Knowledge, evidence
and learning for
development

Urban flood risk management in Africa

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Question

What are the main types of floods and causes of flooding in urban areas in Africa, and what factors increase flood risk in African cities (and particularly in Nigeria)? Drawing on lessons learned from Africa and Asia, what interventions are used to manage urban flood risk in developing countries, and how effective have these interventions been in terms of cost-benefit analysis, number of beneficiaries or other metrics relating to value for money?

Contents

1. Summary

The principal types of flooding that affect African cities are: fluvial or river flooding that occurs when surface water runoff exceeds the capacity of rivers and other channels; pluvial or overland floods caused by rainfall being unable to infiltrate into the ground and instead running over the land; coastal floods due to storm surges; and groundwater floods that occur when the water table in wetlands rises (Jha et al., 2012, pp. 58–63; Ouikotan et al., 2017, p. 3).

The main contributors to flood risk are: poverty, because poorer people are more exposed and vulnerable to flood risk and are more severely affected when floods do occur; poorly managed urbanisation, especially the expansion of settlements into coastal and river floodplains; inadequate solid waste management systems leading to waste blocking drainage channels; climate change impacts, especially sea level rise and increases in extreme weather events; hardening of catchment areas as expansion of built-up areas reduces the ability of rainfall to infiltrate into the ground naturally; and inadequate or poorly maintained drainage systems that are not well-maintained or have not kept up with the pace of urban expansion.

Approaches to managing flood risks include: engineered solutions such as drainage systems, dykes and other flood defences; ecosystem-based approaches such as planting mangroves; floodproofing and elevating buildings; and a range of policy interventions related to governance, land use planning and zoning, early warning systems, and solid waste management.

The literature shows that the costs and benefits of interventions vary greatly from one location to another, depending on specific local geographic, economic, and social factors as well as on specific details of project design and implementation. Furthermore, economic evaluation of flood risk management initiatives involves working with limited data, high levels of uncertainty, and assumptions about intangible and indirect benefits and costs.

Every situation is unique, and choosing appropriate interventions for a particular location is highly dependent on local context. However, based on the literature and case studies examined for this report, the following general themes can be observed (see Figure 1 below):

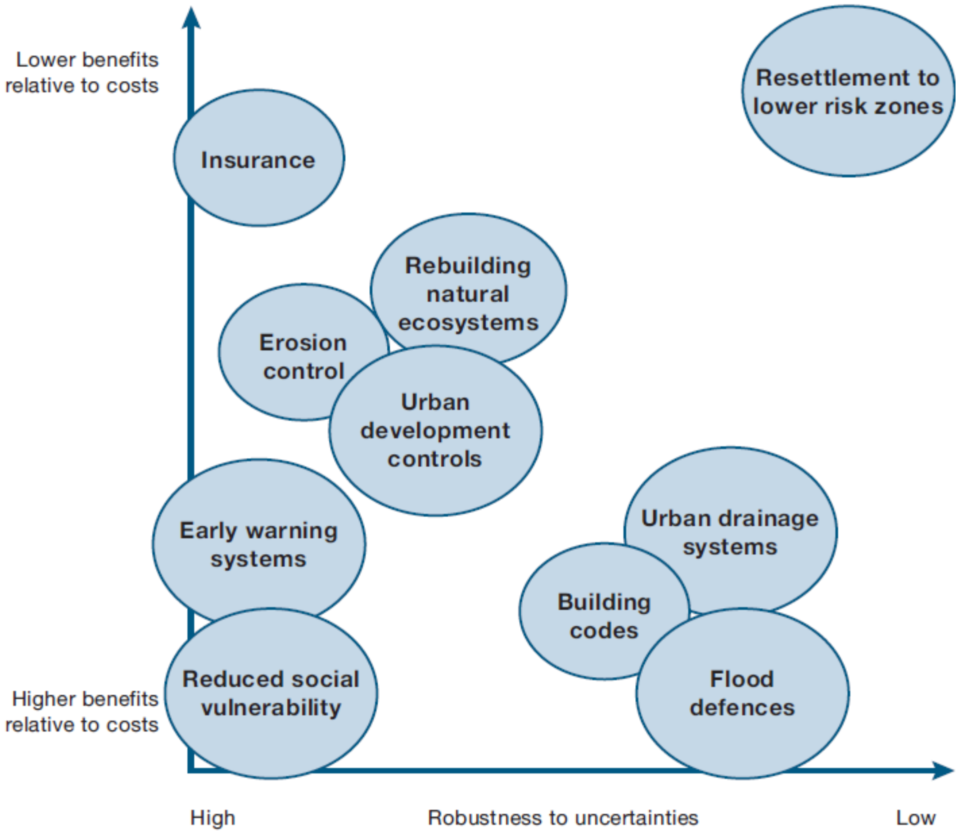
- Structural interventions such as construction of dykes and other engineered flood defences tend to have low benefit-cost ratios. They offer good protection from flooding up to the level of the dyke built, but are expensive and are only economically feasible when protecting high-value assets.
- Ecosystem-based interventions such as planting mangroves and other vegetation to provide wave and storm surge protection tends to be highly cost-effective. They do not provide complete protection from flooding, but reduce the impacts of floods and are generally cheaper than engineered structures.
- Floodproofing or elevating existing buildings tends to produce limited economic returns, but building new structures on stilts or plinths to raise them above the height of expected floods is highly cost-effective as it adds little to the cost of structures but produces significant benefits.
- Early warning systems are fairly inexpensive and are highly cost-effective, especially for frequently recurring floods.
- Regulations on land use and ecosystem protection can be highly cost-effective if enforced, but many examples demonstrate that governments are frequently unable to enforce such regulations effectively.

Figure 1: Benefit-cost ratios of interventions discussed in this report

		Benefit-cost ratio range		
		Low	High	Source
Structural interventions				
Flood diversion	Global	0.1	8.6	Hawley et al., 2012, pp. 22, 24
Dyke	Ho Chi Minh City, Vietna	0.1	0.6	Lasage et al., 2014, pp. 1446–1452
Dyke	Quelimane, Mozambique	0.2	0.2	T. A. Narayan et al., 2017, p. 30
Dams	Global	0.7	1.3	Hawley et al., 2012, p. 14
Dyke	Global	0.3	1.0	Hawley et al., 2012, p. 14
Embankment	Global	0.4	4.9	Hawley et al., 2012, p. 14
Reinforce riverbanks	Lami Town, Fiji	19.0	96.0	Rao et al., 2013, pp. 17–18
Drainage systems, clear out and build ditches	Lami Town, Fiji	28.0	140.0	Rao et al., 2013, pp. 17–18
Sea walls	Lami Town, Fiji	3.0	15.0	Rao et al., 2013, pp. 17–18
Ecosystem-based interventions				
Mangrove planting, excluding ecological benefits	Vietnam	3.1	68.9	IFRC, 2011, p. 8
Mangrove planting, including ecological benefits	Vietnam	28.9	105.0	IFRC, 2011, p. 8
Mangrove planting	Lami Town, Fiji	15.0	77.0	Rao et al., 2013, pp. 17–18
Floodplain restoration	Global	1.3	105.0	Hawley et al., 2012, p. 14
Plant riverbank vegetation	Lami Town, Fiji	29.0	146.0	Rao et al., 2013, pp. 17–18
Floodproofing and elevating buildings				
Floodproofing	Jakarta, Indonesia	0.1	1.2	Hochrainer-Stigler et al., 2011, pp. 9–11
Floodproofing	Global	0.5	8.1	Hawley et al., 2012, p. 14
Floodproofing, wet	Ho Chi Minh City, Vietna	0.3	1.4	Lasage et al., 2014, p. 1452
Floodproofing, dry	Ho Chi Minh City, Vietna	0.3	1.4	Lasage et al., 2014, p. 1452
Elevating buildings	Jakarta, Indonesia	0.6	6.7	Hochrainer-Stigler et al., 2011, pp. 9–11
Elevating buildings	Ho Chi Minh City, Vietna	0.1	1.4	Lasage et al., 2014, p. 1452
Elevating buildings before end of life, no climate	Uttar Pradesh, India	0.0	1.4	Hochrainer-Stigler et al., 2011, pp. 15-18
Elevating buildings before end of life, with climat	Uttar Pradesh, India	1.7	2.9	Hochrainer-Stigler et al., 2011, pp. 18-21
Elevating buildings at end of life, no climate	Uttar Pradesh, India	2.4	9.9	Hochrainer-Stigler et al., 2011, pp. 18-21
Elevating buildings at end of life, with climate	Uttar Pradesh, India	11.0	25.0	Hochrainer-Stigler et al., 2011, pp. 18-21
Policy interventions				
Zoning policies	USA, Canada, Netherlanc	0.6	20.2	Hudson & Botzen, 2019, pp. 6–10
Early warning systems	Global	4.0	35.0	Hallegatte, 2012, p. 16
Early warning systems	Sri Lanka	0.9	0.9	Subbiah, Bildan, & Narasimhan, 2008, pp. 12–26
Early warning systems	Thailand	1.8	1.8	Subbiah, Bildan, & Narasimhan, 2008, pp. 12–26
Early warning systems	Bangladesh	559.0	559.0	Subbiah, Bildan, & Narasimhan, 2008, pp. 12–26
Early warning systems	Tunis, Tunisia	5.0	6.0	Egis BCEOM International et al., 2011, pp. 88–89
Early warning systems	Nepal	24.0	73.0	Rai et al., 2020, pp. 5, 8
Early warning systems	Navua, Fiji	3.7	7.3	Holland, 2008, pp. 9–10
Early warning systems	Global	1.0	70.0	Hawley et al., 2012, pp. 14, 33
Preparedness	Global	3.5	24.0	Hawley et al., 2012, pp. 14, 33
Solid waste management	Accra, Ghana	1.0	1.1	Oteng-Ababio et al., 2020, pp. 28–31
Monitoring ecosystem protection	Lami Town, Fiji	300.0	1,498	Rao et al., 2013, pp. 17–18
Reduce logging	Lami Town, Fiji	407.0	2,037	Rao et al., 2013, pp. 17–18
Reduce coral extraction	Lami Town, Fiji	598.0	2,988	Rao et al., 2013, pp. 17–18
Combined programmes				
Levees and land-use changes	Ho Chi Minh City, Vietna	0.1	0.4	Lasage et al., 2014, p. 1452
Mixed approaches	Manila, Philippines	1.3	2.5	Asian Infrastructure investment Bank, 2017, pp. 16, 55
Mixed approaches	Ibadan, Nigeria	1.4	3.3	World Bank, 2014, p. 21

The findings above are supported by an analysis by Ranger and Garbett-Shiels (2011), shown below. They estimated the benefits, costs, and robustness to uncertainty of various classes of flood risk management options and suggest that the most beneficial classes of options – those shown in the lower-left quadrant of the figure below – are reducing social vulnerability, establishing early warning systems, investing in erosion control, controlling urban development, and enforcing building codes.

