MOZAMBIQUE

UPSCALING NATURE-BASED FLOOD PROTECTION IN MOZAMBIQUE'S CITIES

Knowledge Note

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Project

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ABREVIATIONS

3CP	Mozambique Cities and Climate Change Project
CBA	Cost-benefit assessment
CES	CES Consulting Engineers Salzgitter GmbH
CityCORE	City Coastal Resilience Africa
GUI	Green Urban Infrastructure
KfW	KfW Development Bank
PPCR	Pilot Program for Climate Resilience

1 INTRODUCTION

Mozambique is one of the countries most exposed to coastal and river flooding in Africa. It is also among the countries most vulnerable to current and future climate risk. The World Bank has been active in providing emergency recovery after hydrometeorological disasters in Mozambique and has increasingly been supporting the Government in increasing climate resilience at municipal and regional levels. While traditional infrastructure-based interventions still make up most of the global financing to improve urban resilience, the application of nature-based solutions is gaining momentum. Nature-based solutions are interventions that harness the ability of natural or nature-based features, such as bioswales, wetlands, and mangroves, to meet development goals, such as the reduction of natural hazards, while simultaneously providing environmental, economic, and social benefits.

One of the first nature-based urban flood management interventions supported by the World Bank, with funds from the Pilot Program for Climate Resilience (PPCR), and by the German Cooperation through the KfW Development Bank is the Green Urban Infrastructure (GUI) intervention in Beira, Mozambique. A first-phase to restore the natural drainage capacity of the Chiveve River, a 3.5km-long tidal river flowing through Beira's central business district and low and medium-income residential neighborhoods, was completed in December 2016 with financing from the German Cooperation. Building on this, activities that are being implemented as part of the Mozambique Cities and Climate Change Project (3CP) with financing from both PPCR and KfW focus on further restoring the river's ecosystem (in particular, its mangroves and other natural habitat on the river banks) and upgrading the run-down space surrounding the river as a green urban park, while also unleashing its potential as a recreational amenity. To maximize results from nature-based projects, such as GUI, it is important to review the benefits for urban flood risk management as well as lessons learnt in their implementation and explore how such approaches can be best adjusted and scaled up to other cities in Mozambique and other countries.

In addition to a review of lessons learnt in Beira, two other cities in Mozambique were selected to understand how nature-based approaches could be used to inform future investments to increase urban resilience to flooding and erosion. These were Quelimane, in the Zambezi Province, and Nacala, in Nampula Province. The Mayor of Nacala warned that erosion in the city is becoming alarming, not only threatening its residents but also the future of Nacala as a deep-water port, because of the sediments accumulating in the access channel and in the port itself. In Quelimane, flood risks increased particularly due to the uncontrolled cutting of mangrove trees, leading to a loss of the city's natural protection against storm surges and tides as well as to an extensive, irreversible salinization of coastal waters.

1.1 NATURE BASED SOLUTION FOR FLOOD PROTECTION

Most urban flood protection investments, not only in Mozambique, are still made in the rehabilitation and construction of grey infrastructure, such as drainage canals, retention basins, protection walls and their appurtenant infrastructures. While there are several reasons to consider for and against grey infrastructure, incl. degree of urbanization, existing infrastructure, local capacities (construction and operation), etc., nature-based solutions are increasingly considered by international financing institutions, national agencies as well as local stakeholders for their potential to reduce risk while often bringing other benefits. Especially when looking at small-scale interventions, nature-based solutions can be a more cost-effective option, can complement grey infrastructure, and may also be implemented and operated/ maintained by local agents, including communities and NGOs (e.g. afforestation measures).

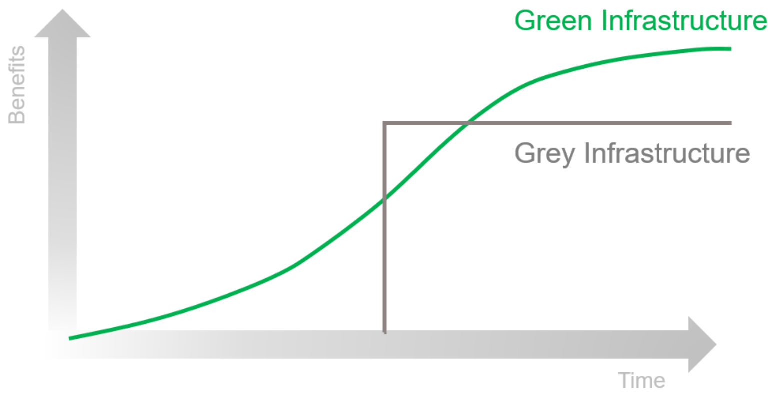


Figure 1-1 Development of Nature-Based Solutions vs. Grey Infrastructure

While the concept of nature-based solutions is firmly rooted in the climate change context, it is currently understood to be able to address a range of policy objectives, ranging from climate change to disaster risk management, stimulating green economies, and addressing poverty and disease (Pauleit et al., 2017). The concept of “nature” is also wide-ranging, including the stock of all-natural capital. Furthermore, the concept aims to foster an integrative and action-oriented approach.

Nevertheless, it needs to be pointed out that nature-based and hybrid flood and erosion protection measures may also be very complex in their planning, especially when looking at their impacts. Ecosystems and their service provision are a condition for the interventions’ success, meaning that many aspects of their functioning need to be considered. Often, a network of ecosystems can be found, which are linked to each other, so that influencing one will also affect the others. Accordingly, the publication ‘Implementing nature-based flood protection’ (World Bank, 2017) concludes that there is no ‘one-size fits all’ solution. Based on a specific hazard and risk assessment, a variety of natural as well as social aspects need to be assessed for a well-designed project. In addition, the temporal development of nature-based solutions can vary heavily compared to grey infrastructure measures which are usually ready to use directly after finalization of construction.

In the context of urban areas pure nature-based solutions may not always be applicable and a mix between green and grey infrastructure is required. In between these two approaches hybrid solutions might be a preferred choice as shown within the following figure.

Figure 1-2 Variety of Nature-Based Solutions for Flood Protection and Urban Drainage Measures

2 LESSONS LEARNT FROM THE GREEN URBAN INFRASTRUCTURE PROJECT IN BEIRA

Beira is among Mozambique's largest coastal city with over half a million inhabitants and one of the largest ports in the country, connecting an extensive hinterland (including neighboring landlocked countries) with the Indian Ocean. Due to its exposed coastal location (low-lying land and high tidal range), its vulnerable infrastructure and population, Beira is considered to be the city most threatened by climate change in Mozambique, and one of the cities most at risk in Africa. Additionally, many of its neighborhoods grew in unplanned manner and can be characterized by high population densities, inadequate residential areas and infrastructure, lack of water supplies, waste and storm water drainage systems, and a high poverty rate, which also make them particularly vulnerable to extreme weather events. In the future, this situation is expected to be exacerbated due to weather extremes, rising ground water and sea levels, inadequate drainage, and ongoing coastal erosion.

To address the climate change issues facing Beira, its Mayor, Daviz M. Simango, made climate change adaptation one of the priorities for urban development. The focus of the city's climate adaptation strategy lies in flood and coastal protection, including as some priority adaptation measures the improvement of its stormwater drainage systems and the rehabilitation of the Chiveve River and the surrounding wetland areas.

The Green Urban Infrastructure (GUI) intervention is being implemented by the Government of Mozambique under the Mozambique Cities and Climate Change Project (3CP) with financing from PPCR and co-financing by the German Cooperation/KfW, building on a first-phase rehabilitation of the Chiveve River to restore and improve its natural drainage capacity (financed by the German Cooperation/KfW). The first phase, which was completed in December 2016, included the restoration of the riverbed and course of the river (including excavation of sedimentation and waste), construction of a tidal outlet at the fishery port with floodgates to regulate the river's discharge and influx, and creation of additional backwater areas to retain potential floodwaters. Building on this, the GUI intervention aims to further improve environmental conditions protecting the green space along the river and safeguard the river's drainage capacity, while also unleashing its potential as a recreational amenity in relatively dense urban areas. To accomplish this, the project is funding the restoration of the valuable riverine and wetland ecosystem, protecting its stormwater drainage and retention function, while upgrading the space surrounding the river as an urban park area. The park incorporates, among others, boardwalks to appreciate the natural habitat, bicycle paths, a botanical garden, playground/sport facilities, sanitation facilities and lighting. These measures were complemented by non-structural interventions such as awareness campaigns and waste management service creation, along with the mobilization of civil society for planting and maintaining mangroves. The GUI project is set to complete later in 2020.

Figure 2-1 Mouth of Chiveve River in 2017

Figure 2-2 Vision of Rio Chiveve Park

The nature-based measures in Beira serve as an important source of experience and lessons learnt to feed back into the national-level and dialog and provide an example that can inspire the uptake of nature-based solutions for disaster risk management and climate resilience in other Mozambican cities. Below is a table that showcases some of the best practices and lessons learnt from the GUI project that can assist in preparing and implementing NBS for flood management in other cities. These lessons were also used as a guide in the assessment of potential nature-based solution approaches in the selected pilot cities. For more details on the experience in Beira, refer to the "Upscaling Nature-Based Flood Protection in Mozambique's Cities: Lessons Learnt" report.

Table 1 Highlights of Lessons Learnt and Best Practices from the Beira GUI project

Project Aspect	Lessons Learnt/Best Practices
Project Preparation	• Coordination of donors is important and necessary and can lead to more sophisticated and beneficial projects. • The restoration of urban green areas proves to have wider social impacts, which should be communicated more prominently to promote NBS with (local) stakeholders. • If the extent and type of social and economic infrastructure is not clear at the start of the project, feasibility studies should include market and social studies as well as participatory workshops to identify adequate options. • Infrastructure projects financed through climate funds or with a climate resilience objective should require the investigation of environmentally sustainable and, where possible, nature-based solutions. • Where ecosystems are part of the project solution or within the project area, clear guidelines and targets should be set by the financing institutions on protection and/ or restoration measures. Consulting teams should then include experts in relevant fields, e.g. ecology, marine biology, botany and zoology. • Community outreach and public participation are key to build understanding of nature-based solutions and public support/buy-in.
Design Process	• NBS may present a larger variety of options and less standard practices. In an urban context, subjective preferences such as aesthetics are also relevant for selection of options. Adaption of project components may come up more frequently during the feasibility and design phases, requiring non-conventional solutions. A certain degree of unpredictability may have to be accepted. Contrary to conventional engineering measures. All this requires flexibility as well as close and regular communication between main entities involved. • The financial feasibility and sustainability of green infrastructure measures need to be assessed looking at O&M costs and local capacities to operate and maintain them. • It would be useful if municipalities had "base data" sets for their own use as well as for consultants working on projects in their jurisdiction to reduce costs and time of data collection and increasing quality and compatibility of outputs.

