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Impact of climate change on sea level rise in Lagos, Nigeria

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Sea level rise and ocean surge are the major potential impacts of climate change in the rapidly growing urban Lagos in Nigeria. Coastal inundation is, however, expected to increase problems of flooding and intrusion of sea water into freshwater sources and ecosystems, thereby heightening the social conflict already prevalent in this area. This article examines the historical trend in the coastal extent of one of the most populous coastal cities in the tropics and projects the potential impact on coastline change using geographic information system (GIS) techniques coupled with scenario-based climate change predictions from three different general circulation models (GCMs). This study aims, therefore, to provide empirical reasoning for the development of sea defence policies which would help in the reduction of possible loss of life or capital asset damage by suggesting adequate and cost-effective flood warning systems as well as by discouraging inappropriate infrastructural development in areas at risk from flooding and coastal erosion.

1. Introduction

Global sea levels have been estimated to rise significantly. Due to changes in both atmospheric temperature and sea surface temperature (SST), precipitation characteristics and storm surges along the coastline in response to the global warming results in sea level changes. Generally, all of Africa is very likely to warm during this century with the warming results expected to be larger than the global estimates (Christensen *et al.* 2007). Although detailed studies have not been carried out on other coastal regions of the continent, any change in tropical cyclone distribution and intensity has been predicted to affect the southeast coastal region including Madagascar (Reason and Keibel 2004). Theoretically, sandy coasts, which are shaped and maintained primarily by wave and tidal processes, occupy about 20% of the global coastline. Over the past 100 years, about 70% of the world's sandy shorelines have been retreating, while 20–30% have been stable and less than 10% have been advancing. With global warming and sea level rise, there will be tendencies for currently eroding shorelines to erode further, stable shorelines to begin to erode and accreting shorelines to wane or stabilize (Bird 1993). Studies have shown that atmospheric pollutants such as nitric acid affect corrosion rates through acidification, eutrophication and deterioration of materials (Ferm *et al.* 2005, 2006); the possibilities of eroding shorelines due to corrosion may accentuate the effects of global warming (or aerosol global cooling, e.g. Tzanis and Varotsos 2008), even though very little is known of these processes in the

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sub-Saharan African region. Local changes in coastal conditions and particularly in sediment supply may modify these tendencies, although Nicholls and Mimura (1998) have indicated that accelerated sea level rise in coming decades makes general erosion of sandy shores more likely.

However, due to the extended drought in the 1970s and 1980s, the factors that determine the southern boundary of the Sahara and rainfall characteristics in the West African region have attracted special interests (Hulme 2001). But globally, interests have moved steadily away from explanations for regional rainfall variations as primarily due to land use changes and towards explanations based on changes in sea surface temperatures (SSTs) (Giannini *et al.* 2003, Lu and Delworth 2005, Hoerling *et al.* 2006). Going by the findings of the Intergovernmental Panel on Climate Change (IPCC), towards the end of this century, projected sea level rise will affect low-lying coastal areas with large populations, and the possible cost of adaptation is expected to near 5–10% of gross domestic product (Christensen *et al.* 2007, Cracknell and Varotsos 2007, Middelkoop 2008). Although the exact relationship between carbon dioxide (CO_2)-forced global warming and the implication for sea level change is not yet fully understood, recent studies have shown that the fluctuations of CO_2 concentration exhibit strong long-range persistence, which implies a long-term memory effect (Varotsos *et al.* 2007) on virtually all global warming consequences including sea level change. Whereas 20% of the world's human population live within 30 km of the sea, and nearly double the number live within the nearest 100 km of the coast (Cohen *et al.* 1997, Gommes *et al.* 1998), estimates have shown that 600 million people will occupy coastal floodplain land below the 1000-year flood level by 2100 (Nicholls and Mimura 1998). According to Singh *et al.* (1999), more than one-quarter of the population of Africa resides within 100 km of the sea coast.