Figure 2: Relative benefits and costs of flood risk management options



Source: Jha et al., 2012, p. 41 (adapted from Ranger and Garbett-Shiels 2011). Permission for non-commercial use granted.

Note: Reduced social vulnerability includes: improved communications; community resource management (such as food and water); heath care, social services and social support for all; better primary education; and flood awareness raising and information (Ranger & Garbett-Shiels, 2011, p. 16).

2. Risk factors for urban flooding in Africa

Hazard, exposure, and risk

Natural hazards are naturally occurring physical phenomena that have the potential to cause harm to people, damage to property or to the environment, or economic losses, depending on how they interact with the environmental, social, and economic context in which they occur (Bokwa, 2013, p. 711). Natural hazards cause damage or loss when a population is exposed to a hazard, is vulnerable or susceptible to it or lacks protection from it, and lacks capacity to cope with its effects (Bokwa, 2013, pp. 711–713; Cardona et al., 2012, pp. 69–70). High vulnerability and exposure 'are mainly an outcome of skewed development processes, including those associated with environmental mismanagement, demographic changes, rapid and unplanned urbanization, and the scarcity of livelihood options for the poor' (Cardona et al., 2012, p. 70). Severe damage or loss resulting from the interaction of hazard, vulnerability, and coping capacity may be described as a disaster (Bokwa, 2013, pp. 712–713). A rainfall event, storm surge, or other hazard is not necessarily a problem in itself; excess water only becomes a flood when it interacts with natural and human-made environments in a negative way, causing harm to lives and property (Jha et al., 2012, p. 134).

Natural hazards: types of flooding

Six types of floods typically affect urban areas:

- **River** or **fluvial floods** occur when surface water runoff exceeds the capacity of natural or artificial channels to accommodate the flow, and the excess water overflows the banks of the watercourse and spills out into adjacent floodplain areas. They are typically a result of rainfall (sustained or sudden) or snow melt, and can be exacerbated by drainage obstructions due to landslides, ice or debris. (Jha et al., 2012, pp. 58–59)
- **Pluvial floods** or overland floods are caused by rainfall or snowmelt that is not absorbed into the ground, and flows over land before reaching a drainage system or watercourse. This often occurs in urban areas where the ground is covered by hard surfaces such as buildings and roads, reducing the ability of water to infiltrate into the ground. Pluvial floods may occur regularly in some urban areas, particularly in tropical climates, draining away quickly but recurring frequently, even daily, during the rainy season. (Jha et al., 2012, p. 60)
- **Coastal floods** are inundations of the coastline by sea water due to a storm (a storm surge), or a tsunami (caused by seismic activity). In the case of a storm or hurricane, a combination of strong winds causes surface water to pile up and low atmospheric pressure produces a suction effect, raising the level of the sea under the storm. When such a storm reaches a coastline, the effect is perceived as a wave or storm surge. Coastal floods caused by tsunamis are less frequent, but can cause severe damage in low-lying coastal areas. (Jha et al., 2012, p. 60)
- **Groundwater floods** occur when the water table, which naturally rises and falls with the seasons, reaches the surface, usually as a result of a long period of sustained high rainfall or when extraction of water from an aquifer stops. Rising groundwater levels can cause flooding in normally dry land, activate flows in seasonal streams, and overwhelm natural drainage systems. Groundwater flooding can take weeks or months to dissipate, and is more difficult to prevent than surface flooding. (Jha et al., 2012, p. 61)

- **Flash floods,** in which floodwater rises very swiftly, are usually caused by heavy rainfall or the sudden release of water from an impoundment created behind a dam, landslide, glacier or ice-jam. Impermeable ground and steep slopes make flash floods more likely; urban areas are notably susceptible because of the high proportion of impervious surfaces where runoff occurs very rapidly. (Jha et al., 2012, pp. 62–63)
- **Failure of artificial systems** such as a burst dam, pipe, or channel can also cause sudden flooding (Jha et al., 2012, p. 62).

West African coastal cities are particularly at risk of (Ouikotan et al., 2017, p. 3):

- fluvial flooding, since they are typically located in low-lying areas of lower reaches of rivers;
- coastal flooding, due to storm surges and tidal effects;
- pluvial flooding, which occurs mainly due to inadequate drainage network capacity; and
- groundwater flooding, which occurs when the water table in wetlands that surround urban areas rises and infiltrates into houses.

Exposure and vulnerability factors

The following are the principal factors that increase exposure, vulnerability, and risk in the context of urban flooding; their significance will of course vary from one city to another.

- **Poverty** leads people to suffer increased exposure and vulnerability to flooding, and increased impacts from flooding. Poorer people often live on low-value land, in risky areas where they are more exposed to hazards (including frequent, low-intensity hazards), receive less protection from public infrastructure and services, live in more fragile dwellings, and have fewer resources to invest in disaster preparedness and risk reduction (Stephane Hallegatte et al., 2017, pp. 4, 26, 27, 43; Jha et al., 2012, p. 140). The impacts of natural hazards are also disproportionately higher for poorer people because their savings are less diversified and more vulnerable to physical damage, they often receive less support to cope with and recover from shocks (Stephane Hallegatte et al., 2017, pp. 44, 51), ‘their livelihoods depend on fewer assets, their consumption is closer to subsistence levels, they cannot rely on savings to smooth the impacts, their health and education are at greater risk, and they may need more time to recover and rebuild’ (Stéphane Hallegatte et al., 2018, p. 4). The monetary value of damage to assets and losses to economic production does not fully reflect the impacts on people’s well-being (Stéphane Hallegatte et al., 2018, p. 4).
- **Poorly managed urbanisation**, especially the expansion of unplanned and informal settlements into coastal and river floodplains lacking adequate housing, infrastructure, and service provision (Jha et al., 2012, pp. 21–23). Where laws and regulations exist to control construction, they are often not enforced due to economic or political factors, or capacity or resource constraints, which leads to development in at-risk areas and obstructions to the natural flow path of water (Jha et al., 2012, p. 58).
- **Inadequate solid waste management systems** are a widespread contributor to flood risk in cities across Africa, Asia, and Latin America as solid waste is frequently responsible for blocking drainage channels and filling floodwater retention ponds (Jha et al., 2012, p. 350; Lamond et al., 2012). In most cities in Nigeria, solid waste is routinely dumped into drainage channels where it creates resistance to the flow of water in the

channel and may become trapped at bridges and culverts, causing overspilling of flood waters (Egbinola et al., 2017, p. 551).

- **Climate change** is likely to lead to increased flooding through rising sea levels, increased frequency of storms leading to more frequent storm surges, increased drought in some locations which can lead to land subsidence; changing precipitation patterns which are generally expected to lead to more extreme weather events, and mountain snow melt (Jha et al., 2012, pp. 24–25, 97–98).
- **Hardening of catchment areas** is a common problem in all urban areas as the ground is covered by buildings, roads, and other impermeable surfaces, preventing water from infiltrating into the soil and causing it to run off into drainage systems and waterways and increasing the chance of pluvial and flash floods (Jha et al., 2012, p. 229).
- **Inadequate or poorly maintained drainage systems** are common in cities in developing countries, where drainage infrastructure is often old, investment in additional flow capacity has not kept up with rapidly-growing cities, and maintenance capacity and resources are limited (see for example Asian Infrastructure investment Bank, 2017, p. 4; Egbinola et al., 2017, p. 551).

Flood risk factors in Ibadan, Nigeria

Ibadan, the capital of Oyo State, suffers regular and severe flooding when the rivers that run through the city overflow their channels into the surrounding floodplains; the upper catchments of the Ona and Ogunpa rivers, in particular, are in densely populated areas which are highly impervious, leading to high runoff when it rains (Egbinola et al., 2017, pp. 547–549).

The principal factors contributing to flood risk in Ibadan are (Egbinola et al., 2017, pp. 550–551):

- **Dumping solid waste**: stream channels are frequently used to dispose of solid waste, especially in low-income neighbourhoods where dumping of refuse has been prohibited and residents cannot afford to pay private waste collectors; residents dump waste in drainage channels early in the morning, late at night, and during rainfall events. These wastes impede storm water flow and become trapped at bridges and culverts, causing overspilling of flood waters.
- **Narrow bridges and culverts**: most bridges and culverts were built in the 1960s and had adequate capacity at the time, but increased urbanisation leading to more impervious surfaces and reduced infiltration has greatly increased the volume of flood flows which now exceed the capacities of most bridges and culverts. Narrow bridges and culverts overflow, are easily blocked by refuse and sediment, and act as dams holding back floodwater upstream.
- **Growth of vegetation along river channels**: Most drainage channels have little or no base flow during the dry season and when it is not raining, which allows vegetation to grow, impeding floodwater flows and reducing the capacity of drainage channels.

Measures that have been attempted to reduce flood risk in Ibadan include channelising sections of some rivers, dredging river channels, rebuilding some bridges and culverts, and improving surface drainage along some major streets (Egbinola et al., 2017, pp. 551–552). The state government has also sought to remove some structures that have been built along river channels and floodplains which obstruct natural flow paths of rainwater, but with limited success (Egbinola et al., 2017, p. 552). Improvements to solid waste management including expanding collection services, providing more refuse bins, and public awareness campaigns have helped reduce the severity of flooding (Egbinola et al., 2017, pp. 552–554).

