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REMOTE SENSING APPLICATION FOR MANGROVE MAPPING IN THE ELLEMBELLE
DISTRICT IN GHANA

By
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ABSTRACT

Despite the immense contributions of mangrove ecosystems through the provisioning, cultural and regulatory ecosystem services they provide, these important ecosystems continue to be exploited the world over. In Ghana, about 24% of the countries mangroves were lost between 1980 and 2006. Ghana's mangroves continue to reduce in health and coverage, especially in areas outside the five Ramsar designated sites in the country. Moreover, the use of compensatory mechanisms in addressing the exploitation of coastal ecosystems and climate change mitigation is in its nascent stages in Ghana because of the uncertainties in their carbon stock estimates due to uncertainties in their areal extent.

The main objective of this study was to apply remote sensing technology to map the past and present areal extent of mangroves in the Ellembelle district in the western region of Ghana, especially in the face of limited data. Three main remotely sensed data were used in the study: a true color orthorectified digital aerial photo (AP); and two satellite data sources - RapidEye and Landsat Thematic Mapper (TM) imagery. Additional data were acquired through a participatory mapping exercise and a GPS survey. Other ancillary data like an existing land use/ land cover map of the area was used for the mapping.

A hybrid method (combination of supervised and unsupervised classification) was used along with principal components analysis (PCA) spectral transformation technique to produce four land cover classes; mangroves, other vegetation, water body and others (other land cover types). The current mangrove map showed that this ecosystem covers about 450 hectares and comprises three species of pure mangroves: *Avicennia germinans*, *Conarcarpus erectus* and *Rhizophora* species.

Additionally a combination of GPS ground reference points and randomly generated reference from the sub meter digital AP reported a producer's accuracy of 80.95% and a user's accuracy of 89.47% for mangroves. An overall Kappa statistics of 0.793 was recorded.

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BACKGROUND/INTRODUCTION

Mangroves are an assemblage of tropical and sub-tropical halophytes (i.e., salt tolerant) woody plants which grow in loose wet soils of brackish-to-saline estuaries and shorelines in the tropics and sub-tropics (Aheto *et al*, 2011; Heumann, 2011). This unique forest type was reported to have covered up to 75% of the world's tropical coastlines (Vaiphasa *et al*, 2006). The total global mangrove coverage is estimated to be about 180,000 km², distributed in 112 countries and territories in the tropics (Aheto *et al*, 2011).

The ecological and economic benefits of mangroves are well established. Globally, they are known to be the most productive and unique coastal ecosystems that support a wide range of goods and services (Aheto *et al*, 2011). The ecosystem goods and services that mangroves provide include protecting the coastline from tidal waves and storm surges; acting as biological filters in polluted coastal areas; supporting aquatic food-chains; and shielding a large number of juvenile aquatic organisms (Vaiphasa *et al*, 2006).

These ecosystem goods and services are estimated to be worth about US \$10,000 per hectare per year or about US \$180 billion globally (Heumann 2011b). The value of mangroves has been recognized by many governmental and non-governmental organizations in recent years as well as international agencies. International programs, such as the Ramsar Convention on Wetlands and the Kyoto Protocol for instance, underscore the importance of immediate protection measures and conservation activities to prevent the further loss of mangroves (Kuenzer *et al*, 2011).

Mangrove forest ecosystems have received greater recognition over the past few years for their ability to sequester green house gases. This is because recent climate change mitigation efforts have focused on the reduction of green house gases especially carbon dioxide (CO₂) through the conservation and restoration of natural systems recognized as efficient carbon sinks (Trumper *et al*, 2009). For instance, the International Panel on Climate Change (IPCC) has predicted that to mitigate about 12–15% of projected CO₂ emissions from fossil fuel burning by 2050, a global program that involves reduced deforestation, enhanced natural regeneration of tropical forests and worldwide re-afforestation will be required to sequester

60–87 Gt of atmospheric carbon for that period (Trumper *et al*, 2009). It has also been reported that blue carbon sinks, which comprises vegetated coastal habitats like mangrove forests, salt-marshes and seagrass meadows, rank amongst the most intense carbon sinks in the biosphere (Nellerman *et al*, 2009; Duarte *et al*, 2005). Donato *et al* (2011) have also established that mangroves are among the most carbon-rich forests in the tropics. Mangrove ecosystems therefore require immediate attention.

Unfortunately, the health and persistence of mangroves are seriously threatened. It

has been estimated that the world had lost a total of about 35% of the area once covered by mangroves since the 1940s, and these important ecosystems are still reducing at a current loss rates of about 1 to 3% per year (Valiela *et al*, 2001). Major threats to mangroves include logging for fuel and timber; land conversion to aquaculture, primarily shrimp ponds; coastal development for shipping; and the direct and indirect effects of urban development including fresh water diversions (Heumann 2011b).

MANGROVES IN GHANA

Mangroves cover about 137 km² (UNEP, 2007), constituting approximately 0.2% of the 81,342 km² of total forest area in Ghana (Gordon and Ayivor, 2003). The mangroves in Ghana are limited to very narrow, non-continuous coastal lagoons and estuaries, notably from the Ivory Coast border to the Cape Three Points; and in the east, bordering the fringes of the lower reaches and delta of the Volta River (UNEP, 2007; Spalding *et al*, 2010; Gordon and Ayivor, 2003).

