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Mangrove vulnerability modelling in parts of Western Niger Delta, Nigeria using satellite images, GIS techniques and Spatial Multi-Criteria Analysis (SMCA)

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Abstract Mangroves are known for their global environmental and socioeconomic value. Despite their importance, mangrove like other ecosystems is now being threatened by natural and human-induced processes that damage them at alarming rates, thereby diminishing the limited number of existing mangrove vegetation. The development of a spatial vulnerability assessment model that takes into consideration environmental and socioeconomic criteria, in spatial and non-spatial formats has been attempted in this study. According to the model, 11 different input parameters are required in modelling mangrove vulnerability. These parameters and their effects on mangrove vulnerability were selected and weighted by experts in the related fields. Criteria identification

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and selection were mainly based on effects of environmental and socioeconomic changes associated with mangrove survival. The results obtained revealed the dominance of socioeconomic criteria such as population pressure and deforestation, with high vulnerability index of 0.75. The environmental criteria was broadly dispersed in the study area and represents vulnerability indices ranging from 0.00–0.75. This category reflects the greater influence of pollutant input from oil wells and pipelines and minimal contribution from climatic factors. This project has integrated spatial management framework for mangrove vulnerability assessment that utilises information technology in conjunction with expert knowledge and multi-criteria analysis to aid planners and policy/decision makers in the protection of this very fragile ecosystem.

Keywords Satellite remote sensing · Data management · Spatial modelling · Environmental monitoring · Coastal management · Vulnerability

Introduction

The coastlands of the world are awashed with various kinds of vegetation. These lowland forests include mangroves that are shrubs and trees with prop roots which strive in saline environment. The vegetation of this environment has come under serious exploitation and constant threat of disintegration in recent times. There are roughly 17 million hectares of mangroves worldwide that are gradually being depleted on a global scale (Gilman et al. 2006). Mangroves are known for their global environmental and socioeconomic value, occupying 14,653,000 ha of coastal area worldwide (FAO 2003) and providing several important functions for numerous species that are dependent on such ecosystems for their existence. With an economic value of the order of US$200,000–900,000 per hectare (Wells et al. 2006), coastal inhabitants benefit directly and indirectly from the many services rendered by mangroves such as provision of food, timber, fuel and medicine (Giri et al. 2007). Despite their importance, mangrove vegetation like other marine ecosystems are now being threatened by a wide variety of natural threats (droughts, floods, land subsidence geologic erosion and sea level rise) and more recently human-induced (climate change, pollution, deforestation, invasion of exotic species, coastal development, saline water intrusion, sedimentation, sand mining, oil exploration and exploitation) processes (Davis and Quinn 2004; Lal 2003; Lovelock and Ellison 2007; MacFarlane et al. 2007; Saleh 2007). These processes damage the mangroves at alarming rates thereby diminishing the limited number of existing habitats. The cumulative effects of natural and anthropogenic pressures make mangrove wetlands one of the most vulnerable natural communities worldwide (Gilman et al. 2006). Vulnerability is a measure of the extent to which a community, structure, service or geographical areas is likely to be damaged or disrupted, on account of its nature or location, by the impact of a particular disaster hazard (IPCC 2001; Renaud 2006).

Previous works including Diop (2003) have developed the science and technology to quantify environmental degradation. However, there is deficiency in providing science-based solutions to decision makers, planners and managers who are more concerned with social and economic implications. Accurate predictions of changes to mangrove area and health, including those originating from climate change effects, enable advanced planning to minimise and offset anticipated losses and reduce threats to coastal development and human safety for specific sections of coastline (Gilman et al. 2006). Therefore, it becomes necessary to identify and estimate the relative importance of a number of socioeconomic and environmental criteria to aid mangrove vulnerability assessment studies.

Mangrove habitat and vulnerability assessment

Mangroves are found in about half of the 177 countries of the world (Wells et al. 2006), confined to 30° north and south of the equator (James et al. 2007) (Fig. 1). Mangroves strive in wetlands which

