USING SRTM AND GDEM2 DATA FOR ASSESSING VULNERABILITY TO COASTAL FLOODING DUE TO SEA LEVEL RISE IN LAGOS:A COMPARATIVE STUDY

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Abstract
Climate change and its associated sea level rise is one of the recent challenging global issues especially in coastal areas, where a large percentage of the world population resides. Sea-level rise (SLR) is expected to increase coastal inundation and erosion. This may disrupt the physical and human processes including economic systems and social structures in coastal regions, which are densely populated. Digital Elevation Model (DEM) especially Shuttle Radar Topography Mission (SRTM) is a common source of elevation data for assessing the risk of flooding due to sea level rise. Recently, a new Advanced Space borne Thermal Emission and Reflection Radiometer(ASTER) Global DEM Version 2 (GDEM2) has been released to the public. This paper compares the flood risk estimations of SRTM and GDEM2. It examines different scenarios of sea level rise and its consequences on flooding in Mainland Lagos. It uses high resolution remote sensing data within Geographic Information System (GIS) environment to visualize the scenarios. The result shows that Lagos Mainland is vulnerable to sea level rise and SRTM (RMSE = 1.98) gives better flood risk estimations than GDEM2 (RMSE = 10.09).
Keywords: geospatial techniques; sea level rise, coastal flooding, SRTM, ASTER GDEM2 and flood risk estimations.

1. Introduction

Global warming and climate change and the associated sea level rise have great impact on the coastal regions which are densely populated and home of most economic activities in the world. About 10% of the world's population lives in the coastal region where the elevation is less than 10 metres above sea level (McGranahan et al., 2007). Sea level rise could cause coastal flooding and other environmental problems. This would disrupt the physical, cultural and socio-economic systems in the region. It therefore poses one of the major environmental challenges and major concerns of today. This made the United Nation General Assembly adopt the Intergovernmental Panel on Climate Change (IPCC) under the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) as the leading international body for the assessment of climate change and its attendant sea level rise. Various countries also set up national action plans on climate change and collaborate with the IPCC. Nigeria, for example, has acknowledged the impacts of climate change, through sea level rise along its coast line, increasing desertification in the north of the country, exacerbated erosion in the east and general land degradation throughout the country.

One of the challenges of climate change and sea level rise is the coastal erosion and inundation. Coastal erosion is wearing away of the coast by waves or other agents, which shape the coast, because the power of wave has a significant influence on the coast. Such influence is aided by sea level rise. This will definitely affect the socio-economic activities of the coastal and densely populated region of the world. The causes of sea level rise may be attributed to the following factors: the increase in water volume that results mainly from thermal expansion of the ocean, melting of mountain glaciers, an accelerated discharge of glacial ice from the ice sheets to the ocean, contributions from thawing of permafrost, sediment deposition, and the continuing adjustment of the ice sheets. Also, geological uplift or subsidence processes occurring in ocean basins and on continents can also influence long-term local sea level changes, and can exacerbate sea level rise impacts in many areas.

In order to study the impacts of climate change and SLR on societies, different climate modeling groups have developed scenarios of SLR given expected rise in temperature. These scenarios are modeled using geospatial data such as Digital Elevation Models like Shuttle Radar Topography Mission (SRTM), ASTER - Advanced Space borne Thermal Emission and Reflection Radiometer and the recently released ASTER Global Digital Elevation Model Version 2 (GDEM2). These terrain analyses are very important in depicting the areas that could be affected by predicted SLR. In this work, five different scenarios (1m, 2m, 3m and 5m) were used in the study area (Lagos Mainland) to assess the impact of predicted sea level rise and compare two different DEM data (SRTM and GDEM2) in a GIS environment.

2. Analysis of the Impacts of SLR Scenarios: The Role of Geospatial Techniques

The Intergovernmental Panel on Climate Change has considered different parameters for climate change simulations based on scenarios. The parameters such as; combinations of demographic change, social and economic development, and broad technological developments have been used to model the key issues in the simulation. The simulations have been carried out by the climate modeling groups as their major contribution to the IPCC Third Assessment Report. The different scenarios adopted by IPCC are known as IS92. The IS92 scenarios include IS92a, IS92b IS92c IS92d, IS92e and IS92f (Rekacewicz and UNEP/GRID, 2005).

