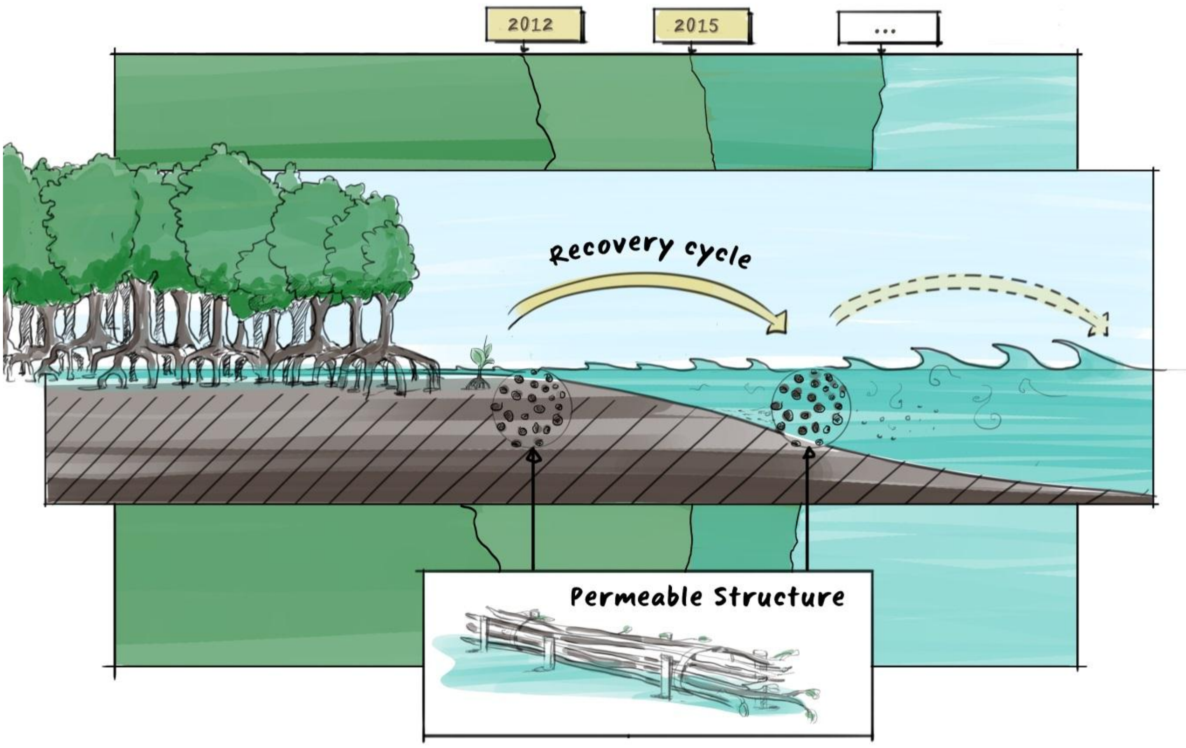
Discussion paper

A sustainable solution for massive coastal erosion in Central Java

~ Towards Regional Scale Application of Hybrid Engineering ~
Discussion paper



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Deltares
Enabling Delta Life

Wetlands
INTERNATIONAL

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All Illustrations by JoostFluitsma, JAM visual thinking

1. Introduction

Deltaic populations in western Indonesia are increasingly threatened by rapid shoreline degradation and erosion. In just a few decades, some coastal areas have retreated by more than two kilometres[1]. Housing, roads and valuable land is literally swept into the sea. This loss of land continues unabated, sometimes by tens of metres per year. The erosion causes saline intrusion, affecting drinking water sources and agricultural production. Erosion along with soil subsidence has also led to massive flooding during storm surge, high tides or periods of excessive rainfall. Fish stocks, timber and fuelwood reserves and other valuable natural resources have collapsed. Meanwhile projected climate change aggravates vulnerability: sea-level rise and increased frequency of extreme events have introduced new challenges to which no adequate coping capacity exists. This increasingly threatens the well-being and self-reliance of millions of poor coastal communities, many of whom live below the poverty line. They are gradually losing the land and natural resource-base on which they depend.

In Demak, central Java, for example local fish pond farmers experienced a decrease in income of 60-80% following erosion of 80 km^2 of land, while fishermen saw their income decrease by 25-50%[2] (seeFigure 1). No less than 3000 villages on Java suffer from similar problems[3].Hard-won development gains are wiped out by coastal degradation. Conflicts around remaining land and resources intensify. As a consequence, an estimated 80 million coastal inhabitants struggle to escape from an intensifying poverty cycle on Java alone[4]. Impacts are also experienced at macro-economic level. The agriculture, aquaculture and fisheries sectors have experienced multi-billion losses and find it increasingly difficult to sustain their operations. These vulnerabilities will further exacerbate if the growing degradation and erosion problems are not addressed.

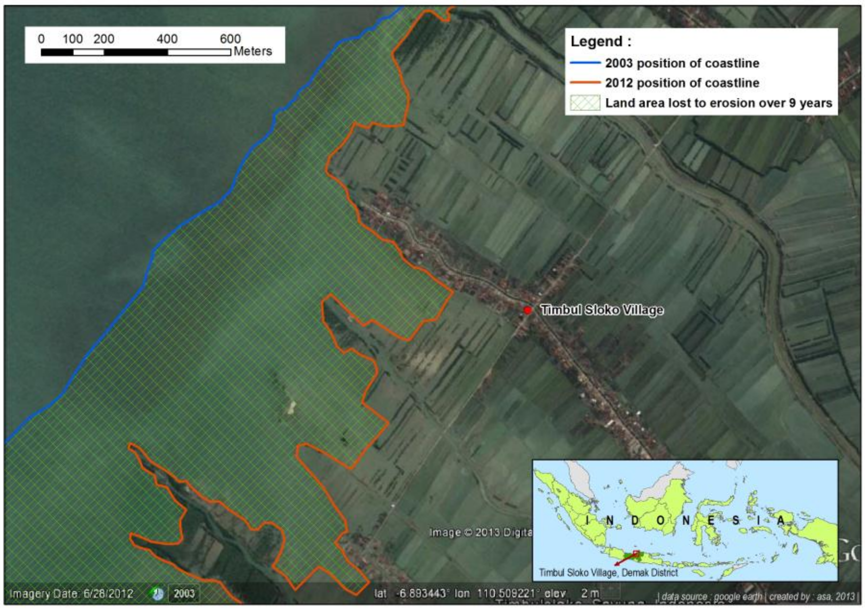


Figure 1. Example of coastal erosion in Demak, Java.

The ill-informed expansion of the aquaculture sector has been a prominent driver of this vulnerability. Since the 1980s, establishment of aquaculture ponds along low-lying sedimentary reaches resulted in the near total destruction of mangrove forests. No less than 750,000 ha of forest were converted, mostly in western

Indonesia[5]. The aquaculture systems offered windfall profits initially, often to rich „patrons" from major cities. Following outbreak of diseases and accumulation of pesticide residues however, most systems collapsed leaving unproductive wastelands to the local population[6]. The removal of the mangroves and confinement of the intertidal range due to construction of earth bunds around the shrimp ponds caused changes in sediment dynamics. This triggered massive erosion and the related land loss, inundation and salt water intrusion problems.

Figure 2. a collapsed structure in British Guyana (photo by H. Winterwerp)

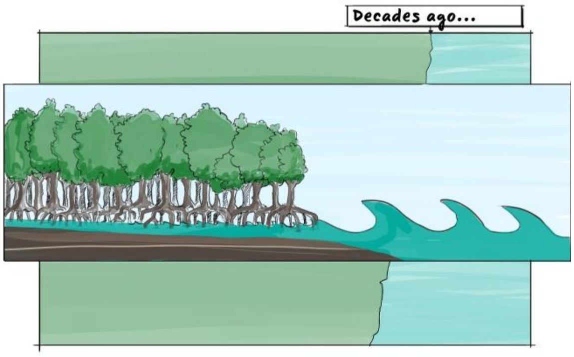
Major investments have been made in traditional infrastructural responses – dams, sea-dykes and groins – in an attempt to resolve these problems. In most cases these failed to provide the desired protection and did not result in sufficient improvements in human welfare and economy (Figure 2). Often hard-infrastructure solutions aggravate erosion problems and subsidence due to unanticipated interferences with sediment flows and soil conditions[7]. Moreover, they do not revive the mangrove values that were lost. Mangrove belt establishment has been widely promoted as an alternative means to enhance coastal resilience. However, mangroves can only be successfully restored if the regional shoreline morphology (sediment flows, bathymetry etc.) and connection of the system to the river is to some degree rehabilitated as well. Most rehabilitation pilots do not reinstate these abiotic conditions. As a consequence they fail to stabilise eroding coastlines. Along many stretches of coast there is no response at all: they continue to degrade at an alarming rate.

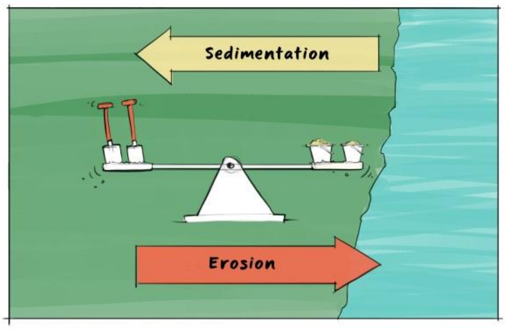
We developed a new approach called 'Hybrid Engineering', which addresses delta and coastal vulnerability in an integrated manner. This approach accommodates economic and livelihood development needs, and combines technical and ecosystem-based solutions. The Hybrid Engineeringapproach is aimed to work with nature rather than against it. It combines engineering knowledge and techniques with natural processes and resources, resulting in dynamic solutions that are better able to adapt to changing circumstances. The focus of this report is on the *technical* solution at regional scale, i.e. a coastal stretch of 10 – 20 km long, building on experience gained with small scale pilots. The ultimate objective of this regional-scale Hybrid Engineering application is to regain coastal protection against erosion and other ecosystem services by re-establishing a mangrove green-belt. A more short-term objective of this regional-scale Hybrid Engineering application is to test and evaluate various methods of Hybrid Engineering.For the approach to succeed the development of socio-economic and governance solutions is equally important – these are however beyond the scope of the present report. In addition,we limit ourselves to coastlines, excluding mangrove rehabilitation along rivers.

In this report, we first explain the rationale for Hybrid Engineering based on system characteristics (Chapter 2).Then we elaborate the site selection process (Chapter 3), which is followed by a description of the site and exploration of potential causes for erosion in the selected site (Chapter 4). In Chapter 5 we briefly discuss conventional solutions. In Chapter 6 we outline a strategyfor implementation of Hybrid Engineering at a regional scale in the selected site. We then conclude with a discussion of next steps needed to bring this innovative approach forward (Chapter 7).

2. Rationale Hybrid Engineering in tropical mud coasts

Intact mangrove forests protect mud coasts by attenuating the height and strength of sea waves[8] and by reducing the impacts of storm surges[9]. In the long term, they provide protection by vertically building up the coast through storage of organic matter and sediment[10]. In addition, healthy mangrove forests provide a variety of ecosystem goods and services, such as fish, shellfish, fuel wood, fibres, water filtration and carbon storage. They are also an important nursery for commercially exploited offshore fish species. Healthy mangrove mud coasts are in a dynamic equilibrium, with sediment naturally eroding and accreting as a result of wave and tidal action. However, in most areas, the net effect of erosion and accretion is more or less stable (see illustrations below).