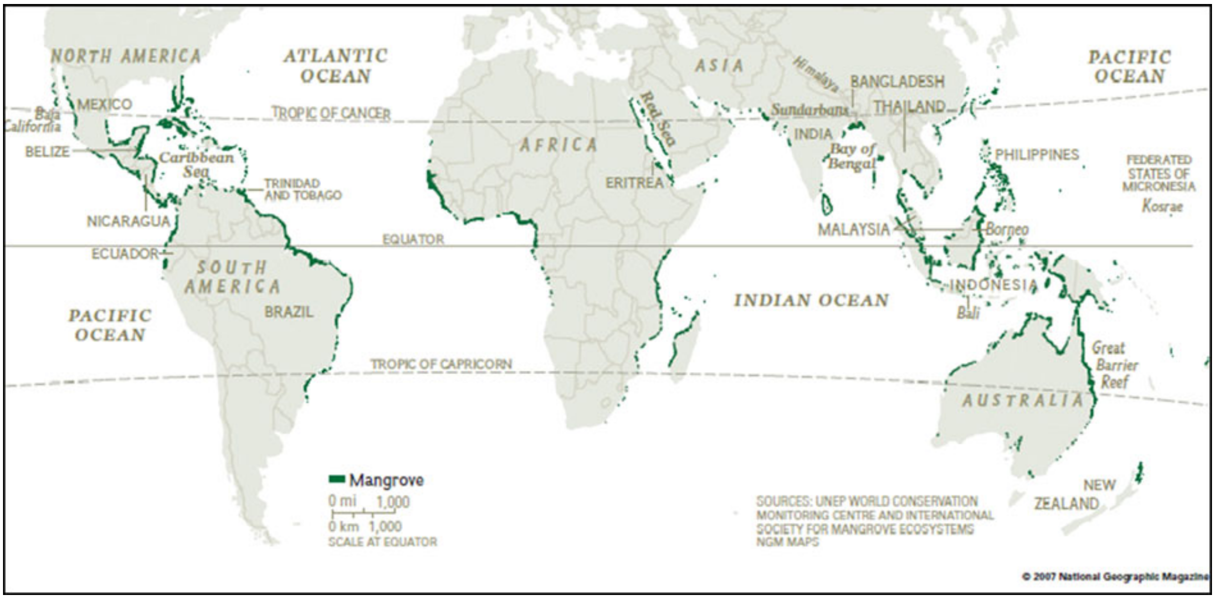

Fig. 1 Global distribution of mangroves (National Geographic Magazine 2007)

are areas of ground that remain saturated at the surface for much of the year (Gilvear and McInnes 1994). According to FAO (2003), climatic factors such as temperature and moisture contribute to their global distribution such that they are mainly located in the interface between land and sea in the tropical and subtropical regions. Mangrove is used to refer to either the vegetation or to the community of mangroves. Within the context of this work the term mangrove refers to the later.

Estimates of current mangrove extent vary significantly from one source to another, possibly because of the difference in definition, methodology, and land cover information used (Burke et al. 2001). The major types of mangrove include *Avicennia/Sonneratia*, *Bruguiera caryophylloides*, *Rhizophora* and *Bruguiera gymnorhiza* (Ibrahim and Hashim 1990).

Vulnerability assessment of Vanuatu coastal areas has been conducted by Phillips (2000). Gilman et al. (2006) have investigated in particular the vulnerability of mangroves in response to climatic change and associated sea level rise in the Pacific Islands. Such vulnerability levels and trends need to be assessed regularly to provide early warning and response measures to reduce the economic costs (Diop 2003).

Methodology

A generalised flowchart of the steps involved in mangrove vulnerability modelling is presented in Fig. 2.

Study area

The mangrove ecosystem of the western region of Delta state, Nigeria covers an estimated area of 23 ha (Fig. 3). It is part of the largest concentration of mangrove in Africa. The closest major city located at the periphery of the mangroves is Warri. The region is part of the Quaternary to Recent Niger delta with a vast floodplain built up from the accumulation of sedimentary deposits from rivers Niger and Benue (Rim-Rukeh et al. 2007). Being a vast interface between land and water systems, it is ecologically very complex (Sokari-George 1989). Due to the high rainfall (average annual of 3,000 mm), flat terrain and poorly drained sediments, a dynamic equilibrium exists between flooding, erosion and sediment deposition. The study area lies in the wet equatorial climatic region with mean daily temperature of 26°C. It is also characterised by high cloud cover and relative humidity above 70%.

