SYNTHESIS REPORT: The Implications of Climate Change and Sea-Level Rise in Tanzania – THE COASTAL ZONES

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SUMMARY

The report first synthesis the existing literature on the impacts of, and key risks from, climate change and sea-level rise, and then presents a summary of the national results on the potential physical and socio-economic damages and adaptation costs for the coastal zones of Tanzania through the 21st century based on a recent continent- and country-level study using the DIVA (Dynamic Interactive Vulnerability Assessment) model application carried out as part of the DFID Economics of climate change in East Africa. It also provides a strategic advice on adaptation in terms of planning for the future.

The study outlined that climate change could pose significant risks in the coastal zones of Tanzania due to the high concentrations of population, significant economic activity, and important ecosystem services within low-lying areas. The low national economy and other development indicators, and high dependence on natural coastal resources add to the challenge. Although uncertainties in climate change and impact projections cause significant challenges globally for anticipatory adaptation responses, the results in this report provide cost estimates of part of the coastal investment that might be considered in Tanzania over the 21st century, helps to facilitate decision making under conditions of deep uncertainty.

Results showed that if no adaptation measures are considered, the physical, human, and economic impacts could be severe with sea-level rise scenarios through this century. Even without climate-induced sea-level rise, there are some damages and costs due to increase in population, population density, and GDP in vulnerable areas. The DIVA results suggest that protection via building and/or upgrading of dikes and beach/shore nourishment could be an effective response to significantly reduce these impacts. However, it is important to note that even with adaptation measures, there are some residual damages. Nonetheless, coastal protection appears to substantively reduce the threats imposed by sea-level rise, and the benefits of adaptation outweigh the costs, as illustrated in the analysis. It is estimated that in 2030 the coastal zones of Tanzania could experience a cumulative land loss of 7624km^2 to erosion and submergence, approximately 1.6 million people per year anticipated being flooded, and a cumulative total of over 852,000 people forced to migrate since 2000, leading to a total residual damage cost as high as US$42 million per year. These impacts rapidly increase with time. The study also shows that adaptation measures can reduce these impacts very significantly. Even so, the costs of adaptation are large, estimated between US$16 and US$62 million per year. The residual damages are estimated at US$15 millions.

Moreover, as there is a strong potential for development to increase future vulnerability, forward spatial planning to ensure flexibility, and to focus population and economic growth in less vulnerable areas and to control the overall growth in the coastal zone could be an important part of a strategic response to sea-level rise, which could significantly reduce exposure, and hence damages and costs. This could be interpreted as a planning policy to define hazardous zones and not developing them, although implementation of such a policy in poor developing country like Tanzania could be a major issue.

The main conclusion is that adaptation costs in response to sea-level rise remain rather uncertain and require further more detailed assessment. The results also show that there is a significant need for coastal adaptation to today's climate as well as future climate change and rising sea levels, which should be carefully considered in future development plans in the coastal zone. Delivering such adaptation will not be an easy task and is almost certainly more costly and difficult than the minimum cost estimates suggested here. For developing countries like Tanzania although adaptation may be required, it may not always be viable financially or economically, as the country is poorly adapted to today's climate highlighting the issue of high adaptation deficit. The analysis does not include this, implying the need for more investments to meet the adaptation needs of today climate before we even start to think about future challenges. Additional challenges to adaptation also exist due to the low adaptive capacity of the country, and even if sufficient funds for adaptation would suddenly be available, the weakness in other capacities (such as limited technology) would impede the implementations of adaptation, highlighting the broader dimensions of the issue.

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1. INTRODUCTION

Climate change represents a global issue posing major challenges for mankind and sustainable development, with the coastal zones being a focus for impacts and adaptation needs. Coastal zones contain valuable ecosystems with high ecological value and economic importance, and typically have higher population densities than inland areas (Small and Nicholls, 2003; McGranahan *et al*., 2007). Sea-level rise and extreme water levels are important components of climate change, and have significant implications to coastal environments and ecosystems including low-lying coastal plains, islands, beaches, mangroves, corals, coastal wetlands, estuaries, etc. There are also potential threats to other sectors such as infrastructure, transportation, agriculture, and water resources within the coastal zone, as well as tourism and provisioning services (*e.g.*, fishing, aquaculture, etc.). The major direct impacts of sea-level rise include inundation of low-lying areas, loss of coastal wetlands, increased rates of shoreline erosion, saltwater intrusion and increased salinity in estuaries and coastal aquifers, and higher water tables and higher extreme water levels leading to coastal flooding with increased damage. Potential indirect impacts include altered functions of coastal ecosystems and impacts on human activities.

The magnitude of sea-level change impacts will vary from place-to-place depending on topography, geology, natural land movements and any human activity which contributes to changes in water levels or sediment availability. The potential impacts are uneven, and are likely to affect the most vulnerable, due to multiple stresses and their lower ability to prepare, adapt and respond. Due to the availability of fewer resources and their lower social, technological and financial ability for adaptation, developing countries, particularly those with low-lying coastal areas with high population density are most vulnerable (Nicholls *et al*., 2007; UNFCCC, 2007; UN-HABITAT, 2008). African coastal countries represent such a vulnerable region to the potential impacts as shown in many previous assessments. Global assessments (*e.g.*, Hoozemans *et al*., 1993; Nicholls *et al*., 1999; Nicholls, 2004; Nicholls and Tol, 2006) and regional assessments (*e.g.*, Boko *et al*., 2007; Brown *et al*., 2009) identified East Africa as one of the most threatened coastal regions in Africa and globally. Their coasts are undergoing rapid population growth, urbanisation, coastward migration, and associated socio-economic growth, which significantly contributes in increasing the exposure of people and assets to sea-level variability and long-term rise (Zinyowera *et al*., 1998; Desanker *et al*., 2001; Nicholls *et al*., 2008).

The coastal zones of Tanzania also contain high population, important ecosystem services, and significant economic activity, such as important port cities that are key infrastructure to the national and regional trade and import/exports. With a large and growing population in the coastal zone and a low adaptive capacity due to low national wealth and other development indicators, Tanzania also appears to be highly vulnerable to climate change and sea-level rise. Historic incidents of severe flooding and other coastal hazards in the Eastern part of Africa (such as impacts of tropical cyclones on Tanzania, Mozambique, and Madagascar) also showed the high vulnerability of coastal settlements in floodplains of the country, highlighting the immediate priorities including the need to address the existing adaptation deficit, and to start planning for the future.

This report outlines a synthesis of the literature on the key risks from climate change, and provides a summary of the national results on the potential impacts and economic costs to the coastal zones of Tanzania based on a recent continent- and country-level study using the DIVA model application (*i.e.*, Brown *et al*., 2009). The study is conducted as part of the DFID Economics of climate change in East

Africa study. The remainder of the report is structured as follows: Section 2 provides a brief description of the country's physical geography and the socio-economic and environmental conditions, and a general note on the potential adaptation responses to climate change and sea-level rise. Section 3 synthesises the existing literature on the key issues from climate change and sea-level rise in Tanzania. Section 4 briefs the methods and data used, describes the cases and scenarios considered, and provides a summary of the national results of the study. Section 5 outlines a proposed action plan for adaptation to climate change for Tanzania based on the preceding analysis, and finally, in Section 6 general conclusions are drawn.

2. TANZANIA AND ITS COASTS

2.1 Physical Characteristics

2.1.1 Physical Geography

The United Republic of Tanzania lies south of the Equator located on the east coast of Africa between latitudes 1^{o}S and 12^{o}S and longitudes 30^{o}E and 41^{o}E (*Figure 1*). It extends from Lake Tanganyika in the west, the Indian Ocean in the east, Lake Victoria in the north, Lake Nyasa and River Ruvuma in the south. It is bordered by Kenya and Uganda to the North, Rwanda and Burundi to the Northwest, the Democratic Republic of Congo to the West, Zambia to the Southwest, and Malawi and Mozambique to the South. The country has an area of 945,000km^2, with the Mainland covering 939,702km^2 (*i.e.*, 881,289km^2 land and 58,413km^2 water such as inland lakes), and the rest covering the two important islands (*i.e.*, Zanzibar and Pemba) and other small islands.

The country's mainland coastal area stretches for over 800km of coastline (about 3,461km including that of the islands; Earth Trends, 2003) with a varying width ranging from 20km to 70km, and gradually rising to plateau. It covers five administrative regions: the country's important commercial and government centre – Dar es Salaam in the east, Tanga to the north of Dar es Salaam, Coast (Pwani) in the west, Lindi and Mtwara in the south, and the islands (*Figure 1*). About two thirds of the coastline has fringing reefs, often close to the shoreline, broken by river outlets including Pangani, Ruvu, Rufiji, Ruvuma, Wami, and Matandu rivers. The continental shelf is 5.8km wide, except for the Zanzibar and Mafia channels where it reaches a width of about 62km. The Exclusive Economic Zone (EEZ), which extends 200 nautical miles out from the Tanzanian shoreline, has an estimated area of 223,000km^2. The main coastal features include mangrove forests and swamps, estuaries, coral reefs, seagrass beds, inter-tidal flats, and sandy and muddy beaches.

Figure 1 also shows Tanzania's eight major coastal towns and the four major rivers discharging to the sea. Dar es Salaam and Zanzibar represent the largest coastal cities with highest population densities, and significantly contribute to the regional and national economy. *Figures 2* and *3* illustrate the topographic distribution of the two cities.

