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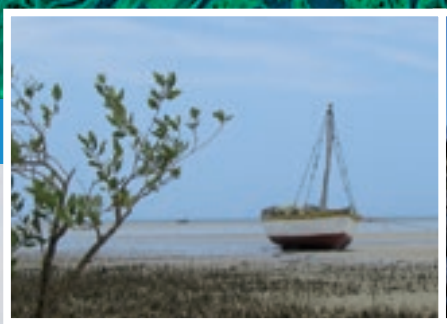

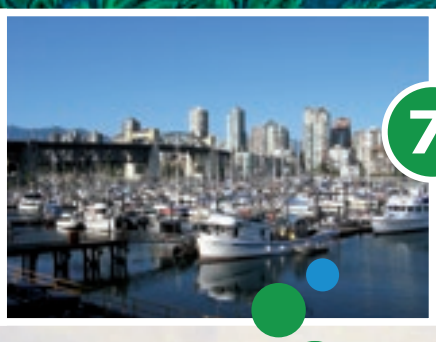

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Deltares
Enabling Delta Life

ALTERRA
WAGENINGEN UR

UNESCO-IHE
Institute for Water Education

TU Delft

Knowledge
for Climate

Comparative assessment of the vulnerability and resilience of deltas

Extended version with 14 deltas

work document

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In addition the World Wide Fund for Nature contributed to the delta descriptions of the Ganges-Brahmaputra-Meghna, Ciliwung and Mekong. The assessment of the Ayeyarwady Delta has been made possible with the support of the Global Water Partnership and the Bay of Bengal Large Marine Ecosystem (BOBLME) project coordinated by FAO.

Internet

For more information about the Delta Alliance and to download this Work document and other related documents go to **www.delta-alliance.org**

Citation

Bucx, T., W. van Driel, H. de Boer, S. Graas, V.T. Langenberg, M. Marchand and C. Van de Guchte. 2014: Comparative assessment of the vulnerability and resilience of deltas – extended version with 14 deltas - synthesis report. Delta Alliance report number 7. Delta Alliance International, Delft-Wageningen, The Netherlands

This research project was carried out in the framework of the Dutch National Research Programme Knowledge for Climate (www.knowledgeforclimate.org). This research programme is co-financed by the Ministry of Infrastructure and Environment (I&M).

Design and lay-out
Deltares

August 2014

Comparative assessment of the vulnerability and resilience of deltas

Extended version with 14 deltas

work document

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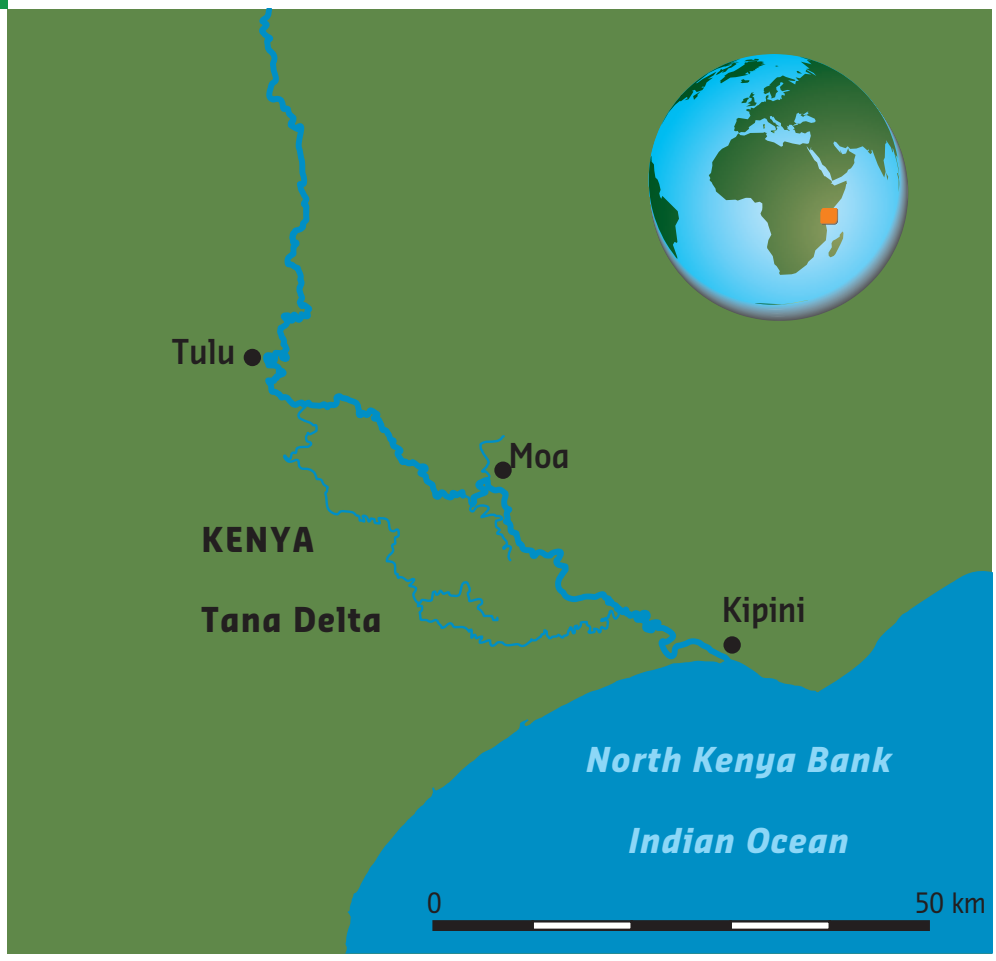
Overview of all 14 deltas with in green the four additional deltas elaborated in this work document. See www.delta-alliance.org for the work document with the descriptions of the other 10 deltas.

Tana delta

No 11



1. Current and future state of the Tana Delta

N.B. This description refers only to the lower Delta region of the Tana River basin (in general 0–40 m above sea level, reaching to 50 km inland).

1.1 Drivers of change

Summary of drivers of change

Demographic trends:
The Tana Delta has ca. 100,000 residents. With the total number of households of 12,457, and a mean household size of ca. 7 persons, the Delta population is growing at an estimated 3,62% a year. Over the past decade, conflicts have been increasing in the Tana River Delta as a result of increasing population, the majority of whom (over 90%) live in the rural areas

Economic developments:
The main economic activities are farming, livestock keeping (pastoralism) and fishing. The settlement patterns are random but are concentrated close to the river. The Tana Delta a dry season grazing area for livestock emanating from other Counties. Fuel wood is derived from forests and woodlands located in the delta. Other products include medicinal herbs, honey and eco-tourism, including several lodges and a wildlife conservancy. Strong developments are expected in the delta due to the implementation of the Lamu Port Southern Sudan-Ethiopia Transport (LAPSSET) Corridor (see 1.1.4 for more information).

Climate change:
Wide fluctuations in climatic conditions including pronounced flooding and droughts are experienced. In the next 20 years rainfall may be more prolonged, bimodal erratic, unreliable, and consequently cause more flooding events (although these may be counteracted by the building of the High Grand Falls Dam, see). In the next 40 years a possible increase of 15-25 cm in mean sea level could significantly reduce the scope of farming on those parts of the lower floodplain lying within 20 to 30 km of the coast.

Subsidence:
Unknown due to lack of data. However, human induced subsidence is likely to occur when downstream sediment supply decreases due to upstream dams and reservoirs, promoting the net change in sea level rise at the coast. Subsidence due to tectonic activity or by compacting organic layers is assumed to be small.

Technological developments:
The technological developemnts in the delta are currently limited in comparison to dams and reservoirs for power and irrigation upstream. However, the planned LAPSSET foresees major development push in infrastructure, large scale agriculture, logistics, and energy and water production.

Research gaps
Research is required in the development of impact assessment tools for various climatic impacts on delta health and functioning. The complete impact of climate change and the planned developments on delta morphology is unknown.

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population and demography
Tana River Delta is an area with a modest population. The area is characterized by a migratory

population consisting of livestock herders who migrate to the lower plains during the drought months. In comparison with the whole Tana district with more than 240,000 people, the population of Tana River Delta district is estimated at ca. 100,000 based on the 2009 census using a growth rate of 3.62% (KNBS, 2009; Government of Kenya, 2010). The total number of households in the delta is 12,457 with mean household size of ca. 7. The population density in the district ranges from 4 – 27 persons per km^2 with a mean of 7.

The main economic activities are farming, livestock keeping (pastoralism) and fishing. Agriculture employs about 60% of the population while 40% work in the livestock sector that in comparison to agriculture requires expansive landscape.
The communities living in the delta are: Pokomos - 44%, Ormas - 44%, Wardei - 8% while the other ethnic groups, including Luo account for the remaining 4%. The Wardei are a smaller pastoralist group originating from Ethiopia. The Pokomo are mainly subsistence farmers who farm along River Tana.

The district suffers under heavy burden of high incidence of poverty estimated at 76% compared with a national average of about 50%. The unemployment rate in the district is estimated at 33% compared with a national average of 20%. Over the past decade, conflicts have been increasing in the Tana River Delta as a result of increasing population, the majority of whom (over 90%) live in the rural areas. The settlement patterns are random but are concentrated close to the river. While rates of chronic malnutrition are evident all across Kenya"s regions, acute malnutrition is extremely high in Northeastern province and the Tana River district of Coast province, under which the Tana delta falls.

It is a dry season grazing area for livestock emanating from other Counties. Fuel wood is derived from forests and woodlands located in the delta. Other products include medicinal herbs, honey and eco-tourism, including several lodges and a wildlife conservancy.

Socioeconomical characteristics and developments
Agriculture and livestock keeping are the most important economic activities in the district contributing 82.2% of the household income. The delta is a dry season grazing area for pastoralists. Pastoralists come from as far as Garissa, Wajir and Mandera to graze in the delta during the dry season. The contribution of the delta to pastoral economy becomes more critical during severe drought when livestock depends exclusively on the delta causing overgrazing. In 2009 the number of livestock in the delta was 140,000, but seasonal influx of cattle (during severe drought) into the delta is estimated at 600,000. The number of cattle, sheep, goats, camels, and donkeys are increasing. This is occurring as pasture decreases leading to overgrazing, thus degradation of delta. As shown in table 3, total area under natural pastures is on the decline.
Common crops are: mangoes, cashew nuts, cotton, rice, maize, cassava, bananas, greengrams, beans, peas, melons, cowpeas, pawpaw, tomatoes, kales, onions, cabbages, sugarcane, and vegetables. The production systems are traditional and are operated mainly for subsistence and outputs are therefore low. Surplus production of meat and mangoes do not reach the markets due to lack of infrastructure. The County is generally food insecure and the population has had to rely on relief supplies.

While an increased frequency of droughts and the establishment of hydroelectric power dams upstream have put significant pressure on the area's traditional livelihoods. Growing interests of investors mainly originating from the bio-fuel sector in the delta are about to impose an additional burden for these livelihood strategies. Several domestic and international investors have proposed projects involving the alienation of tens of thousands of hectares from customary use for establishing large scale bio-fuel plantations.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

In comparison to the Tana River District, that is hot and dry, the Delta area along the Indian Ocean is normally hot and humid with little variations in temperature. The average annual temperature between 25^0C and 30^0C, accompanied by relatively high evaporation rates of 150–210 mm $month^{-1}$.

The immediate coastline can receive 750 -1250 mm of rainfall annually while 50 km inland rainfall may be less than 300 mm. Further upstream the rainfall in the district is generally low (mean annual between 300mm and 500mm, Kenya Meteorological Department). and bimodal with two rainy seasons extending from April to June and from November to December, both of which correspond to the flooding periods for the Tana River in natural conditions. In these circumstances local people are well adapted to coping with climatic fluctuations on a seasonal and annual basis. Local precipitation most likely does not induce the floods but instead acts as a “wetting” event before the arrival of the flood wave. Topographical gradient, overland flow and regional groundwater flows to the floodplains are most likely limited, compared to the water brought by the Tana River.

According to studies that formed the basis of the Tana River Delta Land use planning, it is likely global warming and rising sea level already started to have a significant impact on the Tana Delta. Wide fluctuations in climatic conditions including pronounced flooding and droughts are experienced. In the next 20 years rainfall may be more prolonged, bimodal erratic, unreliable, and consequently cause more flooding events (although these may be counteracted by the building of the High Grand Falls Dam, see). In the next 40 years a possible increase of 15-25 cm in mean sea level could seriously reduce the scope of farming on those parts of the lower floodplain lying within 20 to 30 km of the coast.

1.1.3 Subsidence (natural or human-induced)

There is currently no information available on the occurrence and dynamics of subsidence in the Tana delta. However, seen the constructed and planned dams and reservoirs in the upper catchment it is likely that the downstream supply of sediment will decrease further and as such could play a role in defining the net change in sea level along the coast.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

ICT-based infrastructure is very limited in the Tana Delta, cell towers do provide widespread basic coverage and mobile phone ownership rates in the area are high compared to internet connectivity.

The Seven Folks Hydro Electric Power Stations and Bura and Hola irrigation schemes for modern agriculture are located upstream of the delta. Currently, commercial irrigation farming of rice by TARDA is the only major modern farming in the delta.
Apart from a growing number of settlements in de the delta there are no major technological developments in the Delta itself.

However, The Lamu Port Southern Sudan-Ethiopia Transport (LAPSSET) Corridor project is a transport and infrastructure project in Kenya that, when complete, will be the country’s second transport corridor. The project foresees the development of associated infrastructure sub projects in particular the High Grand Falls in the Tana that is envisaged to produce 500MW of power and provide water to Lamu city, Lamu Port and metropolis and irrigation of mega farms planned for the Tana Delta among other areas within the Corridor. The High Grand falls will be used to create a man-made Lake at its dam with a view to controlling perennial flooding within the lower Tana Basin.

New investment in the region will provide an important economic stimulus which will change and affect the Tana Delta. E.g., as Lamu port expands there will be scope for developing export trade particularly in meat, fish fruit and vegetables and the Plan anticipates the creation of four industrial sites in the Delta; Garsen, Witu, Tarasaa and Kipini. In line of the proposed developments also exploratory activities for other subsurface resources are planned in the Delta.

1.2 Pressures – potential problems / Challenges – opportunities

1.2.1 Land and water use (occupation layer)

Summary of pressures

Pressure on space:
Space in the delta is currently under threat as government, corporations and foreign agencies are implementing large-scale land acquisitions (LSLA). Nomadic pastoralists as well as communities engaging in small-scale subsistence farming will be affected more with current Delta development plans. Driven by high population growth and densification of settlement the pressure on space is likely to increase further.

Vulnerability to flood:
Floods have become less frequent and predictable due to dam and reservoir construction upstream. With the further development in the delta the vulnerability to flooding will increase especially at moments when dam regulation in the upper catchment fails and emergency spilling surprise growing floodplain communities with flashfloods.

Water demand / freshwater shortage:
Water availability per capita in Tana Delta is today ca. 22% of the amount it was 50 years ago. The whole catchment is classified as 'water scarce' mainly as the result of a growing number of farming or pastoralist communities and increasing number of commercial irrigation schemes. With projected socioeconomic developments, water demand will increase leading to prolonged fresh water shortages in time and space throughout the whole Tana delta.

Research gaps
There is need to expand the hydromet services for the delta; currently, only KENWEB appears to do substantive work on continuous data collection.
In 2007, Tana River changed course near Mnadzini; it is not fully known what are the determinants of course change; hence it cannot be predicted.
Food and water demand in the delta is not clearly known.
With projected land use changes a detailed water balance of the delta is required.

Pressure on space
Nearly all the land in Tana River and Tana Delta districts is trust land and a majority of the settlers do not have titles to their ancestral lands although they may have lived on the same place for generations. With a population of an estimated 100,000 people with a growth rate of 3.62% (KNBS, 2009; Government of Kenya, 2010) an increased pressure on delta land and resources is unavoidable.

The Delta provides a key source of emergency and drought pasture, and in years of extreme low rainfall cattle populations more than double. As the flooding regime in the Delta has decreased, dry season pasture and watering points have become limited to the area that is directly adjacent to the river. Traditional patterns of transhumance will disrupt more, grazing pressure will increase, and intensified conflict between pastoralists and floodplain agriculturalists over land and resource use on the Delta are likely (IUCN, 2003).

Furthermore, the delta land is under threat as government, corporations and foreign agencies seek to exploit its riches for export crops, bio-fuels and minerals (Tabel x.).
During the last decade, Tana River Delta has witnessed increased interest in agricultural expansion. Apart from the ongoing rehabilitation of a multimillion TARDA irrigation project, three major irrigation projects are under way, namely Tana Integrated Sugar Project – 33,000ha, G4 International irrigation project – 28,000ha, Bedford International irrigation project – 90,000ha and Matt International irrigation

project – 33,000ha. These proposed projects will cover about 200,000ha of land and will lead to people being evicted cuasing more pressure elsewhere in the delta. These projects are mostly be based on relatively high water demanding furrow irrigation systems and are currently being implemented in the absence of integrated water resources management plan (IWRM). Consequently, the livestock economy depending on sufficient pastureland will be affected. Combined with already decreasing river discharges the available natural resources will likely to decrease.

Table x. List of Proposed Developments in Tana Delta

No	Proponent	Details
1	Coastal Aquaculture Limited	Shrimps and prawns farming
2	TARDA	Irrigated rice (TDIP), 2180 ha
3	G4 Industries	Oul seed farming, 28,000 ha
4	Mumias Sugar Company & TARDA	Large scale sugar plantation and eco- friendly bio-fuels, 24,000 ha.
5	TARDA	Grow rice and maize in response to drought and food shortage, 40,000 ha
6	Mat international	Sugarcane 30,000 in Delta and 90,000 in neighboring districts
7	Bedford Biofuels Ltd.	Bio-fuels farm growing Jatropha curcasm 164,000 ha
8	Gulf state of Quatar	Grow fruit and vegetables to have Lamu port worth € 3.5 billion constructed
9	FAR Ltd. , Australia	Oil and gas exploration
10	Ketraco	High voltage powerline
11	Tiomin Kenya Limited	Titanium extraction from the sand dunes of Tana Delta.

Vulnerability to flood

Discharge in the Tana River delta fluctuates. At present, it sustains flood based farming (using tidal effects) and riverine forests with high and unique biodiversity. Normally, the Delta regions naturally cope with the bi-modal flooding rhythm of the delta and the local people are adapted to coping with climatic fluctuations on a seasonal and annual basis. The floodplain wetlands and in particular the oxbow lakes are considered to be of high value for recession agriculture of sorghum and millet, fishing, reeds for roof thatch, fresh water, grazing, etc. The floodplains have an important function in the attenuation of flood peaks through the over-spilling of the banks, storage on the floodplains and in the oxbow lakes, infiltration into soils raising the ground- water level, etc. thus protecting downstream areas from flooding, erosion but also saltwater intrusion.

However, with increasing densification of settlements in the floodplains driven by rapid population growth (3.62%) and changes in settlement patterns (from seasonal pastoralism to farming and settled pastoral communities with livestock grazing year-round) the vulnerability to flooding is likely to increase. Additionally, with the further planned development of dams and reservoirs upstream, flooding dynamics are likely to be tempered more, allowing communities to move into the floodplain areas directly adjacent to the Delta Rivers. Consequently, and even with the less frequent and predictable natural flooding events, with the expected development in the delta the vulnerability to flooding is real and increasing especially at moments when dam regulation in the upper catchment fails and for example emergency spilling surprise floodplain communities with flashfloods.

Currently, the delta has been affected by increased recurrence of severe floods on the one hand and declining river water discharge on the other. Flooding has damaged infrastructure and settlements in the delta before. E.g., the floods associated with 1997/08 El Nino virtually destroyed a multimillion TARDA irrigation project. Flooding has also contributed to siltation of oxbow lakes and river beds. The impact of flooding has been more visible because of increased settlements in the floodplains.

Flooding at Walkon forcing residents to reallocate.

Water demand / freshwater shortage

The Delta is an extensive zone characterized by water scarcity in time and space. Evapotranspiration rates are high due to the high temperatures. As the flooding regime has decreased (see above), dry season pasture and watering points have become limited to the area that is directly adjacent to the river.

Shortage of water has been a major contributory factor to the recent conflicts in the Tana Delta as some sections of the pastoral and farming communities have fought over access to the river and the damage caused to crops by both livestock and wild animals. These problems become particularly acute during the dry seasons when very large numbers of cattle are driven from isolated areas to the Delta in order to find grazing and water.

Although water availability fluctuates yearly and seasonally, over the years, the normal/low flows of River Tana have significantly declined during the last three decades. On overall, the per capita water availability in Tana Delta has been shrinking. This has been caused primarily by growing populations although there are indications that the delta and upstream storage is decreasing and non-beneficial evaporation is increasing (through barren top soils and poor soil/water conservation measures). Estimations show that water availability per capita today in Tana ca. 22% of the amount it was 50 years ago. This classifies the whole catchment as ‘water scarce’ (TWRMA 2007).

At present groundwater is not used intensively throughout the Delta – with the exception of a few sub catchments. Groundwater is used mainly for drinking water. As the pressure on resources increases one may expect groundwater use to increase for agriculture and livestock too. Plans for irrigation development are currently being drawn up throughout Kenya in line with the government's declared intention to create one million acres of new irrigation by 2030. Since the River Tana carries 70% of the national fresh water flow it is certain that a significant proportion of this irrigation will need to be located within, or adjacent to, the Tana catchment. Current proposals include renovation of the Hola and Bura schemes and promotion of irrigation on the Galena Ranch which falls partly within the Athi River and Tana River Catchments.

It is expected that with current socioeconomic developments the water demand will increase leading to prolonged fresh water shortages in time and space throughout the whole Tana delta.

1.2.2 Infrastructure (network layer)

Summary of pressures

Flood protection:
There is iimproved upstream land use. Also, five major reservoirs have been built in the upper basin that have significantly modified the hydrological regime of the river, with a 20% decrease in the peak flows of May.

Irrigation and drainage:
Upstream dams and the biofuel and large irrigation schemes impact downstream flooding processes by diminishing the possibilities for floodplain agriculture and limiting scheme cropping to the riverbanks. Generally, irrigation and drainage infrastructure are limited and poorly developed.

Water supply and sanitation:
Due to inadequate investment in water infrastructure, the locals depend on surface water taken directly from the Tana River, making them vulnerable to water-borne diseases. Currently supply and sanitation are worsening and little infrastructure is implemented.

Roads, railways, ports and navigation channels:
The delta is not well networked in terms of infrastructure. Although roads and power supplies do connect the major towns in and just outside the delta, the structure is aging and insufficient. With the projected plans in the delta, large infrastructural investments are expected for industrial and urban developments.

Research gaps
Sustainable water engineering is required for allowing full development of the Delta's limited resources now and in the future.

Knowledge on implementing waste water treatment is lacking.

A detailed allocation assessment, including a comprehensive water quantity and quality balance, is needed.

Flood protection:
Modifications in up-stream land use, hydro-electric infrastructure, and increased water withdrawal, in conjunction with climate change, are currently the main factors modifying the flooding dynamics of the delta. Over the past fifty years, five major reservoirs have been built in the upper basins that have

significantly modified the hydrological regime of the river, with a 20% decrease in the peak flows of May (Leauthaud, 2012). The proposed Mutonga-Grand Falls dam would be the last stage in controlling River Tana's waters.
Except in extreme events occurring every 5 and 10 years This would most likely end the regular bi-annual floods, cut off most of the floodplain from water, and significantly lower the local water table (ACCESS , 2014).

Irrigation and drainage:
Other future projects, particularly those of the Grand Falls Dam and also the many biofuel and large irrigation schemes will further impact downstream flooding processes. Numerous delta communities practice flood recession and riverbank farming often the only source of land in the region that is suitable for arable agriculture. These farmers depend both on floodwater to irrigate their crops, and on the depositions of fertile sediments that the floods bring. With dam construction, the possibilities for floodplain agriculture have diminished considerably, and it is likely that after the construction of the Mutonga-Grand Falls scheme cropping will be limited to riverbanks only.

Man-made irrigation and drainage infrastructure are very limited and poorly developed. The River Tana has on many occasions breached its own banks and destroyed flood embankments, canals and levees built as part of large-scale irrigation schemes. The projected irrigation schemes development in the Tana Delta will therefore need to be planned with the utmost care securing foremost safe intake points for abstraction on the main river (a weir or barrage) which can be overtopped in major floods and is not vulnerable to changes in River course or siltation.

Water supply and sanitation:
No significant infrastructural developments have been implemented yet to improve the worsening situation with regard to water shortage and sanitation in the Delta. Reservoir construction (High Grand Falls dam) further stabilizes and regulates the water balance and allocation schemes, allowing for improvements downstream.

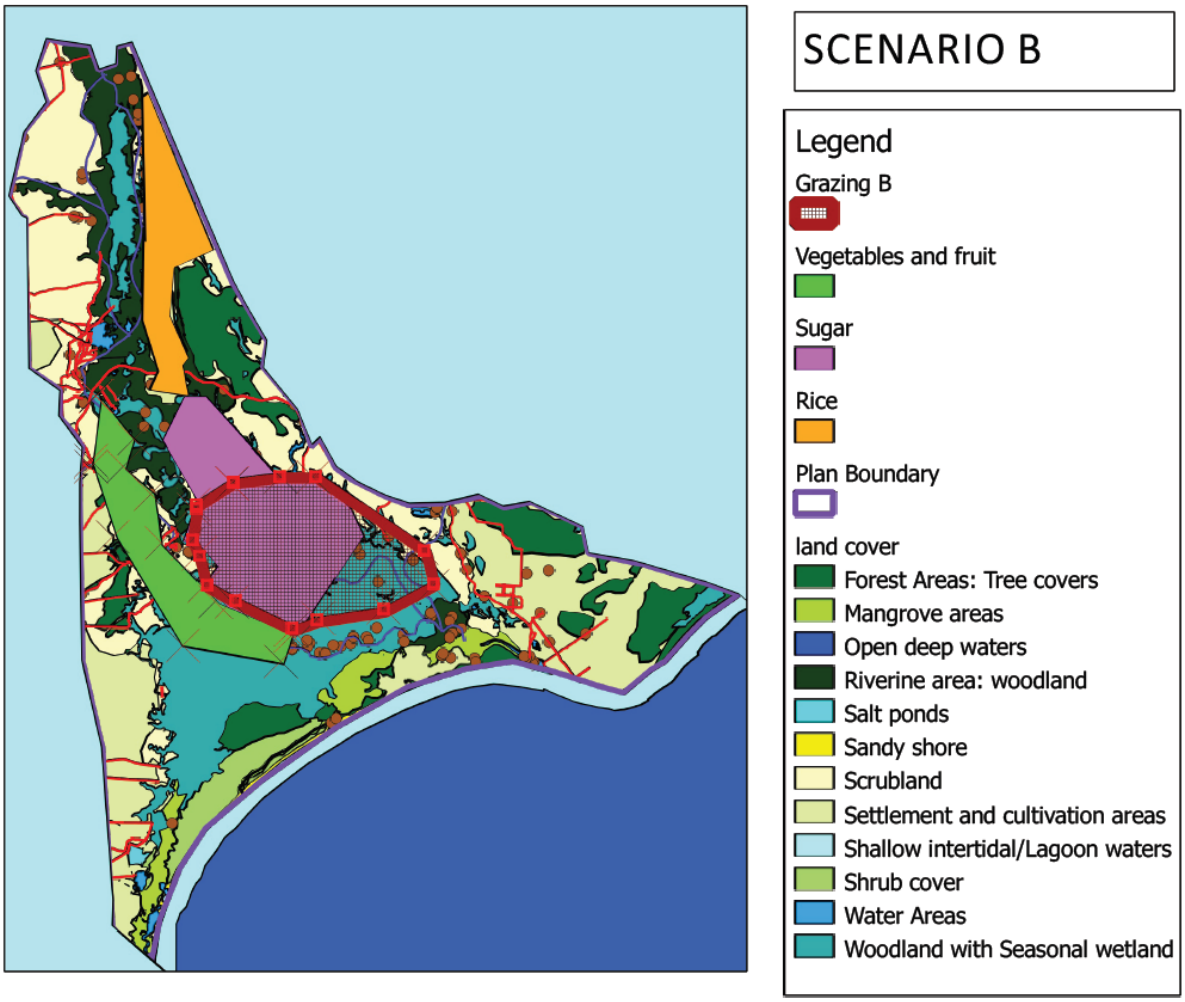
Major infrastructural developments are expected (see bove) since the industrial and domestic water needs of the projected Lamu port and city will most likely be drawn from the Tana system.

Roads, railways, ports and navigation channels:
Infrastructural developments are still few and only some former constructions just upstream of the delta had impact on the lower delta regions. E.g., the River Tana historically flowed from north to south along different channels but the construction of the Garsen-Witu road on an elevated embankment has confined the river to a single exit point under the Iswowe Bridge near Garsen. Also the construction of the Matomba Brook in 1986 has resulted in a major re-alignment of the River Tana which now flows across the Central Flood Plain of the Delta.

The Tana Delta has a major road passing round its perimeter and linking Malindi (and the rest of the southern coastal towns) to Garsen, and Lamu. However, until the advent of the LAPSSET corridor and Lamu Port project, this route had been neglected and currently some parts of the road are severely pot-holed – especially the extension north to Hola and Garissa. The remainder of the road network in the Delta consists of short lengths of tarred road to Tarasaa and Kipini but the majority of roads and tracks are gravel-bound or beaten earth.

Electricity supplies to the principal settlements have been upgraded with the construction of a new national grid power line linking Mombasa and Lamu. Still, much of the rural area is without electricity.

Several scenarios of infrastructural improvements have been proposed by the Kenyan government for implementation largely driven by the economic investments being made in adjoining counties, including the Lamu Port development (up to 20150). E.g., The Kenyan government anticipates the creation of four industrial sites near Garcen, Witu, Tarasaa and Kipini. Boosting town growth and road construction.



Projected development scenarios of the Delta.

Also industrial parks, public institutions (schools, hospitals, administration centres), local feeder roads and individual houses are planned. A nominal area of 1000 hectares is assumed for urban development. This analysis excludes the level of site preparation, land levelling or construction of canals and embankments that would be required for irrigation schemes.

Some infrastructure development scenarios have a hybrid character supporting both industrial estates and commercial farming and livestock. Also here road building would be most important as well as potable water supplies and untreated water for irrigation that require pipeline (and/or canal) construction.

1.2.3 Natural resources (base layer)

Summary of pressures

River morphodynamics:
A rapid analysis of river discharges at Garsen shows that peak discharge rates are largely attenuated and smoothed out between the two stations, with an average decrease in transiting volume of 76%.

Flooding (flood hazard):
The flooding characteristics of wetlands, particularly the flood extent, timing, frequency, duration and flood peaks, have decreased (ca. 20%) but are more irregular.

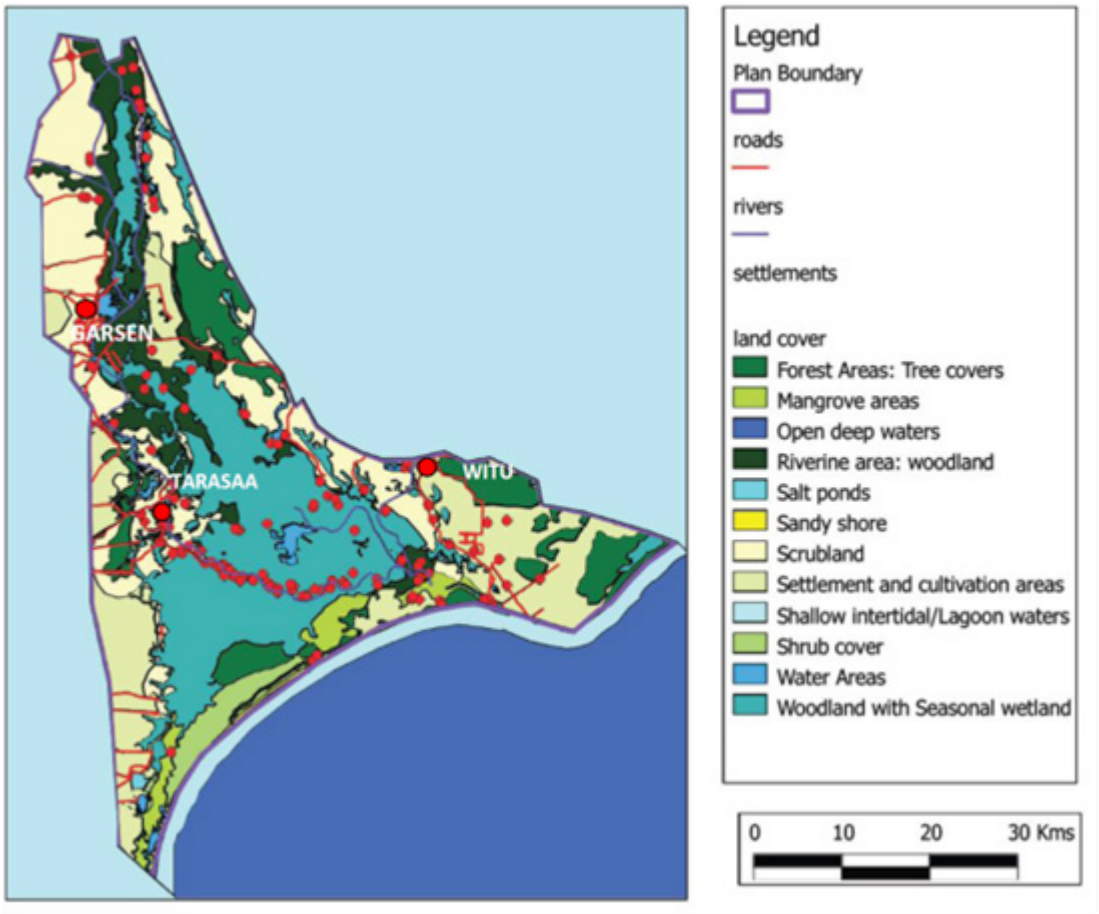
Salinisation/salt intrusion:
Salinity and sodicity problems are common in the Tana Delta where they have naturally formed under the prevailing climatic conditions and due to high rates of evapotranspiration and lack of leaching water. Land degradation by salinization is on the increase in irrigated deltaic areas where irrigation of unsuitable soils or use of poor quality irrigation water is a common practice.

Water and soil pollution:
Pollutants from agriculture sector are relatively high due to lack of standards implementation. Nutrient run-off can cause eutrophication locally with possible algal blooms (including toxic blue green algae) and lowered oxygen content.

Wetland and biodiversity loss:
Biodiversity loss, environmental degradation and poverty is high, resulting from increased human pressures on available delta resources and the disturbance of the (natural) structural functioning of the delta.

Research gaps
Lack of hydrological, climate and topographical data hampers the characterization of the flood events. Commonly, water fluxes are un-gauged and models too course with little predictive power.

Dimensions
The delta area and associated ecosystems cover an area of 1,300 km^2. Tana River delta is Kenya's only major ocean delta. It is a low-lying area composed largely of sediments brought down by the river. It is subject to frequent flooding and changes in the network of channels and canals. The input of water is almost exclusively from the river itself because of the net outward flow of water, except in situations where invasions of saltwater occur. The delta maintains high levels of productivity in a dynamic balance which revolves around the frequency, extent and duration of flooding. Water circulation transports nutrients, influences a wide variety of habitat types, flushes away wastes, controls salinity and disperses and nurtures larval stages of a number of coastal organisms.



Tana Delta area.

Water resources

The delta has many shallow lakes and wetlands resulting from meanders of the Tana and recharged through ground water seepage or by the periodic flooding of the River. These unique habitats also provide food, livelihoods and social benefits to local communities. The basins of oxbow lakes and the deeper parts of dammed lakes where water remains for most of the year include Lakes Bilisa, Shakababo, Kongolola, Kitumbuini, Dida Warede, Harakisa, Moa and Kenyatta.

Kenya is expected to experience a slight increase in the amount of rainfall, higher temperatures and evaporation over the next 50 years. With little groundwater available in the delta, the growing water demand depends mostly on the available surface water. Combined with increased exploitation of water resources in the upper catchment, through dam construction and diversions a significant change in river flow in the lower regions has been reported. Also frequency and duration of major floods has been reduced, while there has been some small increase in minimal flows during the dry seasons as a result of increased storage and daily releases from existing upstream dams. Dam construction in the upper catchment has greatly reduced the amount of silt reaching the Delta. As a result also a reduction in soil fertility is expected, impoverishing the delta base.
With the planned delta developments the coming decades, an increase in pressures on the existing water and soil resources is expected.

Coastal erosion

The River Tana discharges ca. 4,000 million m^3 annually entering the ocean near Kipini at Ungwana Bay. The Tana Delta has accreted extensive coastal plains due to coastal drift and the high sediment loads carried by the Tana River. As stated, dams upstream have reduced water flow and sediment

load reaching the delta and combined with lowered flooding frequency, it causes die-off of the coastal forest. Moreover, extreme sediment loads still occur as a result of poor land use practices in upper catchments causing massive soil erosion especially at moments when dam control fails and water flow is high. Such rates of sediment discharges impact the ecological integrity of marine and coastal habitats such as mangroves, seagrass meadows and coral reefs.
With increased pressure on the lower biotopes (forests, mangroves and reef) and a disturbed sediment and water discharge it is expected that structural integrity of the lower regions of the delta will decrease and consequently coastal erosion to increase.

Flooding (flood hazard)
The hydrological regime of the Tana River and as a result the flooding characteristics of the mid and lower regions of the Tana Delta have changed due to developments upstream (see network layer characteristics). Flood extent, frequency, duration and flood peaks (ca. 20%) have decreased and also the timing of floods has become irregular.

Salinisation/salt intrusion:
Salinity and sodicity problems are common in the Tana Delta where they have naturally formed under the prevailing climatic conditions and due to high rates of evapotranspiration and lack of leaching water. Land degradation by salinization is on the increase in irrigated deltaic areas where irrigation of unsuitable soils or use of poor quality irrigation water is a common practice.

Soil structure deterioration is observed mainly in saline and sodic soils, caused by sodium. The collapsed structure impairs water movement in the soil causing impeded drainage conditions and reduction in oxygen and nitrogen supply. Soils susceptible to crusting and sealing occur mainly in agro-ecological zones.

Water and soil pollution:
Johnson and Ebert (2000) have quantified the pesticide inputs from sugar cane farming into the coastal waters. There is a lack of (implemented) standards at large irrigation projects.
Herbicides and pesticides can be monitored in the delta and in adjacent coastal zones. E.g., Diuron has been shown to have a significant impact on photosynthesis of seagrasses and probably affects productivity in Ungwana bay, an important fishing ground at the mouth of the Tana delta.

The amount of fertilisers and hence eutrophication effects in the delta are unclear. However, in similar systems, there are very clear links between increased nutrient loads and the development of algal blooms (Anderson et al., 2002) some of which are toxic and can cause paralytic shellfish poisoning and as such affect coastal fisheries and tourism. AS the Matomba channel is projected to become the main drainage of a large scale sugar plantation, a reduced flow and increased nutrients. As the flow dynamics through the Matomba channel reduce further can end up in the water bodies downstream causing and may cause anoxia and other problems there.

Nature
Kenya has designated the Tana River Delta as a Wetland of International Importance. As of 2012, the Tana River Delta Ramsar Site in Coast Province, is the second most important estuarine and deltaic ecosystem in Eastern Africa, comprising a variety of freshwater, floodplain, estuarine and coastal habitats with extensive and diverse mangrove systems, marine brackish and freshwater intertidal areas, pristine beaches and shallow marine areas, forming productive and functionally interconnected ecosystems.

This diversity in habitats permits diverse hydrological functions and a rich biodiversity of rare, vulnerable, migratory and threatened species, including coastal and marine prawns, shrimps, bivalves and fish, five species of threatened marine turtles and IUCN red-listed African elephant, Tana Mangabey, Tana River Red Colobus and White-collared Monkey. Over 600 plant species have been identified, including the endangered Cynometra lukei and Gonatopus marattioides.
As one of the only estuarine staging posts on the West Asia - Eastern Africa coastal flyway, it is a critical feeding and wintering ground for several migratory waterbirds such as waders, gulls and terns.

The delta supports many tens of thousands of wetland birds and is internationally important for the survival of no less than 22 species of birds.

The coastal strip provide habitat for turtle nesting. The river gently slopes at the mouth and experiences marine tidal impact. This leads to a zone with fluctuating salinity that can reach far upstream from the river mouth, the estuarine zone. Specialist plant species such as the mangroves are adapted to low or fluctuating salinities. Hence, within the estuary, biodiversity is somewhat lower but densities are very high because of the continuous supply of food and nutrient from the river.

The lower Tana riverine forest is unique to Kenya being remnants of continental forests resembling western more than eastern African vegetation communities.
The forests are characterized by the presence of numerous endemic or restricted-range species of plants, primates (the endangered the Red Colobus, and the Crested Mangabey), amphibians and reptiles and other taxonomic groups that have so far been insufficiently studied. The Lower Tana River itself also harbors a number of endemic fish species. What characterizes these wetland forest ecosystems is their functional dependence on floods for forest regeneration and productivity, groundwater recharge, deposition of fertile loams and clay that constitute an agricultural resource, fisheries productivity, etc. Thus the flooding regime is key to the sustained provision of ecosystem services for delta community well-being.

Fisheries resources
Tana River Delta is an important habitat and spawning area for fishery resources. FISHBASE website has listed 44 fish species, while a study conducted by Luc De vos et al. (2002) recorded at least 30 species in the lower Tana River, most of which were found in the main river channels, particularly in sheltered, low velocity areas, swamps and in the oxbow lakes, which provide unique spawning grounds for fish species.
The fishing communities are engaged in traditional small-scale fishing for the purposes of domestic consumption as well as for sale. Due to population growth, use of inappropriate fishing gear, poorly regulated fishing and siltation of oxbow lakes, the sustainability of fishing in the delta is threatened because of over – fishing and siltation of oxbow lakes.

Kenya ratified the Convention on Biological Diversity (CBD) and prepared National Biodiversity Strategy and Action Plan covering conservation of biodiversity, sustainable utilization and equitable benefit sharing. Nonetheless, environmental degradation and poverty (particularly elements based on food and incomes) will most likely increase, resulting from diminishing production and returns from land. Illegal logging and charcoal burning will continue unabated while land degradation through soil erosion and bush clearing will exacerbate the condition.
Large tracts of land within the Tana Delta have been set aside for large industrial scale farming and for mining by government and private agencies, as well as by foreign governments. In addition, settlement schemes have taken up some of the most important dry season pastures within the Tana delta and communities from outside the pastoral areas were settled there to undertake crop farming. The delta base is therefore under unprecedented threat as corporations and foreign agencies seek to further exploit its riches for export crops, bio-fuels and minerals. While the delta provides immense environmental services to the country, developments that do not take the special circumstances of the delta into consideration may lead to the collapse of most of its services.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government:
Although 14 government institutions are currently involved in the management of the Delta and significant legislation and policy are in place at the national level to guide sectorial developments e.g. water, agriculture and mineral resources policies, the development agenda in the Delta remains largely uncoordinated..

Cooperation between government and private sector:
The Physical Planning (PPA) Act mandates Local Authorities (LA) to regulate development within their areas of jurisdiction to foster orderly and sustainable development. However, government institutions and the private sector have had little constructive dialogue about the future of the Delta. The situation is currently exacerbated by a multitude of large-scale, potentially conflicting development proposals.

Involvement of stakeholders and citizens:
Local communities are not well represented in governance processes affecting the Delta. The communities are largely unorganised; especially the most isolated and marginalised and their views on development proposals do not have formal recognition within to the decision-making process.

Approaches for dealing with risks and uncertainties:
The Land Use Plan (LUP) for the Tana River Delta is supposed to guide the involvement of all stakeholders in the Tana Delta. The LUP framework will guide strategic Planning in the Delta to lower risks and uncertainties, and specifically addresses resource conflicts between local agriculturalists, pastoralists and large-scale agricultural schemes

Research gaps
Uncoordinated research and monitoring programmes that do not adequately inform the management of Delta resources on issues affecting them.

A lack of adequate mechanisms to address risk management issues affecting the Delta such climate change, drought, floods and tsunami and storm surges.

Inadequate partnership and cooperation between government and non-governmental organizations.

Lack of coordinated institutional governance of natural resources and development .

1.3.1 Cooperation between (scale) levels and sectors of government

First, all development proposals for land falling within the Tana Delta will be subject to review by the appropriate County Planning Development Committee (CPDC) and by other licensing authorities, where appropriate, such as NEMA or the Kenya Wildlife Service (KWS) or Kenya Forest Service (KFS).

