The selection and design of vegetated dunes as preferred main coastal protection system for Beira, Mozambique

Odelinde Nieuwenhuis, Royal HaskoningDHV, odelinde.nieuwenhuis@rhdhv.com
Esther Heineke, TU Delft, e.j.heineke@gmail.com
Peter Letitre, Deltares, peter.letitire@deltares.nl
Tom Wilms, Witteveen en Bos, tom.wilms@witteveenbos.com

INTRODUCTION

The coastal city of Beira is vulnerable to cyclones, storm surges, sea-level rise and floods from intensive rainfall events because of its low-lying situation. Cyclone Idai in 2019 has proven this again. A significant improvement of the coastal protection scheme is needed to provide sufficient protection for Beira to protect from hazards from sea and climate change for decades to come. The coastal protection infrastructure is to be integrated into the urban and natural environment of Beira, whilst seeking socio-economic, environmental and urban synergy. In this context, we performed an extensive flood and erosion risk assessment, feasibility study and design, environmental and social scoping study and set up an implementation strategy for the selected preferred alternative and priority measures. This included an intensive stakeholder engagement process throughout the project (2020-2022).

CURRENT COASTAL SYSTEM

The current coastal system in Beira consists of:

- A natural dune ridge along the southern and eastern shoreline (stretch 3 and 4 in Figure 1). Stretch 3 is a developed and urbanized zone, while stretch 4 is currently still less developed (but with plans for further development in the future). In stretch 3 the natural dune ridge is combined with short groins to strengthen the backshore, which are lacking maintenance efforts.
- A very low-lying and frequently flooding area called Praia Nova in the southwestern corner (stretch 2 in Figure 1). Praia Nova has transformed from a mangrove area towards a low-lying and frequently flooding area with informal settlers over the past decades. Only a few small patches of mangroves remain.
- The port area along the western shoreline (stretch 1 in Figure 1). After further discussions, this stretch was excluded from the scope of our interventions.

Several drainage outlets are present; the Rio Chiveve outlet (between stretch 2-3), Las Palmeiras outlet (stretch 3). Also, a new drainage outlet is planned in stretch 4.

Figure 1: Main geographical features Beira coastal zone

PREFERRED ALTERNATIVE SELECTED

The preferred coastal protection intervention selected for Beira is to strengthen, restore and (re)vegetate the existing natural dune ridge along coastal stretches 2, 3 and 4 to obtain a 1:50 per year flood protection level. Also, foreshore nourishments are proposed to compensate for expected erosion losses in the coming 20-25 years.

Only along dedicated short sections, where soft solutions are not feasible, is it proposed to implement a floodwall or revetment. For example; the old seawall in coastal stretch 2 near the port area is planned for reinforcements/ small repairs. Some local floodwalls are envisaged for more inland parts of stretch 2. Along the shorelines starting from Praia Nova at coastal stretch 2 up to stretch 4 (subsections 5 to 9 in Figure 2), dune restoration and strengthening is selected as main solution. Existing small mangrove patches are maintained and strengthened as much as possible. The physical measures proposed are visualized in Figure 2.

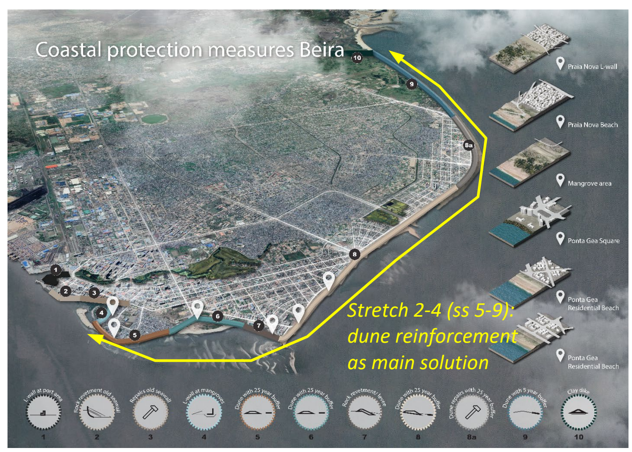

Figure 2: Visualization of proposed coastal protection Beira

The physical measures as indicated above are combined with the implementation of an Early Warning System (impact mitigation for events exceeding the design protection level of 1:50 per year) and institutional measures (land use regulation, coastal setback zone, prevent sand mining, regulate access to coastal zone to allow for healthy dune vegetation, set up O&M organization etc.).