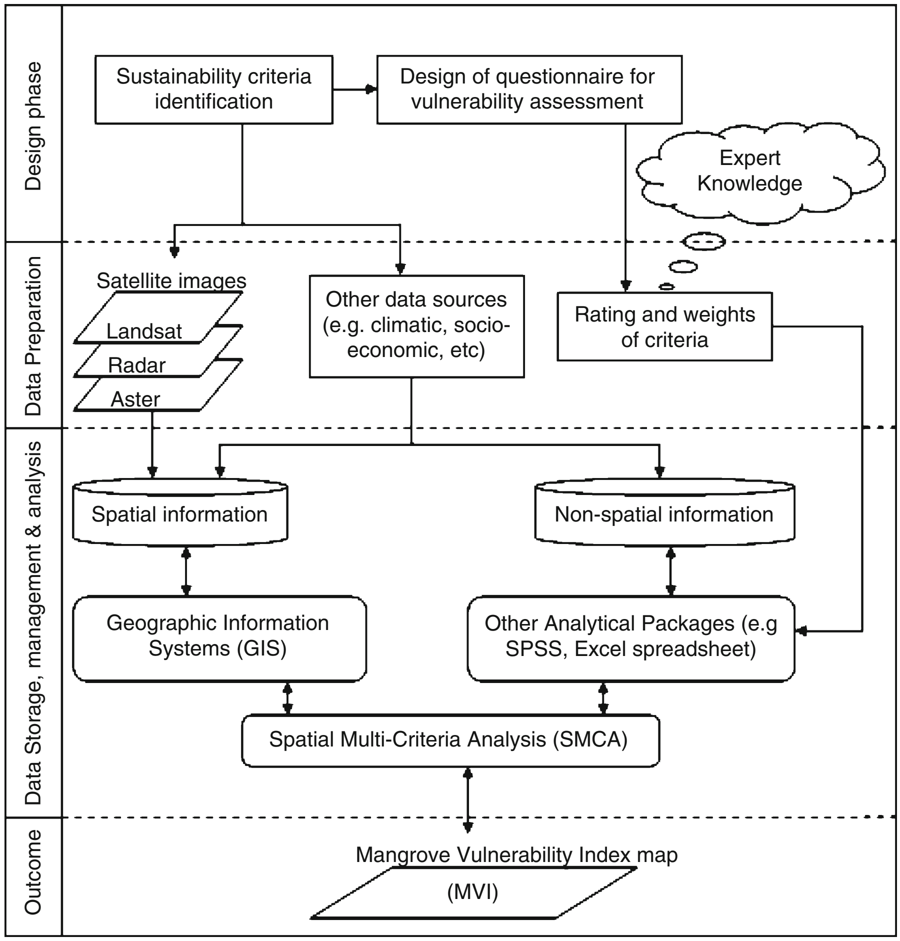

Fig. 2 Flowchart for the determination of mangrove vulnerability

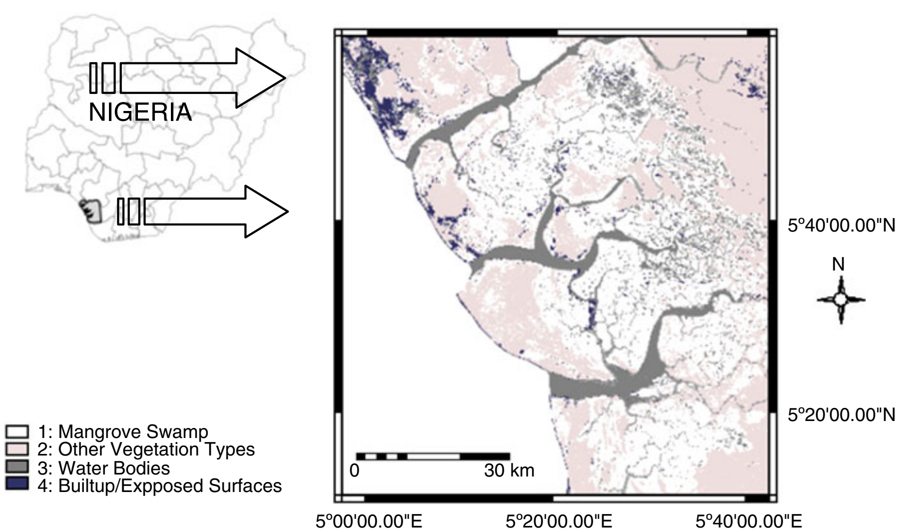

Fig. 3 Location of study area

Its subsurface geology reveals a three-fold lithostratigraphic subdivision, comprising an upper sandy Benin Formation, an intervening unit of alternating sandstone and shale named the Agbada formation and a lower shaly Akata formation (Ophori 2007). These three units extend across the whole delta, and each ranges in age from early Tertiary to Recent (Reijers et al. 1996; Sonibare and Ekweozor 2004).

Identification and selection of criteria for mangrove vulnerability assessment

Expert knowledge is an essential aspect in the identification and selection of criteria for mangrove vulnerability assessment. Such data relevant to this study were collected through questionnaire survey. The questions were carefully prepared and the initial questionnaire was sampled by experts to ensure that the questions were well understood and meaningful within the context of the research. An interactive session involving respondents made up of experts was carried out to refine the questions that were finally used in the survey. These experts made up of lecturers in the fields of environment (geology, microbiology and chemistry) as well as social and economics were involved in the identification and weighing of criteria for mangrove vulnerability assessment. The questions were elicited in such a way to know the impacts of the selected criteria on mangroves. The weights ranged from 1–5, where 1 = least important and 5 = most important. The criteria were based on those that address the sustainability of the mangrove ecosystem. The selected criteria and sub-criteria applied in the assessment process are displayed in Table 1.

Table 1 Mangrove vulnerability assessment criteria and sub-criteria

Criteria	Sub-criteria
Socioeconomic	Population pressure
	Deforestation
	Civil conflicts
	Poverty
Environmental	Carbon dioxide
	Relative humidity
	Temperature
	Sea level rise
	Precipitation
	Alien invasive species
	Pollutant input

Socioeconomic criteria

Population pressure The ability of mangrove ecosystems to adapt to environmental changes depends largely on their geographical location and the size and nature of the local human population. Also, industrialisation and urban settlements impose a high demand for land. Therefore, human population pressure is increasingly a contributory factor in the loss of the mangrove habitat globally. Information on population can be obtained from census figures.

Deforestation High rates of deforestation in mangroves can be linked mainly to agricultural and aqua cultural activities. Hussin et al. (1999) have shown that mangrove deforestation caused by establishment of shrimp ponds can be detected on all optical and radar images. There is increased correlation between the signal polarisation and incidence angle with the ability of particular radar sensors to detect changes in mangrove environments. The crucial point is that the deforestation of mangrove is largely attributed to changing socioeconomic conditions. Rates of deforestation can be extracted from temporal analysis of satellite images

Poverty Poverty in the local populations often results from a destabilisation of their social context and a resulting break in the provision of their traditional resources (Diop 2003). This also leads to greater environmental pressures. Information on poverty can be obtained from http://www.ruralpovertyportal.org/english/regions/africa/nga/index.htm or by interview.

Civil conflicts Civil conflicts can have impact on mangroves' vulnerability (Diop 2003). Mangrove habitat may become ready hide-out for warring parties and the use of dangerous weapons may negatively impact fragile ecosystem native to such environment. Information of civil conflicts can be sourced locally.

Environmental criteria

Environmental factors can be divided into two groups on the basis of external and local influences. External factors include carbon dioxide, relative humidity, temperature, sea-level rise and precipitation. Local factors are alien invasive species and pollutant input.

Carbon dioxide The CO_2 content of the atmosphere is usually expressed in parts per million by weight, and the use of fossil fuels is expressed as so many tons of carbon burned per year. The burning of fossil fuels presently releases seven billion tons of carbon into the atmosphere each year in the form of carbon dioxide gas, CO_2.