The impacts of sea level rise scenarios can be predicted or projected for a particular location. For example, Warrick et al. (1996) made projections of thermal expansion and of loss of mass from glaciers and ice-sheets for the 21st century for the IS92 scenarios using two alternative simple climate models. Several other authors have based their prediction on these scenarios. Onyenechere (2010) madea vulnerability analysis based on climate change and an accelerated sea level rise (ASLR) of 1.0m. The study equally showed the projections of other parameters in the vulnerability analysis. Results of the analysis indicate that more than 13million people are presently at risk and may be relocated due to climatic variations and sea level changes. With the projected climate change and sea level rise of about 0.5m, the number of people that may be relocated assuming there is no development would increase to more than 27 million. With further physical and infrastructural development, the number will be about 53 million people, if the sea level should rise by about 1.0m with the projected climate change.

The Special Report on Emissions Scenarios (SRES) considered the global average sea level change from 1990 to 2100 (IPCC, 2001).Globally averaged sea level is projected to rise between 0.09 to 0.88m by the year 2100 (FME, 2003).The global average sea level rise projected from 1990 to 2100 for the SRES scenarios accounted for various parameters. The parameters like thermal expansion and land ice changes were calculated using a simple climate model calibrated separately for each of seven AOGCMs, and contributions from changes in permafrost, the effect of sediment deposition and the long-term adjustment of the ice sheets to past climate change were added. Each of the six lines appearing in the key,in the report, is the average of AOGCMs for one of the six illustrative scenarios (IPCC, 2012). Other factors considered the contributions from thawing of permafrost, sediment deposition, and the continuing adjustment of the ice sheets to climate changes. The choice of scenario is not the principal consideration; the main point is that the AOGCMs all follow the same scenario, so the range of results reflects the systematic uncertainty inherent in the modeling of sea level changes. IPCC provides good explanation for all the regions and scenarios (IPCC, 2012). The use of these scenarios is better enhanced with the use of geospatial data and techniques.

Geospatial techniques are integrated approaches of gathering, storing, processing, sorting, managing and delivering geographical related information. Geospatial methods usually adopted in sea level rise impact modeling utilise Digital Elevation Models (DEM) for elevation data. In the past, ground surveying methods such as traversing and leveling were used to obtain elevation data for DEM. But it requires rigorous field work and time and cannot be used for time-critical projects over very large areas. Existing topographic maps have also been used for deriving DEM data. Aina (1996) used topographic maps to analyze the impacts of sea level rise based on the contours and spot heights. The accuracy of data from topographical maps depends on the accuracy of the source data and topographic maps are relatively difficult to access compared to DEM data (SRTM and ASTER GDEM). Isioye and Jobi (2011) assessed the accuracy of DEM data derived from topographical maps, Google Earth, SRTM and Total Station instruments. They noted that the accuracy of data from Total Station is the best followed by topographical map data, then Google Earth data and SRTMin their study area (Zaria, Kaduna state of Nigeria).In a recent study, El-Ashmawy (2014) compared the DEM data derived from analytical aerial photogrammetry, GPS observations, total station and terrestrial laser scanning. The study concluded that total station and laser scanning are the most accurate (RMSE of 10 cm and 12 cm) followed by GPS (RMSE of 23 cm) and photogrammetry (RMSE of 42 cm).

Satellite and aerial DEM data such as SRTM, LiDAR and ASTER are being increasingly adopted by researchers to analyse the impacts of predicted sea level rise to their accessibility and coverage. They are used in carrying out national, regional and global studies in which traditional data collection techniques might not be effective. LiDAR data are more accurate than SRTM and ASTER as shown by Schumann et al. (2008) and Van de Sande et al. (2012). However, the cost of acquiring LiDAR data is higher than that of SRTM or ASTER which are freely available on the internet.