HARD VERSUS SOFT SOLUTIONS IN BEIRA

One of the key issues in the selection of the preferred alternative per coastal stretch was the *comparison and choice between hard solutions (levees, dikes) and soft solutions (dunes).* On one hand the hard solutions provide more certainty and lower Operation & Maintenance (O&M) investments/ efforts than soft solutions, and therefore could count on stronger support from (local) stakeholders. However, the implementation of soft solutions has significantly lower capital investment costs, it is more adaptive and flexible to deal with future uncertainties and it can lead to significant socio-economic and/ or environmental co-benefits. It also follows the general desire to shift more towards Nature Based Solutions, working with nature instead of fixating the shorelines with rigid coastal protection structures (which are less flexible to adapt to future uncertainties). It should be noted furthermore that hard solutions, for the Beira situation, would still require compensation of longterm sediment losses/ erosion trends (they do not stop longterm erosion trends), which may even be aggravated by the implementation of hard solutions.

For coastal stretches 2, 3 and 4 in Beira the large-scale implementation of hard solutions does not meet the financial requirements from international financers (low cost-benefit ratio and does not fit within the available implementation budget). Implementation of hard solutions is also advised against from a morphological/ system point of view considering the future uncertainties regarding erosion trends and the potential to aggrevate instead of reduce the erosion impact. This has been accepted by the key stakeholders after extensive stakeholder discussions; only for coastal stretch 2 south a short section with a revetment (at the corner of Ponta Gea) has been selected as optional part of the preferred alternative.

HARD VERSUS SOFT SOLUTIONS IN GENERAL

The above identified pro's and con's for hard and soft solutions and discussions between international financers and (local) institutional stakeholders are encountered often in similar projects worldwide. This is based on the traditional focus on structural coastal protection structures which provide (a feeling of) safety and certainty. It is also partly caused by less confidence in soft solutions, based on a lower level of accuracy in the tools available to calculate and quantify the effectiveness and potential socio-economic and/ or environmental co-benefits of soft solutions. Monitoring and maintenance for soft solutions is also less straightforward, and requires a higher (or at least different) level of expertise from the responsible authority than for hard solutions.

When aiming to shift more towards the implementation of soft solutions/ Nature Based Solutions (which is being advocated more and more in recent years when dealing with climate change issues), it is therefore considered crucial to also tackle the following issues:

1. Raise our effort to improve technical knowledge and tools for quantification of effectiveness and potential co-benefits for soft solutions, to reduce uncertainties and build confidence in such solutions and their benefits. Investments in pilots and experiments as proof of technology are also an important part of this.
2. Include extensive capacity building programs in international investment packages for climate adaptation programs in developing countries, to increase awareness and to build local expertise. This aims to facilitate the discussions about the selection of soft solutions as prefered alternative, and to ensure that the O&M efforts that often come with the implementation of such soft solutions can be adequately carried by the responsible authorities.
3. The need to improve methods to monetize potential social-economic and/ or enviromental co-benefits and set up different financing structures for soft solutions/ Nature Based Solutions. International financing methods traditionally focus on capital investments, while there is a clear need to also address O&M financing to ensure a complete solution which remains effective over the envisaged lifetime.

ROLE OF VEGETATION IN DUNE EROSION

One of the specific uncertainties regarding soft solutions, as identified and encountered also in the Beira project, was the role of vegetation in the dune system and design. Local stakeholders and experts clearly indicated that damage to coastal infrastructure was significantly higher for sections with bare dunes (dunes trampled by people, preventing the development of a healthy dune vegetation) than for sections with healthy vegetated dunes after cyclone Idai in 2019. Therefore, we recommended a (re)vegetation plan for the strengthened coastal dunes as part of the measures/ design. However, due to knowledge gaps, we were unable to exactly quantify the effectiveness of dune vegetation to reduce dune erosion for extreme events in the dune design for Beira.