There are six species of true mangroves in Ghana. These are *Acrostichum aureum*, *Avicennia germinans*, *Conarcarpus erectus*, *Laguncularia racemosa*, *Rhizophora harrisoni*, and *Rhizophora racemosa*. *Rhizophora racemosa* tends to dominate the open lagoons while *Avicennia germinans*, *Conarcarpus erectus*, *Laguncularia racemosa* and *Acrostichum aureum* are often associated with closed lagoons with elevated salinity (UNEP, 2007; Ajonina, 2011). Mangroves in Ghana play very important economic and ecological roles in the country, especially in the surrounding communities. The national economic value for mangrove related harvesting and contribution to marine fisheries alone has been estimated as \$600,000 per year (Ajonina, 2011; Gordon *et al*, 2009). Over the years, mangroves have been exploited by the local populations mostly for wood, and food. People who live in mangrove areas get wood (for fuel, building materials, etc), fish, crabs, snails and oysters either directly from mangrove or its associated environment (Gordon and Ayivor, 2003; Spalding *et al*, 2010, Ajonina, 2011). Ghana's mangrove ecosystems are known for the associated biodiversity they support. They are well noted for the provision of habitat for high concentrations of birds, mammals, amphibians, reptiles, fish and inveterate species. They also serve as habitats, sanctuaries and breeding grounds for migratory birds.

Despite the immense contributions of mangrove ecosystems to the local populations and the country as a whole, their health and survival continue to be undermined. Between

1980 and 2006, the country lost about 24% of its mangroves (UNEP, 2007). Some documented threats to mangroves include population increases leading to the over exploitation and the ultimate conversion of mangroves into other land uses, mostly development of urban centers and industry; engineering in the rivers and coasts such as the construction of dams and sea walls; and land-based sources of marine pollution (UNEP, 2007).

Unfortunately, there is no centralized body responsible for the sustainable use of mangroves. Different government agencies and other organizations perform activities that border on mangroves and biodiversity in general (UNEP, 2007). Some amount of

protection has been provided over the years through a number of traditional management systems. In addition, five Ramsar sites in the central and eastern areas of the country, which include mangrove habitats, have been designated since 1992 (Spalding *et al*, 2010; UNEP, 2007). These Ramsar sites are managed for sustainable conservation, but they are still exploited (Spalding *et al*, 2010)

STATEMENT OF PROBLEM

Ghana's mangroves have decreased considerably over the past few decades and continue to diminish at a relatively high rate (Spalding *et al*, 2010). Mangroves continue to be exploited even in the Ramsar designated sites. This wide-spread exploitation is more imminent in the western part of the country where none of the many mangrove sites is managed by any formal arrangement. The Ellembelle district of the Western region of Ghana is the home to several hundred square kilometers of coastal ecosystems including extensive mangrove forests. Mangrove forest consisting of pure and mixed stands of *Laguncularia*, *Rhizophora* and *Avicennia* species can be found in the near shore lagoons and estuarine areas. However, the vulnerability of these ecosystems, like many other mangrove forest, continues to increase with increasing population and land use change. In light of recent oil discoveries in the off shore areas of the district it is also expected that the west coast in general will become a hub of industrial activities, resulting in social pressures and increased exploitation of mangrove forest and other coastal resources.

The use of compensatory mechanisms in addressing the exploitation of coastal ecosystems is in its nascent stages in Ghana. In the terrestrial environment, climate mitigation mechanisms like the reducing emissions from deforestation and forest degradation (REDD+) has gained some level of acceptance in Ghana. Despite the importance of coastal ecosystems as effective carbon sinks, much has not been done about them and there have been uncertainties in their carbon stock estimates due to uncertainties in their areal extent (Bouillon *et al*, 2008). However, remote sensing has been recognized to play a crucial role for producing detailed and accurate characterizations of mangrove, which is an essential component for supporting ecological understanding and management of mangroves.

This study therefore looks at the application of remote sensing technology for mapping the areal extent of mangroves in the Ellembelle district in the western region especially in the face of limited data.

REMOTE SENSING OF MANGROVE FORESTS

Remote sensing technology has been applied in various ways to characterize mangrove ecosystems. Some of the documented applications include mapping the areal extent, detecting individual species, and providing estimates of structure and parameters such as leaf area, canopy height, and biomass (Heumann, 2011). The main motivation for the characterization of these ecosystems is to monitor and manage them. Generally all the remote sensing application in mangrove ecosystems can be categorized into three broad areas. These broad categories have been identified as resource inventory;

change detection; and selection and inventory of aquaculture sites (Green *et al.*, 2000; Vaiphasa *et al.*, 2006).

The remotely sensed data and the techniques that have been used for characterizing mangrove ecosystems have evolved over time, moving from a traditional remote sensing approach to a more advanced one. Traditional approach includes the use of aerial photography (AP) and some high resolution systems (Heumann, 2011; Green *et al.*, 1998). Aerial photography is sometimes preferred in developing countries because it is most cost effective and more readily accessible. It is very effective over small areas than satellite remote sensing because it can provide fine grain imagery unavailable from satellite remote sensing (Mumby *et al.*, 1999; Heumann, 2011). They can also be essential for the accurate assessment of classification procedures performed on other, lower-resolution, data (Kuenzer *et al.*, 2011). The most common technique associated with aerial photography has been visual interpretation.

