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The Changing Global Climate and its Implication on Sea Level Trends in Tanzania and the Western Indian Ocean Region

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Abstract— Global mean sea levels show a general rising trend that has been accelerated by the recent changes in world climate. This is ascertained through geological and historical records, measurements from *in situ* tide gauges around the globe and since 1992, through satellite altimetry. About 60% of the 34 tide gauge stations in the Western Indian Ocean region with at least four years of data portray rising trends of relative sea levels, while the remaining 40% show falling trends. Sea level records in 14 other stations in the region were not considered in this investigation due to short data spans. Relative sea levels in Tanzania show falling trends in Tanga (1962-1966), Dar es Salaam (1986-1990) and Zanzibar (1984-2004), but portray a rising trend in Mtwara (1959-1962). Published results from satellite altimetry (1993-2003) also concur with the national and regional tide gauge observations, and are similar to those observed in the Eastern Pacific. However, these patterns likely reflect inter-annual and decadal fluctuations rather than long-term trends. Available literature on model reconstructions of long-term sea level trends (1955-2003) show a general rising trend in Tanzania (0.4 to 2.0 mm/yr) and the Western Indian Ocean (-0.4 to 2.4 mm/yr). The global average within this period (-0.4 to 3.6 mm/yr) is basically higher than these national and regional trends.

INTRODUCTION

The level of the sea changes as a result of processes that occur on a great range of space and time scales. The average sea level about which these changes occur is generally called Mean Sea Level (MSL). As indicated by the Third Assessment Report of the Intergovernmental Panel on Climate Change (hereinafter denoted as IPCC TAR), global sea level has risen at an average rate of about 0.1-0.2 mm/yr over the last 3,000 years. According to the IPCC Fourth Assessment Report (henceforth IPCC AR4), global MSL rose significantly during the 20th century at an estimated rate of 1.7 ± 0.5 mm/yr (Bindoff *et al*., 2007). The rate for the period 1993-2003 is about 3.1 mm/yr as a result of increased losses from Greenland and Antarctica ice sheets (Cazenave & Nerem, 2004; Leuliette *et al.*, 2004).

This recent acceleration in global sea level rise coincides with the industrial revolution, implicating human influence (Church *et al*., 2001). Since pre-industrial times, increasing

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emissions of global greenhouse gases (GHGs) due to human activities have led to a marked increase in atmospheric GHG concentrations and consequent warming of the Earth (Levitus *et al*., 2005; Forster *et al*., 2007; Trenberth *et al*., 2007). Global warming causes warming of the ocean and increased melting of the ice sheets and glaciers, thus raising the level of the sea.

The most important studies specific to the Western Indian Ocean region are those of Camoin *et al*. (2004), Church *et al*. (2006) and Ragoonaden (2006). Camoin *et al*. (2004) provided a comprehensive data base in the Western Indian Ocean to document sea-level changes and reef growth history during the late glacial period and the early deglaciation. In their study, they used reef bore-holes, observations and sampling of reef foreslopes, and investigations of outcrops. Results indicated that at 17-18 kyr before present, sea level in the Western Indian Ocean was 110-115 m below modern levels.

Church *et al*. (2006) carried out an investigation on sea-level rise at tropical Pacific and Indian Ocean islands using the PSMSL dataset up to 2001, including 7 of the 48 stations in the Western Indian Ocean which are covered in the present study. Tide gauge records indicated an increasing trend of relative sea levels in 5 of the Western Indian Ocean stations and falling trends in the remaining 2 stations. Ragoonaden (2006) carried out a study on sea level activities and changes on 13 islands of the Western Indian Ocean using monthly series from the Research Quality Dataset of the UHSLC. Ragoonaden (2006) observed that 8 of the 13 sea level stations had rising sea level trends, while the remaining 4 had a falling trend. Apart from the tide gauge records, TOPEX/Poseidon satellite data (1993-2000) over this area also showed similar trends. All the 13 stations have been re-investigated in the current study using the PSMSL dataset, except the Reunion station where the same UHSLC dataset has been used in both studies.

The earliest sea level records from the Western Indian Ocean coasts and islands are from Durban (1926), Mombasa (1932), and Port Louis (1942). The Port Louis and Port Elizabeth stations were installed earlier than the dates for which data is available (1920's and 1937, respectively). In subsequent years gauges have been installed at all the major ports in the region (Fig. 1). These, however, seem to have operated well for rather short spans of time, especially during early 1960's. Between 1970's and mid-1985, data was again scarce, but since then there has been a consistent increase in the number of operational gauges.