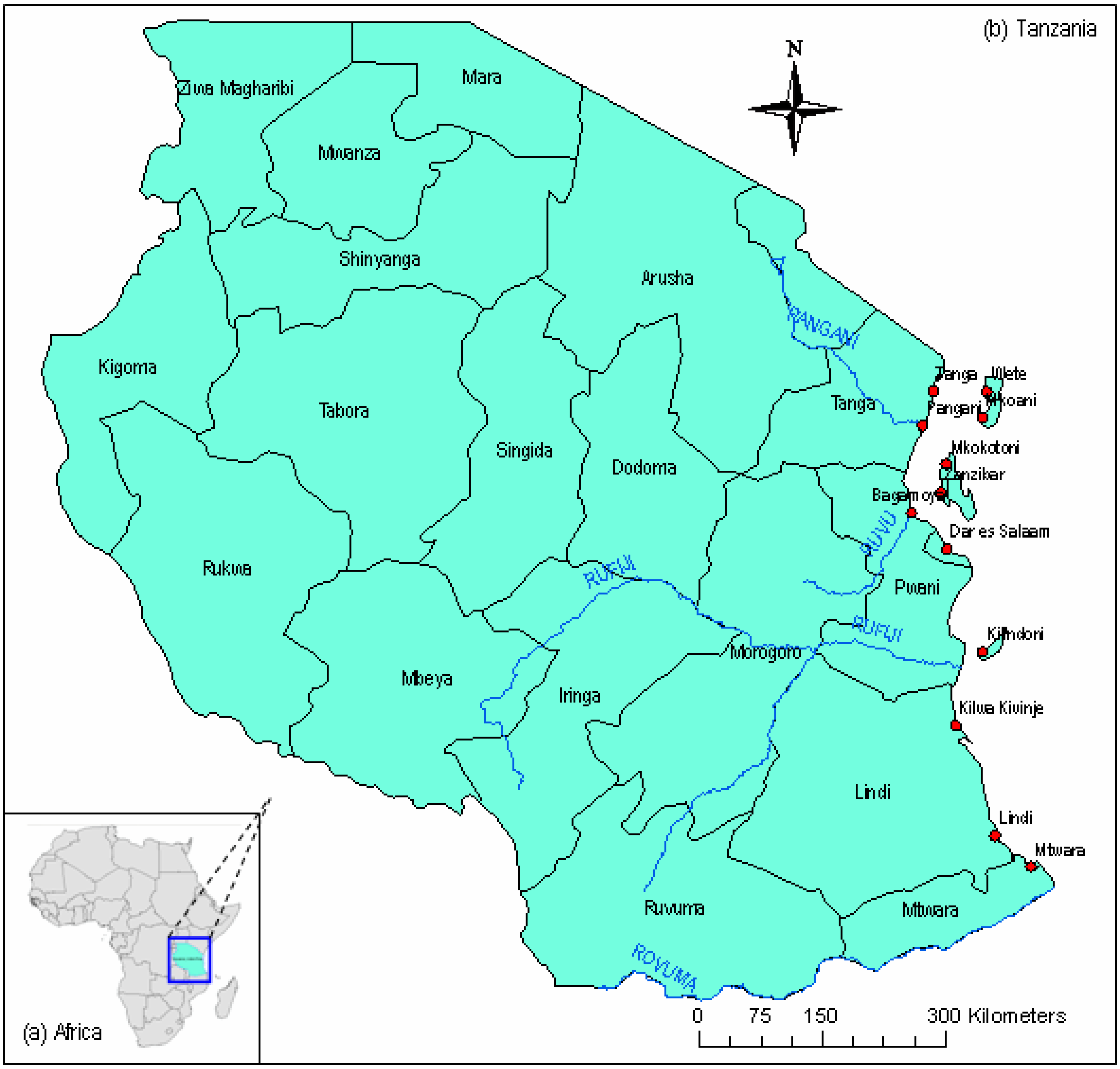
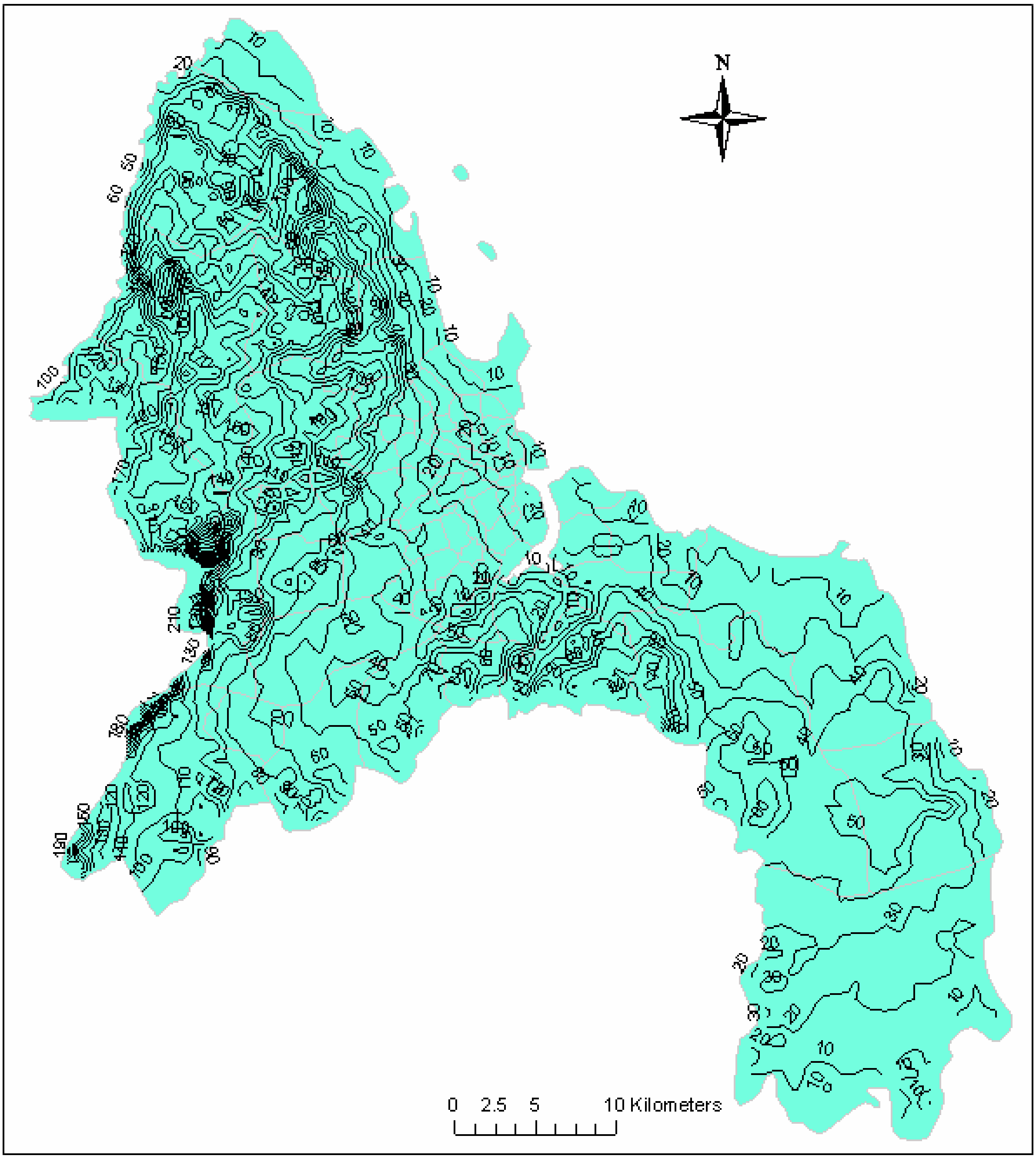


Figure 1: (a) Geographic location in Africa, and (b) Adminstrative units, coastal settlements, and major rivers in Tanzania.



: SRTM Contour map of the capital city Dar es Salaam drawn at 10m contour interval.2Figure

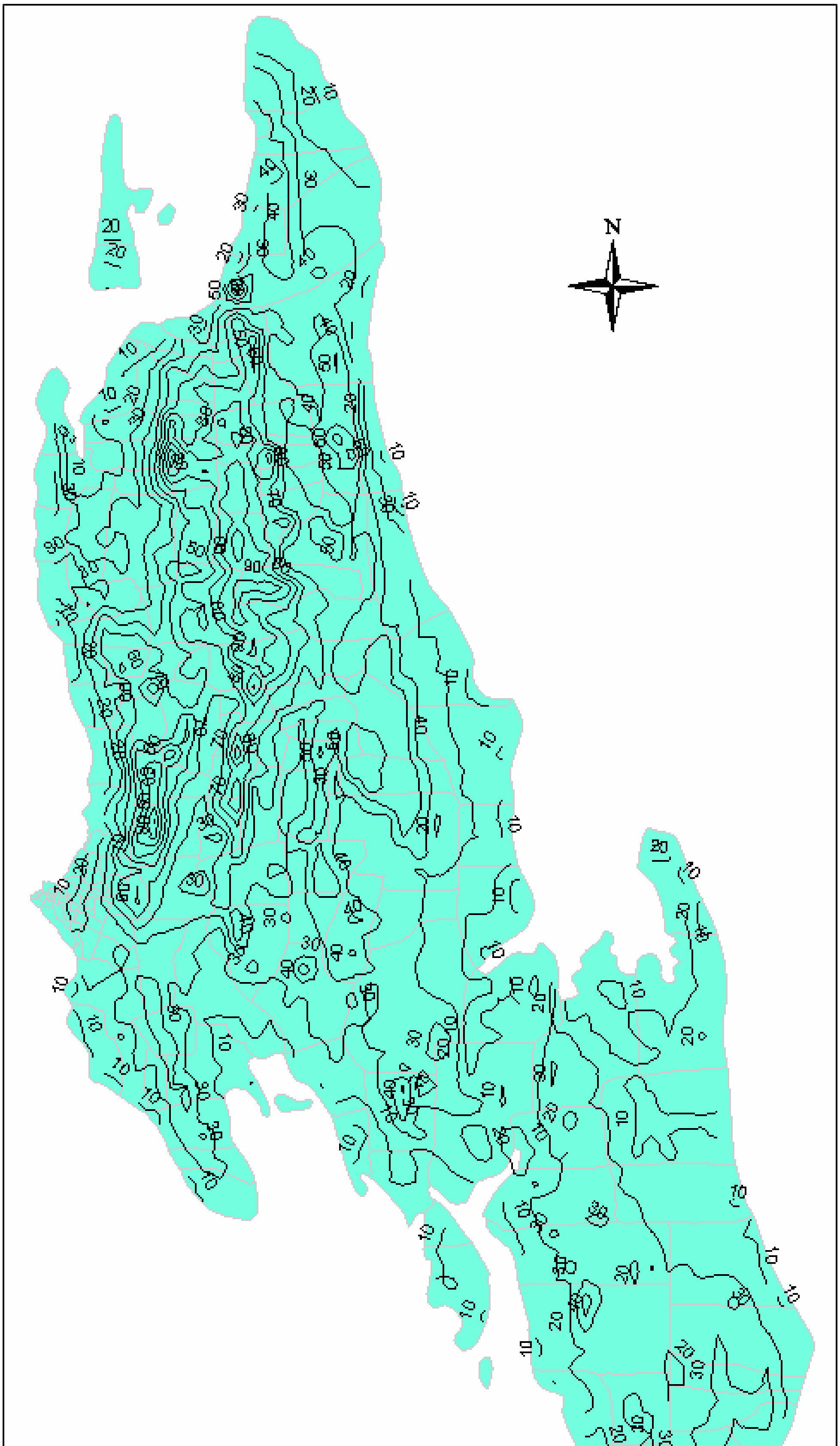


Figure 3: SRTM Contour map of the Zanzibar Island drawn at 10m contour interval.

2.1.2 General Climate and Sea-Level Measurements

General Climate

The climatic condition across the country ranges from semi-desert zone with rainfall less than 600mm per annum in the central and North Eastern Tanzania to the lowland coastal zone with rainfall up to 1,800mm per annum. Average temperatures range between 17°C and 27°C, depending on location. The coastal zone is divided into three sub-zones: the west sub-zone with elevation ranging between 0-500m, and annual rainfall of 1,800mm on average; the humid sub-zone, between 500-1000m of elevation with an annual rainfall ranging between 1000 and 1,800mm; and the drier zone, about 1,000 metres in altitude, with less than 1,000 millimetres of rainfall per annum.