Other traditional mangrove remote sensing applications involve the use of high resolution (multispectral) satellite imagery like Landsat, SPOT and ASTER. Some of the techniques that have been used to detect and delineate mangrove have involved unsupervised and supervised classification techniques, and sometimes a combination of both. Other techniques include spectral transformations such as principal components analysis (PCA) or Tassel-Cap Transformation, or spectral vegetation indices such as Normalized Difference Vegetation Index (NDVI) (Green *et al.*, 1998; Heumann, 2011).

There has been a very rapid advancement in mangrove remote sensing over the past few decades. Development in satellite sensors including very high resolution multispectral systems such as Quickbird, IKONOS, GeoEye and Worldview-2; hyperspectral systems like the Hyperion as well as Radar and LiDAR systems have grown in leaps and bounds. Similar advancement in the remote sensing techniques promises detailed and more accurate mangrove mapping at a finer level (Vaiphasa *et al.*, 2006; Heumann, 2011). Some of the advanced techniques are Object-Based Image Analysis (OBIA), and image texture metrics.

OBJECTIVES

The main objective of this study is to apply remote sensing for mapping the past and current mangrove coverage in the Ellebelle district in Western region of Ghana for monitoring and conservation purposes. The study specifically seeks to:

1. map the current spatial dimension of mangrove forests in the area surrounding the Amanzule river and estuary,
2. make a past land cover map of the same site to detect changes in mangrove extent, and
3. identify mangrove areas potentially at risk of being cleared

Data

Remote sensing data

Three main remotely sensed data were used in the study. These were a true color orthorectified digital aerial photo (AP); and two satellite data sources - RapidEye and Landsat Thematic Mapper (TM) imagery. The digital AP was acquired in May 2005 and has a spatial resolution of 0.5 meters. The RapidEye data were acquired on January 2012 and have a spatial resolution of 7.7 meters. The Landsat TM data on the other hand was captured in December 1986 and has a resolution of 30 meters with 7 spectral bands. The characteristics of the two data sets are shown in Figure 1.

Ancillary data

Other ancillary GIS data like shapefiles of the streams and rivers in the study area were used. In addition to the shapefiles was a land cover/ land use (LCLU) map of the coastal zone between Cape Three Points and the Ivory Coast border. This map was made for CRC- Ghana by Dr. YQ Wang, Christopher Damon and Glenn Archetto at the Laboratory for Terrestrial Remote Sensing in URI.

Survey data

A GPS survey of mangrove sites and a participatory mapping exercise were conducted at the study site. Both datasets were collected through a series of field visits from June to August, 2012. The period for the field trips coincided with the raining regime of the area, making accessibility to certain parts of the forest very difficult, especially for the GPS mapping.

Prior to the site visits, a potential map of wetlands was derived from the LCLU maps of the area. Reconnaissance was conducted with the permission of the local leaders of each of the communities and the assistance of local guides. The survey of the mangrove forests was conducted with a Trimble Juno ST Handheld and a Garmin eTrex Vista HCx GPS. Locations of mangrove patches and stands and other attributes like the mangrove species, adjacent land cover, and condition of mangroves were recorded. Preliminary mangrove maps were then generated (through visual interpretation of the digital AP) based on the initial site visits and the result of the participatory mapping. Follow-up visits to some areas identified on the preliminary maps were conducted to ground truth the mangrove map. The period for the ground truthing coincided with a much drier environment, and this permitted a better access to some areas.