	• The municipalities should improve their data management – important project outcomes such as GIS-based maps of utility systems should be fully backed up so that they can be restored to full functionality when the need arises.
Construction	• Green solutions require adaption of common construction techniques. Especially the use of heavy equipment might have to be limited in favour of manual labour. The use of special equipment (e.g. amphibious excavators for wetlands) should be clearly indicated in the tender documents and instructed for construction. • Clear guidance has to be provided to the construction company and supervisors to prioritise the preservation of the habitat, with flexibility in regard to some of the provided construction targets.
Ecology	• Engineers and environmental experts should work closely together in defining the boundaries for vegetation clearing during the design and at the start of construction works. The loss of flora and fauna should be limited as much as possible. • Including reforestation measures already during construction, involving an experienced local NGO, showed to be a successful approach. • *Avicennia marina* showed a very quick natural recovery. The ecological-based restoration versus reforestation of this species at this particular site may not have been necessary. • The operation of grey infrastructure within a hybrid solution should also be oriented towards maintaining the health of the ecological system and clear operation and monitoring targets should be established. • Vegetation control of mangroves within the embankments and in the park area should not be necessary in a functioning, natural system. Due to the hybrid character of the river and specific interests, potential measures for operation shall be defined with according experts.
Stakeholder Management	• When dealing with NBS, the issue of mosquitos and wildlife is mostly associated with wetlands and highly vegetated areas. Waste dumping is a common problem in many informal settlements and often caused by non-existent collection systems. It is necessary to integrate solutions for such concerns and challenges and include continuous work to slowly change mind-sets, developing an appreciation for nature and showing concrete benefits for local residents and businesses.
Sustainability	• Operation and maintenance of green infrastructures should be done by a competent entity. Especially in an urban context, the management of public green spaces requires funding and expertise. The operation must ensure good environmental management practices, with regular ecosystem monitoring. • Sustainable concepts for the operation and maintenance of the green infrastructure should already be considered during the design phase. Revenue-generating opportunities can be incorporated in the design and fine-tuned during construction.

- If the private sector is included in the operation and maintenance of individual facilities, an early involvement during planning stages needs to be guaranteed. This is mostly the case for urban parks with revenue-generation.
- The overall sustainability of green infrastructure projects depends on how the designed ecosystems are developing after completion of the project. By monitoring the processes and developing monitoring and action plans for the operation phase, the risk regarding the ecological and therefore overall sustainability can be reduced.
- Social infrastructure surrounding the drainage project does create more visible benefits to the population besides the more abstract value of a functioning drainage solution. This increases the acceptance such projects and helps keeping the system clean and functional.

3 RISK ASSESSMENT FOR NACALA AND QUELIMANE

The following chapters provide a summary of the risk assessment results for both cities – Nacala and Quelimane. The assessment integrated existing information and studies, such as the Preliminary City Risk profiles produced by the City Coastal Resilience Africa (CityCORE) Project. Based on the findings, appropriate nature-based measures have been selected as presented in chapter 4. In general, the measures can be scaled to be used in other locations.

3.1 BACKGROUND OF PILOT CITIES

The cities of Quelimane and Nacala are both located north of Beira along the coast, and similarly situated on riverine estuaries. Quelimane and Nacala have a similar size of population, 230,000 and 250,000 respectively. However, when looking at climate risks, particularities in terms of exposure, hazards and vulnerabilities apply for each city.

The city of Nacala is located on a coastal inlet on the Mozambican coast. The city boasts a deep-water harbour and a busy port. The city centre is located on the steep slopes that characterise the west-facing parts of the city. The city's economy is based primarily on the activities around the railroads and the port, and the trades and services associated with these. The city has seen a significant increase in built structures since Independence, as a result of immigration of rural Mozambicans into the city. Houses have been built to high density in parts of the city, even in areas where construction is prohibited. Degradation of soils and erosion in large parts of the central neighbourhoods are becoming an increased social, economic and environmental risk.

Quelimane is situated north of the extensive Zambezi delta, at the bank of Rio Dos Bons Sinais, approx. 25 km inland from the Indian Ocean. The area is rich in floodplain wetlands and mangroves. Soils are sandy in the drier parts of the City, tending towards organic silt in the wetter areas and wetlands. The city of Quelimane is located close to the medium sea level, so inundations after intense rainfall and storm surges together with coastal erosion and saltwater intrusion are major challenges for the city's resilience.

The population of approx. 350,000 (Census 2017) is growing due to increased influx into urban areas. Informal settlements, which still develop in flood-prone parts of the city are particularly exposed and show a high vulnerability due to their socio-economic conditions. Ongoing mangrove deforestation and degradation in and around Quelimane increase the exposure and result in exacerbating storm impacts with flooding and erosion.

Subsistence economy prevails in the entire region with sources of income being artisanal fishery, agriculture as well as informal businesses and trade. Except for the port, noteworthy industry or formal business are largely absent.

3.2 FINDINGS FOR NACALA

The assessment of local conditions and climate risks was conducted in 2019 through general data collection, site visits, a community mapping campaign, the desktop mapping of urban catchments and an assessment of urban expansion. Workshops were organized with municipal staff and stakeholders to collect data and discuss early findings. The main risk identified and assessed in Nacala is erosion. As a principal cause-effect chain, the following was identified:

- Sandy soils and steep slopes within city center
- Urbanization and creation of informal settlements without appropriate drainage systems
- Removal of natural vegetation cover
- High runoff in case of heavy rainfall
- Erosion of material and deposits

V-shaped erosion gullies throughout Nacala

Destroyed house located at an erosion gully

Deposited material at the sea in 2019

Damaged infrastructure at Nacala port

Figure 3-1 Selected Photos of Nacala

The management and maintenance of the stormwater drainage system within Nacala City poses a major challenge. The City has seen rapid urbanisation and densification of houses since the 1980s. There has been repeated encroachment of legal and illegal housing into high risk areas within the City. Industrial complexes have also been constructed across drainage lines. This does not allow for the systematic and effective design of stormwater management systems, which would be able to cope with the volume and velocity of runoff experienced during the high rainfall months.

The proliferation of buildings, industries and roads in the City has led to hardening of the catchments, through soil sealing and this has the direct result of changing the hydrology of surface flow throughout the City. There are several parts of the City where the slopes are steep, which further increases the velocity of surface runoff. The removal of indigenous and exotic tree species throughout the City for use as building materials and for charcoal production, causes instability of the soils by removing stabilising root matter from the soil, and changing the manner in which water falls on the soil – rain falling on bare soil has a higher erosive capacity than the same rain falling on leaves before it hits the soil. The rain falls with greater intensity on bare soil, washing the finer soil particles away and leading to greater soil instability. Unstable soils have a greater potential for erosion, and sedimentation along the coastline where these soils are deposited. Trees, shrubs and grasses also get rid of water through transpiration, thereby reducing the total volume of water exiting the catchment.

Furthermore, formalised stormwater infrastructure in the City appears to be blocked or damaged in several areas. Sand, rubble and litter blocks drainage channels and pipelines, and accumulates in detention and retention basins. These blockages and damaged infrastructure (for instance, the theft of stones and wire from gabions) lead to the switching of flow pathways, from the desired route to alternative routes in residential or industrial areas. Scouring and incision of these alternative routes then follows, and an erosion gully is formed, more sediment being deposited downstream. The steep slopes and unstable soils merely exacerbate the problem. The banks of these erosion gullies are dangerously unstable, leading to loss of properties, infrastructure and even lives where banks have subsided.

In summary, the stormwater infrastructure is not keeping pace with the rapid urbanisation and densification of houses in Nacala City and does not cater for the predicted increases in the frequency and intensity of storms due to climate change across the African continent. Accordingly, the main priorities for Nacala were outlined as follows:

- Reshaping Primary Channels to a stable cross-section and slope protection
- Construct service roads to run parallel to the channels
- Reduce erosion risks wherever possible
- Protect channels with drought-resistant vegetation above the 1:10 year flood elevation (e.g. Vetiver grass or Elephant grass)

Based on the first findings a risk assessment covering 13 catchment areas in Nacala (see figure below) was elaborated. Objective of the risk assessment was to identify catchment areas with highest erosion-related risks and subsequent the highest priority for improvement of the situation and to derive suitable measures. The results are presented in the following figure. As can be seen on the map below, highest priority for improvement of the situation is in the central catchment areas 9 and 10 located in downtown Nacala. Suitable measures for improvement of the situation can be found in chapter 4.

