Population and Assets Exposure to Coastal Flooding in Dar es Salaam (Tanzania): Vulnerability to Climate Extremes

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EXECUTIVE SUMMARY

The objective of this case study analysis was to provide a more broader quantitative estimate of the potential number of people and associated economic assets in the coastal zone of Dar es Salaam (Tanzania), which could be exposed to coastal flooding due to extreme water levels through the 21st century. The assessment was performed using an elevation-based geographic information systems (GIS)-analysis based on physical exposure and socio-economic vulnerability under a range of sea-level rise and socio-economic scenarios. The study particularly considered a worst-case scenario assuming that even if defences (natural and/or artificial) exist, they are subjected to failure under the most extreme events. As such, it provides a first detailed quantitative context of the potential exposure, and hence worst-case impacts due to extreme sea levels under a range of possible futures. These could be used to assist coastal planners and policy makers for a better practice of decision-making under conditions of deep uncertainity in terms of planning for sustainable future development.

The results show that about 8% of Dar es Salaam lies within the low elevation coastal zone, “LECZ” (*i.e.*, below the 10m contour lines). This area was estimated to be inhabited by more than 143,000 people (*i.e.*, about 5.3% of the total city population) and associated economic asset estimated to be worth at least US$168 million in 2005, of which over 30,000 people and US$35 million assets are located within the 1 in 100 year flood plain. By 2030 with no climate-induced sea-level rise, the exposure to a 1 in 100 year coastal flood event is estimated at 60,000 people and US$219 million assets (under the population growth distribution (PGD) scenario 2), and 106,000 people and US$388 million assets (under the PGD scenario 1). Under the PGD scenario 3 assuming potential future population and economic growth occur outside the city boundaries, the exposure is significantly reduced (*i.e.*, about 30,000 people and US$35 million assets by 2030). When sea-level rise is considered, a total number of people ranging between 61,000 and 64,000 people (under the PGD scenario 2), and between 107,000 and 110,000 people (under the PGD scenario 1) across the sea-level rise scenarios are estimated to be potentially exposed to coastal flooding by 2030. Similarly, considering the sea-level rise scnearios the exposed assets are estimated between US$223 and US$236 million (under the PGD scenario 2) and between US$392 and US$404 million (under the PGD scenario 1). The exposure increases significantly with time, reaching over 210,000 people and about US$10 billion assets by 2070 under the highest sea-level rise scenario and the PGD scenario 1. These results highlight that socio-economic changes in terms of rapid population growth, urbanisation, and spatial population distribution and associated economic growth are higher than sea-level rise changes, and this will potentially play a significant role in the overall increase of population and assets exposure to coastal flooding in Dar es Salaam. This is illustrated by the population growth distribution scenarios 1 and 2, which are consistent with observed trends of the city growth and demonstrate that exposure will increase substantially from now to 2070 even if there is no change in extreme water levels. Note that these estimates do not include the actual value of ports and harbours or tourist infrastructure which are not within the scope of this analysis.

Moreover, the population growth distribution scenario 1 illustrates that steering development away from low-lying areas that are not threatened (or are less vulnerable) by sea-level rise and extreme climates could be an important part of a strategic response to significantly reduce the future growth in exposure. However, enforcement of such a policy where informal settlements dominate urbanisation (as in many developing countries), will undoubtedly be a major issue. In addition, appropriate adaptation measures (*e.g.*, protection in terms of beach/shore nourishment and dikes) could also be considered in order to keep risks at an acceptable level, but this will require appropriate capital investment and subsequent maintenance. Lastly, it should be recognised that this analysis only provides indicative results. Limitations of the analysis include lack of sufficient and good quality observational local climate data (*e.g.*, long-term sea-level measurements), finer resolution spatial population and asset distribution and high resolution local elevation data, and detailed information about existing coastal defence systems (natural and/or artificial) and current protection levels. As such it should be seen as a first step towards analysing these issues, and needs to be followed by more detailed, city-based analysis.

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Population and Assets Exposure to Coastal Flooding in Dar es Salaam (Tanzania): Vulnerability to Climate Extremes

1. INTRODUCTION

Climate change poses a range of challenges for people 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 represent important components of climate change for coastal areas, 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 damages to coastal protection works and other infrastructure, water resources, agriculture and aquaculture, fisheries, and tourism, recreation, transportation functions and other provisioning services within the coastal zone. 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 (Nicholls *et al*., 2007; Bicknell *et al*., 2009). Potential indirect impacts include altered functions of coastal ecosystems and impacts on human activities: while they are more difficult to analyse, they have the potential to be important in many sectors, *e.g.*, fisheries.

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 likely to affect the most vulnerable, where populations and associated economic activities are highly concentrated such as in low-lying coastal cities (UNFCCC, 2007; Nicholls *et al*., 2008; UN-HABITAT, 2008). In the developing world, few if any coastal cities are prepared for the impacts of today's extreme events, let alone climate change, particularly sea-level rise (McGranahan *et al*., 2007; Nicholls *et al*., 2008). African coastal cities are situated in such a vulnerable region. 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) have identified East Africa as one of the most threatened coastal regions in Africa and globally. They are typically undergoing rapid and unplanned growth, urbanisation, and coastward migration, and have high population densities and overburdened infrastructure. This will increase the exposure of people and assets to sea-level, and influence the extent of any potential impacts they might face due to the changes in extreme water levels during the 21st century. However, despite all these threats, few coastal cities have been assessed in detail in terms of possible coastal impacts.

Dar es Salaam is Tanzania's largest coastal city, and according to UN-HABITAT (2008), the city is identified, among others, as one of the largest coastal city in Africa highly at risk to sea-level rise. The city is vulnerable to floods, sea-level rise, coastal erosion, water scarcity and outbreak of diseases. The high vulnerability is largely attributed to poor planning (about 70% unplanned settlement), poverty, and lack of infrastructure (*e.g.*, poor storm water drainage systems). The coastal zones of the city contain high population, important ecosystem services, and significant economic activity, such as important port infrastructure that are key infrastructure to the national and regional trade and import/exports, and could be threatened by future extreme climate conditions. However, the literature on the potential impacts of these is limited.

This study provides a more quantitative broader context to the potential impacts of coastal flooding due to extreme water levels in the city based on physical exposure and socio-economic vulnerability. A key objective is to identify the hotspots (or concentrations) of population and economic coastal flood exposure today and through the 21st century, and thus identify places in which investment on adequate flood defences, resilience, and disaster preparedness is, and will become, most important.

The remainder of the report is structured as follows: *Section 2* gives a general description of the study area in terms of the physical geography, sea-level change, and socio-economic and environmental characteristics. The materials and methodology used are detailed in *Section 3*, and results are presented and discussed in *Section 4*. Finally, conclusions are drawn in *Section 5*.

2. STUDY AREA: DAR ES SALAAM

2.1 Physical Characteristics

2.1.1 Physical Geography

Dar es Salaam, located on the east coast of Tanzania, lies between latitude 6.45°S and 7.25°S, and longitude 39°E and 39.55°E. It borders the Indian Ocean to the east, and the Coast (Pwani) region on the other sides. It stretches about 100km between the Mpiji River to the north and beyond the Mzinga River in the south, comprising a total land area of 1,630.7 km^2 (about 0.2% of the entire Tanzania mainland's area) (ILRI, 2007). Administratively, the city is divided into three municipalities (or districts), namely Ilala, Kinondoni, and Temeke – which are divided into 74 wards (local government units) (*Figure 1*).

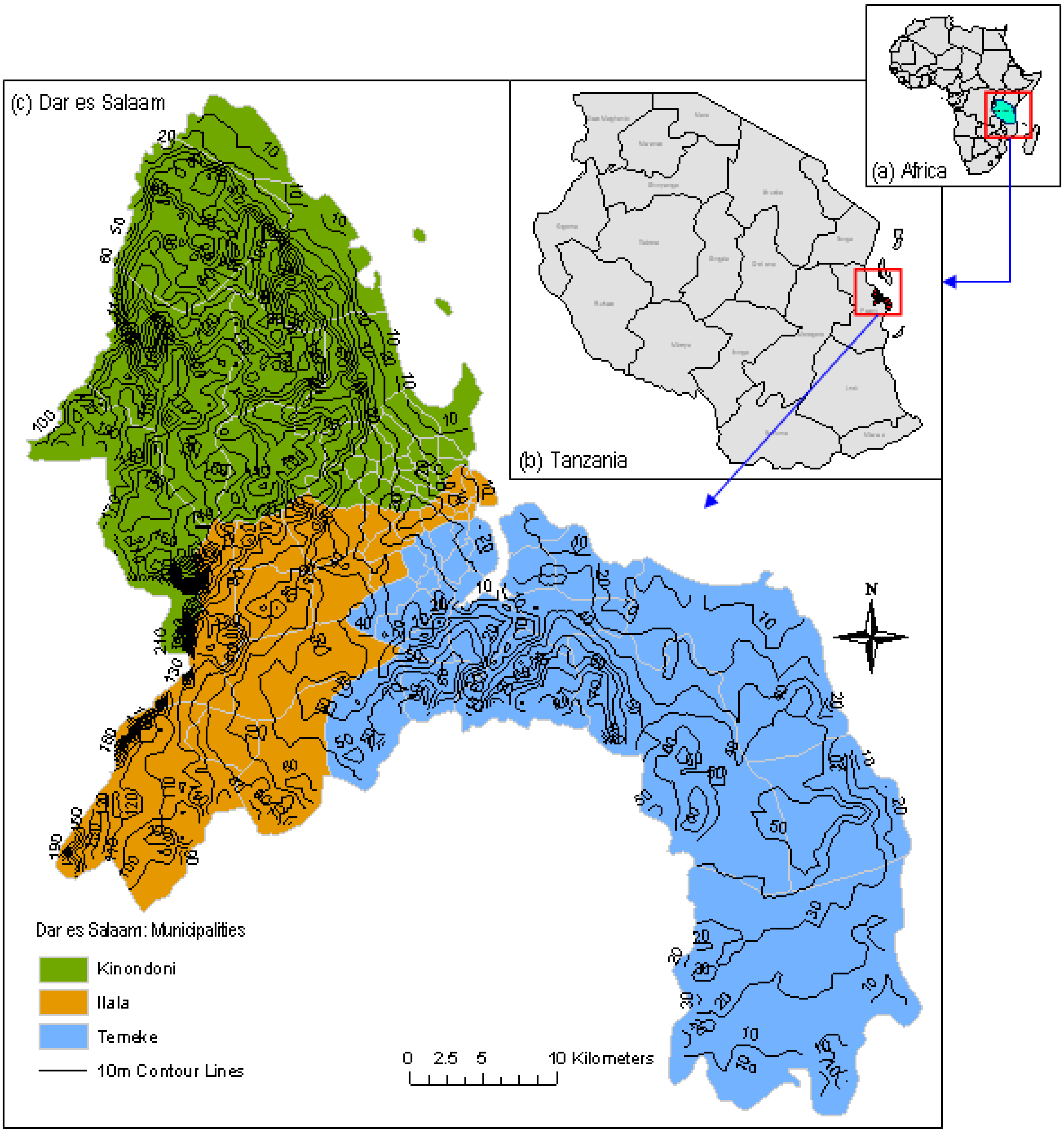


Figure 1: Study Area: (a) Geographical location of Tanzania in Africa, (b) Dar es Salaam in Tanzania, and (c) Municipalities and topographical distribution of Dar es Salaam.