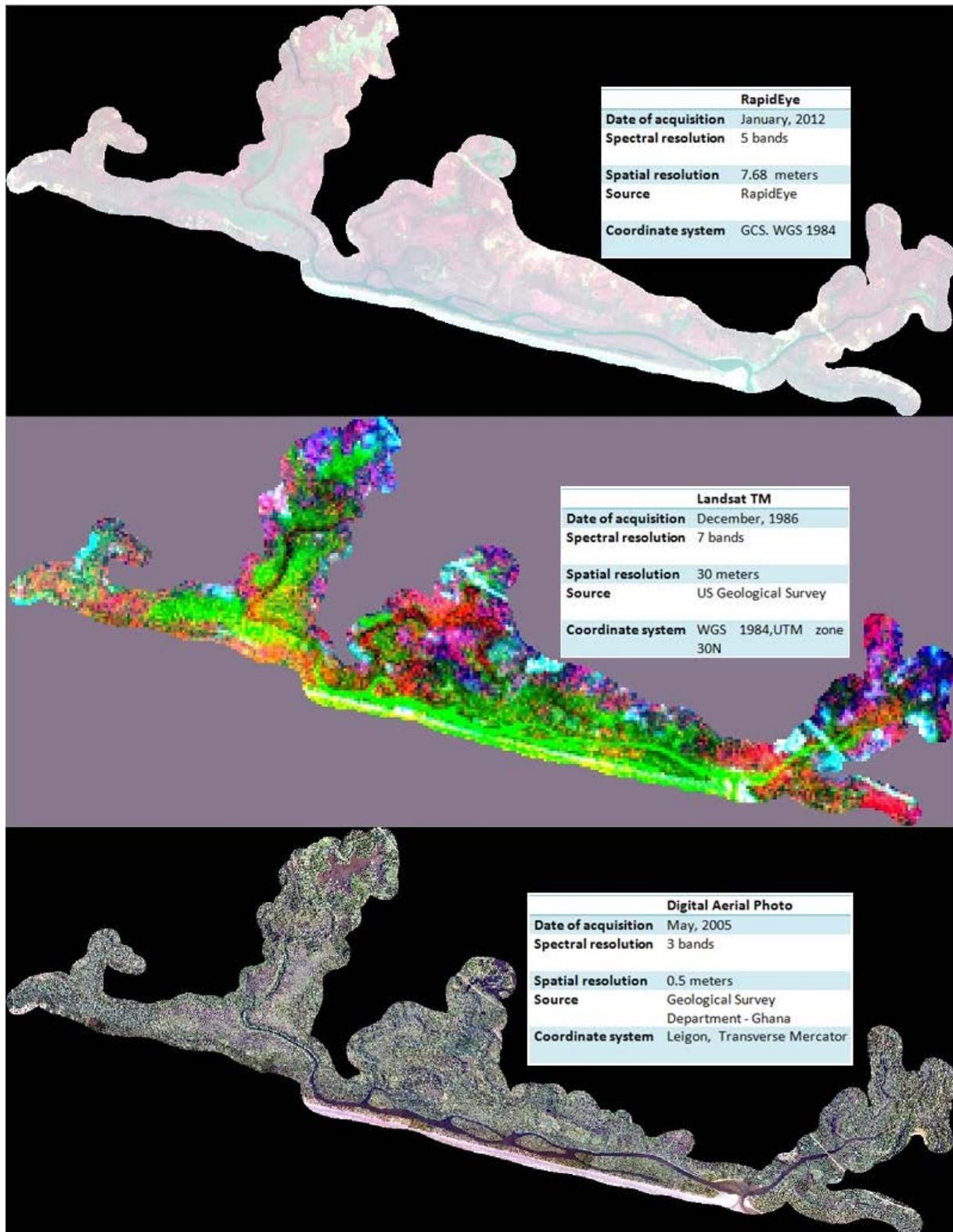


Figure 2 The three datasets that were used for the study

The participatory mapping was conducted in 2 communities in the study area, Ampaim and Bakanta. It involved elderly men and women who had lived in the community for over 20 years and are exposed to the mangroves either through their occupation or other mangrove related activities. Aside mapping the current and the past mangrove extent, the informants were asked questions bordering on a number of mangrove-related issues including the benefits the community derive from the mangrove products and the associated environment; the causes of mangrove degradation in the past; what the current threats to mangroves were; and measures that they believe would help to maintain the mangroves.

It's important to note that these two exercises complemented each other and helped to collect enough data relevant for this study over a relatively short period. In many cases the information on the existence of mangroves from the local informants who were involved in the participatory mapping exercise helped fill up for the extremely inaccessible areas.

Data Processing and Analysis

All the data were geometrical corrected and projected to the Universal Transverse Mercator (UTM) zone 30N (WGS 1984 datum)

The current mangrove map

The 2012 RapidEye image was used for mapping the current mangrove extent of the study area. After stacking the five individual layers, the data were geometrically corrected and reprojected into UTM zone 30N. The area of interest (study area) was then subset. A combination of supervised and unsupervised classification technique was adopted for the thematic information extraction. In the Erdas Imagine environment, an unsupervised classification (using the ISODATA algorithm) was used to extract 10 classes using 6 iterations and a convergence threshold of 0.95. The signature of the unsupervised classification was saved and modified with additional signatures to train the software for a supervised classification. The maximum likelihood algorithm was used for the supervised classification. The additional signatures used for the supervised classification were based on the GPS points and the result of the participatory mapping. Polygons that were manually delineated on the digital AP were used to copy to area of interests (AOIs) and used as training samples. In all four thematic classes were mapped; namely mangroves, other vegetation, settlement, and others (other land cover types).

Past mangrove maps

The past mangrove maps were derived from the Landsat TM imagery. The data are freely available and were downloaded from <http://earthexplorer.usgs.gov/>. The Landsat TM tile that was used for the mapping was acquired on December 29, 1982 and was located on path 149, row 057. The data were geometrically corrected for shift and visually enhanced after the individual bands were stacked together.

The statistics of each of the seven spectral bands were analyzed and the correlations of the bands were generated using Envi 4.7 software. The bands were checked for data redundancy by comparing the correlation between individual bands.

The result of the statistical analysis (figure 3) showed high correlation values among

Basic Stats	Min	Max	Mean	Stdev	Num	Eigenvalue
Band 1	0	255	66.369642	41.937973	1	5757.923836
Band 2	0	219	25.651085	16.579570	2	443.157786
Band 3	0	255	22.598316	15.113307	3	232.634877
Band 4	0	255	18.439106	15.810537	4	22.801974
Band 5	0	255	17.036328	18.002454	5	13.837431
Band 6	0	255	94.406833	59.651887	6	3.427310
Band 7	0	255	8.974074	9.031850	7	2.287915

Correlation	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Band 1	1.000000	0.978784	0.949361	0.754569	0.630932	0.871043	0.676381
Band 2	0.978784	1.000000	0.979317	0.813052	0.704370	0.864918	0.744746
Band 3	0.949361	0.979317	1.000000	0.843989	0.759245	0.848846	0.807400
Band 4	0.754569	0.813052	0.843989	1.000000	0.930177	0.671118	0.848109
Band 5	0.630932	0.704370	0.759245	0.930177	1.000000	0.568755	0.941786
Band 6	0.871043	0.864918	0.848846	0.671118	0.568755	1.000000	0.588300
Band 7	0.676381	0.744746	0.807400	0.848109	0.941786	0.588300	1.000000

Figure 3 Result of the summary statistics of the seven Landsat TM bands

most of the bands, indicating very strong relationship between the brightness values of the bands. Based on the result of the this analysis, a principal component analysis (PCA) was conducted in the Erdas Imagine 2012 software to extract 4 layers that explain most of the variability in the data.