The Tanzanian tide gauge network (Fig. 2) includes only one operational station, Zanzibar, and this has been operating since 1984. The station is considered as one of the prime Indian Ocean stations for monitoring long term changes in world sea level (Church & White, 2006). Historical stations exist in Dar es Salaam, Mtwara and Tanga, with data available for the periods 1986-1990, 1956-1962 and 1962-1966, respectively. A new tide gauge station was re-established at Mtwara in September 2009. A GPS station will also be installed at a nearby site to monitor crustal movements for correction of tide gauge data.

The major objective of this study was to determine the trend of relative MSL from the tide gauge stations in Tanzania and other parts of the Western Indian Ocean (Fig. 1). An understanding of the rate of sea level change is critically important in the assessment of possible impacts on coastal communities, and for the consideration of consequent mitigation and adaptation strategies. The Western Indian Ocean coastal countries and islands are vulnerable to rise in sea-level due to rapid development of settlements, cities, industries, major ports, extensive farmlands and tourist facilities along low-lying areas of the coast. The effects of sea level rise may include increased rates of coastal erosion, saline intrusion, floods, and the frequency and intensity of extreme events such as tropical storms and associated surges. A total of 34 tide gauges in the region comprising both continental and island stations were considered in this investigation. Another 14 stations were not considered due to short time periods for which data are available.