The Tana River delta status, degradation, conservation, its socioeconomic and socioecological developments, and related monitoring and management aspects are covered by a number of acts and policies. There are for example the:
1. National Land Policy, 2009 (especially section 133),
2. Forest Act (2005) and Wildlife Act (Act Cap 376 of 1976),
3. Environmental Management and Coordination Act (EMCA, 1999),

4. Water Act and also the new water bill (2014)
5. Kenya Vision 2030 from 2008, and,
6. Other relevant legislative frameworks; e.g. Local government Act (empowering county councils), Agriculture Act (soil and water conservation), Energy Act (renewable energy).

Inter-government agency collaboration

The Forest Act 2005 establishes the KFS and the Wildlife (Conservation and Management Act of 1977) Revised Edition 1989, establishes KWS and EMCA, 1999 establishes NEMA all to work through management boards composed of all key relevant agencies including environment, NEMA, KWS, KFS, finance and civil society among others. Section 4 of EMCA, 2000 recognizes NEMA as a coordinator through the National Environment Council that includes Ministries of Agriculture, Economic Planning and Development, Energy, Environment, Finance; public universities; specialized research institutions engaged in environmental matters; and NGOs.

Within EMCA institutional coordination structures are provided for, including section 4(1) that establishes the National Environment Council (NEC), section 7(1) that establishes the National Environment Management Authority (NEMA), National Environment Trust Fund (Section 24(1), National Environment Restoration Fund (Section 25(1) and a number of national statutory and decentralized environment committees at the provincial and district levels that are directly linked to NEMA at the national level as detailed in Section 29(1) of EMCA 1999.

Section 7 (j) of the Forest Act 2005, mandates the Forest Board to develop modalities and guidelines for joint management of forests between the Service, local authorities, forest communities, government agencies and the private sector and section 36 empowers the KFS director to enter into an agreement with any persons to manage the forests jointly. Like the Forest Act and the Wildlife Act, the water policy, the Water Act, 2002, The Agriculture Act, Cap 318, the Antiquities and Monuments Act, Cap 215 and the Local Government Act, Cap 265 oblige the Water Resources Management Authority under Ministry of Water, the National Museums of Kenya and the local authorities to collaborate in natural resources management including finance, local authorities, forests and wildlife, fisheries, regional development authorities, and NGOs in their management boards.

The National Land Policy, 2009 provides for setting up of three key land management institutions: the National Land Commission (NLC), the District Land Boards (DLBs) and Community Land Boards (CLBs) whose composition include democratically elected community representatives and will have the mandate of promoting equitable access to land, conservation of cultural sites, protecting minority land rights and redressing historical injustices. The community Land Boards are mandated to manage, document and regulate all transactions of community lands—which should include forests. These boards have not yet been established making the good land-use policy serve as just a paper pack and an academic exercise.

Section 6 of the Energy Act, 2006, provides for powers of the commission that include formulating, enforcing and reviewing environmental, health, safety and quality standards for the energy sector, in coordination with other statutory authorities. The Act's recognition of other sectors is superficial recognizing EMCA 2000 but with minimum reference to forests and their resources.

Not surprisingly, the acts, agreements and policies contain elements that conflict with one another, especially where a number of different aspirations are being promoted within the same physical area. Inadequate communication, education and awareness on Delta management issues hampers the attuning processes. Currently, there is hardly any national coordination of inter-ministerial or inter-sectoral agencies outside management boards and consequently the development agenda in the Delta remains largely uncoordinated.

1.3.2 Cooperation between government and private sector

The proposed social and economic changes outlined above require that strategies, projects and investments are developed for the benefit of the Tana Delta communities and the nation as a whole.

The Tana Delta contains ample valuable resources and should be managed and exploited sustainably. Unfortunately, many previous proposals for investments have been conceived largely for the benefits of external interests whether of the state or private business. These development strategies had three major failings in common. Firstly, they ignored the hydrological constraints imposed by the River Tana's flood regime. Secondly, they assumed that the land was vacant and ignored the existing rights and occupation of land by local people, and thirdly they ignored the symbiosis which exists between human activity, land use and the outstanding natural environment of the Delta. This Plan seeks to provide major development opportunities within a framework in which the overall resources of the Delta are managed sustainably.

The LAPSSET Corridor, including Lamu, infrastructure is being developed to spur growth of other economic sectors within the Corridor. Of great significance here is rich agricultural value chain spanning over ten different economic crops whose implementation has begun with the establishment of large irrigation schemes.

It is important to mention that Public-private–partnerships (PPP) is acquired by the private sector as a vehicle (including alternative modes for financing) implementing future projects.

1.3.3 Involvement of stakeholders and citizens

The Kenyan Constitution (2010), national policies and international conventions that apply for the Tana delta places emphasis on the importance of local communities and on the exceptional environmental qualities which make the Tana Delta of international importance for its biodiversity. The Constitution emphasises the role of a national land policy and the National Land Commission in settling disputes and directing future policy.
Local communities are already aware of the negative impacts of uncoordinated development, for example, the failed TARDA irrigated rice scheme in the 1990s left a legacy of poverty and environmental damage. Furthermore, pastoralists complain that the allocation of land by government to large-scale development proposals conflicts with pastoralists' traditional rights, not recognised in statutory law. However, the communities are largely unorganised; especially the most isolated and marginalised and their views on development proposals do not have formal recognition within to the decision-making process.

Historically, many decisions on land use in the Tana Delta were taken without regard for the interests of the resident population and the local communities who have held the land in trust for generations. This has resulted in large areas of the Delta being held in disputed ownerships and a lack of transparency over land rights and development proposals.

1.3.4 Approaches for dealing with risks and uncertainties

In September 2011, the Government, through the Ministry of Lands and with involvement of other agencies coordinated by the Office of the Prime Minster (OPM), started preparing a comprehensive Land Use Plan (LUP) for the Tana River Delta to guide policy formulation and decision-making on future development of the Delta.
In 2014, the LUP is being scrutinized for implementation. When adopted, this Plan makes a start by considering the legitimate needs of communities and the potential uses of land without regard to ownership structure. The Plan itself cannot alter any legitimate or disputed agreements over land rights which are rightfully matters for the National Land Commission and the courts. But the Plan does make clear what types of use of land and water including are considered acceptable in both the national and local interest and, as a result, the Plan will have major influence over the way in which land disputes are settled.

1.3.5 Other acts, policy, treaties and agreements national and international

Multi-lateral treaties and agreements
The environmental treaties recognized by the EMCA 1999 and the Forest Act 2005 include: Ramsar

Convention, Convention on Biological Diversity- CBD, African Convention on the Conservation of Nature and Natural Resources, Vienna Convention for the Protection of the Ozone Layer, Convention on the Protection of the World Cultural and Natural Heritage, Convention on the Prevention of Marine Pollution, International Convention for the Prevention of Pollution from Ships, Bonn convention, Convention on International Trade in Endangered Species (CITES), United Nations Convention on the Law of the Sea (UNCLOS), Montreal Protocol, United Nations Framework Convention on Climate Change – UNFCCC and United Nations Convention to Combat Desertification (UNCCD), and Lusaka Agreement.

Institutional aspects

The review of institutions responsible for direct natural resources conservation and management showed that the Ministry of Forestry and Wildlife, Ministry of Culture, Gender and National Heritage and the Ministry of Environment and Mineral Resources are responsible for the management and conservation of natural resources in Kenya. The Ministry of Forestry and Wildlife house three government agencies: Kenya Forest Service, Kenya Wildlife Service and the Kenya Forestry Research Institute (KEFRI) while the Ministry of Environment and Mineral Resources (MEMR) house the National Environment Management Authority (NEMA) and the Department for Resource Surveys and Remote Sensing (DRSRS) with the Ministry of Culture and National Heritage housing the National Museums of Kenya.

International and National-level policy and legal frameworks

Ramsar Convention 1971. Kenya is a signatory to a number of international and regional Multilateral Environmental Agreements (MEAs) and conventions. The Ramsar Convention (1971) is the intergovernmental treat that specifically addresses sustainable management of wetlands. Tana Delta is Kenya's sixth Ramsar site, having been designated in October 2012. The Ramsar convention is therefore triggered in order to ensure sustainable utilization and management of the Deltaic wetland resources through the wise-use principle.

Convention on Biological Diversity (CBD). Kenya signed the protocol on 15th May 2000; ratified it on 24th January 2002 and become a party member on 11th September 2003

The United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC (1992) requires parties to take climate change considerations into account. This framework is for the Delta and Kenya as a whole. The Government has in response developed National Climate Change Response Strategy (NCCRS, 2010) as well as an Action Plan aimed at reducing the impacts of climate change and maximising opportunities brought by climate change.

Nairobi Convention and the Africa-Eurasian Water Bird agreement (AEWA). At the regional scale, AEWA, developed in 1993 from deliberations of the Bonn Convection which held its first consultative meeting of range states of African-Eurasian Water bird Agreement (AEWA) in Nairobi in June 1994, is another agreement that offers a good opportunity for the management and conservation of Tana Delta and associated wetlands biodiversity resources. The vast numbers of migratory and resident waterbirds are particularly dependent on the seasonally flooded grasslands and Borassus Palm savannah that cover some 70,000 ha in the heart of the Tana River Delta

1.3.6 Overview of key stakeholders regarding delta management issues

Key stakeholders	Brief description of responsibilities and tasks regarding delta management issues	Related network or cooperation structure
Research institutes		
The East African Wild Life Society, Nature Kenya, Royal Society for the Protection of Birds and Bird Life International	Involved in research and conservation work	There is no tangible co-ordination of independent research institutes in the delta.
Policy makers		
The Inter-Ministerial Technical Committee (IMTC) on the Sustainable Management of Kenya Deltas	Provides policy and technical guidance	The involvement of technical persons from the relevant ministries implies that challenges of funding could be alleviated. The network structure is present.
The County Councils of Tana River and Lamu	They have jurisdiction over delta. The two councils can lead greater grassroots support and legitimacy of land use decisions.	There could be a lack of common understanding between the county and national governments regarding the management of different natural resources.
NEMA	NEMA has statutory mandate to protect the environment through regulation of activities.	
Developers		
TARDA	To undertake integrated regional resources planning, promote and undertake development within the wider Tana	The relationship with WRMA and KENGEN is competitive.
Industry		
Bedford biofuels, Coastal Aquaculture Limited, G4 industries, Mumias Sugar Limited, Mat International Limited, Tiomin Kenya Limited, Galole Horticulture	To meet food security and global renewable energy demands	Some investors have international linkages for export of their produce such as Mat International Limited and Galole Horticulture.
Citizens		
Tana Planning Advisory Committee (TPAC)	Grassroots committee which acts as a link to the local community to ensure the community is fully consulted and involved in the planning process.	They command huge networks but are not funded well.
Community Forest Associations (CFA)	Tasked with management of the forests in the delta	Although all CFA's have a common forum, they do not have links with the generators of knowledge (research institutes).

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	Migration rates, Total number of households/people, Mean household size, Literacy rates
Economic developments	Rate of unemployment
Technological developments	Percentage of GDP allocated to ICT and infrastructure, Subscription rates to mobile phones, Connections to internet
Climate change	Annual rainfall in mm, River discharge (MCM/yr) at designated delta points, Sea-level change (mm/yr), Mean temperature, Precipitation rates
Subsidence	No indicators implemented
PRESSURES/PROBLEMS	**Main indicators**
Land and water use (occupation layer)	Rate of urbanization, Flood Mean Duration, Percentage River Discharge, Number of megawatts generated, Inundation area, Population density, Area under saline water
Network / infrastructure (network layer)	Depth and width of irrigation cannals, Percentage of delta under irrigation, Water sanitation risk index, Number of floods per year, Number of people with access to water
Natural resources (base layer)	Number of conservancies, The index of biodiversity, Area of wetlands protected by law, Erosion rate in m/yr.
GOVERNANCE	**Main indicators**
Multi-level and multi-sectoral cooperation	Existence of land use plans, Existence of inter-ministeral committees
Public-private partnerships	Number of PPP projects in a year
Involvement of stakeholders and citizens	Number of NGO's in the delta, Presense of public consultations, Development of legal instruments
Approaches for dealing with risks and uncertainties	Number of risk response strategies, Number of climate change adaptation strategies, Number of climate change adaptation projects

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.
The following two development scenarios are recognized:

- Scenario 1, moderate perspective 2050: medium economic growth and related medium technological developments, combined with medium climate change and sea level rise.
- Scenario 2, extreme perspective 2050: high economic growth and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Delta	**Land and water use (occupation layer)**	**Infrastructure (network layer)**	**Natural Resources (base layer)**	**Governance**	**Overall Resilience & Sustainability indicator**
Current situation 2010	-	-	0	-	-
Scenario1 moderate 2050	--	-	-	-	-
Scenario 2 extreme 2050	--	0	--	-	--

resilience/sustainability: ++ (very good), + (good), 0 (medium), - (low), -- (very low)

Concluding remarks on score card:
The current situation in the delta can be described as moderate to low in terms of sustainability. Land and water use is high, infrastructure is poor and natural resources are dwindling. The pressures on the occupation layer and the base layer are likely to increase due to significant economic development combined with higher dependence on ecosystem goods and services supporting the livelihoods of the communities in the delta.
The anticipated changes in climate change, sea level rise and upstream hydropower engineering are likely to worsen the situation for all layers with unpredictable and uncontrolled erosion patterns in the delta and at the coast. Many legal frameworks are in place but mainly uncoordinated. Attuning and implementation is needed for assuring the sustainability of the delta and its resources.
Tana, due to its richness, has to cope with very high land and water demands due to high population pressures, which combined with a moderate to inadequate infrastructure lead to significant problems. Furthermore, due to engineering, flood hazards can decrease but due to community behavior and lack of protection systems flood vulnerability remains high.

With regard to the developments on the medium term (2050), we can distinguish two counteracting drivers of change: on the one hand there is the expectation that with economic growth, technological improvements and improved governance, the current problems stemming from inadequate infrastructure and poverty can be ameliorated. On the other hand we find climate change impacting the natural systems and their resources (base layer), which reduces the enabling conditions for continuing working and living in a delta. For several deltas (e.g., the GBM, Mekong, California Bay-Delta and Mississippi River deltas)

It is unlikely that the projected improvements of the network layer following the Lapsset/Lamu corridor developments will outweigh the current rapid and negative developments of the occupation and base layers of the Tana delta, leading to an overall decrease of sustainability of the Tana delta.

2. Overview of adaptive measures in the Tana Delta

Overview of (possible) adaptive measures in the three spatial layers is based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

2.1 Overview of (possible) adaptive measures

Adaptive measures in the Tana delta are few and not well researched.
Additional fresh water reservoirs improve the supply of available water to the livelihoods and livestock. Early warning systems are slowly being implemented in certain areas of the Delta. However, the implementation of a proper data and information system is needed as a basis for such early warning system. Dissemination technology is likely to adapt apps or mobile-based systems.
Tidal river management is a method to restore tidal flows. Consequently any enclosed lands will be frede from water-logging, alluvium will accumulate inside the polders, and as a result the level of land will rise

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
Fresh water reservoir	1, 3	Fresh water reservoirs are constructed to supply water for drinking.	2	2
Early warning	1, 4	The Kenya Meteorological Department is tasked with the responsibility of forecasting flooding and drought patters that affect the Tana Delta	1,2	1, 2
Tidal River Management	1, 4	Tidal river management (TRM) is a method that reduces the water logging in the land and also reduces siltation in the river bed.	2	2

2.2 Examples of best practices

Green Water Credits
An investment mechanism, which enables farmers to get involved (and buy into) durable practice water and land management activities. The Green Water Credits team with ISRIC World Soil Information as the lead agency, assists financiers that are establishing programs and funds for these farmers by performing scenario studies including durable engineering and optimization of provisioning ecosystem services.

Conduct an assessment of the environmental flows needed to sustain key ecosystem components and processes, with particular attention to the plants, animals, and ecological processes of greatest importance to local communities.

Currently, the potential tradeoffs among infrastructure costs, changes in hydropower production (and other dam-related benefits), and provision of environmental flow releases are being analysed.

Stakeholder compensation and mitigation is increasingly incorporated into the stakeholder dialogue and the project design. Durable investments are selected to improve habitat conditions, such as water quality improvements or setting back levees to reactivate floodplain areas, that in turn help to increase the productivity of fisheries and offset losses of other ecosystem goods or services

Within the Tana delta EIA assessments leading to the comprehensive Land Use Planning (LUP), a thorough and inclusive dialogue that encourages full expression of stakeholder concerns, needs, and values is carried out. This also includes the identification of delta-dependent plant and animal

species, or processes such as annual flooding of agricultural or grazing areas in floodplains, that are of considerable economic or cultural importance to local communities.

Re-greening (afforestation) of erosion sensitive regions in the Delta.

3. Overview of technical methods and tools to support delta management and development in the Tana

For the Tana delta several types of flood models exist, ranging from lumped to distributed models. They mainly differ in their physical basis, complexity and data requirements. Distributed models are used when accurate data are available, while conceptual models are better suited to poorly gauged sites where data acquisition is difficult. In recent years, there has been a rapid development of distributed models due to the proliferation of high-quality quantitative data (e.g. topography, remote-sensing imagery) and increasing computational power.

Overview of methods and tools for assessments, planning and decision making on delta management and development issues

Name of tool	Brief description	Institute	Available at
The Tana Inundation Model (TIM)	TIM quantifies essential hydrological variables of ecological importance and provides an annual water balance (Leauthaud et al 2012)	European Geosciences Union	http://www.hydrol-earth-syst-sci-discuss.net/9/11267/2012/hessd-9-11267-2012.html
EMIN	Environmental Monitoring Information Network	Centre for Environmental and Geographic Information Services	http://www.cegisbd.com
SAL Model	Salinity model for river system	Institute of Water Modelling	www.iwmbd.org
Flood Forecasting Tool	Provides flood forecast and warning information to enhance the disaster management capacity of national agencies and communities	Ministry of Water and Irrigation (MWI), is developing a flood mitigation strategy	http://wescoord.or.ke/documents/Keydocs/FloodMitigationStrategy_MoWI_200906.pdf
Drought predicting	Regional Climate Models (RCM)	To help the community adapt to the changes, the Kenya Agricultural Research Institute (KARI)	http://weadapt.org/knowledge-base/national-adaptation-planning/Kenya

4. Knowledge exchange and development

4.1 Lessons learned on delta management

The Tana Delta has gained international attention regarding climate change impacts and livelihoods vulnerabilities

The right approach to ecosystem services valuation needs to be applied large-scale agriculture development projects proposed projects (Lamu Port and 1 million hectares irrigation scheme) will reduce the amounts of water for flood plains hence increasing food insecurity

Changes in climate are already being experienced in the Tana delta, especially with changing patterns of rainfall.

Climate change aspects must be better incorporated in the delta management plan.

A lack of political willingness and governmental support compromises the Tana delta biodiversity.

Too many data gaps in the gauging of water flows and levels in the Tana river, hamper quality of predictions.

Too much of "politics of water" between overlapping stakeholders hamper cooperative actions and consequently lower the control over the waters of Tana.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change, Pressures – potential problems / Challenges - opportunities

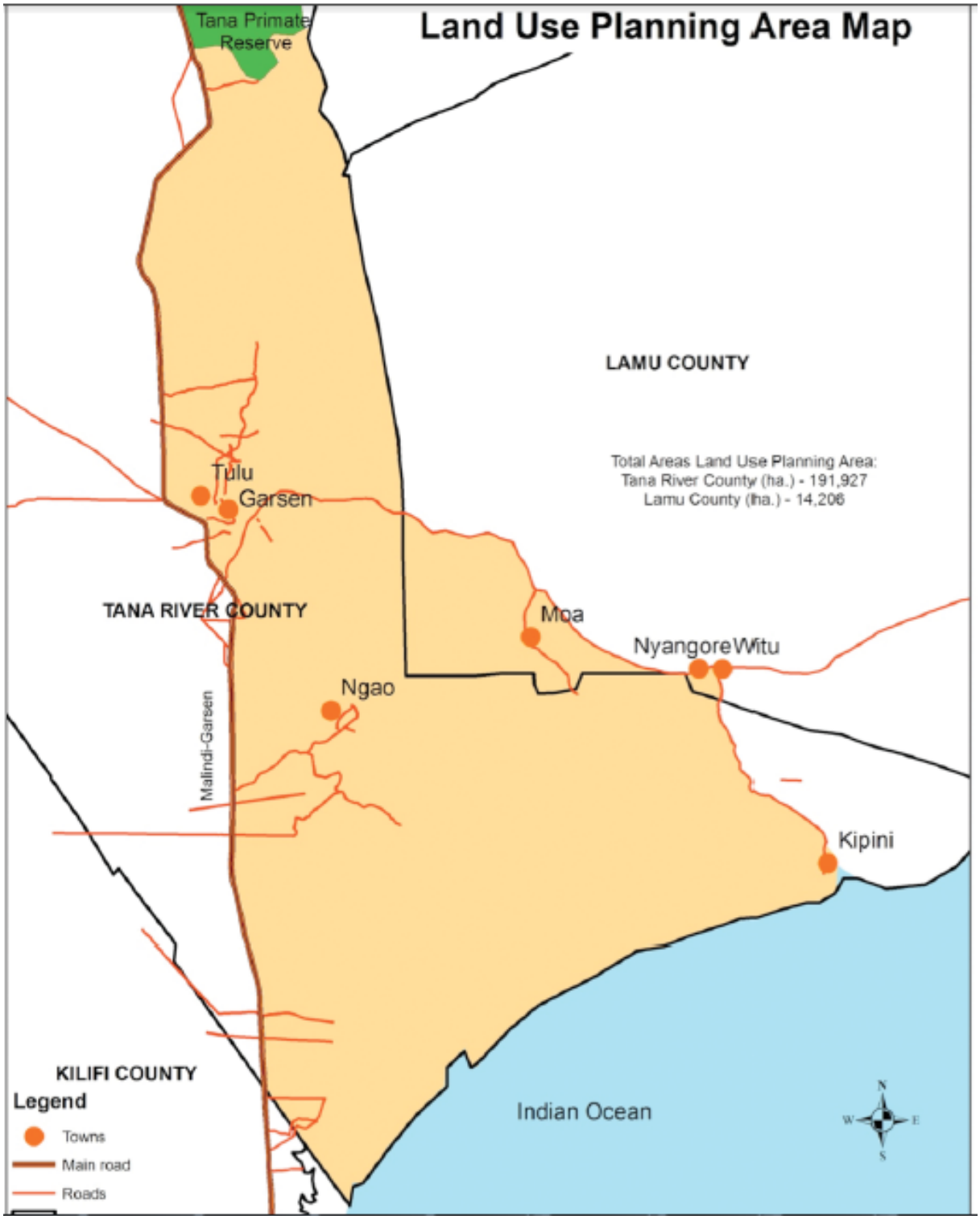
The growing human population and competition for diminishing natural resources, compounded by the effects of climate change, have necessitated a drastic change in the way we do things. Over the last decade, resource use conflicts in the delta have escalated to deadly levels with disastrous consequences as demand for competing land uses, natural resources, nature conservation and community interests have intensified.
The conflicts- human versus wildlife, pastoralists versus farmers, local pastoralists versus pastoralists from outside, large scale developers versus community and conservationists- are likely to increase as demands on river Tana for power generation, irrigation farming and water for domestic and industrial use in Nairobi city, Lamu port and other settlements along river Tana increase.

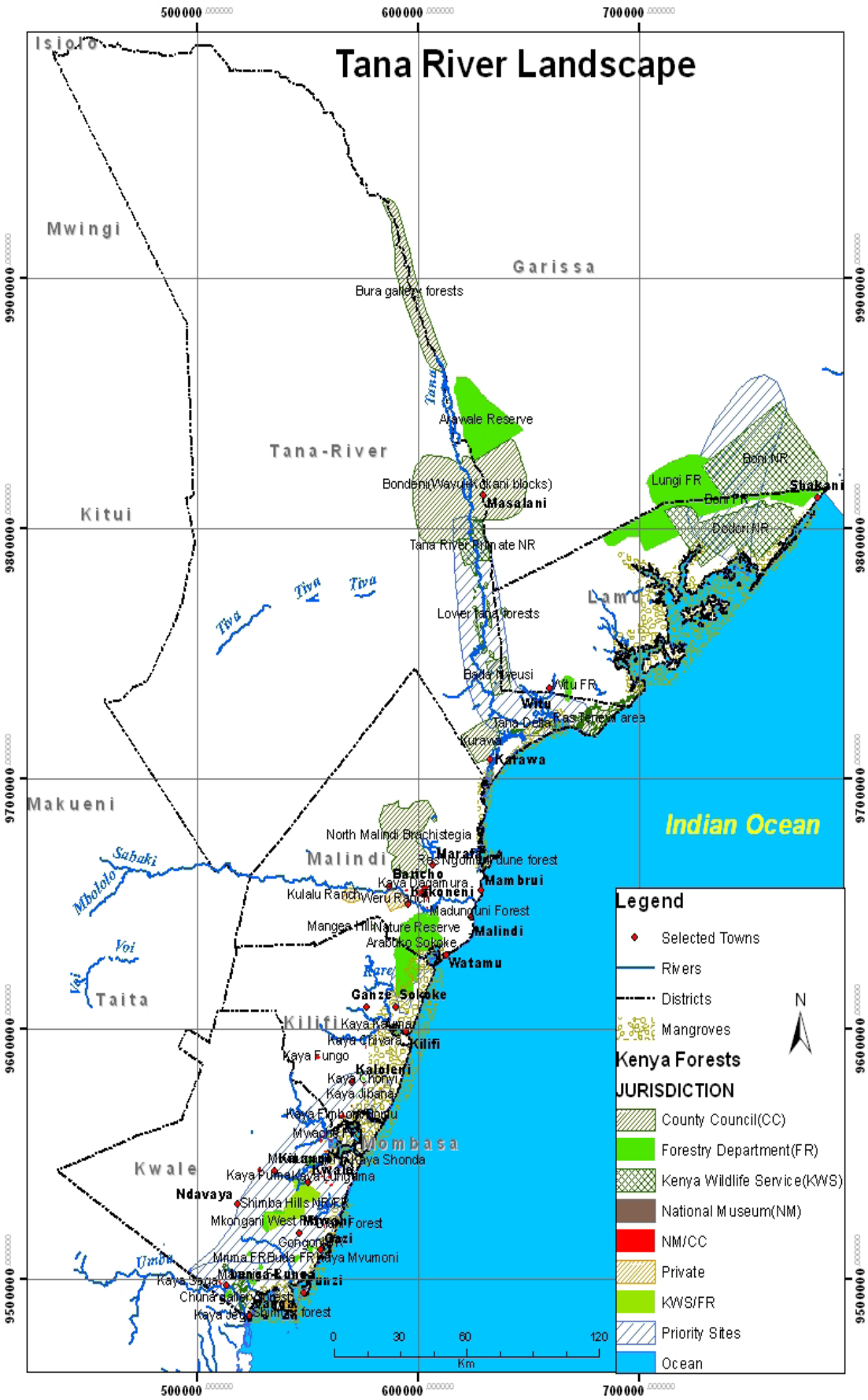
Gaps and needs:
- Organization of Tana information an data management acros the sectors and the ministries.
- Use of sustainable cost-effective water purification, green techniques implementation to lower impact on Tana resources.
- IWRM approaches.
- Green water credits/ negotiated approach / Payment for ecosystem services approaches implemented through the Tana delta system.
- Integrated delta assessment approaches.
- Alternative techniques and knowledge for construction of large dams and reservoirs.

Adaptive measures
- Valuation of ecosystem services is required; consequently it is necessary to estimate the economic and socio-cultural benefits to the locals.
- A continuous process of data collection, monitoring and evaluation is the basis for adaptive management.
- Improved education in the area in a bid to enhance adaptive management approaches
- Climate proof infrastructural installations.
- Implementing a clear plan for the management of river bank erosion such as the Mnadjini area.
- building capacity for institutions working in the Tana delta is imperative
- Sharing information. This is critical, especially regarding the necessary amount of water for irrigation in the delta

Technical methods and tools
- There is need to increase and coordinate all hydromet systems in the Tana Delta.
- It is crucial to develop tools for forecasting erosion and deposition patterns in the delta area.
- Development of socioecological variables needed to assess ecosystem based approaches for all different sectors in the delta.
- To develop a applicable salinity intrusion model for Tana delta.
- Inclusion of climate change variables to predict flooding.

Some available illustrations (map of delta, typical sites, etc.)




Tana River Landscape
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Mwingi
Garissa
Kitui
Tana-River
Lamu
Makueni
Malindi
Taita
Kilifi
Kwale
Mombasa
Indian Ocean
Bura gallery forests
Arawale Reserve
Bondeni(Wayu-Kokani blocks)
Masalani
Tana River Primate NR
Lower Tana forests
Boni NR
Lungi FR
Boni FR
Shakani
Dodori NR
Bada Nveusi
Witu FR
Witu
Tana Delta Ras Tenewi area
Kurawa
Karawa
North Malindi Brachistegia
Marafa
Ras Ngomeni dune forest
Bancho
Kaya Dagamura
Mambrui
Kakoneni
Kulalu Ranch
Weru Ranch
Madunguni Forest
Mangea Hill Nature Reserve
Malindi
Arabuko Sokoke
Watamu
Ganze Sokoke
Kaya Kauma
Kaya Chirwara
Kilifi
Kaya Fungo
Kaloleni
Kaya Chonyi
Kaya dibana
Kaya Fimboni Ribe
Mwache FR
Kaya Shonda
Kaya Pumwani
Kaya Tsunza
Ndavaya
Shimba Hills NR/FR
Mkongani West FR
Mrima FR
Buda FR
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Kaya Jego
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JURISDICTION
County Council(CC)
Forestry Department(FR)
Kenya Wildlife Service(KWS)
National Museum(NM)
NM/CC
Private
KWS/FR
Priority Sites
Ocean

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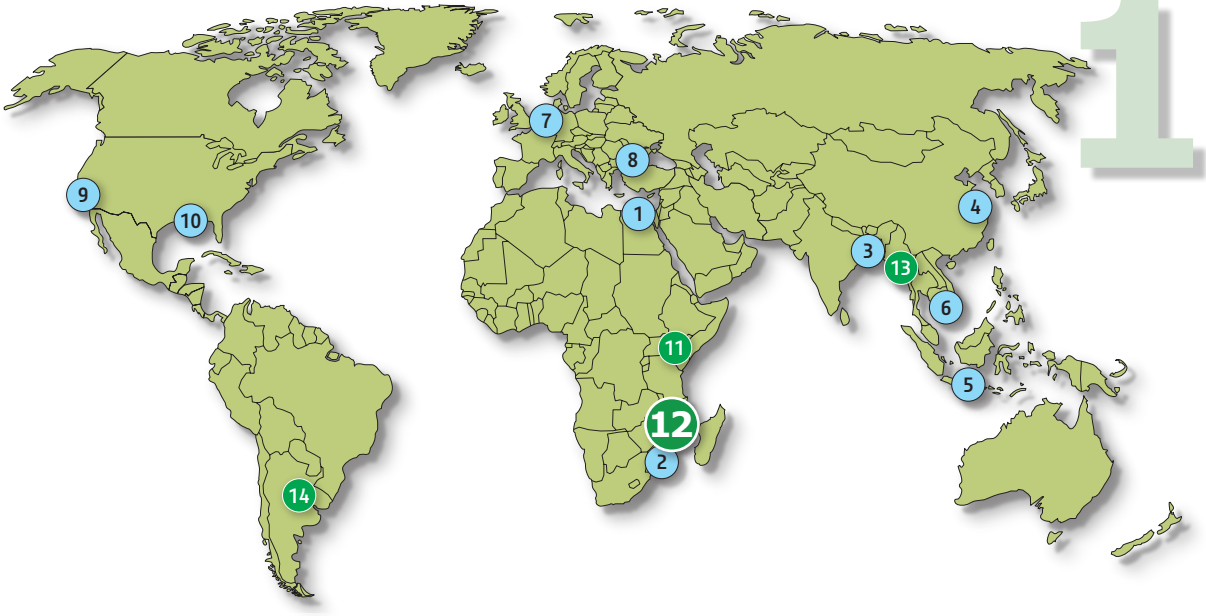
Zambezi delta

No 12



1. Current and future state of the Zambezi delta

1.1 Drivers of change

Summary of drivers of change

Demographic trends:
Although Mozambique has currently a high economic growth (GDP is 14.59 billion USD with an economic growth rate of 7%), it is considered one of the poorest countries in the world. A large part of the population lives below the poverty line, with huge disparities between rich and poor, in income between urban and rural population. Around 328,000 inhabitants (1.4% of the total population of Mozambique) live in the Zambezi delta region. The average population growth rate for the main village is around 4.1%/year, whereas the average growth rate in Mozambique is 3%/year.

Economic developments:
Agriculture is the largest water consumer after hydropower (open water evaporation losses). The main economical developments in the delta region are the SENA Sugar Estates and the shrimp industry. The main highway connecting the South and North of Mozambique also crosses the delta at Caia together with the railway linking the Tete coal mining hub to Beira port further south. More upstream, in the Tete Province there are huge economical developments, mainly hydropower and coal mining which has consequences for the delta.

Climate change:
According to the IPCC (Intergovernmental Panel on Climate Change) prognosis the Zambezi River Basin exhibits the worst potential effects of climate change among the eleven major African river basins, mainly due to the combined effect of temperature increase (order of 0.3 - 0.6 °C) and rainfall decrease (order of 10 - 15%). The climate changes forecasts for Africa also predict that the risk of extreme events like droughts and floods will increase including inundation due to sea-level rise in coastal areas. Estimates suggest that the Lower Zambezi runoff will decrease by 13 - 14% and sea level is expected to rise as well. The World Bank study (2010) shows that the impact of climate change on the Zambezi delta (mainly the increase in temperature) could lead to an irrigation deficit of 27% and a reduction of basin yield of 13% by 2030.

Subsidence:
A topical area in many delta's in the world. Land subsidence has not been reported for the Zambezi Delta so far. Although more than 50% of the population uses groundwater as source of water, mainly from shallow open wells or wells equipped with hand-pump, groundwater exploration is still low in the region so land subsidence due to excessive groundwater abstraction and consequent soil compaction is very unlikely

Technological developments:
The Zambezi delta is developing slowly in terms of technological developments. Small scale farmers and fishermen use old fashioned technology and electricity supply is very limited. Solar panel technology for electricity supply is being promoted. Telecommunications with 3G network and access to internet is available around the main villages. There is a railway branch to Marromeu sugar plantation connected to the SENA railway. Plans for expansion of hydropower also exist with construction of Mphanda Nkuwa and expansion of Cahora Bassa by including turbines on the North Bank.

Research gaps
- There is a need for the development of the monitoring network (eg. river discharge, reliability of rating curves, monitoring of discharge through distributaries, etc.);
- Monitoring of water quality to assess impacts of small scale and large scale agricultural developments, as well as the impacts of the large mining ventures taking place upstream;
- Research to understand the combined river and coastal dynamics and roles of flow regime changes in these dynamics, and monitoring of sediment transport;
- Assessment of potential threats related to delta subsidence;
- Research for diagnosis and economic valuation of ecosystems as well as identification of sound management measures to protect it;
- There is a need to develop integrated urbanization plans taking into account flood hazard and other aspects.

Table 3a: Overview of drivers of change in the studied deltas

	Demographic trends	Economic developments	Technological developments	Climate change	Subsidence
Zambezi	•	•••	••	•••	unknown

• = minimal impacts, now and in the near future (around 10 years)
•• = small impacts
••• = medium impacts
•••• = severe impacts

Table 3b. Overview of delta population (number, density) and growth rate

	Population number (in million)	Population density (inhabitants/km)	Growth rate (%)
Zambezi	0.3	35	2.2 - 4.1

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population
The Zambezi delta area covers territories of three provincial districts in central Mozambique namely Mopeia, Marromeu and Chinde. According to 2005-2006 data around 328,000 inhabitants (1.4% of the total population of Mozambique) live in the Zambezi delta region, in the districts of Marromeu, Mopeia and Chinde. The population density for the delta area is approximately 35 inhabitants/km$^{2.}$ The average population growth rate for the Marromeu district is around 4.1%/year which is greater than the growth rate of the Sofala Province (2.2%/year) and Mozambique in general (3%/year). The rehabilitation of the SENA Sugar Estates in 1998, the SENA railway and the railway-branch to Marromeu attracted an influx of people from the surrounding regions in search for better employment and business opportunities.

Most of the population live in the villages of Chinde (population 121,339 inhabitants), Mopeia (population 89,403 inhabitants) and Marromeu (population 117,795 inhabitants). The population dynamics of the region seem to correlate well with the investment in infrastructure and agriculture.

Although Mozambique has currently a high economic growth (GDP is 14.59 billion USD with an economic growth rate of 7%), it is considered one of the poorest countries in the world. According to the 2013 human development report by UNDP, Mozambique occupies the 185 position in the human development index ranking, out of a total of 187 countries. A large part of the population lives below the poverty line, with huge disparities between rich and poor, in income between urban and rural population and between educated and non-educated people.

Economic development and Industry
There are many hydropower schemes in the Zambezi Basin, the larger ones being the Kariba dam in the Middle Zambezi (installed capacity of 1350 MW) and the Cahora Bassa dam at the upstream edge of the Lower Zambezi (installed capacity of 2050 MW). Additional hydropower dams are being planned in the Zambezi basin (e.g. the Mphanda Nkuwa dam, planned 60 km downstream of the Cahora Bassa dam and turbines at the North Bank of Cahora Bassa).

Mining is another major development that has potential to affect the Lower Zambezi, especially in the Tete province which holds the world's second largest source of coking coal. The coal is of high quality and is attracting international and world player companies and investors around the world, including Rio Tinto (formerly Riversdale), Vale and Jindal Africa. Surveys carried out in 1998 showed that there are no commercially feasible quantities of hydrocarbons in the Marromeu district (Zambezi

delta region), and there are no known mineral resources exploration in the district as well. As the mining activities take place upstream of the delta (in the Tete province) their main effects will probably be related to the alteration they can induce through water abstractions, pollution and transport infrastructure (from Tete to the coast). Possible transport routes include the Sena railway line (which might not have enough capacity). Over the past years the idea of navigating the Zambezi with barges has been tabled, but to date the Government has refused to approve. There are also new railway routes e.g. the proposed Macuze corridor crossing the northern margin of the delta, in advance stage of development with potential impact on the area .

Estimations of the agricultural water demand in the delta (1.2 * 109 m^3/year, World Bank, 2010) and evaporation losses of Cahora Bassa (3.8 * 109 m^3/year) show that the hydropower is by far the largest water consumer. Majority of the agricultural activities are smallholder farmers, using rain fed systems and producing for subsistence or for the local markets. The lower Zambezi basin has an irrigation potential of around 1 million ha, of which only 30,000 ha is currently equipped with irrigation infrastructure, of which hardly half is under cultivation (MER, 2011a). The main agricultural development in the delta region is the SENA Sugar Estate. The potential irrigated area of SENA is 15600 ha, approximately 60% of which they currently cultivate. Studies carried out for the region concluded that 95% of the water extracted in the delta is used by the SENA Sugar Estate for irrigation. Besides producing sugarcane, the SENA Sugar Estate also has a factory in which the sugarcane is processed and transformed into sugar.

With the objective of tapping into the large potential for agriculture production in the lower Zambezi the Government of Mozambique requested the World Bank assistance to address the development constraints and to improve small holder productivity by adopting a community demand-driven approach. The Zambezi Valley Market Led Smallholder Development Project was crafted to increase incomes of five selected districts through broad-based and sustainable agricultural growth. The Project was implemented between 2008 and 2013 in the two adjacent delta districts: Mutarara, Tete Province and Morrumbala, Zambezia Province.

Fishing in the lower Zambezi occurs, in one way or another, over the entire strip from the Cahora Bassa dam till the coast of Chinde and 60% of this catch is sold in the local markets. It is mostly artisanal fishing that occurs in these regions. Commercial fishing only occurs in the coastal regions along the Sofala bank. The important commercial fish in the region are Blunt toothed African catfish (*Clarias gariepinus),* Mozambique tilapia (*Oreochromis mossambicus),* Manyame labeo (*Labeo altivelis)* and Tigerfish (*Hydrocynus vittatus).* These fish species are however not at a similar commercial scale as shrimp but do still contribute to the economy (Beilfuss et al., 2002; Beilfuss and Brown, 2006). The shrimp industry takes advantage of the existence of mangroves and extensive estuaries that support off-shore shrimp fishing in the Sofala bank, which is very important for the economy of the country. According to World Bank (2003) shrimp covers up to 15% of the country's exports.

The Marromeu Complex (11,000 km^2) is primarily a wetland of great biodiversity, it has been designated as a "Wetland of International Importance" under the Ramsar Convention (Beilfuss and Brown, 2010; Tha & Seager, 2008). This region consists of the Buffalo reserve and four surrounding hunting concessions and consists of floodplain grasslands, deepwater swamps and mangrove forests (Beilfuss, 2001a). It is also one of the popularly visited areas for tourism which is primarily linked to wildlife for trophy hunting and as such forms an important contributor to the economy of the region (Beilfuss and Brown, 2006; Guveya and Sukume, 2009).

In recent years the government started initiatives to develop the islands, of the delta in the open sea, for high touristic interest that will potential trigger the development or at least have a spin off effect in the delta area.

Forest and timber exploitation is another area of interest in the adjacent areas of the Delta tapping into the Miombo forest; a number of operators are active in the area. The Government is implementing measures to prevent the negative effect of this activity in the biodiversity of the delta. Some of the

measures include the creation of community based forest management schemes that allow part of the revenue to be channelled back for community development and implementation of reforestation programmes.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

According to the IPCC (Intergovernmental Panel on Climate Change) prognosis the Zambezi River Basin exhibits the worst potential effects of climate change among the eleven major African river basins, mainly due to the combined effect of temperature increase and rainfall decrease. A temperature increase in the order of 0.3 - 0.6 °C is expected while for the rainfall a decrease in 10 - 15% is expected. Beilfuss (2012) states that, according to estimates, the Lower Zambezi runoff will decrease by 13 - 14%. These changes in temperature, rainfall and runoff will likely cause increased open-water evaporation, delayed onset of the rainfall season as well as shorter and more intense rainfall events (Beilfuss, 2012). The World Bank study (2010) shows the impact of climate change on the Zambezi delta (mainly the increase in temperature) could lead to an irrigation deficit of 27% and a reduction of basin yield of 13% by 2030.

The climate changes forecasts for Africa also predict that the risk of extreme events like droughts and floods will increase including inundation due to sea-level rise in coastal areas.

Climate variability is also evident in historic hydrological data of the basin. Studies carried out in the Zambezi basin (Beilfuss and Dos Santos, 2001) concluded that the rainfall and runoff at Victoria Falls follow a cycle of wetter and drier periods with a recurrence interval of around 50 years (see Figure 1) although in the delta area these cycles are less pronounced due to the presence of important tributaries in the Lower Zambezi. The recurrence interval may become shorter due to the effects of climate change. Pekárová et al (2003), have identified a much shorter cycle of around 20 - 22 years for most rivers of the world, including in the Zambezi.

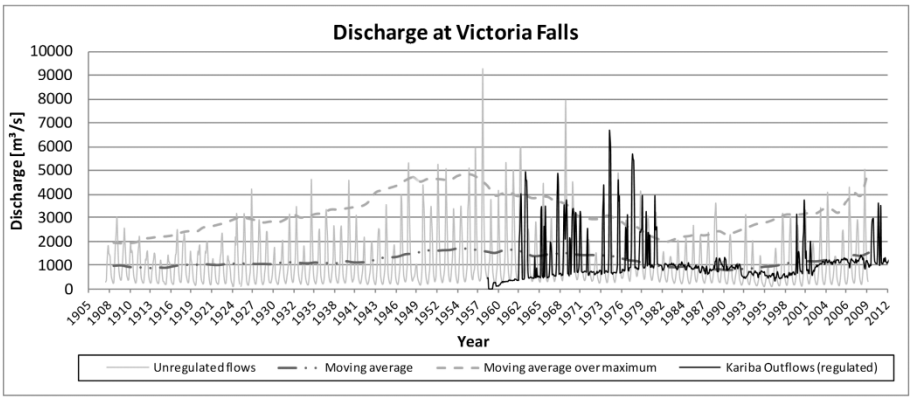


Figure 1 - Discharge at Victoria Falls - cycles of wetter and drier periods (Source: Khan, 2013)

1.1.3 Subsidence (natural or human-induced)

Land subsidence has not been reported for the Zambezi delta so far. Although more than 50% of the population uses groundwater as source of water, mainly from shallow open wells or wells equipped with hand-pump, groundwater exploration is still low in the region so land subsidence due to excessive groundwater abstraction and consequent soil compaction is very unlikely under currently development scenario.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

The Zambezi delta still experiences a rather low technological development. Although agriculture is the basis for the livelihood of most of the population the technology used is traditional and the production is limited and very vulnerable to extreme events like droughts and floods. Mechanized agriculture is

only used in the SENA Sugar Estate. Local fishermen use traditional artisanal methods for fishing which contributes to low productivity.