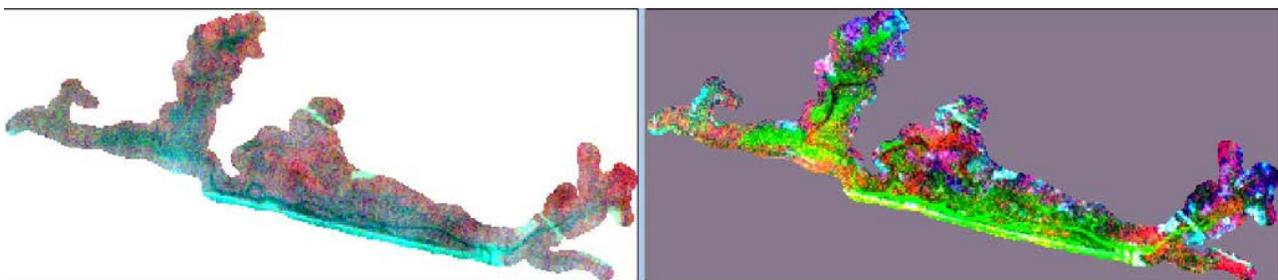


Figure 4 A visual comparison of the Landsat TM image; a) the original image with bands 4,3,2 displayed in RGB, b) the PCA

The area of interest was then clipped and made ready for the thematic information extraction. A similar technique for the current mangrove map was used to classify the PCA data. An initial unsupervised classification, followed by a supervised classification

was used to extract the four classes that were mentioned earlier. However, the additional training signatures, in this case were only based on the result of the participatory mapping.

Accuracy Assessment

The accuracy of the current mangrove map was conducted with a total of 112 reference points. Out of this total, 67 were points that were collected on the field with GPS during the field visit in June-August, 2012. The other 50 points were generated using the equalized random sampling methods. The digital AP was very useful for identifying the reference classes of the 50 additional points.

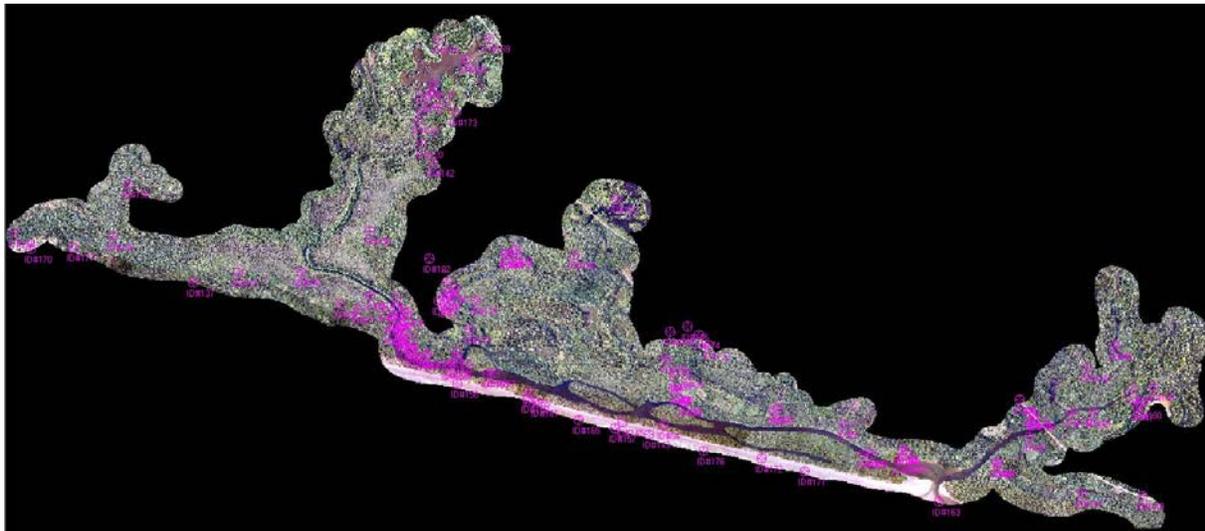


Figure 5 Reference points that were used for assessing the accuracy of the current mangrove map

RESULTS AND DISCUSSION

This section presents the result of the analyses and provides some discussions for each one of them. It is organized to address the three specific objectives of the study.

The current spatial dimension of mangroves

The total subset representing the Amanzule mangrove site covered about 12 km². Out of this total, approximately 37% (450 hectares) was classified as mangroves (all species). The other land cover types that were extracted included broad categories like water bodies (7%), other vegetation (53%), and others (3%). The water body class comprises all open water features such as rivers, ponds and the ocean. Other vegetation consists of all other forms of green vegetation other than mangroves. This includes mostly coconut trees and shrubs. The other land cover types broadly include built-up areas, cleared areas, sandy beach and other impervious surface features like roads.