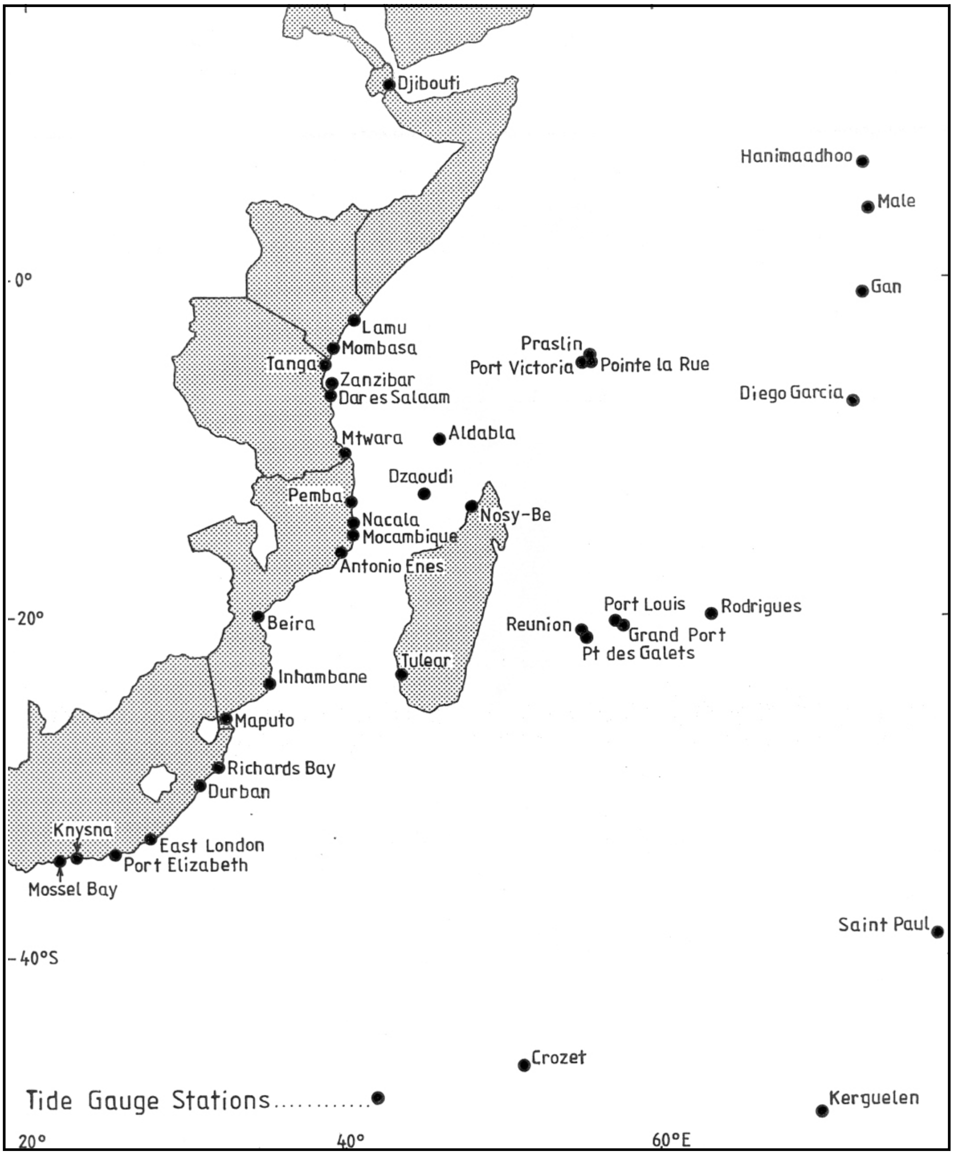

Fig. 1. Tide Gauge Stations in the Western Indian Ocean Coasts and Islands

MATERIALS AND METHODS

MSL series of data were obtained online from the Permanent Service for Mean Sea Level (PSMSL) (http://www.pol.ac.uk/psml). The database archive of the PSMSL contains monthly and annual MSL series from almost 2000 tide gauge stations around the world. The data is in the form of “Revised Local Reference” (RLR) or “Metric” datasets. However, the Metric records can have substantial and unknown datum shifts and their use in time series analysis or for the computation of secular trends is generally not recommended (Church *et al.*, 2006). In the RLR dataset, the monthly and annual means are reduced to a common datum by making use of the tide gauge datum history.

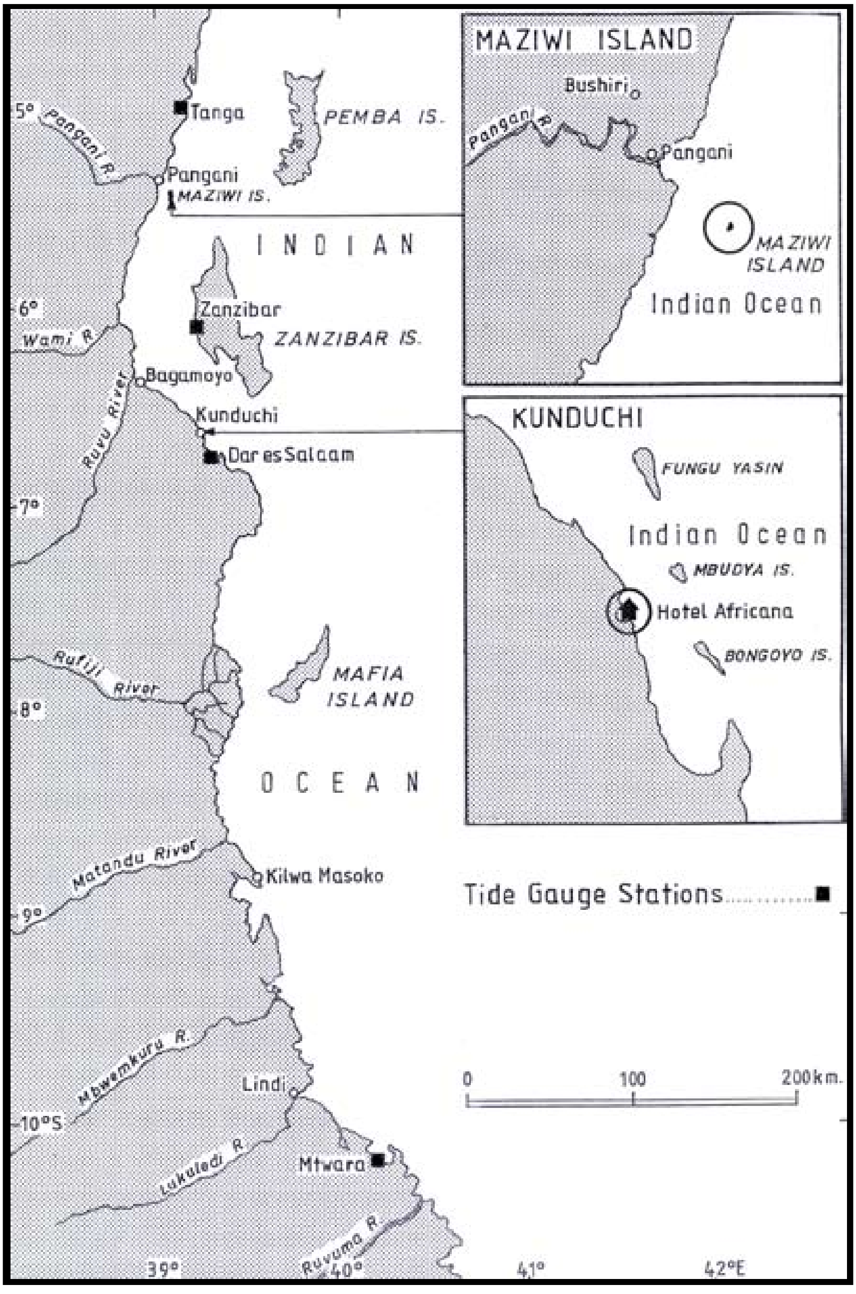

Fig. 2. Tanzanian Coast and Islands Showing Locations of Tide gauge Stations, Maziwi Island and Africana Beach Hotel

Another set of data was obtained online from the "Research Quality" database archive of the University of Hawaii Sea Level Centre (UHSLC) (http://www.ilkai.soest.hawaii.edu). Discrepancies exist in some monthly data series between the PSMSL and the UHSLC holdings due to disparity in the methods used in quality control and filtering of the data. Data from the PSMSL were used in this investigation except for the Reunion station, where the UHSLC data were used. Data for Reunion station were further processed into generic format using SLPR2 software developed by the Joint Archive for Sea Level (Caldwell, 1998). The national and regional records are not long enough to determine the trends using annual values of MSL; hence the monthly data sets were used. The MSL trend in mm/year was then computed for each of the stations by using a quadratic regression on the MSL series, a method also employed by Church *et al*. (2004) and Church & White (2006).