Electrical energy supply is limited to the urban parts of the districts. In the rural areas the use of solar panels as an alternative source of electrical energy for domestic use is promoted however most people still cannot afford it and use other alternatives like petroleum, paraffin, kerosene, wood and candles.

There are two large civil engineering structures around the delta area; the Armando E. Guebuza road bridge and the Dona Ana railway bridge both over the Zambezi River in Caia village, which is located 30 km upstream of the delta. Worth to mention is also the SENA railway and the dike that were constructed in the beginning of the 20th century along the North and South Bank of the river for flood protection of mainly SENA and Marromeu village (Belifuss and Brown, 2006). The road network in the region is in poor conditions and travelling in the delta area is challenging, mainly in the rainy season when it is almost impossible to drive on some of the roads. The Governments of Malawi, Zambia and Mozambique are currently implementing a study for the navigation of Shire and Zambezi stretches of the rivers that will likely include the development of major port infrastructure in Chinde.

Information and communication technology is only available in the urban areas of the district and only accessible for people with better financial conditions. In the urban centres there are three cellular networks with 3G technology that can be used to access the internet. The ministry council of the Mozambican government approved in 2006 the strategy plan for science, technology and innovation for Mozambique. The main objective of the strategy is to define priorities and establish a framework for the improvement of the contribution of science, technology and innovation for the achievement of national goals regarding poverty alleviation, economic growth and social welfare for all Mozambicans.

There are new large-scale irrigation initiatives that have begun operations in the lower Zambezi basin which include the company Grown energy which is currently irrigating around 950 ha of land for sugarcane and has future plans to expand this to 10,000 ha. There are also other companies with plans for cultivation of around 20,000 ha of sugarcane in Muturara, the first phase beginning probably this year with 250 ha. Apart from sugarcane, there are also plans to cultivate around 3500 ha of sunflower, the first phase of which is with 500 ha. There is also cultivation of rice and maize, all of which beginning their first phase with around 200-300 ha. That would total the current irrigated area to more than 11 thousand hectare with a current potential to expand to around 53 thousand hectare (Fanaian, 2013).

1.2 Pressures – potential problems / Challenges – opportunities

1.2.1 Land and water use (occupation layer)

Summary of pressures

Pressure on space:

Pressure on space is in general low due to low population density. Nevertheless, illegal hunting and wood cutting on mangroves pose some pressure in direct vicinity of the main villages. There is large interest to have agriculture development in the delta area which can lead to significant water abstractions and subsidence.

Vulnerability to flood:

After the construction of the Kariba and Cahora Bassa dams the floods became less frequent and timing is less predictable. As a consequence population felt safer and moved their settlements to the fertile floodplains and are sometimes caught by surprise during years with high floods resulting in damage and loss of lives. This encroachment results in high exposure of the community and reduced reaction time to flood waves therefore increasing the vulnerability of the population. Cyclons do occur quite frequently in the Mozambican coast. Over the last 75 years before 2005, the Zambezi Delta was hit by 9 to 15 cyclones (MICOA, 2005). But the flooding events recorded in the Delta region were mainly due to high flows in the Zambezi River coming from upstream. Flooding from sea has not been reported to affect the local communities of infrastructure so far.

Water demand / freshwater shortage:

At the moment water demand is very low compared to the Zambezi average discharge and there is no freshwater shortage in the delta area. Water abstractions are regulated by ARA Zambezi. Water is abstracted from the aquifers in small urban areas but due to limited infrastructure only a small part of the population is covered by the water supply systems and this water abstraction can be considered low. Water for domestic use and farming small areas (less than 1ha) is free of charge

Research gaps

- There is a need for improved planning to control the development of settlements in inappropriate locations such as low lying lands prone to flooding;
- There is a need to develop flood hazard maps to assist in the development of population settlement planning;
- There is a need to develop a flood forecasting model for flood management.

Table 4: overview of status of land and water use in the studied deltas

	Pressure on space (including urbanization)	Water demand/ Fresh water shortage	Flood vulnerability	Overall Score
Zambezi	•	•	••	+

• = no (additional) pressure, now and in the near future (around 10 years)
•• = some pressure
••• = moderate pressure
•••• = severe pressure

Pressure on space

Pressure on space is in general low due to low population density. Most of the inhabitants of the delta are concentrated in the small villages or small communities around the three districts. For the Marromeu district only 6.8% of the land has human occupation (including agricultural fields, industrial areas and settlements) whereas the rest of the 93.2% is covered by different types of vegetation (forests, meadows, wetlands, mangroves, etc.). The population in the delta region extract wood from mangroves mainly for building houses and to make coal for cooking. Due to the resilience of the system this small scale wood extraction only poses danger to the mangroves in the direct vicinity of larger villages, eg in the Northern part of the delta around the city of Quelimane (Njati, 2014).

Illegal hunting has important impacts on the forest areas mainly due to the hunting methods. Poachers, hunting mostly rodents, use fire to catch their prey and due to this it is common to have uncontrolled fires in the region, which devastate large forested areas.

There is large interest for agricultural development in the delta area. The government of Mozambique has set up the Zambezi Valley Development Agency that is meant to spearhead this. A key area of interest is agricultural development looking into food production to global markets with rice and sugar cane as the main crops being considered.

Hydrology

The average annual precipitation in Marromeu is around 900 mm/year (see Fig. 2). Average annual potential evaporation, about 1,560 mm/year, far exceeds rainfall across the basin (Beilfuss, 2012). There are two distinct seasons, one hot and wet from October to March and the other season is cool and dry from April to September. Most of the annual rainfall occurs in short and intense events concentrated in the months of December and January.

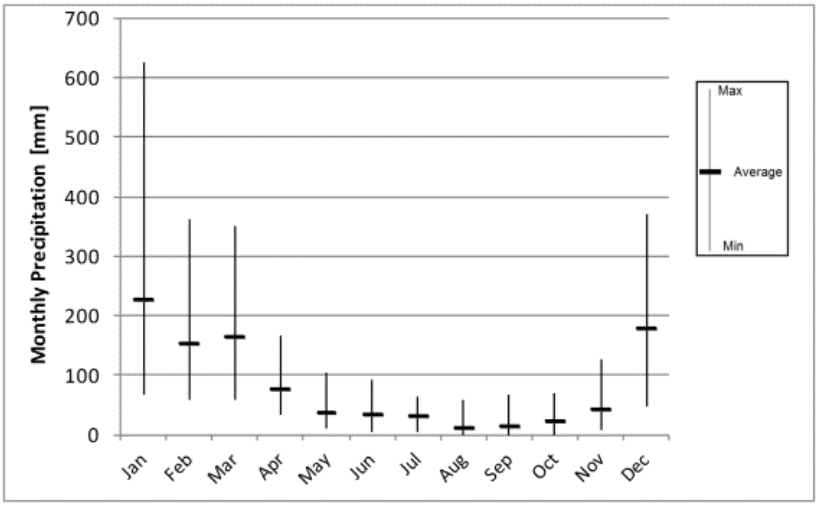


Figure 2 - Monthly rainfall in Marromeu (Source: SENA Sugar Estate)

Beilfuss & Dos Santos (2001) describes the flow to the Zambezi delta as a function of regulated Cahora Bassa outflows, the Shire River inflows and flashy runoff from the Mozambique plateau. The tributaries are contributors of flows to the delta during the wet season but during the dry season Cahora Bassa is the main source of flows, contributing more than 70%.

Water releases from the dam aim for maximizing hydropower production and minimizing floods. With the flow regulation the annual floods were almost eliminated and dry season low flows were drastically increased. Except for the rainy season from December to March where the average discharge is higher at about 2,000 m^3/s, the rest of the time in a year the discharge is more or less at a constant level between 1,600 - 1,700 $m^{3/}s$.

The figure below shows the water levels and discharge for different periods (before and after construction of the dams). It can be seen that nowadays the intra-annual variability is low. The annual average water level in Marromeu is 3.8 meters above the gauge plate zero, which corresponds to approximately 3,500 m^3/s.

The planned Mphanda Nkuwa reservoir, a run-of-the-river dam with an installed capacity of 1500 MW, will regulate daily flows and considerable variations in daily flows can be expected as daily energy demands fluctuate.

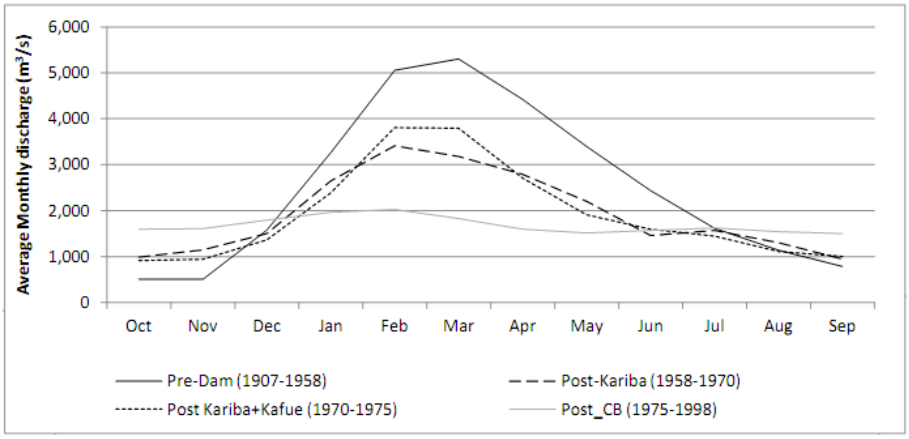


Figure 3 - Flow regime changes at Tete (Source: Njati, 2014)

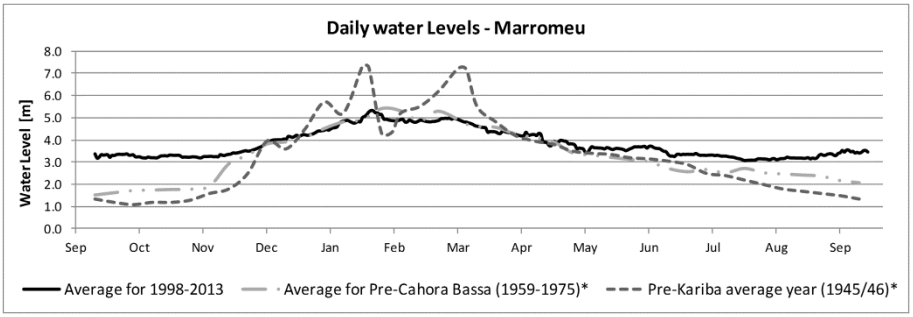


Figure 4 - Water levels at Marromeu gauging station (adapted from Beilfuss and Dos Santos, 2001)

At the Indian Ocean the tide can be classified as meso-tidal with a range up to 3 meters.

Vulnerability to flood

After the construction of the Kariba and Cahora Bassa dams the floods became less frequent and timing is less predictable. The dams are able to attenuate small and some medium floods but large floods still occur with major damages, eg in 1978, 1989, 1997, 2001 and recently in 2007 and 2008 again (Fanaian, 2013). See Figure 5 for the flood extent of the 2008 flood. Since the frequency of cyclical annual floods was drastically reduced the population felt safe to move their settlements closer to the fertile soils of the Zambezi floodplains increasing the exposure and risk. After the civil war (1992) people that fled to Malawi and Zimbabwe started moving back to Mozambique and also into the Zambezi Delta, which was more abundant in water and other natural resources than the surrounding highlands. These newly settled people had no knowledge of the characteristics of the river, and didn't perceive the risks of settling near the river in the floodplains (Artur, 2011 in Paagman etal, 2013).

In 1997 the water level in Marromeu rose up to 7.61 meters which did not happen since 1987, so people were caught by surprise and damage to livelihoods was very high in the delta area. In 2001 the water level reached 7.69 meters and, although this level is not as extreme as before the flow regulation, people in the floodplains were again caught by surprise. 81 people died and 155 000 were left homeless.

Floods in the Lower Zambezi also affect the SENA railway which causes huge losses to the mining companies operating in Tete.

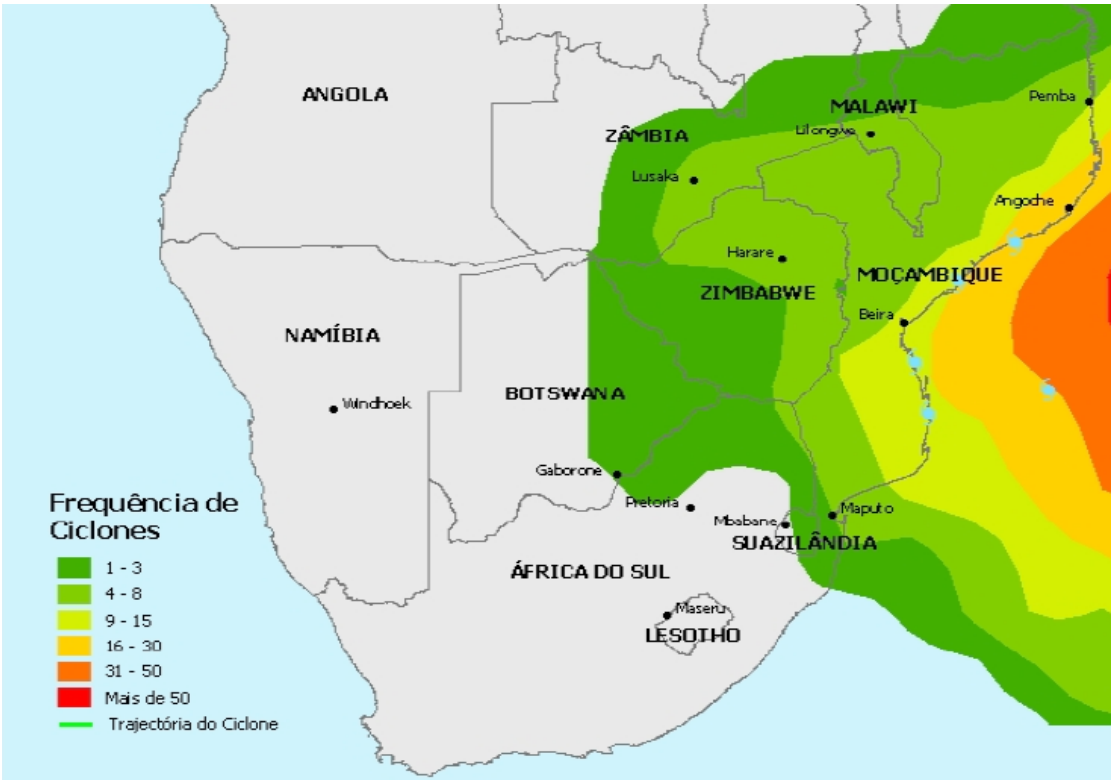


Figure 5 - Cyclone frequency over the last 75 years. Source: MICOA (2005).

Cyclons do occur quite frequently in the Mozambican coast line. Over the last 75 years before 2005, the Zambezi Delta was hit by 9 to 15 cyclones (MICOA, 2005). But the flooding events recorded in the Delta region were mainly due to high flows in the Zambezi River coming from upstream (Cahora-Bassa dam).

Flooding from sea has not been reported to affect the local communities or infrastructure so far.

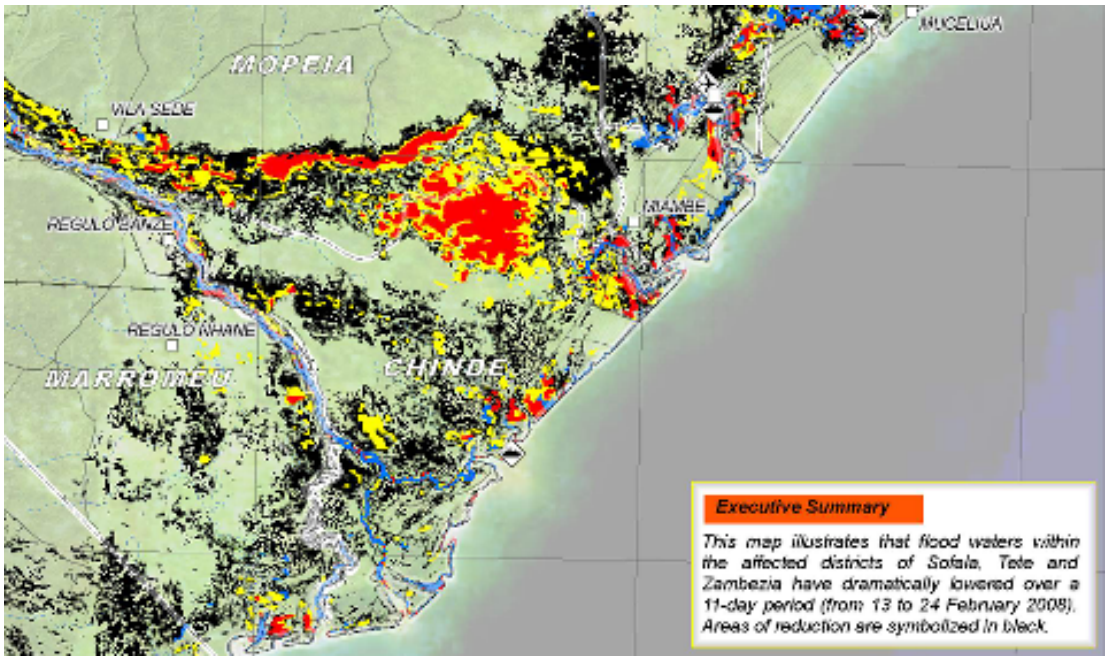


Figure 5 - Flood extent in the Zambezi delta for the floods of 2008. Source: UNOSAT (2008).

Water demand / freshwater shortage
ARA Zambezi is the basin authority in the Lower Zambezi that is responsible for managing water allocation and use of the water in the basin. The large scale water consumers registered by ARA Zambezi are:

- Hidroeléctrica de Cahora Bassa (HCB) - uses water for hydropower production;
- SENA Sugar Estate - uses water for sugarcane plantation (irrigation);
- Rio Tinto - uses water for coal mining activities in Tete;
- Vale Moçambique - uses water for coal mining activities in Tete;
- Mozambique Leaf Tobacco - uses water for tobacco plantation (irrigation);
- Mitete Industrial - uses water for industrial processing activities.
- Grown energy - uses water for irrigation of agricultural fields.

In 2008 SENA Sugar Estates was abstracting 4.2 x 10^6 m^3/month during a period of 5 to 8 months, which corresponds to approximately 1.6 m^3/s. This abstraction is very low compared to the average flow in the Zambezi delta (~3500 m^3/s). With the agriculture development projects planned for the future the irrigation abstractions may become significant.

Smallholder farmers (with land of 1 ha or smaller) also use water in the basin but these are not accounted for by ARA Zambezi because the Mozambican law states that water for domestic use and farming small areas (less than 1 ha) is free of charge (common uses of water). These abstractions are most probably very low as well.

Water is abstracted from aquifers in the small urban areas. Due to limited infrastructure only a small part of the population is covered by the water supply systems and this water abstraction can be considered low.

Studies focusing on the delta ecosystem suggest that the reduction of flood magnitude and frequency is having a negative impact on vegetation patterns and biodiversity in general. Researchers believe that the flow regime alteration is causing the wetlands to become drier, and impacts on fauna have also been identified (e.g. significant reduction in shrimp population, which is very important to the fishery industry). Through the environmental flow initiative (by WWF) there is some research (by e.g. UNESCO-IHE and ETH) to assess the possibility to restore some of the elements of the natural flow regime as an attempt to mitigate these impacts on the delta ecosystem.

In general the there is no water shortage in the Lower Zambezi basin at present.

1.2.2 Infrastructure (network layer)

Summary of pressures

Flood protection:
Flood protection dikes where built around 1893 to protect sugar fields in Mopeia, Marromeu and Luabo. Railway and roads built in the floodplains also act as flood protection. Two large dams (Kariba and Cahora Bassa) were built for flood protection, in addition to hydropower.

Irrigation and drainage:
In the delta area only the SENA Sugar Estate has an irrigated agricultural field. The rest of the agricultural land owned by smallholders is rain-fed.

Water supply and sanitation:
Water supply and sanitation infrastructure is limited to the main village only. In general, the percentage of population without access to safe drinking water is high (around 50 to 60%) and sanitation services coverage is even lower.

Roads, railways, ports and navigation channels:
The road network has 630 km of secondary (earth) roads with good to reasonable conditions and 330 km of tertiary roads in reasonable conditions. Road maintenance is poor. There is a 88 km railway that links with the greater SENA railway. A new railway line between Tete and Macuze in Zambeze province north of Chinde is under development by a Thai enterprise. The railway will cross the northern margin of the delta with a crossing in Shire river at a point called Shire batelão. There are three small airports and barges to transport people and goods from/to Chinde and Marromeu.

Research gaps

- Research to assess low cost water supply and sanitation alternatives;
- Research to study the effects of the flood protection measures in terms of flood risk reduction and impacts to the environment;
- Research to investigate the effect of the new proposed embankments associated with the new Macuze line over the flooding in the delta;
- Feasibility studies for the development of infrastructure in the delta region.

Table 5: overview of status of major infrastructure in the studied deltas

	Flood protection	Irrigation & drainage	Water supply & sanitation	Roads, railways, ports & navigation channels	Overall Score
Zambezi	•••	•••	••••	•••	-

• = Adequate, now and in the near future (around 10 years)
•• = Adequate, but adaptation needed in view of climate change (long term)
••• = Improvements are desirable in view of economic development (medium term)
•••• = Rehabilitation or upgrading urgently needed

Flood protection:
The construction of two large multi-purpose dams in the Zambezi river (Kariba dam in 1958 and Cahora-Bassa dam in 1974) has reduced the magnitude and frequency of floods in the delta.

Some of the flood protection infrastructure in the Zambezi delta was built long time ago. The first embankment for flood protection was built in 1893 around the sugar fields in Mopeia and in the following decades embankments were also built to protect Marromeu and Luabo. These embankments were raised to the maximum level of the observed floods after a large flood event in 1926. There are some dikes built at the beginning of the 20th century on the North and South bank for flood protection. The Marromeu village which is the most vulnerable to floods due to its location and the value of the existing infrastructure (conventional houses, markets, roads, water supply system, sugar factory, etc.) is surrounded by dikes for flood protection. During large floods the dikes are not enough to prevent flooding although they significantly reduce the flood damage. In addition to that a railway and road were built in the floodplains parallel to the Zambezi river between Marromeu and Chupanga which also constrict movement of water and serve as flood protection. On the other hand, the constriction of water movement has negative impacts to the floodplain ecosystem (Belifuss and Brown, 2006).

Irrigation and drainage:
In the delta area only the SENA Sugar Estate has an irrigated agricultural field. The rest of the agricultural land owned by smallholders is rain-fed.

Water supply and sanitation:
A water distribution network only exists in the centre of the Marromeu village and only 3.1% of the population has access to it. Regarding the rest of the population of the Marromeu district, 32.9% have access to improved shallow wells or deep wells with hand-pumps and the rest use unsafe sources

like open wells, rivers and lakes. The existing water supply infrastructure in Marromeu village is old and maintenance is poor. For the Mopeia and Chinde districts most of the population use water from shallow wells or deep wells with hand-pumps (48% and 62% respectively) and also water from rivers or lakes (51% and 38% respectively).

Sanitation is one of the major challenges in the region. The Marromeu district is again the only one having toilets with septic tanks (1.2% of the population) and improved latrines (6.3% of the population). The rest of the population of the Marromeu district only have access to traditional not improved latrines (20.4%) or doesn't have any latrine at all (72.1%). For the districts of Mopeia and Chinde the situation is worse with most of the population without any kind of latrine.

Roads, railways, ports and navigation channels:
The road network in the Zambezi delta includes around 630 km of secondary roads (mainly earth roads) with good to reasonable conditions and 330 km of tertiary roads in reasonable conditions. Due to the clay content in the soils of the region it is almost impossible to drive through these roads after long rainfall events, a fact that is aggravated by the lack of maintenance services.

There is a railway line in the Zambezi delta that links the Marromeu village with the Inhamitanga village in the Cheringoma district. The railway has an extension of around 88 km and then links with the greater SENA railway running from the port of Beira to Malawi, passing through Tete province.

A new railway line between Tete and Macuze in Zambeze province north of Chinde is under development by a Thai enterprise. The railway will cross the northern margin of the delta with a crossing in Shire river at a point called Shire batelão.

There are three small airports in the region with reasonable conditions. One of them is located in the Marromeu Village and belongs to the SENA Sugar Estates.

The Zambezi river is used for navigation by the local population. The boats transport people and commercial products from the (fluvial and marine) port of Chinde to Luabo and the (fluvial) port of Marromeu.

1.2.3 Natural resources (base layer)

Summary of pressures

Coastal erosion:
Recent studies carried out during the preparation of the environmental impact assessment for the navigation of the Zambezi River have shown that the mouth of the Zambezi is very dynamic in terms of sediment transport.

River morphodynamics:
The Zambezi river is a braided to anabranched sand bed river with high sediment transport dynamics, and presenting migrating bars. Sediment trapping at Cahora Bassa dam impacts on the river morphology resulting in a colonizing and stabilizing river bed.

Flooding (flood hazard):
Flooding in the Zambezi delta became less frequent and timing is less predictable after the construction of the large dams upstream. Off-season flooding associated with dam operation has been reported in the Zambezi. The floods were mostly associated with spilling in preparation for the rain season or to accommodate higher than normal flows into the reservoir. The dam releases when done without proper notification to local communities often resultin in loses of agriculture produce by farmers along the flood plain.

Salinisation/salt intrusion:
Salinisation of soils has been reported. The annual floods that became less frequent had an important function of flushing accumulated salts on floodplain soils.

Water and soil pollution:
The cities along the Lower Zambezi river release sewage water without adequate treatment which leads to eutrophication of the river and spreading of water related diseases. Car washing near river banks is also contributing to pollution of the river. With a low population, a low water supply coverage and a high dilution potential from the Zambezi discharge, the problems are however still small.

Wetland and biodiversity loss:
Tributaries of the Zambezi river have become disconnected due to construction of flood protection embankments and change in flow regime has contributed to changes in vegetation patterns in the delta region, including decrease in mangrove area and wildlife numbers. Praagman etal 2013 report that near-coast and riverine fishery have replaced floodplain fishery, although industrial prawn catch has also reduced due to decreasing numbers of prawn. The natural reserve of Marromeu experienced reductions in numbers of waterbirds and wildlife, some of which are already classified as endangered species (Beilfuss 2012). Biodiversity lose as a result of the changes in the extent of the wetland areas have been reported in the Zambezi delta. For the entire Zambezi delta the biggest landuse is grassland (50 - 60%) and mangroves contribute about 3%. The mangrove cover was reduced by 24% with a recovery of 18% for the 1972 - 1979 period and during the 1989 - 2013 the decline was at 14% and recovery at 26%. However the reduction takes place with different rates and in different periods for the different parts of the Zambezi Delta and is not a continuous process in all areas of the delta. Poacher activities cause uncontrolled and devastating forest fires.

Research gaps
- Data collection (sediment characteristics, sediment transport, coastal erosion, salinity intrusion, improved discharge monitoring network, including development of more accurate rating-curves and accurate topographic and bathymetric surveys to produce a digital elevation model) to support analysis, model calibration and validation;
- Community programs to disseminate information about importance of ecosystem services and to tackle issues of illegal hunting and wood extraction as well as water pollution;
- Development of an integrated morphological model (for river and coastal dynamics) to study the main drivers of morphological changes and predict impacts of proposed activities and proposed environmental flows;
- Development of a salinity intrusion model to study the main drivers affecting the salinity intrusion and impacts of proposed flow regimes, other proposed activities and sea level rise including impacts on estuary vegetation and fisheries;
- Research on status of the environment, especially the biodiversity;
- Research on the quantification and importance of ecosystem services benefiting the population livelihoods and economy of the delta region;
- Topographical monitoring for land subsidence evaluation.

Table 6: overview of base-layer pressures in the studied deltas.

	Coastal erosion	River morpho-dynamics	Flooding	Salinisation/ freshwater shortage	Water and soil pollution	Wetland and biodiversity loss	Overall Score
Zambezi	•	•	•	•	•	••	+

• = minor and/or well controlled
•• = intermediate and/or partly controlled
••• = major and largely uncontrolled

Coastal erosion:
No quantitative and systematic evaluation of the delta coastline evolution has been carried out. Ronco et al. (2010) estimated the area change using five LANDSAT images and showed a general negative trend of the delta area extension, with a loss of 2.2 km^2/y for the 1972–1979 period, a less marked loss in the 1979–1991 period (−1.7 km^2/y), an overturning of the erosion/deposition phenomena with an increase of area extension (around 2.4 km^2/y) for the period 1991–2000, and a final prevailing decrease of the delta area (−2.2 km^2/y) in the period 2000–2004. Over the last 40 years the Southern shoreline has accreted approximately 2 km whereas the tidal flats in the Northern part of the channel were infilled with sediments and became colonized by mangroves.

Recent studies carried out during the preparation of the environmental impact assessment for the navigation of the Zambezi river have shown that the mouth of the Zambezi is highly dynamic in terms of sediment transport and the sedimentation and erosion pattern of the riverbed continuously change.

River morphodynamics:
The river can be characterized as a braided to anabranched sand bed river. It has large central and lateral bars that were used to migrate in the past but became colonized and stabilized by vegetation after the flow regime changes imposed by the upstream dams. Its banks are sandy and easily eroded when not covered with vegetation.

Figure 6 - Zambezi sandy banks near Marromeu Village

The sediment load in the Zambezi river has been estimated in Tete as 52 M m^3/year where only 7% is from bed load while 93% is from suspended load.

The river morphodynamices of the Zambezi delta have been poorly studied to date. Very few detailed studies are available on the morphodynamic characteristics of the this large African river. According to the results of a numerical model (Ronco et al, 2009) the two large dams constructed in the river have slightly influenced the erosion and deposition patterns. However, bathymetric surveys of Coba et al. (2011) show that the average river bed level near the Marromeu village have lowered up to 3 meters in some sections in the period 1962-2007. The causes for this are not well understood, but sediment trapping and dregding for transport are mentioned. The analysis of the causes is further compounded by the significant land use modifications taking place in some of the tributaries especially in Luenha river where soil erosion due to bad land use practices has been cause of concern for the authorities. The lowering of the river bed level has negative impacts because with the lowering of river bed levels and water levels the distributaries that feed the vast areas of the delta receive less water or become disconnected from the Zambezi main channel with consequences for the vegetation and biodiversity in general.

Flooding (flood hazard):
Flooding in the Zambezi delta became less frequent, but timing is less predictable after the construction of the large dams upstream. Nowadays it depends on the operation rules of Kariba and Cahora-Bassa dams. According to Hidroeléctrica de Cahora Bassa (HCB), flooding in lower Zambezi begins when discharge exceeds 10,000 m^3/s. Off-season flooding associated with dam operation has been reported in the Zambezi. The floods were mostly associated with spilling in preparation for the rain season or to accommodate higher than normal flows into the reservoirs. These releases where done without proper notification to local communities and therefore often resulted in loses of agriculture produce by farmers along the flood plain

Tha and Seager (2008) suggest three distinct flooding events, based on historic releases of Cahora Bassa:
- Moderate flood, discharge around 6,500 m^3/s, occurrence probability of 1:5 years
- Large flood, discharge around 9,000 m^3/s, occurrence probability of 1:18 years
- Mega flood, discharge around 14,500 m^3/s, occurrence probability of 1:50 years

The flood damage that could be avoided has a substantial economic impact on the basin as well (Fanaian, 2013).

Salinisation/salt intrusion:
Not much information is available about salt intrusion in the delta area. The annual floods have an important function of flushing accumulated salts on floodplain soils (Beilfuss and Brown, 2006). Higher discharge during dry season may have reduced the saline intrusion but, on the other hand the reduction of flooding frequency may have caused an increase in the floodplain soils salinity.

Water and soil pollution:
According to the fact sheet of the Africa facts website, pollution is a major problem. There are a number of cities along the Zambezi river and none of these have an adequate sewage treatment plant so large amounts of polluted water are released into the river. This has led to eutrophication of the river water and the spread of water related diseases such as cholera, typhus and dysentery. In addition to that, in rural areas cars and motor-bikes are usually washed in the river banks and residual waters are released back to the river containing oils and other pollutants. For the delta area with a low population, a low water supply coverage and a high dilution potential from the Zambezi discharge, the problems are however still small.

At the moment there are no reports about soil pollution in the delta area. Mining activities are non-existent in the delta area so the probability of soil pollution is low. However, in the mining concessions in the Tete Province (upstream of the delta area) the soil pollution is an important issue and the environmental management plans related to the mining activities include the monitoring of the pollutants in the soils.

Wetland and biodiversity loss:
The change in flow regime due to the dams and the lack of flooding in the delta has impacted significantly the Zambezi delta. Analysis of satellite images have shown that woody savannah and thicket species have increased in density and colonized far into the floodplain grassland mosaic, where the flood-tolerant species have been displaced by other drought-tolerant species. In the coastal plain, saline grassland species have displaced freshwater species and coastal mangrove has been replaced by saline grassland at the tidal margin. Sandbars have become stabilized and colonized by grassland and woody species. The abandoned alluvial channels and distributaries are undergoing a process of terrestrialization and the wetland area has been reducing over the last years (Beilfuss et al, 2001).

The flood protection embankments constructed at the beginning of the 20th century have compromised the connection between the main channel of the Zambezi and the distributaries in the delta area, mainly on the Southern bank. This was aggravated by the flow regulation at upstream dams which significantly reduced the frequency of annual flood pulses.

A study on the landcover changes (Njati, 2014) revealed that the general trend of area under mangroves in the Zambezi delta resembles that of the global trend of mangrove reduction. For the entire Zambezi delta the biggest landuse is grassland (50 - 60%) and mangroves contribute about 3%. The mangrove cover was reduced by 24% with a recovery of 18% for the 1972 - 1979 period and during the 1989 - 2013 the decline was at 14% and recovery at 26%. However the reduction takes place with different rates and in different periods for the different parts of the Zambezi Delta and is not a continuous process in all areas of the delta.

Some vegetation clearing, mainly on river banks, has been reported which will probably lead to some soil erosion besides the biodiversity loss. It is relevant to mention that the water policy states that the water courses should be protected against these types of actions.

Poaching is growing international activity in the world and the southern Africa region is no exception. In Mozambique the situation is exacerbated by its weak institutional development special the judicial system is not strong enough to deter this kind of practices. In the Zambezi delta the poacher activities is having a negative impact on the forested areas due to their hunting methods using fires to catch mainly rodents. Episodic stories of people caught by police in airports with large quantities of ivory rhino horns suggest that the situation could be worse on the ground.

The use of wetland soils for production of bricks is also a common observed practice by the population which causes the degradation of the wetlands. The bricks are used to construct houses and although at the moment this occurs at a small scale, it is likely that the exploration of the wetland soils will become more intense in the future.

These changes in the Zambezi delta have probably reduced its carrying capacity for the different species that live in the delta like large mammals, water-birds, etc. The feeding and breeding patterns of fish, shrimp, bird and other wildlife species have been disrupted.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government:
The Water Policy created in 1995 pushes toward decentralized administration, where decisions are taken at local/regional levels whereas the government responsibility changes from direct implementation to a more facilitative role. The coordination between different sectors of the government is carried out by technical steering groups which act as advisors to the higher level institutions (the ministries).

Cooperation between government and private sector:
The implementation of the Water policy also led to more involvement of the private sector. The government transferred its administration responsibility for some infrastructures (irrigation, water supply systems, etc.) to the private sector and changed to playing a more facilitative role.

Involvement of stakeholders and citizens:
Stakeholders, interested citizens in general and national and international NGO's can get involved and participate in the definition of policies and decision making process in different ways, such as in basin committees where activities at basin level are discussed.

Approaches for dealing with risks and uncertainties:
The INGC (National institute for disaster management) is an autonomous government institution with the responsibility for coordinating disaster risk management at national, provincial, district and even community levels. The government adopts a precautious attitude to deal with uncertainties.

Research gaps

- Study of adaptive management alternatives for better implementation of the decentralization;
- Research on better institutional structures and capacity building for the government lower levels to enable direct implementation of the administration tasks with success;
- Development of integrated policies (cross-sectoral integration) and integrated master plans for basin level development activities including programs to improve living standards of rural populations;
- Integrated river and coastal management approach;

Table 7: overview of status of governance in the studied deltas

	Cooperation between levels and sectors of government	Cooperation between government and private sector	Involvement of stakeholders and citizens	Approaches for dealing with risks and uncertainties	Overall Score
Zambezi	••	•	••	••	-

• = Practically non-existent, unknown
•• = First initiatives
••• = Developing, mixed results
•••• = Fully developed, satisfactory results

1.3.1 Cooperation between (scale) levels and sectors of government

Following the principles of integrated water management the Water Policy (PA) was created in 1995, which pushes to a decentralized administration. Decisions are taken at local (provincial/districtal) levels whereas the government responsibility changes from direct implementation to a more facilitative role. New government institutions were created at regional levels to carry out the direct implementation of operational management and administration, however these institutions are rather young and due to low technical and financial capacity they face some challenges to fulfil their responsibilities.

The coordination between different sectors of the government is carried out by technical steering groups which act as advisors to the higher level institutions (the ministries).

1.3.2 Cooperation between government and private sector

The decentralization of the government administration not only led to the creation of new regional level institution but also included more involvement of the private sector which in turn increased the economical value of water and the acceptance of this economical value of the water by the society in general.

Under the implementation of the Water Policy, the government transferred its administration responsibility for some infrastructures (irrigation, water supply systems, etc.) to the private sector, but in practice large enterprises carry on without much involvement of the local government.

1.3.3 Involvement of stakeholders and citizens

Stakeholders, interested citizens in general and national and international NGO's can get involved and participate in the definition of policies and decision making process in different ways. For instance, in the agricultural sector, the associations of farmers can participate in the irrigation management board. In the water sector there are the basin committee meetings which are organized by the ARA's (Regional water administrations) at basin level and held regularly (in general, twice a year but with extra-ordinary meetings whenever necessary) and all interested or affected people are invited to join and to express their point of view and get clarifications about important decision at basin level. New activities such as irrigation schemes, changes in dam operation strategies and new public infrastructure plans are all presented to the public during these meetings.

1.3.4 Approaches for dealing with risks and uncertainties

The INGC (National institute for disaster management) is an autonomous government institution under the Ministry of State Administration (MAE) and has the responsibility for coordinating disaster risk management at national, provincial, district and even community levels. The INGC activities are coordinated with other government sectors at district or basin level. For instance, in the water sector the INGC participates in the basin committee meetings and presents mitigation plans for floods and drought, and prevention plans as well. In other cases INGC activities are coordinated with municipalities or district authorities.

The government adopts a precautious attitude to deal with uncertainties. For instance, INGC organizes campaigns to disseminate information about flood risks prior to flooding season and also advises people to move their settlements to higher/safer grounds.

1.3.5 Overview of key stakeholders regarding delta management issues

Key stakeholders	Brief description of responsibilities and tasks regarding delta management issues	Related network or cooperation structure
Research institutes		
○ Eduardo Mondlane University (UEM) ○ UNESCO-IHE Institute for Water Education ○ International Crane Foundation (ICF) ○ Waternet ○ Institute for Fisheries Research (IIP) - Mozambique	Research, capacity building, documentation.	• MOPH • Zambezi Valley Development Agency
○ …		
Policy makers		
○ Ministry of Public Works and Housing (MOPH): ○ DNA ○ ARA Zambezi ○ FIPAG ○ Ministry of Fisheries ○ Ministry of Agriculture ○ Ministry of Coordination of Environmental Affairs (Micoa) ○ National Institute for Disaster Management (INGC)	Policy-setting, planning, monitoring, reporting, facilitating.	• Research institutes; • Private Sector • Citizens
Developers		
○ Zambezi Valley Development Agency (ZVDA)	Present strategies for the socio-economic development and provide technical and financial assistance for agricultural development initiatives.	• Policy makers, • Citizens, industry.

Industry		
○ SENA Sugar Estates	Follow environmental management plan (Monitoring, control/mitigation of possible environmental impacts due to industrial activities)	• Policy makers • Citizens
Citizens		
○ Small scale farmers ○ Small scale fisherman ○ NGO's (WWF, International Crane Foundation,)	NGO's create initiatives for protection of the environment, promote research and disseminate information.	• Policy makers • Developers/industry • Research institutes.

1.3.6 Governance structures and networks of key stakeholders (including international platforms)

At the basin scale the Zambezi River counts with the participation of many institutions at regional, national and international levels which are responsible for the management of the water resources in the basin. At present the main challenge for these institutions is to develop their capacity to perform their tasks in this large and fast developing basin, as most of the institutions have been created very recently.

At the international level there is ZAMCOM (Zambezi Watercourse Commission), covering the entire basin. ZAMCOM was initiated by Southern African Development Community, the agreement was signed in 2004 and ratified in 2011 by the basin states. ZAMCOM has as prime objective "to promote the equitable and reasonable utilization of the water resources of the Zambezi watercourse as well as the efficient management and sustainable development thereof"

At the national level the Lower Zambezi basin has the National Water Directorate (DNA) which is part of the Ministry of Public Works and Housing (MOPH). DNA is responsible for planning the water resources management, constructing hydraulic structures, establish water legislation and monitor its application.

At the regional level ARA Zambezi (Regional water administration for the Zambezi) is responsible for the operational water management of the Lower Zambezi basin inside the Mozambican territory. ARA Zambezi is responsible for managing the water quality and quantity in the Lower Zambezi and their objectives are:

- Ensure rational use of water resources;
- Conservation of water resources including promotion of large and small dams, and other water storage infrastructure;
- Charge taxes for the use of raw water;
- Protect surface and groundwater resources from pollution and inadequate uses.

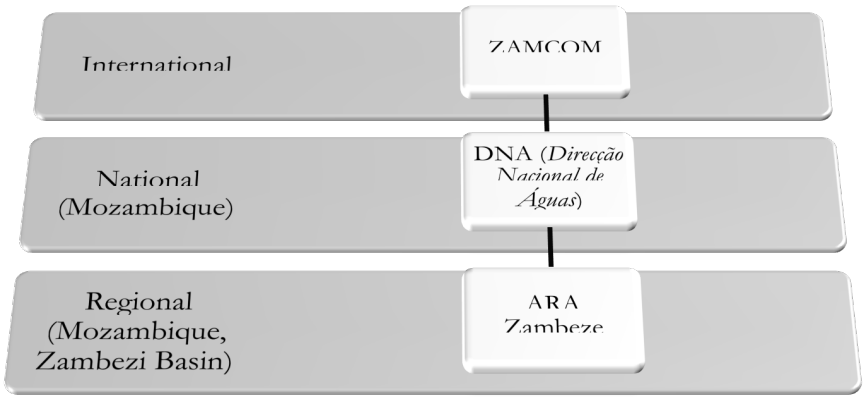


Figure 7 - Governance structure of the Lower Zambezi basin in Mozambique.

Regarding the Mozambican water and sanitation sector, this is still a highly centralized sector. The leading institution is MOPH. DNA which is part of MOPH is the focal point of the sector and, besides the roles mentioned before, it has the responsibility of policy-setting, planning, monitoring, reporting, also for rural water supply and sanitation. For the urban water, some urban areas are under the jurisdiction of FIPAG (Waters Investment and Asset Holding Funds), while others are under the jurisdiction of the newly formed AIAS (Water and Sanitation Infrastructure Management Unit). DNA is also responsible for urban sanitation apart from Municipal government responsibilities.

CRA is the regulator of the water sector. It defines the tariffs and service quality targets, monitors compliance with the targets, reviews investment programs and ensures a balance between the quality of the service, the interests of consumers and the financial sustainability of the water supply systems. Recently CRA coverage was extended to sanitation services as well.

The National Water Council (CNA) was established under the Water Policy as an advisory board for the Government of Mozambique. Its role is to provide advice on inter-sector strategic aspects of water-related policies implementation.

