

Climate Change Adaption Strategies in Developing Countries – Exemplary Flood and Erosion Protection Projects in Mozambique

Dr.-Ing. H. Spekker & Dr. B. Kleinefeld
Inros Lackner SE, Linzer Str. 3, 28359 Bremen, Germany

Abstract: Mozambique is one of the countries most exposed to coastal and river flooding in Africa. The majority of flood and erosion protection investments 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 including the degree of urbanization, existing infrastructure, local capacities (construction and operation), etc., nature-based solutions are becoming a preferred option by international financing institutions, national agencies as well as local stakeholders. Especially when looking at small-scale interventions (e.g. afforestation measures), nature-based solutions can be a more cost-effective option and may also be implemented and operated / maintained by local agents, including communities and NGOs (Non-governmental organization).

INROS LACKNER SE is involved in several climate change adaptation projects in Mozambique. The primary outcomes of the recent project on nature-based coastal protection in the pilot city of Beira and consultancy work on upscaling nature-based flood protection in the cities of Quelimane and Nacala are described and discussed in the present paper.

Keywords: climate change adaption, coastal-protection, nature-based solutions, Beira, Nacala, Quelimane, Mozambique

1 Introduction

Beira, Quelimane and Nacala are meaningful trading and port cities at the coastline of Mozambique. Beira is an important port city with a population of approximately 500,000 people. Quelimane and Nacala are both located at riverine estuaries. Nacala has a population of approx. 250,000 people and Quelimane of approx. 350,000 people.

In Beira, large parts of the city centre are just above sea level and since the Indian Ocean in this area has a very large tidal range of up to 7 m, reliable coastal protection is of great importance. Beira is considered to be the city most threatened by climate change in Mozambique and one of the cities most threatened in Africa. It is predicted that the sea level in this region will rise and that rainfall and dry periods will increase. The situation will get even worse going forward. The inhabitants of informal settlements with their businesses are particularly at risk, as are various parts of the city centre.

The average height of Quelimane is close to the medium sea level and prevailing topographic conditions are similar to those found in Beira and mean high water spring reaches 4.7 m above chart datum. As such, inundations after intense rainfall and storm surges together with coastal erosion and saltwater intrusion are major challenges for the city's resilience and the city and its residents are vulnerable to a combination of climate change impacts, including cyclones, flooding and erosion.

In contrast, the urban area of the City of Nacala has many steep slopes that run towards the sea and intense rainfalls - in particular those deriving from tropical cyclones - cause excessive runoff. These excessive storm waters in combination with fragile soils deprived from vegetation or supporting structures lead to significant erosion problems threatening both, public and private assets. Major

flooding and erosion risks in Nacala are thus mainly associated to its steep terrain and storm water runoff.

In 2019, three extreme weather events (cyclones Desmond, Idai, and Kenneth) have led to catastrophic flooding and storm damages throughout Mozambique. The cyclone, described by the UN as one of the deadliest storms on record in the southern hemisphere, caused a total death toll of more than 1000 including 602 people in Mozambique (Devi, 2019).

Nature-based solutions can help mitigate flood, drought, erosion and landslide (World Bank, 2017). The objective of the manuscript is to present nature-based erosion and flood protection measures in development countries like Mozambique.

2 Beira – Flood Protection, Nature-Based Erosion Protection and Green Infrastructure

The Chiveve tidal river, which runs through the city of Beira over a distance of approximately 5 km, was neglected in the past and became increasingly silted up to the point that it no longer served as a drainage channel for the surrounding area. Rubbish was disposed of on the wetlands and the standing water promoted the spreading of diseases, such as malaria and cholera. During very high tides or storm surges in the adjacent ocean, combined with heavy rainfall, the Chiveve regularly overflowed its banks and flooded much of its catchment area – particularly the informal settlements along its riversides (see Fig. 1).



Fig. 1. Flooded area in the informal settlement Goto during the rainy season.

To enhance the situation for the city's population in the long-term, the German development bank (Kreditanstalt für Wiederaufbau, KfW) on behalf of the German Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit, BMZ) set up and financed a project aiming at the improvement of the city's drainage system and flood protection. The project also included the re-establishment of the original river course and the construction of nature-based erosion protection solutions along the river banks. A second project phase that further refines the project results by the creation of a green landscape park in the river catchment area is financed by KfW and World Bank Group and planned and realized in the period from 2018 to 2021.

