Could Ocean-land Invasion be detected using Multi-temporal Images of Landsat?

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Abstract

One of the most certain consequences of global sea level rise is ocean – land invasion and is likely to increase in the near future. The coastal rural fishing communities are mostly at risk of the invasion. To address the menace spatially through scientific research interventions, different coastal mapping techniques have been adopted over the years for different research problems e.g. shoreline erosion studies, barrier island migration, coastal erosion vulnerability assessment etc. The methods adopted varied from simple analysis, manual analysis of uncorrected topographic maps and aerial photo, digital interpretation of corrected multi-temporal images of low and high resolution images (e.g. Landsat, spot, Ikonos), and hyper-spectral images (e.g. AVIRIS, CASI, hyperion). In complimenting previous studies, this study provides answer to the question "Could ocean-land invasion be detected using multi-temporal images of Landsat?" Orthorectified Landsat remotely sense datasets of MSS (1984), TM (2000), combination of TM & ETM+ (2012) were acquired from GLS portal. The study demarcated 704km^2 around the Eastern Obolo LGA shoreline and processed it using ENVI maximum likelihood and change detection techniques. The classes invaded by ocean were not well revealed due to Landsat low resolution; nevertheless, between 1984 and 2012, ocean invaded about 1.39km^2 of the vegetal class. Ocean downturns which may result to serious invasion in future were also detected. This 28years demonstration shows that Multi-temporal Landsat Images are useful for ocean – land invasion study, but increased spatial resolution may be needed for detecting more subtle changes.

Key words: Coastal, erosion, land, Landsat and temporal

Introduction

One of the most certain consequences of global warming is an increase of global sea level. The resulting inundation from rising seas will heavily impact low-lying areas. The problems of widespread shoreline/coastal erosion have become a cause of global concern over the years (Moore *et al.,* 1999; Morton and McKenna, 1999; Thampanya *et al.,* 2006). In Sub-Sahara Africa, the problem of coastal erosion is attributed to various possible factors including change of storm climate/ storm surges, sediment starvation, glaciation or orogenic cycles, tsunamis, sea level rise, and probably human interference/anthropogenic activities (Carter, 1988; Zhang *et al.,* 2004; Lee *et al.*, 2005; Morton *et al.,* 2005; Nouri *et al.,* 2005; Ferreira *et al.,* 2006; Zviely *et al.,* 2009; Ordu and Demir, 2009; Ceia *et al.,* 2010; Armah, 2011). Amongst the above factors, sea level rise and human interferences are the most plausible causes of current coastal erosion (Leatherman, 1991; Lantuit and Pollard, 2008) as there is no significant increase in storminess magnitude, sediment starvation, and tsunamis (WASA Group, 1998; Zhang et al., 2000; Zhang et al., 2004). Therefore, as sea level rises, the high water line will migrate landward in proportion to the slope of the coastal area (Zhang et al., 2004). The impact becomes severe in the low-lying areas where slope is very gradual as the case of Eastern Obolo shoreline area of Southeastern, Nigeria. An increase in the rate of sea level rise much beyond a few mm per year in such areas can result to a disastrous ocean invasion over nearby community lands. Globally, not less than 100 million persons live in areas within one meter of mean sea level and are at high risk in the coming decades (Zhang et al., 2004).

With changes occurring over different time scales and increasing population in coastal areas, the study of coastal erosion has become a more dynamic issue in scientific research domains, but remains difficult (May et al., 1982; Dolan et al., 1980; Moore, 2000; Armah et al., 2010). As a result, the problem is becoming more complex and unbearable to most shoreline communities. In Nigeria coastal environment especially the Eastern Obolo shoreline area, the problem is severe with serious damage to settlements and sensitive ecosystems.

Therefore, it is very important to take appropriate measures against the sudden and potentially dangerous rises in sea level and ocean invasion hazards (Carter, 1988; Ferreira et al., 2006). The measures should not be limited to reducing the potential effects of the event and reducing the risk of the coastal hazards but also to increasing the vulnerable communities' ability to adapt to the effects of the coastal hazards (Klein et al., 2001; Nicholas and Klein, 2003; Thampanya et al., 2006; Ferreira et al., 2006). These measures are necessary as adaptation mechanisms to withstand short and long-term changes induced by sea level rise, extreme events, and anthropogenic activities etc (Armah, 2011). For ocean disaster preparedness, coastal mapping is also important in order to establish baseline data and for monitoring future trends of shoreline movement (Pilkey and Neal, 1988; Finkl, 1994, Ferreira et al., 2006).