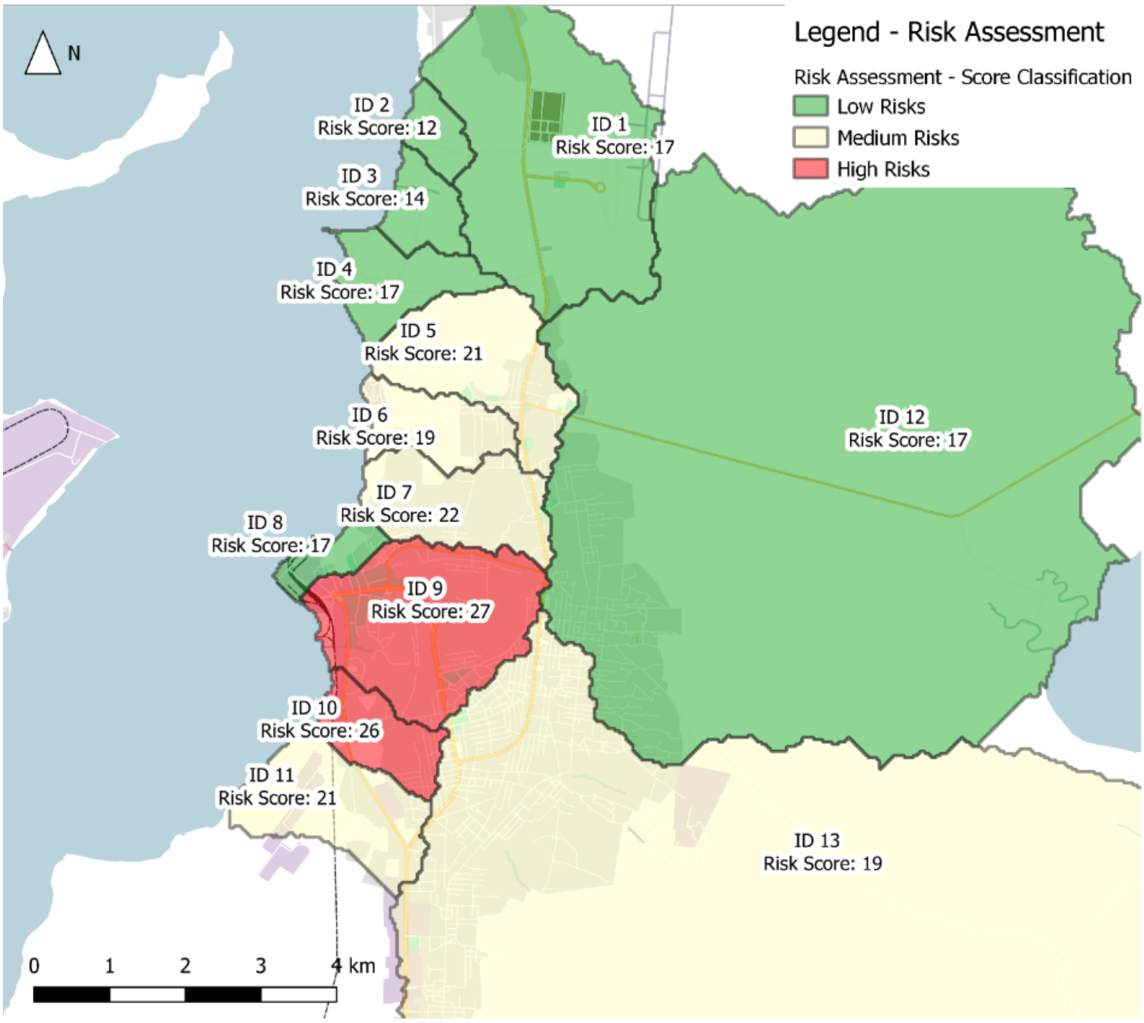


Figure 3-2 Risk Assessment - Total Erosion Risk Score Map for Nacala

3.3 FINDINGS FOR QUELIMANE

The assessment for the city of Quelimane followed the same methodology as Nacala, including field visits, a community mapping campaign and workshops with local stakeholders in 2019. The key problems observed in the sites visited in Quelimane are classified as following (also refer to **Table 2-1**):

- F_D: Flooding due to insufficient drainage / waste management
- F_S: Flooding due to tides, storm surges and / or sea level rise
- E_C: Coastal erosion
- E_T: Terrestrial and watercourse erosion

Houses, industries and road infrastructure are seen to be encroaching into areas of increasing flood risk. There appears to have been repeated encroachment of legal and illegal housing into high flood risk areas within the City, for instance into parts of the City that are inundated daily at high tides. Industrial complexes have also been constructed within wetlands and river floodplains, leading to an increased risk of flooding of these areas. In addition, the proliferation of buildings, industries and roads in the City has led to hardening of the catchments, through soil sealing, and this has the direct result of changing the of surface flow throughout the City.

Insufficient drainage / waste management

Regular flooding of settlements during high tide

Settlements behind bank wall induced by coastal erosion

Watercourse erosion leading to collapse of bridge

Figure 3-3 Selected Photos of Quelimane

As it is the case in Nacala, the removal of mangroves and other indigenous and exotic trees for use as building materials and for charcoal production, causes instability of the soils and increased erosion risks along the margins of the river.

The management and maintenance of the stormwater and flood protection drainage system within Quelimane also poses a major challenge. The formalised stormwater infrastructure in the City appears to be blocked or damaged in several areas. Sand, rubble and litter blocks drainage channels and pipelines, and accumulates in retention basins, and in the streets. These blockages and damaged infrastructure lead to the switching of flow pathways, from the desired route to alternative routes through residential or industrial areas, causing flooding and partly isolation of these areas.

Also, in Quelimane, the stormwater infrastructure is not keeping pace with the urbanisation and densification of houses, roads and infrastructure, not being able to cope with the volume and velocity of runoff experienced during the high rainfall months, especially during storms and cyclones.

Based on the above preliminary results, the potential flood risks have been assessed. These risks, as a combination of their estimated probabilities of occurrence as well as their impacts on the local socio-economics of the local and wider population, have been evaluated, in order to identify sites with higher risks. This may inform decision-making on prioritisation of measures to reduce flood and erosion risks, as proposed within this report.

The performance and reduction in estimated exceedance probabilities depend to a significant extent on e.g. the present design and performance as well as topographic settings, for which no reliable data is available, as well as on the detailed design of the measures to be implemented. The outcomes of this risk assessment, as shown in Table 3-1, should hence be interpreted with due care.

Table 3-1 Risk Estimates for Existing Conditions

No.	Site	Key Risk Event	Probability (%)	Socio-economic Impact (USD)	Risk Value (Mio. USD)
1	Airport / Aeroporto	Rainfall	50	3,318,000	1.7
2	Port & Bank Wall / Porto e Murro de Protecçáo	Sea level	100	1,142,000	1.1
3	Primeiro de Maio	Rainfall	20	11,042,800	2.2
4	Acordos de Lusaka	Rainfall	20	2,568,000	0.5
5	Inhangome	Sea level	100	1,192,000	1.2
6	Chuabo Dembe	Sea level	100	856,000	0.9
7	Torone Velho	Sea level	< 1	2,868,000	< 0.1
8	Incidua	Sea level	100	3,846,000	3.8
9	Ivagalane	Sea level	100	1,106,00	1.1
10	Murrope	Rainfall	20	545,700	0.1
11	Not considered in this assessment				
12	Micajune/Floresta B/A	Rainfall	20	2,540,000	0.5

In case the proposed measures to mitigate the various flooding problems at Quelimane are implemented, it can be assumed that a significant reduction of the probability of occurrence of the risk events can be achieved. For this assessment it is assumed that exceedance probabilities of rainfall and high sea level events would reduce to approximately 1% for properly designed drainage and sea level protection systems, which can cope with all but severe tropical storms and cyclones. While a reduction of probability to 1% is technically feasible, accordingly designed measures may not be financially feasible, depending on investment criteria of financing institutions. On this basis these remaining probabilities, the estimated risk values reduce to those listed in Table 3-2.

Table 3-2 Risk Estimates after Implementation of Proposed Measures

No.	Site	Key Risk Event	Probability (%)	Socio-economic Impact (USD)	Risk Value (USD)
1	Airport / Aeroporto	Rainfall	1	3,318,000	33,000
2	Port & Bank Wall / Porto e Murro de Protecçáo	Sea level	1	1,142,000	11,000
3	Primeiro de Maio	Rainfall	1	11,042,800	110,000
4	Acordos de Lusaka	Rainfall	1	2,568,000	26,000
5	Inhangome	Sea level	1	1,192,000	12,000
6	Chuabo Dembe	Sea level	1	856,000	9,000
7	Torone Velho	Sea level	1	2,868,000	29,000
8	Incidua	Sea level	1	3,846,000	38,000
9	Ivagalane	Sea level	1	1,106,00	11,000
10	Murrope	Rainfall	1	545,700	5,000
11	Not considered in this assessment				
12	Micajune/Floresta B/A	Rainfall	1	2,540,000	25,000

4 PROPOSED NATURE-BASED MEASURES FOR RISK REDUCTION IN NACALA AND QUELIMANE

4.1 NACALA

As presented in the previous chapter, drainage management and erosion protection are the main priorities for risk reduction for Nacala. Based on the risk assessment different measures have been selected for the different conditions in the catchment areas:

I. Less densely populated areas or lots of unused land available (mainly northern catchments):
   a. Large-scale runoff reduction using revegetation measures and soil bunds
   b. Stabilization of existing V-shaped gullies: filter unit rock bags
II. (Small-scale) Combined measures in densely populated areas (inner city)
III. Preventive measures in areas prone to further urbanisation (eastern catchments)

Table 4-1 Summary of Proposed Main and Accompanying Measures per Catchment

Catchment ID	1	2	3	4	5	6	7	8	9	10	11	12	13
Main Measure	**Revegetation and Soil Bunds**					**Combined Measures Approach**						**Preventive Measures**	
Accompanying Measure	Rock Bags for V-Shaped Gullies					-						Combined Measures Approach, Rock Bags (if applicable)	
Remarks	Less densely populated areas in the north					Densely populated areas in the centre of Nacala						Eastern catchments (prone to further urbanization)	

The principle recommendation to minimize erosion risks in Nacala is to reduce the runoff in case of heavy rainfall events as much as possible. The proposed measures aim to reduce erosion and allow damage-free disposal of the rainwater towards the sea. The situation in catchment areas that indicate lots of bare soils due to removal of the natural vegetation cover and which are rather loosely populated is improved if the vegetation cover will be increased and soil bunds are constructed. Densely populated areas require a combination of several measures to improve the situation. If there is still open land available and further major urbanisation can be expected, the establishment of green urban space, e.g. parks, which serve as (meso scale) retention basins in case of heavy rainfall can be foreseen. This measure mainly applies for the eastern catchment areas 12 and 13.

The proposed measures can be combined if found suitable. Still, all measures will be presented separately in more detail within the following chapters. Besides these proposed measures a set of alter-native and accompanying measures will be included to allow additional methods for nature-based flood and erosion protection in Nacala.