Coastal shrubs, Miomno woodland, coastal swamps and mangrove trees represent the main natural vegetation cover in the city. The city is generally divided into four distinct landforms based on its morphological characteristics (World Care, *n.d.*): (a) *upland plateau* which comprises the hilly areas to the west and north, and on average 100-200m above mean sea level, reaching up to 330m at some points, characterised by steep weathered slopes and well drained of unconsolidated gravely clay bound soils, (b) *inland alluvial plains* characterised by rivers originating from Pugu hills to the east, and the Dar es Salaam harbour penetrating almost 10km inland along the Kizinga and Mzinga creeks forming the principal topographical feature in the region, with poorly drained silt clays enriched with organic matter, (c) *coastal plains* characterised by overlain clay bound Pleistocene with fairly uniform relief lying between 15 and 35m above sea level and slopes of less than 3%. Whilst it extends 10kms to the west of the city, the plain narrows to 2km at Kawe in the north before widening to 8km at the Mpiji River, and varies between 8-15km in width to the southwest where the relief is more irregular gradually merges into the more elevated head waters of Mzinga river, and (d) *shoreline and beach* which comprises the shoreland immediately abutting the sea, also characterised by sand dunes and tidal swamps. Hence, Dar es Salaam does not have extensive coastal lowlands.

2.1.2 General Climate and Sea-Level Change

General Climate

The climatic condition in Dar es Salaam is generally hot and humid throughout the year with an average daily temperature about 26°C, which could rise to 35°C during the hottest season (from October to March). The average rainfall is 1000mm (ranging between 800 and 1300mm). The climate is often influenced by the south-westerly monsoon winds between April to October, and north-westerly monsoon winds between November and March, the maximum wind speed ranging from 3 to 8m/s, lowest during the rainy season (Mahongo, 1999). Tides are semidiurnal, with spring tidal ranges of up to 4m; the mean spring tidal range is 3.2m.

Sea-Level Trends

Sea-level data is an important prerequisite in the physical monitoring of coastal processes. 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 2* shows the annual sea-level measurements at the Zanzibar station during the period 1985-2003, as reported by the Permanent Services for Mean Sea Level (PSMSL). The monthly mean sea level measurement in Dar es Salaam is shown in *Figure 3*. These suggest 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 hence it is difficult to interpret Tanzania's sea-level change records as they are less than 20 years long. 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 measured (Magori, 2005; Kibue, 2006). 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. Nonetheless, the Tanzania records point to stable or falling sea levels and if this is correct, this will contribute to future sea-level trends that are slightly smaller than global-mean changes.

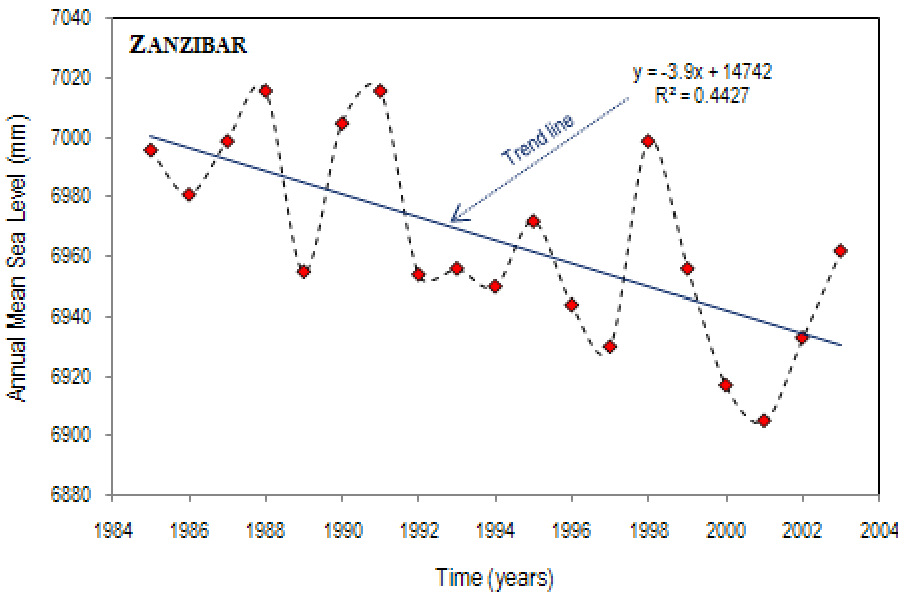


Figure 2: Eighteen years of Annual mean sea level tide gauge measurements for Zanzibar station (06°09.3'S, 39°11.4'E), Tanzania (Source: Permanent Services for Mean Sea Level, PSMSL).

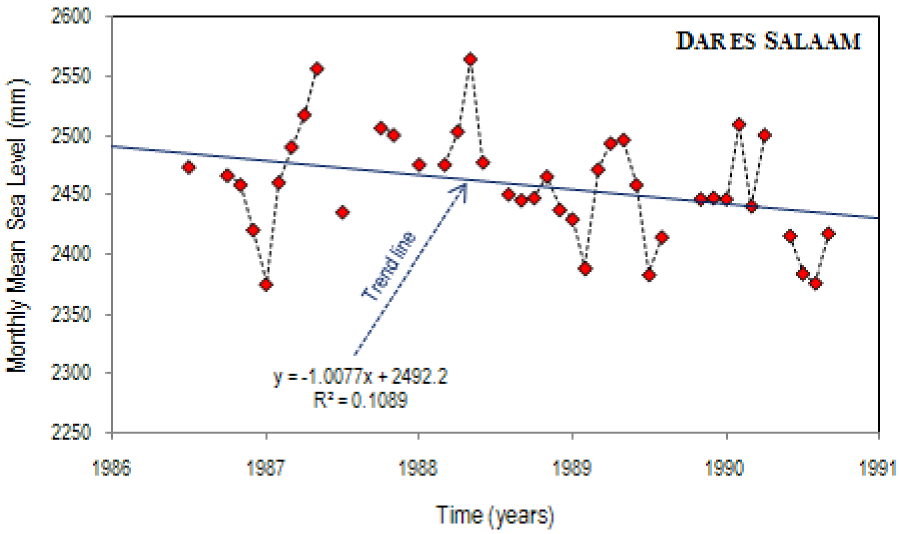


Figure 3: Four years of Monthly mean sea level tide gauge measurements for Dar es Salaam station (06^{o}49.2'S, 39^{o}17.3'E), Tanzania (Source: University of Hawaii Sea Level Center, UHSLC).

2.2 Socio-Economic and Environmental Characteristics

Social Conditions

The city is one of the fastest growing cities in Sub Saharan Africa. It had a population of 2,497,940 (2002 population census report), with a recent growth rate of 4.3% annually (Dar es Salaam City Council, 2004). Hosting about 7.3% of the national population, the city contains about 29% of the country's urban population. The average population density is about 1,532 people per km^2 (*Table 1*). Of the three municipalities, Kinondoni had the highest population of about 1.1 million inhabitants, followed by Temeke, and Ilala districts. The relatively high population growth rate is attributed partly to an influx of people towards urban areas (coastward migration) and increasing birth rate, and more significantly by transient population (about 1million annually). On average, 16% of the city population are migrants from other places in Tanzania. Birth rate is estimated at 4.5% per annum. *Figure 4* shows the historic change in population from 1948 to 2007, and illustrates the rapidly growing population in the city, which increased by a factor of about 46 over the last six decades. It also suggests a continuing rapid growth trend into the future.

Table 1: Distribution of total land area and population of Dar es Salaam by municipality/district (ILRI, 2007).

Municipality (Districts)	Land Area (km^2)	Population (based on 2002 census data report)	
		Population (thousands)	Population density (per km^2)
Ilala	335.0	637.6	1903
Kinondoni	547.2	1,088.9	1990
Temeke	748.5	771.5	1031
Total (Dar es Salaam)	**1,630.7**	**2,497.9**	**1532**

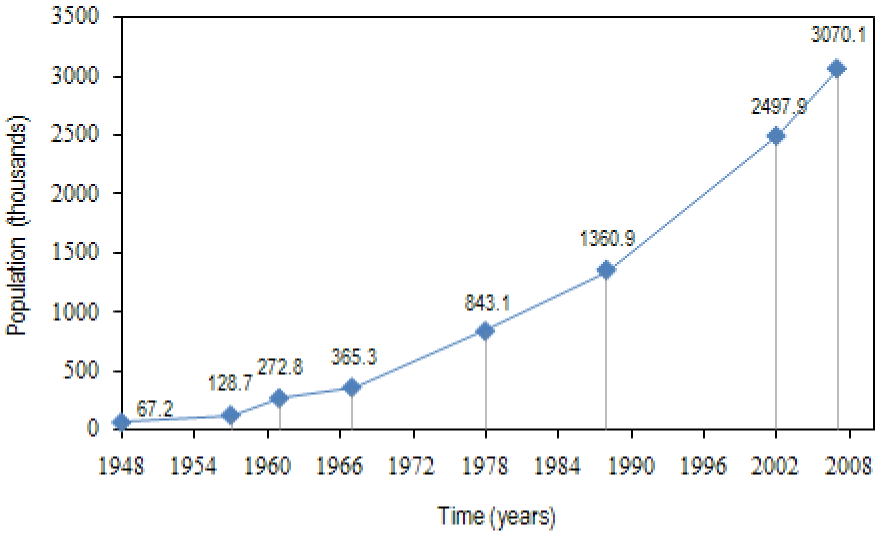


Figure 4: Historic (from 1948 to 2007) population change in Dar es Salaam (Sources: Casmiri, 2008; UN-HABITAT, 2009).