Flood risk factors in Calabar, Nigeria

Calabar (population 525,000), the capital of Cross River State, is vulnerable to flooding across 65% of the city due to its location within a tropical rainforest and close to the coast, ecosystem degradation which has led to the loss of natural protection provided by mangrove ecosystems, uncontrolled urban development, poor solid waste management leading to blocked drainage, inadequate drainage facilities, and weak governance systems (Adekola et al., 2020, pp. 841–847).

The principal factors exacerbating flood risk in Calabar are:

- **Weak municipal governance**: Plans and policies on flood risk management are absent or undocumented, there is no agency with clear responsibility and decision-making powers for flood risk management; the multiple agencies that might have roles to play lack capacity, resources, and clearly defined responsibilities; and there is no mechanism for coordinating and sharing information among relevant actors or to consider a holistic approach to flooding alongside other urban issues (Adekola et al., 2020, pp. 843–847). There is a lack of enforcement of existing planning and zoning laws that could be helpful in controlling urban development and a general disregard of environmental laws even by state agencies (Adekola et al., 2020, pp. 845–847). Government agencies have been created to address climate-related hazards including flooding in Calabar, but the result has been fragmented responsibility without clear coordination, which has ‘entrenched bureaucracy and competition… with none of the agencies taking charge’ (Adekola et al., 2020, p. 848).
- **Solid waste management**: As in many other cities across Africa and Asia, solid wastes frequently block flood drains. The consumption of sachet water has been noted as a particular challenge, although the problem is widespread across Nigeria, not unique to Calabar: where reliable sources of clean water are unavailable, people purchase purified water in sealed plastic sachets to drink, but the empty sachets are often dumped indiscriminately and contribute to the solid waste problem (Adekola et al., 2020, p. 842).
- **Unplanned urban development**: The rapid and large-scale encroachment of settlements onto low-lying wetland areas, floodplains, and across drainage lines without official planning permission or adequate infrastructure is increasing Calabar’s vulnerability to flooding; in many cases, land allocation is informal and may include state actors operating unofficially (Adekola et al., 2020, p. 842).

Flood risk factors in Kumasi, Ghana

In Kumasi, the second largest city in Ghana, flooding in the Aboabo River basin is an annual phenomenon (Jha et al., 2012, p. 140). A survey by the city’s Kwame Nkrumah University of Science and Technology indicated that residents of affected areas feel that solid waste management is the most important factor contributing to flooding, with drains and the river itself clogged with refuse; the next important cause of flooding, according to the survey, was the lack of drains in the area (Jha et al., 2012, p. 141).

The survey also demonstrated that economic factors trap many people in flood risk zones. In Kumasi, despite suffering annual flooding, 61% of respondents to the survey indicated that they could not afford the cost of moving to another place, and 10% stayed on because of proximity to workplaces or because they had their own businesses within the flood risk area (Jha et al., 2012, p. 141).

3. Integrated flood risk management

Approaches to flood risk management

Flood risk management aims to reduce risk through two broad classes of approaches, typically described as structural and non-structural, which are normally deployed together in a comprehensive and integrated strategy (Jha et al., 2012, p. 32; Kryspin-Watson et al., 2017, p. 3). **Structural measures** engage with and reduce flood hazard by creating physical and technical solutions to control and manage the flow of water; these can range from engineered structures (sometimes called 'grey infrastructure') such as flood defences and drainage channels, to more ecosystem-based measures (sometimes called 'green infrastructure') such as wetlands and natural buffers (Jha et al., 2012, p. 32). **Non-structural measures** reduce people's exposure and vulnerability to flooding and increase resilience through planning, management, and policy measures; these can include, for example, land use planning and zoning regulations, early warning systems, and other aspects of urban management (Jha et al., 2012, p. 32).

Measures used in project evaluation

Three metrics are commonly used to evaluate flood risk management projects (Hawley et al., 2012, p. 12; Shyam, 2013, p. 3):

- **Benefit-cost ratio**: a measure of the overall economic evaluation of a project, incorporating all social costs and values as well as financial returns, consisting of the total benefits divided by the total cost of implementation. A benefit-cost ratio greater than one indicates that a project produces more benefits than it costs to implement; the higher the benefit-cost ratio, the better the investment.
- **Net present value**: an estimate of the net benefit of a project measured in currency rather than in relative terms, consisting of the future value of benefits over time minus the cost of implementation. A positive net present value indicates that the project is worthwhile.
- **Internal rate of return**: the rate of growth that would be required to make an investment worthwhile, or the discount rate at which a project would break even (the net present value would be zero).

In all of these calculations, the value of benefits and costs that are expected to occur over time are adjusted by a 'discount rate' that represents the concept that a cost or benefit arising in the future is not worth as much as a cost or benefit that occurs immediately. A review of 17 cost-benefit studies on disaster risk reduction found that discount rates typically[1] range from 3% to 12% (Shyam, 2013, p. 4).

Data quality issues

Economic analysis of disaster risk reduction, especially in developing countries, involves high levels of uncertainty, working with insufficient data on hazards and vulnerability, indirect costs and benefits that are difficult to estimate (such as business interruptions, changes in crop yields, reductions in revenue from reduced tourist inflow, losses to livelihoods, and losses due to service closures), assigning financial values to intangibles, and uncertainty about the impacts of climate

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[1] The study found one outlier of 20%, but the other 16 out of 17 studies were within the 3% to 12% range.

change (Rai et al., 2020, p. 2). Data on the costs and benefits of flood risk management projects are not necessarily directly comparable, and are often difficult to obtain: data are often not reported, or are not reported in a clear and standardised way; there are variations in what cost and benefit components are included in a calculation and this is not always made explicit; they are highly dependent on local circumstances and vary over time; estimates made at the beginning of a project are not followed up with actual figures on completion; and the lifetimes of different measures are not necessarily commensurate or even stated (Aerts, 2018, pp. 1–4, 23). Most of the available evidence focused on tangible, structural investments like flood defences and drainage systems, with very little evidence available on intangible, institutional, policy, or other 'soft' investments (Hawley et al., 2012, p. 36).

Deaths, injuries, physical and mental health impacts, and trauma are often not quantified within cost-benefit analyses, or may be acknowledged qualitatively but not integrated in the financial and economic analysis (Hawley et al., 2012, pp. 2–3; Shyam, 2013, pp. 4–5). For example, a review of 17 cost-benefit studies on disaster risk reduction found that only three of the studies explicitly considered fatalities and injuries, using wildly differing financial values (USD 500,000 per fatality in Colombia, USD 57,000 in Peru, and a cost based on average daily wage rates in India) (Shyam, 2013, pp. 4–5).

Cost-benefit analyses usually do not disaggregate impacts by social and economic groups such as gender, ethnicity, race, disability, or other characteristics; they generally estimate aggregate costs and benefits but overlook how the costs and benefits are distributed (Shyam, 2013, pp. 6, 8).

4. Engineered systems and structures

Drainage and diversion

Engineered drainage systems in urban environments include surface drains and ditches, concrete channels, pipes, and culverts to drain water under gravity towards larger water bodies such as lakes, rivers, or seas (Aerts, 2018, p. 20). Flood diversion strategies include construction of upstream retention ponds, diverting floodwaters into existing estuaries and channels, and developing a polder system, which is considered an artificial retention system encircled by a dam in an upstream area (Hawley et al., 2012, p. 22). In locations where gravity flow is impractical, pumping systems may be used to drain water into larger water bodies. The capital costs of engineered urban-drainage systems are very high (Aerts, 2018, p. 20).

- **Sewer pipes** provide underground drainage routes for floodwater, and vary in cost considerably depending on size and material. Construction costs in the UK and USA have been reported from USD 215 to 453 per metre for concrete pipes (0.15 to 0.45 metres in diameter) and USD 61 to 861 per metre for metal pipes (0.25 to 2.0 metres in diameter) (Aerts, 2018, p. 20).
- **Pumping stations** may be required to move floodwater from low-lying areas and drainage channels into other channels, depending on the topography of a city and configuration of drainage channels. Costs vary between USD 0.4 and 1.7 million per m3/s of pumping capacity and are not closely linked to local labour costs; in developing countries, equipment and technical expertise may need to be imported (Aerts, 2018, p. 20).
- **Retention ponds** temporarily store water during a flood event, gradually releasing it afterwards to avoid overloading drainage systems: dry retention ponds are normally

empty and only fill with water during floods, while wet retention ponds hold a permanent pool of water (Aerts, 2018, p. 21).

A **global** review of flood risk management approaches did not find any studies reporting cost-benefit ratios for drainage works, but did identify five studies of flood diversion, showing **benefit-cost ratios between 0.06 and 8.55** (Hawley et al., 2012, pp. 22, 24).

Dykes and other flood defences

Sea dykes are designed to protect against coastal storm surges in urban areas and other areas with valuable economic assets; river dykes are designed to keep rivers within a defined channel and protect riverside development from flooding. Dykes can be built of concrete, clay, sand, or soil and are often covered with resistant vegetation or armouring material such as asphalt or boulders to protect them against erosion by waves (Aerts, 2018, p. 8). The cost of earthen or clay dykes have been reported as USD 0.1 to 0.2 million per kilometre in Mozambique, USD 0.7 to 2 million per kilometre in Vietnam, USD 4.1 million per kilometre in Laos, and USD 3.4-3.9 million per kilometre in Indonesia (Aerts, 2018, pp. 10–11).