2.1 *The New Flood Barrier*

As one major result of the project, a new flood barrier and new drainage channels (see Fig. 2 and Fig. 3), designed by Inros Lackner SE and Consulting Engineers Salzgitter GmbH are protecting the port city on Mozambique's Indian Ocean coast and improving the city's drainage since 2017.

The barrier's gates allow to control the water level upstream. Due to the construction of a retention basin and a precise control of the gates, the area's drainage system now functions far more effectively and thereby, the flooding situation along the Chiveve River was significantly improved. The barrier's effectiveness was put to the test at the end of February 2017, when approximately 225 mm of rain fell during a 24-hour period – a level of rainfall that, on average, is only expected once every ten years – and no significant flooding occurred in the project area. Moreover, after storm Desmond in January 2019, when approximately 355 mm of rain fell during a 24-hour period, no extreme water levels were measured upstream of the tidal gate, again.



Fig. 2. Aerial photograph of the Chiveve river mouth including the new flood barrier.



Fig. 3. Construction of the drainage channel upstream of the tidal outlet.

2.2 Nature-Based Erosion Protection

The project also included a comprehensive plan for the reestablishment of the original course and nature-based erosion protection solutions along the embankments of Chiveve river. It also comprised dredging of sludge within the fishing port downstream, resettlement measures and the planting of young mangroves along the river banks, including a nearby coastal area (see Fig. 4).

A local NGO is responsible for extensive reforestation measures in order to compensate for the cutting of mangroves that had to take place in the course of the construction works. The mangrove trees were cut into regular wood logs and used by a practical training centre for the manufacture of

school furniture. An Info Point near to the construction site provides broad information of the construction works and the importance of future maintenance to the public.



Fig. 4. Reforestation of mangrove forests in Nhangau.

2.3 Green Urban Infrastructure for Beira

The green belt in the middle of the city centre is expected to protect the course of the river, which is lined with mangroves, from progressing urbanisation. It is developed to become a recreational area for the population, including restaurants, an exhibition centre and amphitheatre, a botanical garden, sports facilities and children's playgrounds. Over 7000 trees will be planted.

The green infrastructure is supported by the project through a grant from the Pilot Program for Climate Resilience, which aims to transform the Chiveve River margin areas into a green urban park that offers ecosystem services (biodiversity, drainage, urban cooling and flood mitigation), as well as economic and recreational opportunities to Beira citizens.



Fig. 5. Planned landscape development along the Chiveve River.

In order to encourage people to use and therefore value the park and river system, passive and active recreational activities, art installations and activation nodes have been located along the river length. These nodes respond to the surrounding urban context and the existing social patterns and needs, providing exciting programming for the park.

3 Quelimane and Nacala - Nature-Based Solutions for Urban Flood Risk Management

In 2018, Inros Lackner SE in joint venture with CES Consulting Engineers Salzgitter GmbH were awarded a contract for consultancy services for upscaling nature-based flood protection in Mozambique's cities by the World Bank. The main objectives of the project were to identify the lessons learnt of the green infrastructure pilot project in Beira as well as to identify and assess different options for nature-based and hybrid solutions to manage urban flood risks in the two pilot cities of Quelimane and Nacala. The outcomes of the services provided are also planned to be used to support the future application of similar solutions in the wider Africa region.

During field visits to Nacala and Quelimane in 2018 and 2019, various locations found to be characteristic of the prevailing conditions in and around the cities were inspected and documented by photographs. Moreover, workshops were held together with local stakeholders and representatives of various authorities aiming at the collection of more specific data on representative sites as well as more detailed information on existing problems. In both cities, the activities were pioneered by a community mapping campaign delivering precious information in the run-up. The results of the field visit and the workshop were used as a basis to categorize the investigated sites and to develop appropriate concepts for the implementation of nature based countermeasures.

3.1 Challenges in the City of Quelimane

The main challenges in the City of Quelimane relate to flooding of infrastructure (houses, roads, airport, agricultural areas, etc; see Figure 6.), deforestation (which exacerbates the flooding), and lack of maintenance of the storm water infrastructure.



Fig. 6. Aerial photograph of informal settlements in Quelimane during high tide.

Flooding:

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 during spring 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 hydrology (i.e. the volume, velocity and frequency) of surface flow throughout the City. This may contribute to flooding, and may exacerbate the lack of capacity of the storm water management system.