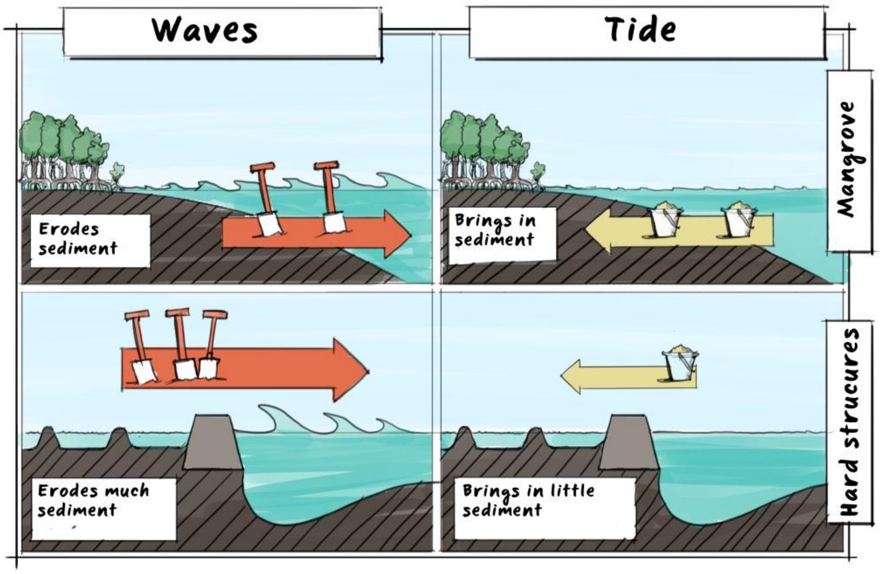




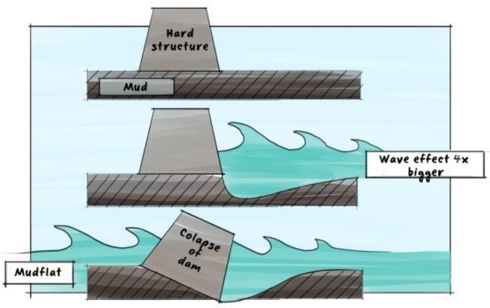
Nowadays, many tropical mud coasts face dramatic erosion. The conversion of mangroves into fish or shrimp ponds has disconnected mangroves from sediment input by the river and led to a loss of their coastal protection function.[11] In some areas, the coastline has receded between 100 and 2000 metres, jeopardizing people's homes and livelihoods (Figure 3).[12] Aquaculture ponds are lost to the sea, and crucial infrastructure is damaged. Other ecosystem goods and services provided by mangroves are also destroyed. These problems are exacerbated by sea level rise and land subsidence. Subsidence can be caused when the floodplain is disconnected from river sediment input and by drainage, peat oxidation or water extraction from both deep and shallow wells.

Figure 3. Local community renovating a flooded house Demak district, Central Java (photo by S. Verschure)

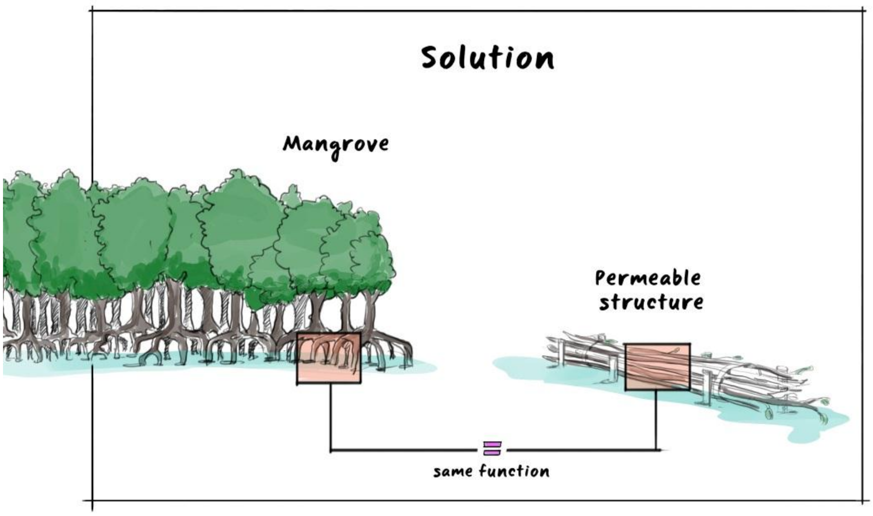
When mud-coasts start to erode as a result of unsustainable land use, the delicate balance between erosion and sedimentation is disturbed. Sediment is lost to the sea through rivers that are disconnected from the surrounding floodplain and through waves by loss of the protective function of mangroves. As result the coastline progressively recedes. Coastal managers often try to fight coastal erosion with classical solutions, such as dikes and seawalls, e.g. with hard structures. In a healthy mangrove ecosystem, waves take sediment away and the tides and rivers bring sediment to the coast. The mangroves' root system helps to capture and stabilize the sediment. The tidal flat is convex up, with a gentle slope and shallow water at the seaward edge of the mangrove forest. Hard structures, such as aquaculture pond bunds and breakwaters, disturb the balance of incoming and outgoing sediment. Waves reflect on the structure, becoming bigger and taking even more sediment away. The tide cannot bring enough sediment in, as it is blocked by the hard structure. The tidal flat becomes concave-up, with steep slopes, and deep water at the seaward edge of the mangrove forest. As a result, waves can penetrate further, enhancing their erosive forces. These processes are illustrated in the cartoon above.



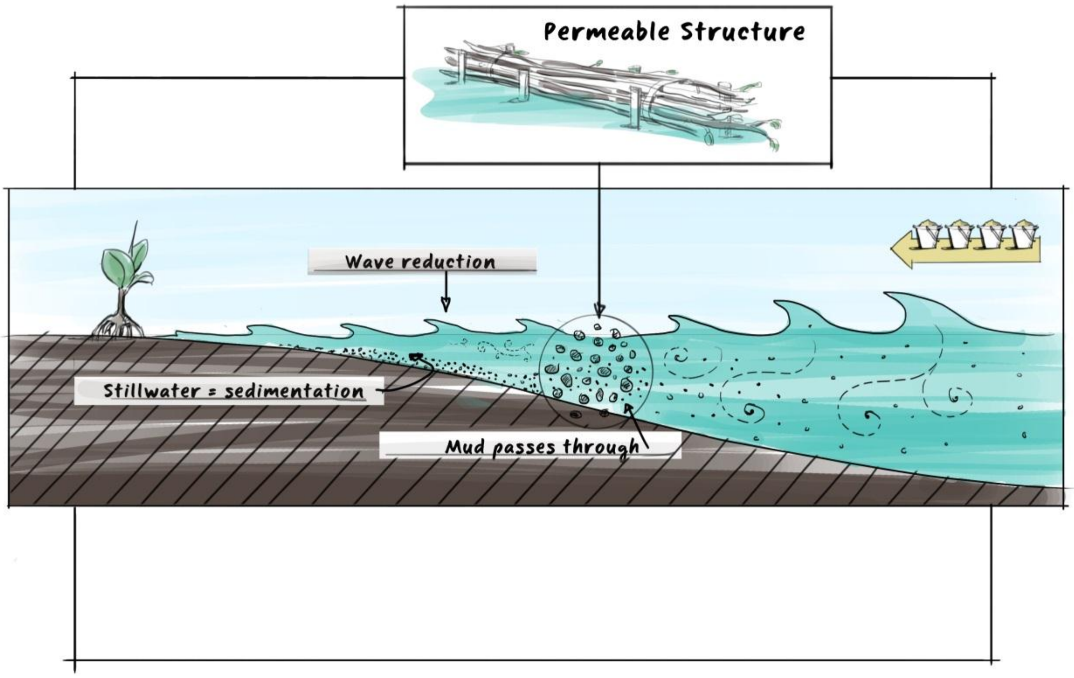
Hard structures therefore only exacerbate the problem (illustration on the right). Waves get bigger when they reflect on a hard structure. These bigger waves can erode 2 to 4 times more soil in front of the hard structure, eventually leading to the collapse of the structure. Such collapsed sea walls are useless in preventing erosion, but still increase the height of the waves.[13]



In order to stop the erosion process and regain a stable coastline, the first necessary step is to restore the sediment balance. More sediment needs to be deposited on the coast than the amount being washed away. A favourable way to do this is by working with nature, using smart engineering techniques – giving nature a little help, but letting nature do the hard work. While increasing sediment input from the river, sediment output by waves from the sea should be limited. Permeable structures made of local materials such as bamboo, twigs or other brushwood can be placed in front of the coastline to reduce sediment loss. These structures let the sea and river water pass through, dissipating the waves rather than reflecting them. As a result, waves lose height and energy before they reach the coastline. The permeable structures also let mud from the seaside pass through, while creating calm water conditions allowing settling of fine sediments. This way the structures will increase the amount of sediment trapped at or near the coast. These devices imitate nature – mimicking the structure of a natural mangrove root system (see illustration below).



The Hybrid Engineering approach combines these permeable structures (to break the waves and capture more sediment) with engineering techniques, such as agitation dredging, which increase the amount of sediment suspended in the water. Once the erosion process has stopped and the shoreline has accreted to sufficient elevation, mangroves are expected to colonize naturally. The new mangrove belt can further break the waves and capture sediment in the long term. The Hybrid Engineering technique described above is applied in grids, or in longer lines of permeable structures to steadily reclaim land from the sea. This technique has been applied successfully in salt marshes in the Netherlands and Germany for centuries. Hybrid Engineering is being increasingly applied in vulnerable coastal areas across the world, replacing hard structures in a cost-effective manner. However, the technique only works if properly applied. Regular maintenance of the permeable structures is needed. New structures need to be placed at the seaward end once sufficient sediment has been trapped on the coast when the desired amount of land is reclaimed. This 'recovery cycle' is shown in the illustration at the cover page.



The Hybrid Engineering approach in tropical mud coasts contains a number of elements, which can be applied jointly or separately (see illustration above):

1. Installation of permeable structures with brush-wood. Such structures have been applied successfully during centuries in temperate coastal wetlands (Netherland, Germany, England) to reclaim fertile land from the sea. Recently, such constructions have also been tested in Vietnam[14].

2. Seabed agitation (symbolised by the arrow with buckets in the illustration above) to enhance fine sediment concentrations in the foreshore. The classical agitation technique is known as agitation dredging through which fine sediments are taken from the seabed, pumped into a barge, and from there the fines may flow freely again in the water column. In the very shallow waters of a mangrove-mud coast, other ways of mechanically stirring the seabed have to be deployed.

3. Mud nourishments (also symbolised by the arrow with buckets in the illustration above), i.e. the placement of mud directly in the area where it is needed, may be used at locations where the tide has difficulties to bring fine sediments to the shore, or where too much sediment already has been washed away. Though beach nourishments with sandy sediments are being carried out throughout the world, nourishments with mud have to be designed carefully.

4. Construction and/or restoration of the so-called cheniers, thin and narrow lenses of sand on top of the muddy bed, at which waves may break, losing part of their energy.

3. Site selection

To illustrate how Hybrid Engineering would work at a regional scale, we elaborate an approach for a real site in the following chapters. This chapter explains the process of site selection and presents the selected site.

3.1 Site selection criteria

Site selection was based on a list of criteria and indicators (see table below).We recognized three main criteria, each characterised by several indicators. The first criterion is the biophysical state of the area, which includes all relevant system characteristics, such as whether an area is eroding and whether it was covered with mangroves previously. The second is the socio-economic context. Here the most important indicator is whether there is local support for the approach. Finally, logistical indicators are identified, such as whether an area is accessible. A description of the required state of the indicator and an indication of its importance is available in Appendix I.

Criteria	Indicators
1. Biophysical	Eroding/stable/accreting
	Previous habitat type
	Seedlings availability
	Hydrodynamics
	Sediment availability
2. Socio-economic context	Local stakeholder support
	Local/regional government support
	Showcase potential
	Current programs/incentives
	Land ownership
	Current dredging works
	Representativeness
3. Logistical	Accessibility
	Potential for up scaling
	Biodiversity value
	Required permits and EIA (AMDAL)
	Data availability

3.2 Site selection for large scale implementation

We explored several areas in Java for their potential suitability for engineering Hybrid Engineering pilot at a regional scale, i.e. along a coastal stretch of 10 to 20 km. For identifying a suitable location we collaborated closely with the Ministry of Marine Affairs and Fisheries (MMAF). In 2011, MMAF launched the 'Resilient Village' program with the goal to improve coastal resilience by improving environmental quality, by increasing the institutional capacity of communities and local government and by increasing preparedness for disaster and climate change. The program started implementation in 2012 with initially 16 villages, including several villages in Demak District. In this initiative in total more than 6000 coastal villages all over Indonesia will be targeted. We decided to select a site in Demak district to explore Hybrid Engineeringat regional scale, because of overall high scores against our selection criteria and because of the opportunity to reach scale through the MMAF Resilient Village if the approach proves to be successful. See Figure 4 for the exact location.