Other types of flood defences include:

- **Floodwalls**: impervious walls made of steel or concrete; costs for a 7-metre T-wall have been estimated at USD 31 million per kilometre, and costs of temporarily deployable floodwalls have been reported as USD 6.6 million per kilometre (Aerts, 2018, p. 8).
- **Breakwaters**: structures parallel to the shore which reduce wave heights, provide shelter to a harbour, and prevent silting sediment deposition in the entrance channel of a port; costs for a breakwater in Vietnam have been reported as between USD 0.13 and USD 0.5 million per kilometre (Aerts, 2018, p. 9).
- **Rip-rap, rock armour, and rubble**: rock or other material used to protect shorelines, streambeds, bridge abutments, pilings, and other structures against erosion; unit costs for riprap protecting coastal zones has been estimated at USD 292 to 780 per metre with maintenance costs of 2-4% (Aerts, 2018, p. 9).
- **Bulkheads**: retaining walls generally made of steel or wood which stretch above and below the water surface to protect pier walls in ports and harbours, prevent soil erosion and flooding, and maintain navigation; unit costs range between USD 12.7 and 51.9 million per kilometre (Aerts, 2018, p. 12).
- **Sandbag walls**: temporary walls composed of individual bags filled with sand, often assembled during a flood event. They are effective, but time-consuming and labour-intensive. Costs for a one-metre sandbag wall in the USA are estimated at between USD 200,000 and 400,000 per kilometre (Aerts, 2018, p. 12).

An analysis of flood protection measures in **Ho Chi Minh City, Vietnam** found that building a two-metre-high ring dyke to protect a 3 km^2 residential district of the city containing 29,000 houses would be uneconomical under all scenarios considered. The cost of the project was USD 89 million, but the analysis pointed to net present values of USD -28 million to -71 million and **benefit-cost ratios of 0.124 to 0.556** (Lasage et al., 2014, pp. 1446–1452).

A cost-benefit analysis of a proposal to build a 5-km earthen dyke to protect the communities of Icídua and Mirazane in peri-urban **Quelimane, Mozambique**, found that the dyke was not financially or economically viable because the high cost of construction outweighed the economic benefit of protecting the houses in the area, which were built of mud and mangrove poles and had very low financial value (T. A. Narayan et al., 2017, pp. x, xii, 30). The analysis commented that 'the average value of the protected houses would have to increase 500 percent for the earthen dike to be financially viable' although it did not quantify and include benefits such as health and safety benefits (T. A. Narayan et al., 2017, p. 30).

A **global** review of flood risk management interventions found benefit-cost ratios in the range of **0.7 to 1.34** for dams, **0.29 to 1.03** for dykes and levees, and **0.38 to 4.9** for embankments (Hawley et al., 2012, p. 14).

Dredging and river widening

Dredging, or clearing vegetation, debris or silt from rivers, aims to preserve the capacity of the channel to carry flood flows by restoring the cross-sectional area of the channel or by reducing roughness (Jha et al., 2012, p. 207). Dredging can be done by hydraulic suction or by mechanical means using a grab or bucket (Aerts, 2018, p. 17). Environmental regulations increasingly require cleaning of dredged material and disposal in controlled areas, which is tending to increase the cost of dredging operations (Aerts, 2018, p. 17).

No cost-benefit analyses for dredging as a form of flood risk management in developing countries were found in the research undertaken for this report. In one study in the town of **Navua, Fiji**, dredging of the river mouth was undertaken to reduce the effects of flooding in the river delta in 1982, 1992, and 2006; this cost approximately FJD 2 million (USD 1.3 million) in 2006, but the 'efficiency and economic benefits' of dredging are 'only poorly understood' (Holland, 2008, p. 22).

Conversely, river widening can increase a river's cross-section while lowering peak water levels, thus maintaining or increasing the river's capacity while limiting the height of embankments, and can reduce the consequences of flooding and the probability of embankment failure (Aerts, 2018, p. 19; Klijn et al., 2018).

5. Ecosystem-based interventions

Ecosystem-based interventions, or 'green infrastructure', reduce flood risk by using natural processes and ecosystem services to retain, slow down, and divert floodwater to prevent it from overwhelming drainage systems and waterways, and to absorb and diffuse wave energy, reduce wave heights, and protect coastlines against flooding and erosion (Jha et al., 2012, p. 250; Soz et al., 2016, p. 3; WBCSD, 2017, p. 7). Ecosystem-based interventions use a wide range of approaches including wetlands, mangroves, various forms of planted buffer zones or 'bioshields', green roofs, swales[2], porous pavements, the use of 'green' materials such as wood, bamboo, and coconut nets, and more (Soz et al., 2016, pp. 1, 4). Nature-based solutions are increasingly being considered by international financing institutions, national agencies, and local stakeholders for their potential to reduce risk while often bringing other benefits; nature-based solutions can be more cost-effective than engineering solutions, can complement other infrastructure, and can often be implemented, operated, and maintained by local actors including communities and NGOs (Zangerling et al., 2020, p. 6). However, nature-based and hybrid flood protection

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[2] Shallow, broad, vegetated channels that store and convey runoff; they may be used as conveyance structures to pass runoff along to other drainage elements, and can promote infiltration where soil and groundwater conditions allow (CIRIA, n.d.).

measures can also be very complex in their planning because of the complexities of natural ecosystems (Zangerling et al., 2020, p. 7).

Ecosystem-based approaches have become increasingly recognised as both physically effective and cost-efficient in many situations: they can be less expensive to construct than engineered alternatives, are often more effective, and are typically less expensive to operate and maintain (WBCSD, 2017, p. 15). Ecosystem-based approaches include a wide range of possible interventions, but the interventions most relevant to flood risk reduction in urban areas, and the ones where the most evidence exists about costs and benefits in developing countries, are mangroves and coral reefs (Bayraktarov et al., 2016, pp. 1056–1058).

Mangroves

Mangroves are salt-adapted trees and shrubs that grow in tropical or subtropical areas (Aerts, 2018, p. 16). They protect coastlines against erosion, flooding, and sea level rise by reducing the force and height of waves, retaining sediments, and stabilising soils, and also provide a range of ecosystem benefits including food, livelihoods, carbon sequestration and climate regulation (Losada et al., 2018, pp. 5–7). Coastal mangroves reduce the height of incoming ocean waves by 31% (S. Narayan et al., 2016, pp. 4–5).

The median cost of restoring mangrove ecosystems in developing countries is approximately USD 1,771 per hectare (Bayraktarov et al., 2016, p. 1058). An analysis of seven mangrove plantation projects in Vietnam showed that mangroves could be three to five times cheaper than a breakwater for the same or better level of wave reduction (S. Narayan et al., 2016, pp. 6–7).

An analysis of a proposal to restore 22 hectares of mangroves on riverbanks and coastal floodplains to protect the communities of Icídua and Mirazane in peri-urban **Quelimane, Mozambique**, found positive financial and economic net present values under all assumptions (T. A. Narayan et al., 2017, pp. x, xii). The financial net present benefits were estimated at USD 33,165 per hectare, and the economic net present benefits (including benefits from the market values of fish, aquaculture, and apiculture, and the value of carbon sequestration) were estimated at USD 35,708 at a carbon price of zero, ranging up to USD 404,041 at a carbon price of USD 25 per tonne of CO_2 equivalent (T. A. Narayan et al., 2017, pp. xi, xii).

In **Vietnam**, the Red Cross planted 8,961 hectares of mangrove forests from 1994 through 2010 to protect shorelines, river banks, and 100 km of sea dykes at a cost of USD 843 per hectare, totalling USD 8.9 million (IFRC, 2011, pp. 3–4). The mangrove plantations have proved highly effective in reducing damage to sea dykes. In one location (Dai Hop), a level 9 typhoon in 1987 damaged three kilometres of sea dyke, requiring USD 300,000 in repairs, but another level 9 typhoon in the same location in 2005, after 835 hectares of mangroves were planted, resulted in no damage (IFRC, 2011, p. 5). Similarly, in another location (Thai Binh), a level 11 typhoon in 1996 damaged 4 km of sea dike at a cost of USD 400,000, but when another level 11 typhoon hit the same location in 2006 after 1,010 hectares of mangroves had been planted, damage was limited to 1.6 km and the cost of repairs was only USD 180,000 (IFRC, 2011, pp. 5–6). The total value of coastal community damage avoided has been estimated at USD 15 million, and indirect benefits such as improved opportunities for aquaculture have been estimated at between USD 0.3 million and 6.7 million. Mangroves also provide additional ecological benefits such as carbon sequestration, nutrient and sediment retention, biodiversity, wastewater treatment, and water supply and recharge (IFRC, 2011, p. 7). Cost-benefit analyses in five of the 166 communes where mangroves have been planted showed **benefit-cost ratios between 3.06 and 68.92** excluding ecological benefits, and ratios as high as **28.86 to 104.96** including ecological benefits (IFRC, 2011, p. 8).

A global study that included 12 mangrove restoration projects (none of which were in Africa) reported that 41% of the project showed benefit-cost ratios greater than one, and that 50% achieved some level of savings from avoided flood damage (S. Narayan et al., 2016, p. 5).

Coral reefs

Coral reefs have the potential to provide protection against coastal flooding and erosion, as empirical studies have shown that they reduce the height of incoming waves by 70% to 84%, and dissipate 97% of the total wave energy, providing a very effective first line of defence against the highest and most powerful ocean waves (Ferrario et al., 2014, pp. 2, 6; S. Narayan et al., 2016, p. 4). Coral reef projects have mostly been undertaken for the purpose of restoring habitat for sea life, rather than for flood protection, and there is limited evidence about the costs and benefits that may be achieved for flood protection (Ferrario et al., 2014, p. 5; S. Narayan et al., 2016, pp. 5–6). The most promising sites for coral reef projects are in East Africa, across Asia, and in the Americas; there is little potential in West Africa, as the natural habitats available along the West African coast are not conducive to the formation of large reefs due to ocean salinity and temperature (Ferrario et al., 2014, p. 6; Spalding et al., 2001 via ReefBase).

The cost of coral reef restoration in developing countries has been estimated at about USD 162,000 per hectare in 2010 (Bayraktarov et al., 2016, p. 1058); examples from the Maldives and Indonesia report costs ranging from USD 60 to 5,080 per linear metre of coastline, depending on the construction techniques used (Ferrario et al., 2014, p. 5).

In a global study that included 19 coral reef restoration projects (two of which were in Africa), only 5% reported achieving some level of savings from avoided flood damage and erosion damage (S. Narayan et al., 2016, p. 5).