Most of the city's growth has occurred along the central and northern part of the coastline with a great majority of the population living in unplanned and informal settlements; and according to UN-HABITAT (2008), the city has now one of the highest proportions (over 65%) of informal-settlement households in East Africa. The spatial population distribution (based on the 2002 census data report) in the city shows that the unplanned settlement is concentrated mainly on the Kinondoni district, followed by the Ilala district, where the Tandale ward (in the Kinondoni district) has the highest inland population density of more than 42,000 people per km^2. However, in terms of coastal population distribution, the Kisutu ward (in the Ilala district) has the highest coastal population density of over 26,000 people per km^2 (*Figure 5*).

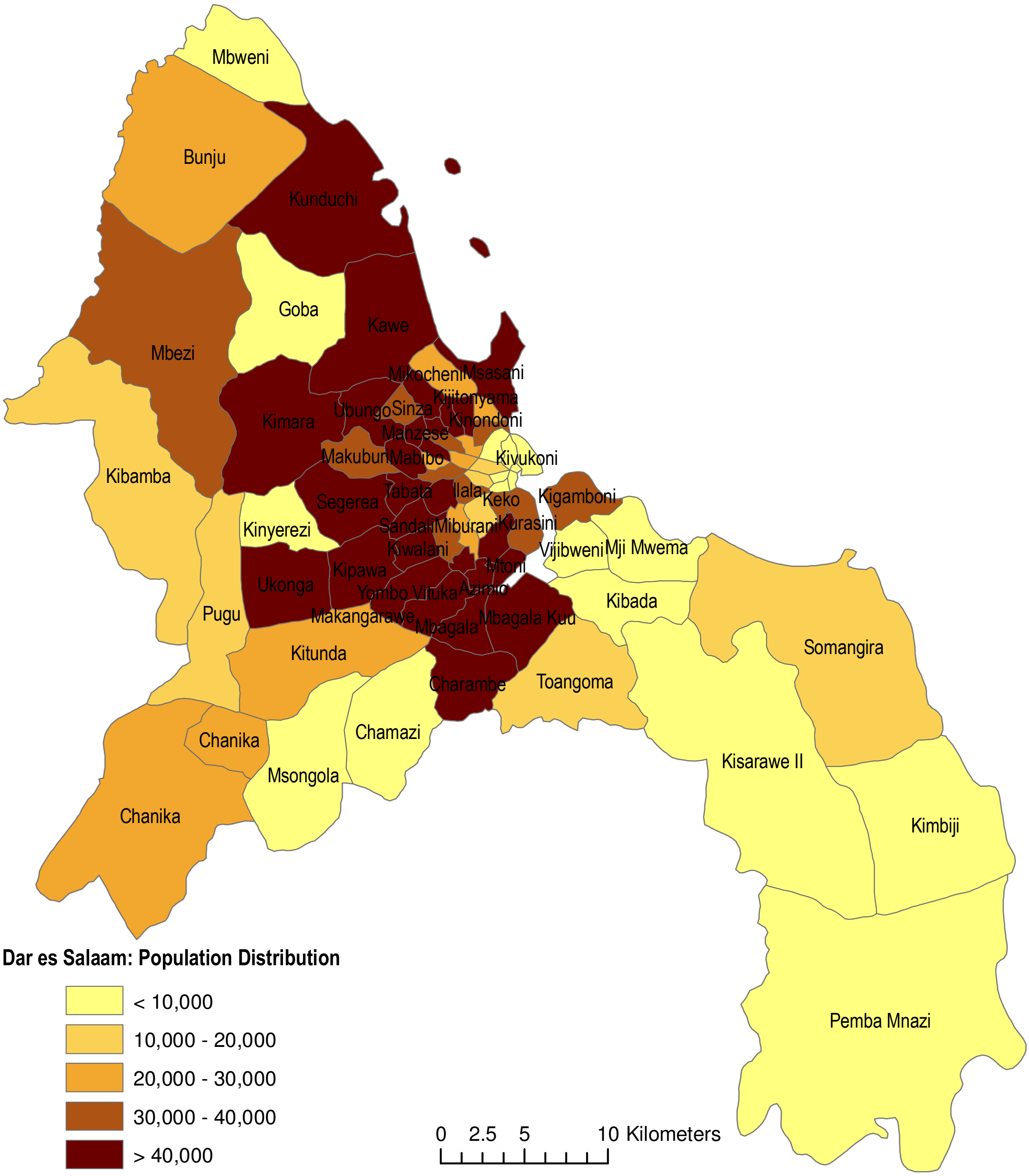


Figure 5: Ward level population distribution in Dar es Salaam (based on 2002 census data report; ILRI, 2007).

Economic Conditions

Dar es Salaam is the major commercial, administrative and industrial city, and the largest urban centre in Tanzania. It plays a significant role to the economic development of the country. The city's Gross Domestic Product (GDP) has increased steadily from 1992 to 2002, and despite the slight reduction between 2002 and 2003, the GDP is expected to continue growing along with the country's GDP (*Figure 6*). In 2002, the GDP of Dar es Salaam was Tshs1,459,013 million (equivalent to US$989 million, NOT discounted), which represented about 16% of the national GDP. The per capita GDP for the city is Tshs584,086 (about US$396, NOT discounted).

The major economic activities in the city include tourism, forestry and fishing, urban agriculture, mining and quarry, manufacturing and others. A total of 110,850 ha (52,000 ha in Kinondoni, 45,000 ha in Temeke, and 13,850 ha in Ilala) of land has potential for agriculture practices, of which over 52% is already in use (Dar es Salaam City Council, 2004). However, the land use is rapidly changing from agriculture to built-up areas (Kombe, 2005). The city accommodates about 40% of the total industrial manufacturing units in the country and contributes about 45% of the nation's gross industrial manufacturing output. The port of Dar es Salaam also plays a significant role for the city's, and hence the nation's economy. The port handles about 95% of Tanzania's international trades, also serving the landlocked countries of Malawi, Zambia, Democratic Republic of Congo, Burundi, Rwanda and Uganda (Tanzania Ports Authority, 2009). In 2007, the port handled a total traffic over 7.4 million tonnage cargo (Lloyd's List Ports of the World, 2009), and this is expected to grow in the future.

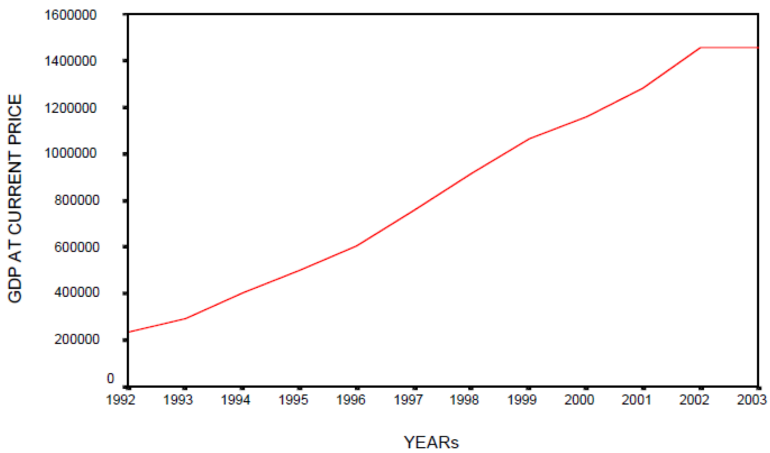


Figure 6: Annual GDP of Dar es Salaam from 1992 to 2003 in Tanzanian Shillings (cited in Dar es Salaam City Council, 2004).

Environmental Conditions

The city's growing population and rapid urbanisation represent the most dynamic factors underlying most of the immediate causes of the degradation of the natural environment. It is estimated that about 70% of the population live in over 40 unplanned communities covering an area of 10,000 ha.

Human activities such as illegal logging, often aimed at making charcoal, also contributes the destruction of the natural rainforest, leading to deforestation and soil erosion (UN-HABITAT, 2009). There are over 2,266 ha (91% in Temeke district, 8% in Kinondoni district, and 1% in Ilala district) of mangrove forests distributed throughout the coastal area (NEMC, 1995). They serve as a natural defence, a nursery for many species and provide physical habitat for numerous fish, crustacean and many varieties of important species, but they are a threatened resource due to unregulated use. They are cut and used by local people for construction, export, firewood, charcoal making, boat building and salt making and release land for rice farms. Indirect impacts of environmental degradation include reduction in sustainable tourism, fisheries, recreation, and other ecological and productivity impacts.

2.3 Coastal Problems and Issues in Dar es Salaam

Due to the low-lying nature of the coastal areas in the city, climate change and sea-level rise threatens the population, infrastructure and other socio-economic development in the coastal zone. Flooding and coastal erosion represent the major threats to the city. This section presents a synthesis of the literature on estimates and predictions of the potential impacts in the city.

According to Casmiri (2008), areas prone to floods include Msasani *bonde la mpunga* (about 60ha mixed residential, commercial and institutional settlements; and is one of the fastest growing settlements in Kinondoni municipal despite being flood prone), Msimbazi valley, Jangwani (a slum area characterised by floods during rainy season almost every year), Mikoncheni (the problem exacerbated by diversion of natural storm water drainage), and the city centre (most flooded area in the city, exacerbated by poor infiltration and outdated un-functioning storm water drainage system). Often located in low-lying areas, shanties are often highly prone to flooding from a variety of mechanisms especially intense precipitation.