Sea-Level Measurements

The Tanzanian sea level network consists of two operational stations of Zanzibar and Dar es Salaam, and three historic non-operational tide gauges at Mtwara, Tanga and Pemba (Mahongo, 2001; Mahongo and Khamis, 2006; Nhnyete and Mahongo, 2007). *Figure 4* shows the annual sea-level measurement in Tanzania based on tide gauge data at Zanzibar station received by the Permanent Services for Mean Sea Level (PSMSL) during the period 1985-2003. These indicate that the coast of Tanzania has experienced a drop in sea level over this period. However, it is important to note that estimates of trends of sea-level change obtained from tide gauge records of short durations (< 50 years) could have a significant bias due to interannual-to-decadal water level variability (Douglas, 2001), and is difficult to interpret Tanzania's sea-level change records as long-term trends. For instance, in Mombasa (located within the same region and with measurements approximately over same duration, 1986-2002), a 1.1mm/year rising sea level trend is recorded (Kibue, 2006; Magori, 2005). This illustrates that careful consideration should be made in interpreting short-duration sea-level measurements; also highlighting that measurements should be continued, and as their duration increases, they will become more useful, both scientifically and for future risk assessment and coastal management purposes.

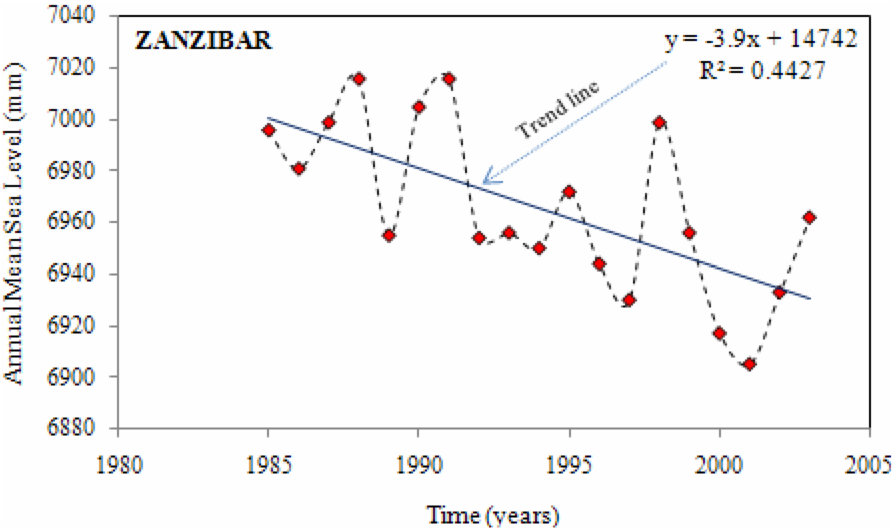


Figure 4: Annual mean sea level tide gauge measurements for Zanzibar station (06°09.3'S, 39°11.4'E), Tanzania (Source: Permanent Services for Mean Sea Level, PSMSL).

2.2 Socio-Economic and Environmental Characteristics

Social-Economic Conditions

According to World Bank estimates in 2000, Tanzania's population was approximately 34.1 million with an annual growth rate of 2.54%. This has increased to over 43.7 million people and annual growth rate of 2.91% in 2009 (World Bank, 2010). The coastal regions encompass about 15% of the country's land area and are home to approximately 25% of the country's population. Although they are smaller in land surface area, Dar es Salaam (with 977 people per km^2), Zanzibar (with 425 people per km^2), and Pemba (with 417 people per km^2), represent the three most densely populated coastal regions in the country (see *Table 1*).

Table 1: Land area and population distribution of the coastal regions (including coastal islands) in Tanzania[*].

Coastal Region	Land area (km^2)	Total Population (thousands)	Population density (per km^2)
Dar es Salaam	1393	1360.9	977
Lindi	66,046	646.6	10
Mtwara	16,707	889.5	53
Pemba	868	362.2	417
Pwani (Coast)	32,407	638.0	20
Tanga	26,808	1283.6	48
Zanzibar (Unguja)	1464	622.5	425
Total	**145,693**	**5803.3**	**40**

[*] *Cited in Gustavson et al. (2009).*

The country is one of the 49 Least Developed Countries (LDCs) in the world with a GNI (Gross National Income) per capita of US$500 (World Bank, 2010), and about 35% of the total population live below the poverty line (NAPA, 2006). In 2005, the GDP per capita was US$723.

The country's economy is heavily dependent on agriculture (including livestock), which accounts for 56% of the GDP, employs 80% of the work force, and provides 60% of export earnings (NAPA, 2006). Other socio-economic sectors include manufacturing industry, mining industry, fisheries, tourism and forestry, water, marine and coastal resources, energy, construction and other activities such as and port exploration. The major ports (Dar es Salaam, Tanga, Mtwara and Zanzibar) handle not only the nation's cargo but also transit goods to land-locked countries of Burundi, Dem Rep of Congo, Malawi, Rwanda, Uganda, and Zambia.

Most rural communities of the coast are very poor, earning less than US$100 per capita. Yet the area contributes about one-third of Tanzania's Gross Domestic Product. Currently, 75% of the country's industries are in urban coastal areas.

The coastal and marine resources play a significant role on the socio-economic well-being of not only the immediate communities but also those far inland and in the overall economic and social development of the country. For instance, coral reefs and mangrove forests represent an important coastal resource. In addition to being complex ecosystems and habitat to a wide diversity of marine flora and fauna, they also play a substantial role for tourism and fisheries industries, which also contribute to the nation's economy. Messages

Environmental Conditions

The coastal zone is rich in natural resources. The environment plays a significant role in the economy, as the country's economic activities focuses mainly on the exploitation of natural resources (such as agricultural farming), and depends majorly on the functional integrity of the coastal ecosystem. However, these resources are over-exploited by different sectors and experience intense pressure. There are signs of environmental degradation, as well as a decline in natural resources and biodiversity, evidenced by declining yields of fish, deteriorating conditions of coral reefs, and continuing reduction in the area of mangroves and coastal forests. This degradation is attributed to unsustainable use of coastal resources as well as pressures from the growing coastal population.

3. SYNTHESIS OF THE LITERATURE

As elsewhere in the world, Tanzania's coastal and marine environment is facing major threats and challenges (*e.g.*, periodic drought and flooding; Paavola, 2003) from both anthropogenic and natural changes (Julius, 2005). These include over exploitation, destructive fishing methods (*e.g.*, fishing dynamiting, poisoning, beach seining), industrial and domestic pollution (*e.g.*, oil spills, effluents, wastes), potential unregulated tourism development, and climate change and sea-level rise.

Climate change along with the high vulnerability of the low-lying coastal areas to sea-level rise threatens the population, infrastructure and socio-economic development in the coastal zone. Potential impacts include land losses, coastal erosion and damage to coastal structure and properties, loss of coastal and marine habitats and resources (*e.g.*, mangroves, seagrass beds, and corals), saline intrusion in fresh water bodies, inundation of low-lying coastal areas and small islands, and coral bleaching (NAPA, 2006). These are majorly attributed to unsustainable use of resources and increased pressures from the rapidly growing coastal population (Ruitenbeen *et al*., 2005). Coastal erosion (*e.g.*, due to illegal sand mining along beaches, coastal streams/rivers) is also one of the major coastal problems in the country (*e.g.*, Masalu, 2002). Future human-induced pressures (such as population growth and water abstraction) on the coastal zone are likely to exacerbate the impacts of sea-level rise.

According to Mwaipopo (2000), about 3520 ha of land (and 1025 ha of mangroves) in the northeast region of the country (Tanga), 3300 ha land area (and 1800 ha seasonal swamps) in the Bagamoyo area (Coast region), and about 2780 ha of mangroves in the Mtwara area are vulnerable to 0.5m of sea-level rise. With a 1m sea-level rise, it is estimated that 9km^2 and 2,117km^2 land could be lost due to erosion and inundation respectively. Dar es Salaam and the islands of Zanzibar and Pemba have the highest population densities that might be threatened due to climate change and sea-level rise. Tourist facilities such as hotels and roads in Dar es Salaam are partly protected from erosion by groynes and a seawall. The cost for building seawalls to protect important vulnerable areas of the city against a 1m rise in sea level has been estimated at US$337 million (Mwaipopo, 2000). It is also predicted that on average about 400m landward retreat would occur in Dar es Salaam under a 1m sea-level rise. According to the Initial National Communication of Tanzania (2003), the total land loss was estimated at 247 km^2 and 494 km^2 for 0.5 and 1 meters of sea-level rise, respectively. In the Dar es Salaam region, infrastructure worth US$48 and US$82 million are vulnerable to a 0.5m and 1m rise in sea level, respectively. However, while the country appears to be one of the African countries most at risk of the impacts of climate change and sea-level rise, the literature appeared to be very limited, indicating the need for further work.

Different response measures (such as introducing a range of management and conservation initiatives) have been taken over the last two/three decades including traditional management systems, enforcement of policies and laws through regulatory mechanisms and collaborative management arrangements (Julius, 2005). Existing adaptation activities such as: (1) Coastal and marine environment management programmes and projects, *e.g.*, Tanga Coastal Conservation and Development Programme (TCCDP), The National Integrated Coastal Environment Management Strategy, Rural Integrated Project Support Programme (RIPS), Mangrove Management Programme (MMP), Rufiji Environment Management Project (REMP), Conservation of Lowland Coastal Forests Project, Zanzibar Coastal Zone Management Programme, Sustainable Dar es Salaam Project, Kinondoni Coastal Area Management Programme; (2) Conservation of marine and coastal resources measures, *e.g.*, Mafia Island Marine Park, Mnazi bay Marine Park, Menai Bay Conservation Area, Misali Island Conservation Area, Chumbe Island Coral Park (NAPA, 2006).

Economic growth could play an important role in increasing the country's capacity to prepare and adapt to the future impacts of climate change and sea-level rise. However, the current state of its infrastructure and technological system is likely an impediment to Tanzania's ability to cope effectively with future climatic risks.

4. SUMMARY OF THE REGIONAL STUDY: NATIONAL RESULTS (Brown *et al.*, 2009)

This section summarises the national results of the work done within the project as part of the DFID Economics of climate change in East Africa study (Brown *et al.*, 2009). The focus is to provide a more quantitative and broader contextual interpretation of the DIVA results for Tanzania on the potential impacts of climate change and sea-level rise and the costs and benefits of adaptation, and to put these in the context of coastal management.

4.1 Method used: Application of DIVA

The regional economics study (Brown *et al.*, 2009) has investigated the potential effects of sea-level rise using the DIVA (Dynamic Interactive Vulnerability Assessment) model. The DIVA model is an integrated model of coastal systems that assesses biophysical and socio-economic impacts of sea-level rise due to climate change and socio-economic development (DINAS-COAST Consortium, 2006; Vafeidis *et al*., 2008; Hinkel *et al.* 2009). The study was based on selected climate (*i.e.*, sea-level rise) and socio-economic (*i.e.*, population and GDP) scenarios. Impacts were determined with and without adaptation, so that the benefits and costs of protection could be considered.

4.2 Sea-Level Rise and Socio-Economic Scenarios

Sea-level rise impacts throughout the 21st Century are dependent upon the sea-level scenarios, the socio-economic scenarios and the adaptation measures employed. The study explored a range of sea-level rise and socio-economic scenarios in order to understand the range of possible changes according to a range of plausible future conditions and known science. Three pairs of sea-level rise and socio-economic scenarios (*i.e.*, A1FI, A1B, and B1) based on the Special Report on Emission Scenarios (SRES) of the IPCC and a fourth sea-level rise scenario (Rahmstorf in conjunction with the IPCC A1B socio-economic scenario) reporting an upper bound, were considered. These represent a global mean sea-level rise ranging between 0.17m and 1.26m from 1995 to 2100 (*Figure 5*).