Other examples of ecosystem-based interventions

- **Salt marshes** occur in the intertidal zone near estuaries or lagoons and reduce wave heights by 72% (Aerts, 2018, p. 16; S. Narayan et al., 2016, pp. 4–5). Creating a salt-marsh zone in front of dykes can help protect the dykes against erosion (Aerts, 2018, p. 16). In a global study that included 17 salt marsh restoration projects (none of which were in Africa), 41% reported achieving some level of savings from avoided flood damage but only 6% reported a benefit-cost ratio greater than one (S. Narayan et al., 2016, p. 5).
- **Seagrass** ecosystems are found in shallow bays, estuaries, and coastal waters; they can reduce current velocity stabilise sediment, and can dissipate wave energy and reduce incoming wave heights by 36% (Aerts, 2018, p. 16; S. Narayan et al., 2016, pp. 4–5).
- **Beach nourishment:** sub-tidal sandflats, bars, beaches, and sand dunes are natural barriers that reduce the impact of storm surges and coastal waves. Beach nourishment, or adding sand (typically dredged from the sea or rivers) to build up dunes and beaches, is an approach used to combat coastal erosion, increase protection against storm surge, increase and maintain coastal ecosystems, and enhance potential for recreation (Aerts, 2018, p. 12). The cost of beach nourishment has been estimated in South Africa and Vietnam as USD 14/m^3 and 5.6/m^3 respectively (Aerts, 2018, p. 13).

- **Sand dunes** are created by winds depositing sand on the beach and provide protection against flooding; restoration of dune ecosystems involves planting native vegetation and installing fencing to trap sand and stabilise bare sand surfaces (Aerts, 2018, p. 14).
- **Nature-based soft bank protection** methods include brush mattresses, vegetation, biodegradable geotextiles, and the use of logs or other natural materials resistant to erosive flows; costs vary between USD 54,000 and USD 978,000 per kilometre (Aerts, 2018, p. 19).
- **River detention areas**: floodwater storage ponds surrounded by a dike and located along river channels, designed to temporarily capture and hold peak river discharges when the river rises above a predetermined level (Aerts, 2018, p. 20).
- **Inland wetlands for water buffering**: creating wetlands in upstream areas enhances the capacity of ecosystems to absorb rainfall before it drains into river channels (Aerts, 2018, p. 20). The cost of restoring inland wetlands is estimated at USD 40,000 per hectare in 2007 (Bayraktarov et al., 2016, p. 1067).
- **Green roofs**, consisting of vegetation planted on flat roofs of buildings, are designed to store and evaporate rainwater to reduce the run-off peak to the sewer system. Estimates of the cost of a green roof include USD 32 to 39 per square metre in South Africa and USD 114 to 225 per square metre in the USA (Aerts, 2018, p. 21).
- **Floodplain restoration** involves restoring land adjacent to a river to its natural state and allowing the river to flood into it; this brings ecological benefits, but in cases where the floodplain has been built upon or even used for agriculture, it raises questions about resettlement and compensation (Hawley et al., 2012, p. 14). A **global** review of flood risk management interventions identified six floodplain restoration projects, which had **benefit-cost ratios of 1.34 to 104.96** (Hawley et al., 2012, p. 14).

6. Floodproofing and elevating buildings

There are three principal ways that buildings can be designed or upgraded to reduce the effects of flooding (Jha et al., 2012, pp. 254–255):

- wet floodproofing (allowing floodwater to enter buildings while minimising damage);
- dry floodproofing (blocking floodwater from entering buildings); and
- elevating buildings above the flood level.

Wet and dry floodproofing

Wet floodproofing allows floodwater to enter buildings, but aims to limit the damage to the structure and contents by locating electrical wiring and sockets higher from the ground than normal, moving high-value equipment and appliances to upper levels, fitting tiled floors that are resilient to water, and using water-resistant building materials (Aerts, 2018, p. 6; Lasage et al., 2014, p. 1448). Studies show a reduction in flood damage of 35% to 40% when wet floodproofing is applied (Lasage et al., 2014, p. 1448). The cost of wet floodproofing was estimated at USD 258 per house in one case study in Vietnam (Lasage et al., 2014, p. 1448), and USD 962 per house in a case study in Brazil (Swiss Re, 2011, cited in Aerts, 2018, p. 7). Maintenance costs are estimated at less than 1% of the initial investment [26].” (Keating et al., 2015, cited in Aerts, 2018, p. 6). In **Ho Chih Minh City, Vietnam**, wet floodproofing was found to have a **benefit-cost ratio of 0.330 to 1.444** depending on assumptions about the magnitude of sea level rise expected (Lasage et al., 2014, p. 1452).

Dry floodproofing aims to fully seal a building to prevent water from entering, by using either permanent or removeable flood shields over doors and windows, and by sealing walls with waterproof coatings, membranes, masonry, or concrete (Aerts, 2018, p. 6; Lasage et al., 2014, p. 1447). it is effective up to flood depths of about 60 to 100 cm, above which water pressure will become too great for the walls to withstand (Aerts, 2018, p. 6; Jha et al., 2012, p. 148; Lasage et al., 2014, p. 1447). Costs of dry floodproofing buildings in Vietnam have been observed between USD 500 and 9,361 per house (in 2013-2014 prices) (Aerts, 2018, p. 6; Lasage et al., 2014, p. 1448) and in Bangladesh between USD 679 and 1,300 (in 2010 prices); annual maintenance will cost about 1% to 3% of the initial cost (Aerts, 2018, p. 6). In **Ho Chih Minh City, Vietnam**, dry floodproofing was found to have a **benefit-cost ratio of 0.326 to 1.376** depending on assumptions about the magnitude of sea level rise expected (Lasage et al., 2014, p. 1452).

A case study in **Jakarta, Indonesia** examining the costs and benefits of improving the flood resilience and resistance of residential properties at an estimated cost of USD 3,100 per house (the exact floodproofing steps proposed are not described in detail) finds that under most assumptions about discount rates, the life of the structure, and the hazard level, floodproofing is not economically worthwhile. The analysis shows **benefit-cost ratios ranging from 0.07 to 1.16**, with the majority of results showing ratios less than one (Hochrainer-Stigler et al., 2011, pp. 9–11).

A **global** review of flood risk reduction measures identified eight studies of floodproofing measures (without distinguishing between wet and dry floodproofing, or between studies in developing countries and in wealthier countries) and found **benefit-cost ratios range between 0.53 and 8.07** (Hawley et al., 2012, p. 14). The authors noted that while floodproofing of homes is a low-cost intervention compared with most other flood risk reduction strategies, the cost is normally borne directly by the homeowner (Hawley et al., 2012, p. 2) which may exclude the poorest.

Elevating buildings

Elevating buildings above flood levels is usually more appropriate for new buildings than for existing ones, although it can be possible to retrofit stilts or plinths under existing buildings (Aerts, 2018, p. 4; Jha et al., 2012, pp. 255–256).

In **Bangladesh**, it has been estimated that building a house on stilts adds no more than 10% to the cost of construction; a single-storey rural house on bamboo stilts may cost USD 500 to 1,250 while using reinforced concrete stilts may cost USD 625 to 2,500 (Biswas et al., 2015, p. 5). In a case study in **Vietnam**, the cost of elevating a house by two metres by building on sand has been reported at between USD 1,544 and 3,088 per house (Lasage et al, 2014, cited in Aerts, 2018, p. 4).

A case study in **Jakarta, Indonesia** examining the costs and benefits of elevating residential properties by one metre (at an estimated cost of USD 9,345 per house) finds that the results are very sensitive to assumptions about discount rates, the life of the structure, and the hazard level. The analysis shows **benefit-cost ratios ranging from 0.61 to 6.73**, with the best results achieved with low discount rates (5%) and long timeframes (25-years) (Hochrainer-Stigler et al., 2011, pp. 9–11).

A case study looking at the feasibility of replacing existing mud or brick houses at risk of flooding with new houses raised on plinths in the Rohini River Basin in **Uttar Pradesh, India** finds that it is not normally cost-effective to replace a house before the end of its serviceable life (5-10 years for a mud house and 25 years or more for a brick house), but that when a house has reached the end of its serviceable life and must be replaced, building on a raised plinth adds little to the cost and is highly cost-effective. The case study estimates that demolishing and rebuilding an existing mud or brick house before the end of its serviceable life produces **benefit-cost ratios ranging from 0.04 to 0.36** under most combinations of assumptions, except for one combination of low discount rate (5%) and long time horizon (25 years) which produced a **benefit-cost ratio of 1.42** (Hochrainer-Stigler et al., 2011, pp. 15–18). However, when dealing with houses that have reached the end of their serviceable lives and need to be replaced regardless of flood risk, building on a plinth produces **benefit-cost ratios between 2.4 and 9.94** as long as the house is otherwise replaced like-for-like (Hochrainer-Stigler et al., 2011, p. 18). Finally, introducing the impact of climate change on flood risks leads to the replacement of most houses becoming more cost-effective, with **benefit-cost ratios ranging from 1.7 to 2.9** for existing mud houses, **11 to 20** for end-of-life mud houses, and **13 to 25** for end-of-life brick houses (Hochrainer-Stigler et al., 2011, pp. 18–21).

7. Policy interventions

Governance

Flood risk management has traditionally been oriented toward technocratic and engineering solutions, but there has been a shift towards greater emphasis on complementary solutions to more holistically reduce risk (Ziervogel et al., 2016, p. 3). Although governance thinking 'has been largely absent from flood risk management' (Ziervogel et al., 2016, p. 4) there is an increasing understanding that collaborative governance is important for providing a favourable enabling environment to support flood adaptation and include the range of stakeholders necessary to address the complexity of the social, economic, environmental and political realities (Adekola et al., 2020, p. 840; Ziervogel et al., 2016, p. 4). Integrated flood risk management should be carried out through a participatory process with coordination and negotiation among actors that include multiple levels of government, public sector companies and utilities, meteorological and planning institutions, civil society, non-governmental organisations, academic and research organisations, and the private sector. It is essential to understand the capacities and incentives of these actors, including how they choose or are able to use their own limited resources under high levels of uncertainty (Jha et al., 2012, pp. 37–39; Ziervogel et al., 2016, p. 2). In addition to economic impacts that can be quantified, policy makers must also consider non-quantifiable impacts, consider social and environmental impacts, cope with large uncertainties, balance priorities and demands for scarce resources, and come to terms with the fact that residual risks can never be completely eliminated (Jha et al., 2012, pp. 39–40).