Coastal erosion problems have also been reported along virtually the whole stretch of the mainland coast of the country and around the islands (Nyandwi, 2001; Makota *et al*., 2004). Areas that are known to be severely affected include the Kunduchi (north of Dar es Salaam) and Bahari beaches (Griffiths and Lwiza, 1988; Masalu, 2002). At the Kunduchi beach area, the coastline has retreated for about 200m over the last 50 years, destroying residential houses, public services (*e.g.*, a mosque) and other tourism facilities (*e.g.*, hotels), as well as the historic fish market (constructed in 1970s) and a seawall constructed to protect the Ocean road (as cited in Casmiri, 2008). The average rate of erosion for the city area has been estimated about 3 – 5 m/year (Fay, 1992). A number of earlier studies have been carried out on various aspects of coastal erosion, and different causes have been suggested such as coastal uplift (Alexander, 1966; 1969), sea-level rise (Fay, 1992), changes in hydrodynamic conditions such as longshore drift (Arthurton, 1992), and other human activities such as extraction of sand from rivers for construction purposes, destruction of the fringing and barrier coral reefs by dynamite fishing, and removal of vegetation from mangrove swamps (Fay and Griffith, 1987; Fay *et al*., 1988).

Other issues include over exploitation and unsustainable use of coastal and marine resources (*e.g.*, coral reefs and mangrove forests), destructive fishing methods (*e.g.*, poisoning, beach seining), industrial and domestic pollution (*e.g.*, oil spills, effluents, and wastes), coral bleaching, and unregulated tourism activities. Climate change and sea-level rise could only exacerbate these issues in the future, and are more likely to lead to significant loss of low-lying areas of the coastal zone with potential impacts on urban areas, tourism industry, agricultural lands, important infrastructure (*e.g.*, ports) and other socio-economic activities located within the vulnerable coastal zone.

For instance, tourist facilities such as hotels and road infrastructures in Dar es Salaam are only partly protected from erosion by groynes and a seawall. According to Mwaipopo (2000), it is predicted that on average about 400m of landward retreat would occur due to erosion in Dar es Salaam under a 1m sea-level rise. A total land loss estimated at 247 km^2 and 494 km^2 is expected for a 0.5 and 1 meter rise of sea level, respectively (Initial National Communication of Tanzania, 2003). In addition, infrastructure worth US$48 and US$82 million are vulnerable to a 0.5m and 1m sea-level rise, respectively. The cost for building a seawall to protect important vulnerable areas of the city against a 1m rise in sea level has been estimated at US$337 million.

Nicholls *et al*., (2008) estimated population and asset exposure to coastal flooding by a 100-year event due to storm surges globally for 136 port cities with population criteria over 1 million. Dar es Salaam represents one of the 19 African largest port cities included in the study, and they estimated that in 2005, the total exposure in the city is about 36,000 people (ranked 74th globally and 7th in Africa) and US$130 million assets (ranked 127th globally and 14th in Africa). In the 2070s, this exposure grows dramatically due to a combination of urbanisation, socio-economic change and sea-level rise, and over 350,000 people and infrastructure asset worth approximately US$5.3 billion could be exposed to the 100-year coastal flood.

However, despite the city being threatened from the potential impacts of climate change and sea-level rise, the literature in general appeared to be very limited, and the lack of information regarding the vulnerability of population and the assets in low-lying areas to critical climate thresholds still remain as a major problem in the city. This highlights the need for further research.

3. MATERIALS AND METHODOLOGY

The analysis follows the approach used in earlier similar studies (*e.g.*, Nicholls *et al*., 2008; Hanson *et al*., 2009; Kebede *et al*., 2010) to determine the number of people and value of assets exposed to extreme water levels over the 21st century under a range of sea-level rise and socio-economic scenarios. Particular focus is given to 'exposure' rather than *residual risk* (which involves consideration of the benefits of defences and other adaptation measures), as it represents the *worst-case* impacts, recognising that even if defences (natural or artificial) are present they are subjected to failure under the most extreme events. Exposure, therefore, indicates the potential worst-case magnitude for any future event, which needs to be considered when planning for the future. Due to the lack of detailed information and accurate data on coastal defence system in Dar es Salaam (if any), protection cannot be assessed here. The analysis, however, assesses exposure under ranges of scenarios giving a good indication of the worst-case scenario in terms of the average population and values of asset which could be flooded in an extreme event. This is conducted within the framework of the SRES[1] scenarios, although insights since the Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4) are also considered.

3.1 Calculation of Extreme Water Levels

The methodology adopted here is based on that developed by McGranahan *et al*. (2007) and Nicholls *et al*. (2008). An elevation-based geographic information systems (GIS)-analysis is used to assess the number of people exposed to extreme water levels. Nicholls *et al*. (2008) calculated extreme coastal water levels from a combination of storm surge, sea level, natural subsidence and human-induced subsidence. For Dar es Salaam, changes in storminess and human-induced subsidence are not considered relevant. The city is located north of the main storm tracks in the region, and does not experience the landfall of tropical storms today and this is not expected to change in the future. Similarly, human-induced subsidence is not recognised as a present issue in Dar es Salaam, as also suggested by the short-term historic sea-level measurements in the region (*Figures 2 and 3*), and this is considered unlikely to change.

Hence, changes in Extreme Water Levels (*EWL*) are given by:

$$EWL = SLR + S100 + SUB_{\text{Natural}} \qquad (1)$$

Where *SLR* is the global mean sea-level rise scenarios, *S*100 is 1 in 100 year extreme water level (estimated as 3.085m), and SUB_{Natural} is the total natural land subsidence (estimated as -1.58mm/year). For the analysis, current storm surge heights and natural subsidence rates were directly taken from the coastal segment in the DIVA[2] database that includes Dar es Salaam (Vafeidis *et al*., 2005; 2008). The water levels were calculated based on *Equation 1* for current levels and four future projected global sea-level rise (SLR) scenarios. The SLR scenarios were selected to cover a wide range of possible changes, including scenarios above the range given by Meehl *et al*. (2007) to reflect the post-AR4 literature on sea-level rise. These include: low (B1), medium (A1B), high (A1FI) (based on the CLIMBER climate model (Ganopolski and Rahmstorf, 2001)), and a further higher scenario termed 'Rahmstorf' (based on Rahmstorf, 2007) for the years 2005, 2030, 2050 and 2070 (*Table 2* and *Figure 7*). Note that even higher scenarios than used here have been suggested (*e.g.*, Vermeer and Rahmstorf, 2009). The ranges of the SLR scenarios used here are considered as a sensitivity analysis to examine impacts on a range of uncertainty. The estimated extreme water levels are given in *Table 3*.

Table 2: Global mean sea-level rise scenarios: 1990 to 2100.

Year	Sea-Level Rise Scenarios (m)				
	Rahmstorf	A1FI high-range	A1B med-range	B1 low-range	No SLR
1990	0.00	0.00	0.00	0.00	0.00
2000	0.04	0.04	0.02	0.01	0.00
2005	0.05	0.06	0.03	0.02	0.00
2010	0.07	0.08	0.04	0.02	0.00
2020	0.12	0.13	0.07	0.03	0.00

[1] The SRES scenarios are the sea-level and socio-economic scenarios based on the Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change (Nakićenović and Swart, 2000; IMAGE Team, 2002).
[2] DIVA is the Dynamic Interactive Vulnerability Assessment model developed in the EU 5th Framework DINAS-COAST project (DINAS-COAST Consortium, 2006) (see Hinkel and Klein, 2009).

2030	0.19	0.19	0.10	0.05	0.00
2040	0.27	0.26	0.14	0.06	0.00
2050	0.38	0.35	0.18	0.08	0.00
2060	0.51	0.46	0.23	0.10	0.00
2070	0.66	0.57	0.28	0.12	0.00
2080	0.84	0.70	0.32	0.14	0.00
2090	1.04	0.83	0.38	0.16	0.00
2100	1.26	0.97	0.43	0.17	0.00

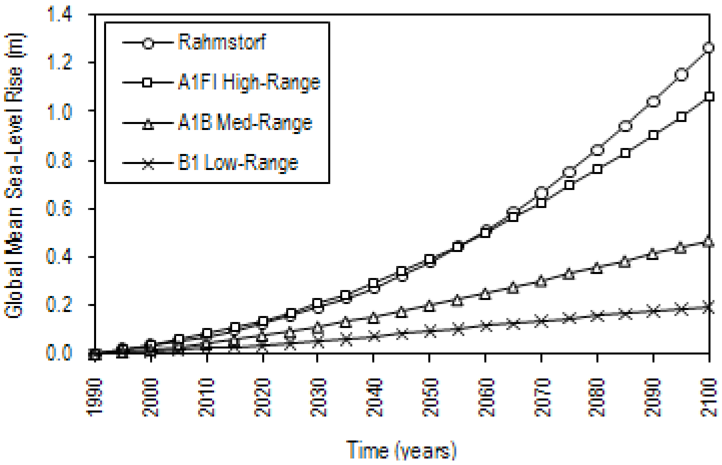


Figure 7: Global mean sea-level rise scenarios.

Table 3: Extreme water levels estimated under each SLR scenario.

Year	Sea-Level Rise Scenarios (m)				
	Rahmstorf	A1FI high-range	A1B med-range	B1 low-range	No SLR
2005	3.11	3.12	3.09	3.08	3.06
2030	3.21	3.23	3.13	3.07	3.02
2050	3.37	3.38	3.19	3.08	2.99
2070	3.62	3.58	3.26	3.09	2.96

3.2 Socio-Economic Scenarios

The analysis of future impacts considers future socio-economic changes based on one scenario of population, including urbanisation, and gross domestic product (GDP) of the city, following the A1 scenario (or 'world')[3]. Future projections were obtained from country level predictions, following the methodology of Hanson *et al.* (2009), which is downscaled for Dar es Salaam based on 2005 population levels reported in UNPD (2007). Projected per capita GDP levels were also taken from the same report. In addition, focussing on worst-case impacts, the *rapid urbanization*[4] scenario is reasonably adopted. *Table 4* gives the socio-economic scenarios used for the base year (2005), and three projected time series of the years 2030, 2050 and 2070.

