing soil retention and creating public space. One of the main barriers for implementing this strategy consist of relocating people living in these areas and businesses.



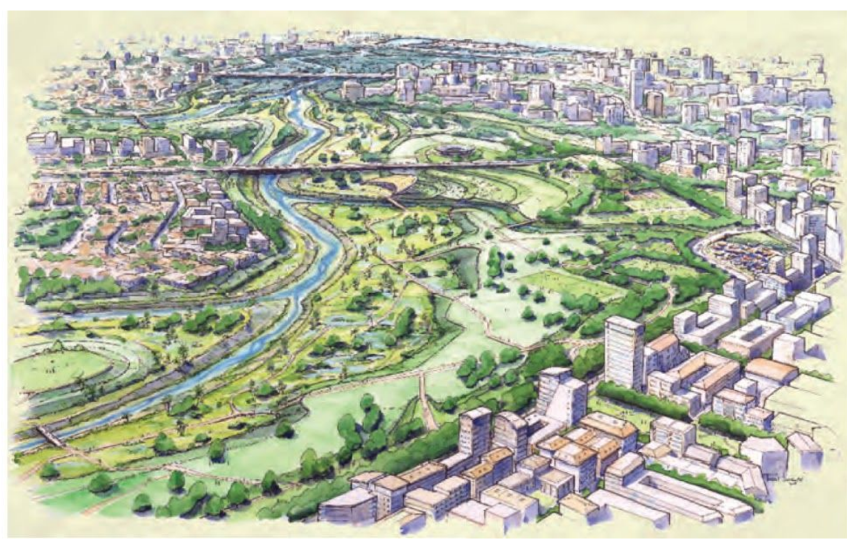


Figure 5: Ecosystem restoration plan for the lower basin of Msimbazi river in Dar es Salaam.
Source: World Bank

[53] Mutisya, E., & Yarime, M. (2011). Understanding the grassroots dynamics of slums in Nairobi: the dilemma of Kibera informal settlements. Int Trans J Eng Manag Appl Sci Technol, 2(2), 197-213.
[54] World Bank, The Msimbazi Opportunity. Transforming the Msimbazi Basic into a Beacon of Urban Resilience. Volume B Detailed Plan for the Lower Basin, 2019

Relocation, Resettlement, and Regularization

These solutions concern strategies for relocating people, whether or not they own the land, from unsafe areas (low-lying areas) to safe places (above flooding levels). Generally used only as a last resort, relocations involve extensive restructuring of the human habitat and include strategies for regularization and/or compensation.

Household resettlement

Resettlement may be considered when extensive flood risk or damage creates an uninhabitable environment The feasibility of resettlement actions, if applied at the individual household level, depends on financial capacity of households, reliability of household's social or family network, and availability of external assistance for moving to other sites. If these conditions exist, individual resettlements may be temporary. Experts interviewed have mentioned that one of the reasons people return after floods happens is because they need to be close to the city where they find job opportunities.[55]

Official plans such as the Msimbazi transformation plan in Dar es Salaam consider a resettlement strategy. This strategy includes establishing unsafe areas, compensation of identified affected households and businesses, and relocation to new and dry areas. The Msimbazi transformation plan includes the development of terraces to elevate the level of low-lying lands. These new terraces, according to the plan, will be used to relocate people in new housing developments.[56]

Relocation measures are highly complex processes that involve planning with participation of all stakeholders including community and local and national authorities. In the case of Mombasa, the Resettlement Action Plan for Kisumu Ndogo informal settlement in Mombasa County (North Mainland of Mombasa Town) concerned approximately 5000-8000 people. The process included setting mapping boundaries, built structures, socioeconomic survey, community consultations, and tenure regularization. The relocation process implemented compensation mechanisms for those affected by the process.[57]