SRTM has been successfully used for assessing the impacts of flooding due to sea level rise (Li et al, 2009) but with some drawbacks such as missing data (‘voids’) and low spatial resolution (90m). In recent times, the ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) GDEM data is gaining attention from researchers due to its resolution (30m) which is higher than SRTM’s resolution. High resolution data such as ASTER GDEM are desirable for local SLR modeling. The ASTER imaging instrument is flying on the Terra satellite - a satellite launched in December 1999 as part of National Aeronautic and Space Administration - NASA's Earth Observing System - EOS. ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's EarthRemoteSensingDataAnalysisCenter(JPL, 2012). ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation.

Studies such as Van de Sande et al. (2012) have found that ASTER GDEM data is less accurate (vertical accuracy) than SRTM in modeling risks and vulnerability associated with SLR. Thus, SRTM despite its lower spatial resolution is still preferable to ASTER GDEM. Forkuorand Maathuis (2012), in a study of two regions in Ghana, concluded that the RMSE of SRTM data is lower than the RMSE of ASTER GDEM1 data in those regions. Thus, SRTM data has a higher accuracy than ASTER GDEM1 data (Forkuor and Maathuis, 2012). In October 2011, a new version of ASTER Global Digital Elevation Model (GDEM2) was made available to the public. The new data set is noted to have improved accuracy over GDEM1 but "the data would still have to be assessed and edited on a case-by-case basis before use in specific applications" (Tachikawa, 2011).

The use of Geographic Information System (GIS) as a tool in the process of data identification and analysis cannot be over-emphasized. GISis used for various analyses including modeling of flood risks due to climate change and sea level rise. In the studies by Li et al. (2009) and Van de Sandeet al. (2012), GIS was adopted to model the impacts of different scenarios of sea level rise on global and local communities. This paper contributes to the research on the sensitivity of flood risk assessment to DEM by comparing two DEM models and evaluating the accuracy of GDEM2 in an area that is prone to cloud cover (Lagos).