Table 4: Population and GDP per capita of Dar es Salaam through the 21st century under the A1 socio-economic scenario with rapid urbanisation.

Projections	Year			
	2005	2030	2050	2070
Population (thousands)	2676	5366	7377	9645
GDP per capita (US$)	235.2	734.6	2840.8	9248.9

[3] The A1 world is derived from the Special Report on Emission Scenarios (SRES) of the IPCC (Nakićenović and Swart, 2000; IMAGE Team, 2002; Nicholls *et al*., 2008).

[4] A rapid urbanisation growth which corresponds to the direct extrapolation of the 2030 UN scenarios to 2080 is used here. If a slower urbanisation scenario was used the exposure would be reduced relative to the numbers determined here.

The process of downscaling the city population projections in Table 4 to ward-level distribution was made based on the 2002 census data (ILRI, 2007). First, the downscaled population distributions for the base year (*i.e.*, 2005) were estimated based on the percentage population distributions over the 74 wards in 2002. Then, snapshot projections of the spatial population distributions in 2030, 2050, and 2070 were developed considering three population growth distribution scenarios, based on the observed population distribution in the base year (as defined in *Table 5*). PGD scenario 1 considers the possible future development at the district scale and assumes uniform growth across the three districts. PGD scenario 2 illustrates the same assumption but with the calculations performed on the 74 wards, so at a much higher spatial resolution than PGD scenario 1. PGD scenario 1 gives the largest growth in coastal population, assuming uniform population distribution per district. PGD scenario 2 gives a smaller population growth as people are presently most concentrated away from the coast in areas not threatened by sea-level rise. A third scenario (*i.e.*, PGD scenario 3) is considered assuming that potential population growth occur outside the city boundaries to demonstrate the possible effect of climate change over socio-economic change as a control scenario. These three population scenarios could be interpreted as potential policy choices and/or responses for managing encouraging future population and economic growth to happen outside the areas threatened by sea-level rise.

Table 5: Population growth distribution scenarios.

Population Growth Distribution (PGD) Scenarios	Scenario Description
1	Assuming uniform population growth per district weighted by 2005 population distribution (*i.e.*, district-averaged population density is considered for the corresponding wards in each district) (high scenario),
2	Assuming uniform population growth per ward weighted by 2005 population distribution (medium scenario),
3	A 'no population growth' scenario, assuming the population in all the city districts is kept at 2005 levels (low scenario). (All growth is assumed to be displaced to locations outside the city boundaries).

3.3 Estimates of Population and Asset Exposure

The sea-level rise scenarios considered are coupled with the A1 socio-economic (with rapid urbanisation) scenarios for estimating the future projected population and asset exposure. This follows the methodology used by Hanson *et al*. (2009). The simulations to estimate exposed number of people and associated economic assets that are located below the 1 in 100 year return period extreme water levels for each scenarios are performed based on a population distribution data available from the International Livestock Research Institute (ILRI) GIS-compatible online spatial data layers [http://www.ilri.org/GIS] (see *Table 1 and Figure 5*) and a Shuttle Radar Topography Mission (SRTM) elevation data of approximately 90m resolution obtained from the U.S. Geological Survey (USGS) server [http://www.usgs.gov]. The population by elevation on a horizontal map of geographical cells is then estimated by mapping the population distribution over the wards of each district onto the SRTM, which allows the total population distribution against elevation to be estimated. In quantifying the infrastructure assets exposed to the 1 in 100 year extreme water levels, a method commonly used in the insurance industry and applied by Nicholls *et al*. (2008) is adopted which estimates the value of assets using the population exposed (*Equation 2*).

$$E_a = E_p \; x \; GDP_{\text{percapita (PPP)}} \; x \; 5 \quad \ldots\ldots\ldots \quad (2)$$

Where, E_a is exposed asset (monetary value), E_p is exposed population, and $GDP_{\text{percapita (PPP)}}$ is the national per capita Gross Domestic Product (GDP) Purchasing Power Parity (PPP). *Figure 8* summarises the methodology.

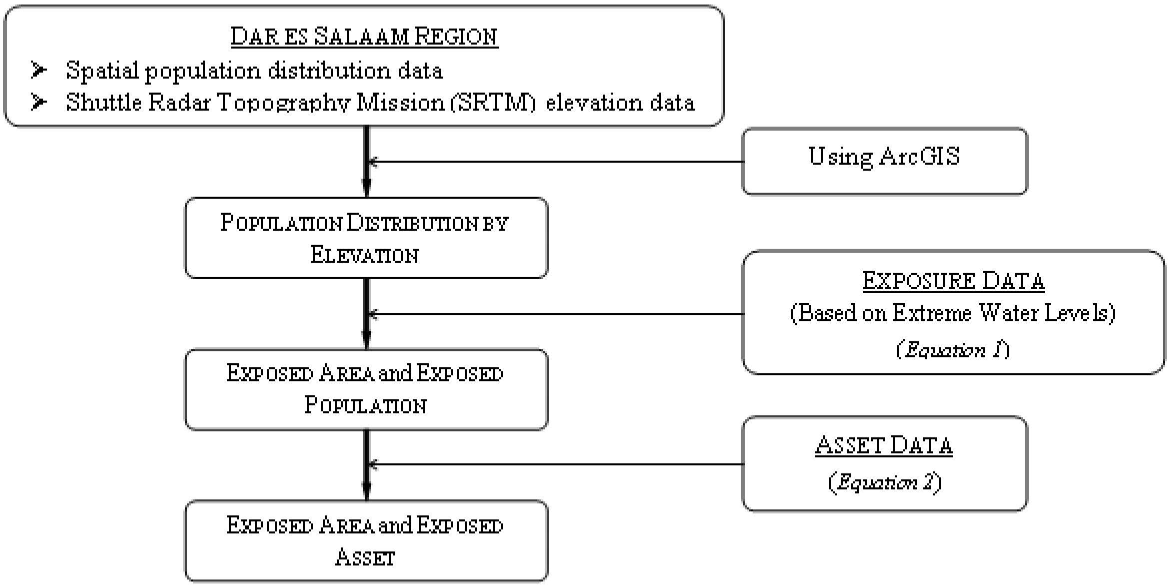


Figure 8: A simplified flowchart of the methodology (adapted from Nicholls et al., 2008).

4. Results and Discussion

Results show that about 8% of the land area of Dar es Salaam (distributed across the districts as 4.4km^2 in Ilala, 35.2 km^2 in Kinondoni, and 89.2 km^2 in Temeke) is below the 10m contour line (which is referred here as the low elevation coastal zone, 'LECZ') (*Table 6*). In 2005, it is estimated that over 140,000 people were located within the LECZ. Despite the large number, this figure represents only about 5.3% of the total city population, which are also concentrated only in few of the central and northern coastal wards. The current distribution of the population with respect to vertical ground elevation across the districts is shown in *Table 6*. The total population living below mean sea level were estimated at about 0.7% (about 18,000 people) of the total city population. This is thought to be unrealistic as there are no defences and hence it illustrates the potential error of the data, at about 14%.

Table 6: Population Distribution in 2005 (base year) against selected ranges of ground elevations.

Elevation Ranges (m)	TOTAL (Dar es Salaam)		Districts					
			Ilala		Kinondoni		Temeke	
	Land Area (km^2)	Population (thousands)	Land Area (km^2)	Population (thousands)	Land Area (km^2)	Population (thousands)	Land Area (km^2)	Population (thousands)
< 0	22.2	17.7	1.3	1.4	5.4	7.8	15.4	8.5
< 2	30.3	23.5	1.4	1.5	7.8	11.4	21.1	10.7
< 5	55.8	54.8	2.1	6.4	16.7	25.1	37.0	23.4
< 10	128.8	143.0	4.4	22.6	35.2	64.6	89.2	55.8
< 20	324.1	594.0	12.8	114.3	82.8	297.3	228.5	182.5
< 40	665.1	1688.6	31.4	338.4	133.5	774.5	500.2	575.6
TOTAL	**1630.7**	**2676.0**	**335.0**	**683.0**	**547.2**	**1166.5**	**748.5**	**826.5**

Exposure to extreme water levels was estimated relative to the baseline (in 2005) represented by exposure to a 1 in 100 year flood event. Without considering sea-level rise, more than 31,000 people are currently at risk of the 1 in 100 year return period storm surge (*i.e.*, about 3.09m water level). This is consistent with the OECD[5] study (Nicholls *et al.*, 2008). *Table 7* presents the total number of people and associated economic assets exposed to the 1 in 100 year return period extreme water levels now and in the future considering the sea-level rise scenarios coupled with three population growth distribution (PGD) scenarios. The PGD scenarios illustrate the sensitivity of future population and asset exposure to changes in the spatial distribution of population settlements and associated

[5] Organisation for Economic Co-operation and Development

economic activities within the city. The estimates demonstrate that exposure is highest under the PGD scenario 1, followed by that of the medium PGD scenario (*i.e.*, scenario 2). By 2030, more than 100,000 people and over US$400 million assets in the city are exposed to the 1 in 100 year flooding due to extreme water levels. This dramatically increases ranging between 193,000 to 213,000 people and infrastructure assets worth between US$8.9 and US$9.8 billion being exposed by 2070 across the ranges of sea-level rise scenarios and considering the PGD scenario 1. Even without climate-induced sea-level rise, exposure as high as more than 180,000 people and US$8.4 billion worth assets are estimated by 2070. However, when a no-population growth scenario is considered where the district population are maintained at 2005 levels (*i.e.*, PGD scenario 3), exposure is significantly reduced to 35,000 people and US$41 million assets even under the highest sea-level rise scenario (*Table 7*). These estimates demonstrate that future population and asset exposure to flooding are much more sensitive to socio-economic change than climate change, with population growth/ urbanisation and spatial distributions of people being dominant controls of change. The estimates also highlight the crucial message that, without action today to ensure sustainable development and planned population settlement, economic growth itself will strongly aggravate the impacts of climate change and sea-level rise on coastal flood exposure. Note that costs are reported in 2005 US$, and are NOT discounted.