Many developing countries have complex governance systems that need to be well understood for flood adaptation to have appreciable and sustained benefits; constructs such as flood adaptation are often based on examples and decision-making processes in high-income countries 'that often do not reflect reality in developing societies' (Adekola et al., 2020, p. 841). Countries and cities with well-performing institutions are better able to cope with natural hazards, but there is often a lack of suitable institutional arrangements and policy frameworks to support integrated and coordinated urban flood risk management. There can be mismatches between official disaster management mechanisms and what is actually needed for implementing integrated flood risk management, the roles of institutions can be poorly established or unclear, and municipal governments may lack technical capacity, funding or resources (Jha et al., 2012, pp. 39, 42). Cities with high levels of inequality and informality pose particular challenges in addressing the vulnerability of people living in informal settlements (Ziervogel et al., 2016, p. 2).

In **Cape Town, South Africa**, for example, flooding is a recurrent problem in informal settlements, due partly to biophysical conditions and settlement patterns, but also due to barriers to collaborative governance (Ziervogel et al., 2016, p. 1). Efforts to reduce flood risks and impacts have been ineffective due in part to ‘a lack of collaboration between the numerous stakeholders that affect or are affected by flooding’ including ‘residents of flood-prone areas, those tasked with installing drainage channels and those managing the provision of emergency shelter’ (Ziervogel et al., 2016, p. 2). Four constraints to collaborative urban flood risk management have been identified in Cape Town (Ziervogel et al., 2016, pp. 13–16):

- the domination of a technocratic approach (partly attributed to the dominant mentalities within departments and partly to the institutional structure);
- a lack of capacities (including staff numbers, skills, and legal and institutional frameworks);
- difficulty sharing the responsibility of managing flood risk across departments and with residents; and
- high levels of political contestation around land development and finance and a lack of long-term planning despite general agreement on the nature of appropriate solutions.

In **Senegal**, urban flood risk management efforts have not proven effective and sustainable, notably in peri-urban areas of **Dakar** which are experiencing uncontrolled urban growth reducing the permeability of ground surfaces, increasing levels of rainfall, and lack of investment in infrastructure and services (Schaer et al., 2018, pp. 243–244, 253). Lack of improvement in flood risk management despite the deployment of multiple initiatives over the past fifteen years has been attributed in part to three governance issues: ‘First, the political and personal appropriation of flood management processes is found to be a practice creating a culture of rumours, distrust and apathy among the actors involved in flood management. Secondly, the reinforcement of the existing dichotomy between central government and decentralized municipalities, where party politics is used strategically to marginalize peripheral actors from the opposition, has reduced the resources applied to flood management. Lastly, a fragmented institutional framework with overlapping institutions, duplicate mechanisms and an ongoing “negotiation” of competencies and interpretation of mandates has limited the impact of flood management in Senegal’ (Schaer et al., 2018, p. 253). The availability of international funds for flood responses has attracted ‘a wide array of competing actors and institutions’ (Schaer et al., 2018, p. 244).

In the time available for this report, it was not possible to identify any programmes of governance interventions aimed at flood risk management with cost-benefit analyses.

Land use planning and flood zoning

Land use planning and the regulation of new development are important tools for managing urban flood risk (Jha et al., 2012, p. 35). Flood risk increases when urban growth compromises natural drainage and storage areas, increases impervious cover, reduces the infiltration capacity of soils, and leads to informal construction of settlements in flood-prone areas without resources and social networks to mitigate the impacts of natural hazards (Kryspin-Watson et al., 2017, p. 3). Land use planning is “the process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses” (UNISDR, 2009, cited in Kryspin-Watson et al., 2017, p. 4). Land use planning seeks to reduce flood risk and maximise economic and recreational benefits and ecosystem services through principles of safe location, safe construction, and safe activities: controlling the location type, density, and timing of development; reducing bad design and construction and promoting construction that is adapted to coping with floodwater; and controlling appropriate land uses and economic activities (Kryspin-Watson et al., 2017, pp. 4–5).

Land use tools used to manage flood risk include spatial plans to guide land use based on flood risk assessments; regulatory instruments such as zoning (to designate floodplains or open spaces) and building codes (to ensure flood-resilient structures), although enforcing compliance has been difficult; economic instruments such as land-based financing and performance incentives; and influencing community behaviour through risk communication and participatory methods (Kryspin-Watson et al., 2017, p. 2). Cities should choose a combination of land use instruments that address the type of local flood risk, are acceptable to the community, can be implemented with local resources and technical capacity, and are integrated across economic sectors, geographic scales (from local area plans to watersheds and national policies), and actors (including local government, the private sector, and civil society) (Kryspin-Watson et al., 2017, p. 23).

Planning, implementation, and enforcement of risk-based land use plans is challenging in every country in the world. Success factors include political will and citizen engagement (often in the wake of a recent flood disaster), educating decision-makers and communities about the role of land use policies in managing flood risks, building technical and governance capacity to manage planning processes, and coordinating among multiple stakeholders and formal and informal institutions (Kryspin-Watson et al., 2017, pp. 3, 23–24). In developing countries, land use plans are often complicated by informal settlement and unclear land tenure, as well as by lack of capacity and resources (Kryspin-Watson et al., 2017, p. 3).

It is widely acknowledged in the literature that in Sub-Saharan Africa and especially in West Africa, laws and guidelines for land planning and management are diverse and uncoordinated; urban planning policies have been weak and unable to prevent settlements in low-lying areas, floodplains, and wetlands (Ouikotan et al., 2017, p. 4). In **Kenya**, for example, national policy designates a 6 to 30 m zone along riverbanks within which all permanent structures are deemed illegal, but this has proven unenforceable and many people have settled in this zone within informal settlements such as the Kibera settlement in Nairobi; one estimate in 2009 suggested that enforcing this policy would require evicting 137,000 people (Mulligan et al., 2016, pp. 271–273, 276). In **Calabar, Nigeria**, rapid and large-scale encroachment of settlements onto low-lying wetland areas without planning permission has increased vulnerability to flooding; in most cases the process of land allocation is informal, with traditional authorities and even state authorities acting outside the formal (legal) process (Adekola et al., 2020, p. 842). Similarly, development on floodplains and other wetland areas is a major flood risk factor in Ibadan, Nigeria, where data from the Oyo State Government in 2011 showed 26,553 buildings within the approved statutory setback of rivers and streams (Egbinola et al., 2017, p. 551).

A 2019 study attempted to identify cost-benefit analyses of flood zoning policies from anywhere in the world using a systematic literature search, and after reviewing 445 published reports related to zoning policies, identified only nine reports that provided benefit-cost analyses, all of which analysed cases in the USA, Canada, or the Netherlands (Hudson & Botzen, 2019, pp. 2–4). Most of these studies showed benefit-cost ratios ranging from a low of 0.61 (for one study that did not consider environmental benefits) up to a maximum of 20.2; the average across all of these case studies was 3.9 (Hudson & Botzen, 2019, pp. 6–10). The authors conclude that zoning policies tend to have positive outcomes in cost-benefit terms when both financial and environmental impacts are considered, but note that many of the studies they reviewed did not account for the full range of potential costs (or in some cases, benefits). They note that the literature on cost-benefit analysis of zoning and land-use policies for managing flood risk is limited, possibly because of the complexity of jointly assessing environmental, social, and economic impacts of a change in land-use and providing monetary values for both market and non-market impacts (Hudson & Botzen, 2019, p. 17).

Early warning systems

Early warning systems give advance notice of an impending flood, allowing people time to make preparations such as moving property to a safe location, setting up temporary floodproofing measures such as blocking doors and windows, shutting off or making safe equipment and systems that could be damaged, preparing emergency response measures, and undertaking traffic control measures (Jha et al., 2012, pp. 387–388). It is widely acknowledged that early warning systems are an important part of disaster risk reduction and many global and regional studies have shown them to be effective in reducing casualties and saving property (Rai et al., 2020, p. 2). However, quantifying the benefits of early warning systems is difficult, and there is limited evidence available about the costs and benefits of flood warning systems (Rai et al., 2020, p. 2).

Early warning systems are made up of four elements (Jha et al., 2012, pp. 389–390):

- Detection of conditions likely to lead to flooding, such as intense rainfall, prolonged rainfall, storms or snowmelt;
- Forecasting how conditions will translate into flood hazards using modelling systems, pre-prepared scenarios or historical comparisons;
- Warning via messages that are relevant to the locality and recipients, and broadcasting these warnings as appropriate;
- Responding to the actions of those who receive the warnings based on specific instructions or pre-prepared emergency plans.

A study of flood risk management in four West African cities (Dakar, Accra, Cotonou, and Lagos) concluded that ‘early warning schemes have not yet worked properly as flood damage reduction measures’ (Ouikotan et al., 2017, p. 6). Early warning systems have been established with support from international agencies but ‘in most cases, after the lifetime of projects, the system fails due to lack of maintenance’ (Ouikotan et al., 2017, p. 6). The data, models, and expertise necessary for flood risk assessment and forecasting are typically lacking (Ouikotan et al., 2017, p. 8).

A **global** study by the World Bank suggests that upgrading hydrometeorological information and early warning systems across all developing countries to the same standards as high-income countries could save between USD 300 million and 2 billion per year of asset losses, save an average of 23,000 lives per year, and produce USD 3 to 30 billion per year in additional economic benefits (Stéphane Hallegatte, 2012, p. 2). Achieving these benefits would require investment in local observation systems; local forecasting capacity; increased capacity to interpret forecasts and translate them into warnings; communication tools to distribute and disseminate information; data, and warnings; and institutional capacity building and improving decision-making capacity on the part of the users of the information produced. However, some of the most expensive components of early warning systems (such as earth observation satellites and global weather forecasting systems) so the additional investments required are estimated at around USD 1 billion per year, leading to **benefit-cost ratios between 4 and 35** (Stéphane Hallegatte, 2012, p. 16).