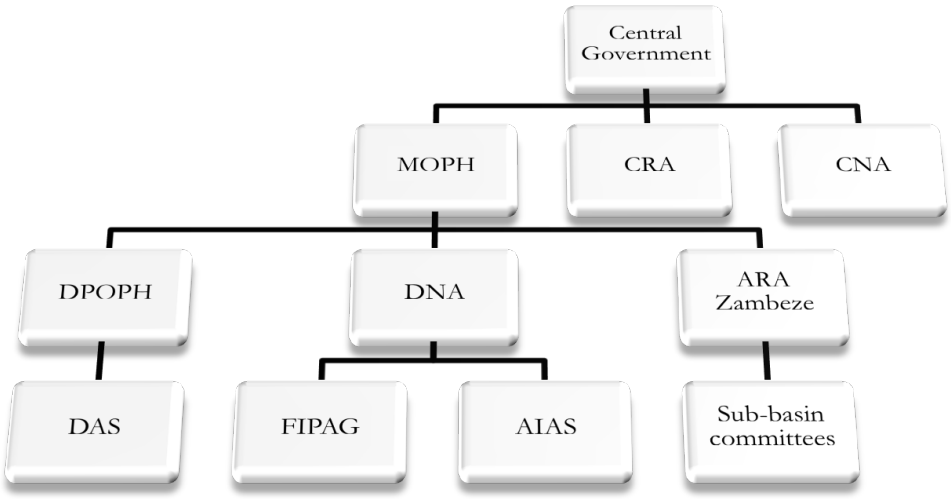


Figure 8 - Governance structure - water sector[3]

On a provincial level there is the Provincial Directorate for Public Works and Housing (DPOPH) that has a Department of Water and Sanitation (DAS) which is responsible for supervision and facilitating strategic planning.

Funding proposals and new sector initiatives comes either from DNA or FIPAG, which means that the decentralization is not completely applied at the moment.

INGC is the National Institute for Disaster Management which works under the Coordinating Council for Calamity Management (CCGC). Its activities include advising the government about policies and strategies for mitigation of calamities, approving calamity management programs and post-calamity reconstruction and rehabilitation projects and approving of humanitarian assistance to calamity victims, propose the president of the republic to announce an emergency alert in case of a calamity, find help from national and international communities to rescue calamity victims, and to propose the ministry council the creation of emergency funds as well as ratification of international conventions about calamities.

3 Please note that DNA is at a bit higher position than the institutions such as the ARAs and DPOPHs

MICOA is the Ministry of Coordination of Environmental Affairs. Its main task is the intersectorial coordination with the aim of assuring adequate management, protection and rational use of natural resources for the well being of the society.

The diagram below illustrates the structure implemented in Mozambique for coordination and natural calamity management including the relationships between the different coordination partners, according to the MICOA's (2006) evaluation of the Mozambican experience on climatic disaster management.

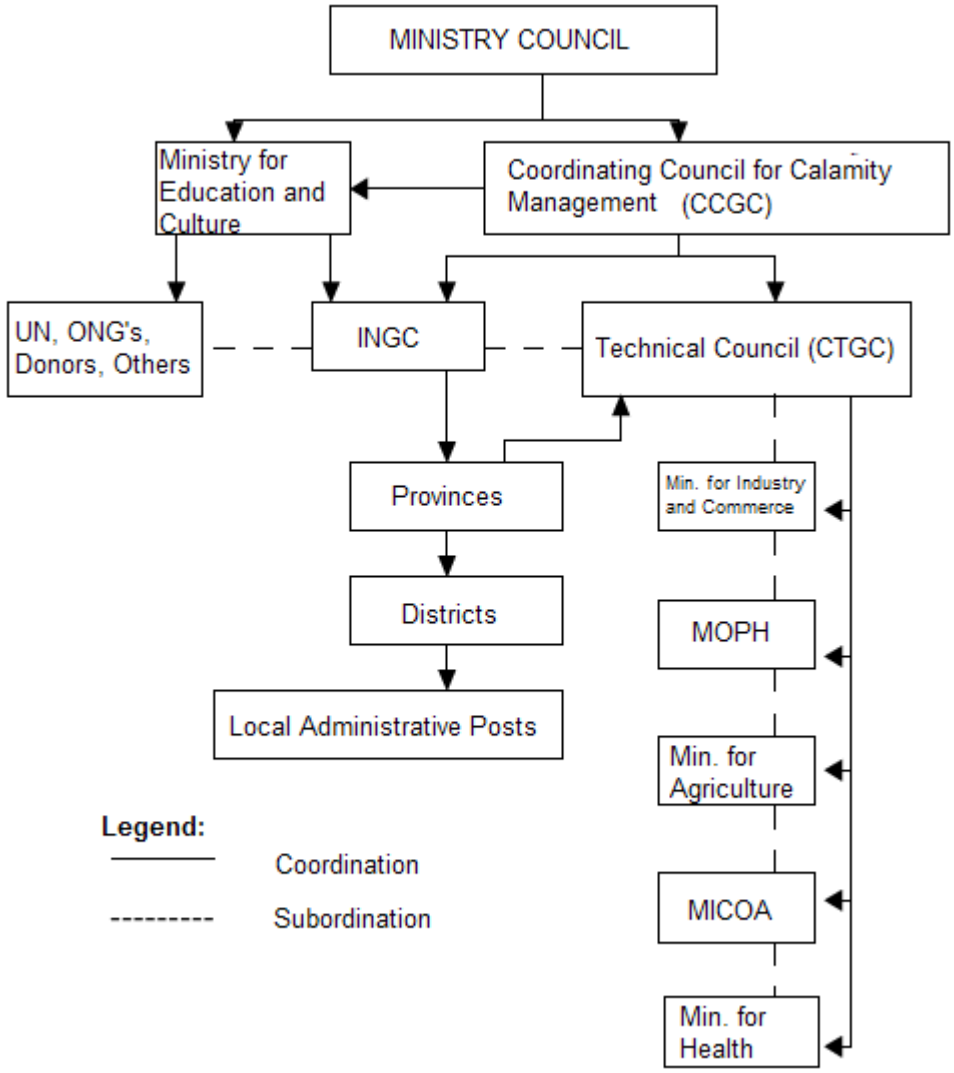


Figure 10 - Calamity Management and Coordination in Mozambique. Source: MICOA (2006)

The Zambezi Valley Development Agency (ZVDA) has been established in 2010 to promote the socio-economic development of the Mozambican part of the Zambezi Valley. It is a public organization, focusing on strategic planning, facilitation of agribusiness development and promotion of investment.

1.3.7 Overview of decision making process (including legal instruments)

For the Mozambican water sector the most important legislation is the PNA (1995) - National Water Policy, created in 1995. It was revised in 2007 in the context of the Millennium Development Goals (MDG's) and sector experience from the past years and became the Water Policy (PA). In 2007 the

Government of Mozambique (GoM) also created the PESA-ASR (Strategic Plan of Rural Water and Sanitation) which defines the objectives and strategies for medium and long terms regarding the global and the Mozambican water sector developments with respect to sanitation.

The National Integrated Water Resources Management Strategy (NIWRMS), approved in 2007, is the main operational instrument of decentralized water resources management. It focuses on participatory basin management and aims to ensure water availability at basin level. The strategy integrates and prioritizes sector-based plans (agriculture, industry, mining, tourism, environment, domestic use, etc) and local government development plans as well as traditional basic uses locally.

The Regulation of Water Licenses and Concessions (RWLC), also created in 2007, is the main legal mechanism used by the regional water administrations (ARA's) to enforce sustainable and efficient water use and conservation. It sets the taxation basis for which the ARA's set fines and specific fees.

Other important sector-based legislations include:
- The Land Policy (1997);
- Environmental Policy (1997);
- The Hydro-Electrical Energy (1997);
- The Mining Act (2002).

In 2012 the Mozambican council of ministries approved the regulation on groundwater prospection and exploration. Groundwater management is also at the responsibility of the ARA's. The regulation was created because of the need to define the technical requirements to be observed in activities regarding groundwater prospection, abstraction and exploration.

The authors are not aware of any master plans that exist for the delta. Government plans do exist but are often made for a district or province or a specific sector such as agriculture or mining. Extracting the relevant action from these plans for the delta has been difficult.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	• Population size and growth rate • Migration trends in the Zambezi delta (annual percentage in/out
Economic developments	• Per capita GDP, growth rate,% contribution by Zambezi delta. • Unemployment rate • main sectors, growth rate • (planned) dams in main stem and/or tributaries in the catchment
Technological developments	• Percentage of GDP spent on innovation and research in each sector
Climate change	• Changes in air and sea water temperature • Changes in sea water level (mm/year) • Changes in precipitation and discharge (mm/year) and (M m^3/year) • Changes in precipitation timing and high and low discharge timing
Subsidence	• Cause of subsidence (e.g. geologic, groundwater extraction or oil exploration). • Subsidence rate (mm/year)

PRESSURES/PROBLEMS	Main indicators

Land and water use (occupation layer)	• Population density (hab/km^2)
	• Urbanization rate (km^2/year)
	• water abstraction (M m^3/year)
	• water shortages experiences (%)
	• water quality (rivers and lakes)
	  ○ Conductivity
	  ○ Turbidity
	  ○ Suspended sediments
	  ○ DBO
	  ○ Heavy metals
	• Changes on different classes of land use (e.g. Forest, mangroves) (km^2/year)
	• Changes in land value

Network / infrastructure (network layer)	• Percentage of population covered by water supply network systems, sanitation network systems, tele-communication networks (%). • Percentage of delta under irrigation (%) • Number of schools, hospitals, markets. • Length of paved and unpaved roads (km) • Number of bridges, reservoirs. Numbers of ports (+ volume of goods) • Flood risk (safety level),% of delta protected (low-medium-high) • Number of floods or flooding days per year • Percentage of infrastructure which needs to be upgraded
Natural resources (base layer)	• Land use- land cover • Annual fish and shrimp catches (tons/year) • Biodiversity index • Mangroves area (km^2) and mangrove deforestation rate (km^2/year) • Percentage of wetlands protected by treaties • River water discharge in the Zambezi River and distributaries like Cuacua, Salone, and others (M m^3/year) • Coastal erosion and accretion rates (km/year) • Soil erosion in the cathcment (M tons/year) • Sediment transport (x 10^6 m^3/year) and percentage of sediments trapped in reservoirs (%) • Percentage of delta with salinity problems • Flood frequency, flood extent.
GOVERNANCE	**Main indicators**
Multi-level and multi-sectoral cooperation	• Existence of integrated plans (delta plans, national adaptation plans) • Existence of multi-disciplinary committees, multi-scale and multi-sector.
Public-private partnerships	• Number of public-private partnerships (PPP's) • scale of PPP's (geographic, budget, time span)
Involvement of stakeholders and citizens	• Existence of user associations / basin committees • Number of NGO's involved in planning and decision making • Existence of legal instruments for participation
Approaches for dealing with risks and uncertainties	• Existence of early warning systems for floods and droughts, emergency systems (short term) • Existence of adaptive risk management and disaster mitigation plans, adaptation strategies (long term)

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). The scores where developed to allow for an inter-comparison between different deltas that participate in the programme. Each item is scored on a 5-points scale, related to resilience and sustainability. The following two development scenarios are recognized:

- Scenario 1, moderate perspective 2050: medium economic growth and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario 2, extreme perspective 2050: high economic growth and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Delta	**Land and water use (occupation layer)**	**Infrastructure (network layer)**	**Natural Resources (base layer)**	**Governance**	**Overall Resilience & Sustainability indicator**
Current situation 2010	+	-	+	-	0
Scenario1 moderate 2050	0	-	0	0	0
Scenario 2 extreme 2050	-	0	-	+	-

resilience/sustainability: ++ (very good), + (good), 0 (medium), - (low), -- (very low)

Concluding remarks on score card:

Pressure on land and water use (occupation layer) is considered good due to the low population density. The delta has very good natural resources (base layer) as it has abundant water, little pollution and natural delta processes with respect to sedimentation and erosion. However it is worth to note that the delta area, flow regime and ecosystem has changed considerably due to the construction of Kariba dam (1958) and Cahora Bassa dam (1974). For the future scenarios the pressures on the land and water use and natural resources are expected to increase due to the economic growth in the country and the river basins specific developments such as expansion of irrigated agriculture, impacts of upstream mining activities and effects of climate change and sea level rise. Frequency of floods and droughts may increase and with sea-level rise salinity intrusion problems may arise. The infrastructure (network layer) is scored low at present as the population has limited access to safe drinking water, no sanitation and mainly secondary roads and dikes. With the strategy plans for science, technology and innovation put in place and with the economical development the situation is expected to improve with time. The governance in Mozambique is transforming to a decentralised administration that is still following vertical channels of communication leading to fragmented actions to deal with natural resources management. There are also weaknesses in term of absence of the necessary cooperation with the private sector and in involving stakeholders and citizens. It is however in its early stages and process is going slowly due to low technical, human and financial capacity.

Mozambique has one of the fastest growing economies in Africa which is very encouraging. However, socio-economical development, infrastructure and governance still largely depend on donors. But even with the development of technology, awareness about the importance of the environment and good governance the pressure in the occupation and base layer is expected to increase so the overall resilience and sustainability will decrease proportionally in time.

2. Overview of adaptive measures in the Zambezi delta

Overview of (possible) adaptive measures in the three spatial layers based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

2.1 Overview of (possible) adaptive measures

As no master plans have been found for the delta the first four measures are based on government plans at district or regional level and/or for specific sectors and based on project reports. The remaining measures of the list can be seen as possible measures identified by the authors.

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
Possible measures based on government plans and/or project reports				
National and community programs for improvement of living standards of rural population.	1,3	Improving access to basic services of water supply and sanitation as well as education for adults and children. Community programs for disseminating new ideas for economical activities in rural areas.	2,3	1
Environmental flows	2,3	Reestablishment of the linkage between river and floodplain to protect the environment and potentiate ecosystem services provided to humans.	1, 2	2, 3
Knowledge exchange	1, 4	Creation of twinning relation between ARA-Zambeze and Waterboard De Dommel (Netherlands) for the development of Busines plan and an Integrated water management plan.	2	3
Improving cooperation with relevant institutions from upstream countries for sharing information and integrated management	1,4	Creation of the ZAMCOM (Zambezi Watercourse Comission) for improved governance at basin level. Establishment of JOTC and bi-annual meetings.	1,2,3	3

Possible measures identified by authors				
Studies on Impact of flow regulation on downstream ecosystems and optimization of water allocation	1,2	Identification of impacts of flow regime alteration on the local peoples livelihoods, floodplain vegetation, fauna, and in-stream fisheries, etc. And optimization of water allocation for maximization of the basin overall benefits.	1,2,3	3
Improvement of institutional structure and capacity building for better implementation of administration tasks (including monitoring) at local/ regional level	1,2,4	Capacity building for human resources at lower levels of the government, including attribution of adequate technology for direct implementation of administration tasks.	1,2,3	1,2,3
Development of integrated policies (cross-sectoral integration)	1, 4	Improving coordination between different sectors of the government trough synergic approach.	1,2,3	2,3
Development of integrated master plans for basin level development activities, including urbanization plans and development of the coastal areas.	1,2,3	Integration of different activities in a master plan for better definition of priorities and study of environmental and social impacts.	1,2	1,2,3
Improvement of flood management at basin level	1,2,3	Application of models for flood forecasting and prediction of flood extent as well as evaluation of existing flood protection measures. And measures for dissemination of information regarding flooding hazard.	1,2	1,2,3

Table 10: overview of the types of adaptive measures proposed for the studied deltas.

	Technical	Ecological	Economic	Institutional
Zambezi	•••	•	••	••

• = none or few
•• = some
••• = many

2.2 Examples of best practices

The INGC (National institute for disaster management) is an autonomous government institution with the responsibility for coordinating disaster risk management at national, provincial, district and even community levels. The government adopts a precautious attitude to deal with uncertainties.

The Zambezi Valley Development Agency (ZVDA) has been established in 2010 to promote the socio-economic development of the Mozambican part of the Zambezi Valley. It is a public organization, focusing on strategic planning, facilitation of agribusiness development and promotion of investment.

Improving access to basic services of water supply and sanitation as well as education for adults and children. Community programs for disseminating new ideas for economical activities in rural areas.

Improving cooperation with relevant institutions from upstream countries for sharing information and integrated management through establishment of ZAMCOM and JOTC.

3 Overview of technical methods and tools to support delta management and development in the Zambezi delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues.

Name of tool	Brief description	Institute	Available at
DRIFT	DRIFT (Downstream Response to Imposed Flow Transformation) is model used to evaluate the impact of different water management scenarios.	Carr foundation (USA), International Crane Foundation (USA), Eduardo Mondlane University, Museum of Natural History.	International Crane Foundation (USA)
HEC 5	HEC 5 is a model that uses a simple water balance approach to model a complex river-reservoir system in considerable detail.	International Crane Foundation (USA)	International Crane Foundation (USA)
Morphological Model	Morphological Model is a numerical model that simulates the interaction between flow and sediment transport including the evolution of bed levels along time.	-	University of Padova - Italy
VIC	Variable Infiltration Capacity (VIC) is a hydrological model that simulates the hydrological processes involved in the transformation of rainfall in runoff. It allows to model the hydrological processes and the assessment of impacts of land-use change on the run-off generation in the basin.	MAE (Ministry of State Administration)	SALOMON, Lda

Mike Flood ARA	An Operational model used by ARA Zambeze for flood prediction downstream of Cahora Bassa.	ARA-Zambeze	ARA-Zambeze
WEAP Water resources management model	Is a model to assist water resources management for the entire Zambezi basin.	ZAMWIS	
HUGO model	Is a model used to advise the operation of Cahora Bassa. Consists of a monthly water-balance spread sheet. All major dams in Zambezi are included.	Hidroelectrica de Cahora Bassa	Hidroelectrica de Cahora Bassa
WRSM2000 Zambezi	Is a hydrological model of the Zambezi Basin in WRSM2000. It is used to asses the Impacts of Climate Change on Hydropower Production	?	?

4 Knowledge exchange and development

4.1 Lessons learned on delta management

The Zambezi delta is an almost pristine delta with a very low population density and few economic developments. Upstream of the delta there are large economic developments, hydropower and mining, which has large consequences for the delta mainly on the ecosystem services (through changes in the flow regime).

Mozambique has one of the fastest growing economies in Africa which is very encouraging. However, socio-economical development, infrastructure and governance still largely depend on donors. But even with the development of technology, awareness about the importance of the environment and good governance the pressure in the occupation and base layer is expected to increase so the overall resilience and sustainability will decrease proportionally in time.

The National Integrated Water Resources Management Strategy (NIWRMS), approved in 2007, is the main operational instrument of decentralized water resources management. It focuses on participatory basin management and aims to ensure water availability at basin level. The strategy integrates and prioritizes sector-based plans (agriculture, industry, mining, tourism, environment, domestic use, etc) and local government development plans as well as traditional basic uses locally.

The authors are not aware of any master plans that exist for the delta. Government plans do exist but are often made for a district or province or a specific sector such as agriculture or mining. Extracting the relevant action from these plans for the delta has been difficult.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

- There is a need for the development of the monitoring network (eg. river discharge, reliability of rating curves, monitoring of discharge through distributaries, etc.);
- Monitoring of water quality to assess impacts of small scale and large scale agricultural developments, as well as the impacts of the large mining ventures taking place upstream;
- Research to understand the combined river and coastal dynamics and roles of flow regime changes in these dynamics, and monitoring of sediment transport;
- Assessment of potential threats related to delta subsidence;
- Research for diagnosis and economic valuation of ecosystems as well as identification of sound management measures to protect it;
- There is a need to develop integrated urbanization plans taking into account flood hazard and other aspects.

Pressures – potential problems / Challenges - opportunities

- Data collection (sediment characteristics, sediment transport, coastal erosion, salinity intrusion, improved discharge monitoring network, including development of more accurate rating-curves and accurate topographic and bathymetric surveys to produce a digital elevation model, topographical monitoring, land subsidence evaluation);
- Research to assess low cost water supply and sanitation alternatives
- Research to study the effects of the flood protection measures in terms of flood risk reduction and impacts to the environment;
- Research on the quantification and importance of ecosystem services benefiting the population livelihoods and economy of the delta region;'
- Feasibility studies for the development of infrastructure in the delta region

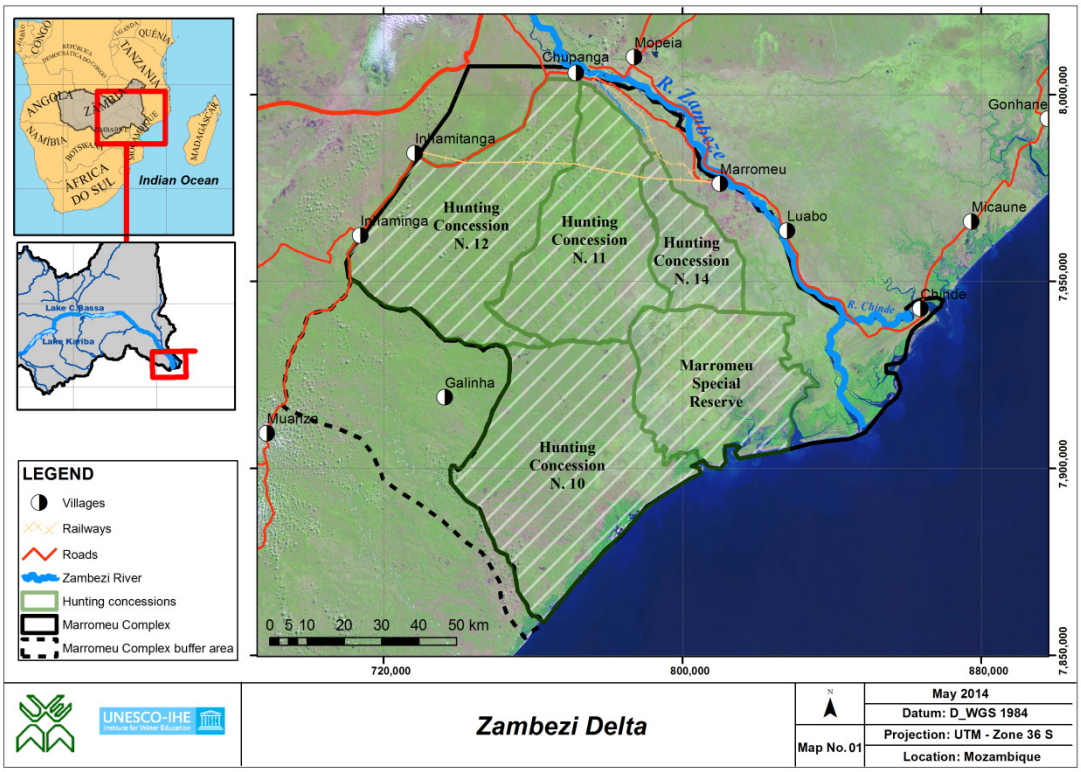
Adaptive measures

- There is a need to develop flood hazard maps to assist in the development of population settlement planning;
- There is a need for improved planning to control the development of settlements in inappropriate locations such as low lying lands prone to flooding;
- There is a need to develop flood forecasting models for flood management
- Community programs to disseminate information about importance of ecosystem services and to tackle issues of illegal hunting and wood extraction as well as water pollution;
- Development of integrated policies (cross-sectoral integration) and integrated master plans for basin level development activities including programs to improve living standards of rural populations;

Technical methods and tools

- Development of models (eg integrated morphological, flood forecasting, salinity intrusion) to study the main drivers of changes and predict impacts of proposed activities;
- Research to assess low cost water supply and sanitation alternatives;
- Feasibility studies for the development of infrastructure in the delta region;
- Study of adaptive management alternatives for better implementation of the decentralization;
- Research on better institutional structures and capacity building for the government lower levels to enable direct implementation of the administration tasks with success;

4.3 Some available illustrations (map of delta, typical sites, etc.)



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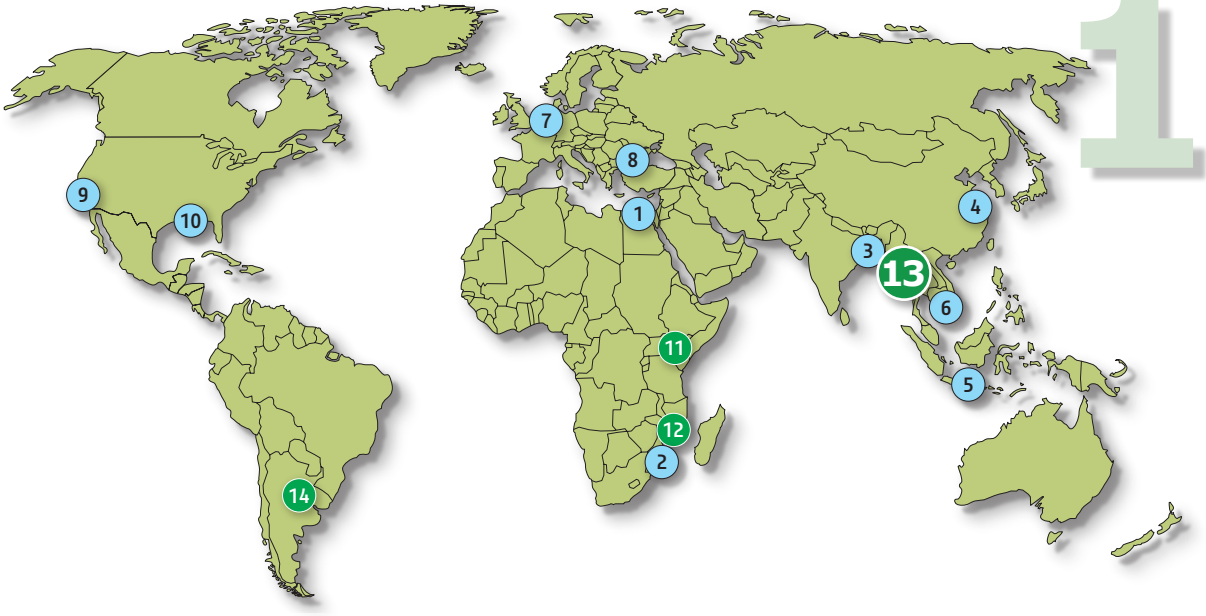
Ayeyarwady delta

No 13



1. Current and future state of the Ayeyarwady delta

1.1. Drivers of change

Summary of drivers of change

Demographic trends:
Population of the country was estimated at 58.38 million during the census of 2008-2009. Taking into account a growth rate of 1.52 percent the actual population will be approximately 62 million. Ayeyarwady Region, covering a large part of the Ayeyarwady Delta has a population of 8,041,084 on an area of 35,032 km^2, hence a population density of 230 inhabitants/km^2. With 250 inhabitants/km^2 the delta is one of the most densely populated regions in Myanmar. This population density in Ayeyarwady Region is e.g. relatively low compared to the one of the Mekong Delta (approx. 500 inhabitants/km^2, excluding Ho Chi Minh City) and the Ganges-Brahmaputra-Meghna Delta (more than 1200 inhabitants/km^2), (Driel and Nauta, 2013).

Economic developments:
The country is one of the poorest nations in Southeast Asia, 37% of the population is unemployed and 26% live in poverty. Myanmar's economy is one of the least developed in the world. In the past, GDP growth has been relatively slow averaging ~2.9% annually. A change of government in 2011, however, induced a number of policy reforms that increased GDP growth to 7.8% per annum. In 2011, Agriculture contributed ~43% to GDP, services ~36.6% and industry ~20.5% (CIA, 2011). Agriculture, forestry, and fisheries constitute the largest contribution to the economy. Approximately 75% of the rural population rely on the agriculture, livestock and fisheries sectors for their livelihoods. Other major livelihood activities in Myanmar utilise the following major products: i) wood and wood products (amongst others through destructive mangrove exploitation for charcoal); ii) copper; iii) tin; iv) tungsten; v) iron; vi) cement; vii) construction materials; viii) pharmaceuticals; ix) fertilizer; x) natural gas; xi) garments; xii) jade; and xiii) gems (Hadden, R. L. 2008). The GDP growth will be around 6.8% (2013) being the GDP per capita $1,700 (CIA, 2013; Ministry of Transport - NAPA, 2012).

Climate change:
The Myanmar's National Adaptation Programme of Action (NAPA) to Climate Change (Ministry of Transport, 2012) includes the climate change predictions as presented in Table 1.

Table 1 Climate change predictions (Source: NAPA)

Climate change predictions for 2001-2020 include:	Climate change predictions (compared to 2001) for 2021-2050 include:	Climate change predictions (compared to 2001) for 2051-2100 include:
• an increase in temperature of ~ 0.7 ºC in the Ayeyarwady region • an increase in clear sky days in Northern and Central Myanmar exacerbating drought events • highly variable rainfall changes throughout the country with however only small increase in the Ayeyarwady region • an increase in floods and droughts resulting from variable rainfall conditions	• an increase in temperature of 1.4 ºC in the Ayeyarwady region • an increase in rainfall of approx. 250 mm in Ayeyarwady Delta • periods of heavier rains • longer dry spells	• an increase in temperature of 3.5 ºC in Ayeyarwady region • an increase of approx. 450 mm of rainfall in Ayeyarwady region • a weakened monsoon climate supported by decreased cloud coverage • an increase in drought periods across most of Myanmar

In Slangen et al. (2013) updated projections for twenty-first century regional sea-level changes are given for two sea level change scenarios (A and B) based on the IPCC-RCP climate scenarios 4.5 and 8.5 with a temperature increase of 1.2˚C–2.7˚C and 2.7˚C–5.4˚C, respectively, between 1986–2005 and 2081–2100.

In total scenario A yields a net global mean sea-level rise of 0.52±0.19 m (mean±1σ) between 1986–2005 and 2081–2100, while scenario B yields a net global mean sea level rise of 0.70±0.26 m for the same period.

According to the Asian Development Bank (ADB), "many more people" in Southeast Asia died as a result of natural disasters between 2001 and 2010 than during the previous decade, primarily due to the 2004 India Ocean tsunami and 2008's Cyclone Nargis, whose aftermath showcased the Myanmar government's inability to respond to extreme weather. Although not directly to be related to climate change, the devastating Cyclone Nargis hit Myanmar with resulting waves of more than 6 meters in May 2008, the strongest ever (U Nyan Win, 2010) killing 138,373 people and leaving about 2.4 million affected. Total damage and loss was estimated at approximately 11.7 trillion Kyats, i.e. 4.1 billion US$ (Ministry of Social Welfare, Relief and Resettlement, 2012).

Subsidence:
Most deltas are subjected to the natural geological process of long-term subsidence. Additionally, extraction of groundwater and fossil fuels may cause significant lowering of the delta surface on the short term. Other short-term processes leading to delta surface lowering at a more local scale are shallow compaction and oxidation of organic sediments, which may also result from human activities such as ground water pumping for drinking water supply of fish and shrimp ponds. However, so far, no real field observation data have been found on subsidence in the Ayeyarwady delta. Syvitski et al (2009) estimated a Relative Sea Level Rise (= Sea level rise plus compaction/ subsidence minus delta aggradation trough sedimentation) of 3.4 – 6 mm/year, and categorised herewith the Ayeyarwady Delta as a delta in peril: 'reduction in aggradation plus accelerated compaction overwhelming rates of global sea-level rise'.

***Technological developments*:**
Myanmar´s science and technology infrastructure is mainly focussing on agriculture research, due to the importance of the agriculture sector for the national development. It includes the development of agricultural products and methods as well as sustainable forestry. Many dams have been built in the mountainous areas around the Upper Delta and more upstream in the Ayeyarwady basin, mainly for irrigation purposes. It is expected that the existing irrigation systems and the polders (to protect the agricultural land from salt water intrusion) will be upgraded and extended. The annual rice production of Ayeyarwady Region of about 6 million tons accounts for 30 percent of the total production in Myanmar of about 22 million tons annually (FAO, 2001/2002). This situation is mainly due to the increase of farmland area, with a rapid 25 percent increase between 1990 and 1994.

Other research focuses are set on biotechnology, renewable energy, health, internet technology and marine science and technology.[1]

According to the World Energy Council, in 2007, Myanmar had coal resources estimated at around 2 million tons, 447.7 TCF of natural gas and 206.9 million barrels of oil. The hydropower potential of Myanmar's four main rivers is estimated at 40,000 megawatts, of which only a small portion has been harnessed. The Myanmar government is undertaking ventures to exploit these energy resources, both as a basis for accelerated overall economic development and for direct social benefit to their residents[2], (Driel and Nauta, 2013).

1 Facts on Science, Technology and Innovation. South Asia and European Union. (SEA-EU-NET) http://www.sea-eu.net/facts/sea/myanmar

2 http://www.myanmarenergyinvestmentsummit.com; http://www.worldenergy.org/documents/ser2007_final_online_version_1.pdf

Research gaps
Apart from statistical data on for instance agricultural production there is not much recent information available on the Ayeyarwady delta, mainly due to the fact that in the last 20 years not much research has been done and most of the monitoring programs have been halted. Therefore research gaps exist for all drivers of change.

The recently performed census 2013 will give new data on the population in the Delta: population number, density, composition, growth rates, etc.

It is expected (and the first signs are clearly visible) that the recent opening of the country will also create new rapid economic developments. Not much information has been found on the expected developments. To stimulate economic development and foreign investments so-called 'special economic zones' are and will be created in the neighbourhood in Yangon, however outside the Ayeyarwady Delta. The special economic zones and other business developments will likely on the urban infrastructure and the availability of fresh water.

In face of climate change developing countries are facing different weather patterns than in the past. They cannot rely on 200 years of past data to prepare for the following years. Bringing a new kind of uncertainty: dry areas get much drier, wetter areas get much wetter, and there is greater unpredictability of rainfall. More knowledge has to be developed on how e.g. hydrological systems will change. New infrastructure needs to be planned accordingly. Apart from the NAPA (Ministry of Transport, 2012) study not much research has been done on the extent and impacts of climate change.

Moreover, investments in research and development are needed in the agricultural sector, being the most important contributors to the GDP (World Bank, 2005). During three Delta Alliance workshops held in respectively Pathein, Hinthada and Yangon in June 2014 the key issue 'knowledge development and innovation' scored among the participants second highest (after flooding) out of 8 key issues for the delta.

1.1.1. Socio-economics (population growth - migration, economic development + most relevant sectorial developments, e.g. for agriculture, fisheries, industry)

Population
It is estimated that Myanmar has a population of approximately 62 million people with an annual growth rate of 1.52% a year. Myanmar has a low fertility rate of e.g. 2.23 in 2011. The recent census 2013 will soon provide new information on total population and population density and composition.

The Myanmar government identifies eight major national ethnic races, which comprise 135 distinct ethnic groups, the biggest are the Bamar (68%), Shan (9%), Kayin (7%), Rakhine (4%), Mon (2%), Kayah, and Kachin, and ethnic race with the remnants minorities.

The population density in Ayeyarwady Region (which does not include Yangon city) is approximately 230 inhabitants/km^{2,} which is three times higher than the country average, but relatively low compared to some other delta´s in the region such as the Mekong Delta (approx. 500 inhabitants/km^2, excluding Ho Chi Minh City) and the Ganges-Brahmaputra-Meghna Delta (more than 1200 inhabitants/km^2), (Driel and Nauta, 2013).

Economic development
The country is one of the poorest nations in Southeast Asia, suffering from decades of stagnation and isolation. The lack of an educated workforce skilled in modern technology contributes to the growing problems of the economy over the last decades. The country lacks adequate infrastructure. Goods travel primarily across the Thai border and along the Ayeyarwady River. Railways are old and rudimentary, with few repairs since their construction in the late 19th century. Some are completely out of order. Rural

roads are normally unpaved, except the highways and primary roads between the major cities. Energy shortages are common throughout the country including in Yangon and approximately only 25 percent of the country's population is connected to the electricity network (UNDP, 2007; CIA World Fact Book, 2009).

Prior to the devastation by Cyclone Nargis in 2008, the economy had reportedly been growing at up to 10% annually. The economy is predominantly agricultural, although employment data are unavailable; it appears that the agriculture sector still accounts for about 70% of total employment. In 2010 the agriculture sector accounted for about 36% of GDP, down from 57% in 2001. In contrast, the share of GDP accounted for by the industry sector has more than doubled, to 26%. Liberalization of the economy and opening up to foreign direct investment (FDI) has prompted rapid growth of the industry sector, notably by among others the export of natural gas. (Asian Development Bank, 2013).

A number of developments contributed to raising Myanmar's international profile as an investment destination, including the award of telecommunications licenses to Norway's Telenor and Qatar's Ooredoo, hosting of the World Economic Forum on East Asia and of the Southeast Asia Games, and selection of investors from the Republic of Korea, Singapore, and Japan as preferred bidders for developing airports (Asian Development Bank, 2014).

The government has initiated a broad array of reforms: unifying the exchange rate, improving monetary policy, increasing tax collection, reorienting public expenditure towards social and physical infrastructure, improving the business and investment climate, developing the financial sector, and liberalizing agriculture and trade. A new central bank law grants the central bank greater operational autonomy. The government has also prepared a strategy for sequenced and comprehensive public financial management reforms (Asian Development Bank, 2014).

In a first ever-countrywide study the Myanmar government found that 37 percent of the nation's population are unemployed and an average of 26 percent live in poverty. In January 2013 Myanmar has announced deals with international lenders to cancel or refinance nearly US$ 6 billion of its debt, almost 60 percent of what it owes to foreign lenders. For instance, Japan wrote off US$ 3 billion, nations in the group of Paris Club wrote off US$ 2.2 billion and Norway wrote off US$ 534 million.

Agriculture

Agriculture is traditionally a very important driver for the Myanmar economy. Although the Ayeyarwady Region occupies only 5 percent of all national land in the Union, it is known as the rice bowl of the country as it produces most of the rice requirements of the country. The annual rice production of Ayeyarwady Region of about 6 million tons accounts for 30 percent of the total production in Myanmar of about 22 million tons annually (FAO, 2001/2002). This situation is mainly due to the increase of farmland area, with a rapid 25 percent increase between 1990 and 1994.

Table 2 Land use in the Ayeyarwady Region 2012 – 2013 (Irrigation Department Bago, 2013)

Type	Area in ha	%
Cultivatable Land	1,818,467	51.91
Forest and Reserved Forest	720,088	20.55
Cultivable Waste Land	149,168	4.26
Virgin Land	23,020	0.66
Other Area	792,447	22.62
Total	**3,503,190**	**100**

The increase of the rice production in the Ayeyarwady Delta got an important boost in the period 1976 – 1988 with the implementation of the Paddy Land Development Projects 1 and 2 (funded by the World Bank). The projects consisted mainly of the construction of polders in the lower delta provided with embankments, sluice gates and drainage systems, hence protecting the land from salt-water intrusion.

Rice accounts for 97 percent of total food grain production by weight. Through collaboration with the International Rice Research Institute (IRRI), 52 modern rice varieties were released in the country between 1966 and 1997, helping to increase national rice production to 14 million tons in 1987 and to 19 million tons in 1996.

In addition to rice farming, aquaculture, poultry and pig farms are being operated. Moreover, some areas (like Labutta Township) are famous for salt production. Some vegetables are grown for home consumption and the surplus as other source of income. Rice is followed by black gram as winter crops.

Cash crop production like vegetables is an important income source mainly for landless farmer. For instance, some farmers in Labutta North Polder cultivate cauliflower, cucumber, water melon, pumpkin, leaf on small-scale farmland. According to the farmers, profit of vegetable production is higher than paddy production. There exists a distinct difference in cropping patterns between the Lower, Middle and Upper Delta mainly related to the availability of fresh water during the various seasons. In fact, due to the ever saline water in the rivers in the Lower Delta only rainfed rice paddy during the monsoon season can been grown with locally some possibilities for a second crop (e.g. beans) on residual water in soil and drainage canals. In the Upper Delta, however, two or three crops can be grown, due to the fact that fresh water is available all year round.

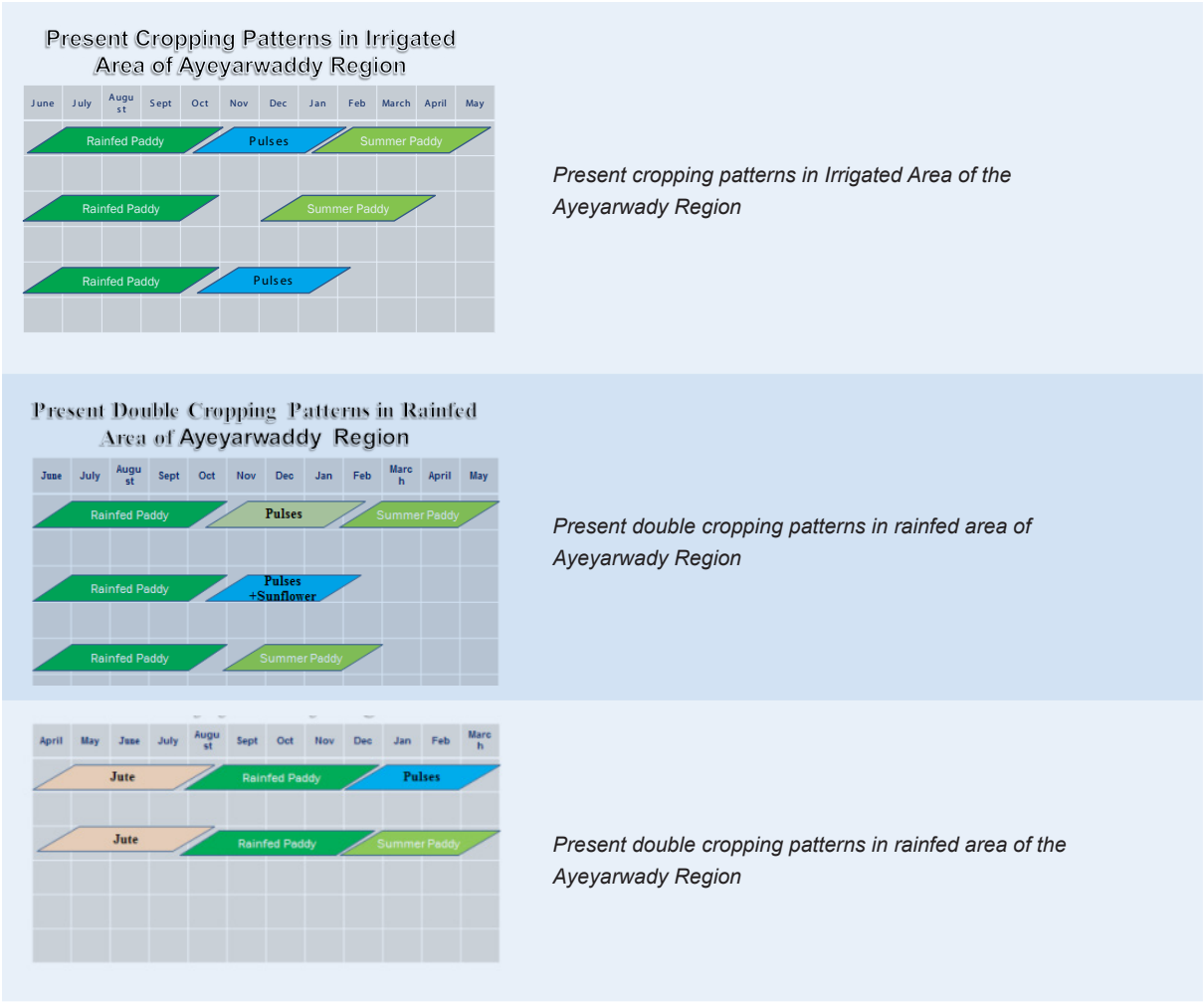


Figure 1. Cropping patterns of Ayeyarwady Region. Ministry of Agriculture and Irrigation (2013).[3]

3 Pulses- sometimes called a “grain legume”. (Wikipedia)

Table 3. Crop area in 2011-2012 for Ayeyarwady Region. Source: Ministry of Agriculture and Irrigation (2012)

Name of Crops	2011-2012 (hectare)	
Paddy	1,933,654	
Monsoon		1,473,564
Summer		460,090
Corn	6,280	6280
Oil Seed Crops	96,672	
Ground nut		46,545
Sesame		10,900
Sunflower		39,227
Pulses	547,127	
Black gram		455,295
Green gram		89,910
Pigeon pea		1,922
Cotton	126	126
Sugar cane	117	117
Total	**2,583,976**	**2,583,976**

Livestock is an important asset and work force for farmers. Most of farmers own water buffalo, pig and/or poultry. It is reported that many villages in the Ayeyarwady Region have inadequate work force due to the loss of huge numbers of water buffalos caused by Cyclone Nargis. (PONJA, 2008).

Fisheries

Fisheries are the second main livelihood option in the Ayeyarwady Delta. The fishery sector is divided into sub sectors: inland fisheries (leasable fisheries, open fisheries and reserved fisheries), marine fisheries (inshore and offshore) and aquaculture production (fish, shrimp). (MYFish, 2012).