RESULTS

Tables 1 and 2 indicate the spans of data for the Western Indian Ocean tide gauge stations. The South African tide gauge stations have the longest records in the region, but have significant gaps. According to Odido and Francis (1999), the earliest sea level records from the Western Indian Ocean region are from Durban (1926), Mombasa (1932), and Port Louis (1942). However, the span of data available for analysis in these stations is short,

Table 1. Span of Revised Local Reference Data and MSL Trends for WIO Stations

Station	Country	Location of the Station	Span of Data	Years of Data	Gap (yrs)	Trend (mm/yr)
Hanimaadhoo	Maldives	06 46 N 73 10 E	1991-2002	12	-	+ 0.98
Male B Hulule	Maldives	04 11 N 73 32 E	1989-2003	15	-	+ 1.22
Gan II	Maldives	00 41 S 73 09 E	1987-2003	17	-	+ 4.73
Mombasa	Kenya	04 04 S 39 39 E	1932-2001	23	47	+ 0.83
Pointe la Rue	Seychelles	04 40 S 55 32 E	1993-2004	12	-	+ 1.68
Zanzibar	Tanzania	06 09 S 39 11 E	1984-2004	21	-	- 3.64
Diego Garcia C	UK	07 17 S 72 24 E	1988-2000	13	-	+ 4.38
Nosy-Be	Madagascar	13 24 S 48 17 E	1958-1972	14	1	- 2.84
Mocambique	Mozambique	15 02 S 40 44 E	1963-1967	4	1	
Rodrigues	Mauritius	19 40 S 63 25 E	1986-2003	18	-	- 0.68
Port Louis	Mauritius	20 09 S 57 30 E	1942-1965	19	5	+ 2.40
Port Louis II	Mauritius	20 09 S 57 30 E	1986-2003	18	-	- 0.16
Grand Port	Mauritius	20 22 S 57 45 E	1958-1960	3		-
Pt des Galets	France	20 56 S 55 18 E	1979-1986	8	-	- 6.49
Maputo	Mozambique	25 58 S 32 34 E	1961-2001	20	21	+ 0.73
Durban	South Africa	29 53 S 31 00 E	1971-2003	28	-	- 0.02
East London	South Africa	33 00 S 27 54 E	1967-2005	21	7	+ 0.68
Port Elizabeth	South Africa	33 58 S 25 38 E	1978-2005	21	18	+ 3.32
Knysna	South Africa	34 05 S 23 03 E	1960-2005	30	16	+ 1.08
Mossel Bay	South Africa	34 11 S 22 09 E	1958-2004	37	10	- 0.82

Data Source: PSMSL Monthly Revised Local Reference Data (http://www.pol.ac.uk/psml)