Fig. 7. Industrial development (within the red outline) in a wetland.

Deforestation:

The removal of mangroves and other indigenous and even exotic trees 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. Trees, shrubs and grasses also get rid of water through transpiration, thereby reducing the total volume of water exiting the catchment.

Storm water management:

The management and maintenance of the storm water and flood protection drainage system within Quelimane pose some real challenges. The formalised storm water 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, 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 in these areas and isolation of parts of the City during these floods.

The storm water infrastructure is not keeping pace with the urbanisation and densification of houses, roads and infrastructure in Quelimane, and does not cater for the predicted increases in the frequency and intensity of storms due to climate change across the African continent. This does not allow for the systematic and effective design of storm water management systems within the City, which would be able to cope with the volume and velocity of runoff experienced during the high rainfall months, especially during storms and cyclones.

According to the Preliminary City Risk Profiles from the CityCORE Africa Project and after evaluation of the visited sites, 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

Moreover, in order to minimize future losses and the extent of the required measures, further development of settlements in the wetlands should be prevented.

The visited locations were categorized according to the prevailing challenges. To account for the objectives described above, adequate protection measures were identified and proposed to be applied to each site. The following measures have been proposed to enhance the overall situation of the city of Quelimane:

- Construction of new drainage channels/pipes
- Maintenance of existing drainage channels
- Enhancement of dikes with green revetments
- Construction of green revetment of slopes
- Protection and regrowing of mangroves
- Construction of retention basins
- Installation of flap gates
- Shore protection by construction of revetments/dikes
- Protection of bridge abutments
- Construction of culverts

3.2 Challenges in the City of Nacala

The situation regarding flood risks in Nacala is quite different from the one in Quelimane. The flooding hazard is mainly existent as an urban flood risk in case of heavy rainfall. The terrain profile of Nacala is quite steep and there is no general risk of flooding of entire districts in Nacala. Main risks elements for Nacala had been previously identified as follows:

- Flood risks
- Erosion risks

The risk for flooding has been determined and assessed within previous steps and the field visits. As a result of this assessment flood risks and possible damages due to flooding of large areas can be neglected for Nacala.



Fig. 8. Erosion due to storm water runoff in Nacala City.

Although heavy rainfalls do not lead to large-area flooding, rainfall induces very concentrated runoff forming multiple gullies which dispose the rainfall towards the sea. The Mayor of Nacala has even warned that erosion in the city is becoming alarming and may even threaten the future of Nacala as a deep-water port as 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.

Due to the high flow velocity and high bed shear stress the gullies tend to deepen every year. This leads to collapsing side slopes and the disposal of this material which results in growing – relating to their width – gullies.

Therefore, the main risk in Nacala is further erosion along existing gullies or forming of new gullies if runoff paths are changed or disturbed. Further erosion along the gullies is endangering people, houses and infrastructure. As an outcome of the collected and assessed data the focus for the municipality of Nacala is on erosion mitigation strategies along the existing drainage canals.

The management and maintenance of the storm water drainage system within Nacala City pose some real challenges. 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 (in terms of erosion and flooding) areas within the City, which has been followed, in some areas, by the removal of families to safer areas, and then the consequent return of families back to the same risky areas. Industrial complexes have also been constructed across drainage lines, leading to the diversion of surface flow into channels and pipelines that cannot always accommodate the volumes of water received.

These boundary conditions do not allow for the systematic and effective design of a storm water management systems within the City, which would be able to cope with the volume and velocity of runoff experienced during the high rainfall months when Nacala receives high rainfall volumes falling in intense rainfall events over short periods. Erosion is the product of rainfall, soil, slope, cover, land-use and cultivation practices. At Nacala, the rainfall lands on soils that are mostly sandy, on steep slopes with little vegetative cover.