Modelling the effects of a 38 cm mean global sea level rise in 2080, Nicholls *et al.* (1999) estimated that the average annual number of people in Africa impacted by flooding could increase from 1 million in 1990 to a worst case of 70 million in 2080. While it has been estimated that Banjul, the capital of the Gambia, could disappear in 50–60 years through coastal erosion and sea level rise, putting more than 42 000 people at risk, threats to coastal areas of Egypt have been identified and the potential risks of East African coastal settlements due to sea level rise have also been advanced (El Raey *et al.* 1999, Jallow *et al.* 1999, Magadza 2000). Remote-sensing data can be used in environmental monitoring programmes, where the objective is to monitor changes in surface phenomena over time (Howarth and Wickware 1981). Digital spatial data analysis and mapping, remote sensing and geographic information systems (GIs) are widely applied in environmental and natural resources monitoring (Lillesand and Kiefer 1994, Jensen 2000). Among the studies that have attempted to quantify the extent of shoreline change is the one by Mushala (1978). Using aerial photographs, it was found that there had been a drastic change of vegetation cover and shoreline recession of more than 50 m in front of both silver sands and Kunduchi Beach hotel for the past 30 years.

This article examines the historical trend in storm tide along the coastal stretch of Lagos, one of the most populous coastal cities in the tropics, and projects the potential impact on coastline change in a bid to provide empirical reasoning for the development of sea defence policies that would help in the reduction of possible loss of life or capital asset damage by suggesting adequate and cost-effective flood warning systems as well as by discouraging inappropriate infrastructural development in areas at risk from flooding and coastal erosion.

2. Methodology

Lagos State is located in the southwestern part of Nigeria, lying within latitudes 6° 20′ N and 6° 40′ N and longitudes 2° 40′ E and 4° 20′ E, with its southern boundary in the Bight of Benin along the coastline of the Atlantic Ocean stretching over 180 km. Of the 3577 km^2 total land area forming the region of this study, 22% (787 km^2) is water in form of creeks and lagoons. However, the human population of the area in 2006 was about 9 013 534, making the region among the most densely populated spots in the African continent. According to the projections of the World Bank and United Nations (UN), the population of Lagos is expected to rise to 24.5 million by the year 2015, making it a mega city among the ten most populous cities in the world.

Historical data on SST, air temperature, rainfall, wind gust, wind speed and number of hours of sunshine were obtained from the archives of the Nigerian Institute for Oceanography and Marine Research (NIOMR). The relationships among the parameters were obtained from Pearson's correlation analysis, indicating the strength of agreements determining the predominant climatic processes along the coastline. Sea level change projections were derived from the Hadley Centre (HadCM3) General Circulation Model (GCM) projections from 1999 to 2099.

Data were analysed to obtain the rate of change in erosion rates and storm surge progression. ArcView 3.3 and ArcGIS 9.2 were used to analyse the imageries. The satellite imageries from LANDSAT Thematic Mapper for 1999 and 2009 (shot on 2 December 1999 and 8 December 2009, respectively, both have a low tidal state) were georeferenced using the Universal Transverse Mercator (UTM) projection Zone 31, along with the World Geodetic System (WGS, 1984) datum. The 1999 image has tidal characteristics of a mean high water spring of 0.45 m and a mean low water spring of 0.042 m; the mean high- and low-water neaps are 0.31 and 0.11 m, respectively, with the mean sea level of 0.34 m. In the same vein, the 2009 image has a mean high-water spring of 0.51 m and a mean low-water spring of 0.039 m; the mean high- and low-water neaps are 0.34 and 0.19 m, respectively, with a mean sea level of 0.32 m. Invariably, the two images have similar tidal characteristics, hence the correlation analysis. On-screen digitizing was used to vectorize the coastal land area into shape format. The resultant two vector layers of the different years were overlaid and the extent of changes was quantified from the resulting overlay layer.