Table 2. Span of Metric Data and MSL Trends for Western Indian Ocean Stations

Station	Country	Location of the Station	Span of Data	Years of Data	Gap (yrs)	Trend (mm/yr)
Djibouti	Somalia	11 35 N 43 09 E	1970-1972	2	1	
Male A	Maldives	04 11 N 73 31 E	1988-1989	2	-	
Male C	Maldives	04 11 N 73 31 E	1988-1989	2	-	
Gan I	Maldives	00 41 S 73 09 E	1962-1963	2	-	
Lamu	Kenya	02 16 S 40 54 E	1989-1989	1	-	
Lamu B	Kenya	02 16S 04 54E	1995-2003	9	-	- 3.62
Praslin	Seychelles	04 21 S 55 46 E	1987-1989	3	-	
Port Victoria	Seychelles	04 37 S 55 28 E	1962-1982	10	11	+ 1.26
Port Victoria B	Seychelles	04 37 S 55 28 E	1986-1992	7	-	+ 12.93
Tanga	Tanzania	05 04 S 39 06 E	1962-1966	5	-	- 0.58
Dar es Salaam	Tanzania	06 49 S 39 17 E	1986-1990	5	-	- 11.44
Diego Garcia	UK	07 17 S 72 24 E	1959-1964	6	-	+ 32.4
Diego Garcia B	UK	07 17 S 72 24 E	1969	1	-	
Aldabra	Seychelles	09 24 S 46 13 E	1975-1977	3	-	
Mtwara	Tanzania	10 17 S 40 11 E	1956-1962	6	1	+ 8.73
Dzaoudi	Comoros	12 47 S 45 15 E	1985-1995	9	2	- 0.22
Pemba	Mozambique	12 58 S 40 29 E	1971-2000	11	19	- 6.14
Nosy-Be II	Madagascar	13 24 S 48 17 E	1987-1998	8	4	+ 1.58
Nacala	Mozambique	14 28 S 40 41 E	1975-1999	6	19	
Antonio Enes	Mozambique	16 14 S 39 58 E	1967-1967	1	-	
Beira	Mozambique	19 49 S 34 50 E	1996-2000	5	-	- 30.09
Reunion*	France	20 55 S 55-18E	1982-1986	5	-	- 0.10
Tulear	Madagascar	23 23 S 43 40 E	1963-1964	2	-	
Inhambane	Mozambique	23 52 S 35 23 E	1995-1995	1	-	
Richards Bay	South Africa	28 48 S 32 05 E	1977-2005	21	8	+ 8.03
Saint Paul	France	38 43 S 77 32 E	1994-2000	7	-	+ 12.21
Crozet	France	46 26 S 51 22 E	1995-2000	5	1	+ 48.84
Kerguelen	France	49 21 S 70 13 E	1993-2000	8	-	+ 4.64

Data Source:

1. PSMSL Monthly Metric Data (http://www.pol.ac.uk/psml)
2. *UHSLC Monthly Research Quality Data (http://www.ilkai.soest.hawaii.edu)

the longest being only 37 years at Mossel Bay in South Africa. The Mombasa station for instance, although long-established, has only 23 years of data available for analysis. Tables 1 and 2 also show results of quadratic regressions on the tide gauge records in the Western Indian Ocean, which indicate that 15 out of the 25 stations with records of at least 8 years (i.e. 60%) have rising trends in MSL. The remaining 10 stations show declining trends. Again, if records of at least five years are considered, 20 out of 34 stations (or 59%) indicate positive trends, while the remaining 14 stations reveal negative trends.

Fig. 3 compares the 95% confidence intervals of the MSL trends from 25 Western Indian Ocean stations with at least eight concurrent years of sea level data. Trends with the narrowest confidence intervals are based on much longer and continuous RLR data sets (e.g. Durban and Rodrigues), while those with the widest confidence intervals are based on data with significant and continuous gaps (e.g. Richards Bay and Nosy-be II). Some stations such as Mossel Bay and Knysna have significant gaps, but the gaps are not continuous hence they have narrow confidence intervals. For both the RLR and Metric records, no confidence intervals were computed for records shorter than eight years. The choice of eight years was arbitrarily chosen to correspond with relatively shorter confidence intervals.

The Tanzanian northern tide gauge stations of Tanga (1962-1965), Zanzibar (1984-2004) and Dar es Salaam (1986-1990) show declining MSL trends at the rate of 0.6, 3.6 and 11.4 mm/yr respectively, while the southern station of Mtwara shows a rising trend of 8.7 mm/yr. Except Zanzibar station which has a