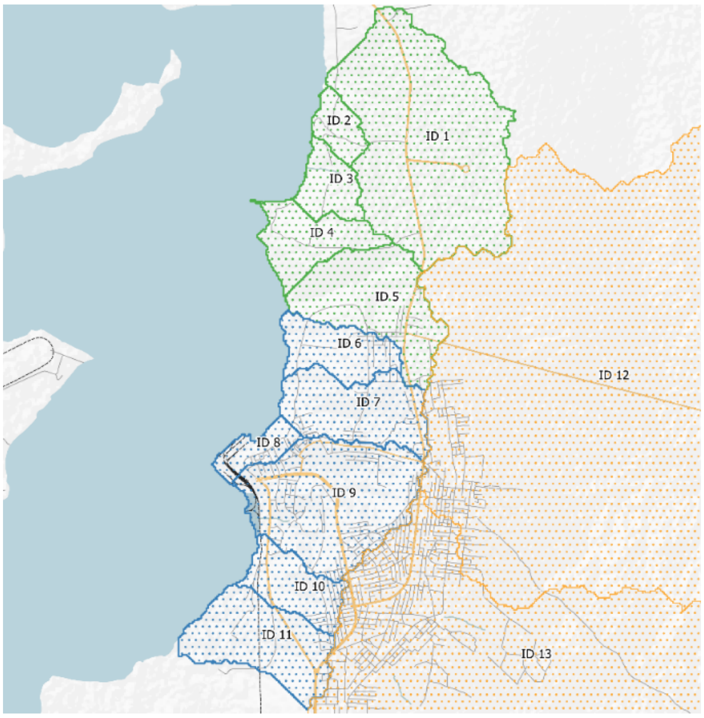


Figure 4-1 Proposed Main Measure per Catchment Area

4.1.1 Revegetation

Revegetation is one of the preferable used measures for the less populated areas ID 1 – 5 in the northern part of Nacala. Besides utilizing revegetation as a large-scale, area-wide measure the method can be used as a general approach for the combined measures approach on a smaller scale which includes planting of different plants in order to stabilise the existing gullies, toe of slope protection or to revegetate unused land for runoff reduction. It can be applied wherever there is unused or open land. The subsequent chapters name different suitable plant species. In addition to simple revegetation to reduce runoff the currently unused areas can be used for urban gardening purposes as well for the benefit of the population.

4.1.2 Soil Bunds

Main parts of the northern catchments in Nacala are used for agricultural purposes, so revegetation of all areas will be unrealistic. In order to achieve runoff reduction in these catchments, soil bunds can be constructed as an alternative or accompanying measure to revegetation.

A soil bund is a structural measure with an embankment of soil, or soil and stones, constructed along the contour lines and stabilized with vegetative measures, such as grass and fodder trees. Bunds reduce the velocity of runoff and soil erosion, retain water behind the bund and support water infiltration. It further helps in ground water recharging and increases soil moisture which can results in better yields as a benefit for local farmers.

4.1.3 Rock Bags (V-shaped gullies)

Most of the erosion gullies within the densely populated areas of Nacala are quite wide (> 30 m). In opposite to this, within the areas foreseen for large-scale measures (northern catchment areas) most gullies are v-shaped with small bottom widths of 1-3 meters only and steep side slopes (up to 8 m). Works at the bottom of these gullies are dangerous due to their instability, making the construction of gabion walls critical in these steep gullies. Rock bags present a good alternative for these particular conditions.

Figure 4-2 V-shaped gully and Rock Bag (source: Sumitomo)

4.1.4 Combined Measures Approach

For the more populated areas in the inner city of Nacala (catchment areas ID 6 to ID 11) a set of different measures is proposed to address the rainwater drainage and erosion problems. The measures include:

- Rehabilitation of natural drains / streams
- Revegetation with appropriate indigenous plant / tree species on a smaller scale
- Green embankments along the existing gullies (embankment erosion protection)
- Detention ponds
- Rehabilitation and improvement of existing drainage infrastructure

Detention Ponds will be the most beneficial measure, as the erosion rate is directly connected to the flow velocity. A detention pond holds water for a short period of time as small-scale structure to be used within the combined measures approach for the inner-city areas of Nacala. It is expected that most of the detention ponds will be sedimented one or two years after construction and thus will serve as check dams further on.

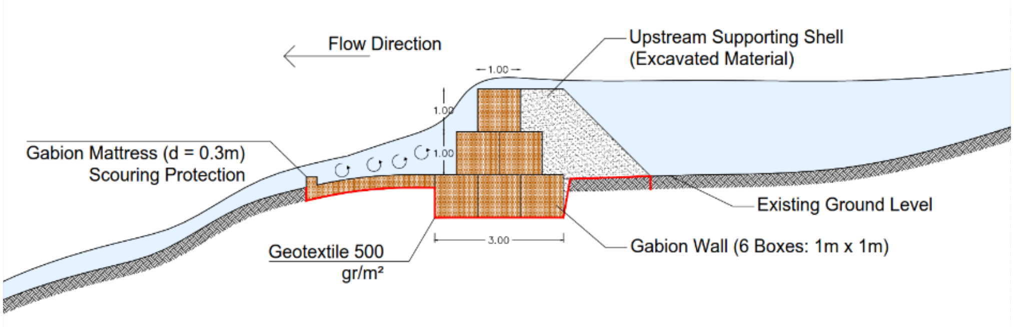
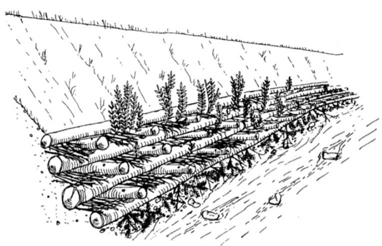


Figure 4-3 Schematic Cross-Section Detention Pond

4.1.4.1 Embankment Erosion Protection Measures

As an additional measure the embankments need to be protected against further erosion. Most of the gullies are not filled with water during rainfall events, so the focus will be to protect the toe of the embankments as erosion rates come from collapsing side slopes into the gully. There are several nature-based solutions to prevent embankment erosion. Due to its characteristic's vetiver grass seems to fit perfect for the requirements. Still, other measures are presented in the table below to show possible alternatives. Protection of slopes is required for the entire length of the gullies.

Vetiver Grass	Stabilisation of the channel can occur through planting of vetiver or elephant grass "weirs" that slow down flow and trap sediment, resulting in terrace formation over time.	
Crib Retaining Wall	Crib walls are one of the oldest gravity wall systems, comprised of a series of stacked members creating hollow cells filled with soil or rock. Cells can be vegetated. Cribs can be made of wood or concrete structures	
Other Retaining Walls	As an alternative embankment protection method various material are suitable to stabilize slopes, e.g. tires or prefabricated concrete blocks filled with soil and vegetated.	 

For the implementation of the combined measures approach the following sequence of works could be applied after selection of gullies to be protected and preparation of all relevant design documents is completed:

1) Removal of waste / cleaning of gullies
2) Large-scale / area-wide runoff reduction measures (revegetation/soil bunds) adjacent to the gully (if applicable)
3) Improvement and cleaning of existing drainage system (if applicable)
4) Installation of several detention ponds for initial stabilization of the gully
5) Stabilization of side slopes (e.g. vetiver grass, see previous chapter) after completion of construction of the detention ponds
6) Fostering of planted slope protection (if required)
7) Silting up of detention ponds will progress, regular checking and maintenance works required

4.1.5 Preventive Erosion Protection Measures / Meso-Scale Retention Ponds

Preventive measures can be used besides the above described measures. For Nacala, these measures are mainly foreseen for the two big catchment areas draining towards the east (ID 12 and 13). As it is expected that further urbanization is heading towards these eastern districts, the creation of green recreational areas that serve as possible retention basins could help to mitigate flood and erosion risks. Green spaces as large-scale retention basins should be prioritized prior to construction of new residential buildings in these areas. Opposite to the detention ponds these meso-scale retention ponds shall not silt up and thus provide retention volume for the long run.

Figure 4-4 SUDS - Recreational Areas as Meso-Scale Retention Basins (source: www.lizlake.com)

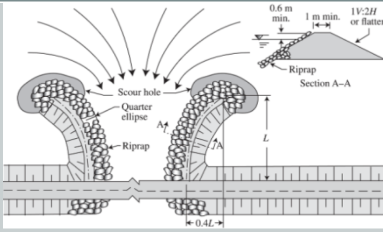
4.2 QUELIMANE

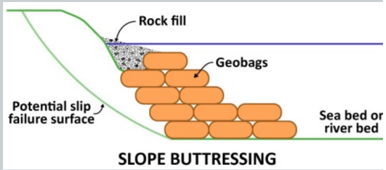
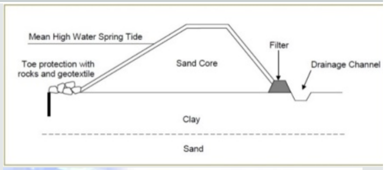
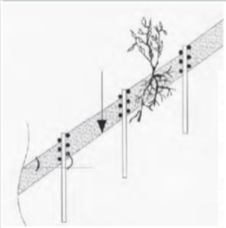
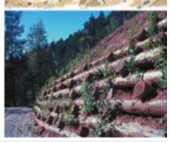
The following strategic objectives were identified for Quelimane:

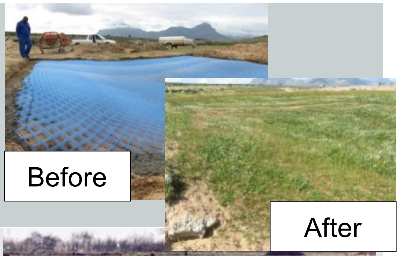
- Expand and improve the city's drainage system
- Improve the city's water capture and supply system
- Introduce Coastal Protection Measures taking into account sea level rise, marine intrusion and storms
- Introduce erosion protection measures

In Table 4-2, suitable flood and erosion measures and concepts are described for each category.