3. Result and discussion

Although quantitative estimates of the effect of variations in the temperature of water in the lagoon and the consequent variation in surface level due to expansion, assuming the lagoon is an isolated water body, have yet to be established, ongoing studies are intended to cover this gap. The diurnal fluctuations in temperature are sometimes large and rather complex, showing a clearly defined mean maximum of about 29.5°C in April with a second maximum of about 28.6°C in November and a mean minimum of about 25.8°C in August. However, the maximum temperature period in the Lagos lagoon complex including the harbour is due to the effect of insolation on the body of water that is largely static at such period of the year, while the minimum temperature period was explained in terms of the influx of cool freshwater into the lagoon complex. The warming up process around the Gulf of Guinea from September to November results in the downward migration of isotherms from the surface to become incorporated in the thermocline zone, thus accounting for the progressively greater range of temperature. Whereas the temperature decline between April and August was due to

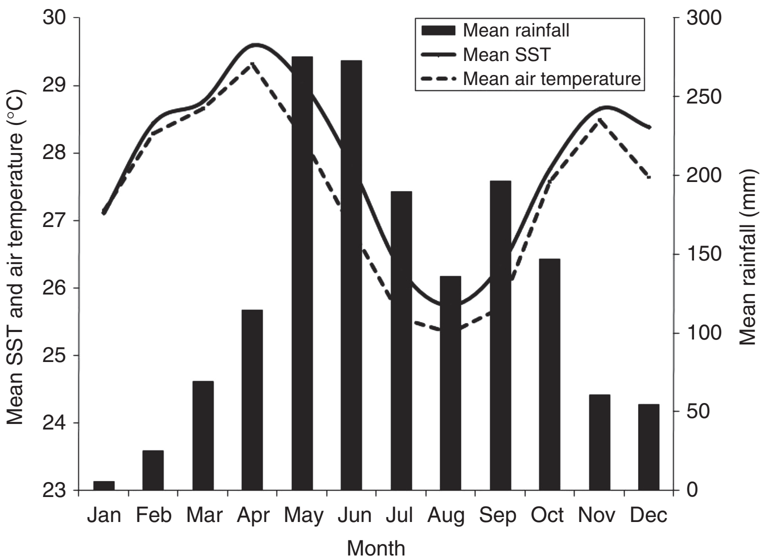

Figure 1. Ten-year (1978–1989) mean monthly variation in sea surface temperature (SST), air temperature and rainfall.

the overall cooling of the Gulf of Guinea and the South Atlantic during this period, as shown in figure 1.

The effects of insolation in terms of diurnal sunshine duration are experienced also to influence the pattern of temperature variations in the Lagos shoreline. Upwelling in the oceans beyond may, however, add to the radiative heating impinging on the seasonal cycle of temperatures, which may also affect both the wind and cloud conditions in the coastal area. Although sufficient wind data of the Lagos coastline are not available, the 1992–1995 records of wind gust and wind speed obtained from the NIOMR were utilized in describing the climatic condition of the area under study. The mean monthly amounts of wind gust and the length of time the sun shines on the area, shown in figure 2, indicate a double maxima of wind gust of about 5.84 and 4.69 m s^{-1} in September and November, respectively, while significant declines are observed in October and January.

While a strong positive correlation of 0.9 exists between the SST and the air temperature, rainfall amounts do not have any influence whatsoever on either, with a negative correlation of 0.2 and 0.3 with SST and air temperature, respectively. However, sunshine hours show a strongly positive correlation of 0.9 and 0.9 with SST and air temperature, respectively, indicating a reasonably significant influence on both parameters, as depicted in table 1. The relationship observed between sunshine hours with SST and air temperature is also in consonance with previous findings (e.g. Longhurst 1964, Oyewo *et al*. 1982, 2001), indicating a probable mechanism, which suggests the influence of the local radiation cycle on the observable temperature pattern along the entire West African coast. Relating climatological forcings to coastal water levels in Louisiana, Childers *et al.* (1990) suggested that air temperature, wind and cloud as historical indicators of the general climatic condition provide reliable inference on water levels in coastal and estuarine areas. They concluded that water level patterns are strongly influenced by various climatological parameters on both short (days to