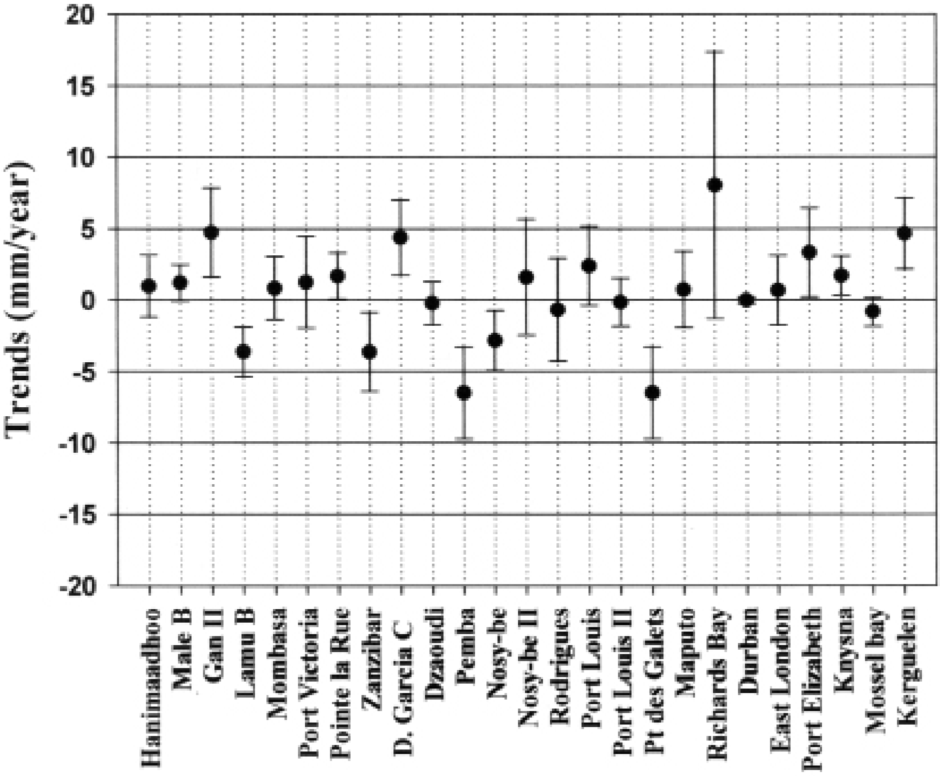

Fig. 3. MSL Trends in the Western Indian Ocean Stations (Records ≥ 8 Years) with 95% Confidence Limits

Data Source: PSMSL Monthly Revised Local Reference and Metric Data continuous record, there are several years of incomplete data for the stations of Tanga (2 years), Dar es Salaam (3 years) and Mtwara (5 years). Results of MSL trends also agree closely with a contour map from satellite altimetry (Bindoff *et al*., 2007) which also show declining trends all over Tanzania during 1993-2003 at the approximate rates of 0 to 3 mm/year in the north, and 3 to 6 mm/yr in the south, respectively. However, a contour map of the regional model reconstruction of sea level using a combination of in-situ tide gauge data and satellite altimetry during the period 1955-2003, shows rising sea level trends from the north (1.2 mm/year) to the south (2.0 mm/year) of Tanzania (Bindoff *et al*., 2007).

The trend of MSL at Lamu B station in Kenya is similar to that of nearby Zanzibar station in Tanzania, which has also found to decline at the same rate of 3.6 mm/year. The monthly variations of sea level from the two stations are strongly correlated (correlation coefficient of 0.82). The monthly sea level variations at Zanzibar station are also correlated with those at nearby stations of Dar es Salaam in Tanzania (correlation coefficient of 0.79) and Mombasa in Kenya (correlation coefficient of 0.72). Both the Zanzibar and Lamu B stations have no gaps in MSL data. The nearby station of Mombasa shows an increasing trend of 0.8 mm/yr, but has a data gap of 47 years with only 23 years of non-continuous data available for analysis.

The monthly variations of sea level at the Kenyan stations of Mombasa (1932-2001, available data are from 1986-2001) and at Lamu B (1995-2003) are highly correlated (correlation of 0.95). However, the data for Mombasa should be treated with caution; there are significant data gaps for a number of years, and there was a change in the type of measuring instruments in 1991 and 1995 which may have affected the records.

Of the seven stations investigated in South Africa, only Durban and Mossel Bay show falling trends of 0.02 mm/yr and 0.82 mm/yr, respectively. The remaining six stations indicate rising trends ranging from 0.68 mm/yr (East London) to 8.03 mm/yr (Richards Bay). These rates concur with the TOPEX/Poseidon satellite altimeter observations (1993-2003), which mostly indicate rising trends on the south-eastern coast of South Africa (Bindoff *et al*., 2007).

In the Maldives, the station records of Male A, Male C and Gan I were not analyzed due to short period for which records exist. In all the stations with longer record, sea level was found to have risen at the rates of 0.98 mm/yr (Hanimaadhoo), 1.22 mm/yr (Male B – Hulule) and 4.73 mm/yr (Gan II). Our results (using PSMSL dataset) for the last two stations agree very well with the findings of Ragoonaden (2006), who used a different dataset (UHSLC) but derived very similar trends. Church *et al*. (2006) also observed rising trends in these three stations, but the rates differ significantly, most probably because of the much shorter data spans they used. The rates were 4.4, 3.7 and 8.4 mm/yr for Hanimaadhoo, Hulule and Gan II, respectively. Church *et al*. (2006) attributed the difference in trends for these three stations as being due to vertical land motion. In contrast, Mörner *et al*. (2003) disputed any claims of sea level rise in the Maldives, but rather affirmed morphological evidence of a significant sea level fall in the last 30 years.

In Mauritius, the old Port Louis station (1942-1965) showed an increasing trend, but the Port Louis II station (1986-2003) as well as the Rodrigues station both show falling trends of 0.16 mm/yr and 0.68 mm/yr, respectively. Both Church *et al*. (2006) and Ragoonaden (2006) found falling trends in the Mauritius stations. Similarly, the nearby French station of Pointe des Galets shows a declining trend at the rate of 6.49 mm/yr. The difference in rates between the present study and that of Church *et al*. (2006) is due to the shorter data span they used, and the slight difference with Ragoonaden's findings is due to the use of different data sets.