In a recent report of Bappennas and Koica , Demak was given a high score on the coastal vulnerability index for sea level rise for the southern part (that experiences severe erosion) and a low score for the northern part (where accreting coastlines are found). The coastal vulnerability index is based on sea level rise rate, maximum wave heights, coastal slope, coastal population and land use.

Figure 4: Java with Demak coast indicated by yellow circle (upper panel) and close-up of Demak district and coastline (lower panel), including indications of residual sediment transport.

4. Regional scale system description

To design a Hybrid Engineering-approach for a specific region, thorough system understanding is required, both from a hydro-sedimentological and ecological/biological point of view. This chapter provides a first description of the system in Demak district.

4.1 Meteorological and physical characteristics

The tide near the Demak coastline depicts a pronounced diurnal signal, with a small semi-diurnal component (Figure 5). Neap-tide tidal range amounts to about 40 cm, whereas spring-tide tidal range amounts to about 60 cm, but can be a bit larger when the semi-diurnal components synchronize with the diurnal components[15]. Currents in Sayung coastal waters vary, with maximal velocities of around 15 cm/s[16/17]. However, it is not known where these measurements were carried out. The majority of the measured currents appear to be directed in between East and South-East, which is more or less perpendicular to the Demak coastline.

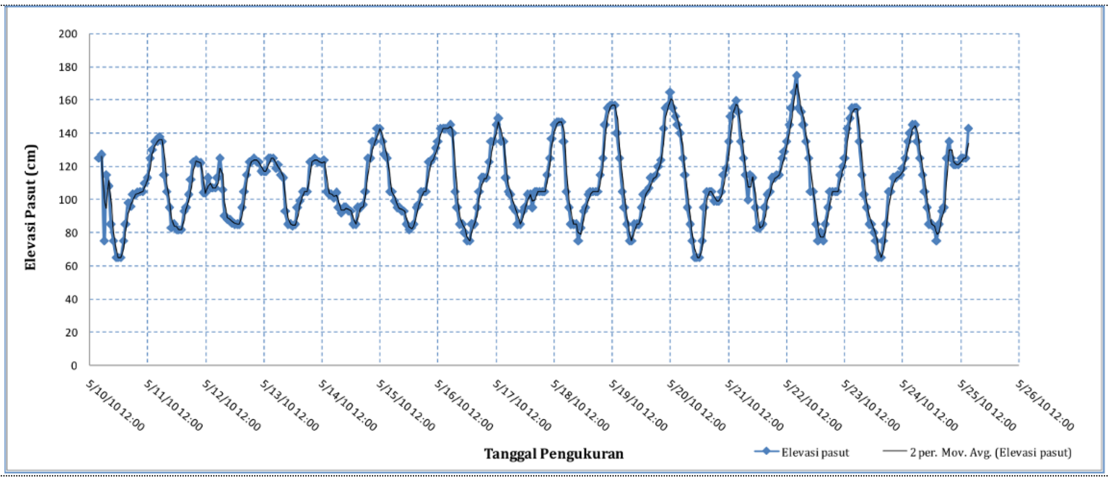


Figure 5 Time series of tidal elevation near Demak coast (after MMAF 2012).

The residual ocean currents along the north coast of Java follow the monsoon[18]. During the SE-monsoon (May – September) residual currents are towards the West, whereas during the NW-monsoon and the two transitional months (October – April), residual currents are towards the East. Though we have no data presently, we presume that the long-term average residual flow, hence also the residual fine sediment transport is towards the East, as northern winds are stronger and persist longer than during the SE-monsoon. The stronger winds occur in the months December through February, which are also the wetter months. Intertidal areas generally extend for about 1 km and have bed slopes of about 1:1000[19], whereas further offshore, the bed is steeper, with a slope of about 1:500. The substrate is muddy. Thickness of mud layers is not known.

Rainfall distribution in Semarang[20](Figure 5) can serve as a proxy for the distribution of the fresh water flow rate from the various rivers discharging into Demak coastal waters. The wind direction should have a profound effect on the dispersion of fresh water in the coastal waters. The wet season in Java is from about November through April, with December, January and February as the wettest months. During the NW-monsoon riverine fresh water plumes are pushed against the coastline, diverting to the East, following wind direction and residual currents. The fresh water distribution than induces a gravitational circulation along large parts of the coast, which keeps fine sediments close to that coast. On the other hand, during the SE-monsoon, which is the dry season (driest months June through August), fresh water is blown into the ocean (Java Sea) and the effects of gravitational circulations are much more localized. Then, no large-scale mechanism works to keep the fine sediments close to the coast.

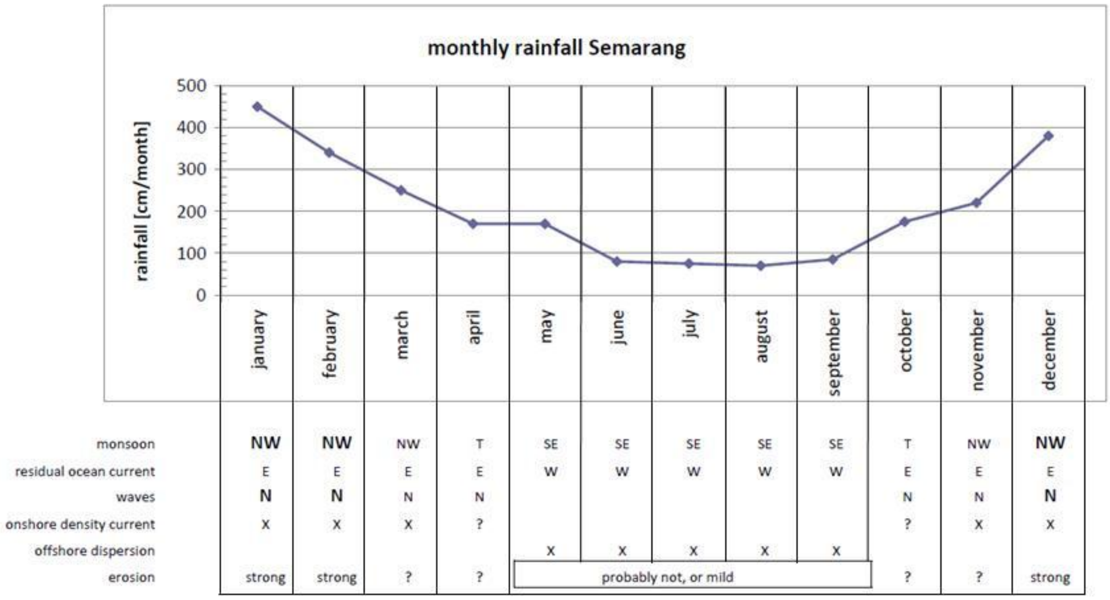


Fig. 5: Rainfall distribution in Semarang (BayongTjasyono et al., 2008) and summary of conditions relevant for the fine sediment dynamics along Demak coast (bold = energetic/dynamic conditions)

Figure6 presents the wave rose as measured in Demak coastal waters[21], about 3.5 km off the original, undisturbed coastline (at the precise location of 110° 26' 41.6" E and 6° 54' 36.9" S). Wave heights up to 1.8 m are reported, whereas the maximum significant wave height amounts to about 1.5 m, with a period of about 5.5 s. An evaluation of 14 years of wave data of the measuring station near Semarang showed that mean wave height in this area equals 0.46 m. and maximum wave height lies between 2.6 -3.0 m[22]. However, the latter is offshore. Note that all relevant waves come from between North and WNW, with the majority of the waves from the North. Of course, the north coast of Java is very much exposed to these waves. Note that for the year 2009 much larger maximum waves are reported, with a significant wave height of about 2.2 m, at a period of over 8 s.

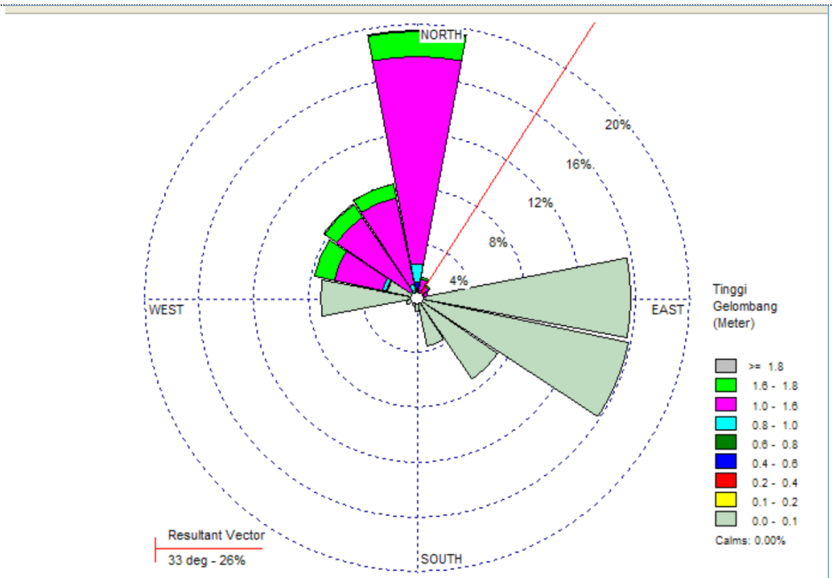


Figure6 Wave rose along Demak coastline for the years 2003-2009 (after MMAF, 2012).

4.2 Factors contributing to erosion

Combining this climatological and bio-geomorphological information yields a qualitative picture of the conditions relevant for coastal stability. Most coastal erosion is expected during the months December through February, when the NW-monsoon winds are strong, and waves are high and from the north. On the other hand, also fine sediments are carried by the rivers, and fines from the river bed are also expected to be mobilized in this season, enlarging the suspended sediment concentration in the coastal zone. Fortunately, large-scale circulations keep these sediments close to the shore, thus available for regeneration of the coast.

Coastal erosion can be caused by multiple factors amongst which the factors as described in section 4.1. However, direct anthropogenic influences in the environment, such as building of harbour peers and jetties and of coastal defences may have profound impact on coastal erosion and deposition patterns as well. For example, the jetties, protecting the port of Semarang, penetrate some 3 km into the sea (Figure 7), affecting eastward oriented residual fine sediment transports.

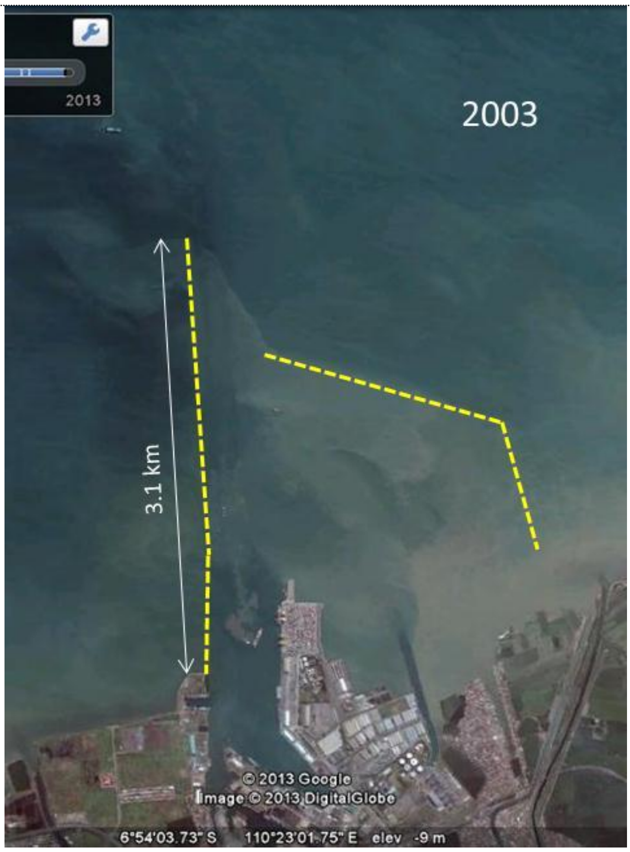


Figure 7: Approximate location of jetties approach channel port of Semarang. Google Earth images suggest that there are some holes in these jetties.