Table 4-2 Description of measures possibly applied in Quelimane

Category	Problem	Method	Characterization / Key Information	Pros (+) and Cons (-)	Examples
Bridges and Bank Wall	Erosion	Guide Banks	• One of the most effective bridge protections where a road embankment crosses floodplain • Consisting of sand fill with stone riprap • Reduces rapidly diverging flow turbulences and scour -> smooth flow, less erosion	+ location of potential damage is moved away from the bridge + natural resources + easy to repair	
		Reinforcement of the Bridge Abutments	• Stone rip rap and gabions at high current velocities • Possible that loose stones will be taken (for building material) • Possible solution: superficial grouting of the stones	+ mostly natural resources + easy to repair	
Bank Wall	Flooding due to storm surges and erosion	"Wave Steps"	• Dissipation vs. Reflection • Research project of Leibniz University, Hanover, Germany	+ high durability, even at high flow velocities - no nature-based solution	
	Flooding due to insufficient drainage	Flap gates	• Fit drainage pipes with flap gates	+ rainwater can drain and tidal water is kept outside - rainfall and tidal high water: no discharge of rainwater possible	

Wetlands and Bank Wall	Flooding due to storm surges and erosion	Geotextile bags	• Filled with sand	+ local resources + easy to repair + logistic, easy to transport (sand filling on site) - a damaged, bag influences position of other bags	 
Wetlands	Flooding due to storm surges	Dikes	• Materials: sand, silt / clay • Covered with reinforced vegetation	+ mostly natural resources + easy to repair + experience - large footprint	 
		Landfill / Backfill	• Backfill the regularly flooded zones	+ local resources + easy to repair - large amount of backfill material (sand required) - only suitable for (up to now) uninhabited areas - erosion protection required	
Wetlands (cont.)	Erosion	Vegetation reinforced slopes and embankments	• Vertical elements (of timber or steel) bring shear forces into the ground. ○ Length 1 to 3 m ○ Diameter 20 to 200 mm ○ In between: vegetation	+ natural resources + easy to repair	  

		Geochutes	• Cells are filled with earth and planted or filled with cement.	+ nature-based solution + can be planted	
Wetlands (cont.)	Erosion	Vegetation reinforced slopes and embankments	• Geotextile and establish vegetation • Robust and adaptable plants necessary (dry and wet season)	+ natural resources + easy to repair	
			• Coconut fibre geotextiles will be covered by soil and grass and thus stabilized • natural revetment of coconut mats, enhancing growths of vegetation • Research project of the Leibniz University Hannover, Germany	+ natural resources + local products + inexpensive + job creation + Involvement of local population + easy to repair - still under research	
			• Covering Vegetation (sea weed and / or mangroves) • Reduction of wave height: (dissipation of energy in percentage according to Leibniz University) Seaweed: 25-45% (strong rooting, sensitive against water pollution) Salt marsh (grass): 62-79% Mangroves: 25-37% (width :800 m–1500 m), 3 to 5 times cheaper than conventional wave breakers. Adaptable: grow with rising sea level	+ plants which can survive in salt water + natural resources - time to grow required - prevention of erosion of seeds during growth process required (geotextiles or coconut fibre mats)	 

Airport and City	Flooding due to insufficient drainage	Retention Basins	• Targeted drainage into basins • Enhance infiltration by use of rubble drains etc.	+ combination: public places (football, parking places) during dry season and flood protection during wet season - risk of malaria if water is stagnant too long - large areas required	
		Rehabilitation of existing drainage channels and / or new drainage channels	• Deepening of the existing channels	+ larger discharge volumes possible	
			• Diverting the drainage system into the surrounding (unoccupied) wetlands	+ decentralisation of discharge	
			• Using vegetation as covering (embankment, trapezoidal shape with reinforced vegetation)	+ natural resources + easy to repair - vegetation cover: difficult to remove waste - larger area required than with concrete solution - maintenance of vegetation required	

5 COST-BENEFIT ASSESSMENT OF NBS IN NACALA AND QUELIMANE

5.1 GENERAL

Cost-benefit assessments (CBA) were conducted for the situations and measures proposed for Nacala and Quelimane in the preceding chapter. The CBA comprised the data and adopted the methodology in the evaluations of the CEADIR activity prepared for USAID (2017). This has allowed the CBA to consider ecosystem services such as carbon sequestration and storage estimations, natural hazards and agricultural production. In addition to further externalities such as climate change impacts over time. (Narayan, et al., 2017)

5.2 CBA RESULTS NACALA

The CBA for Nacala estimated the costs and benefits of revegetation of land in the less densely populated areas and a combined measures approach for inner city areas that included retention ponds, improved drainage system, toe protection of gullies and small-scale revegetation in Nacala city.

The study area for this analysis included 13 catchment areas across Nacala city of a total of 18,519 ha of land, of which 1,296 ha are allocated for the application of solution measures. The study area included 5,401 households potentially affected and a total of 27,005 of affected population. The following table summarizes the total land area in each catchment and the allocated land for the nature-based solutions:

Table 5-1 Total Land Area in Hectares Allocated for Solution Measures in Catchment Areas (Nacala)

Catchment Area	Total land area [ha]	Land area allocated for revegetation of land [ha]	% share of land area allocated for revegetation of land [ha]	Land area allocated for combined measures [ha]	% share of land area allocated for revegetation of land [ha]
Area 1	929	650	70% of total land area		0% of total land area
Area 2	75	53	70% of total land area		0% of total land area
Area 3	108	76	70% of total land area		0% of total land area
Area 4	175	123	70% of total land area		0% of total land area
Area 5	351	246	70% of total land area		0% of total land area
Area 6	164	8	5% of total land area	8	5% of total land area
Area 7	275	14	5% of total land area	14	5% of total land area
Area 8	76	4	5% of total land area	4	5% of total land area
Area 9	533	27	5% of total land area	27	5% of total land area
Area 10	154	8	5% of total land area	8	5% of total land area
Area 11	301	15	5% of total land area	15	5% of total land area
Area 12	5,257	-		-	
Area 13	10,121				
Total	**18,519**	**1,222**		**75**	

The Consultant has regarded revegetation of land by planting a range of tree, grass and shrub species, besides 20% dedicated for urban gardening. This is considered in the calculations when measuring the benefits of revegetating the land.

The combined measures include a toe of slope protection measuring a total of 45,171 meters in length, in addition to rehabilitation of drainage system for 27,118 meters in length, as well as 99 retention ponds.

Potential damages in the catchment areas were defined by the expected storm to hit Mozambique, and two types of storms were regarded; current 2019 rainfall and future heavy rainfall expected in 2036. For each scenario, the consultant estimated costs and benefits using primary data from field studies and benefit-transfer methods, and secondary data from a literature review.

5.2.1 Assumptions Nacala

With-project scenarios: The “with project scenario” includes three components, including: (1) Re-vegetation of unused land project spanning across 1,221 ha of unused land in all catchment areas (2) 20% of the 1,221 ha used for revegetated land will be used for urban gardening (3) A combined measures solution across 75 ha including a toe of slope protection measures of a total of 45,171 m in length, in addition to rehabilitation of drainage system for 27,118 m in length, as well as, 99 retention ponds.

Time period: 50 years

Discount rate: The base case uses 6 percent for economic analyses. Sensitivity analyses used discount rates of 0 percent, 3 percent, and 12 percent. The 6- percent discount rate was used in the sensitivity analysis of other parameters

Price of Carbon: Carbon prices used in the sensitivity analysis of CEADIR CBA were used. CEADIR took into consideration carbon prices in the U.S. Regional Greenhouse Gas Initiative (RGGI) and California Air Resources Board cap-and-trade markets as well as the voluntary carbon offset market. As a result, four carbon prices—$0, $8, $15, and $25 per metric ton of carbon dioxide equivalent (tCO2e) were used in the sensitivity analysis.

Costs: The Consultant estimated the construction costs, enforcement and labour costs, transportation, maintenance costs as well as value of damaged homes for all proposed measures.

Benefits: The Consultant estimated the benefits from erosion protection and revegetated ecosystems, including market values of agricultural produce and economic values of carbon sequestration. The combined measures also provide benefits from erosion protection.

Increased quality of life, reduction of mortality and human health impacts are significant benefits expected to be accrued from erosion protection resulting from both solutions. However, the consultant did not estimate these benefits due to a lack of data. The CBA should thus be interpreted as conservative.

Without-project scenario: The base case assumed storm damage costs under a constant probability of storm events. This assumption would not be realistic if severe storm risks increase over time due to climate change. As a result, the benefits of both project alternatives may be underestimated.

Financial and Economic analysis: The financial analysis reflected the perspective of communities in the study area. Most of the available cost data was in U.S. dollars (USD). The team converted local currency costs and benefits to USD at an exchange rate of 63.97 meticais per dollar (based on CES, April 24th, 2019). The economic analysis adjusted for value added tax of 17%, while the financial analysis excluded these adjustments.

5.2.2 Key Results Nacala

The economic net present values (NPV) of solution measures exceeded those of the financial NPV with a financial rate of return of 1.26% at a 6 % discount rate and an economic internal rate of return of 62.04% at 6% discount rate at carbon price 25 $/tCO2e.

Table 5-2 Annuity Values for Financial and Economic Assessments

Annualized Values - Financial	NPV	FIRR
0% discount rate	$1,885	1.26%
3% discount rate	$1,211	
6% discount rate	$388	
12% discount rate	-$1,343	
Annualized Values - Economic	**NPV**	**EIRR**
6% discount rate (Carbon Price #1)	$836	2.85%
6% discount rate (Carbon Price #2)	$5,725	19.67%
6% discount rate (Carbon Price #3)	$10,002	35.90%
6% discount rate (Carbon Price #4)	$16,112	62.04%

With a total area of 1,296 ha allocated for the solution measures, the total investment cost was calculated to equalling around $ 31 million; of which the following CAPEX were considered:

- Rehousing and resettlement costs with a total of around 11,582 $/ha
- Ecological restoration 157 $/ha and initial planting of 1,996 $/ha for revegetated land allocated to 1,221 ha
- Construction of toe protection gullies, retention ponds and the rehabilitation of the drainage system resulting in a total of 10,193 $/ha

The financial and economic benefits accumulated over the period of 50 years for the total number of hectares of the study area (1,296 ha) were calculated at a 6% discount rate. The following table summarize the results. Although results are sensitive to the carbon price assumption, the solution measures will still have a positive NPV at carbon price of zero.