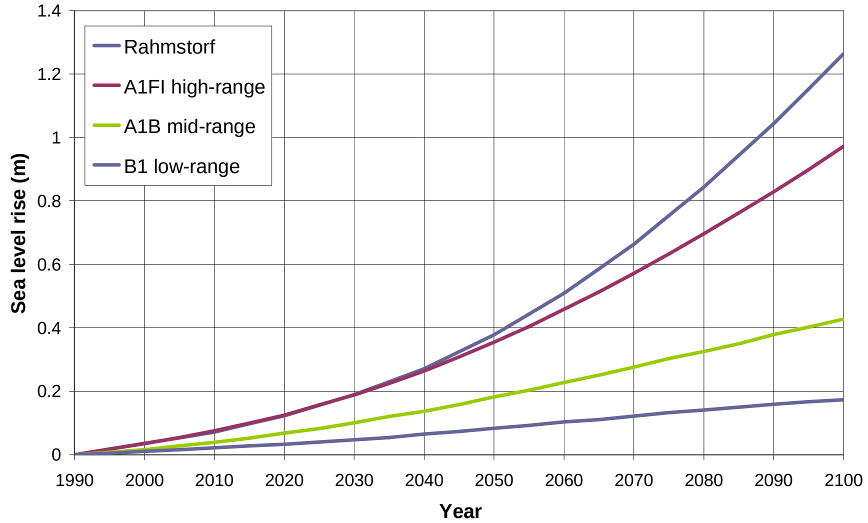


Figure 5: Sea-level rise scenarios used.

Under the A1B socio-economic scenario used in the study, Tanzania Is predicted to experience over 80% growth in population from 2010 to 2075 before it starts to decline, while the per capita GDP increases more than 18 times during the same period (see *Figure 6*). The population scenarios simply inflate the existing pattern of human occupancy of the coastal zone.

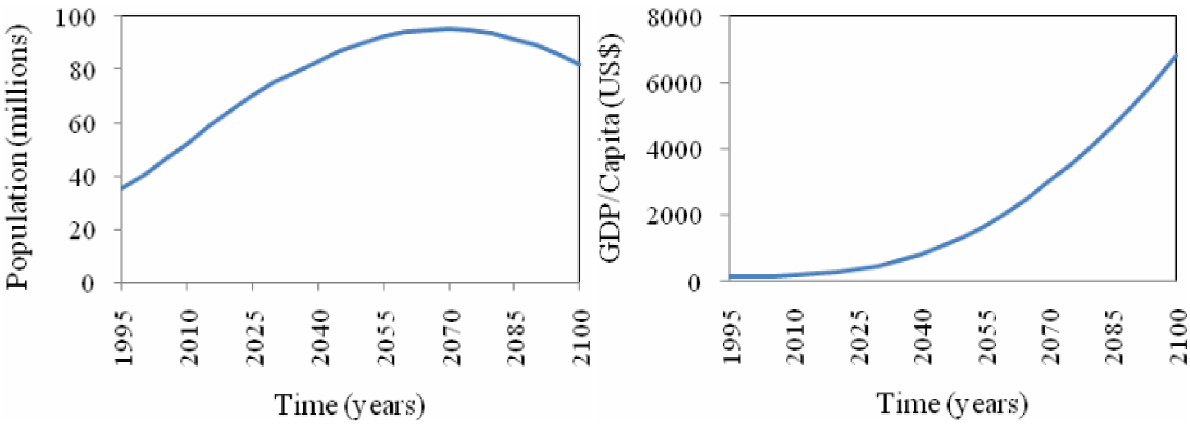


Figure 6: The A1B socio-economic scenarios (relative to 1995 values) used: (a) population change, and (b) per capita GDP growth of Tanzania.

4.3 Adaptation: Benefits and Costs

4.3.1 Potential Adaptation Responses

In order to address the potential risks of climate change to existing assets and people, some form of protection is required for coastal environments, such as cities, ports, deltas and agriculture areas. Despite the international focus on mitigation measures for climate, adaptation is necessary as climate change and its effects are now inevitable (Pittock and Jones, 2000), especially for coastal areas where there is a strong 'commitment to sea-level rise' and a 'commitment to adaptation' (Nicholls *et al.*, 2007). Coastal protection to sea-level rise is often a costly, but a straightforward way to overcome the adverse impacts of climate change. Although developing countries have very limited capacity to adapt, global and regional studies have highlighted that adaptation to climate change in developing countries is very vital and is an urgent priority. However, limitations both in human capacity and financial resources make adaptation difficult for the poorer nations such as Tanzania.

There are a large number of potential adaptation options to address these risks, particularly for protecting market sectors. These adaptation strategies include coastal defences (*e.g.*, physical barriers to flooding and coastal erosion such as dikes and flood barriers); realignment of coastal defences landwards; abandonment (managed or unmanaged); measures to reduce the energy of near-shore waves and currents; coastal morphological management; and resilience-building strategies. Planned adaptation options to sea-level rise are usually presented as one of three generic adaptation strategies (IPCC CZMS, 1990; Bijlsma *et al*., 1996; Klein *et al*., 2001) (see *Figure 7*):

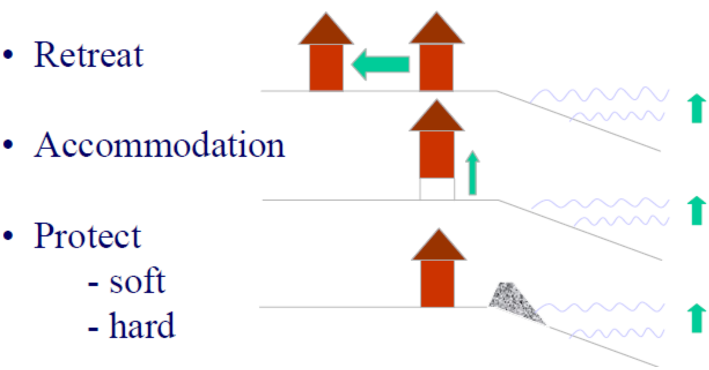


Figure 7: Potential responses to coastal hazards.

- **(Planned) Retreat** – the impacts of sea-level rise are allowed to occur and human impacts are minimised by pulling back from the coast via appropriate development control, land use planning, and set-back zones, etc.

- **Accommodation** – the impacts of sea-level rise are allowed to occur and human impacts are minimised by adjusting human use of the coastal zone to the hazard through early warning and evacuation systems, increasing risk-based hazard insurance, increased flood resilience (*e.g.*, raising houses on pilings), etc.;

- **Protection** – the impacts of sea-level rise are controlled by soft (*e.g.*, beach nourishment) or hard (*e.g.*, dikes construction) engineering, reducing human impacts in the coastal zone that would be impacted without protection. However, a residual risk always remains, and complete protection cannot be achieved even in the richest and more developed countries, such as The Netherlands. Managing residual risk is a key element of a protection strategy that has often been overlooked in the past;

Table 2 shows a list of the physical impacts of sea-level rise and some examples of potential adaptation responses illustrating these three generic strategies.

Table 2: Major physical impacts and some examples of potential adaptation responses to sea-level rise, illustrating the Protect, Accommodate, and Retreat strategies (taken from Nicholls and Tol, 2006; Nicholls, 2007).

Physical Impact of Sea-Level Rise		**Some Examples of Potential Adaptation Responses**
❖ Direct inundation, flooding and storm damage	➢ Strom Surge (sea) ➢ Back water effects (river)	▪ Dikes/surge barriers (P) ▪ Building codes/flood-wise buildings (A) ▪ Land use planning/hazard delineation (A/R)
❖ Loss of wetland area (and change)		▪ Land use planning (A/R) ▪ Managed realignment/forbid hard defences (R) ▪ Nourishment/sediment management (P)
❖ Erosion (both direct and indirect)		▪ Coastal defences (P) ▪ Nourishment (P) ▪ Building setbacks (R)
❖ Saltwater intrusion	➢ Surface Waters	▪ Saltwater intrusion barriers (P) ▪ Change water abstraction (A)
	➢ Ground Waters	▪ Freshwater injection (P) ▪ Change water abstraction (A)
❖ Rising water tables and impeded drainage		▪ Upgrade drainage systems (P) ▪ Polders (P) ▪ Change land use (A) ▪ Land use planning/hazard delineation (A/R)
Note: P – Protection; A – Accommodation; and R – Retreat		

The choice and use of these adaptation strategies with the objective of protecting the human use of the coastal zone would generally depend on the nature of the coastal zone and the type and extent of impacts. These have a site specific context, and if appropriately applied, different adaptation strategies will have different consequences for coastal ecosystems (Nicholls, 2007). For instance, unlike the first option (protection), the two adaptation strategies (accommodation and retreat) reduce or avoid the problem of 'coastal squeeze' (preventing onshore migration of coastal ecosystems) between fixed coastal defences and rising sea levels. However, soft protection measures (such as beach/shore nourishment and sediment re-cycling) can minimise this problem. It is also important to recognise the benefits of applying portfolios of adaptation strategies (see Evans *et al*., 2004a; 2004b), for example dikes can be combined with building codes/flood-wise buildings and flood warning and evacuation systems, and quite different adaptation strategies might be applied in a city versus a rural area.

4.3.2 Adaptation Options Considered

According to Brown *et al*. (2009), adaptation costs are estimated for two planned adaptation options considered: (1) dike (sea or river) building and upgrade, and (2) beach/shore nourishment. Adaptation has both costs and benefits – the costs for planning, preparing, facilitating and implementing adaptation measures, and the benefits expressed in terms of avoided damage costs (*e.g.*, reducing potential climate change impacts) or the accumulated benefits (positive consequences) following the implementation of adaptation measures. DIVA implements the different adaptation options according to various complementary adaptation strategies. The simplest strategy is no adaptation, in which DIVA only computes potential impacts in a traditional impact analysis manner. In this case, dike heights (in 1995) are maintained (but not raised), so flood risk rises with time as relative sea level rises. Beaches and shores are not nourished. With adaptation, dikes are raised based on a demand function for safety (Tol and Yohe, 2007), which is increasing in per capita income and population density, but decreasing in the costs of dike building (Tol, 2006). Dikes are not applied where there is very low population density (< 1 person/km^2), and above this population threshold, an increasing proportion of the demand for safety is applied. Half of the demand for safety is applied at a population density of 20 persons/km^2, and 90% at a population density 200 persons/km^2. Hence, this is not a cost-benefit approach but rather illustrates scenarios of response based on the demand for safety function. For nourishment, a cost-benefit adaptation (CBA) strategy that balances the costs and the benefits (in terms of avoided damages) of adaptation is used in these analyses.