Another important issue affecting coastal stability is (relative) subsidence, which may result from deep and shallow ground water subtraction, drainage, reduced sediment input by rivers and sea level rise. Based on satellite observations, sea level rise along the coastline of Demak is estimated between 4.0 and 4.3 cm per year[23]. Figures8 and 9 suggest that close to Semarang, subsidence rates may be large, up to 8 cm/yr, though no detailed data exist of this area. These graphs suggest that coastal stability/erosion may have been affected by subsidence, particularly close to Semarang. Subsidence rates for the Timbulsloko area are not known. However, there are some signs of subsidence (see Figure 10). Further, the village seems to possess a deep ground water well that might have been used for irrigation purposes as well. More information on this aspect should be collected.

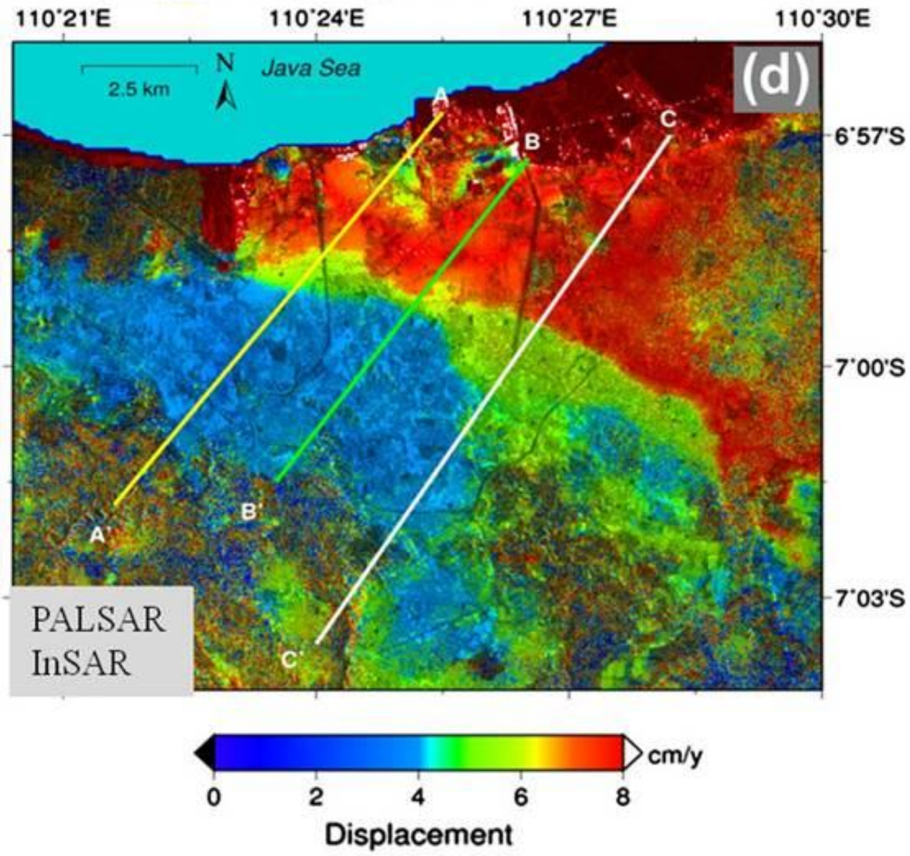


Figure 8 Yearly subsidence in cm/yr based on measurements of Lubis et al. (2011) between Jan 2007 and Jan 2009.[24]

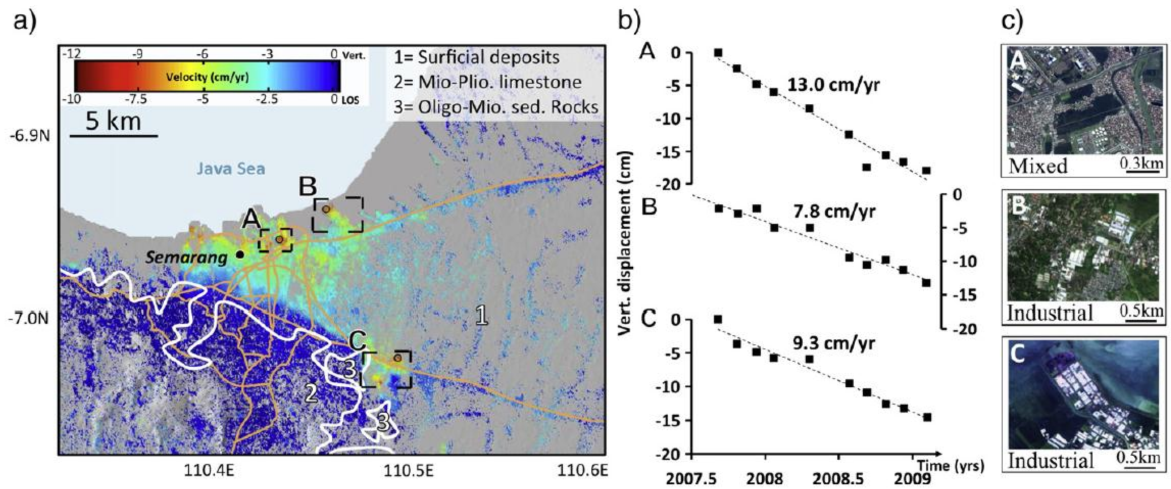


Figure9 Subsidence observed near Semarang. a) Average 2007–2009 subsidence rate map. Roads are shown in light brown and main towns are labelled for reference. The contours of the geologic units are shown by white lines and referred to using white numbers. The black boxes show the locations of the Google Earth optical images displayed in c) corresponding to areas experiencing rapid subsidence. Black circles within the boxes show the location of the pixels whose time-series are showed in b). b) Vertical displacement time-series and corresponding linear rates of subsidence. c) Google Earth optical images showing the type of land use in rapidly subsiding areas[25]*.*

Figure10 Houses close to the coastline in the Wonorejo part of Timbulsloko. The height of the house points at the presence of subsidence (photo B.K. van Wesenbeeck).

4.3. The problem: an eroding coastline in Demak district

In this section we explore the evolutionof a coastal stretch of approximately 19 km inDemak district, from just east of Semarang to Wulan River (Sungai Wulan), see Figure 11. We use both anecdotal information describing the last century and an analysis of Google Earth images of the last decade, see the original series of images in Appendix II. The 19 km Demak coast consists of a northern part with a still fairly stable coastline (referred to in this report as the 'reference coast'), while the coasts erodes progressively when moving south in the direction of Semarang (referred to as 'coast I, II, III'). In the coastal area of Demak houses are mainly built on river banks. This explains the extreme ribbon-building pattern in Demak district.

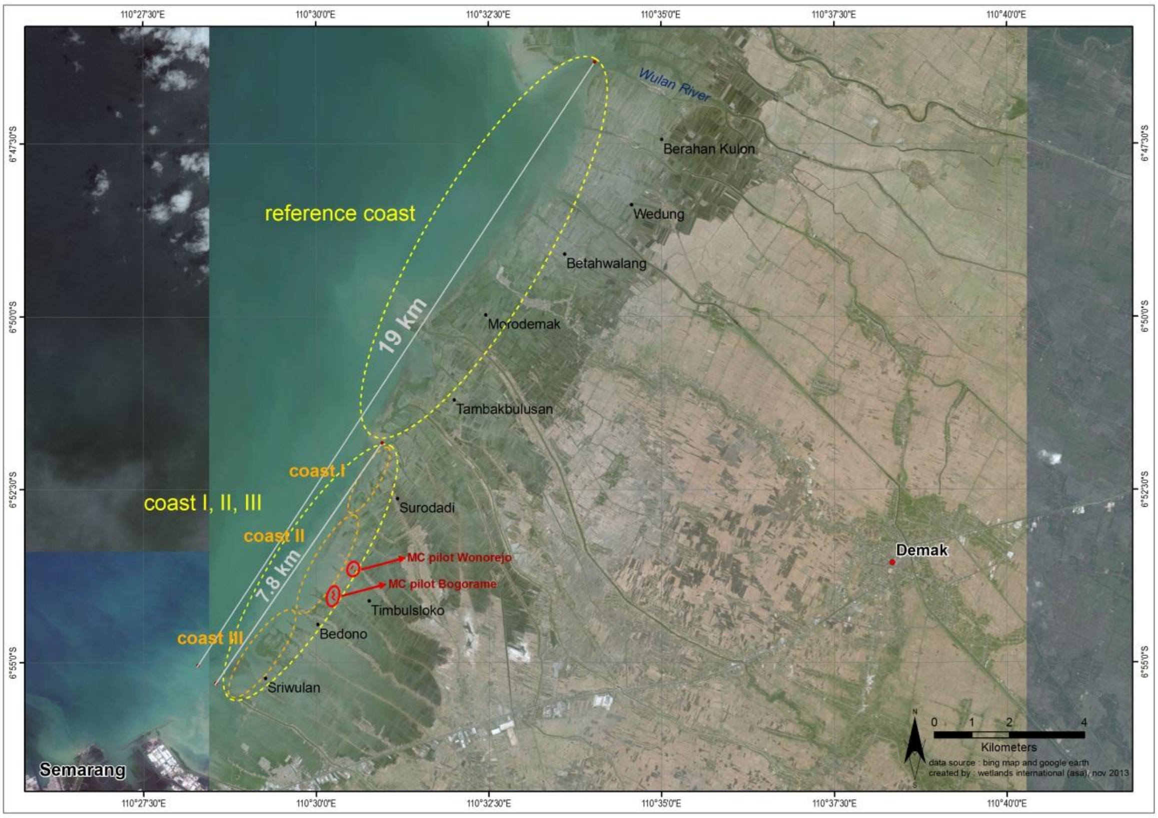


Figure 11Demakcoastline – coastal stretch of in total 19 km for large-scale Hybrid Engineering. The Southern part of Demak coast of around 7.8 km can be sub-divided into three sub-sections, characterized by different erosion patterns. The location of the small-scale Hybrid Engineering-pilot within the framework of Mangrove Capital is indicated (2013 Google Earth satellite image).

From anecdotal information the following historical picture can be drawn:

- 1740: Dutch maps indicates that the area is fully covered by mangroves,
- 1920: Japanese maps already shows some aquaculture ponds in mangrove area,
- 1980s: mangroves are converted because of tiger shrimp boom,
- 1990s: several factors contribute to erosion: water extraction in Semarang leading to subsidence; jetty in Semarang leading to changed currents and changed sediment dynamics; aquaculture pond dykes; fishermen agitating mud to find cockles too close to the shore; sea level rise;
- Around 2000: erosion starting
- Around 2010: loss of 100 – 1000 meters of coast
- Around 2010/2011: start of protective measures by MMAF and MoE; building of hard structures and mangrove rehabilitation (mostly rhizophora, mostly in unsuitable places);

From the Google Earth Images we deduce that the northern 11 km of coastline is still fairly stable, though the landscape has been affected largely by the erection of fish/shrimp ponds. It is likely that this stability is the result of:

- A chain of sandbanks (cheniers) along the coast, formed from sand supplied by the rivers (probably mainly the Wulan River),
- Northward transport of fines by residual currents, mobilized by erosion of the southern part of Demak coast (e.g. Section 2).

This part of Demak coast can therefore serve as a reference in the monitoring program proposed in Section 5 of this report. We do not propose any Hybrid Engineering works along this part of Demak coast.

The southern 8 km of Demak coastline can be subdivided into three sub-sections characterized by different erosion patterns:

- **Coast I:** Mild erosion, with a still more or less intact, closed coastline,
- **Coast II:** Severe erosion induced by breaching of fish/shrimp ponds – extension of erosion controlled by roads; this coast was still more or less intact in 2003,
- **Coast III:** Severe erosion induced by breaching of fish/shrimp ponds, and most likely subsidence – this coast was already severely eroding in 2003.