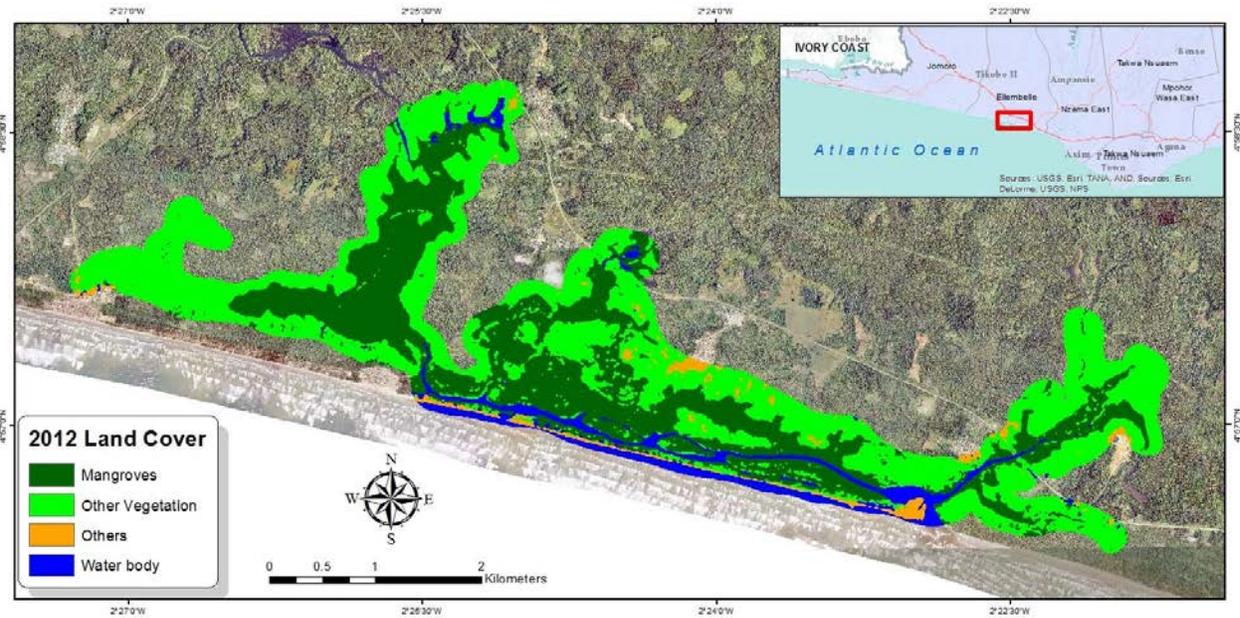


Figure 6 Current (2012) land cover image of the study area showing the four classes

The Amanzule mangrove site comprises relatively healthy contiguous stands mangroves along the Amanzule River and other streams. The mangroves are mostly riverine and basin, with some fringing mangroves along the coastline. The site has three mangrove species: *Avicennia germinans*, *Conarcarpus erectus* and *Rhizophora* species. The dominant mangrove species is the *Rhizophora*, which is very established along the rivers and streams. They look very healthy and tall in areas very close to the water (where salinity is relatively low) and where disturbance is minimal. The *Rhizophora* located in the interior side of the swamps and in drainage depressions are stunted and cutting is predominant.

Small isolated stands of *Avicennia germinans* are found in areas along the estuary where the salinity of the water is high. In Ampain, however, a more contiguous, relatively undisturbed stands of *Avicennia* was found. The *Conarcarpus* species were only identified in few places in Ampain.

Accuracy Assessment

The result of the accuracy assessment that was conducted with ground reference points and randomly generated points produced an overall accuracy of 84.82%. The producer's accuracy and the user's accuracy for the mangroves class were 80.95% and 89.47% respectively. The overall Kappa statistics was 0.7983 and the conditional Kappa for mangrove alone was 0.8316.

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	5	5	5	---	---
Other Vegetation	33	33	26	78.79%	78.79%
Mangroves	42	38	34	80.95%	89.47%
Water body	23	24	21	95.45%	87.50%
Others	9	12	9	100.00%	75.00%
Totals	112	112	95		
Overall Classification Accuracy =		84.82%			

Overall Kappa Statistics = 0.7983

Conditional Kappa for each Category.

Class Name	Kappa
Other Vegetation	0.6993
Mangroves	0.8316
Water body	0.8640
Settlement	0.7282

Figure 7 Result of the accuracy assessment showing the accuracies of the mangrove class