4.4 DIVA Application: National Results (Brown *et al*., 2009)

This section summarises the physical impacts (*e.g.*, damages and damage costs) and adaptation costs of climate change and sea-level rise for Tanzania under a range of sea-level rise and socio-economic scenarios from 2000 to 2100. A much wider set of impact categories has been assessed (see Brown *et al*., 2009). Results indicate that without adaptation, the physical, human, and economic impacts will be significant. In this synthesis report, a particular focus is given to selected parameters, and a summary of the national results are presented and discussed under the following four sub-sections:

(1) Residual damage (non-monetary): comprising total land loss (due to erosion and submergence), people actually flooded, and cumulative forced migration (since 2000),

(2) Loss of wetland value (monetary): comprising monetary values of coastal forest, low un-vegetated wetland, and mangroves in Tanzania,

(3) Total residual damage costs (monetary): comprising land loss costs, forced migration costs, salinisation costs, sea flood costs, and river flood costs,

(4) Total adaptation costs (monetary): comprising beach/shore nourishment costs, basin nourishment costs, wetland nourishment costs, sea dike costs, and river dike costs.

Note that costs are presented in 1995 US$ and are NOT discounted.

4.4.1 Residual Damage

The residual damages presented here include (a) land loss due to erosion and submergence, (b) people actually flooded, and (c) people forced to migrate. These parameters are discussed below.

(a) CUMMULATIVE LAND LOSS

This refers to the total land area lost due to either erosion or submergence. *Figures 8* and *9* show the distribution of the cumulative loss of land from 2000 to 2100 under different sea-level rise and socio-economic scenarios along with the two adaptation modes. With no adaptation, the cumulative land loss is estimated in the range between 1924 and 7624km^2 in 2030, and ranging between 3884 and 8603km^2 in 2100 across all the scenarios (*Figure 8*). More than 99% of these damages are caused by submergence. When adaptation is considered, the land loss is significantly reduced down to 1.3km^2 in 2030 (*Figure 9*). *Figures 10* to *13* present the component land losses (erosion or submergence).

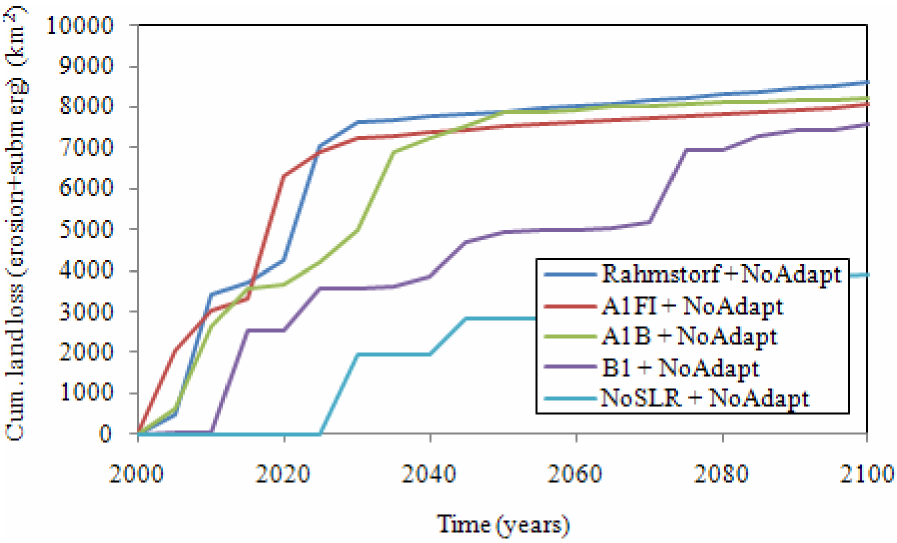


Figure 8: Cumulative land loss (erosion + submergence) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations without adaptation.

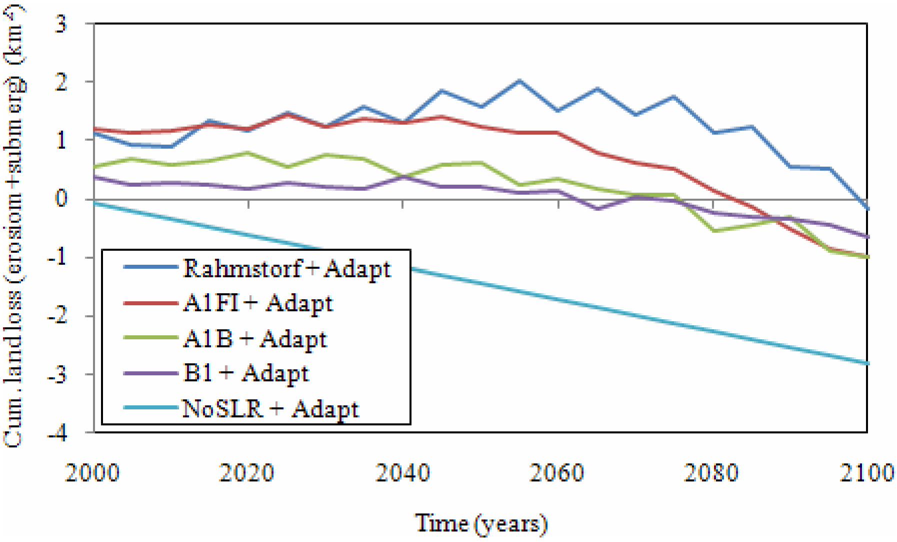


Figure 9: Cumulative land loss (erosion + submergence) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations with adaptation.

- **Land loss due to erosion**

Figures 10 and *11* present the cumulative land area losses due to erosion with and without adaptation, respectively. If no adaptation measures are considered, as high as 12 and 82km² land area could be lost to erosion in 2030 and 2100, respectively. With adaptation (beach/shore nourishment) based on cost-benefit approach, this could be reduced down to 1.3km² in 2030, with an estimated annual nourishment cost of US$27 million per year in 2030.

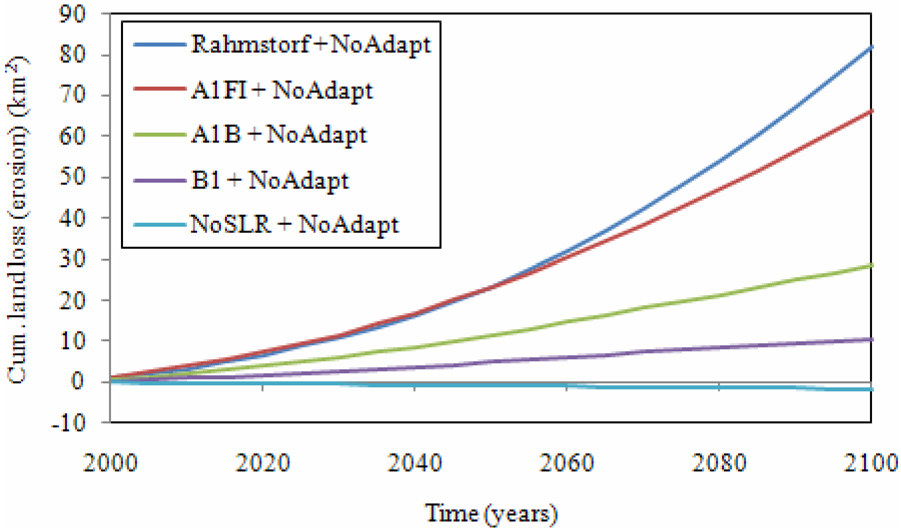


Figure 10: Cumulative land loss (erosion) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations without adaptation.

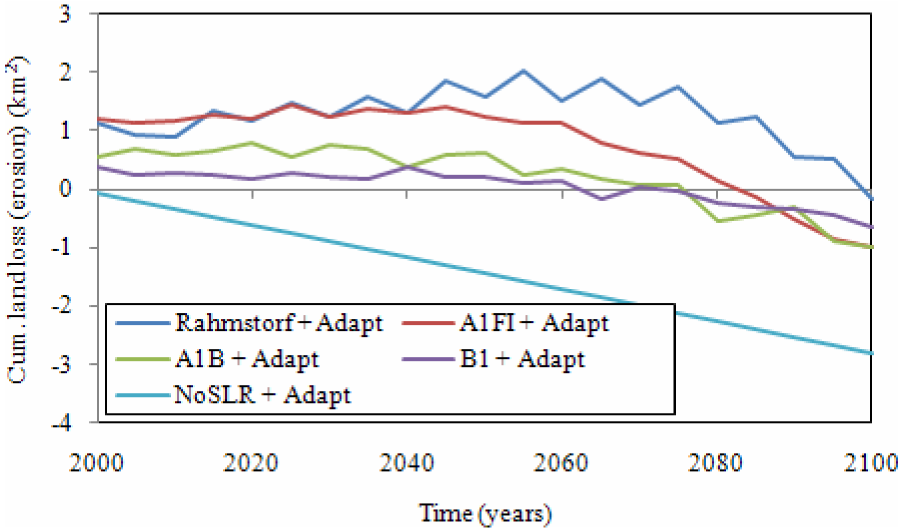


Figure 11: Cumulative land loss (erosion) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations with adaptation.

➢ **Land loss due to submergence**

Figures 12 and *13* present the cumulative land losses due to submergence with and without adaptation, respectively. With no adaptation, the total land loss is estimated between 3576 and 7614km^2 in 2030, and increases between 7563 and 8522km^2 in 2100 across the sea-level rise scenarios. For a reference scenario of no climate-induced sea-level rise, a total land loss of 1924km^2 in 2030 and 3886 km^2 in 2100 could be expected. This highlights that impacts could be significant even without climate change. These damages are concentrated in low-lying areas. However, when appropriate adaptation measures in terms of protection are considered based on the demand for safety, these damages could be significantly reduced down to effectively no loss under all the sea-level rise scenarios.

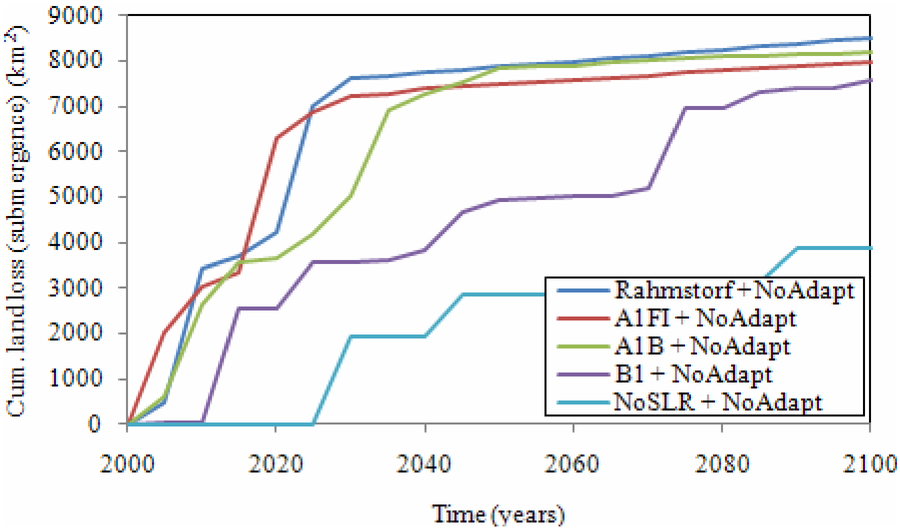


Figure 12: Cumulative land loss (submergence) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations without adaptation.