Concerning fishery (MYFish, 2012) the Ayeyarwady Delta is characterised by:

- Important systems for food production and people;
- Very diverse aquatic agricultural systems;
- Diverse range of captures fisheries systems;
- Large-scale aquaculture operations while small-scale aquaculture is not so well developed;
- Diverse and complex value chains for fisheries products;
- Many fishing and farming households with poverty widespread;
- The impact of Cyclone Nargis, which is still felt in many communities
- Changes to the fishery law impacting on the management of leasable and tender fisheries.

These fishery practices take place in three main ecological zones in the delta which are related to distance to the sea and salinity level (MYFish, 2012):

- A floodplain zone characterized by freshwater or a very low salinity maximum, the presence of freshwater fish species, large scale fencing for fishing and an unknown percentage of migratory species;
- An estuarine zone characterized by multiple waterways, temporary brackish water, typically estuarine species, degraded mangroves along waterways and a patchwork of rice fields, trees and villages, and
- A coastal front characterized by a very flat land, quasi-permanent brackish water, salty soils, almost no vegetation and fishing activities targeting the coastal and marine zones.

Figure 2. Ecological zones (MYFish, 2012)

The fisheries sector offers several opportunities in the Delta area such as: fish catching, fish paste production, dry fish production, fish paste milling, prawn and shrimps catching, dry shrimps production, dry shrimp powder production, crab catching, small and medium crab farms, inland small and medium fish shrimp ponds and commercial scale aquaculture.

Poor fishery households of the Ayeyarwady Delta are struggling to meet their daily food and essential household needs. Chronic food insecurity is occurring in poorer fishery households, according to the "Report on Socio-economy Analysis of the Delta Fishery Villages and Small Scale Fishery Livelihood" (MMRD Research Services, 2014), only 48% of the poor households were able to meet their food needs on a daily basis.

Mangrove forests

The natural vegetation of the lower, tidal delta is mangrove forest (today 46 percent of the total area of mangroves in Myanmar are found in the Ayeyarwady Delta), but this has been heavily exploited and are largely in a degraded state due to human activities such as wood harvesting (mainly for the production of charcoal) and coastal development (paddy fields and shrimp ponds). Most of the remaining forest is in various stages of regrowth.

Four types of forest are recognized (Salter, 1982):

- Low mangrove forest, colonizing soft mud submerged at every tide; characterized by species of Ceriops, Avicennia, Kandelia and Bruguiera.
- Tree mangrove forest, developing on mud banks inland of low mangrove forest and at the edges of tidal streams; dominated by species of Rhizophoraceae.

- Saltwater Heritiera forest, on the landward side of the above two types, but still flooded at every tide; dominated by Heritiera tomes.
- Freshwater Heritiera forest, a closed evergreen high forest, flooded at high tide by only moderately brackish water; comprised mainly of Bruguiera and Heritiera.

Mangroves in Myanmar appear to be classified as primary or secondary areas (FAO, 2003; Wildlife Conservation Society, 2013). Primary areas are protected under jurisdiction of the Ministry of Environmental Conservation and Forestry, are not available for aquaculture and are essentially forest reserve. Significant jurisdiction of the secondary areas seems to be devolved to the Department of Fisheries for availability to conversion to aquaculture. The delineation of primary and secondary areas does not appear to be very clear and even primary forests are exploited by the local communities.

Industry

Resource based Micro and Small Enterprises (MSE) such as rice trading, small rice mills, agri-produces trading, fish paste processing, dry fish processing, fish trading, forestry products producing, salt production, river transport services and trading are commonly found in the Delta. Furthermore, many skilled based MSE (tailoring, carpentry, smiths' works, small repair, etc.) and food and household supply based MSE can be found (MMRD Research Services, 2014). The larger industrial businesses are almost all based in around Yangon. Some industrial activities start to develop in delta towns like Pathein (garment factory) and Hinthada

1.1.2. Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The predicted rainfall and temperature (Ministry of Transport, NAPA, 2013) trends are given in figure 3.

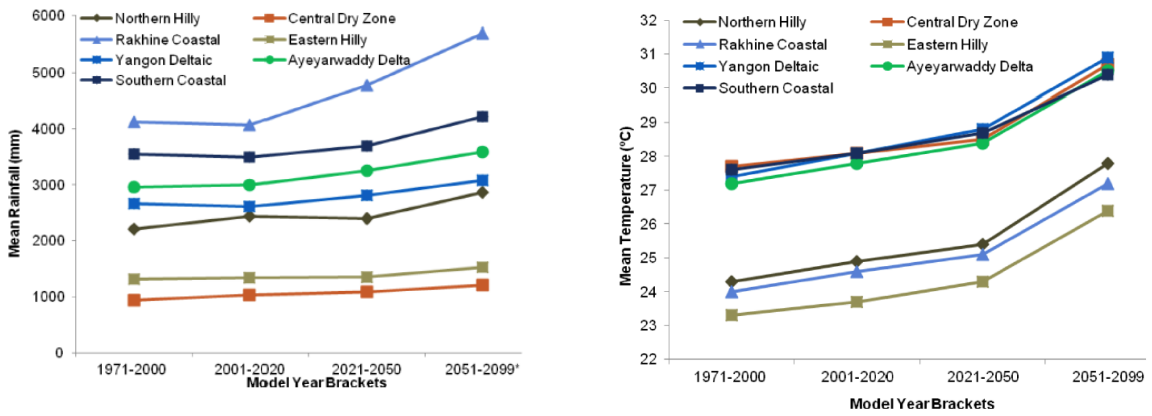


Figure 3. Predicted rainfall and temperature trends for the seven physiographic regions in Myanmar (PRECIS model)

The NAPA indicates also that the Ayeyarwady Region is the most vulnerable region of Myanmar (see figure 4) If population density is taken into consideration then only the Yangon Region (which is also partly located in the delta) is more vulnerable than the Ayeyarwady Region.

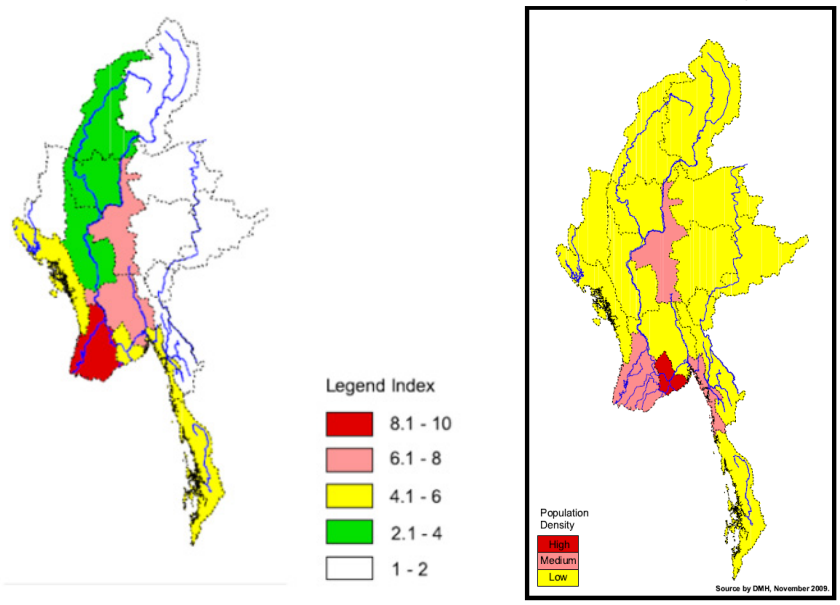


Figure 4 (right) Myanmar's overall climate change vulnerability index (taking into account areas and socio-economic sectors most at risk); and (left) climate change vulnerability index for Myanmar considering population density.

According to the NAPA (Ministry of Transport, 2012) Myanmar is very vulnerable to climate change as a result of the following compounding factors (Lian, K. K. and Bhullar, L., 2010):

- employment and the national income is dependent on climate-sensitive sectors such as agriculture, forestry and natural resources;
- human populations and economic activities are concentrated in the coastal zone as well as in low-lying lands and are therefore exposed to long-term climatic impacts such as sea-level rise as well as an increase in cyclones and storm surge/flooding;
- exposure to both geological and meteorological hazards (e.g. earthquakes, floods, cyclones and tsunamis) as a result of the country's southwest location within the Bay of Bengal
- high poverty levels which affect the capacity of the country to respond to climate change related impacts; and
- limited technological capacity to prepare for the impacts of climate change or the consequences of climate change related events.

Myanmar also comes in second place for the dangers in sea level rise. According to Wheeler dataset (Wheeler, 1974), 4.5 million Myanmar inhabit areas designated at risk from storm surges with very poor coping ability. Regarding the extreme weather, Myanmar ranks fifth on Wheeler's index (Wheeler, 1974).

In Slangen et al. (2013) updated projections for twenty-first century regional sea-level changes are given for two sea level change scenarios (A and B) based on the IPCC-RCP climate scenarios 4.5 and 8.5 with a temperature increase of 1.2˚C–2.7˚C and 2.7˚C–5.4˚C, respectively, between 1986–2005 and 2081–2100.

In total scenario A yields a net global mean sea-level rise of 0.52±0.19 m (mean±1σ) between 1986–2005 and 2081–2100, while scenario B yields a net global mean sea level rise of 0.70±0.26 m for the same period.

A value of 95 cm sea level rise (mean+1σ, rounded to 5 cm) of scenario B projections is proposed as the high scenario for impact and adaptation assessment of coastal areas for the year 2100 relative to 2005. It is not an upper-end scenario; higher values are possible, but have low probability. A value of 35 cm (mean-1σ, rounded to 5 cm) of scenario A projections is proposed as the low scenario for the year 2100 relative to 2005. A central value of the range between the high and low scenario is 65 cm.

For intermediate time periods no regional sea level change projections are available, so interpolated curves of sea level change between present and 2100 should be derived. A rough estimate is derived by using shape of the projected temperature curves (mean of all models), since most processes are temperature dependent. The sea level change scenarios are relative to the year 2005. For all relevant basins the same scenarios are taken. The final results of the projections are too little distinctive to justify different scenario levels (Table 1).

Table 4. Overview of current and projected sea level rise for several scenarios

Aggregated basin	2005	2010	2020	2050	2100
	Current Sea Level Rise	Sea Level change scenarios	Sea Level change scenarios	Sea Level change scenarios	Sea Level change scenarios
Andaman region	3.0 mm/year	high: 4 cm central: 4 cm low: 4 cm	high: 12 cm central: 12 cm low: 12 cm	high: 38 cm central: 31 cm low: 24 cm	high: 95 cm central: 65 cm low: 35 cm

According to the Asian Development Bank (ADB), “many more people” in Southeast Asia died as a result of natural disasters between 2001 and 2010 than during the previous decade, primarily due to the 2004 India Ocean tsunami and 2008’s Cyclone Nargis, whose aftermath showcased the Myanmar government’s inability to respond to extreme weather. Although not directly to be related to climate change, the devastating Cyclone Nargis hit Myanmar with resulting waves of more than 6 meters in May 2008, the strongest ever (U Nyan Win, 2010) killing 138,373 people and leaving about 2.4 million affected. Total damage and loss was estimated at approximately 11.7 trillion Kyats, i.e. 4.1 billion US$ (Ministry of Social Welfare, Relief and Resettlement, 2012).

1.1.3. Subsidence (natural or human-induced)

Most deltas are subjected to the natural geological process of long-term subsidence. Additionally, extraction of groundwater and fossil fuels may cause significant lowering of the delta surface on the short term. Other short-term processes leading to delta surface lowering at a more local scale are shallow compaction and oxidation of organic sediments, which may also result from human activities. So far, no data on subsidence in the Ayeyarwady Delta are available. The establishment of a structural ground water extraction and subsidence monitoring system should be considered for subsidence prone areas zones such as Yangon Region, where due to increasing urbanisation, population growth and industrial development the ground water extraction can be expected to increase due to higher fresh water scarcity.

1.1.4. Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

Civil engineering

Dams

The Ayeyarwady basin counts already many dams, mainly for irrigation purpose, some for hydropower and in some dams the functions are combined.

Within the Ayeyarwady River basin region the government of Myanmar has embarked on a strategy to shift reliance on gas to hydropower via making it the sole source of electricity by 2030, which will result in seven large hydropower developments along the waterway. According to studies by the United Nations and other sources, the hydropower potential of Myanmar is estimated to be as much as 40,000 MW. (Simmance, 2013)

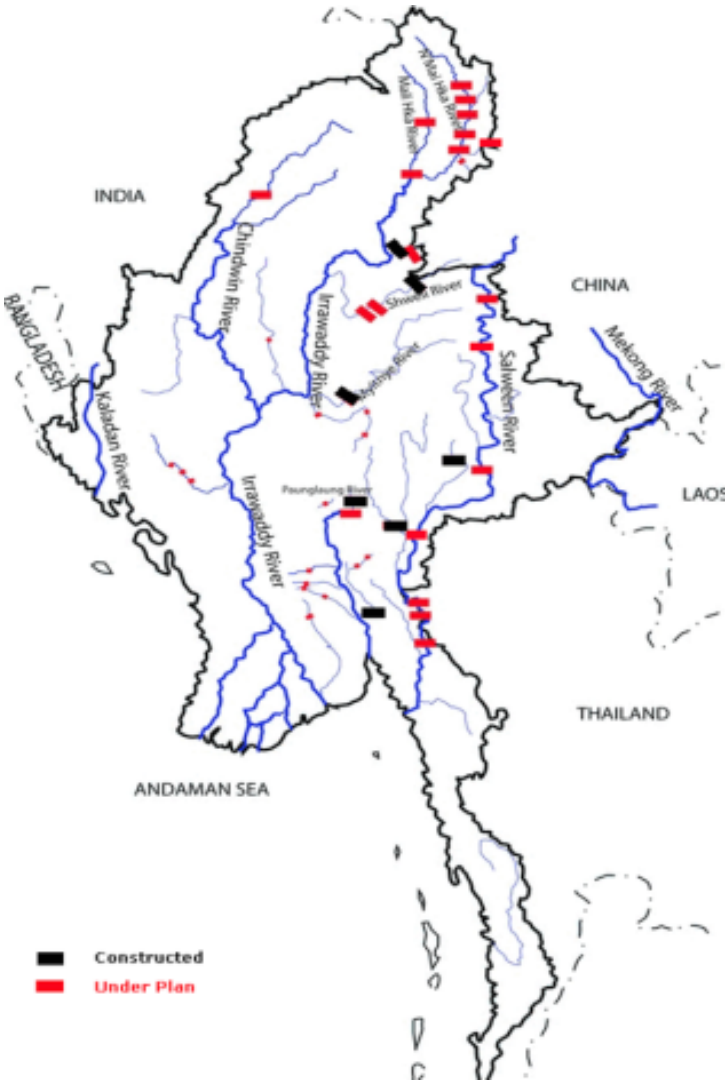


Figure 5 Myanmar Rivers Network, Dams in Myanmar, "Save Myanmar's Rivers", 2010
Source http://www.burmariversnetwork.org/resources/publications/13/499.html

Agricultural developments

Myanmar's agricultural sector has gone through various changes in the last century. During the colonial time (1824 / 1948) the country was open to international trade and free market economy prevailed. During this time a major expansion of rice cultivation took place, and Myanmar became the world's largest exporter of rice (UNDP, 2002 a). According to the 'Strategic Plan on Integrated Water Resources Management in Myanmar' (MoAI, 2006) agriculture is the most important sector in the country's economy because it:

- is the main source of livelihood for about 70 per cent of the population, who live in the rural areas;
- accounts for about 64 per cent of the labour force.
- contributes about 41 per cent to export earnings.

In 2011 it contributes for about 42 per cent to the Gross Domestic Product (GDP).
The cultivated areas are concentrated in the Ayeyarwady River basin, while potential for further expansion lies mainly in upper Myanmar, namely in the Chin, Kachin and Shan states (FAO, 2011). About 60 percent of the delta region, including the Ayeyarwady, Bago and Yangon regions of Lower Myanmar, is cultivated with rain fed paddy. The Sittaung River and its distributaries of the Bago River and others rivulets mainly contribute water to the agriculture sector, especially for paddy irrigation (Naing, 2005).

After decades of producing no surplus because of a low fixed minimum price for paddy to make profit by exporting it, the new objective of the government was to produce surplus paddy production for both domestic food security and promotion of export; also to achieve self-sufficiency in edible oils; and to expand production of beans, pulses and industrial crops for exports (ID, 2007).

In order to achieve these objectives, the government has developed policies like allowing freedom of choice in agricultural production (except for irrigated land); to expand agricultural land; and to encourage the participation of private sector (UNDP, 2008). The strategies include: the development of new agricultural land, provision of sufficient irrigation water, provision and support for agricultural mechanization, application of modern agricultural technologies and development and utilization of modern varieties (ID, 2007). Between 1988 and 2003, the irrigated land increased from around 8% of the country to 16% (WRI, 2009).

Irrigation facilities have been increased since 1988 to reach a number of 193 dams in 2006 / 2007, river pumping stations, tube wells and tapping stations (Le Huu Ti, Thierry Facon, 2004). The Government implemented 129 irrigation projects between 1988 and 2002 (Ministry of Transport, NAPA, 2012). Dams are now irrigating more than 1 million ha of farmland. In addition to the dams, river water pumping stations, underground water tapping stations and small dams has been built throughout the nation. A total of 265 river pumping projects are irrigating about 150,000 ha of cultivated land. In addition, 7,478 tube wells have been provided to irrigate 36,000 ha of farmland (MoAI, 2006).

Energy

Myanmar's per capita electricity consumption is the lowest among the ASEAN-10 countries, estimated at 100-kilowatt hours (KWh) in 2010 (approximately one-twentieth of that in Thailand). The average annual GDP growth between years 2000-2005 was 5.5% in Bangladesh, 9.4% in China, 6.5% in India, 9.15% in Myanmar and 5.0% in Thailand (WRI 2009), explaining the rapid increase in energy demand in Myanmar and its neighbouring countries (Kattelus, 2009).

Data is sparse, but even the most optimistic estimate say that less than 25 percent of the country has access to electric power (Somani, 2013). Electricity consumption in Myanmar has doubled from 3,303 giga watt hours (GWh) in 2000, to 6,093 GWh in 2012 (USEIA, 2013).

Apart from the agricultural sector, the hydropower subsector is the second most important sector in terms of economic development and investment. Dry-season irrigation, especially from river pumping projects, has been successfully increased; as a result, power demand is also increasing annually. Three-quarters of the total supply energy is hydropower. It is not surprising therefore that the country has to 'ration' its power supply to industries during the summer, with scheduled and unscheduled power cuts. (Somani, 2013).

According to a report of the Department of Hydropower Planning (DHP), 2006 the hydropower potential of Myanmar is estimated to be as much as 40,000 MW. In 2002, 35 hydropower stations (including 15 medium-scale projects) had been completed with a total 100-estimated generated power of 390 MW, which is almost 1 per cent of potential generated power in Myanmar. The current status according to (Somani, 2013) is the installed capacity 3500 MW of which 60% is reliably available.

1.2. Pressures – potential problems / Challenges – opportunities

1.2.1. Land and water use (occupation layer)

Summary of pressures

The delta is one of the most densely populated regions in Myanmar. Ayeyarwady Region, covering a large part of the Ayeyarwady Delta has a population of approximately 8 million on an area of 35,032 km^2, hence a population density of 230 inhabitants/km^2, which is three to four times as high as the country's average.

Vulnerability to flooding and erosion:
Most of the delta is still active with unstable river branches and the delta is prone to tropical cyclones with high storm surges. Many people are yearly affected by bank and coastal erosion and also floods are a permanent threat. Floods can be of different nature: floods from the rivers (mainly in the Upper Delta), floods caused by storm surges (mainly in the Lower Delta) and flash floods from the surrounding hilly and mountainous regions.

Agriculture under pressure by climate change, flooding and salinity intrusion:
Agricultural production is facing challenges due to increasing risks of flooding and salinity intrusion.

Overfishing:
The fishery in the Ayeyarwady Delta encounters the pressure of overexploitation, which has been impacting already the livelihood of rural poor. (MYFish, 2013).

Shift in land use upstream:
The effects of the dams are producing a reduction of the sediment supply and therefore erosion of the delta.

Water demand / freshwater shortage:
Due to upstream developments, climate change and sea level rise, critical low flow conditions of the Ayeyarwady River tributaries are likely to increase. Increase of salinity intrusion in the coastal areas is making existing water supply sources (domestic and agricultural) and freshwater ecosystem vulnerable.

Need for more livelihood opportunities:
For a sustainable development of the (rural) Ayeyarwady Delta there is an urgent need for improvement of the livelihood opportunities for the local population. The majority of the people in the Delta is landless and are therefore placed in a non-voluntary dependent position. Lack of or limited access to credit hampers also the economic development of the rural population. Multi-sectorial development is needed to increase the livelihood of the rural population (MMRD Research Services, 2014).

Impact of climate change on public health (directly derived from the NAPA)
Effects of increasing temperatures and erratic precipitation patterns are the spread of infectious diseases, heat stress, heat exhaustion and dehydration. The greatest concern at present is however related to freshwater resources (Lian and Bhullar, 2010).

Research/knowledge gaps
During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:

- Data on population: density, growth rate, current unemployment, projections and current situation.
- Migration both into the delta and out of the delta, due to loss of livelihoods, needs to be considered.
- More insight needed in fishing rights, not aquaculture alone, but captures fisheries in river, estuary and those on delta dependent on marine fisheries as well.
- Inventory of existing (development) plans needed.
- There is need of socio-economic and livelihood profiling of the population to understand the actual vulnerability

Pressure in available space
Population of the country was estimated at 58.38 million during the census of 2008-2009. Taking into account a growth rate of 1.52 percent the actual population will be approximately 62 million. Ayeyarwady Region, covering a large part of the Ayeyarwady Delta has a population of 8,041,084 on an area of 35,032 km^2, hence a population density of 230 inhabitants/km^2, which is three to four times as high as the country's average. However compared to other deltas in the region the population density is relative low: Mekong delta (excluding Ho Chi Minh City) counts approx. 500 inhabitants/km^2 and the Ganges-Brahmaputra-Meghna delta more than 1200 inhabitants/km^2.

Vulnerability to flooding and erosion*:*
Most of the delta is still active with unstable river branches and the delta is prone to tropical cyclones with high storm surges. Many people are yearly affected by bank and coastal erosion and also floods are a permanent threat. There is no regulation on spatial planning nor law enforcement to avoid that people are living in areas that are prone to flooding and erosion. Floods can be of different nature: floods from the rivers (mainly in the Upper Delta), floods caused by storm surges (mainly in the Lower Delta) and flash floods from the surrounding hilly and mountainous regions. The risks of flooding: floods are expected to increase due to the probability of more extreme events, sea level rise and increasing rainfall quantities and intensities.

Agriculture under pressure by climate change, flooding and salinity intrusion *(partly derived from the NAPA)*
Agriculture in Myanmar is extremely vulnerable to climate change. The predicted rise in temperature in Myanmar is expected to have major negative impacts on agricultural production and food security (Wassmann et al., 2009). Higher temperatures will reduce yields of desirable crops (e.g. rice, wheat, maize, soybean and groundnut) and encourage weed and pest proliferation. Changes in precipitation patterns will increase the likelihood of short-term crop failures as well as long-term production declines. According to the IPCC 4th Assessment Report, climate change is expected to affect agriculture in South East Asia in several ways: i) irrigation systems will be affected by changes in rainfall and runoff, and subsequently, water quality and supply; ii) temperature increases of ~2ºC -4ºC will threaten agricultural productivity, stressing crops and reducing yields; iii) changes in temperature, moisture and carbon dioxide concentrations will negatively affect major cereal (e.g. rice, wheat, maize and millet) and tree crops; and iv) increases in rice and wheat production associated with CO_2 fertilization will be offset by reductions in yields resulting from temperature and/or moisture changes. In particular, the increases in occurrence of droughts will result in crop failure in rain-fed agricultural areas and will increase the demand for irrigation. Conversely, increases in the occurrence of intense rains and resulting extreme floods will result in higher yield losses from crop damage (Swe, K. L.,?). A rise of 1 ºC -2ºC combined with lower solar radiation has the potential to cause rice spikelet sterility (i.e. infertile rice seeds). Rice becomes sterile if exposed to temperatures above 35ºC for more than one hour during flowering and consequently produces no grain. This will limit rice production (Karim, 1994). Furthermore, higher temperatures will increase the incidence of crop diseases, insect pests and rodents (Karim, 1996; Singleton et al, 2010).

The highly productive deltaic and low-lying coastal rice/local crop cultivation areas in Myanmar will not only be exposed to increased temperatures, erratic rainfall, droughts, floods and intense rains, but will also be exposed to increased salinity, coastal erosion, and inundation as a result of sea-level rise (World Vision, 2008). The extensive, low-lying Ayeyarwady/Yangon Deltaic regions are particularly vulnerable to sea-level rise. By 2100, global sea level could rise by >0.2 m-0.6 m. A 0.5 m sea level rise would result in the shoreline along the Ayeyarwady Delta advancing by 10 km. This would have a significant impact on local communities and the agricultural sector.

Conversely, increases in drought events will increase utilisation pressures on ground water for expanding irrigated agriculture. Rising sea levels will lead to salt-water intrusion into groundwater supplies particularly as existing water levels decrease. Ground water supplies will be particularly vulnerable to saline intrusion during the dry season as a result of low water volumes in river systems.

Increasing risks of flooding and salinity intrusion will put a stress on agricultural production. The risk of increasing salinity intrusion is largest in the Middle Delta: the area for and time period during which

fresh water is available will likely decrease.More extreme floods with saline water (mainly in Lower Delta) have direct impact on agricultural production. Inflow of saline water into paddy fields by Nargis decreased agricultural production instantly. According to farmers in Labutta North Polder, cropping yield of paddy of immediate crop after Nargis attack was decreased to 10-20 baskets/acre equivalent to minus 50-75 percent from 40-50 baskets of cropping yield before Nargis (local variety), (JICA, 2011).

Increased river and flash floods (mainly in the Middle and Upper Delta) will damage the crops and therefor the income of the farmers. During an increase of the discharges and water levels in the water level, in combination with the increase in development of the area along the rivers and coastal areas, the probability of flooding increases if no proper flood control and protection measures in place. With the help of retention reservoirs in the hilly region and constructions like weirs and good embankments (dikes) can prevent the high discharges from cause damage and possible loss of life in the vulnerable areas (Hassman, 2013).

Agricultural impacts will particularly affect low-income rural populations that depend on traditional agricultural systems or on marginal lands. According to detailed modelling of crop growth under climate change using global agriculture models (Nelson, 2009), climate change will result in the following impacts for South Asian countries: i) severe declines in important crops including rice, wheat, maize, soybeans and groundnuts; and ii) large declines for irrigated crops. This will result in: i) additional price increases for important agricultural crops (rice, wheat, maize, soybeans and groundnut); ii) higher livestock feed prices which will result in higher meat prices; iii) a reduction in meat consumption; iv) a substantial fall in cereal consumption; and v) a decline in calorie availability which will increase child malnutrition by 20%.

Overfishing:
In the current situation the fishery (and aquaculture) sector in the Ayeyarwady Delta encounters the following pressures: a decline catch of natural fish, smaller individual fish sizes, uncontrolled fishing, lack of empowerment in preventing illegal fishing (using smaller mesh in fish nets, less awareness on fisheries closure season and increase using of fishing methods that may destroy natural habitat and environment) which has been impacting the livelihood of rural poor. (MYFish, 2013). The shrimp farming sector was well established in Myanmar, but now suffer from technical problems, such as diseases, low productivity and vulnerability to market demand and price fluctuations. For more sustainable production, better environmental management of the farming system is a priority. Many mangrove areas have been lost to shrimp farms, human settlements, rice farms etc. and further clearance needs to be stopped if coastal fisheries are to be maintained at high production levels. Integrated production systems should be encouraged. There is some evidence to suggest that production from extensive, integrated mangrove-shrimp-fish, shrimp-rice-salt pan systems is higher than is shrimp monoculture systems. (MYFish, 2013).

Shift in land use upstream:
The effects of the dams are producing a reduction of the sediment supply and therefore erosion of the delta.

Water demand / freshwater shortage:
Due to upstream developments, climate change and sea level rise, critical low flow conditions of the Ayeyarwady River tributaries are likely to increase. Increase of salinity intrusion in the coastal areas is making existing water supply sources (domestic and agricultural) and freshwater ecosystem vulnerable. Also the urban and industrial development in and around Yangon will put extra pressure on water availability. The local existence of arsenic contamination of the ground water often hampers the use of shallow tube wells (around 30 m depth)

Need for more livelihood opportunities:
For a sustainable development of the (rural) Ayeyarwady Delta there is an urgent need for improvement of the livelihood opportunities for the local population. The majority of the people in the Delta is landless and are therefore placed in a non-voluntary dependent position. Lack of or limited access to credit hampers also the economic development of the rural population. Multi-sectorial development is needed to increase the livelihood of the rural population (MMRD Research Services, 2014).

Impact of climate change on public health (directly derived from the NAPA)
Increasing temperatures and erratic precipitation patterns will create favourable conditions for the spread of infectious diseases. Additional effects of increasing temperatures on human health, including inter alia heat stress, heat exhaustion and dehydration. The greatest concern at present regarding climate change impacts on human health is related to freshwater resources (Lian and Bhullar, 2010). Increases in intense rain events and tropical storms will lead to increases in flooding events and storm surges. This will affect freshwater sources as they become contaminated by rising flood water levels. Furthermore, rising sea-levels will result in fresh groundwater resources being displaced with salt water.

1.2.2. Infrastructure (network layer)

Summary of pressures

Demand for more transportation facilities (roads, ports and waterways):
Road transportation is the most important way of transport in Myanmar, but until rather poorly developed. Most towns and cities are accessible only by land route. Myanmar has 5.099 km of railway, only a few towns and cities are connected by railway lines, but the condition of train services in Myanmar make it too difficult. There are currently no rail links to adjacent countries. Some towns are also reachable by rivers, but river travel is very slow compared to road transportation. Most people have to rely on road transportation to travel in Myanmar. The lack of infrastructure is hampering the economic development.

Maintenance and upgrading of agricultural engineering works
In the last four decades important infrastructure has been constructed for agricultural production: dams, diversion weirs, irrigation systems, and polders. There are plans to further increase agricultural production by the construction of new irrigation systems and the upgrading and repair of existing infrastructure.

Need for embankments against flooding
In order to prevent flooding from the river extensive flood protection embankments have been constructed along several rivers in the Ayeyarwady Delta, mainly in the Upper Delta. Similar embankments have also been constructed in areas that are prone to flash floods. Some of these embankments need maintenance.
More embankments are needed against flooding in the Middle and Upper Delta. Due to the expected more extreme weather events this need will increase the coming decades.

***Lack of water supply and sanitation*:**
Only a small percentage of the rural population is connected to a public drinking water supply system. Due to climate change and sea level rise the need for drinking water supply systems will only become more urgent, certainly in the areas that are affected by salinity intrusion and arsenic contamination. . and waste water treatment plants. Urbanisation and industrial development of Yangon (and some major cities in the Delta like Pathein and Hintada) will articulate the need for proper sanitation facilities, waste water treatment plants and water quality monitoring.

Impact of dams
The constructions of dams pose a threat to the ecological integrity and flow regime of the river basin. Dams also result in adverse impacts to the flow regime of a river with grave implications to the health of floodplains and delta ecosystems and the ecosystem services they provide to local livelihoods

Lack of and ageing infrastructure:
Infrastructure to support transportation, water supply, communications, and power supply is generally rather poorly developed. Maintenance of roads, embankments, polder sluices, drainage canals and irrigation systems is a recurrent problem. (Driel and Nauta, 2013).

Research/knowledge gaps

During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:

- Present status and future plans of the transportation sector (Ministry of Public Works).
- Current programs and plans, for drinking water supply and sanitation facilities, etc.
- Plans for township development (Min. of Border Affairs, DRD).
- Cost-efficient and innovative infrastructure
- Innovation in agricultural engineering

More demand for transportation (roads, ports and waterways):

Road transportation is the most important way of transportation in Myanmar. Most towns and cities are accessible only by land route. Myanmar has 5.099 km of railway, however only a few towns and cities are connected by railway lines. There are currently no railway links to adjacent countries. Some towns are also reachable by rivers, however most people have to rely on road transportation to travel in Myanmar. Outside the monsoon season transport over sea south of the delta is possible; during the monsoon this is too dangerous.

Myanmar has approximately 3,200 of paved roads and 24,000 km of unpaved roads (Wikipedia, 2008). There are three main highways or corridors running north-south in Myanmar. In terms of importance and traffic they are: Yangon – Mandalay (695 km), Yangon – Pyay (288 km) and Western Union Highway, Pathein – Monywa Highway, which connects towns and cities on the west of Ayeyarwady River. The road network of the Ayeyarwady Region is underdeveloped due to the existence of many rivers and creeks and the high costs involved for the construction of bridges.

Figure 6 Road map Myanmar. (http://www.mapsofworld.com)

Inadequate infrastructure as roads, bridges, canals, railways, ports and communication facilities impedes economic growth. Myanmar's long coastline is home to many excellent natural harbors such as Pathein, Bhamo, Mandalay, Yangon, and Dawe. The government has taken steps to develop new ports and maintain the existing ones, although all the ports are not used to their maximum capacity. A salient geographic feature of Myanmar is its many rivers, especially the Ayeyarwady. The country's waterways remain the most important traditional mode of transportation to many remote areas of the country. Of more than 12,800 kilometers (7,954 miles) of waterways, 3,200 kilometers (1,988 miles) are navigable by large commercial vessels (World Bank, 2000). However, in many of these waterways sedimentation problems occur.

Since the economic liberalization in 1989, the government started many public works programs. Early in the 1990s the government used forced rural labor to work on these projects. These projects did not bring about major improvement in the infrastructure needs of the country. The result has been that economic expansion was made difficult because in the absence of adequate transportation facilities, distribution of goods and services has been extremely difficult and costly.

Maintenance and upgrading of agricultural engineering works

Paddy Land Development Projects 1 and 2

The monsoon paddy cultivation in the lower delta is only possible if the land is effectively protected against intrusion of saline water through the construction of polders, mainly consisting of embankments, sluice gates and drainage systems. For that purpose the Paddy Land Development Projects 1 and 2 have been realised. Figure 7 presents the progressive salinity intrusion in the delta during the dry season.

Figure 7 Average salinity intrusions (1 ppt line) in the Ayeyarwady Delta (MYFish, 2012)

In view of the precipitation quantities supplementary irrigation is not needed during the monsoon season. There is also no need to store abundant rainwater during the rainy season. Contrary, due to the heavy rainfall intensities, the role of the drainage canal is very important. The slide gates of the sluice are kept open from 15 May to mid-September and the drainage is controlled by the flap gates of the sluice to keep the water level of the drainage canals as low as possible. The old river courses are functioning as major drainage channels and small artificial drainage canals are connected as required in the areas with embankment. Whereas in the areas surrounded by polder dikes, artificial drainage canals are predominant. (Driel and Nauta, 2013).

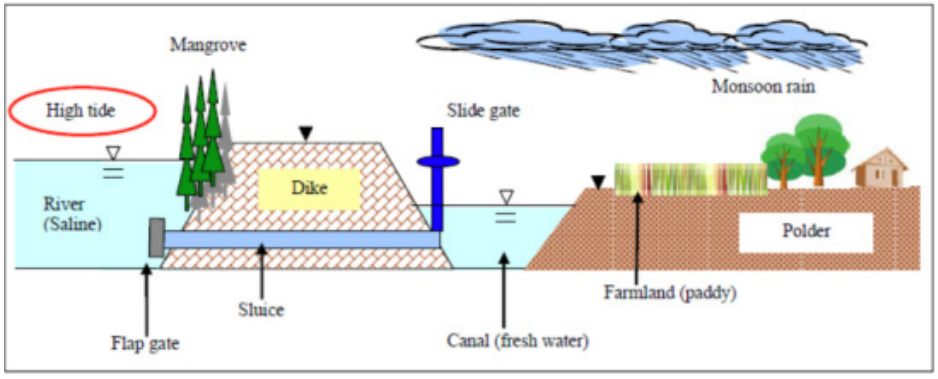


Figure 8 Functioning of a polder in the lower delta (JICA, 2011)

In the final stage of the rainy season the slide gates of the sluice located end points of the drainage canal are closed to store the fresh rainwater in the drainage canals. However, the salt water intrusions are occasionally found through the degraded slide gates and also through leaking flap gates; hence the water impounded in the drainage canal is contaminated with salty water. (Driel and Nauta, 2013). Similar projects have also been realised in the Middle Delta.

Irrigation systems

In the Middle and Upper Delta several more traditional irrigation systems have been built by the Irrigation Department of the Ministry of Agriculture and Irrigation to be used during the summer season for paddy rice or other crops. The irrigation schemes are provided with water stored in reservoirs behind dams or diverted from rivers by means of the use of diversion weirs. These are government owned schemes where the land is leased to the farmers, which have to pay a fee for the use of the water (in 2014 an amount 2000 Kyat/acre) and to obey to the government established cropping schedule. In addition to these (generally gravity) schemes large areas of land are irrigated by individual farmers with (often small) motor pumps lifting water from rivers, creeks and drainage canals. These farmers have more freedom with regards to the crops they want to grow. Many of the irrigation systems are in need of upgrading to more modern standards and maintenance.

Need for embankments against flooding

In order to prevent flooding from the river extensive flood protection embankments have been constructed along several rivers in the Ayeyarwady Delta, mainly in the Upper Delta. Similar embankments have also been constructed in areas that are prone to flash floods (see figure 9). Some of these embankments need maintenance.

More embankments are needed against flooding in the Middle and Upper Delta. Due to the expected more extreme weather events this need will increase the coming decades.

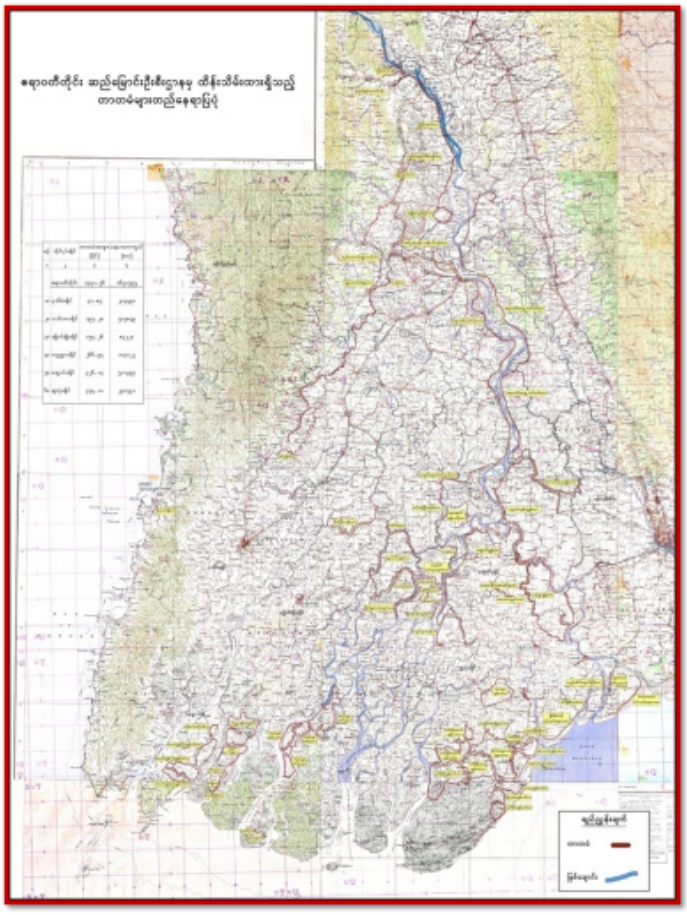


Figure 9 Embankments (red lines) in Ayeyarwady Region. (Source: Irrigation Department)

Impacts of dams
The constructions of dams pose a threat to the ecological integrity and flow regime of the river basin. Dams also result in adverse impacts to the flow regime of a river with grave implications to the health of floodplains and delta ecosystems and the ecosystem services they provide to local livelihoods. Unnatural changes in the flow regime of a river will result in: riverbank destruction due to increased erosion; altered flood cycles and disruption to the replenishment of wetlands, floodplains and delta ecosystems. This results in a decline of fisheries and aquatic plants dependent on these nutrients rich ecosystems. In addition, water quality will be reduced resulting in a decline of fish species and knock on impacts to the abundance and diversity of bird populations within the basin. Socio-economic conditions will be affected. The changed hydrological regime will reduce the productivity of agriculture, fisheries and the health of forest ecosystems such as mangroves along the Ayeyarwady Delta, which provides nearly 60% of Myanmar's rice. (Simmance, 2013). Moreover, often whole communities that live in the reach of the future reservoir have to be displaced.

It has to be mentioned however, that dams projects can also have positive effects such as the harnessing of a renewable natural resource, lower levels of air and water pollution compared with fossil fuels, increasing water flows in the dry season, lower flows in the wet season and generating electricity to increase industrial output and to raise standards of living. The latter is very important in the case of Myanmar due to the fact that energy shortages are common throughout the country including in Yangon; only 25 percent of the country´s population has electricity. Conditions for sound implementation of new dams imply availability and application of hydrological data and models and extensive (Strategic) Environmental Impact Assessments.

Other positive impacts to be considered are once reservoirs become established they can become important sites for birdlife. Some dam projects have implemented specific habitat restoration measures that can to some extent compensate for their negative impacts.

Need for drinking water supply and sanitation infrastructure
In view of the in section 1.2.1. (Occupation layer) observed increasing vulnerability of the fresh water supply (caused by climate change, sea level rise, arsenic contamination) investments are needed in appropriate drinking water supply infrastructure. Also the urban and industrial development in and around Yangon will put extra pressure on water availability. Urbanisation and industrial development of Yangon (and some major cities in the Delta like Pathein and Hintada) will articulate the need for proper sanitation facilities, waste water treatment plants and water quality monitoring.

Lack of and ageing infrastructure
Industrial production and expansion are limited due to inadequate production and intermittent supply of electric power. Chronic shortages and frequent disruptions of supply exist. Therefore, state and private enterprises operate far below their capacity. Moreover, very often they have to depend on their own diesel-run power generators to meet their electrical needs.

Poor infrastructures such as lack of proper roads, electricity, limited telephone networks and dependency on the river transport with slower locally assemble boats, limits the Delta MSE (Micro and small enterprises) to have easy access to market. Poor access to roads, no electricity, poor access to school, poor access to health care, etc. are also fuelling the prolonged poverty of the fishery (and other rural) households (MMRD Research Services, 2014).

During the Delta Alliance workshops and field trips in July 2013 and June 2014 it has become clear that a large part of the infrastructure is ageing and needs maintenance. This concerns the maintenance of many of the roads in the delta as well as the maintenance of the water management infrastructure: degraded embankments, sediment aggradation in drainage canals, degraded irrigation systems, need for dredging of blocked waterways for navigation, leaking sluices and flap gates, etc.

1.2.3. Natural resources (base layer)

Summary of pressures

Impact of climate on water resources
Climate change-induced changes to hydrological cycles will deteriorate water quality, quantity, and accessibility. Several sections of the hydrological cycle are vulnerable to climate change: flooding, contamination of water resources, erosion and limited replenishment of waterways, increase of risk of flash floods as well as decrease ground water recharge. Conversely, increases in drought events will increase utilisation pressures on ground water for expanding irrigated agriculture. Rising sea-levels, however, will lead to salt-water intrusion. (NAPA, Ministry of Agriculture and Irrigation, 2012).

Coastal and riverbank erosion:
Riverbank and coastal erosion is one of the major issues**.** River bank erosion takes mainly place in the Upper Delta, where the river geomorphology is still very dynamic. Coastal erosion is mainly due to mangrove destruction and the decrease in sediment load caused by the construction of dams upstream. There is a lack of legislation, regulation and enforcement to avoid the settlement of (mainly fishermen communities on the erosion (and flooding) sensitive coasts and river banks.

River hydrology and hydrodynamics:
Given all the projected water uses (hydropower, irrigation, drinking water supply, navigation, industrial and mining abstractions) water allocation priority problems may arise and an impact on the minimum environmental flow requirements may exist. Water balances and allocation studies are necessary to address these future water resources problems.