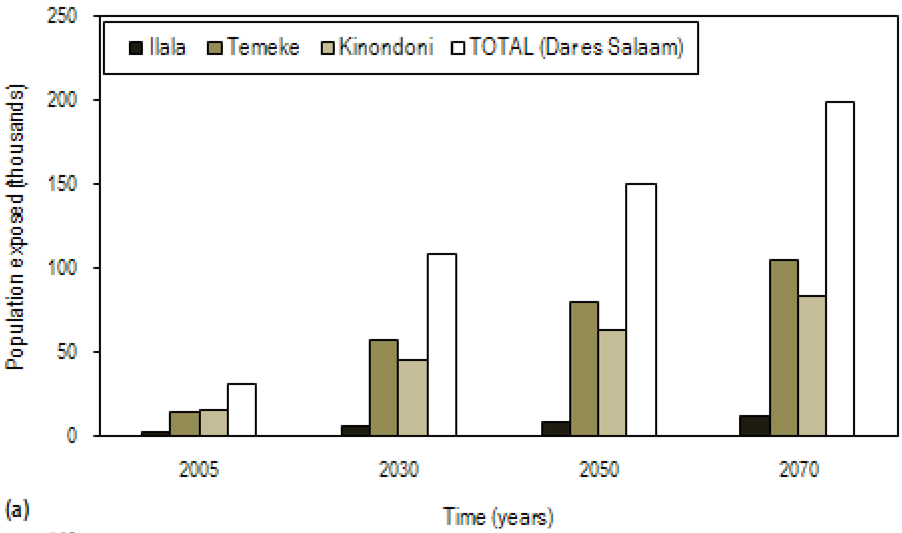
Table 7: Population and assets exposed to the 1 in 100 return period extreme water levels in Dar es Salaam under the ranges of sea-level rise scenarios.

Year	Extreme Water Levels (m)	Population Exposed (thousands)			Assets Exposed (in US$ millions)		
		Population Growth Distribution Scenarios			Population Growth Distribution Scenarios		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
No climate-induced SLR Scenario							
2005	3.06	30.1	30.1	30.1	35.4	35.4	35.4
2030	3.02	105.7	59.6	29.7	388.1	218.8	34.9
2050	2.99	140.6	79.1	28.7	1996.8	1123.3	33.7
2070	2.96	182.4	102.7	28.5	8434.4	4748.7	33.5
B1 low-range SLR Scenario							
2005	3.08	30.4	30.4	30.4	35.8	35.8	35.8
2030	3.07	106.8	60.8	30.3	392.4	223.1	35.6
2050	3.08	147.3	83.9	30.4	2092.4	1192.3	35.8
2070	3.09	193.1	110.5	30.7	8929.5	5112.0	36.1
A1B med-range SLR Scenario							
2005	3.09	30.7	30.7	30.7	36.1	36.1	36.1
2030	3.13	108.0	62.3	31.1	396.7	228.8	36.5
2050	3.19	150.2	87.7	31.8	2132.9	1245.7	37.4
2070	3.26	198.9	116.4	32.3	9197.7	5380.6	38.0
A1FI high-range SLR Scenario							
2005	3.12	31.1	31.1	31.1	36.5	36.5	36.5
2030	3.23	110.0	64.3	32.0	404.1	236.0	37.7
2050	3.38	155.7	91.5	33.2	2212.2	1299.9	39.0
2070	3.58	208.8	122.0	34.6	9658.0	5643.7	40.6
Rahmstorf SLR Scenario							
2005	3.11	31.0	31.0	31.0	36.5	36.5	36.5
2030	3.21	109.7	63.9	31.9	402.8	234.8	37.5
2050	3.37	155.5	91.3	33.1	2208.9	1297.1	39.0
2070	3.62	212.6	126.1	35.0	9831.1	5832.3	41.2

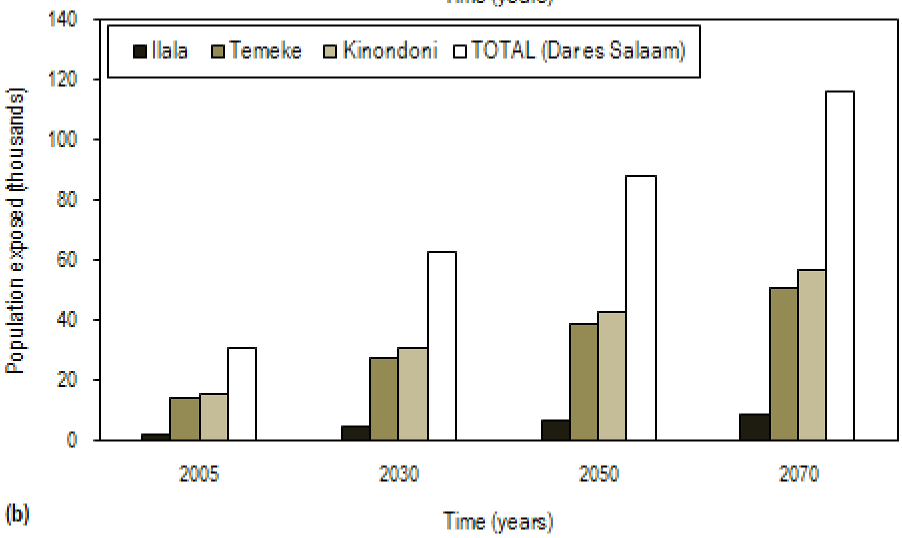
Figures 9 and *10* illustrate the distribution of population and assets exposure across the districts of Dar es Salaam under the A1B med-range SLR scenario along with the three population growth distribution scenarios considered. Results show that exposure increases with time due to the projected increase in population of each district, and are highest in the Kinondoni district due to its higher population density, followed by the Temeke district, distributed as 49% in Kinondoni, 44% in Temeke, and 7% in Ilala districts under the PGD scenario 2. By 2070, about 9,000 people and US$396 million asset in the Ilala district, 51,000 people and over US$2.3 billion asset in the Temeke district, and 57,000 people and more than US$2.6 billion asset in the Kinondoni district are exposed to a 1 in 100 year flood event due to extreme water levels (see *Figures 10* and *11*). However, when considering the PGD scenario 1, the spatial distribution of the exposure changes, and become highest (51%) in the

Temeke district due to the potential future urbanisation of the current large rural coastal areas in the district. For instance by 2070, the exposure in the Temeke district is more than doubled to 104,000 people and US$4.8 billion asset. Note that these estimates do not include the actual value of ports and harbours or tourist infrastructure which are not within the scope of this analysis.

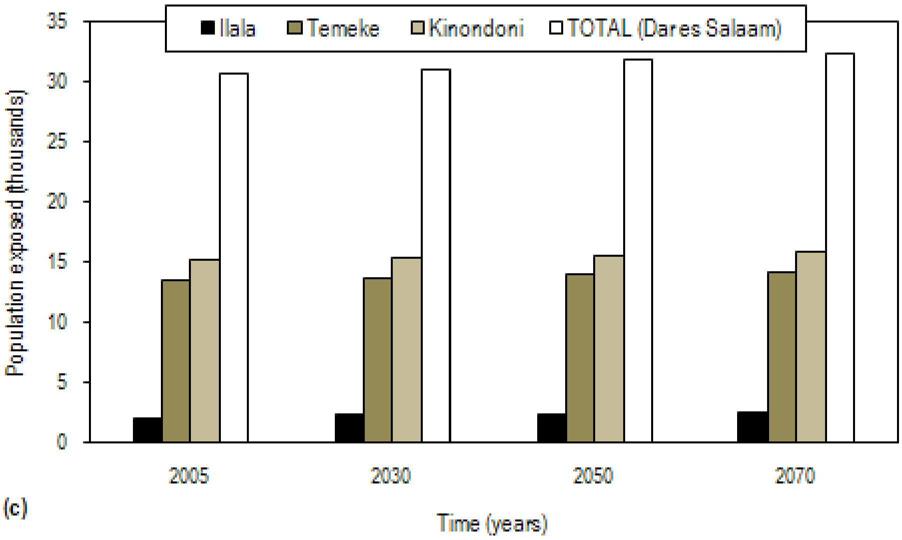
These estimates provide a broader quantitative context to the potential threats of coastal flooding in Dar es Salaam due to extreme water levels through this century. The assessment is made based on physical exposure and socio-economic vulnerability. The analysis identified the hotspots (or concentrations) of population and economic assets that are exposed to a 1 in 100 year flood event today and in the future, considering a worst-case scenario under which, even if natural or artificial defences are present, it is assumed that they are subjected to failure under the most extreme events. The ranges of scenarios considered provide a wide range of possible futures that need to be considered when planning for the future. The results clearly outlined that population growth and urbanization are factors which significantly contribute in the increase in the number of people and economic assets exposed to flooding, and this will continue to be an important factor during the 21st century independent of other drivers as demonstrated in the analysis. However, it is recognised that there is a potential scope within the city limits, and the risks of sea-level rise in Dar es Salaam could be significantly reduced using a sustainable spatial planning for population settlement and economic activities in the coastal zone and by steering future development to areas that are not threatened by sea-level rise.