At the Island of Madagascar, the Nosy-Be station (1958-1972) showed a declining trend of 2.84 mm/yr, while the Nosy-Be II station (1987-1998) showed a rising trend of

1.58 mm/yr. Analysis was not made for the Tulear station, which has a very short record (1963-1964). Ragoonaden (2006) also found a rising trend at Nosy Be II, but the rate was higher (3.31 mm/yr). The Comoro station of Dzaoudzi showed a falling trend of 0.22 mm/yr. Conversely, Ragoonaden (2006) observed a rising trend there of 0.40 mm/yr over the same period (1985-1995).

The Seychelles stations of Pointe la Rue, Port Victoria and Port Victoria B indicate rising trends at the rate of 1.68 mm/yr, 1.26 mm/yr and 12.93 mm/yr, respectively. Records for Praslin and Aldabra are too short to enable any trend analysis to be made. The rate for Pointe la Rue as observed in this study agrees well with the rising rate of 1.69 mm/yr obtained by Ragoonaden (2006). The French southern stations of Saint Paul, Kerguelen and Croz*et* all indicated rising trends. The tropical French island of Reunion and Pointe des Galets indicated falling trends of 0.10 mm/yr and 6.49 mm/yr, respectively. The Crozet trend however, may not be reliable because the tide gauge has not been operating well since its installation (Ragoonaden, 2006).

In the present study, the Mozambican stations of Nacala and Beira indicated falling trends at the rates of 7.52 mm/yr and 30.09 mm/yr respectively, while Maputo indicated a rising trend of 0.73 mm/yr. Records from the stations of Moćambique (1963-1967) and Antonio Enes (1967) were not analyzed due to significant gaps and transitory nature of the records, respectively. The Somalia station of Djibouti and the UK Territory station of Diego Garcia B had very short records; hence the analysis for these two stations was not made.

DISCUSSION AND CONCLUSION

Although the majority of tide gauge records in the Western Indian Ocean generally show a rising trend of mean sea levels, the data sets are not long enough to give any conclusive evidence on MSL change in the region. In short tide-gauge records, inter-annual and decadal sea-level variability may obscure any longer-term sea-level change, or the variability may be misinterpreted as a regional change. For instance Church *et al*. (2006), utilizing a combination of satellite altimeter data (1993-2001) and in-situ tide gauge records, showed large rates of sea-level falls in the Western Indian Ocean and eastern Pacific (approaching −10 mm/yr). It was noted that the large variability (e.g. El Niño) signals and the shortness of many of the individual tide-gauge records contributed to uncertainty in determining historical rates of sea-level change.

Results from satellite altimetry (1993-2003) also show that most parts of the Western Indian Ocean region have been experiencing a falling trend (Bindoff *et al*., 2007). According to the IPCC AR4, the falling trend pattern in these regions likely reflects decadal fluctuations rather than long-term trends. Also, whereas Bindoff *et al*. (2007) have noted an approximately 10 mm rise and fall of global mean sea level accompanying the ENSO episode of 1997–1998, Nerem and Mitchum (2002) have demonstrated that large volcanic eruptions are capable of generating inter-annual and decadal fluctuations in the global mean sea level.

According to Douglas (1992), fairly long and continuous records of at least 50 years are needed in precise determination of local sea level trends because of the influence of natural variability in the climate system. However, averaging over such a period makes the investigation of shorter term changes difficult (Nerem, 1997). Thus, although the mean sea levels show falling trends in northern Tanzania and some parts of the Western Indian Ocean, this is most probably due to local and regional inter-annual and decadal fluctuations. Reconstructed sea level records over the period 1955–2003 using TOPEX/Poseidon satellite altimeter record (1993-2003) combined with historical tide gauge data, indicate a general rising trend in the Western Indian Ocean region at the rate of up to 2.4 mm/yr (Bindoff *et al*., 2007). Only a small portion around 5°S and 70°E shows a declining trend of about -0.4 to 0 mm/yr. In

Tanzania, the rate is about 0.4-2.0 mm/year, increasing southwards. Similarly, previous reconstructions for 1950-2000 (Church *et al*., 2004) and 1950-2001 (Church *et al*., 2006) also indicate a general rise in sea level all over the region.

Possible Consequences of Sea Level Change in Tanzania

An attempt to assess the vulnerability of the Tanzanian coastline due to sea level change has been made by Mwandosya *et al*. (1997), who employed two sea-level rise scenarios of 0.5 m and 1.0 m for a period of a century. Topographical maps of 2 m and 20 m contours were used to estimate the loss of coastal area and infrastructure by considering first order approximations where the land is assumed to rise linearly from the sea level. Results revealed that, with a 0.5-m and 1-m sea-level rise, about 2,090 km^2 and 2,117 km^2 of land would be inundated, respectively. Projected damage was expected to be about TZS 50 billion for a 0.5-m rise and TZS 86 billion for 1-m rise (1997 rates). Aerial Videotape-assisted Vulnerability Analysis (AVVA) together with ground truthing was also made for the city of Dar es Salaam and the Island of Zanzibar with the purpose of identifying important areas to be protected from the two sea-level rise scenarios.