3. Methodology

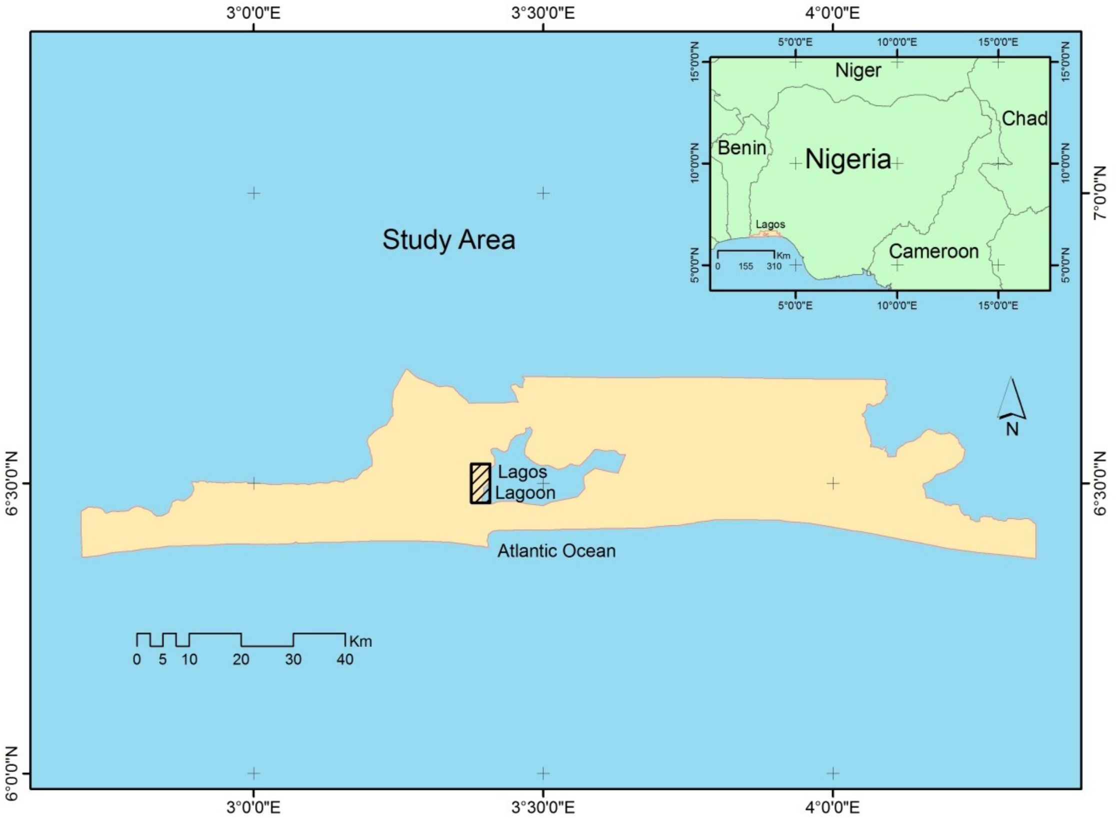
Study area

Lagos state lies approximately between longitudes $2^0 42'$ and $3^0 42'$ east of the Greenwich Meridian and latitudes $6^0 22'$ and $6^0 52'$ north of the Equator. The state is bounded in the south by the Atlantic Ocean, Benin Republic in the east and Ogun State in the north and west. The study area is located in Lagos Mainland and is bounded in the west by Lagos Lagoon another important water body in the area (Figure1). This area is vulnerable to sea level rise because of the presence of large water bodies (Atlantic Ocean and Lagos Lagoon), its low-lying nature and flooding as a result of heavy rain.

Materials and methods

SRTM data (global land cover facility) and ASTER GDEM2 (METI and NASA) data of 90m and 30m resolutions respectively were downloaded from the internet (http://www.landcover.org/ and http://gdem.ersdac.jspacesystems.or.jp/). IPCC adopted scenarios of sea level rise were searchedfrom the literature. The surge of 1 in 200years was also considered in assessing the vulnerability to flooding due to sea level rise. The same approach was adopted by Van de Sande et al. (2012). Thus, the scenarios of 1m, 2m, 3m and 5m were adopted in this work. ArcGIS 9.2 software was used to analyse the data. The hardware components used have sufficient facility to cater for the exercise. A number of GIS analyses were performed on the geo-referenced image of both SRTM and GDEM2. Different heights corresponding to the different adopted scenarios (1m, 2m, 3m, 4m and 5m) were extracted (using ArcGIS Spatial Analyst Tools) from the images to compute the areas that would be affected by inundation. The statistics (mean, standard deviation and standard error) of the SRTM and GDEM2 images were also computed. Efforts were made to retain the original values of the DEM images by just extracting the heights without further interpolations or using nearest neighbour method whenever interpolation could not be avoided.

Figure 1. Study Area



In order to ascertain the suitabilityof these data for estimating vulnerability to coastal inundation in the study area, two different analyses were carried out. In the first analysis, SRTM was selected as base of the comparison because Tachikawa et al. (2011) affirmed that GDEM2 data is generally comparable to SRTM while Van de Sande et al. (2012) asserted that SRTM is more suitable than GDEM1. In the second analysis, about 25 orthometric height data points (Table 1) were used as base of comparison to compute the root mean square error (RMSE) of SRTM and GDEM data.

4. Results and Discussion

According to the study by Van de Sande (2011), the study area will not be inundated by3.1m storm surge using GDEM1 while the area will be affected by flooding as indicated with the use of SRTM data. The results of the ASTER GDEM2 are shown in Figure 2. The height values of 140m above the sea level in areas covered by Lagos lagoon differed fromexpected values. It shows that the ASTER GDEM2data does not represent the Lagos lagoon very well as there are high values in the Lagos Lagoon area which is very unlikely for a water body because water will always find its level. Lagos Lagoon is expected to have height value close to mean sea level, since EGM96 is adopted for ASTER GDEM2.Therefore, extremely high values such as 140m to 536m which occurred in the study as shown in Figure 2are indications of the deviation from expected values. The black colour in the southern part of the study as shown in Figure 2 is an indication of the deviation from expected values. These couldbe considered as the areas with artifacts "pits and "bumps" in the GDEM2 data as noted by Tachikawa et al. (2011).