In the following sections, we will discuss these three coast types sequentially.

4.3.1 Coast I: mild erosion

Figure 12 depicts the coastline of Demak coast I in 2003 and 2013, suggesting an erosion of about 100 – 300 m. The coastline seems to have retreated fairly regularly, except for three "cavities" (a, b, c), where erosion follows the lay-out of fish/shrimp ponds. Further zooming in with Google Earth suggests that most of this coastline is still fairly well protected by a series of cheniers (e.g. thin and narrow lenses of sand on top of the muddy seabed), indicated in Figure13 showing details of coast I.

Figure 12 Demak Coast I with approximate coastlines 2003 and 2013 (Google Earth images); see Figure 13 for details.

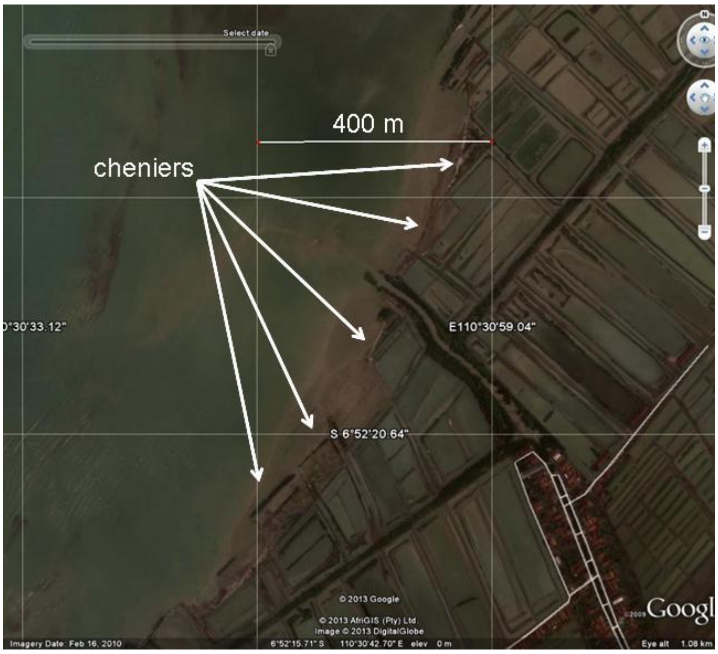


Figure 13: Details of coast I, showing some cheniers along the coast.

4.3.2 Coast II: severe erosion

Figure14 presents Google images of Demak coast, coast II in 2003, 2005, 2007, 2009, 2012 and 2013. We have indicated the coastline in 2003 in all figures. Up to 2007, the coastline is fairly stable, with some erosion.In between 2007 and 2009, the coastline has retreated largely, by many hundreds of meters, at locations up to 1 km. This big response might be attributed to the larger waves in 2009 (e.g. Section 4.2). However, there may be other causes:

- A slow, but continuous erosion of the sand bank (cheniers) over time; when they become too small, they lose their protective function, and the hinterland gradually becomes more exposed,
- Desertion of fish/shrimp ponds and/or negligence of (some) bunds around these ponds
- Reduction of sediment input from rivers
- Subsidence caused by decreasing sediment input or shallow and deep compaction.

Possibly, the real cause of the sudden decline in coastline between 2007 – 2009 can be discovered from interviews with local communities and from thorough data analysis.

Figure 14 shows that erosion is difficult to control from 2009 onwards, and land is continuously lost. The road connecting Wonorejo and Bogorame sub village now seem to control further erosion of the hinterland. However, signs of deterioration of the road are already visible. In certain parts the road is almost continuously submerged (except for very low tides) and in other parts erosion of the road is clearly visible. Safeguarding this road seems a vital step in stopping erosion from proceeding further inland. The road can be protected by placing permeablegroin structures in front of the road. However, the main construction and the base of the road should be improved simultaneously.

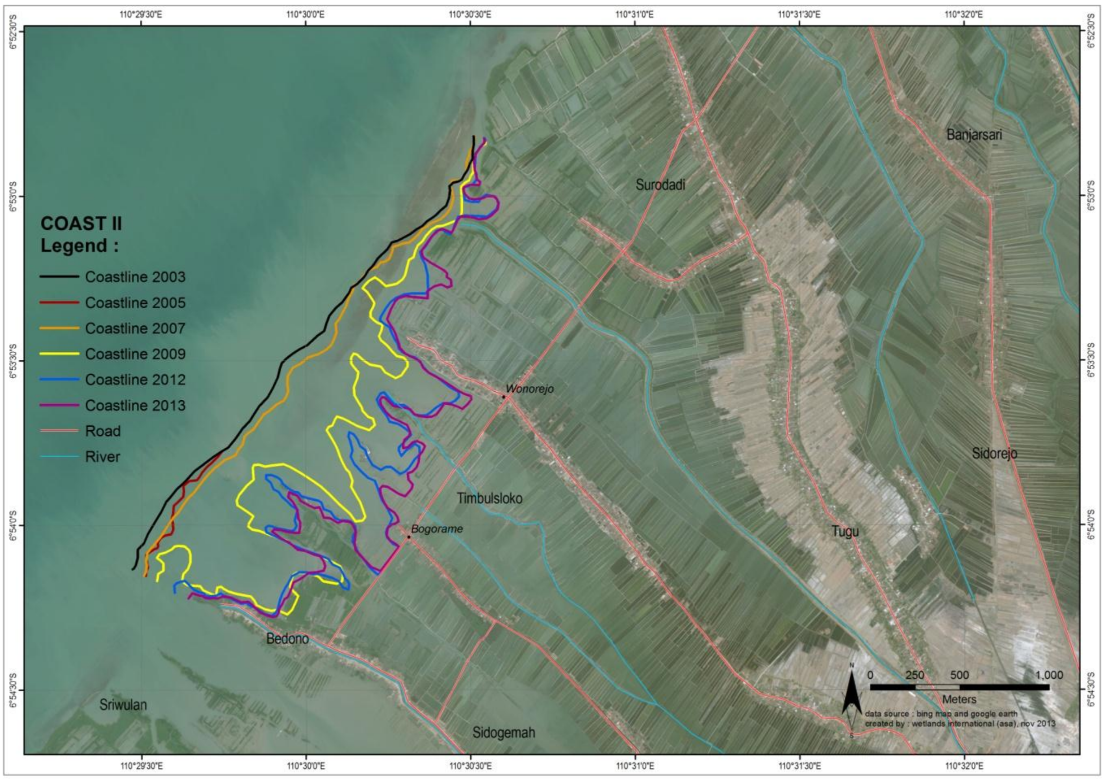


Figure 14 Demak Coast II, showing progressive coastal retreat from 2003 to 2013. Google Earth Images.

4.3.3 Coast III: severe erosion and subsidence

Figures 15 and 16 present Google images of Demak coast III, for the years 2003, 2005, 2007, 2009, 2010, 2012 and 2013. Figure 15 shows that the southern part of coast III was already severely eroding in 2003. It is hypothesized, that this erosion is to be attributed to either of the following:

- Early erection of fish/shrimp ponds, close to the city of Semarang,
- The large subsidence measured in and around Semarang (Section 4.2),
- Anthropogenic structures influencing long-shore sediment transport (harbour jetties of Semarang).
- Reduction of sediment flows from rivers through large scale damming projects.

Figure 15 Demak coast III, showing the approximate coastline in 2003, 2005 and 2007 (Google Earth Images).

Between 2007 and 2009 this part of the coastline seems to collapse rapidly. As the road seems still to be intact, flooding and eroding seem to have occurred through "the back door", as indicated by the yellow arrow in Figure 16.In the years following 2009, the fish/shrimp ponds behind the road degenerate further, owing to negligence of the remaining bunds, further wind-induced erosion, and/or ongoing subsidence.

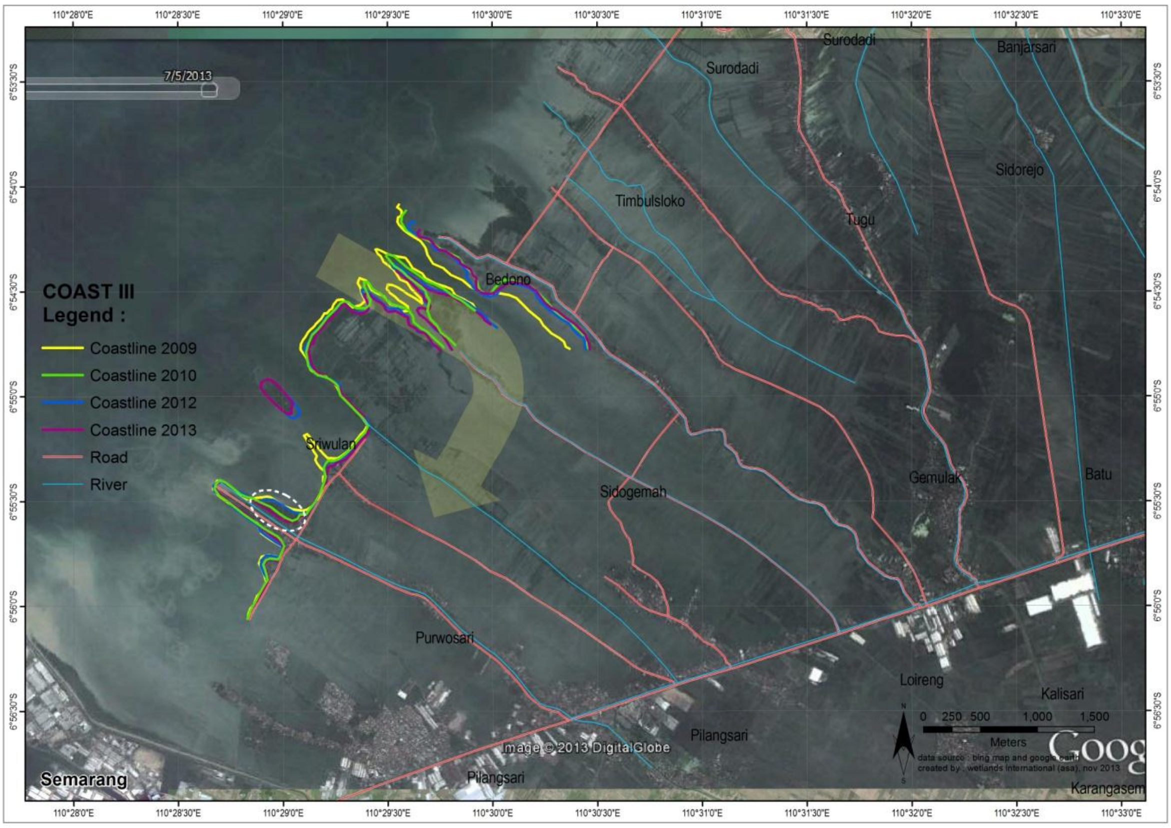


Figure 16 Demak coast III, approximate coastline 2009, 2010, 2012, 2013 (Google Earth Images). Yellow arrow indicating erosion 'through the back door'.

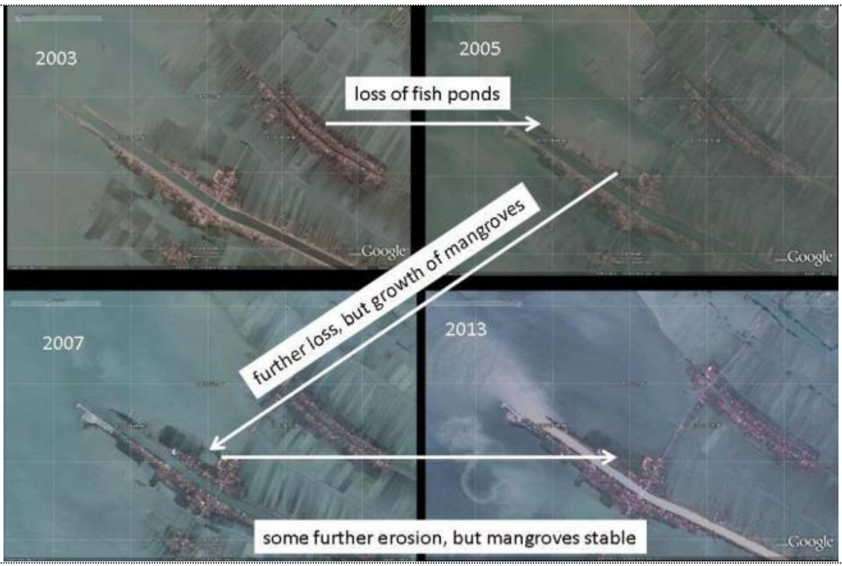


Figure 17 Details of coastal development around Bedono village (e.g. Fig. 21 for location).