Flooding (flood hazard):
Myanmar is prone to cyclones, mainly during the months April, May, October, November and December. The coastal region such as the Lower Ayeyarwady Delta is also prone to storm surges. During Cyclone Nargis, 90 percent of the 140.000 deaths were caused as a direct consequence of the storm surge.
The Ayeyarwady Delta is a fragile and intricate ecosystem of mangrove swamps and tidal estuaries. Non-saline arable areas are limited and becoming scarce due to the erosion of riverbanks, saltwater intrusion, and increasing soil salinity. Poor water control and drainage works contribute to periodic flooding and crop losses.
The effect of an increase in rainfall and its intensity is the increase in run-off. Deforestation contributes to these processes. Also it can damage vulnerable crop and can create flash floods from the surrounding mountain ranges in the lowland areas of the delta (Hassman, 2013)

Drinking water: quality and quantity
Water scarcity has become a daily challenge in Myanmar's Ayeyarwady Delta in the dry season, especially in the Lower Delta where the river water (and often also the groundwater) is saline. The delta's inhabitants traditionally source drinking water from rainwater harvesting.
Arsenic contamination of drinking water sources is an emerging public health issue in Myanmar. However, the magnitude of arsenic contamination of groundwater sources in Myanmar is still rather unknown.

Salinization / salt water intrusion:
Salinity and its seasonal intrusion gradients are dominant factors for coastal system, fisheries, agriculture and drinking water supply. Therefore, any changes on present spatial and temporal variation of salinity will affect the biophysical system of coastal area.

Water and soil pollution:
Agricultural inputs, such as chemical fertilizers and pesticides are increasingly being used. The utilization rate of chemical fertilizers in the delta happens to be the highest among the agricultural regions in Myanmar. This will result in an increasing state of pollution.
Water quality concerns are also being raised with regard to mining activities and the growth of cities and industrial zones. The disposal of untreated domestic wastewater and the increase in industrial and mining activities will further affect the water quality in the delta with a range of additional parameters (heavy metals, organic micro-pollutants and oils).

Mangroves and biodiversity loss:
Especially the mangrove forests are highly valuable but also under high pressure from encroachment and exploitation and are largely in a degraded state due to human activities such as wood harvesting (mainly for the production of charcoal) and coastal development (paddy fields and shrimp ponds). Most of the remaining forest is in various stages of regrowth.
Moreover, they are also vulnerable to accelerated climate change and sea level rise, as they pose major new challenges to biodiversity conservation and nature in general.
The root causes of these threats are low conservation awareness, poverty, poor livelihood conditions (lack of alternatives), weak systematic biological monitoring systems, low grassroots support for conservation and weak law enforcement. Environmental conservation in parallel with economic development opportunities is one of the greatest challenges for Myanmar in the 21st century (Wildlife Conservation Society, 2013).

Research/knowledge gaps
During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:

- Need for overview of all hazards and consequences.
- Hydrological and monitoring data
- Water balances and allocation studies are necessary to address future water resources problems.
- Information on Ayeyarwady tributary behaviour and characteristics.
- Trends, programs, leading to water quality problems. Baseline conditions.
- Knowledge on arsenic contamination of groundwater.
- Monitoring system needed for anthropogenic subsidence and groundwater exploitation
- Size of loss of wetlands.
- Potential impacts of climate change and sea level rise on mangroves and biodiversity conservation.

Impact of climate on water resources (directly derived from the NAPA)
Climate change-induced changes to hydrological cycles will deteriorate water quality, quantity, and accessibility. Several sections of the hydrological cycle are vulnerable to climate change. The rate of snow and glacial melt is expected to increase resulting in changing river flows and unpredictable flooding events. The late onset and early withdrawal of the monsoon period will result in large quantities of rain falling over short periods. This will result in flooding, contamination of water resources, erosion and limited replenishment of waterways. Furthermore, changes in river flow and discharge will increase the risk of flash floods as well as decrease ground water recharge. Vast areas of lowland regions will be regularly inundated as a result of flooding events. Conversely, increases in drought events will increase utilisation pressures on ground water for expanding irrigated agriculture. Rising sea-levels, however, will lead to salt-water intrusion into groundwater supplies particularly as existing water levels decrease. Ground water supplies will be particularly vulnerable to saline intrusion during the dry season as a result of low water volumes in river systems. Furthermore, regardless of the quantity of water available increased temperatures from climate change will increase evaporation rates, raising the concentration of dissolved salts in the water often deeming it unsuitable for drinking purposes (Ministry of Agriculture and Irrigation, 2012).

Coastal and riverbank erosion
Riverbank and coastal erosion is one of the major issues. River bank erosion takes mainly place in the Upper Delta, where the river geomorphology is still very dynamic. It causes not only every year casualties and displacement of many people, it results also in loss of agricultural land and large scale sedimentation in the river beds with serious restrictions for navigation and costly dredging activities as a result.

Coastal erosion is mainly due to mangrove destruction and the decrease in sediment load caused by the construction of dams upstream. In coastal areas large-scale destruction of coastal ecosystems (e.g. mangroves and other coastal ecosystems) has occurred as a result of increasing human populations, infrastructural developments (e.g. shrimp farming), over exploitation (timber and fire wood), and pollution that affects the water quality.
Apart from a lack of spatial planning processes and procedures, there is a lack of legislation, regulation and enforcement to avoid the settlement of (mainly fishermen communities on the erosion (and flooding) sensitive coasts and river banks.

River hydrology and hydrodynamics
The discharge in the Ayeyarwady River is at its lowest in February and March and there is a sharp rise in April-May as a result of melting snow in the upper catchment, followed by a further steep rise in May-June with the onset of the monsoon. The maximum flow occurs in July or August. Most waterways are un-engineered natural watercourses, and there is no extensive system of dredged canals, the only major canal being the Twante canal which links Yangon with the western part of the delta. The tide in the Ayeyarwady Delta is diurnal. The tidal variation shows a distinct pattern of spring and neap tides. The tidal influence enters deep into the delta, which offers opportunities for tidal irrigation. Many sectors are making increasingly use of the water resources of the Ayeyarwady River: hydropower, irrigation, drinking water supply, navigation, industrial and mining abstractions. In view of the further economic development of Myanmar in all these sectors water allocation priority problems may arise and an impact on the minimum environmental flow requirements may exist. Water balances and allocation studies are necessary to address these future water resources problems.

Flooding (flood hazard):
Myanmar is prone to cyclones, mainly during the months April, May, October, November and December. The coastal region such as the Lower Ayeyarwady Delta is also prone to storm surges. During Cyclone Nargis, 90 percent of the 140.000 deaths were caused as a direct consequence of the storm surge.
The Ayeyarwady Delta is a fragile and intricate ecosystem of mangrove swamps and tidal estuaries. Non-saline arable areas are limited and becoming scarce due to the erosion of riverbanks, saltwater intrusion, and increasing soil salinity. Poor water control and drainage works contribute to periodic flooding and crop losses.
The effect of an increase in rainfall and its intensity is the increase in run-off. Deforestation contributes to these processes. Also it can damage vulnerable crop and can create flash floods from the surrounding mountain ranges in the lowland areas of the delta (Hassman, 2013)
Myanmar has limited technology for remotely and automatically forecasting extreme weather events. This reduces the time available for local communities to take necessary actions and preparations relative to Early Warning Systems in other more developed countries. However, even in cases when technology has been effective in providing sufficient lead-time for local communities to prepare, lives have still been lost and property damaged. This is as a result of three main reasons: i) warnings do not reach communities in remote areas; ii) communities do not know how to respond; iii) communities do not understand or cannot interpret the warning received. For example during Cyclone Nargis communities in the Ayeyarwady Delta refused to respond to warnings as they did not understand/ realise the magnitude of the threat. (NAPA, Ministry of Transport, 2012)

Drinking water: quality and quantity
Drinking water scarcity has become a daily challenge in Myanmar's Ayeyarwady Delta in the dry season. The delta's inhabitants traditionally source drinking water from rainwater harvesting, communal water ponds and tube and open wells, since most villages do not have access to piped water and nearby tidal rivers are saline. The ponds help villagers during the dry season, which stretches from November to May, but can be insufficient.

The main issue related to water quality is the provision of reliable drinking water. Arsenic contamination of drinking water sources is an emerging public health issue in Myanmar. In early 2000, Save the Children UK's (SC UK) Water and Sanitation Programme identified arsenic contamination of groundwater in rural parts of the Ayeyarwady Delta (Tet Nay Tun, 2003). Since that time, there has been growing interest, concern and action related to arsenic testing, communication and mitigation in Myanmar. However, the magnitude of arsenic contamination of groundwater sources in Myanmar is still rather unknown, as no comprehensive studies have been conducted. Recommendable activities are:

- Retesting and confirmation of arsenic levels of water sources
- Arsenic education/awareness raising
- Community mobilization and immediate protection measures
- Identification and implementation of alternative drinking water sources

According to information of the DWR arsenic groundwater is found at depths of about 30 m. The solution to avoid contamination of the drinking water is to install deeper tube wells. Likewise, groundwater is widely used as a water resource in the Ayeyarwady Delta. The salinity of the groundwater is affected by the flood and high waves through cyclones or monsoons (Miyaoka et al, 2012). However, surface water – groundwater interaction differs per season and region.

Water and soil pollution

Due to various policy reforms the agricultural sector changes the way it operates and functions. As a result agricultural inputs, such as chemical fertilizers and pesticides are increasingly distributed either partially or wholly by the private sector. Moreover, the utilization rate of chemical fertilizers in the delta happens to be the highest among the agricultural regions in Myanmar. This will result in an increasing state of pollution.

Water quality concerns are also being raised with regard to mining activities and the growth of cities and industrial zones. The disposal of untreated domestic wastewater will lead to increased oxygen demand and deteriorating hygienic conditions of the surface waters and the increase in industrial and mining activities will further affect the water quality in the delta with a range of additional parameters (heavy metals, organic micro-pollutants and oils).

Mangroves and biodiversity loss

Mangroves in Myanmar appear to be classified as primary or secondary areas (FAO, 2003; Wildlife Conservation Society, 2013). Primary areas are protected under jurisdiction of the Ministry of Environmental Conservation and Forestry, are (in principle) not available for aquaculture and are essentially forest reserves. Significant jurisdiction of the secondary areas seems to be devolved to the Department of Fisheries for availability to conversion to aquaculture. The delineation of primary and secondary areas does not appear to be very clear and even primary forests are exploited by the local communities.

Myanmar is undergoing a rapid transition from one of the world's most isolated countries to an emerging democracy and opening up to the world through increased international investment. Hence, environmental conservation in parallel with economic development opportunities is one of the greatest challenges for Myanmar in the 21st century (Wildlife Conservation Society, 2013). Human encroachment, commercial overexploitation of animals and fish, agricultural expansion/conversion of wetlands and logging are seen as the greatest current threats. The lower, tidal delta mangrove forests have been heavily exploited and are largely in a degraded state due to human activities such as wood harvesting (mainly for the production of charcoal) and coastal development (paddy fields and shrimp ponds). Most of the remaining forest is in various stages of regrowth. Expected environmental and water quality deterioration will add to this soon.

The effects of climate change on biodiversity are already evident in Myanmar. For example, shifts in the range as well as migration patterns of certain species of insects, marine/terrestrial mammals, birds and fish of have been observed. Climate change is likely to affect both the distribution and composition of forests in Myanmar. In certain areas, climate-induced succession will result in forest conversion to less productive grasslands (NAPA, Ministry of Agriculture, 2012)

An increase in sea-level will provide a higher base for storm surges and other extreme climate events. However, there are yet no studies on the potential impacts of climate change and sea level rise in Myanmar (Wildlife Conservation Society, 2013). The root causes of these threats are low conservation awareness, poverty, weak systematic biological monitoring systems, low grassroots support for conservation and weak law enforcement. It is known, however, that sea level rise and increased water temperatures are projected to accelerate coastal erosion and cause degradation of the mangroves and more offshore coral reefs, which in turn will negatively influence fisheries productivity.

The development strategies of the Myanmar government are sustainable development, sustainable utilisation of recourses and forest conservation. The Forest Department has developed a 30-year Master Plan (2001/02 to 2030/31), aimed at undertaking forest conservation and restoration. By the end of the 30-year plan, the following work will have been completed:

- The formulation of land-use plans for all states and divisions of the country with three revisions.
- The establishment of 199,355 ha of watershed plantations in the whole country.
- The establishment of 295,431 ha of community forest in the whole country

1.3. Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) Levels and Sectors of Government:
Myanmar counts many ministries which are often working in quite a sectorial way. Efforts are underway to improve core governance systems. In Myanmar land and water are managed by many ministries, agencies and departments. Several departments, under their respective ministries, remain for instance responsible for the supply and management of water for agriculture, industrial, domestic and sanitation purposes. Different departments have different acts, proclamations and laws, but most of them need to be strengthened in order to overcome problems caused by the lack of regulations on land and water. There is also a lack of coordination and collaboration between the different institutions, including a lack of sharing of data and information.

Cooperation between Government and Private Sector:
Economic santions on Maynamr prevented western investments and trade for most of the last twenty years). The recent relaxation of sanctions and political change have led to both the Myanmar government and foreign investors seeking to significantly increase investment across economic sectors (Henley, 2014). Although the private sector is looking into opportunities in Myanmar with great interest, it should be noted that only 30 percent of the transactions is successful according to McKinsey (2013). This is mainly due to the lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships. The privatization of public sector industries need to be further developed

Involvement of Stakeholders and Citizens:
Stakeholder consultation at planning and implementation phase of a project in different parts of the country needs to be further encouraged.

Approaches for dealing with Risks and Uncertainties:
To reduce loss of lives and property, Myanmar needs to focus on the development of flood forecasting and warning systems. Coastal area has already been practiced the early warning system for cyclonic storm surge and got the benefit. Disaster Reduction Plans have been developed for all districts.

Research gaps
Lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships. Improved land administration by increasing dialogue on land issues with political leaders, by funding technical expertise to assist land administration functions and land governance processes. (Henley, 2014)

Myanmar is still a fragile state undergoing a period of profound economic and political reform following a period of conflict and isolation (Henley, 2014). As the poorest country in South Asia, land is the main asset for many people, especially in rural areas such as the Ayeyarwady Delta. In Myanmar land and water are managed by many ministries, agencies and departments. Several departments, under their respective ministries, remain for instance responsible for the supply and management of water for agriculture, industrial, domestic and sanitation purposes. Different departments have different acts, proclamations and laws, but most of them need to be strengthened in order to overcome problems caused by the lack of regulations on land and water. There is also a lack of coordination and collaboration between the different institutions, including a lack of sharing of data and information.
The recent political changes have profound implications for security of land tenure. Land legislation passed in 2012 is meant to strengthen the formal land administration and provide more rights for landholders, including the right to lease and sell land. At the same time the , the government's policy to open up to foreign investments for large scale agriculture, mining and industrial zones threatens to place further pressure on land (Henley, 2014).

Apart from a lack of spatial planning processes and procedures, there is a lack of legislation, regulation and enforcement to avoid the settlement of (mainly fishermen communities on the erosion (and flooding) sensitive coasts and river banks.

1.3.1. Overview of key stakeholders regarding delta management issues

Table 5 Stakeholder map of Myanmar (Deltares and Delft University of Technology, 2013).

Ministry/City/Other	Duty and function
Agriculture & Irrigation (MOAI)	Provision of irrigation water to farmlands
Agriculture & Irrigation (MOAI)	Pumped irrigation and rural water supply
Transport (MOT)	River training and navigation
Transport (MOT)	Water assessment of main rivers
Industry (1), Industry (2) (MOI)	Industrial use
Livestock, Breeding and Fisheries (MOLFRD)	Fishery activities
Yangon, Mandalay and Nay Pyi Taw	City water supply and sanitation
Ministry of Livestock and Fisheries and Rural Development (MOLFRD)	Domestic water and rural water supply, and sanitation
private entrepreneurs	Domestic water supply, navigation, irrigation and fisheries
Ministry of Environmental Conservation and Forestry (MOECAF)	Reforestation, conservation of (mangrove) forests and environment
Construction (MOC)	Domestic and industrial water supply and sanitation
Construction (MOC)	Domestic water supply
Health (MOH)	Environmental health, water quality assessment and control
Health (MOH)	Social mobilization, health, etc.
Science and technology (MOST)	Training and research
Transport (MOT)	Port development in Yangon
Planning (MONPED)	Planning of SEZ's – Thilawa
President's Office	Think tank for governance, socio-economic development and legal affairs
Electric Power (MEP)	Implement and construction hydropower project
Foreign Affairs (MOFA)	

Mining (MOM)	Geological mapping. Geological, geochemical, geophysical drilling techniques.
Sports (MOS)	Sports and Physical Education
Hotels and Tourism (MOHT)	Hotels and Tourism services
Borders Affairs (MOBA)	Progress of border areas and national races
Finance and Revenue (MOFR)	Budget
Commerce (MOCOM)	Export, import, trade promotion
Border areas and National Races, Development Affairs (MOPAN)	
Social welfare Relief and resettlement (MOSWRR)	Relief and resettlement, social welfare
Education (MOED)	Education, planning and training
Cooperatives (MOCOO)	
Culture (MOCUL)	Historical research, archaeology, library
Energy (MOE)	Energy planning, petrochemical industries, oil and gas
Immigration and population (MOIP)	Immigration and population
Communications, posts and telegraphs (MOCPT)	Telecommunications and communications
Defense (MOD)	Police force, prison, special investigation
Home Affairs (MOHA)	
Information (MOINF)	Radio, television, public relations
Labour, Employment and Social Security (MOLESS)	Labour relations
Rail transport (MORT)	Road transport, railways, transport planning
Religious Affairs (MORA)	

1.3.2. Governance structures and networks of key stakeholders

Administratively, Myanmar is divided into seven states (named after the major national group that inhabits the region) and seven regions (generally areas with Bamar majority). Apart from the national capital Nay Pyi Taw, each state and region has a designated regional capital. In a descending order of administrative hierarchy, there were 64 districts, 324 townships, and 2,471 wards as well as 13,747 village tracts (grouping of villages). Figure 10 gives the Government Organisation of the Ayeyarwady Region.
With exception of the main cities and some township development councils, water management planning and budgeting is governed by the central ministries and delegated, regarding execution of activities, to district offices. The influence and role of the academic sector is negligible. Also the role of NGO's is still limited.

Although the private sector (mainly Myanmar people living abroad and interested to start investing in their home country) is looking into opportunities in Myanmar with great interest, it should be noted that only 30 percent of the transactions is successful according to McKinsey (2013). This is mainly due to the lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships (Driel and Nauta, 2013).

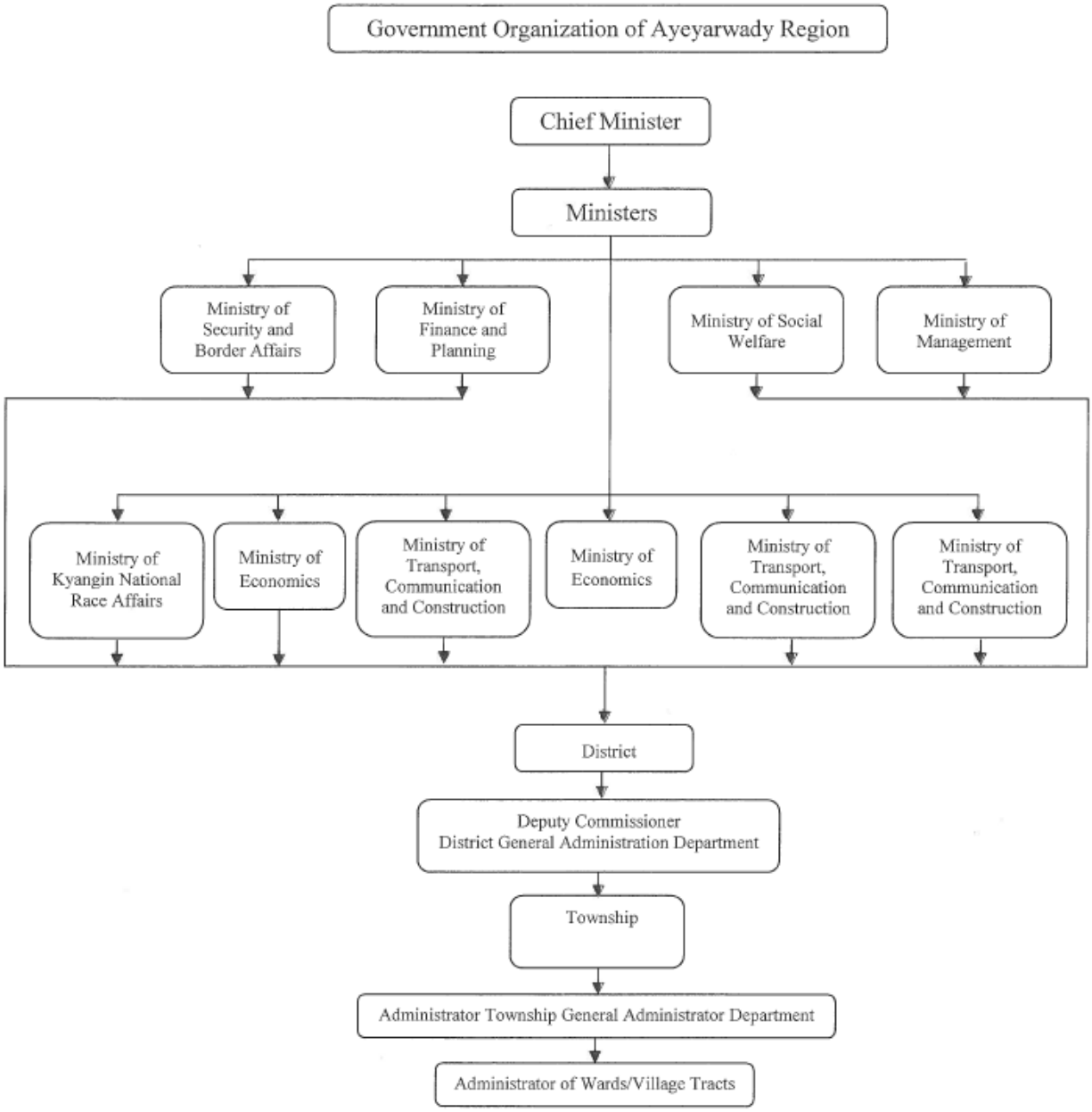


Figure 10 Government organisation of the Ayeyarwady Region.

1.4. Main indicators for drivers, pressures and governance

Table 6 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators	Values/comments
Demographic trends	Growth rate of the delta population	Estimated at1.52%
Economic developments	GDP/capita GDP av. Growth	$1,700 (2013) 6.8 %(2013)
Technological developments	Research and development Knowledge-intensive industry	Low Low
Climate change	Increase mean temperature change in 2050 Increase mean precipitation change in 2050 Increase in river peak discharge Sea level rise in 2050 Extreme events	+ 1.4˚C. + 250 mm Unknown Approx. + 0.30m More cyclones, strong winds, flooding, drought.
Subsidence	Tectonic subsidence Human induced subsidence	No data available
PRESSURES/ PROBLEMS	**Main indicators**	
Land and water use (occupation layer)	Population density Urbanization Fresh water demands Flood vulnerability	230 inhabitants/km^2 Increasing in and around Yangon High High
Network / infrastructure (network layer)	Flood protection standards Irrigation and Drainage Water supply and sanitation Road, railways and ports	Rivers: moderate. Coast: low Moderate condition Low Low
Natural resources (base layer)	Storm surges/cyclones Coastal/fluvial erosion Ecosystems health Biodiversity loss Water quality Freshwater shortage/salinity intrusion	Up to > 6m (Nargis) High Moderate Moderate (mangroves loss) Moderate Problem in lower delta
GOVERNANCE	**Main indicators**	
Multi-level and multi-sectorial cooperation	Existence of integrated plans Existence of multi sectorial/multilevel committees	No integrated plans. IWRM strategy in development NWRC (National Water Resources Committee)
Public-private partnerships	Number of PPPs Scale of PPPs (geographically/financially)	Low No information
Involvement of stakeholders and citizens	Existence of legal instruments for participation Number of NGOs involved	No information NGOs present, no information on their role
Approaches for dealing with risks and uncertainties	Existence of adaptive management (strategies) Existence of risk management and emergency systems	No Yes

1.5. Score card

The scores in the scorecard are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:
- Scenario 1, moderate perspective 2050: medium economic growth and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario 2, extreme perspective 2050: high economic growth and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 7 Score card delta resilience

Delta	Land and water use (occupation layer	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2014	-	--	--	-	-
Scenario1 moderate 2050	0	+	-	0	0
Scenario 2 extreme 2050	-	-	--	0	-

resilience/sustainability: ++ (very good), + (good), 0 (medium), - (low), -- (very low)

Concluding remarks on scorecard:
The population density is relatively low compared to the one of the Mekong or the Ganges-Brahmaputra-Meghna Deltas, but yet 3 to 4 times as high as the country's average. The pressure on space is not that high. The demand for water and the flood vulnerability score high. It is expected that through economic development the livelihood conditions might improve under the moderate scenario.

The current infrastructure concerning transport is badly developed. Many works have been done with regard to river embankments, construction of polders and irrigation systems, of which the maintenance could be improved. In the moderate scenario it is expected that important investments will be done to upgrade the road and other infrastructure. It is expected that the area of irrigated agriculture will increase.
The delta is and will always be very vulnerable in view of the risk of (increasing) extreme events such as storm surges, cyclones and extreme rainfall. Also salinization will be threat for mainly the Lower and Middle Delta.
The governance of the delta is currently at a rather low level. There are opportunities for the application of more integrated and participatory approaches.

2. Overview of adaptive measures in the Ayeyarwady Delta

Overview below gives an overview of (possible) adaptive measures in the three spatial layers based potential adaptation projects as identified by the NAPA (Ministry of Transport, 2012). The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer). Section 1.2.1 gives a description of the (possible) adaptive measures.

Table 8 Overview of adaptive measures

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occupation. 2. Network 3. Base
Improve agricultural productivity and food security agriculture	1,2,3	• Developed small-plot water technologies. • Linkages between farmers and fruit and vegetable markets. • Rice varieties have been introduced.	2	1
Early Warning Systems	1,4	• 161 manual meteorological observation stations across the country. • Training and awareness raising campaigns at grass-root, regional and national levels. • Early warnings to local authorities that transfer warnings to district and grass-root levels. • Community-based pilot programmes for training local communities in respond to early warnings. • Multi-hazard risk assessments.	1	1
Sustainable and community-based forestry	1,2,4	• Sustainable forest management Plan including natural, plantation and community forests. • A people centred Community Forestry approach promotes sustainable management of natural forests. • Reforestation ~65,108 ha of plantation forests comprising mangrove and other forestry species. • Management Project implemented to ensure sustainable management of mangrove ecosystems. • Awareness conducted using pamphlets and posters.	1,2	1,3
Reduce health risk	1,4	• Using newspapers, TV and posters to prevent climate-related health risks. • Twenty national hospitals and 32 state and regional hospitals exist in Myanmar supported by the World Health Organisation since 2006. • Pan and pipe sanitation systems for reducing outbreaks of water-borne diseases. • 'National Sanitation Week' annually, to highlight the importance of personal hygiene and sanitation for decreasing health risks.	1	1,2
Water resources	1	• Implementation tube-wells to supplement piped water supply from reservoirs. • Using artesian tube-well to utilise ground water for irrigation. • The Electric-powered Water Pumping Project and the Meiktila-Thazi Groundwater Irrigation Project were recently implemented. • Local and international NGOs provide pumps for assisting communities to obtain drinking water in rural areas. • Small-scale water impoundments during 2010 and 2011 in the whole country.	1,2	1,3

Sustainable and community-based coastal management	1,2,3,4	• Programme promotes sustainable marine ecosystem management and sustainable coastal livelihood development to improve the lives of coastal populations with effective regional management of marine biodiversity and fisheries. • Four Marine Protected Areas (MPAs) have been established along Myanmar's coast. • Plan to establish a Marine Planning Areas Network System. • A number of different agencies are undertaking mangrove and coastal forest restoration efforts following damage from recent cyclones in Myanmar's coastal areas. • Established an aquaculture research centre.	1,2	1,3
Energy and Industry	1,2,3,4	• Projects have been implemented for harnessing Myanmar's solar energy. Has been implemented Solar Power Village Electrification Scheme. • Research on solar energy is being conducted, including the development of prototypes of solar equipment and the potential use of solar energy. • Research/implementation of pilot projects using 'biogas' is being conducted to capture cheap and efficient energy from methane gas produced from animal waste, particularly cow dung. • National 30-year Energy Development Plan invests in measures to improve energy supply particularly in rural areas.	1,2	1,2
Biodiversity	2,3,4	• An extensive Protected Area system comprising this surpasses the 5% target set by the Myanmar's Forest Policy but is under the 10% set by the National Forest Master Plan. • Protection and restoration of the spawning and feeding habitats for fish and other marine species. • Sustainable utilisation of aquatic resources through closed seasons, licensing, surveillance and enforcement of existing Fishery Law. • Restrictions on removal and trade of restricted species. • Community based approaches for site based conservation by Biodiversity And Nature Conservation Association BANCA including identifying Important Bird Areas in Myanmar. • Wildlife conservation training courses and small research grant programs are being undertaken by Wildlife Conservation Society.	1,2	1,3

2.1. Overview of (possible) adaptive measures

All (possible) adaptive measures mentioned below are derived from the Nation Adaptation Programme of Action (NAPA) (Ministry of Transport, 2012).

Improve agricultural productivity and food security Agriculture.

- The Government implemented 129 irrigation projects between 1988 and 2002 in the whole country. This includes the Thaphanseik dam, which is the largest dam in Southeast Asia.
- The International Development Enterprise (IDE) project: i) developed small-plot water technologies e.g. micro-irrigation facilities (treadle pumps and engines); and ii) created linkages between local farmers and fruit and vegetable markets. This has enabled certain farmers in Myanmar to move from subsistence rain-fed farming to small-scale commercial (and thus income-generating) farming.
- In the Ayeyarwady Delta, a range of rice varieties have been introduced for cultivation including traditional quality, salt-tolerant, deep-water, waterlogged and submerged rice varieties e.g. Pawsan Hmway, Pawsan Baygyar and Phyarpon Pawsan rice varieties are highly valued and cover ~20% of the Delta region.

Early Warning Systems.
The following measures have been implemented in Myanmar to ensure effective early warning for severe weather events:

- The Department of Meteorology and Hydrology (DMH) collects analyses and archives meteorological, hydrological and seismological related data to inform early warnings for extreme weather events. This is achieved using 161 manual meteorological observation stations across the country in combination with satellite-based estimation techniques and forecast information received from Global Producing Centres. Early warnings and weather related bulletins are disseminated using television and radio.
- The Relief and Resettlement Department (RRD) conduct disaster response and recovery activities including training and awareness raising campaigns at grass-root, regional and national levels.
- The RRD and DMH collaborate to disseminate early warnings to local authorities that transfer warnings to district and grass-root levels.
- Regional Integrated Multi-hazard Early Warning Systems (RIMES) are conducting community-based pilot programmes for training local communities to prepare for and respond to early warnings received from DMH and RRD.
- The United Nations Development Programme developed multi-hazard risk assessments for Ayeyarwady, Bago, Yangon and Rakhine Regions/States in 2011.

Sustainable and community-based forestry.

- A Thirty year Forest Action Plan has been developed on disaster risk reduction, sustainable forest management including natural, plantation and community forests.
- A people centred Community Forestry approach (Community Forestry Instruction 1995) is being used in several regions including the Ayeyarwady Delta, Yangon Deltaic region and Central Dry Zone. This approach aims to promote sustainable management of natural forests through decentralisation to established Forest User Groups (~30-year lease).
- Reforestation efforts are being undertaken in the Ayeyarwady Delta and Yangon Deltaic region. This includes the establishment of ~65,108 ha of plantation forests comprising mangrove and other forestry species.
- The Integrated Mangrove Rehabilitation and Management Project (Japan International Cooperation Agency [JICA] 2007-2013) is being implemented to ensure sustainable management of mangrove ecosystems and poverty alleviation in the Ayeyarwady Delta.
- Awareness rising is being conducted using pamphlets and posters distributed throughout the Ayeyarwady Delta and Yangon Deltaic regions.

Reduce health risk.
The following measures have been implemented in Myanmar to reduce health risks to local communities associated with climate variability:

- The Department of Health raises awareness using newspapers, TV Spot and posters on the necessary precautions (appropriate behaviour changes) vulnerable communities should take to prevent climate-related health risks such as heat-related disorders and the spread of water-borne diseases.
- Twenty national hospitals and 32 state and regional hospitals exist in Myanmar. These hospitals have been supported by the World Health Organisation (WHO) since 2006.
- The Department of Health (DoH) provides local communities with pan and pipe sanitation systems for reducing outbreaks of water-borne diseases.
- 'National Sanitation Week' is held annually to highlight the importance of personal hygiene and sanitation for decreasing health risks.

Water Resources.
Considerable investments have been made to ensure water security across Myanmar. The Government initiated a number of irrigation schemes from 1988 to 2010 to maintain agriculture productivity during dry periods. Additional measures to assist water security in Myanmar include:

- The Yangon City Development Committee (YCDC) has been implementing tube-wells to supplement piped water supply from reservoirs.
- The Water Resources Utilization Department (WRUD) is using artesian tube-wells in the Sagaing Region and shallow/deep tube-wells in the Mandalay Region to utilise ground water for irrigation.

- The Electric-powered Water Pumping Project and the Meiktila-Thazi Groundwater Irrigation Project were recently implemented in the Meiktila plain.
- A range of local and international NGOs provides treadle pumps for assisting communities to obtain drinking water in rural areas.
- The Irrigation Department in collaboration with the Italian Government and Food and Agriculture Organisation (FAO) installed a number of small-scale water impoundments during 2010 and 2011 in the whole country.

Sustainable and community-based coastal management

- The Government of Myanmar is currently involved in the Bay of Bengal Large Marine Ecosystem (BOBLME) Programme, which promotes sustainable marine ecosystem management and sustainable coastal livelihood development. The programme aims to improve the lives of coastal populations through effective regional management of marine biodiversity and fisheries.
- Four Marine Protected Areas (MPAs) have been established along Myanmar's coast, including i) Moscos Island; ii) Thamihla Kyuun; iii) Mainmahla Kyuun; and iv) Lampi.
- The Department of Fisheries in collaboration with Biodiversity And Nature Conservation Association (BANCA) and Fauna and Flora International (FFI) are planning to establish an MPA Network System that will incorporate existing MPAs, for example, the Shark Reserves in the Myeik archipelago (Lampi MPA).
- A number of different agencies and organisations, including JICA (Japan International Cooperation Agency), FREDA (Forest Resource Environment Development and Conservation Association), and UNDP/MERN (Mangrove Environmental Rehabilitation Network) are undertaking mangrove and coastal forest restoration efforts following damage from recent cyclones in Myanmar's coastal areas.
- The Department of Marine Science within the University of Mawlamyine has established an aquaculture research centre.

Energy and Industry.

Many industries and economic sectors in Myanmar have limited capacity or financing to use modern technologies for harnessing efficient and renewable energy sources. The Water Resources Sector, for example, has limited access to energy efficient water purification technologies. Therefore, many communities suffer from scarcity of safe water supplies. Despite this, efforts are currently being made to support/promote the utilisation of efficient and renewable energy sources in the country. These include:

- Projects have been implemented for harnessing Myanmar's solar energy, including: i) Photovoltaic Power Systems are being installed in remote villages under the Technical Cooperation among the Developing Countries Programme; ii) a number of pilot projects are being undertaken by Solar Photovoltaic Battery Charging Community Enterprise; and iii) the Myanmar Scientific and Technological Research Department (MSTRD) in collaboration with the Department of Physics (Yangon University) are implementing the Solar Power Village Electrification Scheme.
- Research on solar energy is being conducted, including the development of prototypes of solar equipment and the potential use of solar energy in: i) cooking and other household purposes; ii) water pumps; iii) solar drying for grain and fish products; and iv) salt extraction from seawater.
- Research/implementation of pilot projects using 'biogas' is being conducted to capture cheap and efficient energy from methane gas produced from animal waste, particularly cow dung. Approximately 400 biogas stations have been constructed in the rural areas throughout Myanmar to provide cooking gas and light energy.
- Myanmar's fourth short-term five-year plan (2006/2007 to 2010/2011) of the National 30-year Energy Development Plan indicated that the country will invest in measures to improve energy supply, particularly within rural areas.

Biodiversity.

Myanmar has made concerted efforts to protect biodiversity within the country including:

- An extensive Protected Area (PA) system comprising 43 PAs (35 designated and 8 proposed) covering 49,500 km^2 (7.3% of total land area). This surpasses the 5% target set by the Myanmar's Forest Policy but is still under the 10% set by the National Forest Master Plan (2001).
- Protection and restoration of the spawning and feeding habitats for fish and other marine species as well as conservation of sea turtles through extension services and education activities.

- Sustainable utilisation of aquatic resources through closed seasons, licensing, surveillance and enforcement of existing Fishery Law e.g. closed fishing season during June-August (spawning and feeding season of juvenile fish and shrimp species).
- Restrictions on removal and trade of restricted species e.g. Asian elephant (Elephas maximus), Bengal tiger (Panthera tigris tigris), Saing/Banteng/wild cow (Bos javanicus), Ayeyarwady- linpaing/ Irrawaddy Dolphin (Orcaella brevirostris), Golden deer/Brow antlered deer(Rucervus eldi eldi) and Spotted deer (Axis axis) through the Protection of Wildlife and Conservation of Natural Areas Law, International Union for Conservation of Nature and Natural Resources (IUCN) red data list as well as Convention on International Trade in Endangered Species (CITIES).
- Community based approaches for site based conservation by Biodiversity And Nature Conservation Association BANCA including identifying Important Bird Areas in Myanmar and promoting biodiversity through research, partnerships, environmental education and improvement of rural livelihoods. BANCA has identified more than 1000 bird species in Myanmar, including a rediscovery of the critically endangered Gurney's pitta (Pitta gurneyi) in 2003 within the Ngawun Reserved Forests.
- Wildlife conservation training courses and small research grant programs are being undertaken by Wildlife Conservation Society (WCS) for Hkakaborazi National Park, Hukaung Tiger Reserve, and Hponkanrazi Wildlife Sanctuary. WCS is currently exploring additional areas for potential PAs and environmental education programmes.

3. Overview of technical methods and tools to support delta management and development in the Ayeyarwady Delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues.

Table 9 Overview of modelling tools for Myanmar

Name of tool	Brief description	Organisation/ institute	Available at
Delft3D	Delft3D is a flexible integrated modelling suite, which simulates two-dimensional (in either the horizontal or a vertical plane) and three-dimensional flow, sediment transport and morphology, waves, water quality and ecology and is capable of handling the interactions between these processes. For the Ayeyarwady Delta and adjacent coastal waters a 2D hydrodynamic model has been developed for water circulation and salinity intrusion.	Directorate of Water Resources & Improvement of River Systems (Ministry of Transport, Myanmar) and Deltares	Deltares (open source) http://www.deltaressystems.com/hydro/product/621497/delft3d-suite
SOBEK	SOBEK is a powerful modelling suite for flood forecasting, optimisation of drainage systems, control of irrigation systems, sewer overflow design, river morphology, salt intrusion and surface water quality. The current application is a hydraulic and morphodynamic 1D Ayeyarwady River model.	Directorate of Water Resources & Improvement of River Systems (Ministry of Transport, Myanmar) and Deltares	Deltares (open source) www.deltaressystems.com/hydro/product/108282/sobek-suite
WFlow	Wflow is a distributed hydrological modelling platform generating rainfall-runoff for all major river basins and serves as input for RIBASIM and SOBEK	Deltares	Deltares (OpenStreams providing the building blocks that make up integrated hydrological models) publicwiki.deltares.nl/display/OpenS/wflow+-+PCRaster-Python+based+distributed+hydrological+models

Name of tool	Brief description	Organisation/ institute	Available at
RIBASIM	RIBASIM is a generic model package for simulating the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin.	Irrigation Department (Ministry of Agriculture and Irrigation, Myanmar) and Deltares	Deltares www.deltares.nl/nl/software/101928/ribasim

4. Knowledge exchange and development

4.1. Lessons learned on delta management

There is still little experience with integrated delta planning and management. A very sectorial approach is still being applied, with relatively low level of cooperation between the various governmental agencies. A start has been made with a strategy study on IWRM for the whole country, including the Ayeyarwady Delta. There is a growing understanding that the real challenges (now and in the future) can only tackled through an interdisciplinary, integrated approach. Knowledge development and capacity building are high on the priority list of key issues identified during the Delta Alliance workshops organised in July 2013 and June 2014.

5. Summary of research gaps and related needs for knowledge exchange

Drivers of change

Apart from statistical data on for instance agricultural production there is not much recent information available on the Ayeyarwady delta, mainly due to the fact that in the last 20 years not much research has been done and most of the monitoring programs have been halted. Therefore research gaps exist for all drivers of change.

- The recently performed census 2013 will give new data on the population in the Delta: population number, density, composition, growth rates, etc.
- Not much information has been found on the expected economic developments and their impacts on land pressure, urban infrastructure and availability of fresh water.
- Climate change brings a new kind of uncertainty: dry areas get much drier, wetter areas get much wetter, and there is greater unpredictability of rainfall. More knowledge has to be developed on how e.g. hydrological systems will change. New infrastructure needs to be planned accordingly.
- Moreover, investments in research and development are needed in the agricultural sector, being the most important contributors to the GDP (World Bank, 2005).
- During three Delta Alliance workshops held in respectively Pathein, Hinthada and Yangon in June 2014 the key issue ‘knowledge development and innovation’ scored among the participants second highest (after flooding) out of 8 key issues for the delta (see Figure 11)

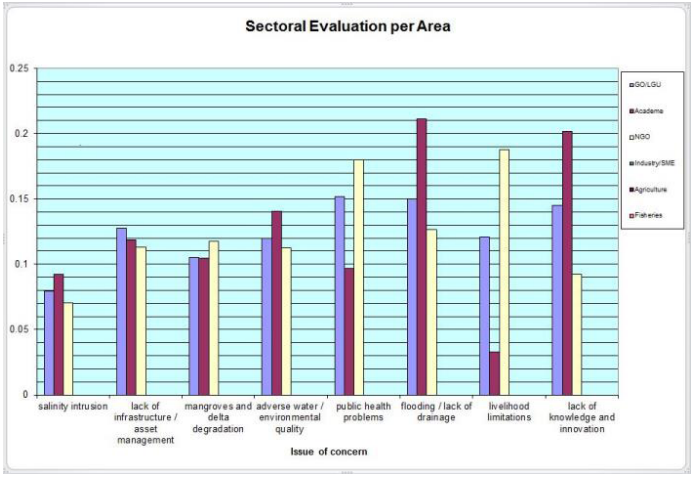


Figure11 Scoring of 8 key issues for the Ayeyarwady delta during 3 Delta Alliance workshops (2014)

Pressures – potential problems / Challenges – opportunities

Occupation layer:
- Data on population: density, growth rate, current unemployment, projections and current situation.
- Migration both into the delta and out of the delta, due to loss of livelihoods, needs to be considered.
- More insight needed in fishing rights, not aquaculture alone, but captures fisheries in river, estuary and those on delta dependent on marine fisheries as well.
- Inventory of existing (development) plans needed.
- There is need of socio-economic and livelihood profiling of the population to understand the actual vulnerability

Network layer:
- Present status and future plans of the transportation sector (Ministry of Public Works).
- Current programs and plans, for drinking water supply and sanitation facilities, etc.
- Plans for township development (Min. of Border Affairs, DRD).
- Cost-efficient and innovative infrastructure
- Innovation in agricultural engineering (irrigation, etc)

Base layer:
- Need for overview of all hazards and consequences.
- Hydrological and monitoring data
- Water balances and allocation studies are necessary to address future water resources problems.
- Information on Ayeyarwady tributary behaviour and characteristics.
- Trends, programs, leading to water quality problems. Baseline conditions.
- Knowledge on arsenic contamination of groundwater.
- Monitoring system needed for anthropogenic subsidence and groundwater exploitation
- Size of loss of wetlands.
- Potential impacts of climate change and sea level rise on mangroves and biodiversity conservation.

Adaptive measures are being implemented in terms of:
- Improve agricultural productivity and food security agriculture.
- Early Warning Systems.
- Sustainable and community-based forestry.
- Reduce health risk.
- Water resources, ensure water security.
- Sustainable and community-based coastal management.
- Energy and industry. Promote the utilisation of efficient and renewable energy sources in the country.
- Protect the biodiversity.