As indicated above, the adopted sea level rise scenarios were 1m, 2m 3m and 5m. The different scenarios for GDEM2 of coastal inundation are shown in Figure 3 and different scenarios of coastal inundation based on SRTM are as shown in Figure 4. Since both images have different spatial resolutions, the area of each of the pixels was calculated to be 8100sq.m for SRTM and 900 sq.m GDEM2. The number of pixels for each of the scenarios was calculated as shown in Table 2. Total surface area covered by each of the two methods under study was computed for each of the scenarios as shown in Table 2. The areas that might likely be inundated due to sea level rise using SRTM are larger than the areas computed using GDEM2 for all the scenarios. The largest difference was obtained at the scenario of 5m. Table 3 shows the statistics for GDEM2 and SRTM images. The standard deviation and standard errors of GDEM2, 14.172 and 0.26 respectively, are larger than the corresponding values from SRTM.

The figures, tables and analysis below show that SRTM DEM data are more suitable than GDEM2 data in the study area. The outrageous values (over 140m) in GDEM2 data were considered as outliers in the statistics since they were more than 3 standard deviations and therefore removed from the values used in the statistical table above. The RMSE of 22.79 was obtained for GDEM2, when SRTM was assumed to be the standard data. The RMSE is too high compared to RMSE of 4.01 and 8.68 for SRTM and GDEM2 respectively obtained by using orthomeric as benchmark in the validation carried out by Tachikawa et al. (2011). The RMSE obtained by using orthomeric data as the reference data was 1.98 for SRTM data and 10.09 for ASTER GDEM2 data (still higher than the RMSE computed by Tachikawa et al. (2011)). The artifactsand errors of the GDEM2 data might have resulted from cloud contamination because the area is prone to heavy cloud being a tropical rainforest area.