Presently, the mangroves like other forest zones are sinks to the excess CO_2 emitted. They act as buffer protecting the environment from the full effect of global warming. Increased CO_2 enhances productivity, but this is dependent on other limiting factors such as salinity, humidity and nutrients (Ball et al. 1997). The overall impact of CO_2 on mangroves has not yet been fully understood and is still under investigation (McLeod and Salm 2006). The global estimation of the CO_2 in the atmosphere was estimated from the amount released from fossil fuel burning can be obtained form the United States NASA website http://data.giss.nasa.gov/co2_fung/.

Relative humidity Water vapour is the most important heat-trapping greenhouse gas in our atmosphere. Specific humidity refers to the actual amount of water vapour in the air. Relative humidity relates to the saturation point, the amount of water vapour in the air divided by the maximum amount of water the air is capable of holding at a given temperature. As air temperatures rise, warm air can hold more water, and the saturation point of the air also increases.

Temperature Mangrove species usually occur where annual temperature is high, and temperature amplitude is small. Seasonal temperature changes of less than 10°C are favourable for good growth. The ideal temperature for photosynthesis is 35°C. Low temperature reduces the tree size, leaf area index and species composition of the flora as well as the complexity of communities. Typically, mangroves occur in areas where mean annual temperatures do not drop below 19°C (66°F) (Waisel 1972). Short-term extreme temperatures of 4°C to 60°C can be tolerated but these should never suddenly arise but rather increase or decrease slowly. According to Lovelock and Ellison (2007), increased air and sea temperatures generally lead to reduced productivity at low latitudes and increased winter productivity at high latitudes

Sea-level rise Regional sea-level rise is affected by tectonic movements that can cause land subsidence or uplift. Natural and human induced sediment compaction can also exacerbate the impacts of sea-level rise. Humans contribute to land subsidence through coastal development that causes deficits in the sediment budget, shipping channels that cause bank erosion, groundwater or oil extraction that causes submergence, and dredging and mining that causes losses of land (McLeod and Salm 2006). Global mean sea level is projected to rise 9 to 88 cm between 1990 and 2100 (Gilman et al. 2006). Estimation can be used to assess site-specific mangrove vulnerability to projected sea level rise.

Precipitation Changes in precipitation patterns caused by climate change may have a profound effect on both the growth of mangroves and their areal extent (McLeod and Salm 2006). Mangrove areas experiencing increased rainfall will experience an increase in area, with mangrove colonisation of previously non-vegetated areas of the landward fringe, and there will be an increase in diversity of mangrove zones and growth rates (Ellison 2000).

Alien invasive species A major anthropogenic factor contributing to the degradation and depletion of the mangroves is the invasion of the non-native Nypa palm (Nypa *fruticans*). For Instance, in Nigeria, the Nypa palm was first introduced in Calabar in 1906 and later in Oron in 1912. The species rapidly established itself successfully and in the process displaced the native mangrove vegetation (CEDA 1997). Unfortunately, it failed to play the role of erosion control for which it was introduced to Nigeria; rather, it has helped to reduce the firmness of the coastal sediments. Other problems caused by the presence of the invasive palm include the general habitat conversion with attendant reduction in fish catch, poor navigation, ecological degradation and loss of biodiversity.

Pollutant input Important parameters are required for monitoring pollution level in coastal regions where mangrove strives. A wide variety of pollutants affects the world's mangrove. Pollutants include nutrients, pathogens, persistent organic pollutants and heavy metals, oil and solid waste (Burke et al. 2001). Of particular interest are petroleum residues which can contaminate marine and coastal waters through various routes: accidental oil spills from tankers, pipelines and exploration sites; regular shipping and exploration operations, such as exchange of ballast water; runoff from land and municipal and industrial wastes (Burke et al. 2001). Also, heavy metals pose a threat to the survival of mangrove and those that are commonly monitored include cadmium, copper, mercury, lead, nickel and zinc.

Assignment of criteria ratings and weights

Criteria ratings were mainly extracted from threshold values obtained from an exhaustive review of literature. Weights were obtained from expert knowledge through a means of questionnaire survey. When reporting results from a nonparametric questionnaire survey, it is relevant to note that the mean and standard deviation which is usually associated with normal distributed sampling is not applicable. The median and range are used instead (Field 2005). For the derivation of the central tendencies for weight the grouped median was calculated using the equation

$$\mathrm{GM} = L + I \times \left(\frac{N/2 - F}{f}\right) \quad (1)$$

where:

- L lower limit of the interval containing the median,
- I width of the interval containing the median,
- N total number of respondents,
- F cumulative frequency corresponding to the lower limit,
- f number of cases in the interval containing the median.

This central tendency has the advantage over the median value as it allows one to recognise that, for example, a five-point rating scale constrains responses to a small set of discrete values when the underlying attribute being measured is really a continuous scale.

Use of satellite images

The development of modern earth observation techniques, such as the United States of America's—Landsat, IKONOS, Quickbird sensors, France's—SPOT, Nigeria's—NigeriaSat and India's IRS, with particular reference to multispectral/temporal remote sensing data greatly enhances the mapping and monitoring possibilities of the earth's features. Satellite images provide the spatial information for mangrove vulnerability assessment as accurate mapping by ground survey is extremely difficult, time consuming and expensive as a result of remote and inaccessible nature of the terrain. Digital image processing and GIS technologies therefore provide a rapid and cost-effective means of acquiring, storing and analysing the necessary information.