Coastal changes mapping techniques are many (El-Nahry and Khashaba, 2006; Dogan, 2007; Ordu and Demir, 2009; Barducci *et al.,* 2009; Monprapussorn et al., 2009) and varied from simple analysis of uncorrected aerial photos, manual interpretation, digital interpretation of corrected multi-temporal images of low and high resolution images (e.g. Landsat, spot) to hyper-spectral images (e.g. Hyperion). On the other hand, the tools for characterization and quantification of the changes also vary over space and time (Collins and Woodcock, 1996; Song et al., 2001; Rogan et al., 2002; Thieler et al., 2009; Bonyad, 2005; Dhaimat and Dhaisat, 2006). However, because remote sensing tools provide a synoptic view and multitemporal information, it has been noted as the most useful tool for classification and change detection over varying spatio-temporal scales (Carlson and Azofeifa, 1999; Guerschman et al., 2003; Dwivedi et al., 2005; Demers, 2005; Fan, et al., 2007; Reis, 2008; Rimal, 2011)

Various studies have been conducted and published on coastal erosion/shoreline mapping using these remote sensing tools but most of the studies addressed mainly the spatial coverage of the vulnerable areas (Yaw and Merem, 2007; Kuenzer *et al., 2011*). The authors infrequently address the invasion through a spatio-temporal change detection mapping. Therefore, the objective of this study is to provide answer to the question "Could ocean-land invasion be detected using multi-temporal images of Landsat? To answer this question with respect to Eastern Obolo coastal environment of Southeastern, Nigeria, we presents results of a remote sensing study on 28year patterns of ccean – land invasion variations using orthorectified Landsat images between 1984 and 2012.

Study Area

This study area lies between longitudes 7° 32` and 7° 50` East, and latitudes 4° 27` and 4° 33` in Akwa Ibom State, Nigeria. The area of demonstration covers about 704 km^2 on both land and water bodies (Fig. 1). Its shoreline is about 34.1km^2 with mangrove and shrubby vegetation. The area is characterized by poorly drained alluvial soil with much influence of Atlantic Ocean and creeks systems. During the high tide, the ocean overflows the shoreline and the village environment (Fig. 2).

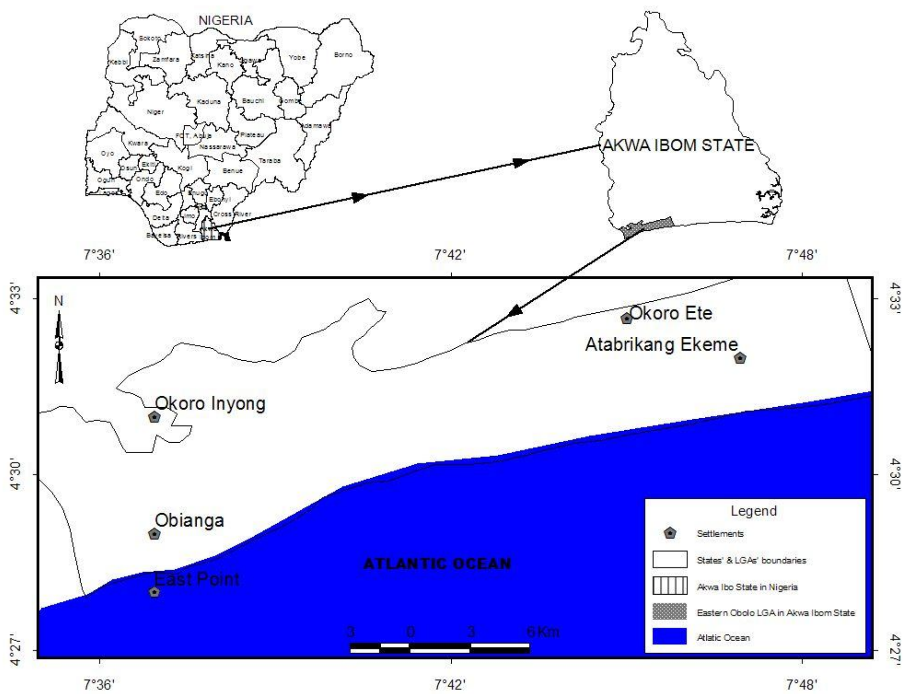

Fig. 1: The study Area

Fig. 2: Erosion invasion and downturn in 2011

Methods

The analysis time period was between December, 1984 and January 2012 with particular focus on recent years, 2005 and 2012. Orthorectified Landsat imagery including MSS (1984), TM (2000), combination of TM & ETM+ (2005 & 2012) were acquired from Global Land System (GLS) portal (Table 1).