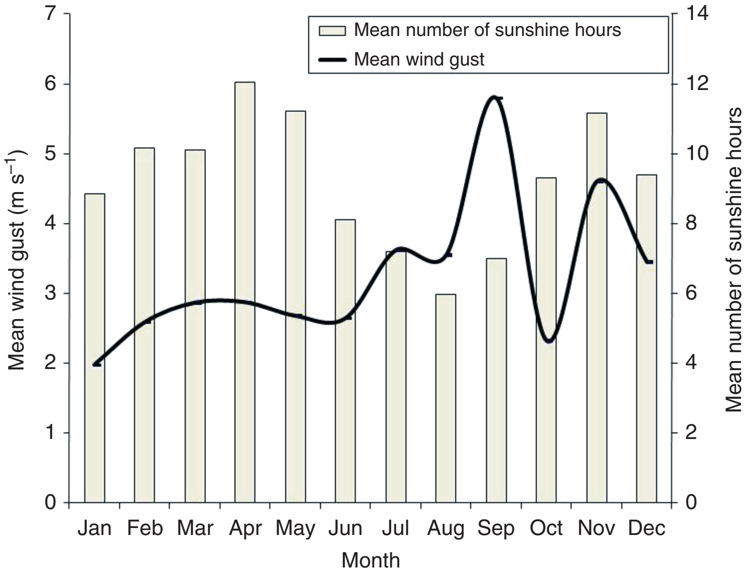

Figure 2. Mean (1992–1995) wind gust and sunshine hour along the Lagos shoreline.

Table 1. Correlation matrix among SST, air temperature, rainfall, wind gust, sunshine hours and wind speed.

	Mean SST (°C)	Mean air temperature (°C)	Mean rainfall (mm)	Mean wind gust (m s^{-1})	Mean number of sunshine hours	Mean wind speed (m s^{-1})
Mean SST (°C)	1					
Mean air temperature (°C)	0.9	1				
Mean rainfall (mm)	−0.2	−0.3	1			
Mean wind gust (m s^{-1})	−0.3	−0.4	0.1	1		
Mean number of sunshine hours	0.9	0.9	−0.2	−0.3	1	
Mean wind speed (m s^{-1})	−0.6	−0.6	0.3	0.4	−0.6	1

Note: SST, sea surface temperature.

week) and intermediate (months to year) timescales (Conner and Day 1987, Turner 1987). Hence, estimates of future sea level rise are driven by considerations of global temperature rise, particularly the SSTs, which have steric effects causing water expansions. The IPCC concluded that by 2030, global mean temperature would rise 1.1°C above the 1990 temperatures and 2.5°C by 2050; hence, all sea level scenarios show that sea level rises smoothly. The UK HadCM3 model shows a linear trend of the form $y = 0.0026x - 0.018$, with a likelihood of consistent annual sea level change, where y represents the year and x the increase in sea level annually.

The satellite imagery of the Lagos coastline as at 1999 is shown in figure 3, indicating the extent to which the coastline is stretched from the shoreline through the beach to the land area, where the built-up parts of the city commenced in the hinterland.