Government subsidies for relocation

The Kenya Slum Upgrading Programme (KENSUP) was initiated by the Kenyan government and UN-Habitat to improve the life quality of slum residents through enhancing security of tenure, housing improvement, income generation, and physical and social infrastructure. Soweto East, a part of Kibera slum in Nairobi, was selected for the pilot program, based on the following selection criteria:1) good road access, 2) high ethnic diversity and economic stability, and 3) on-going social infrastructure development. One barrier to the KENSUP relocation program in Soweto East was that residents had additional financial pressure from saving the down payment, which was 10% of the cost of the new housing unit. With an average monthly income of USD 55 for a family in Kibera,[58] making the down payment for one-room unit (USD 6,000) and three-room unit (USD 13,500) may not be a viable and affordable option.[59] Therefore, the government subsidies can be considered as essential in order to successfully implement the relocation program as a part of slum improvement strategies.

[55] Interview with Priscila Izar, Dar es Salaam City Lab, August 2020
[56] Ibid., 27
[57] Mombasa County, Resettlement Action Plan: Kisumu Ndogo Informal Settlement, 2019
[58] Andrew, S. L., & Orodho, J. A. (2014). Socio-Economic Factors Influencing Pupil's Access to Education in Informal Settlements: A Case of Kibera, Nairobi County, Kenya. International Journal of Education and Research, 2(3), 1-16.
[59] Mitra, S., Mulligan, J., Schilling, J., Harper, J., Vivekananda, J., & Krause, L. (2017). Developing risk or resilience? Effects of slum upgrading on the social contract and social cohesion in Kibera, Nairobi. *Environment and Urbanization*, *29*(1), 103-122.

Recommendations and Future Work

This work summarizes the current *status quo* of flood damage reduction technologies and strategies implemented in four East African highly populated urban cities including Dar es Salaam, Mombasa, Kisumu, and Nairobi. Based on the desk research and expert interviews, we were able to identify solutions and their barriers and diffusion drivers for enhancing flood resilience adopted by different parties from individual householders to multilateral organizations. While conducting this current work, we are able to draw the following suggestions for future work to further investigate the impacts and feasibilities of those solutions:

a) Conduct interviews with local building material suppliers to understand the significance of retaining a stable supply chain especially during the reconstruction stage.

b) Conduct interviews with local builders (contractors, architects, engineers, self-builders) for further understanding of construction techniques and potential areas of innovation.

c) Combine qualitative observations with data-driven mapping data to analyze the effectiveness of the solutions.

d) Perform building material life cycle cost analysis of building materials used in those cities to find an optimal material selection.

Conclusion

This work sought to contribute to existing knowledge about resilient housing in flood-prone urban areas in East Africa by identifying current technologies/strategies/actions implemented to reduce the physical vulnerability of houses. To answer this question, the research team described different measures implemented at the household level to improve housing infrastructure and superstructure.

Overall, most of the measures cited fall into the category of low-cost technologies and low-technical skills required, mainly relying on household knowledge and income level to access good quality building materials and qualified labor. Solutions such as building walls around the house or raising steps of door entrance, for example, can be seen as measures adapted by those with less economic affluence and requiring minimal technical knowledge. On the other hand, measures such as raising house foundations require technical assistance and funds.

At the academic level, it can be seen that there is an effort to promote low-cost technologies that use local materials and manual labor to produce building materials such as soil-cement blocks and tiles. These building technologies also respond to local traditional practices facilitating social acceptance, as it is with the case of soil-cement blocks made with machines in Dar es Salaam, as an example of widespread used technology.

However, there are many barriers for implementing improvements in housing structure including financial and technical capacity. Beside structural issues such as planning and infrastructure as mentioned in this study, both financial and technical capacity of households are some of the main barriers that limit them to build more resilient houses.

To conclude, achieving resilient and affordable housing for low-income communities in flood-prone areas requires improving infrastructure services, building technical capacity for building materials quality control and construction methods, and determined leadership at all levels to organize planning and reorganization of space.

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