Figure17 zooms in on the evolution around Bedono village. The important observation here is that after the loss of fish ponds, mangroves seem to recover where conditions are favourable, i.e. in sheltered areas. This recovery has been observed at other locations around Demak district as well, in particular around Bogorame. In sheltered and rapidly accreting areas (often in between still present bund of eroding fish ponds that are filled with sediment) natural recovery of Avicennia marina has been observed (pers. obs.).

5. Conventional Solutions

In response to the problem of coastal erosion, several solutions have been tried, with varying degree of success. Many mangrove rehabilitation efforts using *Rhizophoramucronata* have been launched in the area, which is praiseworthy. For example, mangrove rehabilitation is carried out by MMAF already since 2003 in Bedono Village with help from other organizations, such as OISCA (Figure 29). These rehabilitation efforts are typically successful in sheltered and accreting areas, while in areas with disturbed sediment balance rehabilitation tends to fail. In those cases the tidal flat needs to be restored first such that the profile is convex-up again.

Further, MMAF (DKP) and the Ministry of Environment are also involved in several projects where construction of breakwaters (called APO) and seawalls takes place (Figure 18). Many of these structures are permeable.However, sometimes these structures were somewhat too permeable, so that they do not dissipate the wavesenough. In other cases, concrete structures are placed. These structures reflect the waves so that eroding forces increase and they prevent sediment input to the tidal flat(see Chapter 4.2). Although these structures may provide some relief in the immediate term, they will eventually exacerbate the problem.

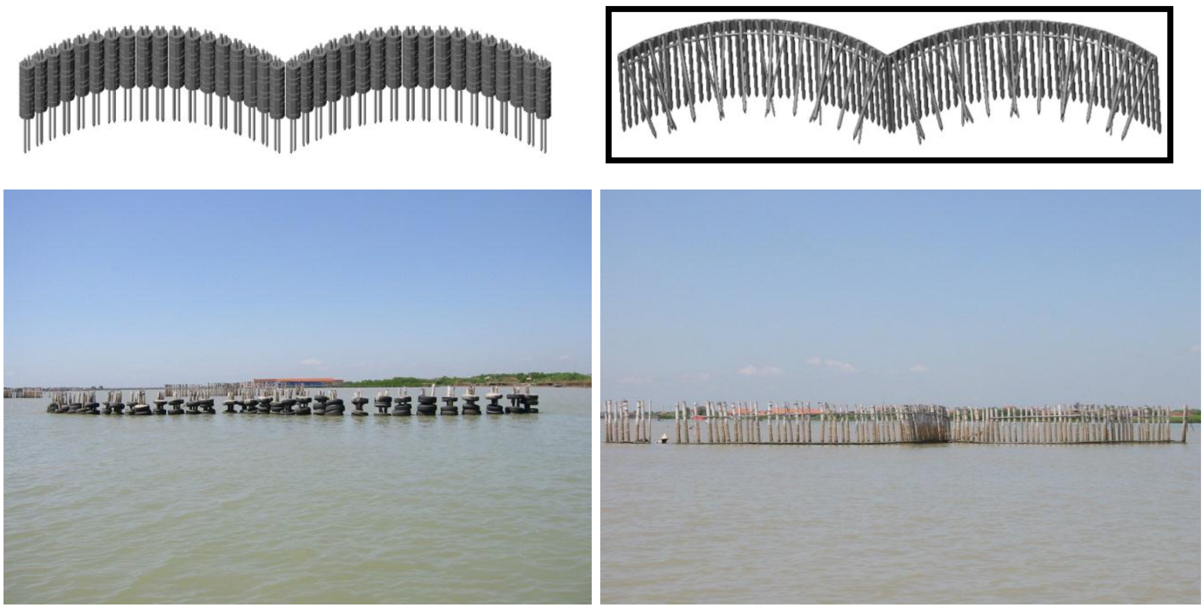


Figure 18 Illustrations (top) and photos (bottom) of wave breakers (APO) along Demak coast.

Concrete seawalls show signs of deterioration sometimes already within a year of their construction. This is the result of the enhanced erosion rates at the foot of such structures, as explained above.

6.Towardsa Hybrid Engineering approach at regional scale

6.1. Proposed Hybrid Engineeringapproach

Although this study is only a first inventory to the potential causes of and solutions for erosion, some first conclusionsemerge. As explained in Chapter 4.4, the 19 km Demak coast consists of a northern part with a still fairly stable coastline, and going south with a progressively eroding coast. Erosion and coastal degradation seem to be affected by subsidence, in particular close to Semarang. Further, the presence of sand banks (cheniers) has a stabilizing effect on the coastline and may be a crucial influence in allowing mangrove development. This may be true for any sand bar parallel to the coastline. Roads protect the land and fish/shrimp ponds behind from further erosion, thereby functioning as a sort of seawall, as long as they are thoroughly maintained. When these protections are gone, rapid retreat of the coastline occurs by erosion patterns following the lay-out of the fish/shrimp ponds.

Houses are mainly built along the rivers, which have deposited some sands on their banks – this explains the extreme ribbon-building pattern in Demak district. The stronger erosive conditions are likely occurring in the midst of the NW monsoon, during the months December – February. Concerning restoration of these coastlines, the coastal waters and foreshore substrate still seem to contain abundant amounts of fine sediments. It is expected that in the months December through February suspended sediment concentrations in the foreshore are high because of wave-induced erosion of the seabed, and possibly supply by the rivers. Observations indicate that when conditions are favourable, mangroves are able to recover naturally. However, we may wish to study whether active planting and/or seeding may accelerate recovery.

These observations lead to the followingHybrid Engineering approach for the restoration of the eroding coastlineof Demak district:

- Safeguarding the roads close to the coast should be a priority, for their protective function but also for socio-economic reasons.

- Protection ofthe most exposed, protruding coastal villages (ribbon-building along small rivers) by restoring local cheniers (sand bars) instead of vertical concrete walls because the latter increase erosion (see Chapter 2)

- Protect villages from flooding behind sand bars and permeable structures with earth walls built of local materials. These walls should be constructed with a broad base, to reduce subsidence of the walls. Erosion of the walls should be mitigated by placement of the permeable dams or by nourishment of the sand bar.

- Create sheltered areas for mudflat and mangrove recovery, by placing grids of permeable structures.

- In specific situations speed up mudflat recovery by mechanically nourishing eroded areas and/or mechanically increasing suspended sediment concentrations in the foreshore by mechanically agitating the seabed and/or restoring protective cheniers (sand bars).

- In specific situations speed up mangrove rehabilitation by actively sowing propagules and/or planting mangroves in places where eco-hydrodynamic conditions are favourable[26]

- An adaptive management approach is required including careful monitoring and rapid response and adaptation of design.

It is essential to start anyHybrid Engineering measures at the end of the SE-monsoon (i.e. June, August), so that the response of the various mitigating measures can be evaluated during storm conditions, when also abundant fine sediments are expected to be in the water column.

6.2Permeable structure design

In collaboration with local stakeholders we prepared a prototype design for the permeable structures, see Figure 19. This design needs to be adapted to each location.A design for TimbulSloko area, a village situated in coast II, is available[27].Materials to be used for these permeable structures may be adapted to the local circumstances and availability. Materials should be sustainable from ecological, social and economic perspectives.

Alternatively, Geohooks may be tested. These are slender one-dimensional structures bent along seven ribbons of a cube, made of bio-degradable material (Figure 20). Geohooks become intertwined, forming a stable, semi-permeable structure.

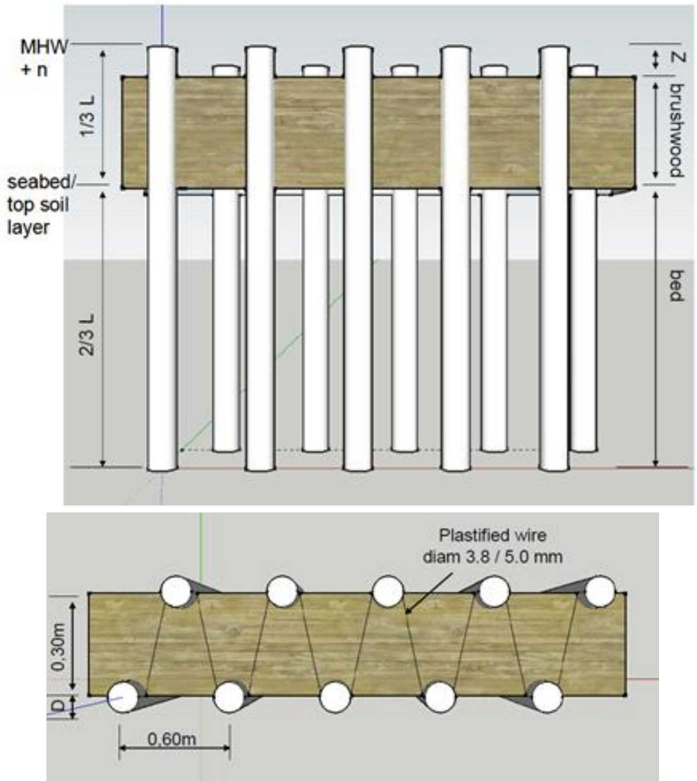


Figure 19 Permeable structure design. MHW = Mean High Water. Top: view from the side, bottom: view from above.

Figure 20 Geohooks

6.3. Approach tailored to sub-sections of Demak coast

6.3.1 Proposed measures Coast I: prevention

Coast I is experiencing only mild erosion until now and the key need is therefore to prevent the situation from getting worse while that is still possible. To prevent escalation, we propose a twofold approach:

1. Create sheltered areas in the "cavities" a, b, and c (Figure 12) with permeable structures, similar to those presented in Chapter 4.3.

2. Build out the coast parallel to the 2013 coastline with permeable structures spaced about 100 m from each other, following the lay-out of former bunds for the foundation of the structures. We propose the following:
    - Application of different materials for the permeable structures in dialogue with local parties, including Boskalis'geohooks for one particular stretch;
    - Enhancing the suspended fine sediment concentration in the foreshore by mechanical means (mechanical agitation of the seabed).

6.3.2Proposed measures Coast II: land reclamation

Coast II is suffering from severe erosion since 2009 and is in need of targeted interventions to prevent further erosion in the immediate term and to start a process to reclaim lost land in the longer term:

1. Protect the entire road through erection of permeable structures parallel to this road, at a distance of 50 – 100 m from the road; using the lay-out of the former bunds for the foundation of the permeable structures.

2. Build small sand bars, mimicking the role of naturalcheniers to protect the exposed heads of Wonorejoand Bogorame (both sub villages ofTimbulSloko Village).Detailed measures and lay-out should follow from studying intact cheniers further north along Demak coast.

3. Restore the seawall extending from the front northern coastline of Wonorejo on the Western side of the village down South. Halfway, the concrete wall ends and adjacent an earthen wall is constructed. During the last storm in May 2013 this earthen wall eroded heavily. Later a hole eroded in the wall through which the sea can now freely enter the village. It is recommended to close this hole and to restore the earthen wall. Parts of the concrete wall have already become unstable as well and permeable structures may protect it from further erosion (see 4).