Table 1: Landsat Images Scene Identifier

S/N	Paths	Rows	Dates & Years of Acquisition	Landsat Scene Identifier
1	188	057	13/12/1984	LM51880571984348AAA03
2	188	057	07/01/1991	LT41880571991007XXX03
3	188	057	13/01/2005	LE71880572005013ASN00
4	188	057	01/01/2012	LE71880572012001ASN00

Source: http://glovis.usgs.gov

Since the area falls within one path and row, the image for each time T year was downloaded and imported into ENVI software (an image processing software) for bands re-ordering and layer stacked. Approximately, 704km^2 (about 33.79km by 20.85 km) around the shoreline was masked out from each stacked part and row image using the region of interest (ROI) in ENVI. Subsequently, maximum likelihood (MLH) classification was used to classify the subset image into vegetation, built up, sand bar, ocean, and creek. Based on the field experience and knowledge of the area by the first author of this study (Fig. 2), and in conjunction with high resolution Google earth imagery (3) and true colour composite images (Fig. 4), pure pixels for the various land cover types were selected for training and validation of the MLH classifier.

Fig. 3: high resolution Google earth imagery (Insert: First Author taking location coordinates along study area shoring during field work on 30/08/2011)

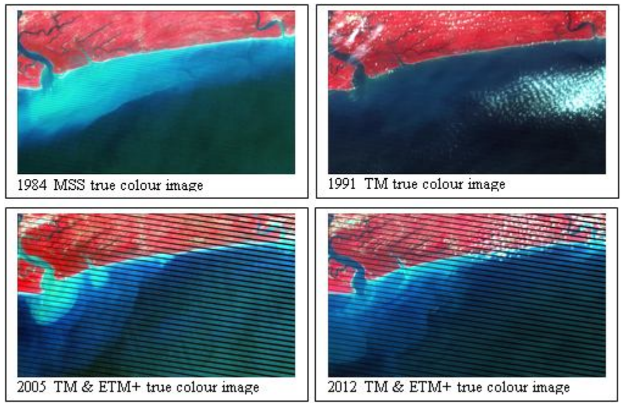

Fig. 4: True colour composite images

The 2005 and 2012 Landsat images are characterized by missing strips. Because of this, the classified images were exported into Erdas Imagine where they were corrected using re-code tool. Subsequently, all classified images were re-imported to the ENVI environment for change detection analysis and interpretation. The change detection matrix for the time period between 1984 and 2012 was produced using ENVI change detection statistics.

Results and Discussion

Change occurred more along shoreline segments between 1991 and 2005, and between 2005 and 2012 than in the 1984 and 1991(Fig. 5a through 5d).

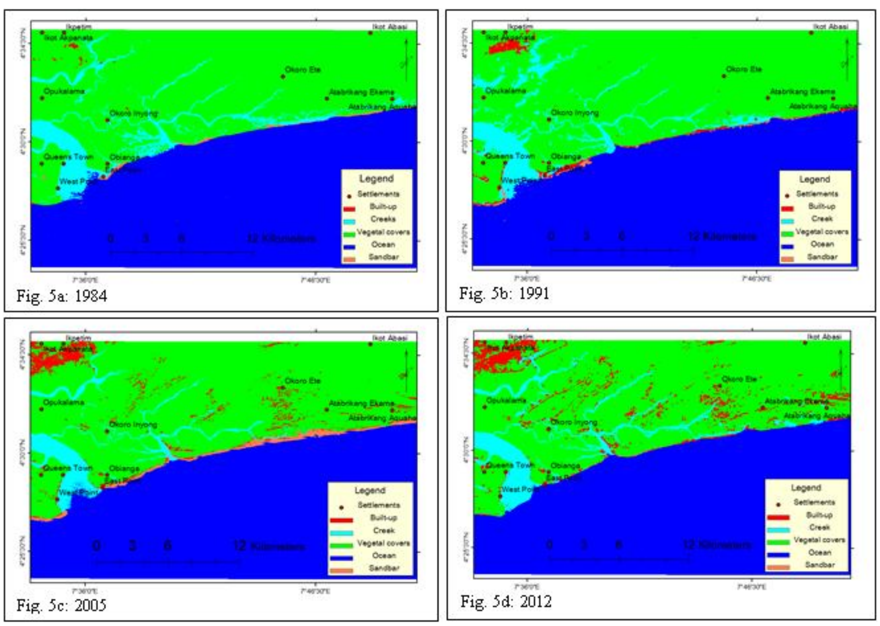

Fig. 5a through 5d: Time T classes

In Table 2, change matrices revealed that built-up showed the highest increase in area, difference of 7.09km^2 (i.e. an increase of 770.7% in 7years). Built-up losses 0.64km^2 (69.6%) out of 0.92km^2 baseline area covers in 1984. The classes with decreasing cover include vegetation (21.99km^2), sandbar (2.4km^2), ocean (8.82km^2), and creeks (19.91km^2) with negative image differences of -0.19km2 (0.06%), -0.03km^2 (13.3%), -6.81km^2(1.87%), and -0.26km2 (0.66%) respectively. High proportion (17.26km^2) of vegetal covers changed to creeks within the 7years (between 1984 and 1991). Within the same period, 65.32% and 44.17% of sandbar and creeks changed to vegetal covers.