Table 5-3 Financial and Economic Net Present Values of Solution Measures at a 6% Discount Rate

Total Value in USD for 1,296 hectares at 6 % discount rate	
Scenario:	**Solution measures**
Financial Net Benefits	$7,932,270
Financial Annualized Value	$503,262
$0 Carbon Price	
Economic Net Benefits	$17,087,108
Economic Annualized Value	$1,084,084
$8 Carbon Price	
Economic Net Benefits	$116,936,556
Economic Annualized Value	$7,418,961
$15 Carbon Price	
Economic Net Benefits	$204,304,823
Economic Annualized Value	$12,961,978
$25 Carbon Price	
Economic Net Benefits	$329,116,632
Economic Annualized Value	$20,880,574

5.2.3 Conclusion for Nacala

The CBA for Nacala assessed the financial and economic viability of the proposed nature-based flood management solutions for Nacala City. A study area across 11 catchment areas and 1,296 ha were allocated for the solution measures where 977 ha was used for revegetation of land, 244 ha used for urban gardening and 75 ha used for combined measures (rehabilitation of drainage system, toe protection of gullies and retention ponds). The solution measures had a positive economic net present value which exceeded that of the financial net present value in the base scenario. For the project to reach financial breakeven the discount rate should be 1.26%. It could have resulted with a higher bound estimate of the total financial and economic viability if the value of human health and safety and other benefits were considered. More research would be required to help estimate benefits that were not included in this analysis, including reduced human health and safety risks as well as water filtration, biodiversity, and existence values for the revegetated land.

5.3 RESULTS QUELIMANE

The CBA for Quelimane estimated the costs and benefits of a combined measure approach including the construction of multiple retention ponds, drainage channels, shore protections and green revetments, in addition to planting a number of trees/plants ranging from dry grass and wetland communities as well as mangroves. The project in Quelimane city focuses on both natures based and grey based protection measures across 11 catchment areas for rehabilitation and protection.

The CBA quantified the potential costs and benefits of mix of plantation, improved drainage systems, retention ponds, shore protections and green revetments in Quelimane in monetary terms to help determine the risk factors of the project's investment decisions against the potential benefits accrued.

The study area for this analysis included 11 catchment areas across Quelimane city. The study area encompasses around 16.8 million m² or 1,686 hectares (ha) of land that was designated as prioritized protection areas. The study areas included 100,540 households potentially affected and a total of 63,375 of affected population. The following table summarizes the total land area size in each catchment area and the corresponding allocated land for the nature-based solutions:

Table 5-4 Total Land Area in Hectares Allocated for Solution Measures in Catchment Areas (Quelimane)

Location	Total area of catchment sites [ha]	Area used for Grass community [ha]	Area used for Wetland plant mix [ha]	Area used for Mangroves [ha]	Area used for Construction Measures [ha]	Total area used for solution measures [ha]
Whole area of Quelimane	**3,009**					
Site 1	214	11	11	0	11	32
Site 2	34	0	0	0	2	2
Site 3&4	509	8	5	0	25	38
Site 5	158	3	0	13	8	24
Site 6	64	3	0	13	6	22
Site 7	29	1	0	0	1	3
Site 8	288	0	0	7	14	22
Site 9	293	0	15	0	7	22
Site 10	50	1	0	0	2	4
Site 12	47	2	2	0	2	7
Sum (Sites 1 to 12)	**1,686**	**30**	**33**	**33**	**80**	**175**

For each scenario, the consultant estimated costs and benefits using primary data from field studies and benefit-transfer methods, and secondary data from a literature review.

5.3.1 Assumptions Quelimane

With-project scenarios: The "with project scenario" includes two components, including: (1) Green revetment with a total area of 95 ha which includes (1a) 30 ha for grass communities such as Vetiver grass, elephant grass, LM grass and red grass (1b) 33 ha for wetland plant mix including multiple cyperus species, common reed and more (2) A combined measures solution across 80 ha including construction of drainage systems, shore protections, retention basins and protection bridges.

Time period: 50 years

Discount rate: The base case uses 6 percent for economic analyses. Sensitivity analyses used discount rates of 0 percent, 3 percent, and 12 percent. The 6- percent discount rate was used in the sensitivity analysis of other parameters

Price of Carbon: Carbon prices used in the sensitivity analysis of CEADIR CBA were used. CEADIR took into consideration carbon prices in the U.S. Regional Greenhouse Gas Initiative (RGGI) and California Air Resources Board cap-and-trade markets as well as the voluntary carbon offset market. As a result, four carbon prices—$0, $8, $15, and $25 per metric ton of carbon dioxide equivalent (tCO2e) were used in the sensitivity analysis.

Costs: The Consultant estimated the construction costs, enforcement and labour costs, transportation, maintenance costs as well as value of damaged homes for all proposed measures.

Benefits: The Consultant estimated the benefits from household protection including market value of mat weaving production and economic values of carbon sequestration.

Increased quality of life, reduction of mortality and human health impacts are significant benefits expected to be accrued from flood protection resulting from both solutions. However, the consultant did not estimate these benefits due to a lack of data. The CBA should thus be interpreted as conservative.

Without-project scenario: The base case assumed storm damage costs under a constant probability of storm events. This assumption would not be realistic if severe storm risks increase over time due to climate change. As a result, the benefits of both project alternatives may be underestimated.

Financial and Economic analysis: The financial analysis reflected the perspective of communities in the study area. Most of the available cost data was in U.S. dollars (USD). The team converted local currency costs and benefits to USD at an exchange rate of 63.97 meticais per dollar (based on CES, April 24th, 2019). The economic analysis adjusted for value added tax of 17%, while the financial analysis excluded these adjustments.

5.3.2 Key Results Quelimane

The economic net present values (NPV) of solution measures exceeded those of the financial NPV with a financial rate of return of 19.29% at a 6% discount rate and an economic internal rate of return of 117.51% at 6% discount rate at carbon price 25 $/tCO2e.

Table 5-5 Annuity Values for Financial and Economic Assessments

Annuity Values - Financial	*NPV*	*FIRR*
0% discount rate	*$17,407*	19.08%
3% discount rate	*$15,584*	
6% discount rate	*$13,596*	
12% discount rate	*$9,409*	
Annuity Values - Economic	***NPV***	***EIRR***
6% discount rate (socio-economic benefit by reduced risk)	$35,075	52.64%
6% discount rate (Carbon Price #1)	$14,472	22.48%
6% discount rate (Carbon Price #2)	$52,610	81.11%
6% discount rate (Carbon Price #3)	$85,980	158.17%
6% discount rate (Carbon Price #4)	$133,652	573.15%

With a total area of 175 ha allocated for the solution measures, the total investment cost was calculated to equalling around $ 8.7 million; of which the following CAPEX per site were considered:

Table 5-6 Annuity Values for Financial and Economic Assessments

Site No.	Total Investment cost per SiteUS $	
Site 1	$	980,073
Site 2	$	750,000
Site 3&4	$	724,449
Site 5	$	47,235
Site 6	$	3,397,991
Site 7	$	1,156,829
Site 8	$	742,262
Site 9	$	51,000
Site 10	$	596,275
Site 12	$	230,652
various	$	71,300
Total	**$**	**8,748,066**

The financial and economic benefits accumulated over the period of 50 years for the total number of hectares of the study area (175 ha) were calculated at a 6% discount rate. The following table summarize the results. Although results are sensitive to the carbon price assumption, the solution measures will still have a positive NPV at carbon price of zero.

Table 5-7 Base Sensitivity: Financial and Economic Net Present Values of Solution Measures at a 6% Discount Rate

Total Value in USD for 175 ha at 6% discount rate	
Scenario:	***Solution measures***
Financial Net Benefits	$33,285,526
Financial Annualized Value	$2,389,644
Socio-economic benefit by reduced risk	$85,868,901
$0 Carbon Price	
Economic Net Benefits	$35,430,210
Economic Annualized Value	$2,543,615
$8 Carbon Price	
Economic Net Benefits	$128,795,971
Economic Annualized Value	$9,246,551
$15 Carbon Price	
Economic Net Benefits	$210,491,011
Economic Annualized Value	$15,111,619
$25 Carbon Price	
Economic Net Benefits	$327,198,212
Economic Annualized Value	$23,490,288

5.3.3 Conclusions for Quelimane

The CBA for Quelimane assessed the financial and economic viability of the proposed nature-based and hybrid storm management measures for Quelimane City. A study area across 11 catchment areas and 175 ha were allocated for the solution measures which included: 1) Green revetment with a total area of 95 ha (30 ha for grass species, 33 ha for wetland plant mix); 2) Combined measures solution across 80 ha including construction of drainage systems, shore protections, retention basins and protection bridges.

The solution measures had a positive economic and financial net present value. For the project to reach financial breakeven the discount rate should be 19.29%. Similar to Nacala, it could have resulted with a higher bound estimate of the total financial and economic viability if the value of human health and safety and other benefits were considered. More research would be required to help estimate benefits that were not included in this analysis, including reduced human health and safety risks as well as water filtration, biodiversity, and existence values for the revegetated land.

6 RECOMMENDATIONS FOR THE PILOT CITIES

6.1 NACALA

Erosion in Nacala is becoming alarming and may even threaten the future of Nacala as a deep-water port. There is a danger that one day these deep waters may cease to exist because of the sediments accumulating in the access channel and in the port itself. Most of the erosion gullies in Nacala are in areas of informal settlements without any regular drainage system. The proposed nature-based solutions are centred on erosion reduction in the city.

Several nature-based solutions have been identified to stabilize these gullies and to reduce to the overall direct runoff in case of heavy rainfalls. Measures with the highest identified overall potential to improve the situation in Nacala are:

- Large-scale runoff reduction:
    - Revegetation measures
    - Urban gardening initiatives
    - Soil bunds
- Stabilization of existing V-shaped gullies:
    - Filter unit rock bags
- Combined measures in densely populated areas (inner city):
    - Detention ponds
    - Gully embankment protection measures
    - Small scale revegetation / urban gardening
    - *(Rehabilitation and improvement of existing drains and drainage infrastructure, re-quired grey and/or hybrid solutions)*
- Preventive measures in areas prone to further urbanisation (eastern catchments)
    - Meso-scale retention ponds

The identified nature-based solutions will help to improve the situation in Nacala. Nevertheless, it needs to be stated that a general drainage master plan will have to be elaborated for Nacala to change the situation in a holistic way. Besides the above-mentioned green infrastructure measures a hybrid approach including both – green and grey infrastructure measures will be most realistic result of a drainage mater plan as in densely populated areas the use of nature-based solutions only will require lots of land and thus high support by the local population.