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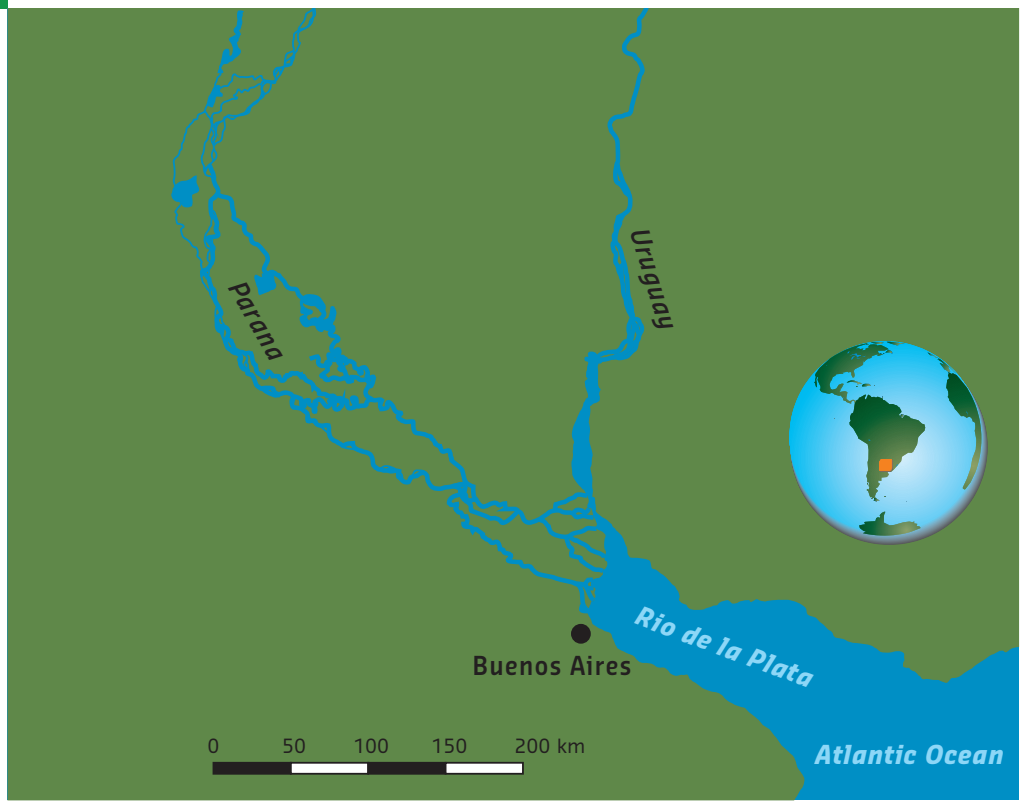
Parana delta

No

14



1. Current and future state of the Parana Delta

The main characteristic of the Parana Delta is its heterogeneity. Since it comprises a vast extension of more than 22.000 km^2, it presents dissimilar situations as a result of the variety of landscape units which constitute the islands of the delta, and also as a product of the different types and scales of cities settled along its edges. These contrasts are exacerbated near the Lower Delta, where the Metropolitan Area of Buenos Aires appears as a special case of high-density which differs considerably from the rest of the cities along the delta. Influenced by the natural, economic and demographic dynamics, the reality of the islands of the Lower delta is also extremely different from the ones located in the Middle and Upper Delta regarding environmental, ecological and economic issues.

The aim of this document is to illustrate the most relevant circumstances and contrasts of the delta, with the purpose of reaching conclusions that might contribute to the discussion of delta management for this particular case.

1.1 Drivers of change

Summary of drivers of change

Demographic trends:
About 24.000 inhabitants are living in the Delta, resulting in a density of 1 inhabitant per km^2. More than half of the population is concentrated in the Lower area, which represents around 43% of the total surface of the delta. The Delta is located near the most populated conurbation of the country, Buenos Aires Metropolitan Area, which has more than 12 million inhabitants with a density of around 5.400 inhabitants per km^2.

Economic developments:
The Parana Delta is a heterogeneous region with a wide range of resources and, consequently, many production related uses. The main economic activities that characterize the islands of the delta are forestry, cattle raising, beekeeping, fishing, hunting and recreation and tourism. Nowadays, these traditional activities are threatened by new production processes originally designed for terrestrial systems, like large-scale agriculture and particularly soy crop and cattle industry on a large scale. Cattle raising contributes to approximately 85 % of the GVP estimated for the main economic activities carried out in the Delta. But livestock overload gives consequent effects of overgrazing, soil erosion and possible biological and chemical contamination of water resources with negative impact on the ecological integrity of the wetlandsFisheries in the delta involve different modalities: subsistence fishing, commercial/artisanal fishing, commercial/industrial fishing and recreational fishing.The conflicts between them have been exacerbated as a consequence of the increase of industrial fishing for export, dissimilar provincial legislations, presence of new actors and climate change impacts.
Along the borders of the delta, different cities have based their development on industrial or port activities, being the Lower Delta the area which is most influenced by the dynamics of the Buenos Aires Metropolitan Area, essential in Argentina's economic life. This region concentrates most of the industrial and financial activity of the country, contributing with around 55% of the countries' GVP (Gross Value of Production). As illustration the iron and steel industry located in the province of Buenos Aires provides more than 60% of the value generated by this sector. The per capita GDP is USD 16.840 and most people are employed in services and industry.

Climate change:
There are observed and future (direct and indirect) impacts of climate change on the Parana Delta, related to the variations in the Parana River discharge and sediment load, changes in the river´s hydrologic regime and streamflow variability might affect the frequency of occurrence of extraordinary floods and droughts. and temperature increases. Streamflow variability primarily affects the Lower Delta and is mainly influenced by the Rio de la Plata and by the climatic events such as the "Sudestada", which consists of persistent South-eastern winds coming from the Atlantic Ocean. Those drivers may accelerate trends in land use change, including extensive conversion to commercial forestry, livestock production and, less frequently, to agricultural uses with extended biodiversity alteration and loss.

Subsidence:
At regional level, the Parana River Delta is considered at great risk because the subsidence rate is higher than forecasts of sea-level rise. The rate of surface mineral soil subsidence is 60 mm per year as a result of porosity losses in the top 10 cm of the profile (Ceballos et al. 2013). This finding confirms that wetland soil compaction is an important and intense process in the system, suggesting that profile de-saturation is a key driver (Hadas 2006).

Technological developments:
The large scale infrastructural interventions located along the River and its Delta are: five big dams built upstream the river (Ilha Solteira, Jupia, Porto Primavera, Yaciretá and Itaipu), the Parana-Paraguay Waterway, two viaducts (Zárate-Brazo Largo and Rosario-Victoria) and one re-gasification port in Escobar built on the Parana de Las Palmas river. In addition, the construction of the Atucha Nuclear Power Station, located in Zárate in the coasts of Parana de las Palmas River, represents a potential risk to the delta region. Besides large infrastructure works, other low scale technological developments are also developed such as polders and embankments mostly associated with production activities such as agriculture, cattle industry and urban developments. Other heavy engineering works have been realised to expand shipping and spur economic development throughout the region.

Research gaps
- Need for the development of climate change projections at the Delta and local scales.
- Multi- disciplinary assessment of the combined impacts of human activities on the wetland and its resilience capacity in a context of climate change. Generation of future scenarios.
- Research on strategies to include climate change projections and impact assessments into policy and guidelines.

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

The Parana River drains a 2.310.000 km^2 area and is considered the third largest river in the American Continent, after the Mississippi in the United States and the Amazonas in Brazil. It is located in South America and it runs along 2.570 km, through Brazil, Paraguay and Argentina, where it flows into the Rio de la Plata. Through the Parana Delta and the Rio de la Plata estuary drains to the Atlantic Ocean the second major hydrographic basin of South America (La Plata Basin), which surface is 3.100.000 km^2. The Parana Delta is one of the largest coastal wetlands systems of Argentina. It is a 300 km-long funnel shaped area with a variable width of 18 to 100 km, which covers a surface of 17.500 km^2 (Malvárez, 1997). In this work we will use a political definition of the Parana Delta which also includes some sectors of the floodplain of the Parana river, totaling an area of 22.587 km^2 (Secretaría de Ambiente y Desarrollo Sustentable, 2011). The larger part of that area is located in the province of Entre Rios (82,2%), while the rest belongs to the provinces of Buenos Aires (16,3%) and Santa Fe (1,5%), involving a total of 19 jurisdictions in those three provinces.

The Parana Delta region is a complex floodplain having unique biogeographic and ecological characteristics in South América (Malvárez 1997, Quintana and Bó 2011). Broadly speaking, the region can be divided into three major ecological sectors or sections: the Upper delta, the Middle delta and the Lower delta (Malvarez 1995), and includes at least 11 different environmental units (Malvarez, 1999). The Parana Delta is also located near the largest urban-industrial corridor of Argentina, which exerts pressures on the delta in different ways.

Population
Argentina has about 40 million inhabitants with a growth rate of around 10% in the period 2001-2010. According to the INDEC (Instituto Nacional de Estadisticas y Censos, 2010) 12.806.866 inhabitants (32% of the total population) are located in the largest conurbation of the country, the Buenos Aires Metropolitan Area, which covers less than 1% of the national territory. This conurbation, located near the delta, is constituted by the city of Buenos Aires and 24 departments of the homonymous Province.

Three of those departments (Escobar, Tigre and San Fernando) are located in the delta area. Other significant population clusters along the borders of the delta include the capitals of Santa Fe and Entre Rios provinces (Santa Fe and Parana cities, respectively), Rosario in the province of Santa Fe, and Tigre and Escobar in the province of Buenos Aires. In fact, these two last departments were those ones that most increased their population between 2001 and 2010, followed by Ramallo, Campana, Zárate and Baradero, all in the Province of Buenos Aires, and the department of San Lorenzo in Santa Fe (Galperin et al., 2013).

Notwithstanding the available data on the population living in the islands of the delta is fragmented and outdated. During the 1930s, the population reached 40.000 inhabitants as a consequence of the policies which encouraged the occupation of the delta territories (Secretaría de Ambiente y Desarrollo Sustentable, 2011). Between 1940 and 1990 the region showed a depopulation trend due to the economic crisis, the low competitivity of the area vis a vis other neighbouring regions and the recurrent severe floods (Galafassi, 2011). According to Galperin et al. (2013), the population of the delta was recently estimated in 24.000 inhabitants with a very low population density (1 hab/ km^2). More than 5.000 people concentrates in the first section of islands which belongs to the Department of Tigre, (Fundación Metropolitana and Municipio de Tigre, 2013). This effect is a result of the influence of the dynamics of the whole metropolitan area and due to the role of touristic node that Tigre plays. In fact, in spite of having a permanent island population of approximately 5.000 inhabitants, this number doubles during the weekends due to the touristic short-term activities while statistics show that touristic activity has increased by about 300% in the last 10 years (Fundación Metropolitana and Municipio de Tigre, 2013).

Economic development

The regional role of the Delta is related to its strategic location along the most relevant economic corridor of the country, which is also the most important commercial route of the Mercosur, connecting Santiago de Chile (Chile) with Sao Paulo (Brazil). Along the borders of the delta, different cities have based their development on industrial activities (such as Escobar, Zárate, Campana, Ramallo and San Nicolas), port activities (San Pedro, San Nicolas and Campana) or the leisure industry (Tigre) (Dirección Provincial de Estudios y Proyecciones Económicas, 2012). The Lower Delta is the area which is mostly influenced by the dynamics of the economy of the Buenos Aires Metropolitan Area which has a central role in Argentina's economic life. This region concentrates most of the industrial and financial activity of the country, contributing with around 55% of the countrie´s GVP (Gross Value of Production) (Fritzsche and Vio, 2002). The per capita GDP is USD 16.840 (CEPAL, 2014), most people is employed in services and industry with an unemployment rate of 7,1% (INDEC).

Traditional production of delta

The Parana Delta is a heterogeneous region with a wide range of resources and, consequently, many production related uses. The main economic activities that characterize the region are forestry, island cattle raising, beekeeping, fishing, hunting and recreation and tourism (Galperin et al., 2013). There are other small-scale activities like cultivation of wicker and Phormium, floriculture and fruit cultivation, harvesting of reeds and silk production (Galafassi, 2011; Quintana, 2011). Nowadays, these traditional activities are threatened by new production processes originally designed for terrestrial systems, as in the case of agriculture (particularly soy) and cattle industry on a large scale.

Agriculture and cattle industry

Between 1974/75 and 2006/07, the expansion of cultivated cereals and oilseeds in Argentina was 17.8 million ha, of which 90% were soybean (Giancola et al., 2009, OEA, 2009). In the past two decades, the expansion of this crop and the deepening of the "agriculturization process" caused a territorial reconfiguration of livestock production across the country. As a consequence, the cattle stock was largely displaced from the Pampas to other areas, marginal territories less suitable for agriculture. This is the case of the islands of the Parana Delta, which shifted from a system of extensive and seasonal cattle production to a more intensive and continuous activity (Quintana and Bo 2010). In addition, other factors also favored the increased use of islands for cattle raising, such as the construction of the Rosario-Victoria viaduct (which decreased the costs of transportation to the delta islands) and the policy of leasing public lands (encouraged by the province of Entre Rios), among other factors (Donadille et

al., 2010). Additionally, there are other infrastructures such as dams and embankments that facilitated the movement of people and animals.

Between 1997 and 2007 the number of animals in the Delta multiplied by almost 10, going from 160.000 to 1.500.000 heads, with the consequent effects of overgrazing, soil erosion and possible biological and chemical contamination of water resources (Quintana and Bo 2010). In some cases, the increasing level of activity also involved an alteration of the hydrological regime due to construction of dams or blockage of water courses by ramparts to facilitate the movement and prevent the entry of water into the fields. This livestock overload resulted in an uncontrolled use of fire for pasture regrowth, which in 2008 got out of control burning then about 11% of the delta area (207.000 ha; Kandus et al., 2011) and causing severe air contamination effects in the surrounding cities. In addition, many areas resulted affected by overgrazing and trampling of soils, with consequent negative impacts on the ecological integrity of wetlands.

Fisheries
While in Argentina the activity is mostly concentrated in ocean fisheries, inland fishing (river and lake) play a major role for local communities. Fisheries in the delta involve different modalities: subsistence fishing, commercial/artisanal fishing, commercial/industrial fishing and recreational fishing (Baigun and Minotti, 2011). While all these types have coexisted without much difficulties encouraged by the hydrologic heterogeneity and the wide variety of species of the delta, the conflicts between them have been exacerbating. This is a consequence of the increase of industrial fishing for export, dissimilar provincial legislations, presence of new actors and climate change impacts.

Between 1994 and 2002, exports of freshwater fish coming from the Delta Area increased from around 3.000 to over 20.000 ton/year. It is estimated that around 80% of those exports were “Sábalo” (*Prochilodus lineatus*) (Taller Ecologista 2010). Between 2003 and 2006, “Sábalo” exports increased up to around 30.000 tons. Since 2007, the volume of exported fish fluctuates between 10.000 and 20.000 ton/year (Galperin et al., 2013).

Industry
Several industrial clusters are located in the Metropolitan Area of Buenos Aires and along the delta. The iron and steel industry located in the province of Buenos Aires provides more than 60% of the value generated by this sector; the main activities take place in Rosario, Villa Constitucion, Ramallo, San Nicolas, Campana, and Ensenada (near La Plata city). The three leading companies located in those areas participate with approximately 95% of the national steel industry production (Direccion Provincial de Estudios y Proyecciones Economicas, 2012). Petrochemical and automotive industries are also relevant, being located in Buenos Aires, Zárate, Campana and Tigre (Direccion Provincial de Estudios y Proyecciones Economicas, 2012).

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

There are observed and future impacts of climate change on the Parana Delta. Those impacts can be direct and indirect ones. Firstly as a consequence of climate change there will be: (i) variations in the Parana River discharge and the sediment load (both produced by variations in the upper Parana Basin) that will modify the rate of advancement of the Delta Front (presently, around 50 m/year on the right bank of the Plata River), a phenomenon with significant economic and social implications; (ii) changes in the Parana River hydrologic regime (also linked to the upper basin) that might affect the frequency of occurrence of extraordinary floods, which have strong implications in the evolution of the Delta morphology; (iii) temperature increases that may lead to variations in local water balances, affecting the different land uses and promoting land use change. Secondly, associated with these effects, but also with broader trends in agriculture and livestock production at the national scale, stimulated by changes in precipitations that allow for the expansion of cash crops agriculture and displacement of livestock production into increasingly marginal lands, there is an incipient but accelerated trend in land use change, including extensive conversion to commercial forestry, livestock production and, less frequently, to agricultural uses with extended biodiversity alteration and loss. Increasing deforestation

and degradation of wetlands is carried through in the absence of national or regional adaptation plans specifically conceived for the Parana Delta to address these large scale transformations and even without consideration of the contribution of these actions to increasing national greenhouse gas emissions. The observed and expected changes might preclude benefiting from environmental services and are carried through in spite of the value of the wetlands from diverse perspectives.

In addition, and according to the Intergovernmental Panel on Climate Change it is likely that temperatures will increase from 0.4°C to 1.8°C in the next ten years and up to 7.5°C in the next eighty years (Magrin et al. 2007). Other studies carried out by Barros and Bejaran (2005) for the La Plata Basin demonstrate that there is upward trend of precipitation levels of about 16% comparing the periods from 1951-1970 and 1980-1999, mainly for the Western Buenos Aires area and that of the province of Corrientes. Such increasing trends in precipitation have given place to simultaneous trends in river streamflows. In fact, it is estimated that for every percentage point of change in precipitations there is a two percent change in river streamflow (Berbery et al. 2006). In the middle and upper sections of the Parana Delta, the effects of streamflow variability are associated with longer periods of droughts and floods, a typical characteristic of wetlands. Even though variability in river streamflow primarily affects the Lower Delta, it is mainly influenced by the Rio de la Plata and the climatic events associated with this basin. In fact, the hydrology of the Lower Parana Delta is influenced by the discharges of two large rivers (Parana and Uruguay), but also by precipitations, tides and the meteorological phenomenon known as “Sudestada”, which consists of persistent South-eastern winds coming from the Atlantic Ocean not always followed by precipitations.

Although regional trends show an increase in precipitation levels for the upper and middle sections of the Delta, increasing river’s streamflow and Extreme Hidrological Events (EHE) which affect the surrounding areas of the water courses, it does not affect the level of the Rio de la Plata in a significant way (Barros et al. 2003 and 2006). On the contrary, the level of the Rio de la Plata is influenced by Sea Level Rise, but mostly, by the action of the winds which drag water into or out of the estuary (according to their direction) altering the level of the river. Hydrodynamic model simulations developed in the National Centre for Environmental Prediction / National Centre for atmospheric Research (NCEP/ NCAR), indicate that changes in the direction and intensity of winds could explain 5 of the 13 cm water level rise observed in the area of the Port of Buenos Aires during the twentieth century (Barros 2006 and Kalnay et al. 1996). In addition, a two-dimensional hydrodynamic model developed by the University of Buenos Aires (Re and Menendez 2006) shows that the increase of the average level of the Rio de la Plata is expected to affect the low lands of the coast of Buenos Aires province. The flood risk associated with this phenomenon is related to the Sudestadas, which exacerbate the increase of the river level jeopardizing the Parana Delta Front. These Sudestadas are associated with the ENSO (El Niño Southern Oscillation) cycle, which is a phenomenon that takes place in the tropical Eastern Pacific Ocean and is characterised by a change in temperature and pressure of surface waters. The ENSO is the main cause for climate variability in South America (Berbery et al. 2006).

Further a number of studies have demonstrated that strong anthropogenic interventions have accelerated the natural dynamic resulting in severe environmental impacts that are exacerbated by climate change adverse effects, in particular those related to extreme hydrologic events linked to climate variability and change, particularly in terms of the more frequent, longer in duration, and more intense floods and extensive droughts that periodically affect the area of study as a result of the El Niño/La Niña cycles.

1.1.3 Subsidence (natural or human-induced)

Natural subsidence and accelerated subsidence reduce the volume of deltaic deposits and soils. Natural subsidence involves natural changes in the void space within sedimentary layers (for example dewatering, grain-packing realignment and organic matter oxidation) and is typically ≤3 mm yr–1 (Syvitski, 2008). Accelerated subsidence is the anthropogenic (compaction) contribution to volume change as a consequence of subsurface mining (oil, gas or groundwater) or drainage and land use change (Afforestation). Human-influenced soil drainage and accelerated oxidation can exceed natural subsidence by an order of magnitude. In the Lower Delta, a study showed that the surface mineral

soil subsided at a rate of 60 mm per year as a result of porosity losses in the top 10 cm of the profile (Ceballos et al. 2013). This finding confirms that wetland soil compaction is an important and intense process in the system, suggesting that profile de-saturation is a key driver (Hadas 2006).
According Syvitski et al. 2009, the vulnerability of a Delta is a result of sediment compaction from the removal of water from the delta's underlying sediments, the trapping of sediment in reservoirs upstream and floodplain engineering in combination with rising global sea level. At regional level, the Parana River Delta is considered for these authors among Deltas at greater risk because the subsidence rate is higher than forecasts of sea-level rise.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

Technological change has had impacts on the current conditions of the Parana Delta primarily through very large scale infrastructural interventions such as those major infrastructure projects located in the Parana Delta region. First, the big dams built upstream the river (Ilha Solteira, Jupia, Porto Primavera, Yacireta and Itaipu), which generate significant impacts on the courses of the river and its tributaries. Second, the Parana-Paraguay Waterway (Bucher et al., 1993), which resulted from dredging a deeper channel along the 3,400 kilometer river system, remove rocks and river curves, and undertake other heavy engineering works to expand shipping and spur economic development throughout the region. The Waterway links the Rio de la Plata with the Paraguay river consolidating a fluvial corridor of 15 ports, four of which are located in the delta region (San Martin-San Lorenzo-Rosario port complex and the ports of San Nicolas, Zárate and Campana) (Machain et al. 2013). Third, the viaducts of Zárate-Brazo Largo and Rosario-Victoria (60 km). The latter was built in 2003 to connect the cities of Rosario and Victoria (located in the provinces of Santa Fe and Entre Rios, respectively), and has had a great impact since it included 12.282 km of bridges y 47.149 km of embankments, resulting in changes in both the hydrological regime of the Upper Delta and in land value. Fourth, the re-gasification port of Escobar built on the Parana de Las Palmas river, which started to operate in 2011. Finally, the construction of the Atucha Nuclear Power Station, located in Zárate in the coasts of Parana de las Palmas River, which represents a risk to the delta region.

In the Delta, other low scale technological developments are also developed such as dams and embankments mostly associated with production activities such as agriculture, cattle industry (Blanco and Mendez, 2010) and urban developments (Fabricante et al., 2012).

1.2 Pressures – potential problems / Challenges – opportunities

1.2.1 Land and water use (occupation layer)

Summary of pressures

Pressure on space:
In the Parana Delta there is a clear trend towards land use. concentration, which consists mainly in land property and use changes from many small producers to just some few big companies. The pressure on space is mostly associated with large-scale production processes, such as cash crops agriculture as Soybean, livestock production and forestry. Nevertheless, it is also related to the influence of the nearby urban conurbation of the Buenos Aires Metropolitan Area, which expansion leads to the introduction of metropolitan patterns in the delta.

Water demand / freshwater shortage:
Changes in land uses such as the urbanization of rural areas, the increment of the number of dwellings and the increase of the scale of production cause a rise of water demand in the cities. The average water demand of the Metropolitan Area of Buenos Aires in 2003 was estimated in around 4.179.000 m³/day.

Research gaps

- Comprehensive database on climatic, natural resources and socio-economic parameters in order to support research and development of initiatives. Availability of the information for research purposes.
- Study on the effects of the different occupation typologies on the wetland (residential, production, recreation, etc.). Research on innovative solutions to prevent the increase of the terrestrialization trend, finding new ways of occupation according to the context.
- Research on innovative solutions for the government to recover its key role on territorial planning and management.
- Development of models regarding flooding scenarios in order to integrate them to planning decision-making. Study of the vulnerability to flood of coastal cities.
- Production of detailed land use maps
- Impact assessment of large-scale cattle raising on wetlands, biodiversity and other local productions like beekeeping.

Pressure on space
In the Parana Delta there is a clear trend towards land concentration. The pressure on space is mostly associated with large-scale production processes, such as cash crops agriculture as soybean and livestock production (Machain et al. 2013), but it is also related to the influence of the nearby urban conurbation.

Agriculture
Agriculture in polder areas currently holds approximately 11% of the total dike area distributed close to the axis of the main course of the Parana (Minotti and Kandus, 2013). The introduction of soybeans and other crops on a large scale (wheat, sorghum, rice), together with the increase of large polders and new technologies, including the use of agro chemicals, affect the natural ecosystem and its services jeopardizing the population of the region (including the City of Buenos Aires and the metropolitan region) which depends on the resources of the delta.

Livestock production
Island cattle raising is one of the most important production activities in the Middle and Upper Delta and has gained relevance during the last two decades (Quintana and Bo 2010). Recently, this activity has become more important in the Lower Delta, where it is also combined with forestry (Quintana et al., 2014). Cattle raising contributes to approximately 85 % of the GVP estimated for the main economic activities carried out in the Delta (Galperin et al., 2013).

Forestry
Forestation with Salicaceae (*Salix* spp. and *Populus* spp., Willow and Poplar) is mainly associated with the production of paper pulp and covers about 4% of the Parana Delta region and 36% of the total dike surface (Kandus et al., 2011, Minotti and Kandus 2013). The Delta is the most important area of Argentina in relation to the cultivation of these species, an activity that is carried out mainly in the delta area of Buenos Aires (delta Bonaerense) and, to a lesser extent, on the islands of the Lower Delta of Entre Rios province, totalling around 83.000 ha planted (Galperin et al. , 2013). In the delta Bonaerense there are 35.800 ha in full silvopastoral production and some flood control works are being undertaken to improve productivity and diminish flood risks (PROSAP 2011).

Urban pressures on the delta

Each city located near the delta exerts a different level of pressure on the territory according to its specialization and scale. Buenos Aires Metropolitan Area is certainly the conurbation that exerts more pressure on the delta despite not being located in that area. The metropolitan structure evolved from the centre of the city of Buenos Aires to the periphery incorporating new departments along the railway networks. During the 1990s, the construction of new transportation infrastructure, mostly highways and turnpikes, changed the evolving urbanization pattern basing it on private transportation. This change was also encouraged by the political and economic context of that decade, defined by structural changes such as state reform, economic deregulation and monetary stabilization through a currency board (convertibility), privatization of public services and new urban codes (Ciccolella, 2002; Ciccolella et al., 2006; AABA, 2010). In light of this scenario, the diminished of the role of the State encouraged private developers to finance and largely determine the morphology of the urban fabric and growth trends, leading to the development of private gated communities (neighbourhood with a closed perimeter, isolated from the rest of the urban fabric) (Zagare, 2014). Focused in the upper-middle and higher income groups, the success of these developments generated a displacement of population from the city of Buenos Aires to the suburbs. The number of private urbanizations increased from 100 to 350 in the period 1995-2000 and today it exceeds 400. According to Ciccolella (2002) and Cohen (2007), the surface occupied by private urbanizations is near 500 km^2 (larger than Buenos Aires city). In 2001, due to the collapse of the currency board a severe political and socio-economic crisis took place. Due to the crisis unemployment rate surged and informal settlements vastly expanded -those settlements are usually called *villas* and *asentamientos*, which are lands without infrastructures or services illegally occupied by low income social groups to fulfill the demand for residential space (Zagare, 2012). It is estimated that from 2001 to 2005, 60% of the new inhabitants settled informally forced by the economic crisis (Cravino et al., 2009). The result of this combination is an unplanned fragmented space with a severe social polarization.

The advancement of the urban developments at the expense of wetland areas in the past three years occurred at the rate of 1.650 ha/year, encouraged by the lower price of the land in comparison with the surroundings Pampas; In fact, in the Delta area a recent study identified 88 private urbanizations in different stages of development (Fabricante et al., 2012). This effect produced an increase in land values due to the change of use.

Vulnerability to flood

The Parana Delta is a wetland system that is exposed to pulses of floods and droughts (Kandus et al., 2011). There are two different types regarding vulnerability to flood: the islands and the continental area of the coasts along the delta, where cities are located. On the islands, the natural flood regime determines the species that inhabit the area. Settling there implies being aware of the possible risks associated to floods, so native constructions are specially designed on stilts to deal with those recurrent flows. There is basically no flood-proof infrastructure that was developed by the government on the islands; on the contrary, all the interventions to address exposure to floods are made by families or economic actors, and they are mostly focused on protecting production from water level variability.

Conversely, on the continental land, the occupation of the flood plain represents a threat for the now consolidated urban cores and consequently, the government needs to provide the necessary infrastructure to reduce vulnerability. The waterfront of the Upper and Middle Delta usually gets flooded as a result of precipitations and the increase in river discharges, while the Lower Delta is also affected by the Sudestadas, strong South Eastern winds coming from the Atlantic Ocean, which increase the level of the Rio de la Plata blocking the natural drainage of the delta. When all these events coincide in time and space, the outcome is disastrous. The drainage system of the urban fringe collapses due to the drainage blocking caused by the South Eastern currents, leading to floods and their negative consequences (Zagare, 2014).

Although it is true that the area should not have been urbanized in the first place (at least not in the traditional way) because it is a floodplain, the reality is that it is already urbanized and so the local authorities must address the problem providing infrastructure to reduce vulnerability. As an example, the urban fringe of Tigre and San Fernando are located between the original ravine and the right bank of the

Parana River in what Bonfils (1962) defined as a Halo-Hidromorphic terrain. This land is a plain territory highly susceptible to flooding (Salvia, 2010) and it is occupied by the city cores of the Municipalities, which are the most densely populated areas. The main infrastructures developed by the governmental authorities for dealing with this problem are focused on the improvement of the system by the construction of drainage channels and river tubing. Still, another problem arises due to the unplanned urban growth and the prevalence of the private interests on the urban decision-making. As the land is sensitive to flooding, the gated communities are constructed by diking the area and generating changes in the topography modifying its ecological characteristics (Daniele et al., 2005). The result is a mosaic of large private (protected?) elevated areas and public (vulnerable) depressed zones. The first ones block the natural drainage of the lands increasing the vulnerability of the rest of the city, inhabited not only by the medium social class but also by the poorest sectors of the society, which are the less prepared for facing a disaster and recover from the loses (Zagare, 2014).

Water demand / freshwater shortage

Even though the Parana Delta and the Rio de la Plata system constitutes one of the most important sources of surface water of the country (World Bank, 2000), it also has a high concentration of urban and economic activities, which have an elevated pollution potential. Changes in land uses such as the urbanization of rural areas, the increment of the number of dwellings and the increase of the scale of production cause a rise of water demand either in the continental areas or on the islands. The average water demand of the Metropolitan Area of Buenos Aires in 2003 was estimated in around 4.179.000 m³/day (AABA, 2010).

1.2.2 Infrastructure (network layer)

Summary of pressures

Flood protection:

Flood protection is built in the Parana Delta for production and residential purposes. In the last three years, the polder surface increased in around 16.5%, reaching 240.748 ha of polders. Apart from the polders, other used technique is the open ditch system, usually developed in small family production units, which consists in opening small channels or ditches connected with a watercourse to allow runoff from the fields by the action of gravity. Both types of works are developed by privates and alter the regime of the wetland. Thus, some other land movements have been carried on for the construction of residential developments. The topography of the affected islands has been modified to create marinas, clubs and large-scale residential areas, even reaching to a level of 5 m AMSL. These works are a clear consequence of the introduction of the concepts of gated community and consumption areas on the islands, as a product of the metropolitan model of urban growth

Irrigation and drainage:

In recent years, the Parana Delta has been a centre of attention due to wetland degradation and the modification of the hydrologic pattern (building of embankments, polders and paths, closure of water courses and streams), to favour large-scale livestock farming, commercial forestry systems and agriculture systems (Soybean crops). In the case of forestry, new technologies are under development to manage water entrance into the polders (with lock-gates) in order to avoid hydric deficit during the periods of droughts.,

Water supply and sanitation:
The islands of the Delta have no water supply or sanitation network. On the contrary, the cities along the borders of the Delta (including the Metropolitan Area of Buenos Aires) have an average coverage of the water supply network of around 50% and 20% of sewage system. Water supply captured from surface water courses represents 96% of the total daily production, while the rest 4% comes from yhe underground aquifers. The main source of surface water is the Rio de la Plata and the underground water sources are the Pampeano and Puelches aquifers.The aquifers are located between 20 and 120 m (lower sea level) and present flows between 3 and 100 m^3/h. Regarding sanitation, the system is divided into four areas and the catchment of the North area is treated in a plant located in San Fernando (in the Lower Delta), which has a capacity of treatment of 78.000 m^3/day and serves 270.000 dwellings of the departments of San Isidro, San Fernando and Tigre.

Roads, railways, ports and navigation channels:
The Parana Delta is connected to the metropolis and other urban areas by railways and highways. At the beginning of the urban expansion, the train had an essential role for the area as transport modality for passengers and freight. During the last decades of last century, public investment on highways encouraged the integration of the Delta into the dynamics of the metropolitan expansion from the basis of private transportation and favoured rapid access through land connections. The mobility network runs along the perimeter of the Delta, only crossing it through two systems of bridges and the routes run parallel to the coasts in the continental area. The terrestrial mobility network of railways and highways has always been deeply integrated with the port system that is located along the delta, which is the most important fluvial network of the country. It is the connection with the Atlantic Ocean and also holds the Parana-Paraguay waterway or ship channel (Hidrovía Parana-Paraguay) that links Nueva Palmira port in Uruguay with Caceres Port, located in Brasil

Research gaps
- Research on the positive and negative impacts of infrastructure for production purposes on the community and the delta. Innovative solutions to decrease negative effects of infrastructure.
- Studies of the consequences / impact of polders and embankments in terms of lost of wetland good and services, using and “accumulated impacts” approach.
- Studies on the impacts of the waterway development on the local economy and natural environment.
- Introduction and assessment of new approaches like natural infrastructure and hybrid engineering

Flood protection:
The main infrastructures developed to prevent flooding are the dikes and atajarrepuntes. Both elements are embankments usually formed by natural sediments of the river (mostly sand and mud), which main difference is related to their size. While the dikes can reach to a height of 4,8 to 5 m AMSL, the level of the atajarrepuntes varies from 3,5 to 3,8 m (Alvarez, 2011). The choice of constructing one or the other option (and also the design of the section) is based on the cost-benefit analysis of the production activity.

Dikes are built in the Parana Delta for different purposes. In 2013, a total of 240.748 ha of closed perimeter dikes were documented (Minotti and Kandus 2013). More than 36 % of the total diked surface was constructed for forestation purposes, while cattle raising, agricultural and urban uses occupy each about 10 %, and the rest 25% (a significant fraction) in for unknown aims. In the region, has also been recorded a total of 1.060 segments of embankments that run a total length of 5.181 km (Minotti and Kandus 2013). There is an increasing trend where new polders are located on the island sector and lowlands (Bajios Ribereños), expanding along the Lower Parana-Parana Guazu axis in front of the industrial belt between Campana and Rosario (Minotti and Kandus, 2013). In the last three years, 31.589 ha of new polders were built, representing an increase of 16.5 % comparing with 2010 (Minotti and Kandus 2013).

The open ditch system (sistema de zanja abierta) is still used in family-production units and consists in opening small channels or ditches connected with a watercourse, which allows runoff from the fields by the action of gravity. This method is often combined with “atajarepuntes” technique, to prevent the entry of water to the field in times of high river discharges (Donadille et al. 2010).
Both types of methods alter the hydrological regime of the wetland. In the case of family-type system, the output of water by pipeline trenching produces a significant loss of organic matter and nutrients. Large dams however produce a much more dramatic change in the structure and functioning of the wetland as they prevent the entry of water into the islands leading to a “terrestrialization” process (Quintana and Bo 2010). Other works related to water management are the clogs of streams and channels and the pipes in certain areas in order to drain the land (Bó et al., 2010; Quintana et al., 2014).

It is important to note that apart from the infrastructure works for production purposes, some other land movements have been carried on for the construction of residential developments. The topography of the affected islands has been modified to create marinas, clubs and large-scale residential areas, even reaching to a level of 5 m. These works are a clear consequence of the introduction of the concepts of gated community and consumption areas on the islands, as a product of the metropolitan model of urban growth (Zagare, 2014).

Irrigation and drainage:
Hydrological fluctuations dictate the alternation of aerobic and anaerobic conditions by regulating ecosystem functions and services. In addition to that, human activities influence (intentionally or not) the hydrology of the delta through of the conversion from a ‘‘wet’’ to a ‘‘dry’’ condition, which is often implemented through the simultaneous development of local infrastructure of water evacuation and flood control.

Infrastructure of water evacuation often includes drains (sometimes coupled with pumps at the plot level and channels at the regional level), while flood control infrastructure includes barriers such as dikes or other embankments capable of preventing surface water inputs. These interventions are mainly developed for production purposes (especially for forestation) and are complemented by lock-gates in order to manage the entrance water to guarantee the irrigation during periods of droughts. Drainage and wetland endikement generates a mecanism of reduction of the interaction between the river and the wetland affecting some of its ecosystemic services such as the decontamination of the water and the regulation of floods.

Water supply and sanitation:
The islands of the Delta have no water supply or sanitation network. On the contrary, the cities along the borders of the Delta (including the Metropolitan Area of Buenos Aires) have an average coverage of the water supply network of around 50% and 20% of sewage system. The production of water for consumption to serve the Metropolitan Area (including the Lower Delta) departments comes from two big water capture and treatment plants (Gral San Martin and Gral. Belgrano -located in the city of Buenos Aires and in the Department of Quilmes-), a third smaller plant (Dique Lujan), and the new Parana de las Palmas plant, both located in the Department of Tigre. The amount of water produced by the plants is 3.1 million m^3/day, 1.9 million m^3/day, 2.000 m^3/day and 1.2 million m^3/day respectively (AySA, 2014). The latter plant was built due to the increase in the demand of water caused by the densification of the continental areas of the Departments of Tigre and San Fernando and it is expected to cover the demand of other departments as well (AySA, 2014). Water supply captured from surface water courses represents 96% of the total daily production, while the rest 4% comes from underground aquifers (AABA, 2010). The main source of surface water is the Rio de la Plata and the underground water sources are the Pampeano and Puelches aquifers. The aquifers are located between 20 and 120 m (lower sea level) and present flows between 3 and 100 m^3/h (AABA, 2010).

Regarding sanitation in the region, the system is divided into four areas: Southwest, North, Ezeiza and Berazategui. The catchment of the North area is treated in a plant located in San Fernando, which has a capacity of treatment of 78.000 m^3/day and serves 270.000 dwellings of San Isidro, San Fernando and Tigre. In the future, it is expected to reach its expansion to serve a population of approximately one million people. The liquids treated at this plant return are being dumped at Reconquista River, one of the most important watersheds in Greater Buenos Aires (AySA, 2014).

Roads, railways, ports and navigation channels:

Routes and highways

The Parana Delta is connected to the metropolis and other urban areas by highways and railways. Running parallel to the coasts of the Parana River, the National Route RN9 connects all the departments of the Delta Bonaerense with Rosario in Santa Fe Province, which is also connected to Santa Fe (the capital of the province) and other northern departments by RN11. Transversely, the delta is only crossed by two National Routes, RN174 and RN12. The first one, located in the Upper Delta, connects the city of Rosario with Victoria (in the Province of Entre Rios). Also called *Rosario-Victoria Bridge*, it was built between 1998 and 2003. The latter, RN12, also crosses the delta in the Lower part, connecting the Province of Buenos Aires with the provinces of Entre Rios, Corrientes and Misiones. It starts in Zárate overpassing the Parana de las Palmas and the Parana Guazu Rivers, reaching the city of Brazo Largo in Entre Rios. The first stretch of this route materialises into a highway and railway bridge complex called *Zárate Brazo-Largo*. After crossing the delta, in the province of Entre Rios, the route joins with the Provincial Route 11 which runs parallel to the river along the entire eastern coast of the delta joining the Lower delta with the city of Parana (Entre Rios).

Public investment on large scale infrastructure favoured rapid access through land connections. The construction of the first stretch of the RN9 (also called *Panamericana* highway in this area) and especially its deviation called Ramal Tigre set the scene for the urbanization of the Lower Parana Delta, particularly the first section of the islands, the closest area to the continent. In fact, rapid access form city centre to the peri-urban zone favoured not only the urban sprawl in the northern area of the metropolis but also increased the settlement of residents who commute daily to work in the city centre.

Railway

The rail began operating in the country in 1857 in the city Buenos Aires, and with a start stretch of only 9 km, it expanded rapidly having a deep influence on the physical growth of the city and its relation to the delta and the entire country (Zagare, 2008). At the present, four railway lines run through the delta. Two of the lines travel parallel to the RN9, along the delta connecting Buenos Aires with Rosario. One of them is for passenger transportation (the 180 km-long *Ferrocarril Mitre*) while the other is for freight transport (*Ferrocarril Belgrano*). The third line (*Ferrocarril Urquiza*) crosses the delta through the Zárate-Brazo Largo Bridge complex, going through Entre Rios to the Mesopotamia and with connections to Uruguay´s railway network. The forth line, *Tren de la Costa*, is a local railway that travels along 15.4 km from Buenos Aires up to the Lower Delta (the terminal station is located in Tigre). After the inauguration in 1891 and it closure in 1961, the service was re-established during the 1990s following a new concept of train station, combined with leisure activities and commercial areas, encouraging the recognition of the area, especially Tigre, as a touristic node. According to Academia Nacional de Ingeniería (2011), the amount of annual passengers transported by this line reached 3 million in 1997, decreasing up to 1 million in 2010 and becoming more touristic due to the high rate of the service in comparison with the Mitre line.

Fluvial transportation

The terrestrial mobility network of railways and highways has always been deeply integrated with the port system (Basadonna, 2002). The Rio de la Plata-Parana River water corridor is the most important fluvial network of the country as it is the connection with the Atlantic Ocean and also holds the Parana-Paraguay waterway or ship channel (Hidrovía Parana-Paraguay) that links Nueva Palmira port in Uruguay with Caceres Port, located in Brasil (Salvatori et al., 2002). Apart from being relevant for Mercosur commerce, it allows accessibility to the Middle and Upper Delta.

Regarding fluvial passenger transportation of the Lower delta, from the port of Tigre there is a public service of boats, which travels along most rivers and canals. The frequency and coverage area is proportional to the proximity to this fluvial port. Thus, some remote areas are not covered by the public service of boats or have a frequency of only one or two services a day. That is the case of the second section of islands, which belongs to the Department of San Fernando. Other fluvial ports in San Fernando, Campana and Zárate serve as connection, especially for private services and large boats.

1.2.3 Natural resources (base layer)

Summary of pressures

Coastal erosion:
Although most coastal erosion existing on the Parana Delta is caused by natural processes, it is also induced by cattle raising, intensive agriculture and navigation.

River morphodynamics:
The Parana Delta is a complex estuarine system because, in contrast to other deltas, it does not discharge its sediments directly to the sea, but through the estuary of the Rio de la Plata. The Parana River presents a discharge of 18.000 m^3/sec and transports around 160 mill ton/year of sediments (28% clay, 56% mud and 16% sand). The sand which is deposited on the river mouth increases the length of the delta, while the mud influences on incrementing the size through the emergence of banks that become islands. In consequence, the delta has a rate of increased surface of around 617 km^2/year and in spite of a slight decrease of the growing rate during the latest decades, the delta front will continue advancing being expected to reach Buenos Aires city's coast in about 110 years.

Flooding (flood hazard):
The functioning and structure of the Delta wetlands are conditioned by periodic flooding influenced mainly by the discharges of the Parana river but also, in a lesser degree, by precipitations contributed by the tributaries of the continental margins, tides and the meteorological phenomenon known as "Sudestada". Those consist on persistent South-eastern winds coming from the Atlantic Ocean which increase the level of the Rio de la Plata.

Salinisation/salt intrusion:
Even in an extreme condition, the levels of salinization will not bring any consequence on the water quality for consumption supplied by the Rio de la Plata (surface source) for the Buenos Aires Metropolitan Area. Nevertheless, it could generate local negative effects that will have to be consequently evaluated. The estimated salt concentration is expected to reach 17% by the end of this century. Underground source of water (aquifers) suffers from salinization near the coast of Rio de la Plata and the Lower Delta, and below water courses, which may alter the quality of extracted water.

Water and soil pollution:
Water quality in the Parana Delta region is good, however there exists some evidences of organic pollution and eutrophication in some specific areas, mainly caused by te effects of agricultural expansion like livestock waste, pesticides, urban and industrial waste and sewage. The tributaries of the Parana River are examples of the adverse impacts of the anthropic activities due to their high levels of pollution, which exacerbates in the middle and lower sections of the rivers, where the water is not suitable for human consumption and even worse.

Wetland and biodiversity loss:
The use of natural levees (*albardones*) that surround the Lower Parana Delta's islands by settlers has resulted in the loss of native woodlands, Besides, the polders and embankments produce a drastic change in the structure and performance of the wetland as it prevents the entry of water into the islands leading to a "terrestrialization" of the area. The rate of wetland lost due to polderization was estimated in around 10.500 ha/year.
The Delta region includes also 25 protected areas of different size, jurisdiction and degree of implementation, totalling 488.000 ha under protection. Except those of national jurisdiction, the other protected areas lack of management plans or effective control measures.