Figure 2. GDEM2 values for the study area

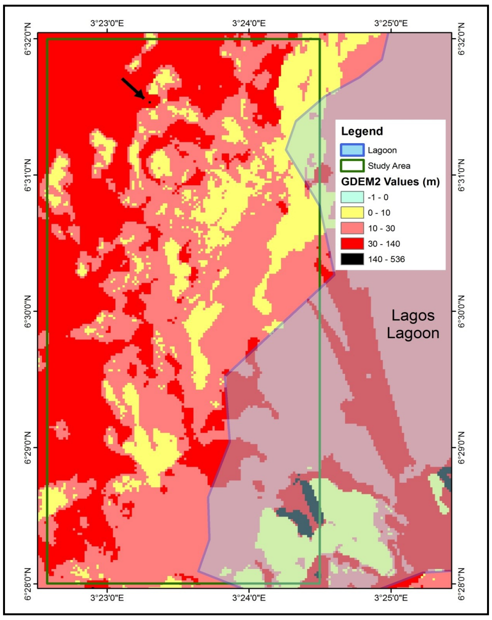


Figure 3. Different scenarios of coastal inundation based on GDEM2 data

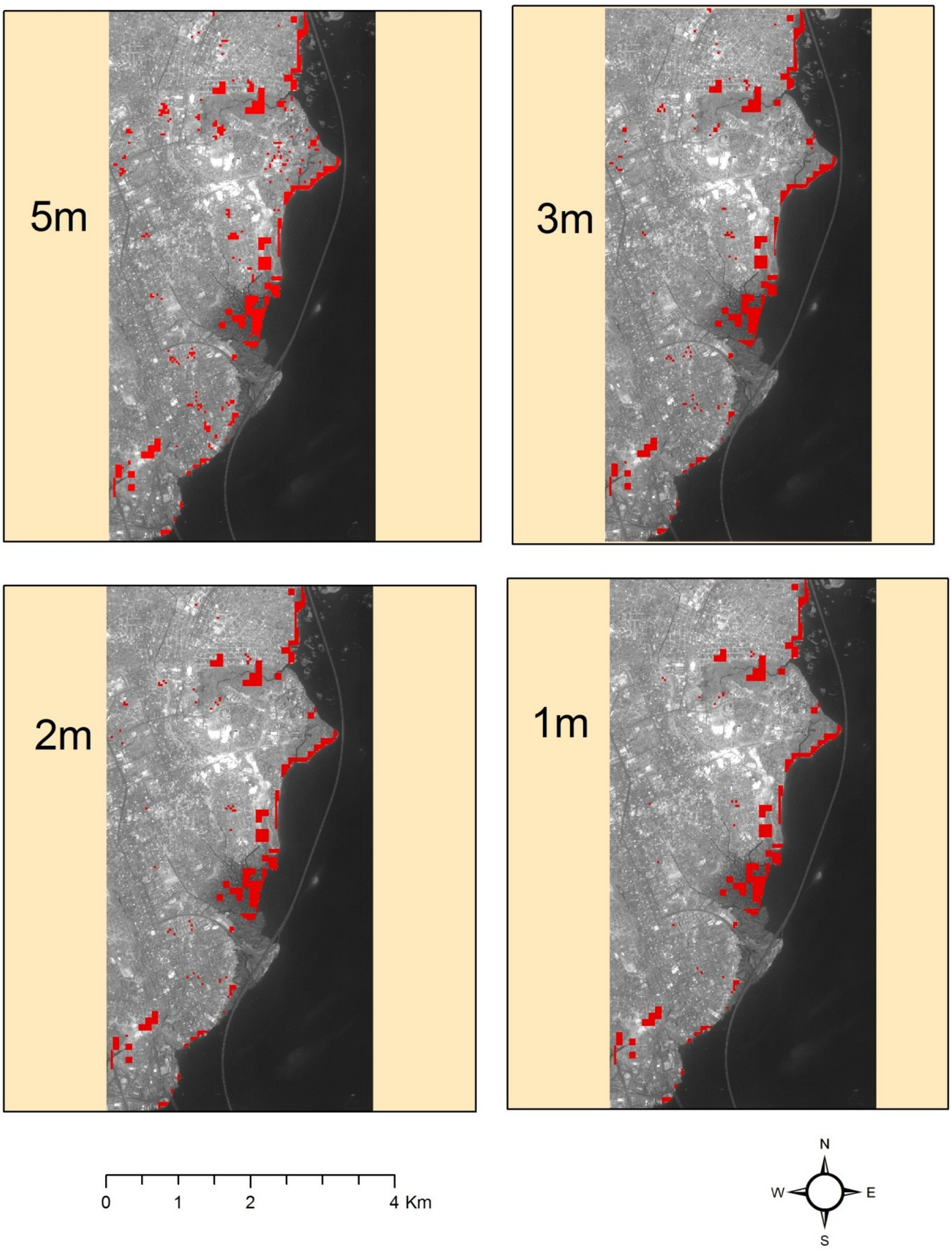

5m
3m
2m
1m
0 1 2 4 Km
N
W
E
S

Figure 4. Different scenarios of coastal inundation based on SRTM data

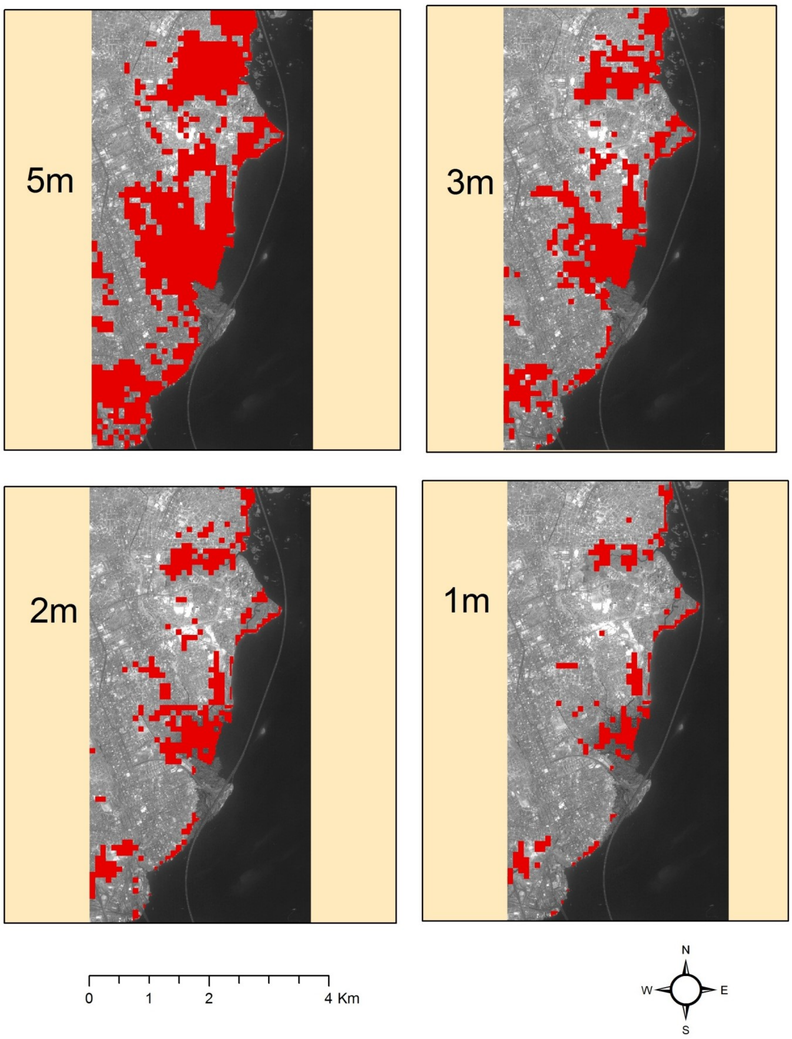


Table 1. Heights of control points (Orthometric, GDEM2 and SRTM)

POINT	LATITUDE	LONGITUDE	ORTHOMETRIC	SRTM	GDEM2
1	6.517765	3.402264	0.00	0	0
2	6.517490	3.402327	1.82	0	0
3	6.518575	3.401920	1.64	0	0
4	6.518696	3.399188	7.53	8	37
5	6.518642	3.393875	7.41	9	22
6	6.518929	3.392505	5.84	8	27
7	6.519092	3.391300	5.58	7	25
8	6.518737	3.391432	5.75	8	24
9	6.517145	3.391709	3.52	5	14
10	6.515366	3.391728	3.40	6	31
11	6.515062	3.391663	3.25	6	32
12	6.514972	3.391644	3.23	6	31
13	6.511630	3.389092	3.81	3	14
14	6.511631	3.389093	3.45	3	14
15	6.512873	3.389560	5.08	6	12
16	6.518270	3.389619	6.63	9	3
17	6.518446	3.389824	5.86	9	4
18	6.519157	3.391290	4.98	7	25
19	6.513006	3.392199	2.94	6	15
20	6.513297	3.393490	4.63	4	11
21	6.513756	3.395709	5.35	7	8
22	6.513867	3.395922	7.02	7	5
23	6.516708	3.397546	7.41	10	8
24	6.516707	3.397552	7.52	10	8
25	6.532325	3.399299	2.53	0	0

Table2.Areas covered by each scenario for GDEM2 and SRTM

Scenario	Number of Pixels		Area Covered by the scenarios	
	SRTM	GDEM2	SRTM (m^2)	GDEM2 (m^2)
1m	148	746	1198800	671400
2m	286	774	2316600	696600
3m	472	803	3823200	722700
5m	831	952	6731100	856800

Table 3. Statistics for the sampled elevationsof both GDEM2 and SRTM