6.2 QUELIMANE

The situation encountered in Quelimane reveals a complex picture regarding the necessity of technical and analytical support to contribute in the upscaling of nature-based solutions for urban flood risk management. The kind of problems and their impact on the population of Quelimane depends on the actual environment studied within the city's boundary. In summary, the main problems encountered during the site visit and desktop studies are:

- Flooding (including daily inundation at high tides)
- Deforestation
- Lack of stormwater management

The situation is strongly influence by the ongoing development of informal settlements including industries that develop into flood-prone parts of the municipality; often being associated with deforestation of mangrove trees for fuelwood and timber.

The incorporation of wetlands, rivers and landscapes into nature-based or hybrid solutions for flood protection provides cost-effective, long-term options for service delivery to people that can supplement or even substitute built infrastructure.

Measures, either nature-based or hybrid that have been identified to be applicable in and around Quelimane comprise (amongst others):

- Stormwater Management:
    - Installation of flap gates
    - Expansion/ Rehabilitation of wastewater /drainage system
    - Continuous maintenance of existing drainage channels
    - Construction of retention basins

- Reinforcement of Bridges and Bank walls:
    - By various – mostly hybrid – solutions

- Protection of Wetlands:
    - From informal settlements
    - From deforestation
    - By stabilisation of slopes

The implementation of a combination of the described measures will be capable to improve the situation for the city of Quelimane. However, it is important to assure that any of the described solutions, either green, grey or hybrid, need to be implemented involving the local population and stakeholders in order to assure their long-term success.

The main proposed measures for both cities – Nacala and Quelimane – are summarized and presented within the fact sheets attached to this Knowledge Note. The sheets could be described best as initial technical guides to inform selection of various NBS measures, actionable recommendations for policy makers which provide key-findings for the broader knowledge community around nature-based solutions. The fact sheets are prepared for a basic overview of the proposed measures. For more information please refer to the detailed description of the measures in the task 3 report (Nacala and Quelimane Report).

7 REFERENCES

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Fact Sheet - 01

Revegetation

Description

Revegetation aims to reduce runoff on a large scale by planting of different plants which allows to reinstate a natural vegetation cover.

Besides utilizing revegetation as a large-scale, area-wide measure the method can be used on a smaller scale as well in order to stabilise existing gullies, as a toe of slope protection or to revegetate unused land for runoff reduction.

Type of Measure:	Area-Wide
Plants to be used:	- Vetiver Grass - Elephant Grass - Moringa Tree

Grey vs. Green Infrastructure Scale

Rating – Revegetation

Design Efforts	Low
Construction Time	High
Implementation Costs	Medium
Maintenance Efforts*	Medium

* depends on location

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

Low · Medium · High

Specific Use in Nacala

Revegetation as an area-wide measure can be applied in the less-densely populated areas in the northern part of the city as a main measure. As an accompanying measure it can be used anywhere to reduce erosion risks.

Fact Sheet - 02

Soil Bunds

Description

A soil bund is a structural measure with an embankment of soil, or soil and stones, constructed along the contour lines and stabilized with vegetative measures, such as grass and fodder trees.

Bunds reduce the velocity of runoff and soil erosion, retain water behind the bund and support water infiltration. It further helps in ground water recharging and increases soil moisture which can result in better yields as a benefit for local farmers.

Type of Measure: Area-Wide
Required Equipment: - Manpower
- Shovels

Grey vs. Green Infrastructure Scale

Rating – Soil Bunds

Design Efforts

Construction Time

Implementation Costs

Maintenance Efforts

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

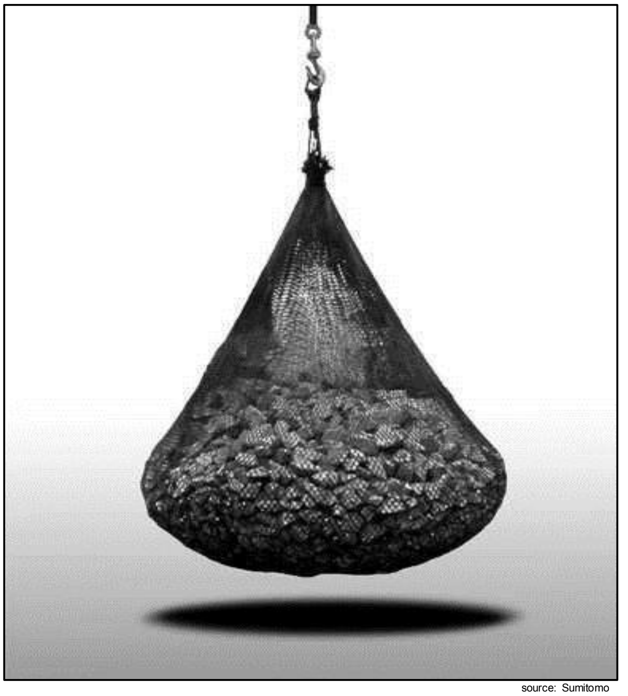
Low Medium High

Specific Use in Nacala

As an alternative to revegetation measures soil bunds can be constructed in the northern part of the city. Due to a simple design an implementation with minor efforts will be possible.

Fact Sheet - 03

Rock Bags (Filter Units)



source: Sumitomo

Description

For v-shaped erosion gullies with small bottom widths (1-3 meters only) and steep side slopes the installation of rock bags (filter units) is beneficiary. As the rock bags can block the entire width of these narrow gullies they will serve as small check dams.
The bags have a simple design as they are made of recycled synthetic material and filled with stones available at the location. Total size of the rock bag can be 2,4 or 8 metric tons. After filling is completed the bag can be lifted by a mobile crane and deposited in the gully.

Type of Measure: Single-Spot
Required Equipment: - Bags + Stones
- Crane

Grey vs. Green Infrastructure Scale

Rating – Rock Bags

Design Efforts

Construction Time

Implementation Costs*
*) depends heavily on the availability of stones at the location

Maintenance Efforts

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

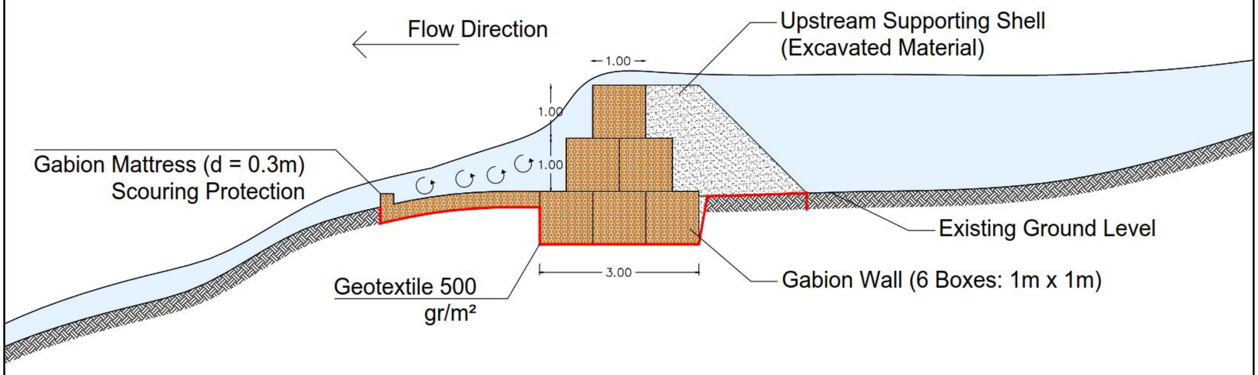
Low Medium High

Specific Use in Nacala

In locations with steep v-shaped gullies rock bags will be beneficial for avoidance of further erosion in the gully. The northern parts of the city are preferred locations for implementation.

Fact Sheet - 04

Detention Ponds



Description

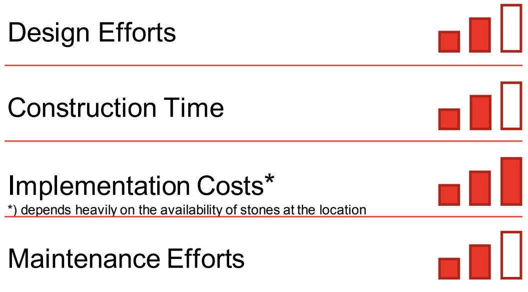
The main purpose of a detention pond for erosion protection is to reduce the flow velocities within wide gullies. As the erosion rate is directly connected to the flow velocity this will be a highly beneficial measure if several ponds will be installed on a variable distance (depends on longitudinal slope).
Principle design for one pond can be:

- entire width of a gully
- crest height of up to 2 meters
- core of gabion walls (stabilization)
- geotextile for scouring protection
- planting of vegetation on top

Type: Single-Spot Measure
Material: Gabion Boxes, Stones, Geotextile, Seedlings

Grey vs. Green Infrastructure Scale

Rating – Detention Ponds



Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

Low Medium High

Specific Use in Nacala

The detention ponds can be used in densely populated areas with wide gullies as identified in the most central parts of the cities. Accompanying measures can be gully embankment protection and an overall improvement of the drainage system.

Fact Sheet - 05

Preventive Erosion Protection Measures

(Recreational Parks as Meso-Scale Retention Ponds)

Description

As a preventive erosion and flood protection measure creation of recreational areas that serve as possible retention basins could help to mitigate flood and erosion risks. Recreational areas (parks) that can be flooded as a large-scale retention basis should be prioritized in town development plans and prior to construction of new areas.

In addition to the construction of recreational areas low share of sealed surfaces and remaining a high vegetation cover can be considered.