Mangrove mapping using optical satellite images has been attempted by James et al. (2007) in the Niger delta region of Nigeria, Saleh (2007) in Abu Minqar Island located near the coastline of the Egyptian Red Sea, Giri et al. (2007) in Bangladesh and India and Benfield et al. (2005) in Punta Mala Bay, Panama.

Medium resolution Landsat TM and ETM+ satellite images of two scenes were obtained from the ESDI interface of the GLCF website. The two scenes of the Landsat TM and ETM+ images consist of WRS-2, Path 189, Row 056 and WRS-2, Path 190, Row 56 (Table 2). While, the Landsat TM images formed the base map for this study, Landsat ETM+ was used to monitor the degree of degradation of mangroves. The images were imported into the Integrated Land and Water Information System (ILWIS) 3.31 image processing and GIS software for further image analysis.

Table 2 Description of spatial data used for mangrove vulnerability assessment

Data set	Path	Row	No. of bands used (bands combined)	Attribute/description	Date of acquisition
Landsat 7 TM	189	56	3 (5,4,2)	Ortho-rectified	21–12–1987
Landsat 7 TM	190	56	3 (5,4,2)	Ortho-rectified	15–01–1987
Landsat 7 ETM+	189	56	3 (5,4,2)	Ortho-rectified	28–01–2002
Landsat 7 ETM+	190	56	3 (5,4,2)	Ortho-rectified	13–12–1999
SRTM				DEM data	2000
Polygon maps				Crude oil facilities/rivers	2005

The images were already ortho-rectified and projected with a root mean square (RMS) error of 50 m. The two Landsat TM images were merged together and a sub-map of the study area was derived. This formed the base map for subsequent image analysis and mangrove vulnerability assessment. All other data used were resampled to the same georeference and size to allow for further analysis.

Image classification and GIS techniques

In order to determine the spatial extent of the mangroves, image classification was executed. A training set consisting of 16 and 23 sites representing the landcover types of interest were applied for the image classification of Landsat 7 TM image of 1987 and Landsat 7 ETM+ 1999/2002, respectively. The supervised Maximum Likelihood classification method was used for the analysis. To reduce classification errors, post-classification was done using elevation data from SRTM, conditional statements and secondary data such as polygon map of rivers. This was done to restrict the misclassified pixels that fell beyond the mangrove swamps. A 3 × 3 majority filter was finally applied to eliminate the “salt and pepper” appearance on the classified images.

In recent years GIS has become an invaluable information technology tool for a wide range of environmental applications, particularly for monitoring and studying the effects of humans in ecosystems that are difficult to access and analyse, such as mangrove habitats (Davis and Quinn 2004). GIS technique was applied to combine the different data obtained from diverse sources with different formats into a convenient spatial analysis and mapping framework. GIS was thus used to evaluate multidisciplinary expert values associated with establishing mangrove vulnerability. Information collected (field survey) or obtained from existing data (satellite images, vector maps, metrological etc) can be integrated for vulnerability assessments in order to determine areas affected by natural and anthropogenic changes.

The first step involved the conversion of all data into the raster format with all images having the same georeference. Nearest neighbour spherical distance method was used to extrapolate point data for average monthly minimum and maximum temperature differences. The distance formula was further used to create distance maps for the different criteria.

Spatial Multi-Criteria Analysis

Spatial decision problems usually involve a large set of feasible alternatives with multiple conflicting and incommensurate evaluation criteria (Malczewski 2006). The problem is then to identify the best (i.e. the most preferred) alternative and also determine a ranking of the alternatives when all the decision criteria are considered simultaneously (Triantaphyllou et al. 1997).

Spatial planning and decision making requires methods that make the outcome more transparent and credible. The ILWIS–Spatial Multi-Criteria Evaluation (SMCE), is one of such systems designed for planning and decision making processes and was applied in this work.

Standardisation and normalisation of criteria

An important phase in vulnerability assessment is the standardisation of input maps. The criteria for determination of mangrove vulnerability are usually measured on different scales; therefore, standardisation is necessary in order to obtain meaning estimate. Standardisation is applied to obtain comparable scales in raw datasets, to allow comparisons among criteria. It involves defining the ratings (values) of a parameter in [0, 1] using the appropriate function to create a membership degree (gradient) of mangrove vulnerability (susceptibility) map.

In order for the weight values to be combined, the process of normalisation was carried out by dividing each weight by the sum of the weights such that their total sum equals unity. The normalised weights were derived using the following Eq. 2

$$z = y_i / \sum_{i=1}^{n} y_i \tag{2}$$

Where z is the normalised weight value for the ith class, y_i is the raw weight.

Evaluation of criteria

In order to develop a method for the assessment of mangrove vulnerability, establishing the factors responsible for mangrove survival is an essential component. Creating a hierarchy is essential, and it refers to the actual process of defining the overall goal, objectives, criteria and (if present) sub-criteria (Strager 2002). Eleven different input parameters were used to model mangrove vulnerability in the study area. These parameters and their parametric effects on mangrove vulnerability were selected and rated by experts. Criteria selection was mainly based on effects of climatic change associated with mangrove survival (McLeod and Salm 2006).

Evaluating mangrove vulnerability assessment essentially involves applying the Direct or Weighted Linear Combination as displayed in Eq. 3.

$$V = \sum_{i=1}^{n} wixi \prod_{j=1}^{m} cj \tag{3}$$

where V is the vulnerability index, w_i is the weight of factors i, x_i is criterion score of factors i, n is the number of factors and c_j, is the criterion score (1 or 0) of constraints j and m is the number of constraints. In other words, Boolean images are created to represent each constraint, where the Boolean image has a value 1 for reclassified cells that satisfies the constraint and 0 otherwise.