Statistics	GDEM2	SRTM
Number of points	2970	2970
Minimum	0	0
Maximum	61	12
Mean	20.472	3.711
Standard Deviation	14.172	2.938
Standard Error	0.260	0.053
RMSE (using orthometric height data as reference) (25 data points)	10.09	1.98

6. Conclusion and Recommendations

The study has compared the use of STRM and ASTER GDEM2 to analyse the impact of sea level rise in Lagos Mainland. The IPCC scenario of sea level rise for 1m, 2m, 3m and 5m were used for the analyses. The study indicates that SRTM DEM data shows better accuracy than GDEM2 in depicting areas prone to inundation due to sea level rise in Lagos Mainland.

The impact of sea level rise should be studied and assessed using geospatial techniques and data such as SRTM, which gave a fairly better result. Though other data sources such as LiDAR and ground surveying that are more accurate than SRTM are available, the accessibility of the SRTM and GDEM2 to the public will still be an important factor in adopting these data.

Lagos state government has acquired LiDAR data of Lagos and it is recommended that this data be used in analyzing different scenarios of climate change. The data was available online (http://gis.lagosstate.gov.ng/LAGIS/WebPages/Map/MapViewer.aspx)for acquisition by researchers for a short period of time and the website has gone offline since then. It would be better if the data can be made available to researchers to stimulate better research on sea level rise.

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