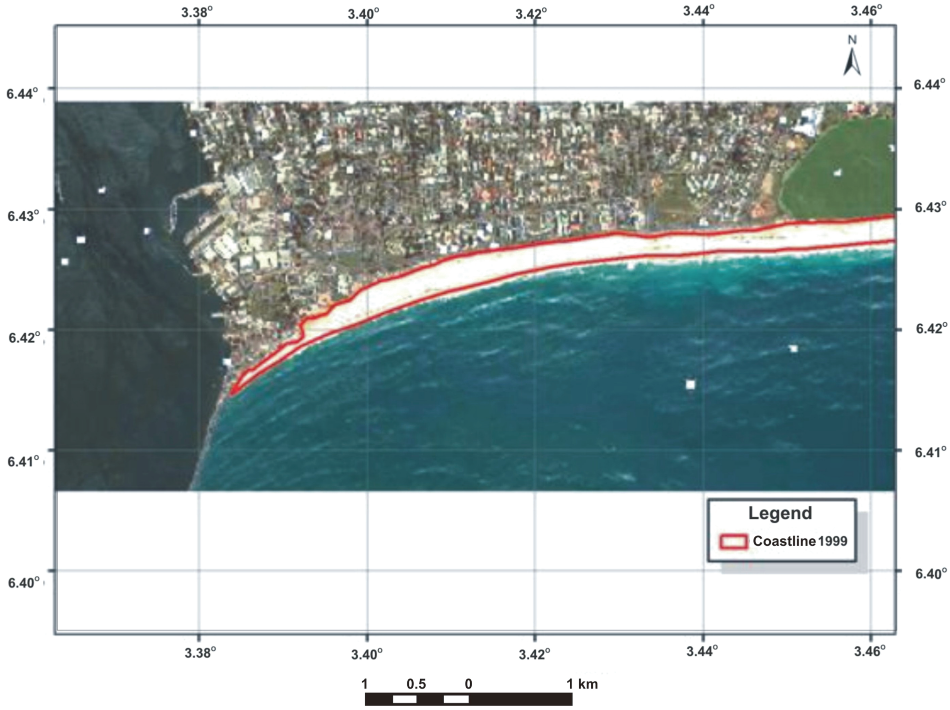

Figure 3. Satellite imagery of Lagos coastline in 1999.

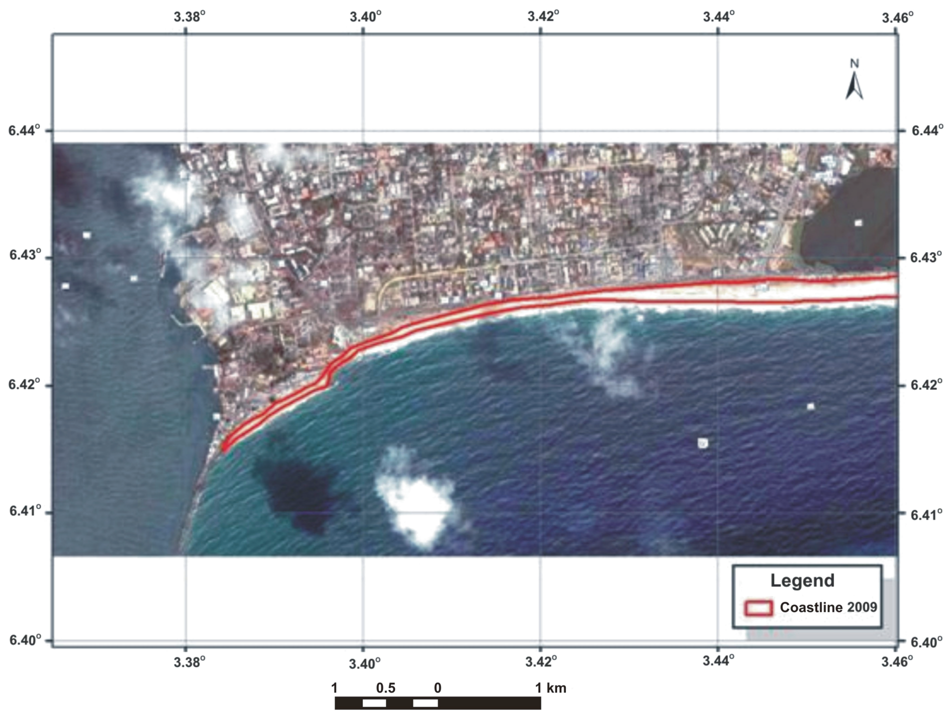

Figure 4. Satellite imagery of Lagos coastline in 2009.