Results and discussion

The results obtained from questionnaire survey for the ranking of sustainability criteria for mangrove vulnerability assessment shows that pollutant input ranked the highest while relative humidity was adjudged to rank the lowest. The normalised grouped median of the derived weights for the three expert groups and total median are presented in Fig. 4. Pollutant input recorded the highest value probably due to

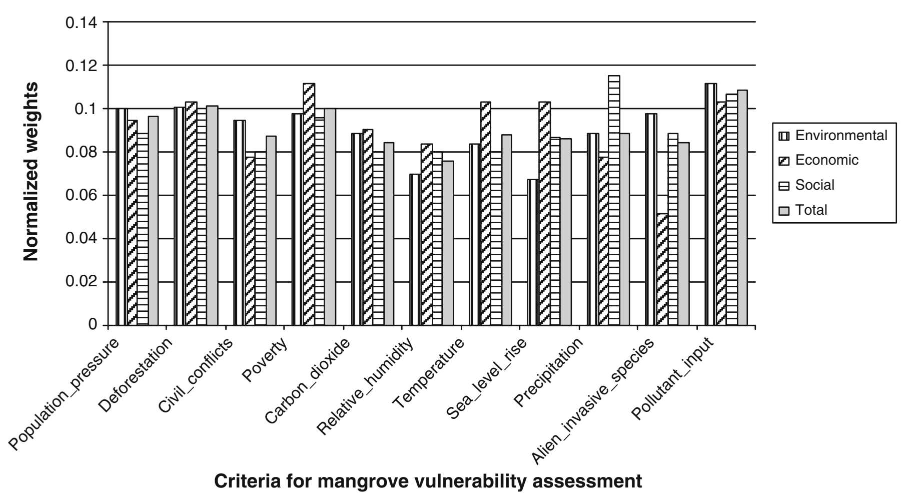

Fig. 4 Relative importance (weights) of criteria using median values for mangrove vulnerability assessment

the level of oil spills (between 1976 and 2005, 3,121,910 barrels of crude oil have spilled) that have been experienced locally (Egberongbe et al. 2006; Inoni et al. 2006).

The spatial extent of the mangrove swamp derived from post image classification of Landsat 7 image of 1987 was 23 ha. Within the study area, three major categories of vulnerability have been delineated (Fig. 5).

Category 1 is restricted to the eastern segment of the study area and is dominated by the socioeconomic factors, with high vulnerability index of 0.75 (Fig. 5a). This corresponds to areas with the highest population density which instigates deforestation predominantly for shelter, agriculture, industry and social infrastructures. Category 2 is broadly dispersed but more concentrated in the central and western margin of the study area. The vulnerability indices within the zone are equally distributed (ranging from 0.00–0.75; Fig. 5b–d). This category reflects the greater influence of local environmental factors such as pollutant input from oil wells and pipelines and minimal contribution from climatic factors. Its broad spatial distribution is reflective of the wide network of petroleum pipelines and the tidal influence of the sea that aid in the transportation of spill petroleum products inland.

Some of the criteria namely, poverty, precipitation carbon dioxide and relative humidity were excluded from the mangrove vulnerability assessment. Poverty, carbon dioxide and precipitation are found to be equally distributed and, hence, their impact in the study area. Relative humidity is dependent on atmospheric temperature.

A comparison of temporal Landsat TM of 1987 and ETM+ of 2002 revealed a decrease in mangrove population by 15% (Fig. 6). This indicates