Past Mangrove extent

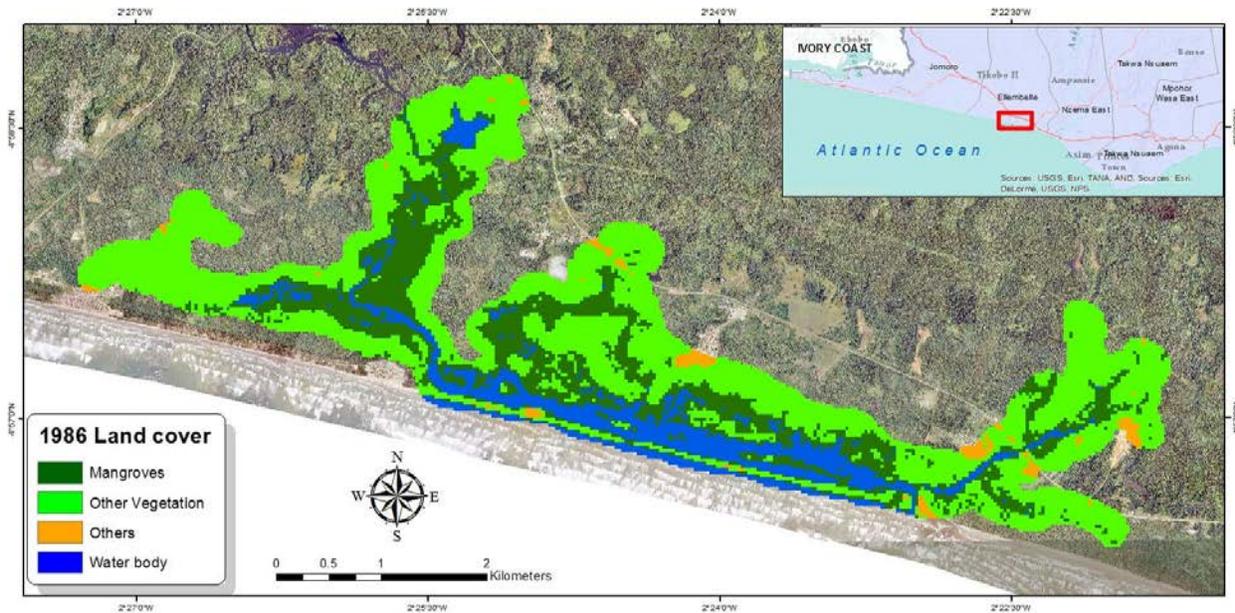


Figure 8 Past (1986) land cover of the study area showing the four classes

The past land cover map was generated from the 1986 Landsat TM image. Though the general distribution of the various land cover types remained relatively unchanged, the areal extent showed some significant variations. A change analysis was not conducted due to the difference in the resolution; however, a comparison of the changes in area covered over time indicates that there were fewer mangroves along the channels of the rivers and streams in the past.

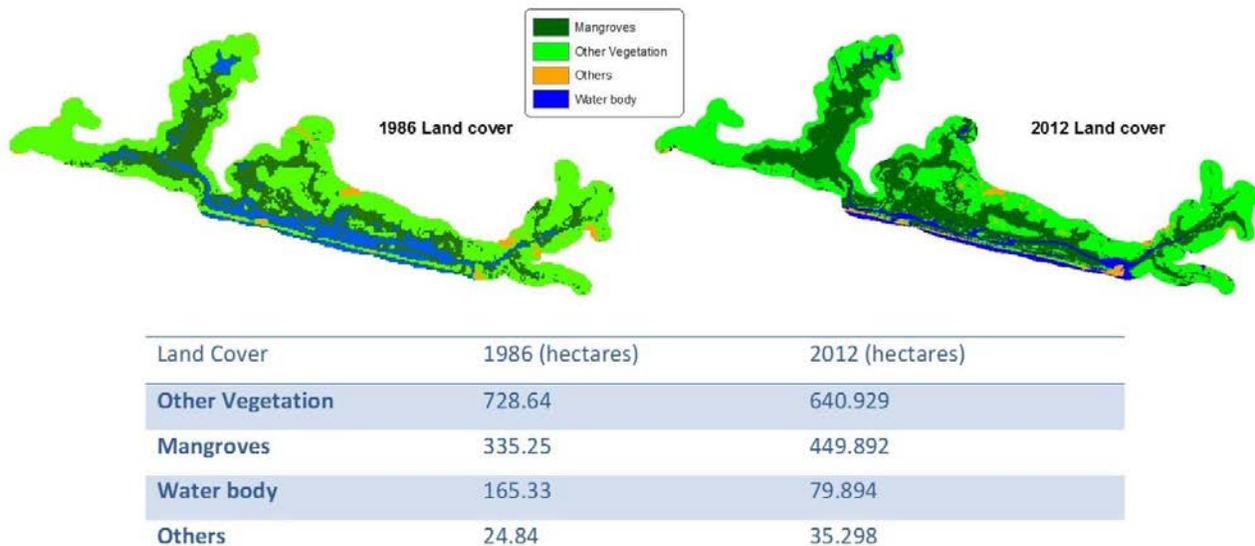


Figure 9 A comparison of the areal extent, by classes, (in hectares) of the past and current land cover

Though this result may have been influenced by the inability of the 30 meter-resolution Landsat TM image to identify the fringing mangroves (and other vegetation), it actually confirms the perception of the changes in the mangrove coverage by the local folks. According to the participatory mapping exercise and other informal discussions with local informants, the local folks believe that mangroves have actually grown extensively along the rivers and streams, making accessibility difficult in most places. They believe that the *Rhizophora* species may eventually close up the water channels.

Areas potentially at risk

The study identified a number of benefits that the mangrove environment as well as the mangrove products themselves offers the surrounding communities. Chiefly among these socioeconomic benefits are the cutting of the mangroves for fuel; building materials for houses; fishing of black tilapia and other fish species; and catching of crabs and other crustaceans and molluscs. Mangroves are the main source of fuel for the local people. In the rainy season (May- August), they are often harvested in the interior side of the swamps where mangroves are often stunted. During the dry season however, the roots and branches of the mangroves along the rivers and streams are also cut because accessibility is enhanced. It was also gathered through informal conversations that some local folks use the mangroves for charcoal production.



Figure 10 Some disturbed mangroves

Though the traditional authority and the residents realize the immense contribution of mangroves through the provisioning, cultural and regulatory ecosystem services they

provide, these important ecosystems continues to be exploited. In some areas, human disturbance has resulted in very poor conditions of the mangroves.