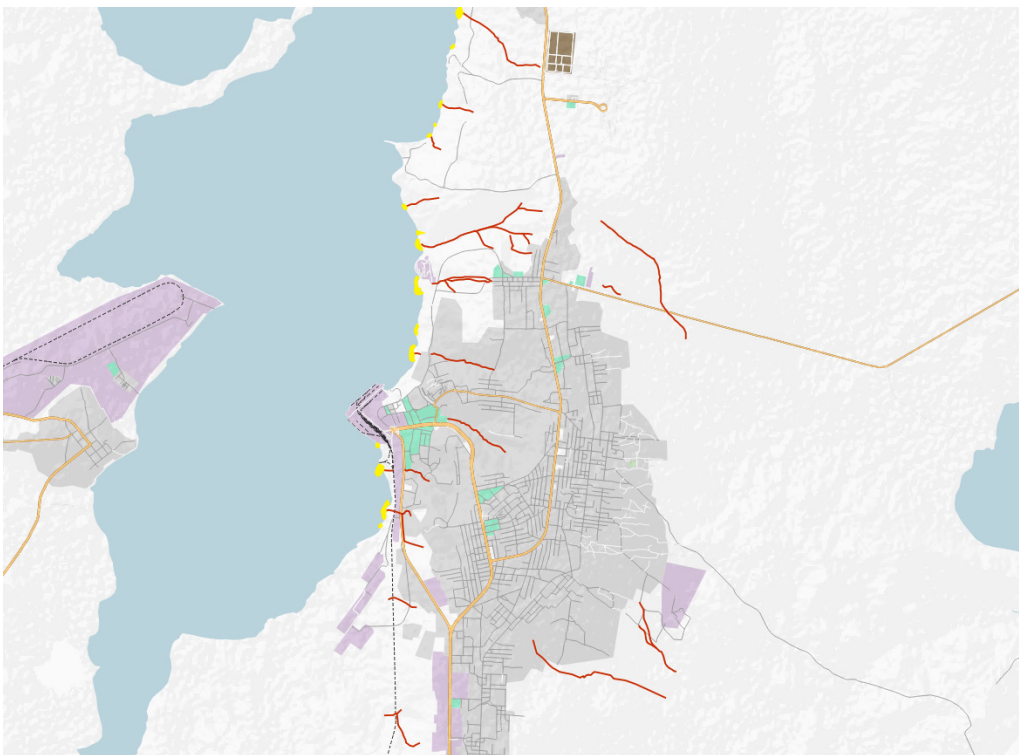


Fig. 9. Location of Erosion Gullies (Red) and Deposits in the Sea (Yellow).

Additionally, the proliferation of buildings, industries and roads in the City has led to hardening of the catchments, through soil sealing and thus changing the hydrology (i.e. the volume, velocity and frequency) 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 further instability of the soils. Unstable soils have a greater potential for erosion, and sedimentation along the coastline where these soils are deposited. Trees, shrubs and grasses would also dissipate water through transpiration, thereby reducing the total volume of water exiting the catchment.

Furthermore, formalised storm water 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 forms a new erosion gully depositing more sediment downstream. The steep slopes and unstable soils merely exacerbate the problem. In some cases, the banks of these erosion gullies are dangerously unstable, leading to loss of lives where banks have subsided. In other cases, roads and houses are washed away and parts of the City become flooded and/or isolated.

In summary, the storm water 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.

Based on the findings of the field visit in August 2018 the main priorities for Nacala are – amongst others:

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

To round off the field and conceptual work performed at both pilot cities, the study was supplemented by a risk assessment, ecological mapping and a cost benefit analysis. So far, only first estimates on costs, the potential to mitigate risks and the dimensioning of green infrastructure could be given due to the conceptual concept of the project. However, the results of the project already provide a profound basis for future works in the region of Quelimane and Nacala

References

- Avellán, T. & Gremillion, P., 2019. "Constructed Wetlands for Resource Recovery in Developing Countries". *Renewable and Sustainable Energy Reviews*, Volume 99, January 2019, Pages 42-57, DOI: 10.1016/j.rser.2018.09.024
- Cairncross, S. & Alvarinho, M., 2013. "The Mozambique floods of 2000: health impact and response." *Flood Hazards and Health*. Routledge, 123-139.
- Cohen-Shacham, E. et al., 2016. "Nature-based Solutions to address global societal challenges", IUCN, Gland, Switzerland, DOI: 10.2305/IUCN.CH.2016.13.en
- Devi, S., 2019. "Cyclone Idai: 1 month later, devastation persists." *The Lancet* 393.10181 (2019): 1585.
- Renaud, F.G. et al. 2016. "Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice", Springer, Switzerland
- Spekker, H, Heskamp, J., 2017. Flood protection for the City of Beira, *Bautechnik* 94 (2017), issue 12, vol. 94, (872-874), DOI: 10.1002/bate.201710102.
- World Bank. 2017. "Implementing nature-based flood protection: Principles and implementation guidance." Washington, DC: World Bank.