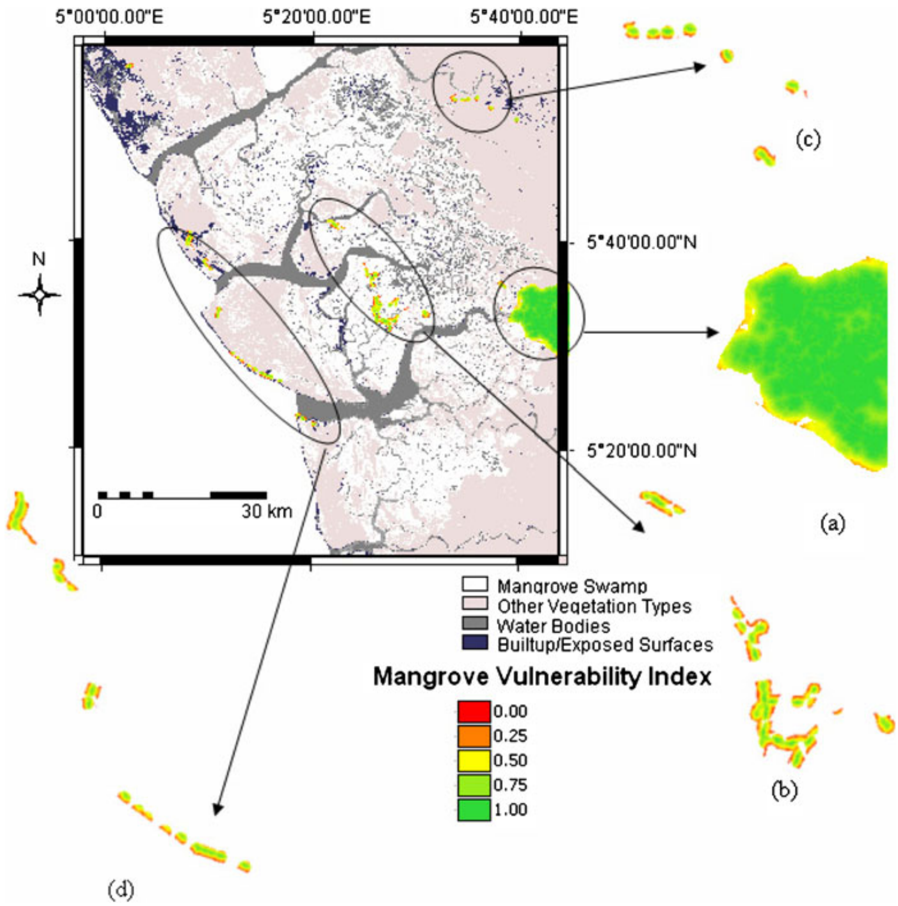

Fig. 5 Mangrove vulnerability index map of study area

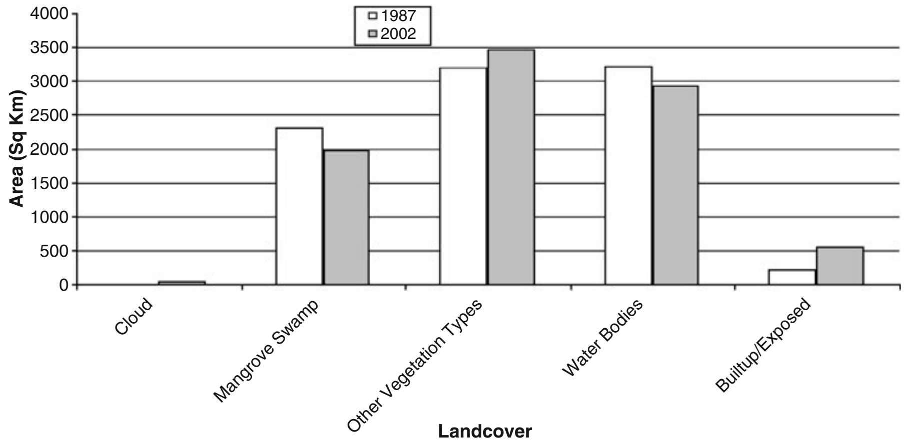

Fig. 6 Landcover change between 1987 and 2002

that the outlined factors above are actively in operation either impacting positively or negatively on the mangrove ecosystem. The intensity of impact of each of these factors must be the focus of future research work.

The model developed in this work applied SMCE and this was implemented in the ILWIS GIS platform. A case study area to test this model came from the Niger Delta region of Nigeria. This paper has revealed the importance of spatial remote sensing data and GIS tools and SMCE in mapping the spatial extent of the mangroves and also projecting the degree of degradation that could be experienced by the mangroves as a result of environmental and socioeconomic processes. The study revealed the ability of coupling expert judgment and stakeholder values in a transparent and sustainable manner. Results from such study can be incorporated into an environmental decision making framework for mangrove ecosystem planning and management. A major problem encountered in the mapping of the mangroves was the difficulty in spectrally separating the mangroves from vegetation that exhibit similar spectral reflectance such as the Nypa invasive species using Landsat data. Additional studies using medium to coarse resolution data in conjunction with RADAR should be undertaken for establishing protected areas and also to facilitate the mitigation and recovery measures of mangrove ecosystem.

This paper also highlighted the capabilities of mapping and monitoring the mangrove ecosystem which to a large extent is presently remote and inaccessible due to natural (environmental) and anthropogenic (crisis) causes

Conclusion

The environmental vulnerability assessment model developed above has provided the capability to integrate varied natural and anthropogenic data in conjunction with expert knowledge. Its application to the vulnerability of the mangrove within a portion of western Niger Delta revealed a declining mangrove population. This is also confirmed by the Landsat 7 ETM+ 2002 classified image.

This model can also be applicable to similar environments in the world such as the Amazon Basin in South America., experiencing rapid deforestation.

The available of higher resolution spatial data such IKONOS and Quickbird would enhance the use of this model and will greatly improve the accuracy of its outcome. This will in no small measure assist policy and decision makers in the better management of this fragile ecosystem.

References

Ball, M. C., Cocharane, M. J., & Rawson, H. M. (1997). Growth and water use of the mangroves *Rhizophora* *apiculata* and *R. stylosa* in response to salinity and humidity under ambient and elevated concentrations of atmospheric CO2. *Plant Cell and Environment, 20*, 1158–1166.

Benfield, S. L., Guzman, H. M., & Mair, J. M. (2005). Temporal mangrove dynamics in relation to coastal development in Pacific Panama. *Journal of Environmental Management, 76*(3), 263–276.

Burke, L. A., Kura, Y., Kassem, K., Revenga, C., Spalding, M., & McAllister, D. (2001). *Pilot analysis of global ecosystems: Coastal ecosystems*. Washington: World Resources Institute.

CEDA (1997). *Coastal profile of Nigeria*. Abuja: Federal Environmentl Protection Agency.

Davis, B. E., & Quinn, N. (2004). Using GIS in human impact analysis of mangroves. *The South Pacific Journal of Natural Science, 22*(1), 1–11.

Diop, S. (2003). Vulnerability assessments of mangroves to environmental change. *Estuarine, Coastal and Shelf Science, 58*(1), 1–2.

Egberongbe, F. O. A., Nwilo, P. C., & Badejo, O. T. (2006). Oil spill disaster monitoring along Nigerian Coastline [Electronic Version]. Available online at http://www.fig.net/pub/fig2006/papers/ts16/ts16_02_egberongbe_etal_0223.pdf. Accessed on 4 September 2007.