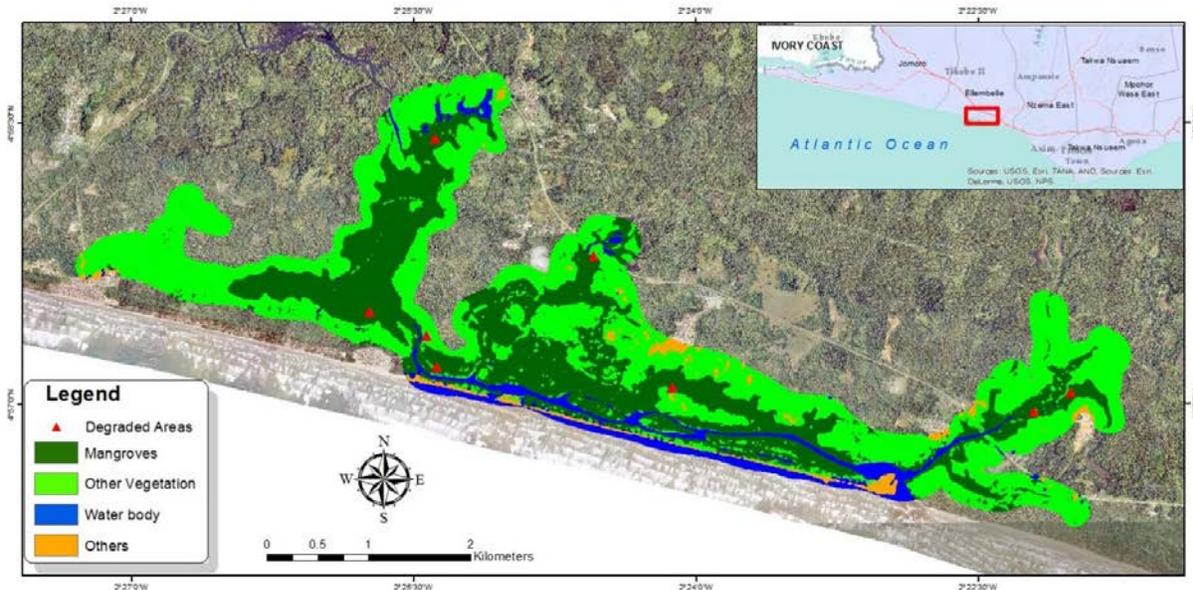


Figure 11 Map of the Amanzule mangrove sites showing some degraded areas

CONCLUSIONS

The application of traditional remote sensing approach for mapping mangroves is well documented. Traditional mangrove remote sensing typically involves the use of aerial photography and high resolution satellite image (i.e., spatial resolution between 5 and 100 m) and techniques such as supervised and unsupervised classification of image (Green *et al*, 1998; Heumann, 2011). This study applied a traditional approach for characterizing mangrove forests in the Amanzule mangrove site in the Ellembele district in the western region of Ghana. Three different data sets (digital aerial photograph, a RapidEye image and Landsat TM) were used with different techniques to map the past and mangrove extents of the study site. A hybrid method (combination of supervised and unsupervised classification) was used along with principal components analysis (PCA) spectral transformation technique (PCA was only used for the 1986 land cover map) to produce four land cover classes; mangroves, other vegetation, water body and others (other land cover types).

Heumann (2011) reports that when traditional data and techniques are used classification accuracies of mangroves classes range from 75% to 90% for producer's and user's respectively. In this study a combination of GPS ground reference points and randomly generated reference from a sub meter digital AP reported a producer's accuracy of 80.95% and a user's accuracy of 89.47% for mangroves. The accuracy assessment

was only conducted on the current land cover map. An overall Kappa statistics of 0.793 was recorded. This statistical value expresses the proportionate reduction in error generated by a classification process, compared with the error of a completely random classification. This implies that the entire classification process avoided about 80% of the errors that a completely random classification would generate.

The following steps represent a relatively robust way of mapping mangroves in developing areas, especially, when challenges like data availability and time restrictions are inevitable. The current mangrove map may serve as the basis for mangrove monitoring and management in the study area. It could also serve as baseline data for future studies such as biomass estimation, carbon accounting, change analysis, conservation planning, among others. A similar approach could be used to produce detailed and accurate characterizations of mangrove throughout the country to support ecological understanding and management of mangroves.

Recommendations for future mangrove mapping of this scale could be refined if more GPS reference points distributed evenly across the mapped classes are collected for the accuracy assessment. Additional points would also provide enough information to map the mangrove species. Closely related to this recommendation is the time of year when the GPS survey is conducted. Accessibility is greatly hindered during the raining season (May-August) therefore, field visits should be planned to take advantage of the drier periods of the year.

Additionally, advanced techniques like Object-Based Image Analysis (OBIA) could be used to enhance the classification. OBIA, a classification technique that uses objects rather than just individual pixels for image analysis, could take advantage of the textual differences between mangroves and the adjacent coconut trees. In terms of data, future mangrove mapping could benefit from high resolution elevation data, possibly LiDAR data or DEM. Since all mangroves must grow in intertidal conditions elevation data could help to determine this zone before classification is performed. A pan-sharpened Landsat Enhanced Thematic Mapper plus (ETM+) could improve the classification process, if available. The spectral merging of the panchromatic band of the Landsat ETM+, (with a resolution of 15 meters) with the other bands could benefit from a lower resolution (15 meters) and still maintain the original spectral characteristics.

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