(a)

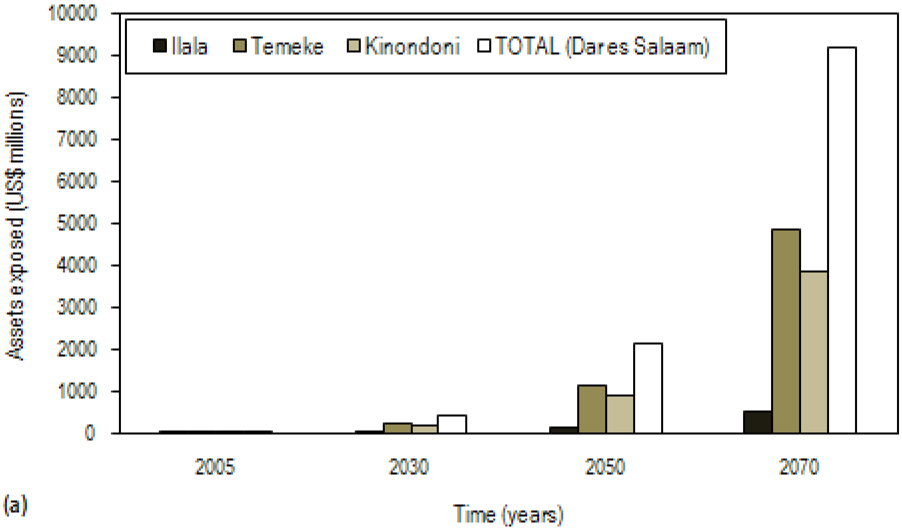


(b)

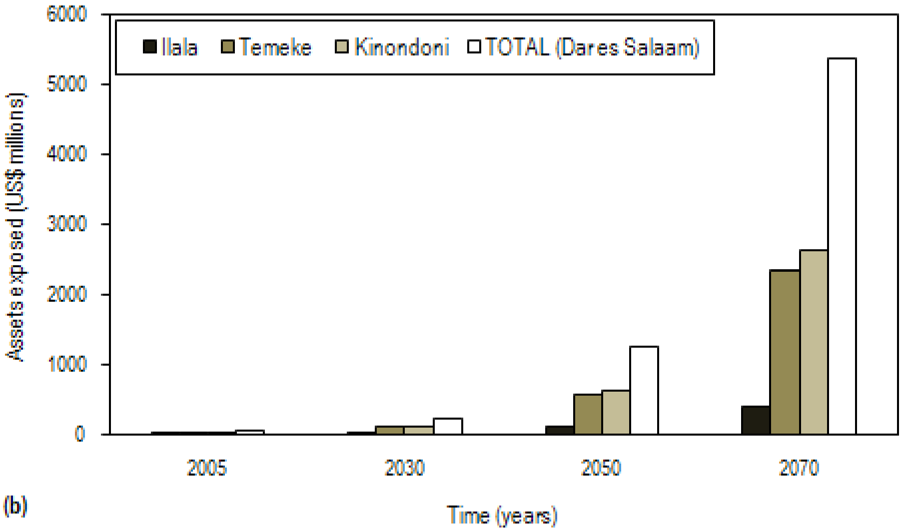


(c)

Figure 9: Exposed population in 2005, 2030, 2050, and 2070 under the A1B mid-range SLR and the three Population Growth Distribution (PGD) scenarios ((a) – Scenario 1, (b) – Scenario 2, and (c) – Scenario 3). Note different scales on y-axis.



(a)



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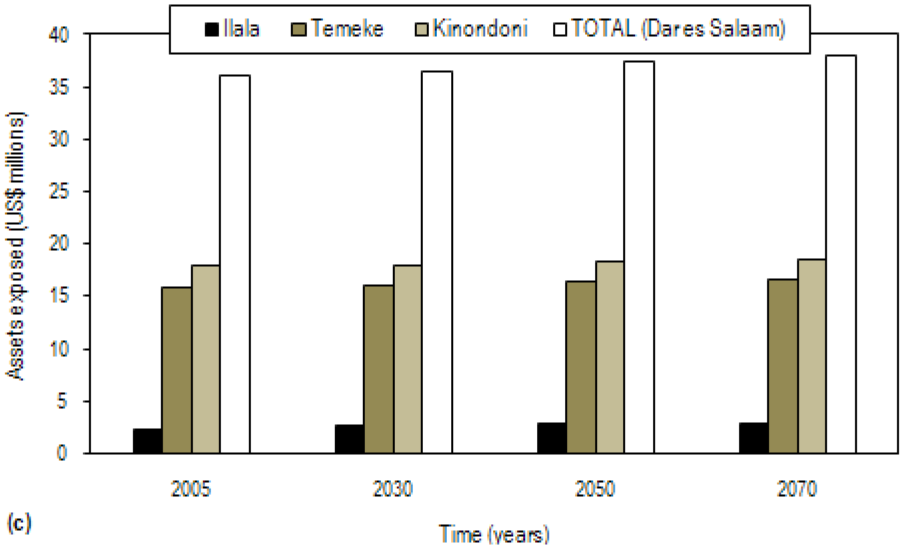

Figure 10: Exposure of assets in 2005, 2030, 2050, and 2070 for the A1B mid-range SLR and the three Population Growth Distribution (PGD) scenarios ((a) – Scenario 1, (b) – Scenario 2, and (c) – Scenario 3). Note different scales on y-axis.

5. Conclusions

This assessment based on an elevation-based geographic information systems (GIS)-analysis on the potential impacts of climate extremes and sea-level rise has made a first detailed quantitative estimate of the potential number of people and associated economic assets in the coastal city of Dar es Salaam which could potentially be exposed to coastal flooding due to extreme water levels under a worst-case scenario (*i.e.*, assuming that even if defences (natural and/or artificial) exist, they are subjected to failure under the most extreme events). As the city is projected to experience a significant population growth, rapid urbanisation and growing associated economic development in the coastal zone through the 21st century, the estimates in this analysis provide a broader quantitative context of the potential exposure, and hence worst-case impacts due to extreme sea levels under a range of possible futures. These can assist coastal planners and policy makers to make better decisions for sustainable future development.

The GIS-based analysis results show that about 8% of Dar es Salaam's land area lies within the low elevation coastal zone (LECZ, *i.e.*, below the 10m contour lines). This area was estimated to be inhabited by more than 143,000 people (*i.e.*, about 5.3% of the city's population) and to contain associated economic asset worth more than US$168 million in 2005. (These estimates do not include the actual value of ports and harbours or tourist infrastructure which are not considered here).

Without considering sea-level rise, it is estimated that over 30,000 people live within the 1 in 100 year flood plain due to extreme sea levels in 2005. By 2030 with no climate-induced sea-level rise, about 30,000 people and US$35 million assets (under the PGD scenario 3), about 60,000 people and US$219 million assets (under the PGD scenario 2), and about 106,000 people and US$388 million assets (under the PGD scenario 1) are potentially exposed to a 1 in 100 year coastal flood event. When sea-level rise is considered, the exposure is estimated between 30,000 and 32,000 people (and associated assets between U$S36 and US$38 million) across the sea-level rise scenarios and under the PGD scenario 3. Considering the PGD scenario 1, between 107,000 and 110,000 people (and associated assets between U$S392 and US$404 million) ranging across the sea-level rise scenarios are estimated to be potentially exposed to flooding. The exposure significantly increase with time, and under the highest sea-level rise scenario and the PGD scenario 1 the estimates of exposure reach over 210,000 people and about US$10 billion assets by 2070. Hence, future socio-economic changes in terms of rapid population growth and urbanisation and associated economic growth in the city, potentially play by far the most significant role in the overall increase of exposure of population and assets to coastal flooding in Dar es Salaam. This is highlighted under population growth distribution scenarios 1 and 2, which are consistent with observed trends of the city growth and demonstrate that exposure will increase substantially from now to 2070 even if there is no change in extreme water levels.

These estimates provide a broader more quantitative context and magnitude of the potential impacts/threats of coastal flooding due to extreme water levels which need to be considered when planning for the future. The population growth distribution scenario 3 illustrates that steering development to areas away from low-lying areas that are not threatened (or less vulnerable) by sea-level rise and extreme climates could be an important part of a strategic response to significantly reduce the future growth in exposure. However, enforcement of such a policy where informal settlements dominate urbanisation (as in many developing countries), will undoubtedly be difficult and such a policy may be of more theoretical than practical interest. In addition, appropriate adaptation measures (*e.g.*, protection in terms of beach/shore nourishment and flood defence structures (see Linham and Nicholls, 2010)) could also be considered in order to keep risks at an acceptable level, but this will require appropriate capital investment and subsequent maintenance. (Port and harbour infrastructure would also require upgrade).

Limitations of the study include lack of sufficient and good quality observational climate data (*e.g.*, long-term sea-level measurements), finer resolution population and asset distribution and local elevation data, and detailed information about existing defence system (artificial measures, if any and/or natural features such as effects of corals, mangroves, etc.) and current protection level. However, this analysis should be considered as a first step towards a better understanding of these issues, and needs to be followed by more detailed, city-based analysis.

6. REFERENCES

Alexander, C.S., 1966. The method of descriptive shore class fixation and mapping to the northeast coast of Tanganyika. *Annals of the Association of American Geographers*, New York, 56(1), 122–140.

Alexander, C.S., 1969. Beach ridges in north-eastern Tanzania. *Geographical Review*, New York. 59 (1), 104–122.

Arthurton, R.S., 1992. Beach erosion: Case studies on the East African Coast, pp. 91–95. In: *Proceedings of the International Convention on the Rational Use of the Coastal Zone*. UNESCO-IOC and Bordomer Organisation, Bordeaux.

Bicknell, J.; Dodman, D., and Satterthwaite, D., (eds.), 2009. *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*. London, UK: Earthscan, 397p.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., Yanda, P., 2007. Africa. In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Editors), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contributions of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge UK, 433-467.

Brown, S., Kebede, A.S. and Nicholls, R.J., 2009. Sea-Level Rise and Impacts in Africa, 2000 to 2100. *Unpublished report to Stockholm Environment Institute*, Oxford, pp. 215.

Casmiri, D., 2008. Vulnerability of Dar es Salaam City to Impacts of Climate Change. *EPMS*, Dar es Salaam, 22 pp.

Dar es Salaam City Council, 2004. *United Republic of Tanzania, Dar es Salaam City Profile*. Dar es Salaam City Council and WHO. City Director, Dar es Salaam, 93pp.