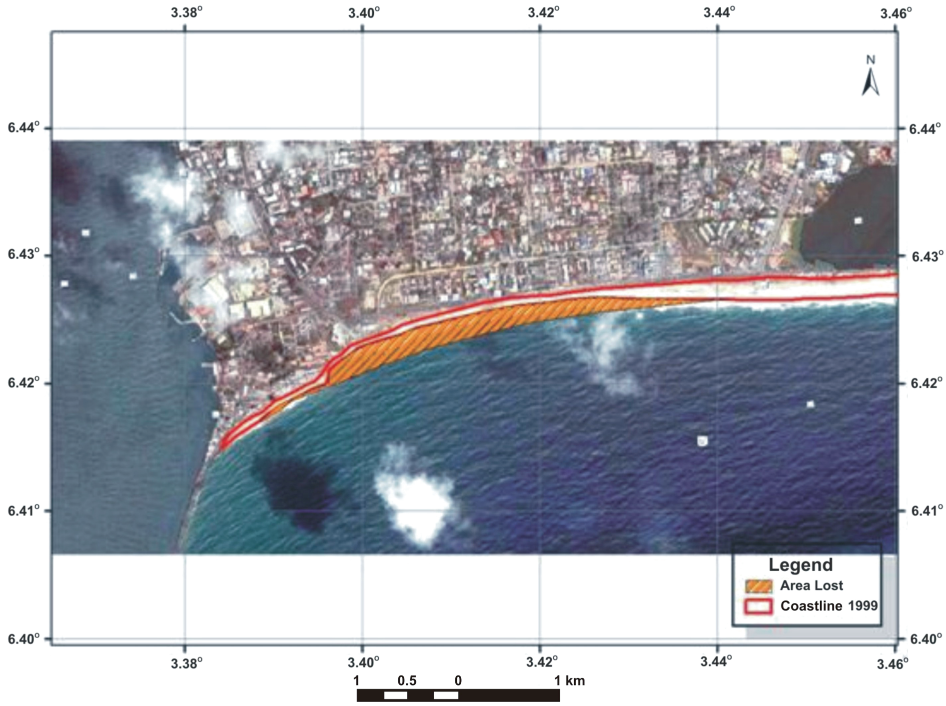

Figure 5. Satellite imagery of Lagos coastline showing the area lost between 1999 and 2009.

While the total area of the coast in 1999 was about 1.64 km^2 of beach, by 2009 the extent had reduced to about 0.89 km^2 (figure 4), thereby indicating the total loss of a 0.75 km^2 of beach land as shown in the overlaying of both imageries in figure 5. This invariably means that an annual rate of inundation of about 0.075 km^2 is operative along this very important coastline. The HadCM3 GCM sea level change projections and the coastal extent resulting from the projections of the 1999–2009 rate of inundation indicate the period when the water level falls below the coastal line and the shore becomes submergent as a result of the coast having been inundated due to a relative rise in sea levels.

4. Conclusion

The rate of coastal inundation will have serious implications for the low-lying areas of Victoria Island and Ikoyi in Lagos. Even though the considerable range of variability of tidal conditions around Nigeria has not been considered due to the lack of data, the result of the projection of coastal extent at the 1999–2009 rate of inundation reveals that before 2029 the rate of inundation would have entered a negative figure, which is indicative of the complete disappearance of the beach and an invariable loss of built-up land area into the ocean. It has been shown that much of the Lagos coastal lowlands are already at risk and would become more at risk if the sea level rises in the future or if the ground altitudes fall below the sea level due to increase in storminess and extreme sea water levels. A flood early warning system, which would integrate the collection of tidal data with that of surface meteorological parameters into a community-based information dissemination scheme, should therefore be developed in the country. Furthermore, given the unpredictability of the climate due to global warming, the current infrastructural developments around the low-lying barrier beach of Lagos should be reversed and the human population concentration in the area be reduced. Further and more detailed studies on the rate of erosion, SST variability and the marine geological processes in the area are also to be encouraged.

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