Fay (1992) drew attention to the disappearance of Maziwi Island in Tanga (Fig. 2) during the late 1970s, associating the disappearance with the possible sea-level rise. The island was originally famous for being the most important single turtle nesting ground in east Africa. The most significant event was first observed during 1960s by uprooting of casuarina trees. The last tree is believed to have fallen by 1977 and by 1978 the entire island was already submerged. Fay (1992) believed sea level rise to be the main causative factor. He ruled out all other possible causes such as direct human interference with the ecosystem, subsidence caused by crustal movements and erosion due to extraordinary stormy events.

However, Fay's findings were rebutted by Shaghude (2004), who linked the disappearance to anthropogenic clearing of the island vegetation. Apart from the disappearance of Maziwi Island, shoreline erosion in Tanzania has sometimes been associated with the possible sea level rise, among other factors. Shaghude *et al*. (1994) for instance, have identified sea level rise as being one out of the six factors causing shoreline erosion in Tanzania.

Another reference to sea level change in Tanzania is the disappearance of Africana Hotel which was originally located along Kunduchi beach area in Dar es Salaam (Fig. 2). According to Kimunya, Amani and Alexander (www.assets.panda.org), the hotel was constructed in 1967 when the sea was located about 200 m away. At that time this distance was deemed safe, as the sea had never before advanced more than 100 m from the site. The first signs of shoreline erosion became evident in early 1980s when the beach shelters were being washed away one after the other. Since 1984 the hotel location started receiving fiercer waves, also causing damage to the hotel itself, until it completely collapsed in 1996. The original hotel building has now disappeared completely, except three small huts (guards' shelter, horses' shelter and a canteen) which were located farther away from the sea.

While assessing the impact of sea level change, it is the local and regional trend in relative sea level that matters, not the global average. The disappearance of Maziwi Island and Africana Beach Hotel in Tanzania in 1978 and early 1990s respectively, cannot be sufficiently explained by the sea level records due to lack of sufficient tide gauge data during those periods. If the Tanga and Dar es Salaam stations were in operation by the time of disappearance of Maziwi Island and Hotel Africana Beach Hotel, it could have been possible to link their disappearance with sea level change. In general, issues on shoreline erosion can be explained much more clearly if local sea level data is available.

CONCLUSION

Sea level data is an important prerequisite in the physical monitoring of coastal processes. The Western Indian Ocean region coastal countries and islands have long coastlines with different meteorological and oceanographic conditions, but the absence of adequate operational tide gauge stations is a limiting factor in determining the regional sea level trends. Hence, the region should invest more on tide gauges and must ensure that the installed equipments are properly maintained on a long-term basis.

While the region is currently embarking on expansion and upgrade of the existing sea level network, there is an urgent need to build capacity in satellite altimetry so that current trends in sea level can be monitored by both methods. Altimeters have provided a measure of absolute sea level relative to a precise reference frame realized through satellite tracking stations whose origin coincides with the Earth's centre of mass (Nerem, 1997). Sea level change based on satellite altimetry is not distorted by land motions, except for a small component due to large-scale deformation of ocean basins from Post Glacial Rebound (PGR). Space-borne sensors have also demonstrated that meaningful estimates of global averaged MSL change can be made more accurately and over much shorter periods than is possible from the sparse array of in situ gauges (Cabanes *et al*., 2001). However, satellite observations need careful processing, and the in-situ sea level gauge records are still required for calibration.

The Western Indian Ocean coastal countries and Islands should establish ways of adapting to the changing global climate and consequent rise in sea level as projected in the IPCC AR4. Future projections indicate that during the 21st Century, global sea level will rise by 310 ± 30 mm more than during 1990 (Church & White, 2006). Mid-line projections for sea level rise towards the end of the century (2090-2099) vary from 2.8 to 4.3 mm/yr for the full range of emissions scenarios presented by the IPCC AR4 (Meehl *et al*., 2007). As in the past, sea level change in the future will not be geographically uniform because of the readjustment of the ocean circulation to climate change, and also due to the different magnitudes of local vertical land movements. Even if GHG emissions were stabilized now, substantial rise in sea level would continue for several centuries because of the long residence time of anthropogenic CO_2 in the atmosphere and the thermal inertia of the climate system (Tans, 1998; Meehl *et al*., 2005).

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