Figure 3: Illustration of dune vegetation in Beira

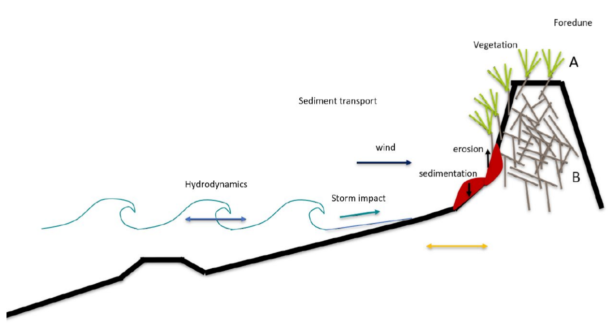

Figure 4: Illustration of relevant processes for erosion of vegetated dunes

In an additional graduation project linked to our project, the role of vegetation in dune erosion was assessed in more detail. It was attempted to simulate two physical experiments (Bryant, 2019 and Mendoza, 2017), which both showed a 30-40% dune erosion reduction in extreme storm conditions resulting from healthy and well-developed dune vegetation. The physical experiments are simulated with a 2D numerical Xbeach model, to assess whether Xbeach can be used as design tool to quantify the impact of vegetation on dune erosion.

The 2D Xbeach model has become a standard tool for dune design in the Netherlands in the past decade, calculating a storm erosion profile during the design storm to determine which minimum dune volume (and minimum dune dimensions based on that) is needed to guarantee a minimum safety profile during/ after the design storm without dune breaching. Based on the physical experiments, it is expected that including vegetation in the Xbeach calculations would reduce erosion during the design storm event and therefore reduce the required design dimensions of the dune.

The graduation study led to the following main conclusions:

- There are four main methods to take vegetation into account in Xbeach: vegetation module, roughness approach, root model and avalanching module.
- XBeach could be a useful tool to assess the potential impact of vegetation in dune rehabilitation projects and dune design; Xbeach is able to reproduce the physical laboratory experiments reasonably well.
- It was shown that the avalanching module and the root model in Xbeach can adequately simulate the vegetation effects as demonstrated in the physical laboratory experiments.
- The use of the avalanching module is most consistent with the laboratory results on a large scale. The (underground) vegetation on dunes leads to steeper slopes (a higher critical angle) before avalanching occurs, which reduces the erosion during a storm event.

Concluding, dune vegetation could add robustness or additional lifetime to a dune system, if the vegetation is well developed aboveground and especially underground (root system to allow for steeper profiles before avalanching occurs).

It must be noted however that significant knowledge gaps and limitations have still been identified (limited number of experiments, small scaled/ scale effects, vegetation representation in experiments, very situation dependent), and no final conclusions can be drawn with certainty yet based on the simulations as performed in this graduation project. For example, though the consensus is that vegetation reduces dune erosion rates during storm conditions, literature was also found suggesting that dune vegetation may also aggravate erosion in certain situations.

The following main recommendations for follow up studies resulted from the graduation project:

- Conduct more (large scale) lab experiments and field studies with focus on:
  - Additional dune strength due to vegetation and occurring slope
  - Effect of vegetation characteristics
  - Effect of vegetation destroyment
- Develop XBeach modules:
  - Validation of vegetation approaches
  - Process-based avalanching module

IMPACT VEGETATION ON DUNE DESIGN BEIRA

The Xbeach simulations *with and without vegetation have also been used to assess the potential impact on the Beira dune design*. Calculations for the case study of Beira with dune vegetations, indicates that dunes with a full-grown mature vegetation root system result in a higher critical angle. The dunes with vegetations could withstand the design storm in 2070 with a higher sea level rise of +20-30 centimeters or a +0.5-0.8 meter higher design wave height (Hs) than for in the situation without vegetation according to the Xbeach calculations.

The dune design in Beira is now based on calculations without vegetation, also considering that a full-grown mature vegetation is not in place directly and needs to develop over time. It was however shown in the graduation project that including a healthy vegetation will add to the robustness of the dune belt as flood protection for Beira towards the future. The suggested higher sea level rise of +20-30 centimeters suggests for example an increase in design lifetime of approximately 15-20 years. While a non-vegetated dune might be able to resist a 1:50 per year storm in 2070, this research shows that a vegetated dune could be able to withstand a storm with similar wave conditions up to 2085-2090.

REFERENCES

Bryant (2019). The response of vegetated dunes to wave attack. Coastal Engineering, 152 (March):103506.
Mendoza (2017). Measurements and Modelling of Small Scale Processes of Vegetation Preventing Dune Erosion. Journal of Coastal Research, 2017-Spring(July):19–27.