A study by the Asian Disaster Preparedness Center for the World Bank produced cost-benefit assessments of several country-wide early warning systems, with widely-varying results (Subbiah et al., 2008, pp. 12–26). In **Sri Lanka**, the authors estimated benefits in the form of avoidable flood damage across five districts in the southern part of the country valued at USD 1.62 million over ten years against estimated costs of operating an early warning system of 1.75 million over the same time period, for a **benefit-cost ratio of 0.93**, indicating that in this case, the early warning system was not economically justifiable. A similar study in **Thailand** estimated benefits of USD 9.16 million against costs of 5.2 million, for a **benefit-cost ratio of 1.76**. Most remarkably, a country-wide analysis of **Bangladesh** estimated benefits of USD 1.733 billion against costs of 3.1 million, for a **benefit-cost ratio of 559**. The latter figure is surprisingly high, although other studies have also found quite high benefit-cost ratios for early warning systems: an assessment of the European Flood Awareness System, which provides twice-daily flood forecasts across Europe, found a 'base case' benefit-cost ratio of 159, and that varying assumptions about avoided damages, discount rates, and accuracy of forecasts could produce benefit-cost ratios ranging as high as 403 (Pappenberger et al., 2015, pp. 286–287, 279).

A study of natural disaster preparedness and adaptation in cities in North Africa, which covered multiple types of natural hazards but identified flooding as the main risk in all cases, found that early warning systems are "incredibly effective investments" (Egis BCEOM International et al., 2011, p. 93), out-performing almost all of the other initiatives for which data were available. Analysis for **Tunis** indicated a **benefit-cost ratio between 5 and 6**, and in **Casablanca between 14 and 15** (Egis BCEOM International et al., 2011, pp. 88–89).

A more recent case study examining an existing early warning system protecting communities in the Karnali River Basin in **Nepal** estimated **benefit-cost ratios between 24 and 73**, depending on assumptions about income resiliency of households, availability of financial institutions, adaptation behaviours, and cost increases (Rai et al., 2020, pp. 5, 8). The results also suggest that improved forecast lead times significantly increase the benefits of early warning systems: a one-hour forecast lead time can increase benefits by 1.8 times, and two hours by 2.6 times (Rai et al., 2020, pp. 5, 8).

In **Navua, Fiji** (population 5,400), an early warning system was proposed which would provide three hours' warning of impending floods and produce benefits ranging between FJD 2.1 and 4.2 million (USD 1.3 to 2.6 million) over 20 years by reducing losses to households, businesses, agriculture and fisheries as well as reducing the cost of humanitarian relief (Holland, 2008, pp. 8–9). The early warning system, consisting of rainfall and river monitoring gauges with remote monitoring, an automatic flood forecast model to predict the likelihood and severity of flooding, and systems for disseminating alerts and warnings to emergency agencies and the public, was estimated to cost approximately FJD 0.6 million (USD 0.4 million) over 20 years (Holland, 2008, pp. 9, 22–27). The overall economic returns were estimated to produce a **benefit-cost ratio of 3.7 to 7.3** in the 'most likely' scenario, ranging from a low of 1.8 in the worst case to 10 in the best case (Holland, 2008, pp. 9–10).

Another **global** study of flood risk management interventions found that forecasting and early warning systems showed **benefit-cost ratios between 0.96 and 70** while other preparedness measures, including mobility, support from family and social networks, community grain banks, community seed banks, self-help groups, purchasing of a community boat, flood adapted agriculture, and strengthening healthcare, showed **benefit-cost ratios of 3.5 to 24** (Hawley et al., 2012, pp. 14, 33). The same study notes that early warning systems are most effective when events are frequent; an early warning system for an event that has a return period of 200 years, for example, would be unlikely to be cost-effective (Rogers and Tsirkunov, 2010, cited in Hawley et al., 2012, p. 2).

Case study: Early warning system in the Lower Karnali River Basin, Nepal

Communities in the Lower Karnali River Basin experience flooding on an almost yearly basis. Between 2000 and 2016, 1,519 houses were destroyed; 2,247 families were evacuated, and 23,130 people were affected; the estimated value of damage caused by floods was USD 879,000.

In 2010, Practical Action and the Government of Nepal incorporated an existing flood gauge station into an early warning system for the basin. When water levels at the gauge reach predetermined thresholds, warning and response procedures are triggered, providing two to three hours' warning of flood events. At the first threshold ('alert level'), community members, the police, and the army are notified through phone calls and SMS. Community disaster management committees and task forces use hand sirens, flags and megaphones to warn local populations. At the second threshold ('warning level'), the early warning system task force receives a second phone call and SMS from the gauge station and they request people to evacuate to safer places and provide assistance to vulnerable people. If the river level exceeds the highest threshold ('danger level'), a final message is communicated to evacuate and prepare for a destructive flood event.

Households report that the early warning system has reduced casualties and health issues, and enabled them to save assets ranging from food and livestock to money, personal valuables, and vehicles, valued at USD 1,083 per household. In a survey, 98% of households indicated that they would be willing to pay directly for the cost of operating the system if it were to become locally-managed, which would cost USD 0.70 per household per year.

During the floods of 2013, the early warning system proved to be effective in saving lives and property, although farmlands were still damaged. In 2015-2016, hydrological forecasts were integrated into the system to provide a probabilistic forecast that increased lead times by five hours, meaning that downstream households can now receive flood warning information as much as seven to eight hours in advance.

Source: Rai et al., 2020.

Solid waste management

Poor solid waste management is a major factor contributing to urban flooding in cities across Africa, Asia, and Latin America, and requires joint responses at the local community level and the broader municipal level, with waste management adopted as part of integrated flood management programmes (Lamond et al., 2012, pp. 1, 7–9). It is important to engage with communities, educate people and work to change individual behaviour around waste disposal and reduction, but community-based measures also need to be part of wider waste management and flood management plans with a long-term commitment from municipalities to make a permanent and scalable difference to waste dumping and flood risk (Lamond et al., 2012, p. 9).

In **Accra, Ghana**, an approach to improving waste management called the ‘camp-size model’ has been tried, in which the challenge of solid waste collection is broken down into small, manageable units such as neighbourhoods, markets, and stadiums, which are contracted out individually to service providers to undertake various sanitation duties; local waste pickers collect and transport rubbish using cargo tricycles and separate out recyclable materials (Oteng-Ababio et al., 2020, pp. 27–28). The costs of setting up the system are GHS 1.2 million (USD 204,000) per camp, with operating costs also GHS 1.2 million (USD 204,000) per year, and the benefits of a cleaner community, improved health, and reduced flooding, although indirect, were estimated using surveys to elicit residents’ potential willingness to pay for waste collection services as GHS 1.5 million (USD 255,000) per year, leading to a **benefit-cost ratio of 1.0 to 1.1** depending on the assumed discount rate (Oteng-Ababio et al., 2020, pp. 28–31).

8. Case studies of flood risk management interventions

Nacala, Mozambique

Nacala (population 250,000) is a densely built-up city located on a coastal inlet with a deep-water harbour and a busy port (Zangerling et al., 2020, p. 12). Degradation of soils and erosion are becoming an increased social, economic and environmental risk (Zangerling et al., 2020, p. 12). Contributors to flood risk include the development of informal settlements in high-risk areas without adequate drainage, removal of trees and other natural vegetation cover, industrial development across drainage lines, urban development leading to hardening of the catchments, and sandy soils and steeply-sloping terrain that increase the velocity of surface runoff and the likelihood of erosion (Zangerling et al., 2020, pp. 13–14). Stormwater infrastructure in the city is blocked by sand, rubble, and litter, and suffers from damage including theft of stones and wire from gabions, leading to overflowing drainage channels and the formation of unstable gullies that damage property and infrastructure (Zangerling et al., 2020, p. 14).

A participatory risk assessment process identified the main priorities for Nacala as reshaping and stabilising drainage channels, building service roads alongside drainage channels, reducing erosion risks, and protecting drainage channels with drought-resistant vegetation (vetiver grass or elephant grass) (Zangerling et al., 2020, p. 14). In less densely populated districts in the northern and eastern parts of the city, interventions included revegetation, soil bunds[3], lining erosion gullies with rock bags, and creating recreational areas that can serve as retention basins; in the more populated inner city, interventions included rehabilitating natural drains and streams, revegetating embankments with indigenous plant species to protect gullies from erosion, building stormwater detention ponds, and rehabilitating and improving drainage infrastructure (Zangerling et al., 2020, pp. 19–21).

The financial analysis examined revegetating 1,221 hectares of unused land, 20% of which was reserved for urban gardening, and a combination of approaches on 75 hectares that included toe-of-slope protection measures along 45 km of channels, rehabilitation of 27 km of drainage channels, and the construction of 99 retention ponds, at a total cost of USD 31 million (Zangerling et al., 2020, pp. 27–28). Benefits were estimated over a 50-year timeframe arising from erosion protection and revegetated ecosystems, including market values of agricultural

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[3] An embankment of soil, or soil and stones, constructed along contour lines and stabilised with vegetation such as grass and trees. Bunds reduce the velocity of runoff and soil erosion, retain water behind the bund, support water infiltration, support ground water recharging, and increase soil moisture. (Zangerling et al., 2020, p. 19)

produce, and the economic value of carbon sequestration was also estimated for various carbon prices; additional benefits related to quality of life and reduction of mortality and health impacts were expected but were not quantified (Zangerling et al., 2020, pp. 28–29).

The proposed measures produced a **financial internal rate of return of 1.26%**, and taking into account broader economic impacts, the measures were considered economically viable (positive net present values) under all carbon pricing assumptions including a carbon price of zero: **economic internal rates of return ranged from 2.9% to 62%** at carbon prices from zero to USD 25 per tonne of CO_2 equivalent (Zangerling et al., 2020, pp. 27–29).