4. Create sheltered basins in the eroded areas, using permeable structures similar to those presented in Chapter 4.3 and building from existing coastlines. We propose to carry out experiments similar to those described for coast I:
    - Application of different materials for the permeable structures in dialogue with local parties, including BoskalisGeohooks for one particular stretch;
    - Enhancing the suspended fine sediment concentration in the foreshore by mechanical means (mechanical agitation of the seabed).

We recently started prototype testing this approach together with MMAF, Diponegoro University and local NGO Kesematand we include the applied layout of permeable structures here as an example. Coastal erosion in sub villageBogorame has already proceeded until the road and also the village itself is severely threatened. No breakwaters were yet constructed in front of the coast which is an advantage since breakwaters may interfere with sediment transport to the coast and thereby influence the effectiveness of the permeable structures. The layout of permeable structures in gridsfor this location is presented in Figure 21.

Figure 21 Design of two permeable structure grids at the coastline of Bogorame.

In sub villageWonorejowe apply a different layout since the area is more fragmented. The area West of Wonorejo is already heavily influenced by planting of Rhizophora on old bunds of shrimp ponds. Certain plantings of Rhizophora are growing rapidly and are forming lines in the landscape. In between these lines, old fish ponds have filled in with sediment, especially those ponds bordering the river. Note that this may also be caused by the fact that these ponds are protected and not fully exposed to most heavy wind and wave directions. In the areas that filled in with sediment,natural Avicennia recruitment can be observed. As fetch in this area is not so large, while erosion in the area near the seawall of Wonorejo is large, we chose to enhance sedimentation in a larger area at once by constructing a single large permeable structure on the front. This permeable structure is meant to reduce wave impact from the front edge and allow sediment to settle in the area behind. The permeable structure borders the present seawall of Wonorejo in the west and the small river in the east. There are three openings in the dam (each of 5 meters wide) to allow the seawater

Figure 22. Design of permeable structure near Wonorejo.

to move in and out (Figure 22).

5. <u>Large-scale mud nourishment</u>, guided by alternating permeable structures, creating semi-enclosed basins. We anticipate that this semi-enclosed lay-out will help to create the proper slopes of the nourishments. A lay-out for the area west of TimbulSlokois sketched in Figure23 Mud volumes to be nourished should follow from numerical modelling.

Figure23: Sketch of mud nourishment around TimbulSloko with six semi-permeable structures (yellow dotted lines) and floating pipeline supplying fluid mud (white line) – over time, the pipeline should be withdrawn in seaward direction.

6.3.3 Proposed measures Coast III

Coast III is characterised by severe erosion and subsidence. Hence we consider it wise to wait with efforts to rehabilitate this part of Demak coast until we have gained valuable experience from the other coastal sections. Hence our proposed strategy is to safeguard the infrastructure for socio-economic reasons:

1. <u>Safeguard the road</u> with the construction of road-parallel permeable structures at a distance of 50 – 100 m from the road.

2. Stop or <u>reduce erosion around the existing villages</u> by placing permeable structures at a distance of 50 – 100 m from the ribbon-building.

3. Protect the exposed heads of the villages by <u>small sand bars</u>, mimicking the role of cheniers.

6.4 Additional data needs and monitoring

A detailed design for large scale implementation of Hybrid Engineering in Demak district still needs additional research. Main focus points of this research should be to achieve a large-scale and long term understanding of the watershed system and behaviour of the coastal zone of Demak. This long term system understanding should be complemented with field and measurement data of the current system, containing available sediment budgets from the sea, available sediment budgets from rivers and current subsidence rates. Specific attention should be paid to coastal evolution and the evolution, role and behaviour of sand bar on different time-scales. Additionally, anthropogenic influences on sediment transport and sediment availability should be understood. This information will finally help us in assessing the suitability of measures on different locations and the evaluation of effectiveness of potential measures and of their large-scale effects. Ideally, this extensive analysis is part of a larger integrated coastal management plan that also investigates socio-economic factors and drivers in the region, measures to protect and upgrade vital infrastructure, such as houses and roads and works towards an integrated water resource management plan, a waste management plan and building codes.

The following information is e.g. required for further specifying the design:

1. Large-scale bathymetry, including lay-out of (previous) bunds, waterways, drainage channels and sand bars,

2. Sediment composition of the foreshore – in particular thickness of mud deposits to evaluate possibilities of mechanical interventions(nourishments and agitation) and possible contamination should be examined as well

3. Deep and shallow water wave conditions – in particular wave dissipation rates over the muddy foreshore as a function of water depth

Moreover, a numerical model should be built to assess whether fine sediments can indeed reach locations of the semi-permeable structures, the volumes needed for nourishment, and possibly to optimize nourishment works. A numerical model will also help establish whether the new coastline will be stable and can continue to grow with sea level rise. We will need some additional data to calibrate this numerical model – these data will be specified in a later phase.Such a numerical model is required also to formalize the knowledge and experience gained during the proposed regional-scale Hybrid Engineering-application, making these generic and applicable to other conditions.

Upon implementation of Hybrid Engineering, long-term monitoring is required. The northern part of Demak coast (the northern "11 km" of Figure 11) is suitable to serve as a reference. Various aspects need to be taken into account in monitoring e.g.:

- Rates of wave dissipation over the various Hybrid Engineering-structures
- Suspended sediment concentrations and fine sediment fluxes towards the coast
- Siltation rates and resulting bed slopes
- Mangrove recovery, growing speeds, and success of replanting, if carried out.

6.5 Limitations of Hybrid Engineering

Hybrid Engineering does not resolve flooding of the villages, as no sediment is brought into the villages but rather onto the surrounding mudflats. Hence, other methods are needed to solve flooding problems. One may think of pumping/mechanical drainage, artificial dwelling mounds, houses on poles, etc. – the actual solution should be discussed with local inhabitants and authorities. In Bedono, a village situated in coast III, several houses have already been placed on poles, thereby preventing flooding of houses.

Also, villages are currently flooded frequently, not only because of coastal erosion but also because of (local) subsidence. Pumping of water usually increase subsidence rates, hence deep ground water winning should be stopped. To enable use of surface water instead, a proper waste management plan and water purification facilities are needed. Also, individual harvesting of rainwater and purification on a household level are possibilities to ensure availability of clean water.

Lastly, the development of socio-economic and governance solutions besides the technical Hybrid Engineering solution is equally important to ensure long term sustainability of the reclaimed land. These socio-economic and governance solutions should ensure that the reclaimed land is used sustainably in such a way that the coastal protection function remains intact. Communities may embark on new sustainable and income generating activities that make optimal use of the restored environment. Examples include the cultivation of seaweed, crab-cage farming and shellfish production. This advancement of livelihood strategies along with a decrease in incidence or even complete elimination of specific coastal hazards will improve resilience, reduce poverty and enhance self-reliance of the local population.

7. Conclusion

In this discussion paper we explored the causes of coastal erosion in (former) mangrove areas and explained the rationale for an innovative solution called 'Hybrid Engineering'. The Hybrid Engineering approach entails building with nature rather than fighting against nature. We illustrated how this approach may be implemented at regional scale by providing a design for a specific location in Indonesia and then indicated next steps. This approach is in general also applicable to many other tropical (former) mangrove areas suffering from erosion, e.g. Malaysia and Vietnam.

It is our vision to recover coastal zones that suffer from severe erosion and to recreate a resilient mangrove-based economy in which people make optimal use of mangrove resources and are protected by a mangrove buffer zone. This buffer zone harbours rich biodiversity and stores substantial amounts of carbon. To stimulate local economic prosperity and toavoid future mangrove losses, communities may develop new sustainable and income generating activities that make optimal use of the restored environment like seaweed cultivation and crab-fishing.

1. Current situation
Unsustainable aquaculture development, following mangrove conversion has rendered many coastal areas highly vulnerable: productivity has collapsed, carbon stocks are lost and coastal erosion and soil subsidence cause land loss, flooding and saltwater intrusion.

2. Rehabilitation phase
By combining small-scale engineering works (establishment of semi-permeable groins, agitation dredging) and mangrove rehabilitation measures, coastal erosion is halted. Revival of mangrove services boosts productivity of the land.

3. End-situation
A resilient mangrove-based economy has been created: people make optimal use of mangrove resources and are protected by a mangrove buffer zone. This buffer zone harbours rich biodiversity and stores substantial amounts of carbon. To avoid future mangrove losses, communities are supported to develop sustainable alternative to harmful livelihood activities.

Appendix I

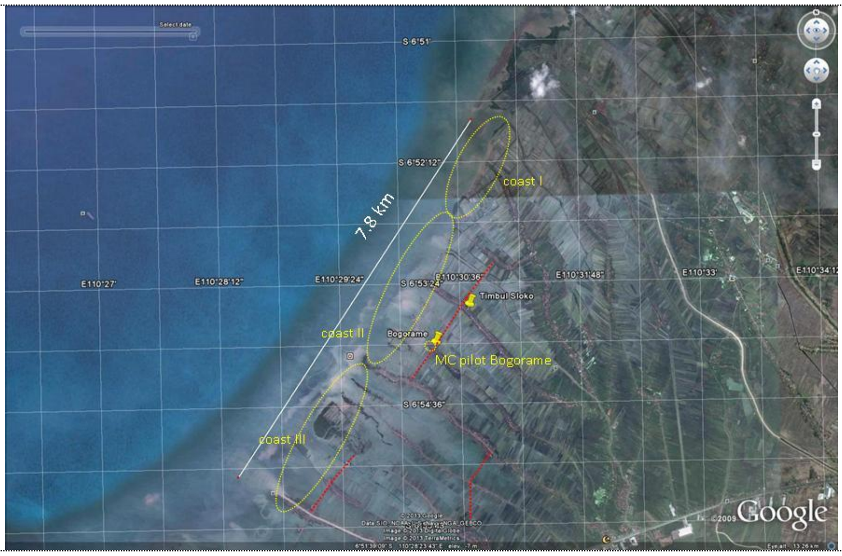
Criteria	Indicator	Required condition	Importance
1. Biophysical	Eroding/stable/accreting	The aim of the project is to restore eroding coastlines	Very high
	Previous habitat type	Mangroves should have been present before degradation	Very high
	Seedling availability	Seedlings should be able to reach the area for natural colonization	Moderate
	Hydrodynamics	Hydrodynamics should allow for natural and sustainable mangrove persistence after manipulation	Moderate
	Sediment availability	Sediment content in the water should allow for natural and sustainable mangrove persistence after manipulation	Moderate
2. Socio-economic Political, legal	Local stakeholder support	Local pond owners and villagers need to support the approach and be willing to collaborate	Very high
	Local/regional government support	Local and regional governments need to support the approach and be willing to collaborate	Very high
	Showcase potential	Site needs to serve as showcase, and be suitable for hosting national and international governmental officials	Very high
	Current programs/incentives	Joining forces with ongoing programs and initiatives on sustainability or coastal erosion is regarded as very beneficial	High
	Land ownership	It needs to be clear who owns the land now and who will own the land after restoration	High
	Current dredging works	Joining forces with ongoing projects that have a surplus of dredged material is regarded as very beneficial	High
	Representativeness	The site should be representative for the coastal erosion problems due to fish/shrimp farming in Indonesia	High
3. Logistical	Accessibility	The site should be relatively easy accessible to allow construction of pilots and monitoring	High
	Potential for up scaling	Rapid expansion of project adjacent to existing pilot should be possible	High
	Biodiversity value	Areas where restoration of mangroves increases biodiversity and ecosystem resilience considerable are given preference	Moderate
	Required permits and EIA (AMDAL)	An EIA will be done in any case. However, if less permitting is required in a certain site this will speed up implementation.	Moderate
	Data availability	If data on the pilot site is already available this is considered an advantage	Low

Appendix II

Series of Google Earth Images used for analysis in Chapter 4.

Overview

Demak coastline – coastal stretch of 19 km for large-scale Hybrid Engineering pilot (2013 Google Earth satellite image).