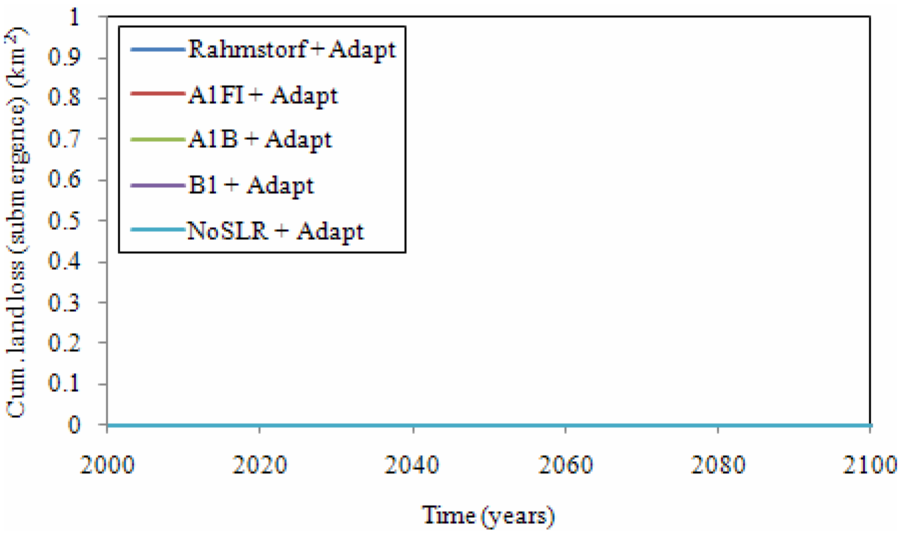


Figure 13: Cumulative land loss (submergence) due to sea-level rise from 2000 to 2100 for Tanzania under the simulations with adaptation.

(b) PEOPLE ACTUALLY FLOODED

People flooded considers the expected average number of people subjected to annual flooding taking into account coastal topography, population and defences, as well as sea level. Assuming no adaptation, the number of people flooded increases with time under all scenarios considered before it starts to decline towards the end of the century (*Figure 14*). Even under the no climate-induced sea-level rise scenario, impacts are significant, and the number increases due to coastal development and local sea-level rise caused by subsidence from about 99,000 people per year in 2000 to over 234,000 and 907,000 people per year in 2030 and 2100, respectively. Under the highest scenario (*i.e.*, a 1.26m sea-level rise by 2100), 1.6 and 2.2 million people will experience flooding at least once a year in 2030 and 2100, respectively, if no adaptation measures are taken. Assuming adaptation in terms of upgrading dikes and nourishing beaches reduces the number of people flooded in 2100 by factors ranging between 69 (*e.g.*, to 32,000 people per year under the highest scenario) and 438 across the scenarios (*Figure 15*), when compared to the no adaptation simulations.

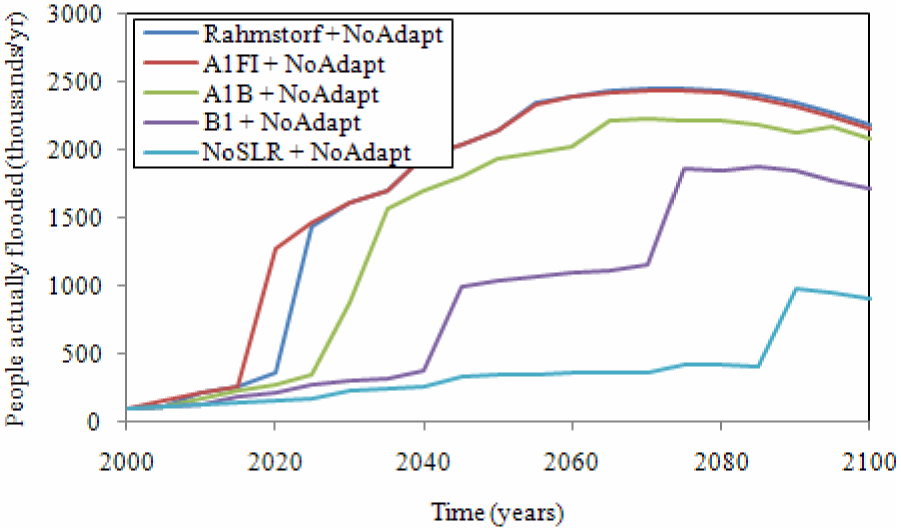


Figure 14: Number of people actually flooded per year from 2000 to 2100 for Tanzania under the simulations without adaptation.

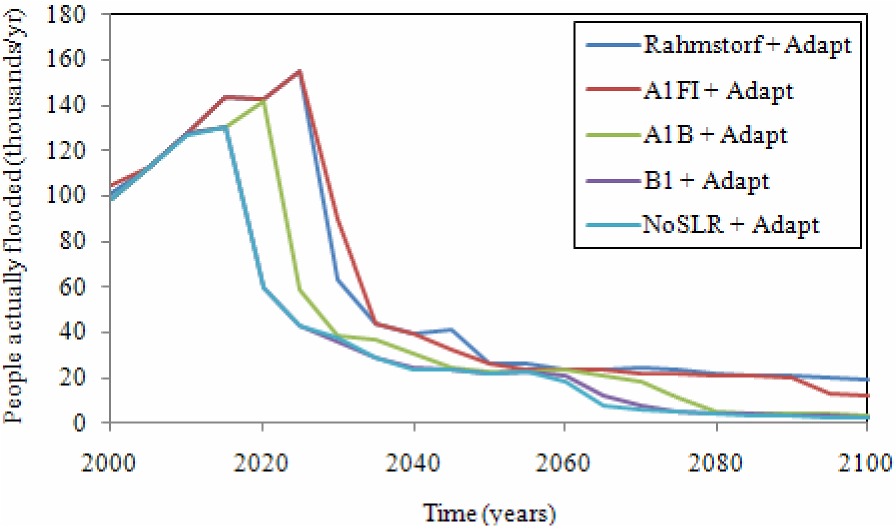


Figure 15: Number of people actually flooded per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

(c) CUMULATIVE FORCED MIGRATION

Under forced migration, it is assumed that if land is lost (due to submergence based on the area below the one year flooding, and erosion), then the people dwelling on the land will be forced to migrate.

Figures 16 and *17* illustrate the distributions of the cumulative number of people forced to migrate since 2000 across the ranges of sea-level rise and socio-economic scenarios, under the simulations without and with adaptation, respectively. With 5cm–19cm global sea-level rise in 2030, between 67,000 to 852,000 people could be forced to migrate since 2000. In 2100, this could increase between 1.1 to 1.2 million people to be forced to migrate across the range of sea-level rise scenarios. Under the no climate-induced sea-level rise scenario, as high as 34,000 people in 2030 and over 506,000 people in 2100 will be forced to migrate since 2000 (*Figures 16*). Adaptation reduces these numbers significantly down to almost negligible numbers, even under the highest scenario (*Figures 17*).

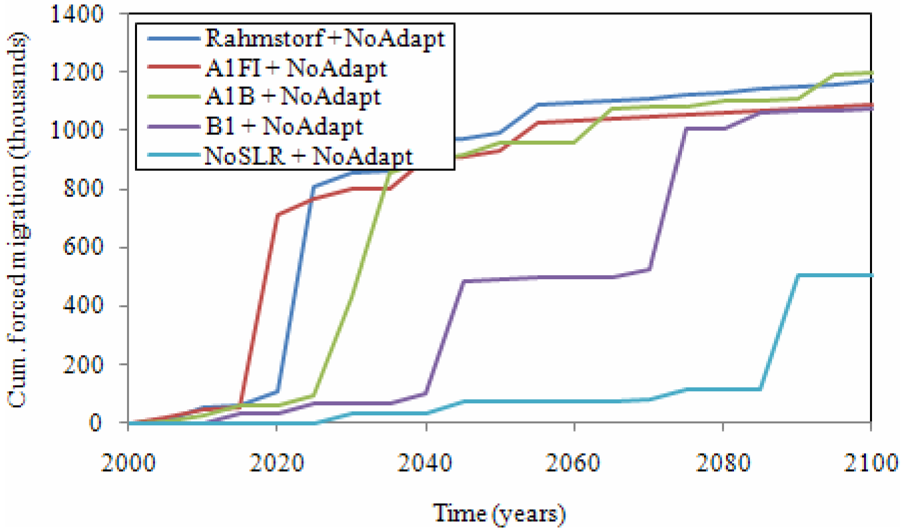


Figure 16: Cumulative number of people forced to migrate from 2000 to 2100 for Tanzania under the simulations without adaptation.

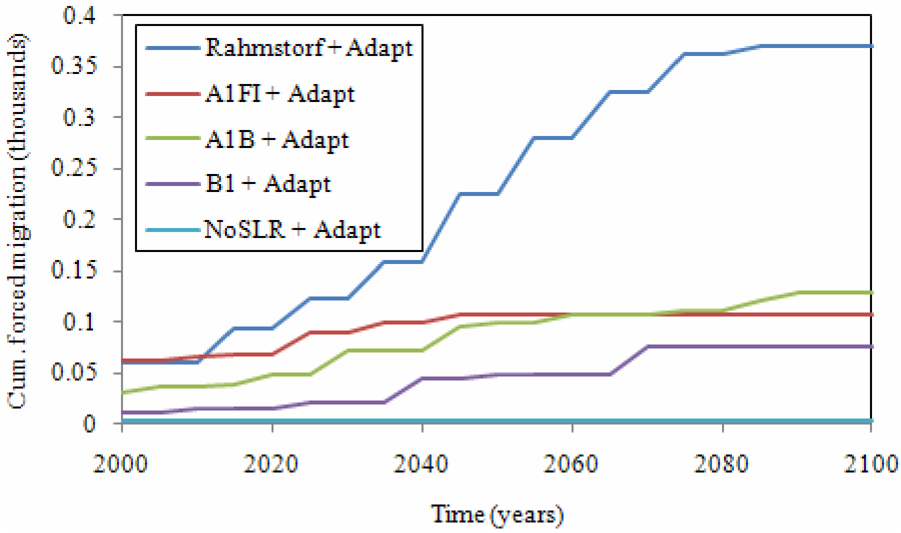


Figure 17: Cumulative number of people forced to migrate from 2000 to 2100 for Tanzania under the simulations with adaptation.

4.4.2 Loss of Wetland Monetary Value

As sea level rises more rapidly, coastal wetlands will increasingly decline in area. This section presents this wetland loss expressed in terms of loss of monetary value that is determined within DIVA. Wetlands in Tanzania comprise coastal forest, low un-vegetated wetlands, and mangroves. Valuation follows the method outlined in Brander *et al.* (2006), and is a product of the GDP, population density, locality and wetland area. Hence, the unit values are dynamic with socio-economic scenario. Note that this loss could also occur due to non-climatic factors such as due to direct destruction (*e.g.*, Hoozemans *et al*., 1993; Coleman *et al*., 2008), but this was not investigated.

Figure 18 illustrates the distribution over time of the total loss of wetland monetary value across the ranges of sea-level rise scenarios. In 2030, on average about US$2.7 million wetland monetary value could be lost, over 24% of which represent loss of mangrove monetary values. This could increase up to US$47 million in 2100. With up to 19cm rise of global mean sea level, approximately 8% of Tanzania's wetland could disappear by 2050 (Brown *et al.*, 2009). This loss could also be interpreted as to further exacerbate damages such as erosion and flooding due to the loss of the natural protection provided by the wetlands. This will also presents important challenges to ecosystems in the coastal zone due to the loss of ecological values associated with the wetlands.