Type: Single-Spot Measure
Requirements: - Recreational Areas
- Flood Control Structures

Grey vs. Green Infrastructure Scale

Rating – Preventive Measures

Design Efforts	Medium
Construction Time	Medium
Implementation Costs*	Low
Maintenance Efforts	Medium

* Recreational Areas will be beneficial beyond flood protection purposes

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

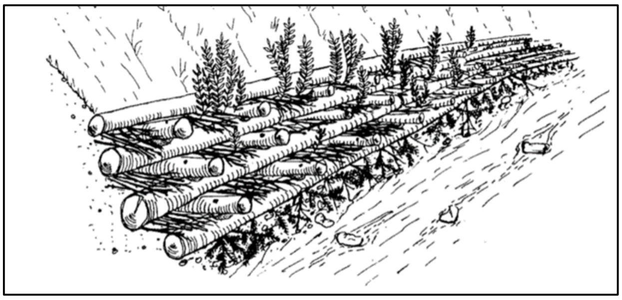
Low Medium High

Specific Use in Nacala

In contrast to the densely populated central areas there is more land available towards the eastern end of Nacala which will be prone to further urbanization. Creating recreational areas which can be used as retention ponds will be beneficiary.

Fact Sheet - 06

Gully Bank Stabilisation Measures



Description

As an accompanying measure the embankments of existing erosion gullies need to be protected against further erosion. As most of the gullies are not completely filled during rainfall events the main focus will be to protect the toe of the embankments as most of the erosion rates comes from collapsing side slopes into the gully because of previously eroded material at the toe of these slopes.

Different stabilization solutions could be:
- Planting Vegetation (e.g. Vetiver)
- Crib or Tyre Retaining Walls
- (Plantable) Concrete Blocks

Type: Linear Measure
Requirements: Plants / Cribs / Tyres / Concrete Blocks

Grey vs. Green Infrastructure Scale

Rating – Bank Stabilisation

Design Efforts

Construction Time

Implementation Costs

Maintenance Efforts

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

Low Medium High

Specific Use in Nacala

All presented solutions for embankment erosion protection measures for existing erosion gullies are feasible in Nacala. The use of vetiver grass could be the solution of choice due to its characteristics as highly nature-based method.

Fact Sheet - 07

Green Revetment of Slopes

Description

Vegetation reinforced slopes and embankments provide effective erosion protection along river banks and wetlands. Green revetment can be achieved/stabilised by spreading out geotextiles or geochutes that prevent new soil from erosion until vegetation and the root system is strong and widespread enough to take over this protective effect.

Type: Linear measure

Material:

- Geotextile (from coconut fibre) or geochutes filled with earth and planted to establish a durable vegetation cover,
- Robust and adaptable plants (for dry and wet season)

Grey vs. Green Infrastructure Scale

Rating – Green Revetment of Slopes

Design Efforts

Construction Time

Implementation Costs

Maintenance Efforts

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

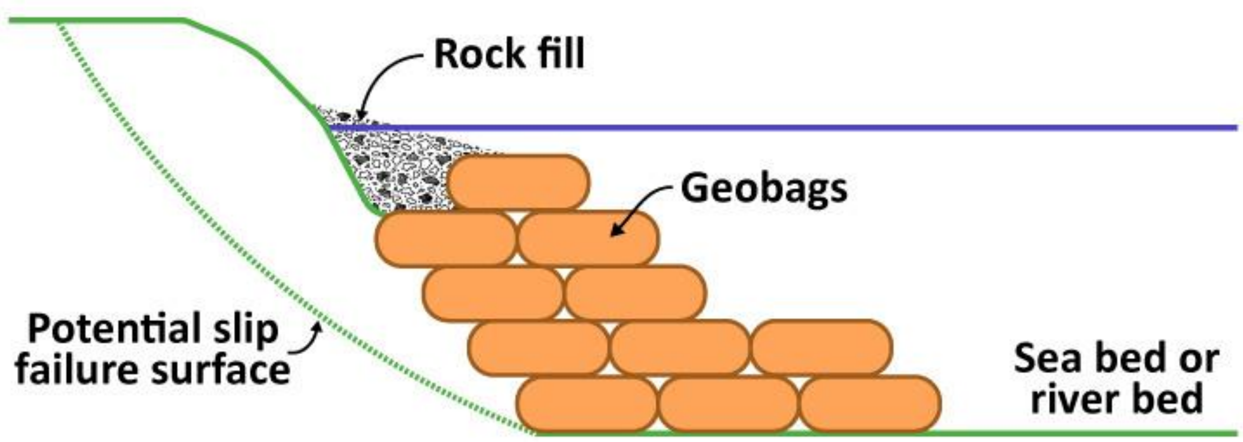
Low Medium High

Specific Use in Quelimane

To protect the coastline and river banks of Quelimane from further erosion, the green revetment of slopes and dikes can provide an effective protection against flooding and erosion due to storm surges or high tides.

Fact Sheet - 08

Coast Protection with Geotextiles



SLOPE BUTTRESSING

Description

Buttressing of slopes by sand-filled geotextile bags haven proven to provide an effective protection of shorelines against erosion and flooding. The use of local resources, their low construction and maintenance efforts are a well-known advantage of this solution. Bags can normally be filled with sand directly on-site.

Type: Linear measure

Material:

- Geotextile bags filled with sand (mostly natural resources)

Grey vs. Green Infrastructure Scale

Rating – Geotextiles

Design Efforts	Low
Construction Time	Medium
Implementation Costs	Low
Maintenance Efforts	Medium

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

Low Medium High

Specific Use in Quelimane

To protect the coastline of Quelimane the installation of sand-filled geotextile bags can provide an effective protection against flooding and erosion due to storm surges.

Fact Sheet - 09

Reinforcement of Bridge Abutments

Description

Flow velocities in the riverbeds can be very high during the tides. In combination with the narrowing of river's cross section by bridge abutments and erosion-prone soils, this may result in a very high risk of watercourse erosion.

Type: Single-spot measure

Material / Requirements:

- Stone rip rap and gabions (mostly natural resources)
- To prevent loose stones to be taken away (for building material), superficial grouting of the stones can be foreseen

Grey vs. Green Infrastructure Scale

Rating – Bridge Abutment

Design Efforts

Construction Time

Implementation Costs

Maintenance Efforts

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

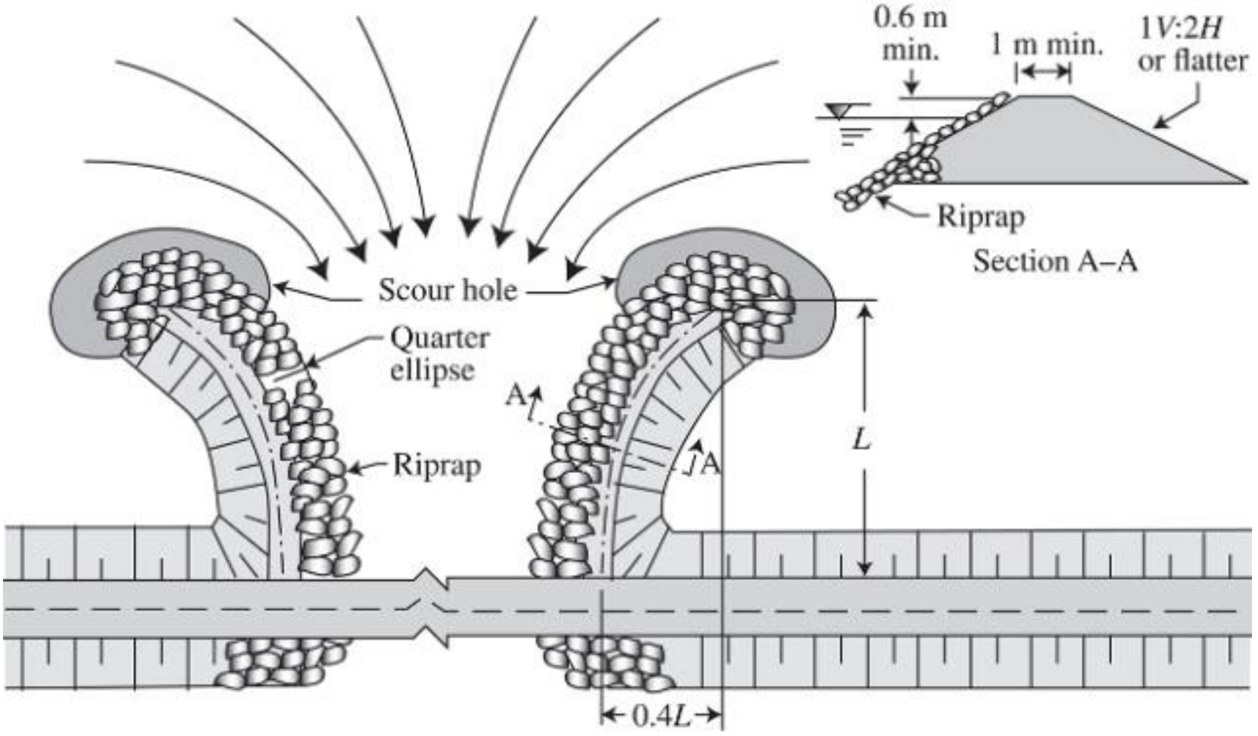
Low Medium High

Specific Use in Quelimane

At some places, watercourse erosion already led to the collapse of the original bridges. To prevent ongoing erosion at the bridge site, planning for better protection of the bridge abutments should be taken into account.

Fact Sheet - 10

Guide Banks



Description

Guide banks are one of the most effective bridge protections where a road embankment crosses a floodplain. It rapidly reduces diverging flow turbulences and scour leading to a smooth flow and thus less erosion.

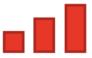
Type: Single-spot measure

Material:

- Sand fill with stone rip rap (mostly natural resources)
- To prevent loose stones to be taken away (for building material), superficial grouting of the stones can be foreseen

Grey vs. Green Infrastructure Scale

Rating – Guide Banks

Design Efforts 

Construction Time 

Implementation Costs 

Maintenance Efforts 

Design Efforts	Design efforts (time, knowledge) required for implementation.
Construction Time	Time until full impact of the measure will be achieved.
Implementation Costs	Estimated costs for implementation in relation to its impact.
Maintenance Efforts	Annual efforts for sustainment of the structure / measure.

Low  Medium  High 

Specific Use in Quelimane

At some places, watercourse erosion already led to the collapse of the original bridges. To prevent ongoing erosion at the bridge site, planning for better protection of the guide banks could offer a valuable solution.