Table 2: Change matrix between 1984 and 1991(km^2)

		1984											
		Vegetal		Built-up		Sandbar		Ocean		Creek		Class Total	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1991	Vegetal	*275.35*	92.60	0.46	50.0	1.62	65.32	2.46	0.68	17.51	44.17	297.46	42.22
	Built-up	3.97	1.34	*0.28*	30.4	0.14	5.65	2.65	0.73	0.97	2.45	8.01	1.14
	Sandbar	0.05	0.02	0	0.0	*0.08*	3.23	1.84	0.51	0.21	0.53	2.18	0.31
	Ocean	0.71	0.24	0.07	7.6	0.01	0.40	*355.52*	97.58	1.22	3.08	357.53	50.75
	Creek	17.26	5.80	0.1	10.9	0.63	25.40	1.58	0.43	*19.73*	49.77	39.38	5.59
	Class Total	297.34	100	0.92	100	2.48	100	364.34	100	39.64	100	704.56	100
	Class Changes	21.99	7.4	0.64	69.6	2.4	96.77	8.82	2.42	19.91	50.23		
	Image Difference	-0.19	0.06	7.09	770.7	-0.33	13.3	-6.81	1.87	-0.26	0.66		

As shown in Table 3, the areas well qualified for vegetal covers, ocean, and creeks classes between 1991 and 2005 changed by 16.46km^2 (5.53%), 4.24km^2 (1.19%), and 15.51km^2 (39.4%) with negative image differences of -0.67km2 (0.22%), -2.84km2 (0.79%), and -12.88km^2 (30.2%) respectively. Built-up and sandbar showed increased coverages of 4.87km^2 (60.8%) and 1.7km^2 (77.98%) with positive image differences of 9.68km^2 (120.9%) and 5.71km^2 (261.92%) respectively. The decrease in vegetal cover was highly reflected in the increase in built-up class while in the same period the analysis expressly stated that the decrease in ocean class mostly result in more accumulation of sandbar in 2005.

Table 3: Change matrix between 1991 and 2005 (km^2)

		1991											
		Vegetal		Built-up		Sandbar		Ocean		Creek		Class Total	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
2005	Vegetal	*281.01*	94.5	2.67	33.3	0.12	5.50	0.24	0.07	12.75	32.4	296.8	42.1
	Built-up	13.82	4.7	*3.14*	39.2	*0.29*	13.3	0.06	0.02	0.38	0.97	17.69	2.51
	Sandbar	0.92	0.31	1.65	20.6	0.48	22.0	3.34	0.93	1.5	3.81	7.89	1.12
	Ocean	0.21	0.07	0.09	1.12	0.22	10.1	*353.3*	98.8	0.88	2.24	354.7	50.3
	Creek	1.5	0.50	0.46	5.74	1.07	49.1	0.6	0.17	*23.86*	60.6	27.49	3.90
	Class Total	297.46	100	8.01	100	2.18	100	357.5	100	39.37	100	704.56	100
	Class Changes	16.46	5.53	4.87	60.8	1.7	77.98	4.24	1.19	15.51	39.4		
	Image Difference	-0.67	0.22	9.68	120.9	5.71	261.92	-2.84	0.79	-12.88	30.2		

The LULC change detection results are summarized for the years 2005 and 2012 in Table 4. The results show that negative changes have occurred in vegetal covers class and sandbar classes. Within the period vegetal covers and sandbar decreased by 21.82km^2 (7.35%) and 7.57km^2 (95.94%) commensurate with image differences of -13.18km^2 (4.44%) and -6.7km^2

(84.91%) respectively. On the other hand built-up, ocean, and creeks fetched increase of 6.5km2 (36.74%), 2.19km^2 (0.62%), and 2.01km2 (7.31%) with corresponding positive image differences of 8.31km^2 (46.97%), 2.98km^2 (0.84%), and 8.59km^2 (31.25%). The rate of ocean invasion and accretion was higher over sandbar along the shoreline.