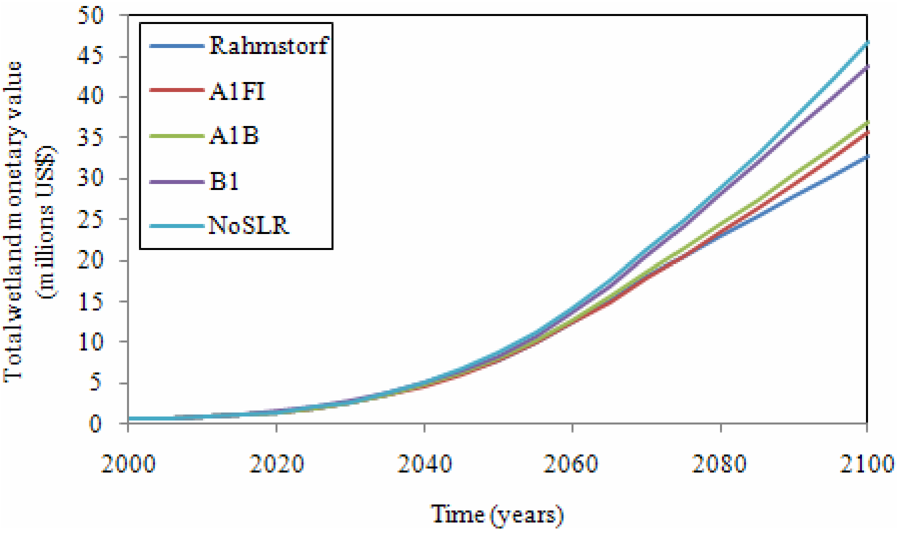


Figure 18: Total loss of wetland monetary value from 2000 to 2100 for Tanzania.

4.4.3 Total Residual Damage Costs

Total residual damage costs comprise five component costs: (1) forced migration costs, (2) land loss costs, (3) salinisation costs, (4) sea flood costs, and (5) river flood costs.

Without adaptation, the total residual damage costs are estimated between US$20 and US$42 million per year in 2030 under the ranges of sea-level rise scenarios. These costs become greater with time as sea level rises, increasing on average between US$318 and US$478 million per year in 2100 (*Figure 19*). Note that the spikes show real-model-values but are related to the threshold assessment approach used in the DIVA model, where results peak when passing certain threshold values.

However, when adaptation measures are considered the total residual damage cost were reduced to about US$15 million per year in 2030, and between US$136 and US$232 million per year in 2100 (*Figure 20*).

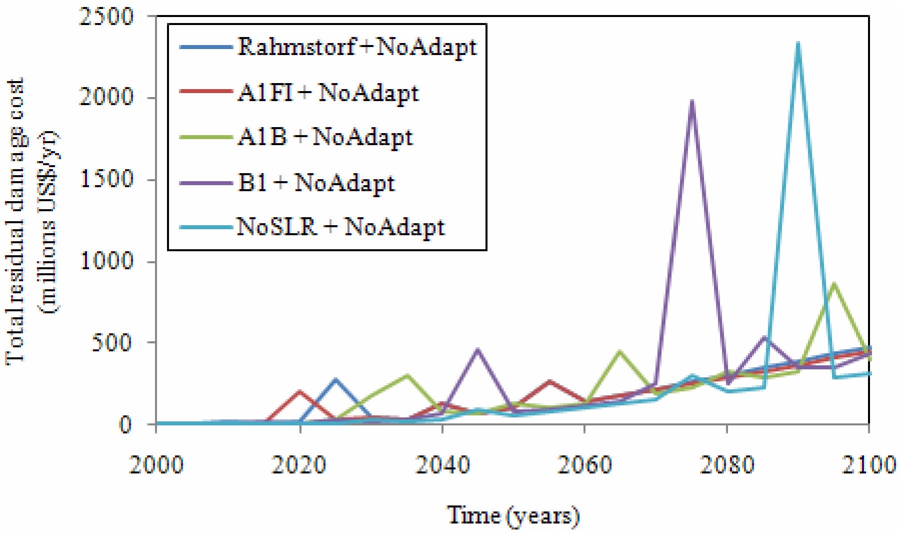


Figure 19: Total residual damage cost per year from 2000 to 2100 for Tanzania under the simulations without adaptation.

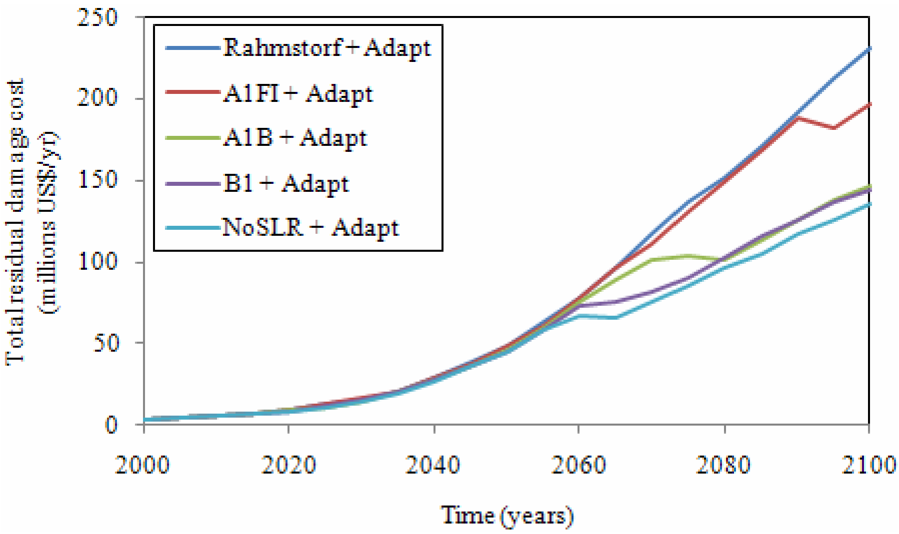


Figure 20: Total residual damage cost per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

4.4.4 Total Adaptation Costs

Brown *et al*. (2009) investigated the potential incremental costs of adaptation for coastal zones in Tanzania using an application of the DIVA model. These costs assume a well developed adaptation infrastructure which can be incrementally upgraded. As already noted, this is not the case and addressing this adaptation deficit is a major and costly issue which is beyond the scope of this paper. Hence, these costs are only the coastal investment that might be considered in Tanzania over the 21st century. The study has considered two planned adaptation options: (1) dike (sea or river) building and upgrade, and (2) beach/shore nourishment. Adaptation has both costs and benefits. The study demonstrated that when adaptation measures are applied, the potential impacts and economic costs can be significantly reduced. It shows that adaptation has large potential benefits in reducing coastal erosion and inundation, that can be expressed in terms of avoided damage costs (*e.g.*, reducing potential impacts as illustrated above) or the accumulated benefits (positive consequences) following the implementation of adaptation measures.

Figure 21 presents the total adaptation cost estimates for Tanzania under the ranges of sea-level rise scenarios. These costs comprise (1) beach/shore nourishment costs (*Figures 22*), (2) sea dike costs (*Figures 23*), and (3) river dike costs (*Figures 24*).

The costs increase with time for higher sea-level rise scenarios (*Figure 21*). With 5cm–19cm global mean sea-level rise in 2030, the total adaptation cost is estimated between US$25 and US$62 million per year. In 2100, these costs could reach as high as US$229 million per year. Under the no climate-induced sea-level rise, the cost is estimated at about US$16 million per year in 2030 and halved to US$8 million per year in 2100. In 2100, beach nourishment costs dominate the total costs of adaptation under high scenarios, while sea dike costs dominate under low scenarios. For instance under the Rahmstorf scenario, the total annual adaptation cost comprise: beach nourishment cost of US$152 million (about 66.5% of total) (*Figures 22*), annual sea dike cost of US$77 million (33.5%) (*Figures 23*), and annual river dike cost US$3.3 thousands (*Figures 24*) per year in 2100. Under the no climate-induced sea-level rise scenario, about 93% of the total annual adaptation cost is from building or upgrade of sea dikes.

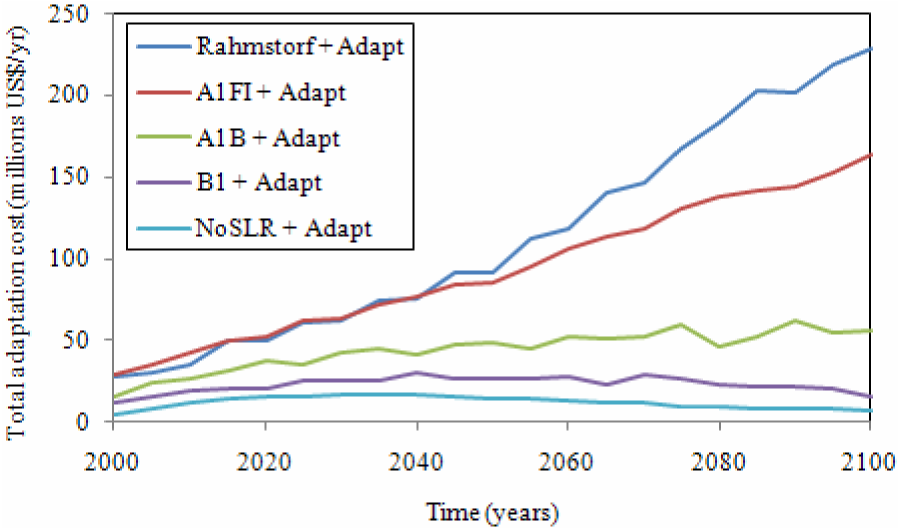


Figure 21: Total adaptation cost per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

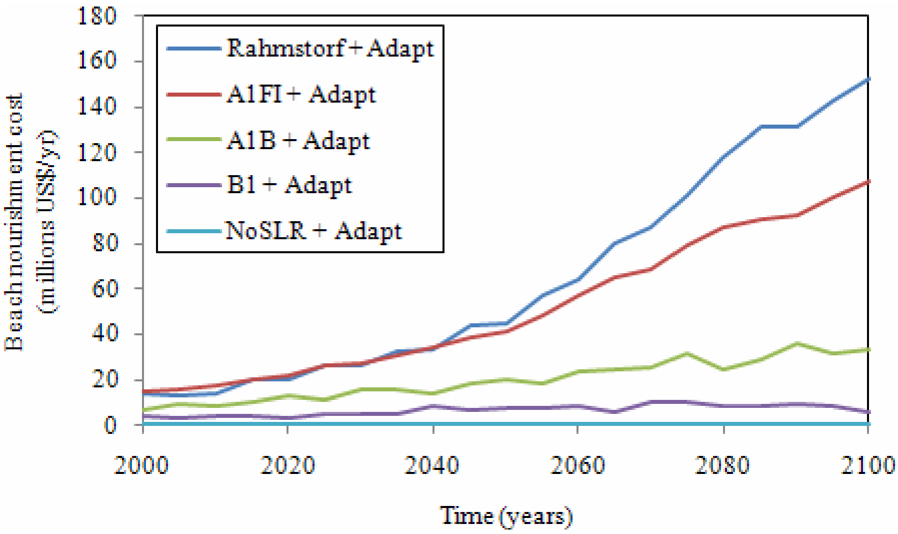


Figure 22: Beach nourishment cost per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