Research gaps

- Study the impact on biodiversity and ecosystem services resulting from human intervention and particularly those related to large-scale productions.
- Interdisciplinary research on water and soil pollution and their effects on biodiversity and local communities. Particularly studies regarding the impact of agrochemical use in the aquatic biota, fisheries and other traditional production activities, including and assessment of economic losses.
- Studies on the invasion and impacts resulting from alien species.
- Studies and monitoring of the fish stocks and local fisheries of the Parana Delta

Coastal erosion:

Although most coastal erosion existing on the Parana Delta is caused by natural processes (Facultad de Ingeniería y Ciencias Hídricas, 2006), it is also induced by cattle raising, intensive agriculture and navigation. Ships can increase erosion by generating strong currents as they navigate parallel to the coasts. The consequences of extreme erosion are the change in sedimentation rates, the loss of the capacity to regulate the hydrologic regime, flooding, alteration of native ecosystems and disappearance of coastal vegetation and animal species (Moiraghi de Perez, 2001). It also represents a danger in terms of contamination and dissemination of diseases along the river. According to a study developed in the INTA (Instituto Nacional de Tecnología Agropecuaria) based on the use of Wischmeier and Smith's Universal Soil Loss Equation -USLE-, the Delta has a low-medium risk with an expected loss of 30 to 60 ton/ha per year (Orue et al. 2007).

Regarding dredging, according to the analysis developed in the University of La Plata (Facultad de Ingeniería y Ciencias Hídricas, 2006), although the estimated harm caused by this activity is not significant, more specific studies should be developed to measure the real damage considering also the possible changes of the internal channels´ streamflow (Stancich, 2007; Moiraghi de Perez, 2001). Apart from dredging, the erosion is also related to the waves that the ships generate as they travel along the river. This movement of water affects the shores.

River morphodynamics:

The Parana Delta is a complex estuarine system because, in contrast to other deltas, it does not discharge its sediments directly to the sea, but through the estuary of the Rio de la Plata (Parker and Marcolini, 1992). From a geographic perspective, the Delta was originally restricted to the terrestrial scope, but, from a geomorphologic point of view, the Delta may be analyzed together with the estuary due to the interaction between the delta plain and its natural limit, the Rio de la Plata (Parker and Marcolini, 1992; Cavallotto et al., 2005). Following the distinction of the components of deltas developed by Hori and Saito (2003) it is possible to observe that the subaqueous part of the Parana Delta overlaps with almost the entire Rio de la Plata's river-bed. It implies a relevant influence of the sedimentary processes that form the Delta over the estuary and its coastline. In fact, the Parana River presents a discharge of 18.000 m^3/sec and transports around 160 mill ton/year of sediments (28% clay, 56% mud and 16% sand). The sand which is deposited on the river mouth increases the length of the delta, while the mud influences on incrementing the size through the emergence of banks that become islands (Pittau et al., 2004). The linear advance of the front of the subaerial delta reaches a rate of 50/100 m per year for the sub-front of Parana de las Palmas and of 0/25 m per year for the Parana Guazu. During the period 1750-2010, the delta has increased its surface in around 617 km^2/year (Medina and Codignotto, 2011) and in spite of a slight decrease of the growing rate during the latest decades, the delta front will continue advancing being expected to reach Buenos Aires city's coast in about 110 years (Sarubbi & Menendez, 2007).

Flooding (flood hazard):

The functioning and structure of the Delta wetlands are conditioned by periodic flooding influenced mainly by the discharges of the Parana river but also, in a lesser degree, by precipitations contributed by the tributaries of the continental margins, tides and the meteorological phenomenon known as "Sudestada", which consists on persistent South-eastern winds coming from the Atlantic Ocean and rises of the

Uruguay river (Kandus et al., 2011). The pulse rate varies according to climatic processes defined by the general circulation of the atmosphere and anomalies such as El Niño Southern Oscillation. The extraordinary rises of the last 20 years are a good example of this variability presenting the alternation of wet and dry cycles that sometimes last decades (Kandus et al., 2011).

As a consequence of climate change, the Rio de la Plata is increasing its average level. This effect is caused by sea level rise, changes in the direction of the prevailing seasonal winds and increases in the discharges of the tributaries. Thus, increases in the frequency of storm surges from the ocean have significant influence on the future behavior of the Parana Delta. The effects of these phenomena imply greater vulnerability of coastal areas to flooding, which is determined by the progressive increase of recurrences. At the present, the most vulnerable areas in terms of flooding of intra-annual recurrence are West Escobar and Northern Tigre (including the islands), with annual average durations of between four and eight weeks (Fundación Metropolitana and Municipio de Tigre, 2013).

Salinisation/salt intrusion:
The process of salinisation that affects the delta is characterised by the movement of the salt wedge towards the Rio de la Plata due to the increase of the sea level. The scenario of maximum estimated increase of mean sea level by 2100 is 1 meter, generating a salinity front advance of about 10 km into the Rio de la Plata (Kind, 2004). It is estimated that this process will produce no significant effects to require the development of mitigation measures. For scenarios of extreme CO^2 concentrations, which estimate a sea level rise of around 4 meters, the salt wedge is not expected to advance more than 50 km. Even in that extreme condition, it will not bring any consequence on the water quality for consumption supplied by the Rio de la Plata for the Buenos Aires Metropolitan Area. Nevertheless, it could generate local negative effects that will have to be consequently evaluated. The estimated salt concentration is expected to reach 17% by the end of this century (Kind, 2004). Nevertheless, aquifers suffer from salinization near the coast of Rio de la Plata and the Lower Delta, and below water courses, which may alter the water quality extracted from underground.

Water and soil pollution:
Water quality in the Parana Delta region is good, however there exists some evidences of organic pollution and eutrophication in some specific areas (Puig et al. 2011); the livestock waste generates organic and microbiological contamination (parasites and pathogens), while traces of organochlorine pesticides were detected in fish tissues that are subject to subsistence fishing and sports (Puig et al. 2011). The Lujan and Reconquista rivers, tributaries to the Lower Delta, are examples of the adverse impacts of the anthropic activities. The water quality of the river´s courses is threatened and pollution levels exceed the guide values (AABA, 2010). This situation exacerbates in the middle and lower sections of the rivers, where the water is not suitable for human consumption and even worse, not suitable to be used even for production or recreational activities. The quality of aquifers is also affected but by salinization, generally produced on the coast of Rio de la Plata and the Lower Delta, and below water courses (AABA, 2010). The main causes of pollution within the Parana Delta and its tributaries are related mainly to industrial waste, sewage and the use of agrochemicals.

Wetland goods and services
The Parana Delta wetlands provide a number of ecosystem functions that ensure a good quality of life for both, local people and neighbouring areas inhabitants (Kandus et al. 2010, Oddy and Kandus 2011). Among the main regulation functions of hydrology given by the system it is worth to mention slowed flow and decreased water turbulence, water retention, long and short term water storage, and regulation of evapotranspiration. Different biochemical regulation processes enhance water quality and freshwater availability such as storage, transformation and degradation of nutrients and pollutants and salt regulation. From an ecological point of view, most herbaceous plant communities of the Delta are highly productive, sequestering carbon in soil and biomass (Pratolongo et al. 2007, 2008, Ceballos et al. 2012) and offering forage production for livestock and wildlife species of interest (Quintana et al. 1998, Pereira et al. 2003, Gonzalez et al. 2008, Magnano et al. 2013). More than 25 % of wildlife is used by local people for meat, leather and feathers (Bó and Quintana 2013, Quintana and Bó 2013). The region is good for offering sport fishing throughout the year and for supplying large migratory species of commercial value for export, fishmongers and restaurants (Baigún et al. 2009).

Biodiversity lost
The use of natural levees (*albardones*) that surround the Lower Parana Delta's islands by settlers has resulted in the loss of native woodlands, Besides, the polders and embankments built in the Delta produce a drastic change in the structure and performance of the wetland as it prevents the entry of water into the islands leading to a "terrestrialization" of the area. The rate of wetland lost due to polderization was estimated in around 10.500 ha/year (Minotti and Kandus 2013). This process not only decreases the buffering capacity of the marshlands environment to prevent floods but also affects many of the typical species that inhabit the islands (Bo et al., 2010; Bo and Quintana, 2011; Sica et al., 2013).). The dikes in the Delta can also cause a replacement of the original vegetation cover, changes in the characteristics of the soil, loss of habitat for wetland-dependent species, appearance of foreign plants and animals typical of terrestrial ecosystems (Fracassi et al., 2010; Bó y Quintana, 2011), loss of water quality and effects on wildlife due to the use of agrochemicals (Bo et al., 2010).

Protected Areas
The Delta region includes 25 protected areas of different size, jurisdiction and degree of implementation, totaling 488.000 ha under protection. The largest ones are *"Parque Nacional Predelta", "Parque Nacional Islas de Santa Fe", "Reserva Natural Estricta Otamendi (Sitio Ramsar)", "Reserva de Usos Multiples Islas de Victoria", "Reserva Natural Delta en Formacion", "Reserva Natural Parana Guazu"* and "*Reserva de Biosfera Delta del Parana"* (Boscarol 2013). Except those of national jurisdiction, the other protected areas lack of management plans or effective control measures.

Impact on fisheries
The embankments built for the development of livestock and large-scale agriculture, increasingly abundant in the Parana Delta, as well as the obstruction of streams and channels, disrupt the free flow of the runoff into the floodplain, restricting the filling of internal lagoons and watercourses and limiting the entry or exit of fish and the consequent development of fishing practices (Baigun 2013).

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government:
The network of jurisdictional authorities, competences and boundaries is complex. It is divided into three subnational jurisdictions (Provinces) and 19 local governments (Municipalities or Departments). There is a complex network of institutions that have the competence to decide on the Parana Delta region. The diversity of functional authorities, complex institutional arrangements and conflicting visions on the area's role, converge in making the design and implementation of policies and measures, including water management and land use strategies, a difficult task. In addition, frequently decisions taken by agencies are conflicting with the functions allocated by the regulatory framework and their legal assignment of competences, and in between government agencies, so the conflict on environmental issues is reflected within the institutions, at the different levels of government and even in the decision making process itself

Cooperation between government and private sector:
The private sector is very diverse and includes from small scale cooperatives up to large institutions. Beyond some initiatives developed by the INTA (Instituto Nacional de Tecnología Agropecuaria) and the INTI (Instituto Nacional de Tecnología Industrial) or programs like PROSAP (Programa de Servicios Agricolas Provinciales), the level of cooperation between the public and private sector is low. One remarkable Public-Private enterprise is the Management Plan for the Delta of Tigre (Plan de Manejo de las Islas del Tigre), developed by Fundación Metropolitana and the government of the Department of Tigre in 2013.

Involvement of stakeholders and citizens:
The civil society is strongly involved in the Parana Delta, either through research institutions and local groups who fight for the fulfillment of environmental rights and the protection of the region. Today there are more than 35 civil society organizations that focus their work on the Parana Delta and the surrounding area. The level of participation has increased as the threats manifest more visible. Also, an increase in the participation of NGOs in the design of public policies and monitoring processes of territorial planning is observed.

Approaches for dealing with risks and uncertainties:
The National Water Institute (Instituto Nacional del Agua, INA) has an important role through hydrological alerts and warnings of flood events, which has a great importance Apart from that, there are no approaches to dealing with risks and uncertainties in terms of processes and policy.

Research gaps
- Need for enforcement of existing legislation and plans.
- Increase of the tools for citizen participation in decision making process.
- Development of integrated management plans taking into account the heterogeneity of the delta and the different kinds of actors involved

1.3.1 Cooperation between (scale) levels and sectors of government

The Parana Delta region involves the governments of three provinces (Entre Rios, Buenos Aires and Santa Fe) and 19 departments (Secretaría de Ambiente y Desarrollo Sustentable, 2008). In the province of Entre Rios, the delta occupies part of the departments of Parana, Diamante, Victoria, Gualeguay, Gualeguaychu and Ibicuy Islands. In the province of Buenos Aires it comprises part of the departments of San Nicolas, Ramallo, San Pedro, Baradero, Zárate, Campana, Escobar, Tigre and San Fernando. In Santa Fe, the delta occupies a portion of the departments of La Capital, San Geronimo, San Lorenzo and Rosario. The Federal Government has also competence in the area through the Integral Strategic Plan for the Conservation and Sustainable Development of the Parana Delta Region (Plan Integral Estrategico para la Conservacion y el Desarrollo Sostenible de la Region Delta del Parana PIECAS-DP) process and through conservation agencies as the National Parks Administration (Administracion de Parques Nacionales APN), extension services as the National Institute of Agricultural Technology (Instituto Nacional de Tecnología Agropecuaria INTA), the Ministry of Agriculture, Livestock and Fisheries (Ministerio de Agricultura, Ganaderia y Pesca) and has enacted national policies and programs to promote production activities (PROSAP - Programa de Servicios Agricolas Provinciales-, etc).

There is a complex network of institutions that have the competence to decide on the Parana Delta region (Machain et al., 2013), which in many cases have different views and positions on the role of the islands. This is highly visible among institutions at different level of government, which in some cases promote production development activities while their mission is the protection of natural resources and the environment: while environmental agencies are intended to mitigate and minimize impacts on natural systems, agencies that regulate production activities often simultaneously promote an increase of development activities in the same areas. In addition, frequently decisions taken by agencies are conflicting with the functions allocated by the regulatory framework and their legal assignment of competences, and in between government agencies, so the conflict on environmental issues is reflected within the institutions, at the different levels of government and even in the decision making process itself.

Even though in the environmental governance system in place in Argentina provincial states are the ones that have the domain over natural resources in their territory, national policies to encourage production activities, the structure of incentives prevailing and the current international context driving the demand of food products have an influence in economic activities developed in the Delta, including soybean monoculture.

Among provinces and municipalities there are different levels of decision making powers and that, in practice, often generate distinctions in policy implementation according to the capacities of each municipality and also due to the political position of their governmental authorities. The municipalities are motivated by their need to generate their own resources and development potential.

The cooperation between different levels of government is clearly displayed on the PIECAS-DP (Plan Integral Estrategico para la Conservacion y el Desarrollo Sostenible de la Region Delta del Parana), where the three provinces that share the Delta and the nation are committed to working together to achieve sustainable development in the region (Secretaría de Ambiente y Desarrollo Sustentable, 2011). This practice is sometimes not so easy to implement given the existence of conflicts between the jurisdictions.

1.3.2 Cooperation between government and private sector

The private sector is very diverse and includes from fishing cooperatives and small producers (mimbreros, etc) to institutions that gather large producers such as the Argentine Forestry Association (AFoA) and the Rural Society of the Ibicuy Islands, among others (Machain et al. 2013).

Depending on the activity they develop, their level of information, the immediacy within the environment, their importance in the market and their contribution to the regional and local economy, production sectors differ in their knowledge about the environmental value of the Delta, the impacts of their activities on the environment and the need to internalize these costs.

Cooperation between governments and production sectors of the Delta can be viewed from different perspectives. Some national institutions such as INTA and INTI (Instituto Nacional de Tecnología Industrial) and programs like PROSAP are working with producers to strengthen development of production activities in the Delta. The provinces and municipalities have the power to authorize infrastructure (dams, roads, etc.) in their territories of the Delta, and the responsibility of monitoring and enforcement of existing regulations.

1.3.3 Involvement of stakeholders and citizens

The deterioration of the Parana Delta due to the advance of large-scale gated communities (Blanco and Mendez, 2010) has encouraged the interest and active participation of civil society in the area, resulting in the creation groups of interest and political influence. These groups of people are concerned about the environmental and social impacts that the development of some activities have, and about the increasing impossibility of control by the authorities. The groups perform various actions such as generation of knowledge, working with producers in development and implementation of more sustainable production practices, public demands and communication and education initiatives. Today there are more than 35 civil society organizations that focus their work on the Parana Delta and the surrounding area.
Regarding participation of citizens in the decision making processes of the Delta, it can be mentioned that in Argentina there is a regime on Free Access to Public Environmental Information, which seeks to guarantee the right of access to the information that is under the State domain, either under the national, provincial or municipal spheres. In addition, the Environmental Public Hearing process provides the community and organizations with the opportunity to learn about the works, activities or projects that are being (or are going to be) developed, and the positive or negative impacts that they may have on the Delta (Fundación Ambiente y Recursos Naturales, 2012) .

1.3.4 Approaches for dealing with risks and uncertainties

At the present, there are not many approaches to dealing with risks and uncertainties in terms of processes and policy. However, considering climate change effects, it is expected that this approach

may be incorporated in the policy agenda. One iniciative is the one developed by the National Water Institute (Instituto Nacional del Agua, INA), which has an important role through hydrological alerts and warnings of flood events, being important to guide the decisions of some productive sectors of the region, such as farmers.

1.3.5 Overview of key stakeholders regarding delta management issues

Key stakeholders	Brief description of responsibilities and tasks regarding delta management issues
Research institutes	
3iA - UNSAM	Research and knowledge generation based on the Delta and other processes involving the region as a basis to help management.
GIyEH- ISU, UBA	
Fundación Torcuato Di Tella	
EEA Delta del Parana (Instituto Nacional de Tecnología Agropecuaria - INTA / MAGyP)	Research, transference and extension of the chain of Salicaceas forestation, cattle industry, beekeeping and Walnut Pecan production. Research about issues affecting production, such as rural development chains, regional systemic competitiveness, sustainability and environmental health.
Policy makers (nacional level)	
SAyDS / PIECAS	Design and implementation of national environmental policy, rational use of natural resources and preservation of the human environment, in coordination with the provinces. PIECAS Secretaríat and coordinator of the High Level Committee comprises representatives of the provinces of Entre Rios, Santa Fe and Buenos Aires,
Administracion de Parques Nacionales	Design, conduct and monitor the implementation of the necessary measures to conserve and manage protected areas under its jurisdiction in the Delta policy.
• Instituto Nacional del Agua (INA)	Research, development and delivery of specialized services for the use and preservation of water. Hydrological Alerts for the Delta.
Prefectura Naval Argentina (PNA)	Law enforcement attributions and control of activities in the Delta.
• Programa de Servicios Agricolas Provinciales - PROSAP	Encouraging initiatives that promote the competitiveness of small and medium farmers. Development of infrastructure in the Delta.
Policy makers (provincial level)	
Gobierno provincia de Entre Rios (Secretaría de Ambiente, CORUFA, etc)	The provinces have the original domain of natural resources under their jurisdiction, and they develop the policies that promote resource´s use and enjoyment. This task is carried out by the ministries or agencies of implementation, in every jurisdiction, having among its missions the management and preservation of natural resources.
• Gobierno provincia de Buenos Aires (OPDS, Direccion provincial de Islas, etc)	
Gobierno provincia de Santa Fe (Secretaría de Ambiente, etc)	

Policy makers (local level)	
Gobiernos municipales	Municipalities are units of local administration responsible for the daily management of their territorial framework, coinciding with the law enforcement of the Provincial Government to whose they belong to.
Consejo Intermunicipal del Delta - CONINDELTA	Inter-municipal cooperation for production development of the region.
Developers	
Camara Empresaria de Desarrolladores Urbanos	Urban development and real estate.
Empresas de negocios inmobiliarios	
Industry	
Sector forestal (AFoA, empresas, productores etc)	Production activities based on the use of natural resources of the Delta. Development of sectoral policies, including the promotion of best production practices. Development of infrastructure by private sector.
Sector apicola (SADA, apicultores, etc)	
Sector ganadero (sociedades rurales, productores, SRA, FAA Delta, etc)	
Sector pesquero (cooperativas de pescadores, acopiadores, etc)	
Sector agricola (productores, etc)	
CSOs / citizens	
Fundación Humedales / WI	Contribution to knowledge and sustainable development of the Delta, as well as the defense of the interests of its people.
Fundación MBigua	
Taller Ecologista	
Fundación ProTigre y Cuenca del Plata	
Fundación Oga	
Asamblea Delta y Rio de la Plata	

1.3.6 Governance structures and networks of key stakeholders (including international platforms)

The complexity of the Parana Delta region needs an integrated approach, which is addressed in the PIECAS Letter of Intent, signed in September 2008 by the provinces of Entre Rios, Santa Fe and Buenos Aires and also by the Secretariat of Environment and Sustainable Development of the Nation (Secretaría de Ambiente y Desarrollo Sustentable de la Nacion - SAyDS). Within the PIECAS there is an Inter-jurisdictional Committee (Comité Interjurisdiccional de Alto Nivel - CIAN), formed by members of the governments of the three provinces that share the region and the SAyDS, which has the role of coordinating and executing the necessary measures to guarantee the cooperation and the achievement of the objectives of the Plan.

1.3.7 Overview of decision making process (including legal instruments)

The Parana Delta region is a complex area from a governance perspective given the number of jurisdictions and agencies involved and with management functions, as well as due to the diversity of

pertinent legislation (Machain, 2010). Thus, a variety of decision-making processes that take place at different levels and are articulated in greater or lesser degree is observed, among which we highlight the PIECAS -DP and the Management Plan for the Delta of Tigre (Plan de Manejo de las Islas del Tigre).

- PIECAS -DP (Secretaría de Ambiente y Desarrollo Sustentable, 2008): The complexity of the Parana Delta region needs an integrated approach, which is addressed in the PIECAS-DP Letter of Intent, signed in September 2008 by the provinces of Entre Rios, Santa Fe and Buenos Aires and also by the Secretaríat of Environment and Sustainable Development of the Nation (Secretaría de Ambiente y Desarrollo Sustentable de la Nacion). It is a process with high social and political value which continuity must be assured to set the bases for the territorial organization of the region.

- Management Plan for the Delta of Tigre (Fundación Metropolitana and Municipio de Tigre, 2013). In July 2012, the Municipality of Tigre (located in the Province of Buenos Aires) constituted the Special Committee of the Environmental Management Plan for the First Section of the Delta Islands. The plan, approved in March 2013, promotes the sustainable development of all human activities on the islands and poses strategic axes preserve the wetland and water resource. Among other objectives, the aims are the adaptation to the environmental conditions, the regularization of the domain of the lands and the promotion of the inclusion and integration of the population.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends Population in Delta [I] Migration [I]	(Of the Delta and of the Major conurbation) • Population. • Density. • Population growth rate. • Migration trend in/out Delta. • Rates of Poverty and Unemployment.
Economic developments Status of total economy [I] Sectorial developments [I]	• Diversity of income generating activities. • GDP: annual, grow rate, per capita, sectorial, % contribution of Delta and of the major city. • Annual production by sector, grow rate. • Unemployment rate. • % of contribution of Delta traditional activities. • Front runner position in green and clean technologies.
Technological developments Agricultural and aquaculture Civil engineering ITC Energy generation	• % contribution of the city/the Delta to GDP in construction sector, transportation and communication (ITC), and services. • Levees, dikes, or other infrastructural works.

Climate change Air and sea water temperature Sea level rise Precipitation / discharge	(Down scaling of global IPCC scenarios) • Change of air and sea water temperature and evaporation rates. • Change of sea level (mm/year). • Change of precipitation (mm/year) and river discharge (m^3/year). • Change in frequency / intensity of storms and flood events. • Change in drought index. • Change in number of days with extreme rain intensity or more than 100 mm/day (days/year). • Rate of coastal wetland to the total municipality area. • Salinity intrusion. • Greenhouse Gases. Emissions.
Subsidence natural and human induced subsidence	• Cause of subsidence and annual rate (mm/year). • Sedimentation vs. subsidence rates at the river mouths.
PRESSURES/PROBLEMS	**Main indicators**
Land and water use (occupation layer) pressure on space Shift in land use / urbanization Degradation of mangroves Water demand Flood vulnerability	(Of the Delta and of the Major conurbation) • Population. • Density. • Rate of urbanization in wetland areas (Delta and surroundings). • Rate of wetland loss due to embankments (Delta). • Changes in land uses and values. areas (Delta and surroundings). • % area vulnerable for flooding / number of vulnerable people / value of vulnerable assets. • Navigation intensity / no. of transiting ships.
Network / infrastructure (network layer) Flood protection system Irrigation and drainage Water supply & sanitation Roads, railways and ports	• Flood risk (safety level), % of delta protected (high medium - low). • % coverage of public/domestic water supply network (Delta) • Dwellings with sewage system (24 Departments of Metropolitan Area, with the exception of the city of Buenos Aires) • Dwellings with sewage system (Coastal cities of the Parana Delta) • Extent of linear embankment infrastructures (length of network in the Delta). • Extent of paved routes (in the Delta). • Number of ports (+ volume of goods). • % of Delta area with polders (forestry, agriculture, cattle raising).

Natural resources (base layer) Sediment supply Mobility of delta distributaries Coastal erosion / wetland loss Wetland degradation Fisheries resources Biodiversity loss Pollution Freshwater shortage / Salinity Land reclamation River network Natural gas	• Erosion rates (cm/year). • Fluvial sediment transport. • River discharge (peak/low and variability) Flood – drought pulses. • Recurrence of extreme events (floods and droughts). • Frequency of storms (storm surge) “Sudestadas”. • Number of dry days. • Number of days with extreme rain intensity over the 90th percentile. • Area of wetland lost within the Delta due to polderization. • Total area of protected wetland.
GOVERNANCE	**Main indicators**
Multi-level and multi-sectorial cooperation	• Existence of integrated plans (delta plan, national adaptation plan etc.). • Existence of interministerial committees, multi scale level and multidisciplinary committees etc. • Plan development and results. • Enforcement (implementation of relevant laws, regulations and policy).
Public-private partnerships	• Number of PPP’s. • Scale of PPP’s (geographic, budget, time span).
Involvement of stakeholders and citizens	• Existence of legal public instruments and forum for involvement in planning and decision making. • Existence of NGO’s and public associations. • Number of NGOs involved in planning and decision making.
Approaches for dealing with risks and uncertainties	• Existence of adaptive management, adaptation strategies etc. (long term). • Existence of risk management, emergency systems etc. (short term). • Communes with adaptation plans.

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.
The following two development scenarios are recognized:

- Scenario 1, moderate perspective 2050: medium economic growth and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario 2, extreme perspective 2050: high economic growth and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	+	0	-	0	+
Scenario1 moderate 2050	0	0	+	+	0
Scenario 2 extreme 2050	-	+	0	+	-

resilience/sustainability: ++ (very good), + (good), 0 (medium), - (low), -- (very low)

Concluding remarks on score card:

Even though the pressure on land use and the negatives impacts of human activities are high in some sectors of the Delta, they are concentrated mainly in the Lower Delta, which represents 43% of the total area of the region. In both scenarios (moderate and intensive), the pressures on land use and natural resources are expected to increase due to the growth of Buenos Aires Metropolitan Area and other big cities located in the margins of the delta- together with the introduction of “continental” residential typologies into the islands-, as well as a result of the expansion of production activities, especially large-scale agriculture and forestry. In terms of infrastructure, only under an extreme scenario the implementation of innovative technologies for sustainable development is expected because nowadays it is not considered a priority by the gonvernments. On the contrary, the Delta is still being underestimated regarding its values and potentialities. In terms of governance, an improvement is expected resulting from the implementation of the integrated plan of PIECAS and the coordination of actions among the different jurisdictions that share the region. Besides, the increasing movilization and participation of citizens and Civil Society Organizations (CSOs) would contribute to enhance governance through increased adaptive capacity.

2. Overview of adaptive measures in the Parana Delta

Overview of (possible) adaptive measures in the three spatial layers based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

2.1 Overview of (possible) adaptive measures

The adaptive measures described below are just a few examples that have been for selected for the purpose of this assessment, although it is emphasized that there are more cases that could be addressed in further investigations.

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
Plan for the Conservation and Sustainable Development of the Parana Delta Region-PIECAS-DP (Secretaría de Ambiente y Desarrollo Sustentable 2008)	4	Plan under development with participation of the Governments of Entre Rios, Santa Fe and Buenos Aires provinces and the National Government (SAyDS).	1, 2	1, 2, 3
Parana Delta Fire management Sub-commission	1, 4	Program to prevent the fires in the Parana Delta, under the coordination of the National Government.	1	1, 2, 3
Management Plan for the Delta of Tigre (Fundación Metropolitana y Municipio de Tigre 2013)	4	Plan to order land use and occupation patterns in the island sector of Tigre.	1, 2	1, 2, 3
Creation of protected areas	1, 2, 4	Creation, implementation and management of protected areas.	1, 2	1
Water management in dikes for forestry production	1, 2	INTA is working to develop specific technology to avoid water stress in forestry production in polders within the Delta.	1, 2	2, 3
Multisectorial dialogue platforms	1, 2, 3, 4	Promotion of cooperation between different sectors and stakeholders of the Parana Delta.	1, 2	1, 2, 3
Hydrologic alert for cattle industry by the Instituto Nacional del Agua (INA)	1, 2	Periodic reports on the hydrological situation and potential rises of water within the Parana Delta	1, 2, 3	1, 2

2.2 Examples of best practices

A series of manuals and protocols were or are being developed to promote best production practices within the Parana Delta; these are:

- Protocol for biodiversity conservation in forestry lands (http://inta.gob.ar/unidades/714000).
- Manual for environmental management of artisanal fishing and good fishing practices in the Paraná River basin (Baigún, 2013).
- Manual for environmental management of island cattle raising (Quintana et al. in prep).

3 Overview of technical methods and tools to support delta management and development in the Parana Delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues.

The technical methods and tools listed below are just a few examples that have been chosen according to this assessment, although it is emphasized that there are more cases that could be addressed in further investigations.

Name of tool	Brief description	Institute	Available at
ECOSER Protocol	Protocol for assessment of ecosystem functions. Used in the Lower Parana Delta by Oddi and Kandus (2011).	INTA (Instituto Nacional de Tecnología Agropecuaria)	inta.gob.ar/ unidades/714000
Urban and environmental scenario analysis	Scenario analysis for an integral approach to urban and environmental dimensions in the Lower Parana Delta.	TUDelft, Fundación Humedales / Wetlands International	www.deltasud.org
Remote Sensing analysis	Mapping of wetland habitats and land uses based on the classification of satellite imagery and GIS analysis.	LETyE / 3iA / UNSAM	www.unsam.edu.ar
Environmental Management manuals for producers	Development of manual on artisanal fisheries and island cattle raising in partnership with Delta producers and INTA	Fundación Humedales / Wetlands International	http://lac.wetlands.org/
Manuals of best Forestry production practices	Best Practices Guide for the sustainability of forest plantations in the Parana Lower Delta. Protocol of biodiversity conservation in the Parana Delta.	INTA (Instituto Nacional de Tecnología Agropecuaria)	inta.gob.ar/ unidades/714000

Capacity building workshops	Workshops directed to decision makers and CSOs of the Parana Delta, regarding wetlands vs. land planning and ecosystem based adaptation to climate change.	Fundación Humedales / Wetlands International	http://lac.wetlands.org/
Observatory of rural sustainability	Observatory of rural sustainability of the area "Zona Núcleo forestal" (Forest Core Area) of the Lower Delta.	INTA (Instituto Nacional de Tecnología Agropecuaria)	inta.gob.ar/unidades/714000
Socio-economic valuation of ecosistems services	Socio-economic valuation of ecosistems services of the Parana Delta wetlands.	Fundación Humedales / Wetlands International	http://lac.wetlands.org/
Georreferenced environmental sustainability indicators in wetlands at regional scale	Develop a protocol for georeferenced environmental sustainability indicators in wetlands based on the provision of ecosystem goods and services on a regional scale, from the integration of satellite observations and field data.	LETyE / 3iA / UNSAM and other partners	www.unsam.edu.ar
Water management in dikes for forestry production	INTA is working to develop specific technology to avoid water stress in forestry production in polders within the Delta.	INTA (Instituto Nacional de Tecnología Agropecuaria)	www.inta.gov.ar

4 Knowledge exchange and development

4.1 Lessons learned on delta management

The Para Delta is a complex area with many stakeholders involved and where different production activities are being developed. This fact, combined with the multiplicity of jurisdictions with different roles and views on the Delta, make the management of the region a difficult task.

The integrated management of the region and the coordination between the different jurisdictions of the Parana Delta is essential.

Baseline information is difficult to find and analyse at regional scale, particularly because sometimes this information is patchy or exist only at local level. The access to information is also difficult to achieve.

Governmental presence and controls are essential to order the use of the land and water towards the sustainable development of the region.

To maintain the ecological integrity of the Parana Delta, a "cumulative impacts" analysis should be performed in any decision making process, even if it is related to a local development.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

Need for the development of climate change projections at the Delta and local scales.

Multi-disciplinary assessment of the combined impacts of human activities on the wetland and its resilience capacity in a context of climate change. Generation of future scenarios.

Research on strategies to include climate change projections and impact assessments into policy and guidelines.

Pressures – potential problems / Challenges - opportunities

Comprehensive database on climatic, natural resources and socio-economic parameters in order to support research and development of initiatives. Availability of the information for research purposes.

Study on the effects of the different occupation typologies on the wetland (residential, production, recreation, etc.). Research on innovative solutions to prevent the increase of the terrestrialization trend, finding new ways of occupation according to the context.

Research on innovative solutions for the government to recover its key role on territorial planning and management.

Development of models regarding flooding scenarios in order to integrate them to planning decision-making. Study of the vulnerability to flood of coastal cities.

Research on the positive and negative impacts of infrastructure for production purposes on the community and the delta. Innovative solutions to decrease negative effects of infrastructure.

Studies on the impacts of the waterway and viaducts development on the local economy and natural environment.

Interdisciplinary research on water and soil pollution and their effects on the communities. Monitoring of changes in the area.

Studies of the consequences / impact of polders and embankments in terms of lost of wetland good and services, using and “accumulated impacts” approach.

Studies regarding the impact of agrochemical use in the Delta populations, aquatic biota, fisheries and other traditional production activities, including economic losses.

Adaptive measures

Research on adaptation and climate proofing measures for the specific reality of this delta.

Need for improve data collection, monitoring and evaluation system and for integrate them to delta management.

Need for improvement of flood, drought and storm surge awareness, response and mitigation system. Development of integral scenarios addressing climate change, urban growth, production and technological changes.

Need for a quantification of ecosystem services and estimation of benefits to livelihoods and the economy.

Need to promote integrated delta management addressing the main land (catchment) and coastal lands and the dynamic between them. Need for a relation between delta and cities' planning systems to prepare for future scenarios of climate change.

Technical methods and tools

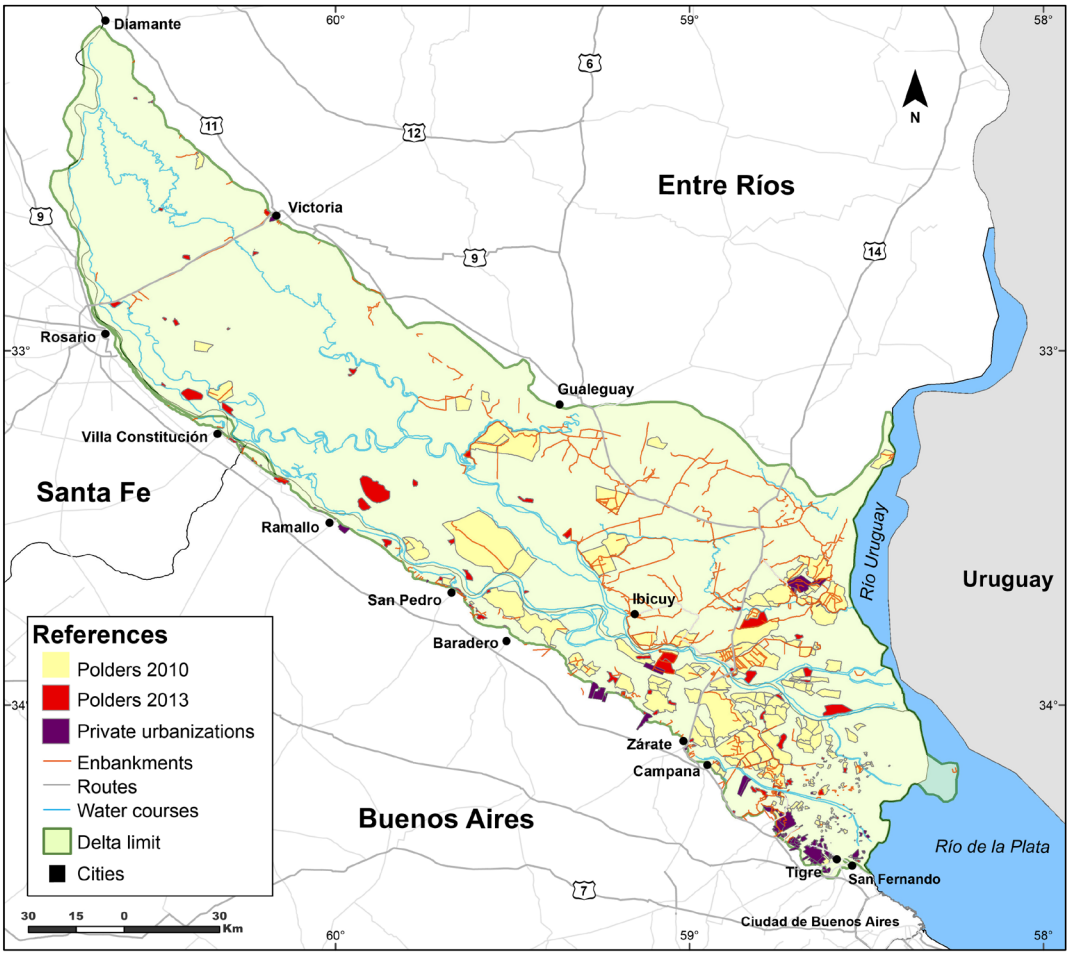
Need for an exchange of knowledge and tools and also for the development of models of integrated spatial planning and study flood vulnerability in the coastal cities.

Need for the development of tools for forecasting of erosion and deposition pattern in the delta, high resolution regional climate models to generate multi-ensemble high spatial and temporal resolution and also to downscale global/regional climate models.

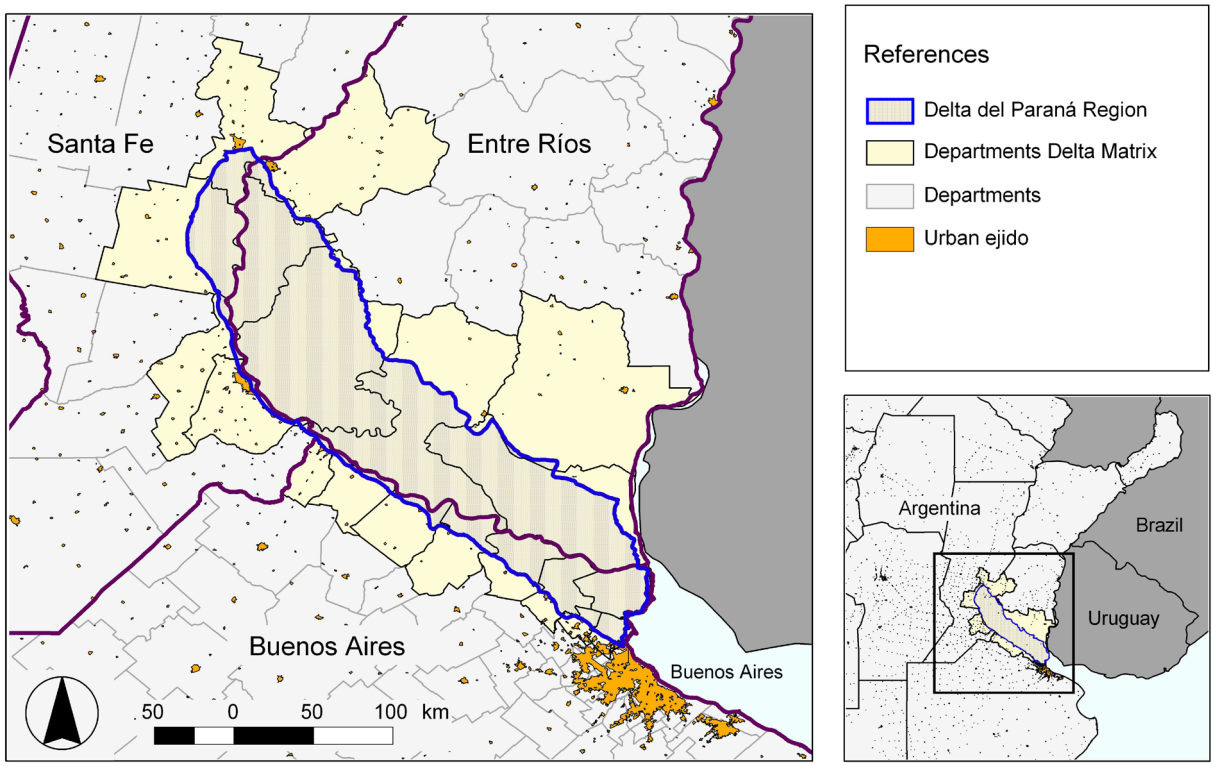
Need for the development of a socio-economic model to project future economic development and demographic change, and land use change model to identify areas of potential growth.

Need of creation and implementation of a Water Observatory for monitoring water quality within the Parana Delta.

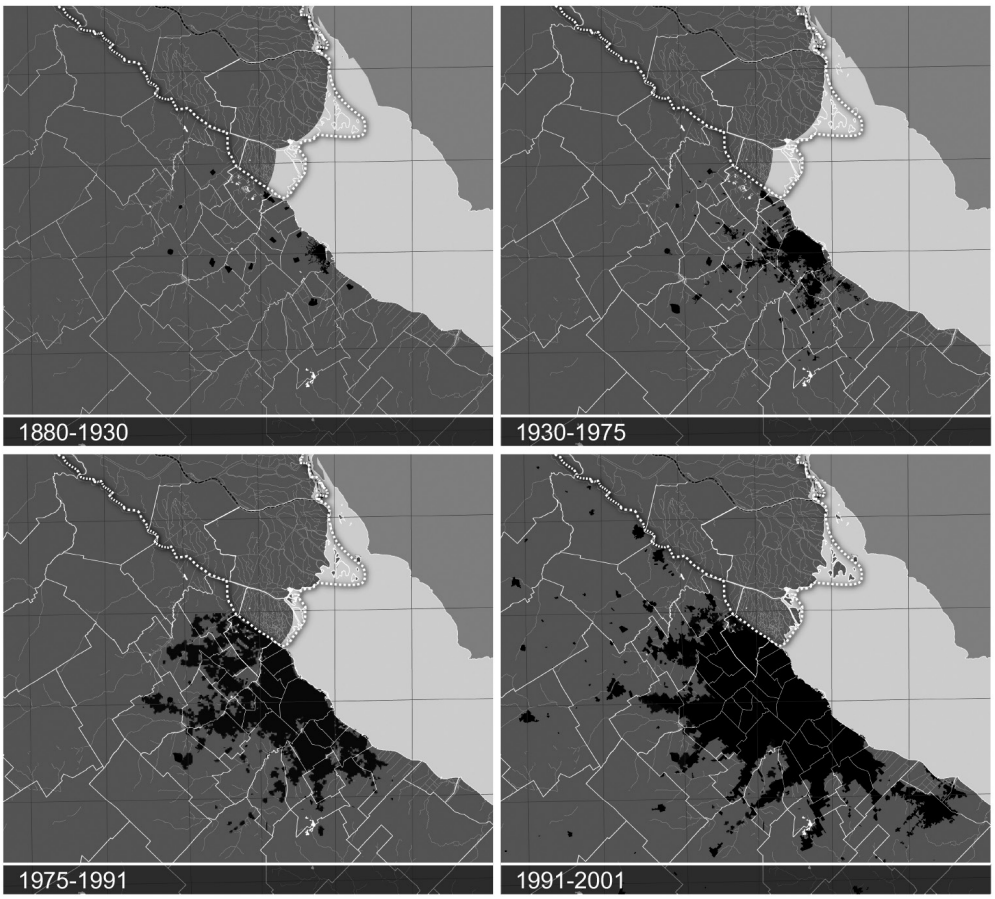
4.3 Some available illustrations (map of delta, typical sites, etc.)



Polders, enbankments and private urbanizations in the Parana Delta Region. [Minotti et al. (2013)]



Parana Delta. [Fundación para la Conservación y el uso sustentable de los Humedales / Wetlands International].



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Big cities located around the Delta. [Ruben Quintana] Region. [Minotti et al. (2013)]

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Sheeps over a dike in the Parana Delta. [Natalia Machain]

Aerial view of the islands of the Delta (left) and the continental area (right). [Verónica Zagare (2014)]

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