DINAS-COAST Consortium, 2006. DIVA 1.5.5. Potsdam Institute for Climate Impact Research, Potsdam, Germany, CD-ROM. Available at http://www.pik-potsdam.de/diva

Douglas, B.C., 2001. Sea Level Change in the Era of the Recording Tide Gauge. *In*: Douglas, B.C.; Kearney, M.S., and Leatherman, S.P., (eds.), *Sea Level Rise: History and Consequences*. International Geophysics Series, California, USA: Academic Press, Vol.75, 37-64.

Fay, M.B. 1992. Maziwi island off Pangani (Tanzania): History of its destruction and possible causes. *UNEP Regional Seas Reports and Studies*, No. 139 UNEP, 43pp.

Fay, M. and Griffith, C.J., 1988. Beach erosion along the coast north of Dar es Salaam (Tanzania): Magnitude and possible causes. Mogadishu, Somali National University. Geosom 87, p63.

Fay, M., Griffith, C.J, Hemed, I.A. and Lwiza, K.M, 1988. Beach erosion along Kunduchi Beach, north of Dar es Salaam. Beach Erosion Monitoring Committee, Dar as Salaam, National Environment Management Council, 55pp.

Ganopolski, A. and Rahmstorf, S., 2001. Rapid changes of glacial climate simulated in a coupled climate model. *Nature*, 409 (6817), 153-158.

Griffiths, C.J. and Lwiza, K.M., 1988. Physical background of the study area. *In:* Beach erosion along Kunduchi beach, north of Dar es Salaam. A Report for NEMC by Beach Erosion Monitoring Committee, 55 pp.

Hanson, S.; Nicholls, R.J.; Hallegatte, S., and Corfee-Morlot, J., 2009. The effects of climate mitigation on the exposure of the worlds large port cities to extreme coastal water levels. UK: AVOID Programme DECC/DEFRA, *Project Report,* (in review).

Hinkel, J. and Klein, R.J.T., 2009. The DINAS-COAST project: developing a tool for the dynamic and interactive assessment of coastal vulnerability. *Global Environmental Change*, 19(3), 384-395.

Hoozemans, F.M.J., Marchand, M. and Pennekamp, H.A., 1993. *A Global Vulnerability Analysis: Vulnerability Assessment for Population, Coastal Wetlands and Rise Production on a Global Scale*, 2nd edition, Delft Hydraulics, the Netherlands.

ILRI (International Livestock Research Institute), 2007. GIS Services. Available from http://www.ilri.org/GIS (last accessed 04 October 2010).

IMAGE Team, 2002. IMAGE 2.2. http://www.mnp.nl/en/themasites/image/index.html (Accessed August 2009).

Initial National Communication of Tanzania, 2003. United Republic of Tanzania Initial Communication under the United Nations Framework Convention on Climate Change (UNFCCC), Dar es Salaam, available on-line: http://unfccc.int/resource/docs/natc/tannc1.pdf (last accessed on 29 September 2010).

Kebede, A.S., Nicholls, R.J., Hanson, S., and Mokrech, M., 2010. Impacts of Climate Change and Sea-Level Rise: A Preliminary Case Study of Mombasa, Kenya. *Journal of Coastal Research*. (accepted)

Kombe, W.J., 2005. Land use dynamics in peri-urban areas and their implications on the urban growth and form: the case of Dar es Salaam, Tanzania. *Habitat International*, 29, 113-135.

Linham, M and Nicholls, R.J., 2010. *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. Zhu, X. (ed.), UNEP Technology Needs Assessment (TNA) Guidebook Series.

Lloyd's List *Ports of the World*, 2009. *Volume 1: Albania – Lithuania, and Volume 2: Madagascar - Yemen*. London, Informa Maritime and Professional.

Mahongo, S.B., 1999. Sea level measurement and analysis in the Western Indian Ocean. National Report, Tanzania Fisheries Research Institute, Tanzania. *Intergovernmental Oceanographic Commission (of UNESCO)*, 25 pp.

Makota, V., Sallema, R. and Makika, C., 2004. Monitoring Shoreline Change using Remote Sensing and GIS: A Case Study of Kunduchi Area, Tanzania. *Western Indian Ocean Journal of Marine Science*, 3(1), 1-10.

Mahongo, S.B., 2001. The Tanzania Sea Level Network: A National Report (Draft). *Tanzania Fisheries Research Institute*. Available on-line at: http://www.gloss-sealevel.org/publications/documents/tanzania_2001.pdf (last accessed on 11 October 2010).

Mahongo, S.B. and Khamis, O.I., 2006. The Tanzania National Sea Level Report. *Tanzania Fisheries Research Institute and Department of Survey and Urban Planning*. Available on-line at: http://www.gloss-sealevel.org/publications/documents/tanzania2006.pdf (last accessed on 11 October 2010).

Masalu, D.C.P., 2002. Coastal erosion and its social and environmental aspects of Tanzania: A case study in illegal sand mining. *Coastal Management*, 30(4), 347-359.

McGranahan, G., Balk, D. and Anderson, B., 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanisation*, 19(1),17-37.

Meehl, G.A.; Stocker, T.F.; Collins, W.D.; Friedlingstein, P.; Gaye, A.T.; Gregory, J.M.; Kitoh, A.; Knutti, R.; Murphy, J.M.; Noda, A.; Raper, S.C.B.; Watterson, I.G.; Weaver, A.J., and Zhao, Z-C., 2007. Global Climate Projections. *In*: Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M., and Miller, H.L. (eds.), *Climate Change 2007: The Physical Science Basis. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Mwaipopo, O.U., 2000. Implications of accelerated sea-level rise (ASLR) and climate change for Tanzania. *In*: A.C. de la Vega-Leinert, R.J. Nicholls, A. Nasser Hassan and M. El-Raey (Editors), *Proceedings of the SURVAS Expert Workshop on "African Vulnerability and Adaptation to Impacts of Accelerated Sea-Level Rise (ASLR)*", Cairo, Egypt, pp. 53-54.

Nakićenović, N. and Swart, R. (eds.), 2000. Special Report on Emissions Scenarios. *A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK*, 570pp.

NEMC (National Environment Management Council), 1995. An aquamarine Profile of Dar es Salaam region.

Nhnyete, I.K. and Mahongo, S.B., 2007. National Report of The United Republic of Tanzania on Sea Level Measurements. *Tanzania Ports Authority and Tanzania Fisheries Research Institute*. Available on-line at: http://www.gloss-sealevel.org/publications/documents/tanzania_gex2007.pdf (last accessed on 11 October 2010).

Nicholls, R.J., 2004. Coastal flooding and wetland loss in the 21st Century: changes under the SRES climate and socio-economic scenarios. *Global Environmental Change*, 14,69-86.

Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R., 2008. Ranking *Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Papers, No. 1, OECD publishing, doi: 10.1787/011766488208.

Nicholls R.J., Hoozemans, F.M.J. and Marchand, M., 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, 9,69-87.

Nicholls, R.J. and Tol, R.S.J., 2006. Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century, *Philos. Trans. R. Soc. Lond. A*, 364, 1073-1095.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S. and Woodroffe, C.D. 2007. Coastal systems and low-lying areas. *In*: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (Eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, p. 315-356.

Nyandwi, N., 2001. Reassessment of the nature of beach erosion north of Dar es Salaam, Tanzania. *In*: Richmond, M.D., Francis J., (eds), *Marine Science Development in Tanzania and Eastern Africa*. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania, 28 June – 1 July 1999, Zanzibar, Tanzania. IMS/WIOMSA, p. 107-120.

Penrose, K., Castro, M.C.d., Werema, J. and Ryan, E.T., 2010. Informal Urban Settlements and Cholera Risk in Dar es Salaam, Tanzania. *PLoS Neglected Tropical Diseases*, 4(3), e631. Doi:10.1371/journal.pntd.0000631.

Rahmstorf, S., 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science*, 315, 368-370.

Small, C. and Nicholls, R.J., 2003. A Global Analysis of Human Settlement in Coastal Zones. *Journal of Coastal Research*, 19(3), 584-599.

Tanzania Ports Authority, 2009. Ports: Dar-es-Salaam Port. *http://www.tanzaniaports.com* (accessed on 26 October 2010).

UNFCCC (United Nations Framework Convention on Climate Change), 2007. *Investment and Financial Flows to Address Climate Change*. Climate Change Secretariat: Bonn, Germany.

UN-HABITAT, 2008. State of the World's Cities 2008/2009 - Harmonious Cities, UN-HABITAT (United Nations Human Settlement Programme), Nairobi, Kenya. Available from: *http://www.unhabitat.org/pmss/getPage.asp?page=bookView&book=2562* (Accessed in August, 2009).

UN-HABITAT, 2009. Tanzania: Dar es Salaam City profile. UN-HABITAT (United Nations Human Settlement Programme), Regional and Technical Cooperation Division, Nairobi, 36 pp.

UNPD (United Nations Population Division), 2007. Population Division of the Department of Economic and Social Affairs, *World Population Prospects: The 2006 Revision* and *World Urbanization Prospects: The 2007 Revision*. Available on *http://esa.un.org/unup*

Vafeidis, A.T.; Boot, G.; Cox, J.; Maatens, R.; McFadden, L.; Nicholls, R.J.; Spencer, T., and Tol, R.S.J., 2005. *The DIVA Database Documentation*. Available on DIVA CD and *www.dinas-coast.net*

Vafeidis, A.T.; Nicholls, R.J.; McFadden, L.; Tol, R.S.J.; Hinkel, J.; Spencer, T.; Grashoff, P.S.; Boot, G., and Klein, R.J.T., 2008. A new global coastal database for impact and vulnerability analysis to sea-level rise. *Journal of Coastal Research*, 24, 917-924.

Vermeer, M. and Rahmstorf, S., 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences,* 106(51), 21527-21532.

World Care, *n.d.* Dar es Salaam Marine Ecology Conservation Project. Concept Paper. World Care, Dar es Salaam, Tanzania, 17 pp. Available from *http://www.reefball.org/album/tanzania/worldcareproject/dar_es_salaam_marine_ecology_conservation_project.pdf* (last accessed 2 November 2010).