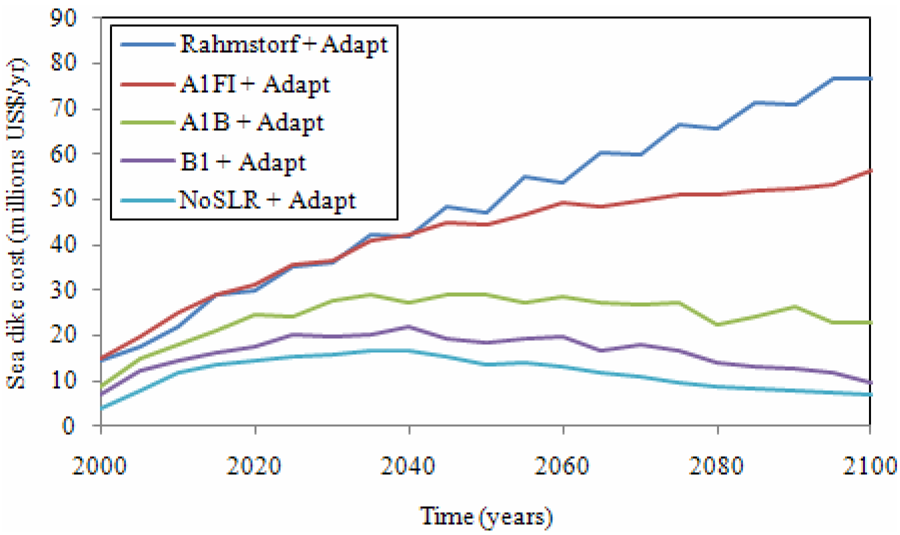


Figure 23: Sea dike cost per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

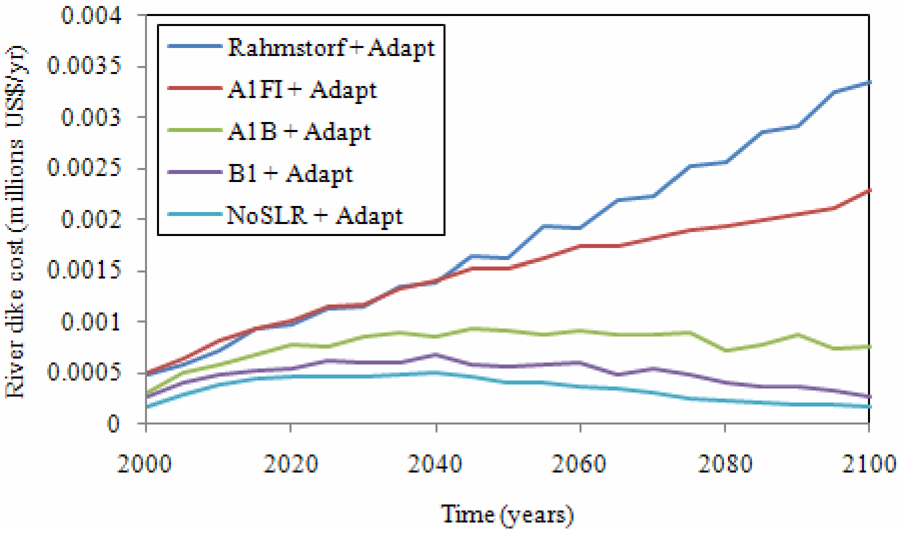


Figure 24: River dike cost per year from 2000 to 2100 for Tanzania under the simulations with adaptation.

4.4.5 Summary

To summarise, without adaptation the physical and economic impacts of sea-level rise are estimated to be high under all the scenarios. Even without climate-induced sea-level rise, there are some damages and costs due to natural and locally-induced subsidence and increase in population, population density, and GDP. However, results demonstrate that these impacts and costs can dramatically be reduced if standard protection measures of adaptation (in terms of beach/shore nourishment and dike construction and upgrade) are employed where cost-benefit approach and demand for safety function suggests it is the optimum response.

For instance, for the A1B sea-level rise scenario it is estimated that adaptation measures with an annual cost of US$43 million per year by 2030 could reduce the cumulative land loss by a factor of 6452, the number of people flooded by a factor of 23, the number of people forced to migrate since 2000 by a factor of 5977, and the total residual damage cost by a factor of 12.

5. An Adaptation Plan for Coastal Zones and Climate Change In Tanzania

The literature showed that Tanzania's coast faces important challenges even without climate-induced sea-level rise. The impact and adaptation assessment also outlined that the coastal zones and its small islands are currently vulnerable to significant damages and costs; future climate change and sea-level rise could only exacerbate these issues. Socio-economic scenarios could also play a significant role in determining the potential impacts in the future as demonstrated by previous studies (*e.g.*, Nicholls, 2004).

If no adaptation measures are considered, the physical, human and economic impacts could be severe, rising with sea-level rise scenarios. The DIVA results suggest that protection via beach/shore nourishment and building and upgrade of dikes could be an effective response. In addition, forward planning to focus population and economic growth in less vulnerable areas and to control the overall growth in the coastal zone could be an important part of a strategic response to sea-level rise, which could significantly reduce exposure, and hence damages and costs. This could be interpreted as a planning policy to define hazardous zones and not developing them. However, whether this is a practical policy in a poor developing country like Tanzania with a rapidly growing population is unclear, which could raise issues of implementation?

Note that adaptation costs could be significant and they depend mainly on the magnitudes of future sea-level rise. There is a significant need for coastal adaptation to today's climate and future climate change and rising sea levels, which should be carefully considered in future development plans in coastal areas. However, it is important to note that adaptation will not completely avoid all impacts and may even exacerbate some impacts such as degradation of mangroves and other wetlands. In addition, delivering such adaptation will not be an easy task and could be more costly and difficult than the costs suggested by the DIVA analysis. For instance, for developing countries like Tanzania although adaptation may be required, some adaptation options may not always be viable financially or economically, as they are poorly adapted to today's climate highlighting the issue of high 'adaptation deficit' as in many developing countries (Parry *et al*., 2009). This analysis does not consider this, which implies the need for more investments to meet the adaptation needs of today climate, before we even start to think about future challenges. Additional difficulties to adaptation also exist due to the low adaptive capacity, and even if sufficient funds for adaptation would suddenly be available, the weakness in other capacities (such as limited technology) could impede the implementations of adaptation.

However, there is a much wider range of adaptation measures available as discussed in earlier studies (*e.g.*, Klein *et al*. 2000; 2001; Linham and Nicholls, 2010). The coastal zones of Tanzania contain high populations, significant economic activity and important ecosystem services. These areas are at risk from future sea-level rise. One of the major coastal challenges in the coastal zone of Tanzania is coastal erosion (*e.g.*, Nyandwi, 2001; Masalu, 2002). On such an eroding coast where much of the coast has well developed today, building setbacks could be considered as a low cost planning local approach to retreat, although enforcement may be problematic. Other coastal issues include loss of habitats, industrial and domestic-based pollution, declining resources and conflict between users, poor planning and decision making, greater dependency of coastal community on natural resources, and additional pressures due to increasing trend of coastward migration and population growth.

Conventionally, coastal management practices have in nature been more sectoral focusing on single-goaled management practices than addressing the multifaceted pressures that affect the coastal zone. These highlight that future planning and responses to climate change (at a local, regional and national scale) will need to address more than just climate change, and the need for a more diverse and integrated cross-sectoral measures to address the impacts of climatic and other non-climatic drivers of change. Hence, it is fundamental to develop the institutional capacity to make these decisions which implies investment on Integrated Coastal Management (ICM). This will provide a basis for making the many decisions that coastal adaptation require (*e.g.*, Hay, 2009; Klein *et al*., 2000; 2001; USAID, 2009) and provide capacity to address all the coastal problems be they climate or non-climate-related.

Future planning should also incorporate accurate monitoring in the coastal zone, including sea-level rise, and where and by how much the coast is changing with time. Although the available sea-level change measurement records show a declining trend, it is difficult to interpret this as a long-term trend as the duration of measurements are very short and could simply reflect interannual-to-decadal water level variability. Hence, it is important that measurements are collected and analysed as sufficiently long (*e.g.*, > 50 years; Douglas, 2001) and good as possible in order to be able to have a maximum insight into the future and to plan to prepare and adapt for future impacts as appropriate. In addition, as the country continues to look at the yet available coastal resources for future economic development, sustainable management of resources should be given a priority and coastal activities need to be more coordinated and coherent for a more predictable, sustainable and equitable future socio-economic development in the coastal zone, and hence in the country.

Therefore, future development planning should consider all these factors for a better future management of the coastal zone and sustainable development and prosperity of the nation as a whole.

6. CONCLUSIONS

The coastal zones of Tanzania contain high populations, significant economic activity, and important ecosystem services. These areas are at risk from future climate change and sea-level rise. Without adaptation the physical and economic impacts of sea-level rise are estimated to be high in the future. Even without climate-induced sea-level rise, there are some damages and costs due to high increase in population, population density, and GDP in vulnerable low-lying areas. However, results demonstrate that these impacts and costs can dramatically be reduced if standard protection measures of adaptation are employed. But it is important to note that even with adaptation measures, there are some residual damages. Nonetheless, coastal protection appears to substantively reduce the threat imposed by sea-level rise at a relatively low cost, and the benefits of adaptation outweigh the costs, as illustrated in the analysis. Delivering such adaptation will not be an easy task and is almost certainly more costly and difficult than the minimum cost estimates suggested here. For developing countries like Tanzania although adaptation may be required, it may not always be viable financially or economically, as the country is poorly adapted to today's climate

Moreover, while it is possible and probably desirable to protect many areas of coasts through adaptation, this does not address all coastal threats. Under projected climate change and sea-level rise scenarios, coastal ecosystems would be highly threatened. These habitats could be severely reduced or disappear during the 21st century. These highlight that future planning and responses to climate change will need to address more than just climate change, and the urgent need for a more diverse and integrated cross-sectoral measures (*e.g.*, Integrated Coastal Zone Management, ICZM). This will provide a basis for making the many decisions that coastal adaptation require and provide capacity to address all the coastal problems be they climate or non-climate-related.

Some additional factors are also important. Adaptation may be more costly and difficult than the headline numbers suggested in the study. This reflects several factors: (1) the adaptation costs are partial, (2) the large adaptation deficit, reflecting that Tanzania is poorly adapted to today's climate, and (3) the low adaptive capacity. Further investigation of these issues is recommended.

The study also shows there is a need to focus on existing disaster risk reduction, as well as to start planning for future change now. There is a strong potential for development to increase future vulnerability, *i.e.*, if future economic zones are located in areas that have high future risks with sea-level rise. This necessitates a need for spatial planning. A key element of long-term planning will be to ensure flexibility, and hence forward planning to focus population and asset growth in less vulnerable areas could be an important part of a strategic response to sea-level rise. The analysis also highlights consideration of future thresholds for flooding, to allow decision pathways to be developed.

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