Quelimane, Mozambique

The city of Quelimane (population 350,000) is located on the Zambezi delta, on the bank of Rio Dos Bons Sinais, approximately 25 km inland from the Indian Ocean. It is located close to sea level and suffers from flooding after intense rainfall, storm surges, coastal erosion, and saltwater intrusion (Zangerling et al., 2020, p. 12). The city is expanding into wetlands and floodplains, leading to hardening of the catchments, and mangrove deforestation and degradation have contributed to soil instability and erosion along the river (Zangerling et al., 2020, pp. 15–16). Drainage systems are blocked or damaged in several areas by sand, rubble and litter, causing flooding in residential and industrial areas, and the drainage infrastructure has not kept pace with urbanisation and densification and is unable to cope with the volume and velocity of runoff experienced during high rainfall months, especially during storms and cyclones (Zangerling et al., 2020, p. 16).

The cost-benefit analysis examined creating green revetments including 30 hectares of grasses, 33 hectares of mixed wetland plants, and 33 hectares of mangroves, as well as a range of structural measures including drainage systems, shore protection, retention basins, and protection bridges at a total cost of approximately USD 8.7 million (Zangerling et al., 2020, pp. 29–31). Benefits over a project lifetime of 50 years included the market value of mat weaving production and economic values of carbon sequestration; increased quality of life and reduction of mortality and health impacts were additional expected benefits but were not quantified (Zangerling et al., 2020, p. 29).

The analysis estimated the **financial internal rate of return as 19%**, and taking into account broader economic impacts, the **economic internal rate of return was at least 22%** (assuming a carbon price of zero), and up to 573% at a carbon price of USD 25 per tonne of CO2 equivalent (Zangerling et al., 2020, pp. 30–32).

Ho Chi Minh City, Vietnam

Ho Chi Minh City, in southern Vietnam, is built on the floodplain of the Dong-Nai and Sai-Gon river systems and is exposed to flooding both from rivers and from the sea, with 40-45% of the city having an elevation of less than one metre above sea level. Low-lying areas are flooded with each spring tide, and socio-economic development and urban expansion are contributing to increased exposure (Lasage et al., 2014, pp. 1441–1443).

A study focusing on a primarily residential district with 29,000 houses estimated the expected annual damage from flooding at USD 0.31 million per year, increasing to as much as USD 0.78 million per year in 2100 under various assumptions for changes in land use and sea level rise; the increase in annual damage is mostly due to the projected rate of sea level rise, which is expected to cause a 115% increase in damage over this time (Lasage et al., 2014, pp. 1448, 1450).

The following strategies for reducing flood risk were modelled (Lasage et al., 2014, pp. 1446–1448, 1452):

- building ring dykes 2 metres high at a cost of USD 89 million plus ongoing maintenance;
- wet floodproofing of buildings at a cost of USD 258 per house or USD 7.5 million in total;
- dry floodproofing buildings at a cost of USD 645 per house or 19 million in total;
- elevating buildings and roads to between 2.11 and 3.37 m above sea level at a cost of USD 31 to 116 million; and
- a combined strategy that included constructing levees and implementing land-use changes at a cost of USD 129 million plus ongoing maintenance.

Impacts were forecast through the year 2100 under various assumptions for discount rates, land use changes, and rising sea levels. The least expensive interventions – wet and dry floodproofing, and elevating buildings by 2.11 m – showed the best economic performance, although under the assumption of no sea level rise, none of the interventions were economically viable. Under the assumption of 30 cm of sea level rise by the end of the century, the strategies of wet and dry floodproofing and of elevating buildings by 2.11 m showed benefit-cost ratios greater than 1.0 under low discount rate conditions, while all other interventions continued to show benefit-cost ratios of less than 1.0 (Lasage et al., 2014, pp. 1451–1452).

	Benefit-cost ratio ranges for different sea level rise assumptions	
	No sea level rise	30 cm sea level rise
Ring dyke	0.124 - 0.270	0.266 - 0.556
Wet floodproofing	0.330 - 0.681	0.709 - 1.444
Dry floodproofing	0.326 - 0.657	0.689 - 1.376
Elevating buildings to 2.11 m above sea level	0.410 - 0.832	0.677 - 1.352
Elevating buildings to 2.53 m above sea level	0.194 - 0.394	0.321 - 0.640
Elevating buildings to 3.37 m above sea level	0.109 - 0.221	0.179 - 0.358
Combined strategy (levees and land-use changes)	0.100 - 0.186	0.101 - 0.384

(Lasage et al., 2014, p. 1452). Licensed under CC BY 3.0

Lami Town, Fiji

Lami Town, a small town near Suva, the capital of Fiji, experiences coastal flooding from storm surges and waves, flash flooding from rivers especially where hillsides have been cleared of vegetation, and surface flooding where rainfall pools in low lying areas (Rao et al., 2013, pp. 6, 10).

A participatory process involving the town council identified locations and activities of interest for reducing flood risk in the town, producing eight initiatives which were evaluated: planting coastal mangroves, planting riverbank and streamline vegetation, protecting natural ecosystems through increased monitoring, reducing upland logging, reducing coral extraction, reinforcing riverbanks, improving drainage, and building sea walls (Rao et al., 2013, pp. 1, 17). The process of estimating the benefits of each activity was hampered by limited data on the effectiveness of the different approaches and a lack of detailed design information for the interventions (Rao et al., 2013, p. 25).

		Cost over 20 years (USD)	Benefit-cost ratio range
Ecosystem-based activities	Replant mangroves, 64 ha	1,689,000	15 – 77
	Replant riverbank and streamline vegetation, 32.5 ha	887,000	29 – 146
	Protect natural systems through increased monitoring	87,000	300 – 1,498
	Reduce upland logging	64,000	407 – 2,037
	Reduce coral extraction	44,000	598 – 2,988
Engineering activities	Reinforce river bank using gabion baskets (120 m^3), realign river (150 m), protect river with spall-filled reno mattresses (1 km), dredge selected areas of rivers (30,000 m^3)	1,357,000	19 – 96
	Clear out blocked drains and build drainage ditches, 82.8 km	927,000	28 – 140
	Build sea walls with concrete, rock, or tyres, 7.4 km	8,505,000	3 – 15

Source: author’s own. Data taken from Rao et al., 2013, pp. 17–18, https://ian.umces.edu/pdfs/ian_report_392.pdf

Manila, Philippines

Metro Manila suffers from recurrent flooding, especially during the typhoon season (June to October); the city receives flash floods from mountains to the north and northeast, is frequently flooded by the Pasig-Marikina river system, and natural drainage tends to be restricted during rainfall by high river and seawater levels (Asian Infrastructure investment Bank, 2017, p. 4).

The Department of Public Works and Highways and the Metro Manila Development Authority carry out flood management work including operating pumping stations and dredging rivers and waterways, but many pumping stations and other infrastructure are outdated and ‘no longer function as designed’ (Asian Infrastructure investment Bank, 2017, p. 4). Solid waste such as plastic bags, styrofoam and Tetrapak containers, and small single-use sachets accumulates at pumping stations and in waterways, reducing capacity (Asian Infrastructure investment Bank, 2017, p. 5). Informal settlements that house 2.8 million people, almost one fifth of the city’s population, are common along and over drainage channels, impeding the flow of water and access to waterways for maintenance (Asian Infrastructure investment Bank, 2017, p. 5).

The Metro Manila Flood Management Project will involve building an estimated 20 new pumping stations and modernise 36 existing ones at a cost of USD 375 million; reducing solid waste in waterways near pumping stations through improved collection services, community mobilisation and awareness-raising (USD 48 million); resettling about 2,500 households away from flood drainage infrastructure areas (USD 56 million); and include project management and coordination activities costing USD 20 million (Asian Infrastructure investment Bank, 2017, pp. 8–

11). Benefits of the project will include reduced flood damage and economic productivity losses, as well as unquantified benefits for education, health, and other public services (Asian Infrastructure investment Bank, 2017, p. 16). The cost-benefit analysis of the project based only on avoided flood damage showed **benefit-cost ratios of 1.3 to 1.9**, and adding the avoided productivity losses increases the **benefit-cost ratio to 2.5** (Asian Infrastructure investment Bank, 2017, pp. 16, 55). No analysis of the costs and benefits of the individual components of the project (drainage systems, solid waste management, and resettlement) was available.

Ibadan, Nigera

Ibadan, the capital of Oyo State, is highly exposed to frequent flooding, particularly in crowded and poor residential districts that have developed in low-lying areas (World Bank, 2014, pp. 4–5, 7). The principal risk factors facing the city include the safety of the Eleyele dam (used for water supply storage), drainage infrastructure, solid waste management, land use planning, and flood control asset management (World Bank, 2014, p. 8).

The Ibadan Urban Flood Management Project, funded by the World Bank, is made up of three components: (1) flood risk identification, prevention, and preparedness measures including the development of strategic plans and feasibility studies (USD 23 million), a flood forecasting and early warning system (USD 7 million), and emergency response funding (13 million); (2) flood risk reduction measures including rehabilitation of drains, culverts, roads, and dams, upgrading critical public infrastructure (USD 149 million); and (3) project administration and management support (USD 28 million) (World Bank, 2014, pp. 9–10).

These measures are expected to reduce average annual losses significantly: the early warning system is expected to reduce losses by 5% (USD 5.3 million) per year, improvements to critical infrastructure 18% (USD 19.4 million), reductions in runoff from upper catchment areas 14% (USD 15.3 million), and improvements to urban drainage are expected to reduce average annual losses by 42% (USD 44.6 million) (some of these benefits overlap and are not cumulative, so the total benefit from implementing all of these measures is 52% or USD 55.0 million) (World Bank, 2014, p. 21). The overall project's **benefit cost ratio is between 1.4 and 3.3** for discount rates between 15% and 0% (World Bank, 2014, p. 21) and is likely to be higher, as some benefits were not quantified in the analysis and the impacts of climate change on flood frequency were not considered (World Bank, 2014, p. 22). Separate benefit-cost ratios for the individual elements of the programme were not available.

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