Table 4: Change matrix between 2005 and 2012 (km^2)

		2005											
		Vegetal		Built-up		Sandbar		Ocean		Creek		Class Total	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
2012	Vegetal	*274.97*	92.65	6.05	34.20	1.32	16.73	0.11	0.03	1.16	4.22	283.61	40.25
	Built-up	12.92	4.35	*11.19*	63.26	1.66	21.04	0.04	0.01	0.19	0.69	26	3.69
	Sandbar	0.79	0.27	0.06	0.34	*0.32*	4.06	0.02	0.01	0	0.00	1.19	0.17
	Ocean	0.47	0.16	0.16	0.90	3.88	49.18	*352.51*	99.38	0.66	2.40	357.68	50.77
	Creek	7.64	2.57	0.23	1.30	0.71	9.00	2.02	0.57	*25.48*	92.69	36.08	5.12
	Class Total	296.79	100	17.69	100	7.89	100	354.7	100	27.49	100	704.56	100
	Class Changes	21.82	7.35	6.5	36.74	7.57	95.94	2.19	0.62	2.01	7.31		
	Image Difference	-13.18	4.44	8.31	46.97	-6.7	84.91	2.98	0.84	8.59	31.25		

The ocean – land invasion between 1984 and 2012 in the coastline of Eastern Obolo LGA of Akwa Ibom State Nigeria was analyzed by maximum likelihood classification technique. The changes detected over time were due to ocean downturn resulting from sea level rise. Sea level rise plays crucial role by elevating water level over low-lying areas during coastal storms and increases long-term erosion rates (French et al., 1995; Nicholls and Mimura, 1998; Popoola et al., 2011). The class that consistently changed negatively in the course of time was vegetation. The study observed intense change in vegetation class between 1984 and 2012 with -0.19km^2 between 1984 and 1991, -0.67km^2 between 1991 and 2005, and -13.18km^2 between 2005 and 2012. Nonetheless, the change in the vegetal covers seems low between 1984 and 1991 (0.06%). In addition, the vegetal class in the form of shrubs and grasses along the shoreline were mainly invaded by ocean erosion in 2012 (Fig. 2). It is because of the fact that the area is a low-lying terrain (between 0 and 50m above sea level) which allows easy passages of coastal erosion (Reis, 2008). Erosion of sandbar was highly noted in the 1991 and 2005 change detection analysis. Sandbar increases from 2.18km^2 to 7.89km^2 in 1991 and 2005 respectively (Fig. 5b; Fig. 5c, and table 3).The changes from sandbar to ocean also affected the built-up in the area. The 2005 and 2012 change detection analysis revealed reclamation of sandbar by the ocean (Fig. 5c; Fig. 5d, and table 4). These may involve redistribution process of sand from the ocean to the shoreline and back to the ocean which commonly occurs during coastal storms. These storms are accompanied by a temporary increase of local sea level that aids energetic storm waves to move ocean sands higher and deposit it in the ocean adjacent low-lying areas (Zhang et al., 2000; Zhang et al., 2004). There are changes to built-up class from all kinds of classes of lands, but the invasion from ocean was relatively less. Similarly, because of the nature of creeks in the coastal areas, the creeks class increases and decreases over time. The creek areas changed into built-up areas were noted to have originated from the creeks recession over time. This fluctuation may also have impacts on water transportation in the area particularly during the high tide (Baloglu et al., 2003).

Conclusion

The study shows the potential of using Landsat multi-temporal images for ocean-land invasion mapping that is necessary for coastal erosion adaptation mechanisms. The classification adopted and its results produce an overall accuracy that fulfills the coastal erosion threshold study. It was seen that the change were mostly occurred along the shoreline and around the creeks low-lying areas, although, the rate of ocean/shoreline invasion varied along the coastline between 1984 and 2012. For instance, the vegetation areas in the delineated image had a noticeable negative change as depicted in matrix analyses. The high changes in vegetation within the 28 years were caused mainly by the positive changes in built-up areas. Ocean invasion had its impact in the area but within the range of shoreline and creeks point of discharge.

From the maximum likelihood classification and change detection results, more devastated future Ocean – land invasion should be expected if proper shoreline planning and management (shoreline mangrove conservation; shoreline barrier protection) are not well channeled in the area. This study therefore encourages more application of remote sensing techniques in coastal erosion research as demonstrated in this study to open up more comparative research in coastal erosion, landuse/landcover, and global change impacts on shoreline communities. More high resolution earth observation datasets (e.g. spot) and hyper-spectral images (e.g. Hyperion) should be adopted for such research. This is because change information from high resolution images is more effective and accurate in change detection study.

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