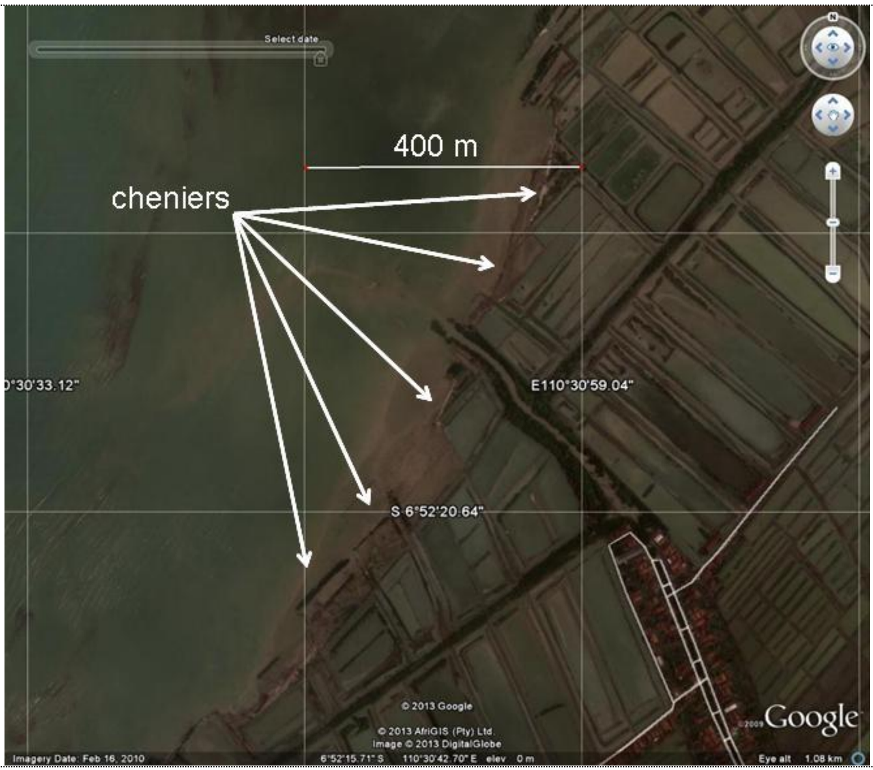


Southern part of Demak coast. This 7.8 km coastline can be sub-divided into three sub-sections, characterized by different erosion patterns. The location of the small-scale hybrid engineering-pilot within the framework of Mangrove Capital is indicated as well (e.g. Fig. 2), (2013 Google Earth satellite image).

Coast I: mild erosion

Demak coastline; coast I with approximate coastline 2013

Demak coastline;coast I with approximate coastline 2013.



Details of coast I, showing some cheniers along the coast.

Coast II: severe erosion

Demak coastline; coast II – 2003

Demak coastline; coast II – 2005

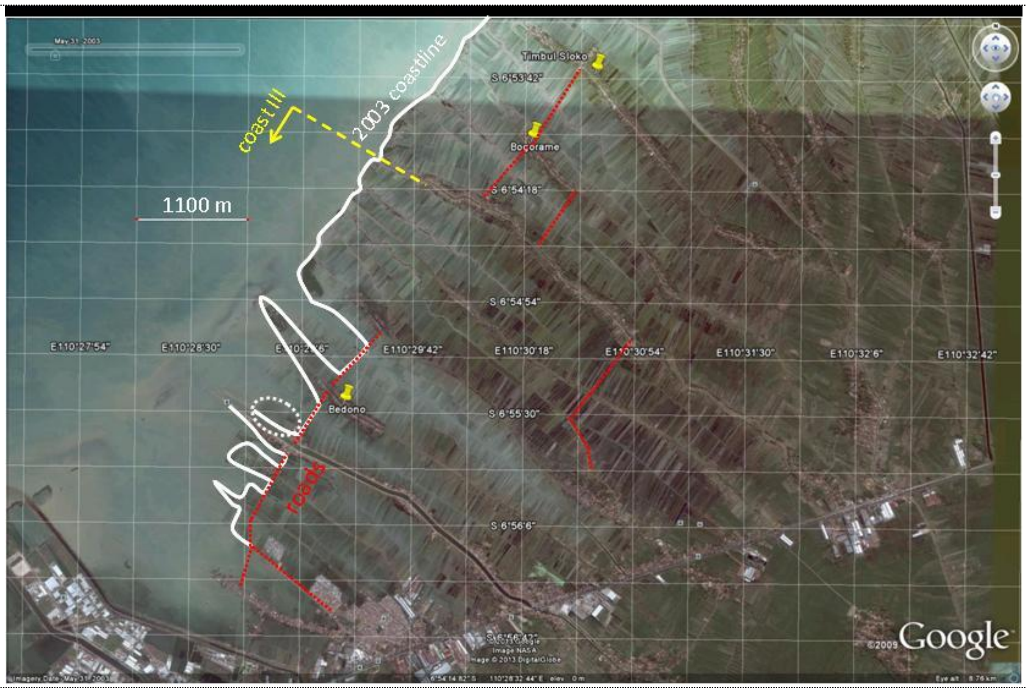
Demak coastline; coast II – 2007

Demak coastline; coast II – 2009

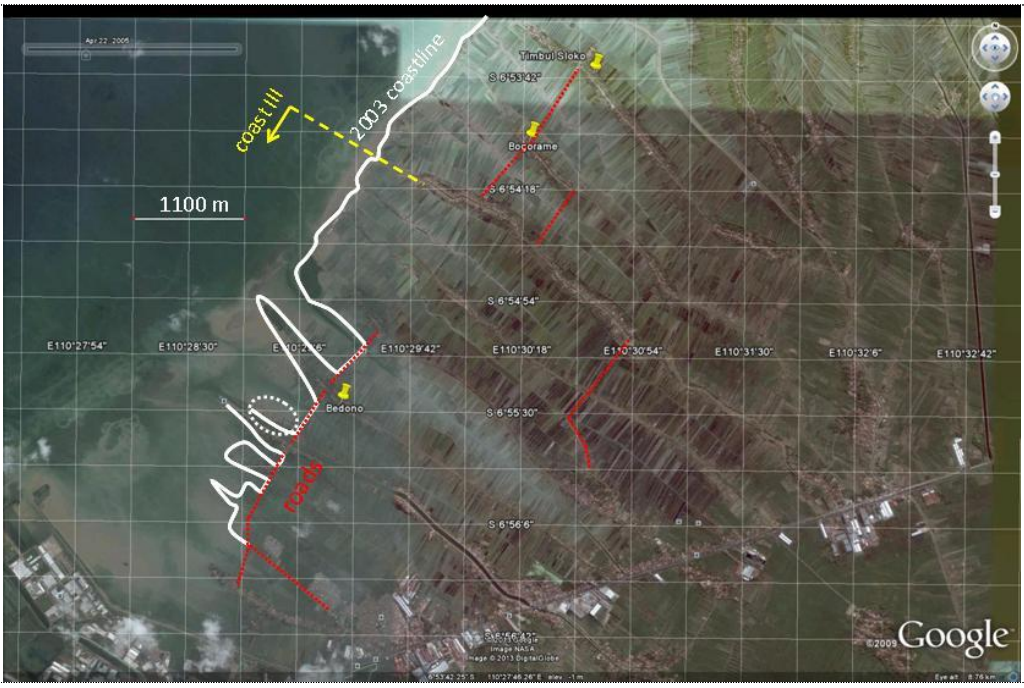
Demak coastline; coast II – 2012

Demak coastline; coast II – 2013

4.3.3 Coast III: severe erosion and subsidence



Demak coastline; coast III – 2003

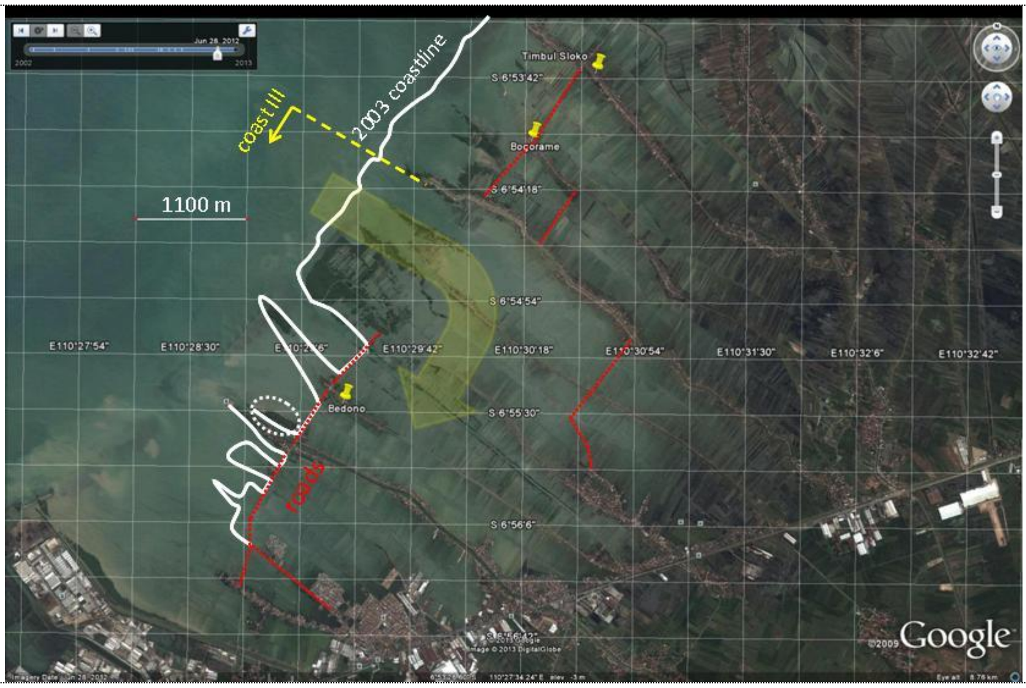


Demak coastline; coast III – 2005

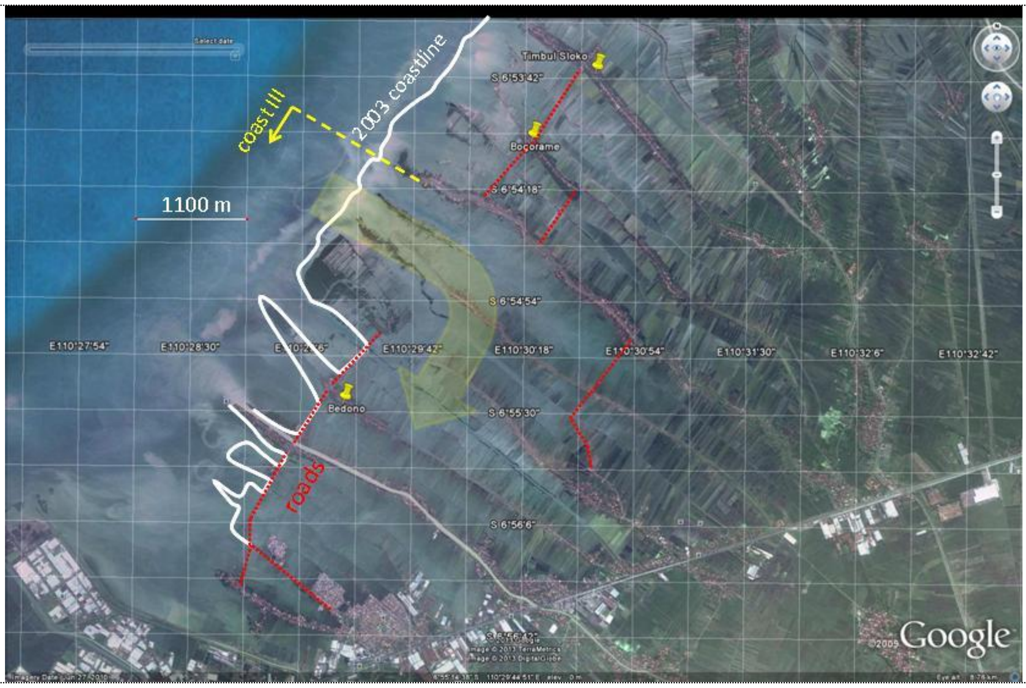
Demak coastline; coast III – 2007

Demak coastline; coast III – 2009

Demak coastline; coast III – 2010



Demak coastline; coast III – 2012



Demak coastline; coast III – 2013.

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