Ellison, J. C. (Ed.) (2000). *How South Pacific mangroves may respond to predicted climate change and sea level rise*. Dordrecht: Kluwer.

FAO (2003). *Status and trends in mangrove area extent worldwide*. Rome: Forest Resources Division, Food and Agriculture Organization of the United Nations.

Field, A. P. (2005). *Discovering statistics using SPSS: (and sex, drugs and rock 'n' roll)*. London: Sage.

Gilman, E., Van Lavieren, H., Ellison, J., Jungblut, V., Adler, E., Wilson, L., et al. (2006). *Pacific Island mangrove in a changing climate and rising sea*. Nairobi: United Nations Environment Programme.

Gilvear, D. J., & McInnes, R. J. (1994). Wetland hydrological vulnerability and the use of classification procedures: A scottish case study. *Journal of Environmental Management, 42*(4), 403–414.

Giri, C., Pengra, B., Zhu, Z., Singh, A., & Tieszen, L. L. (2007). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multitemporal satellite data from 1973 to 2000. *Estuarine, Coastal and Shelf Science, 73*(1–2), 91–100.

Hussin, Y. A., Zuhair, M. M., & Weir, M. (1999). *Monitoring mangrove forests using remote sensing and GIS*. Paper presented at the proceedings of the Asian conference on remote sensing, 22–25 November 1999, Hong Kong, China.

Ibrahim, S., & Hashim, I. (1990). Classification of mangrove forest by using 1:40 000-scale aerial photographs. *Forest Ecology and Management, 33–34*, 583–592.

Inoni, O. E., Omotor, D. G., & Adun, F. N. (2006). The effect of oil spillage on crop yield and farm income in Delta state, Nigeria. *Journal of Central European Agriculture, 7*(1), 41–48.

IPCC (2001). *Technical summary: Climate change 2001: Impacts, adaptation, and vulnerability*. A Report of Working Group II of the Intergovernmental Panel on Climate Change.

James, G. K., Adegoke, J. O., Ekechukwu, S., Nwilo, P., & Akinyede, J. (2007). Satellite-based assessment of the extent and changes in the mangrove ecosystem of the Niger Delta. *Marine Geodesy, 30*, 249–267.

Lal, P. (2003). Economic valuation of mangroves and decision-making in the Pacific. *Ocean & Coastal Management, 46*(9–10), 823–844.

Lovelock, C. E., & Ellison, J. C. (2007). Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change. In C. E. Lovelock, & J. C. Ellison (Eds.), *Climate change and the Great Barrier Reef: A vulnerability assessment*. Sydney: Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia.

MacFarlane, G. R., Koller, C. E., & Blomberg, S. P. (2007). Accumulation and partitioning of heavy metals in mangroves: A synthesis of field-based studies. *Chemosphere, 69*(9), 1454–1464.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature—Review article. *International Journal of Geographical Information Science, 20*(7), 703–726.

McLeod, E., & Salm, R. V. (2006). *Managing mangroves for resilience to climate change*. Gland: IUCN.

Ophori, D. U. (2007). A simulation of large-scale groundwater flow in the Niger Delta, Nigeria. *Environmental Geosciences, 14*(4), 181–195.

Phillips, B. (2000). *Vanuatu vulnerability assessment: An approach to integrated regional assessment*. Paper presented at the APN/SURVAS/LOICZ joint conference on coastal impacts of climate change and adaption in the Asia-Pacific Region, Kobe, Japan.

Reijers, T. J. A., Petters, S. W., & Nwajide, C. S. (Eds.) (1996). *The Niger Delta Basin*. Warri: SPDC Corporate Reprographic Services.

Renaud, F. G. (2006). Environmental components of vulnerability. In J. Birkmann (Ed.), *Measuring vulnerability to natural hazards: Towards disaster resilient societies* (pp. 117–127). Tokyo: United Nation University Press.

Rim-Rukeh, A., Ikhifa, G. O., & Okokoyo, P. A. (2007). Physico-chemical characteristics of some waters used for drinking and domestic purposes in the Niger Delta, Nigeria. *Environmental Monitoring and Assessment, 128*(1–3), 475–482.

Saleh, M. A. (2007). Assessment of mangrove vegetation on Abu Minqar Island of the Red Sea. *Journal of Arid Environments, 68*(2), 331–336.

Sokari-George, E. (1989). Planning for coastal zone management programme in Nigeria. *GeoJournal, 18*(3), 285–289.

Sonibare, O. O., & Ekweozor, C. M. (2004). Identification of bicyclic sesquiterpanes in oils from the Niger Delta, Nigeria. *Journal of Applied Sciences, 4*(3), 508–512.

Strager, M. P. (2002). *Integrating criteria preferences and spatial data to prioritize lands Virginia University for* *preservation in the Cacapon river watershed West Virginia*. Paper presented at the Final Report for the Canaan Valley Institute, Task Order NRAC 2002-09 West Virginia University Research Corporation Morgantown.

Triantaphyllou, E., Kovalerchuk, B., Mann Jr, L., & Knapp, G. M. (1997). Determining the most important criteria in maintenance decision making. *Journal of Quality in Maintenance Engineering, 3*(1), 16–28.

Waisel, Y. (1972). *Biology of halphytes*. New York: Academic.

Wells, S., Ravilous, C., & Corcoran, E. (2006). *In the front line: Shoreline protection and other ecosystem services from mangroves and coral reefs*. Cambridge: UNEP.