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Spatio-temporal assessment of mangrove cover in the Gambia using combined mangrove recognition index

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Abstract

This study is an effort to assess mangrove cover in The Gambia utilizing Landsat Data. The gradual land use and land cover variations along the coastal estuarine area of The Gambia provoked this paper to assess variation on the mangrove forest cover. The aim of this research is to do spatiotemporal monitoring and mapping to detect changes in mangrove forest cover of the Gambia from 2000 to 2020. For analyzing change, the technique of supervised classification with CMRI was applied on three multi-temporal Landsat images. Combined Mangrove Recognition Index (CMRI) approach is used in this research which is an index for distinction of mangrove forest from non-mangrove area. In this study, mangrove forest cover decline has been found to be approximately from 1811km^2 to 853km^2 in the last two decades. The main vegetation being deforested in Greater Banjul Area is mangroves. This impact has significantly increased the vulnerability of residents to flash floods after heavy rainfalls especially in towns like Serrekunda, Tallinding, Bundung, New Jeshwang and even the Capital City, Banjul. These findings can be significant for conservation authorities and research groups. The maps presented in this analysis will be a valuable guide and provide soft grounds for coastline regulatory body to formulate better sustainable development strategies for this region. Alongside, it a matter of global concern because its deforestation has not only threatened the mangrove ecosystem but also increased vulnerability of the nearby communities and fish breeding grounds. The results of the study will help environmental protection agency, agriculture and forest departments to design location specific strategies to reduce mangrove cover degradation.

1. Introduction

Globally, mangroves are distributed in more than one hundred countries, but in the past four decades, mangrove forests have suffered an intense decline [1]. Mangroves offer a wide range of functions and advantages to humans and wildlife; therefore, their loss is significant [2]. Woody plants known as mangroves are found in tropical and subtropical areas and once covered an area of around 18.8 million hectares [3]. However, deforestation has caused mangroves to shrink to 13.7 million hectares and later to 8.3 million hectares [4-5]. The mangrove ecology is in danger due to this alarmingly quick decline. Additionally, it is a cause for concern on a worldwide scale because deforestation has increased the vulnerability of the local communities and fish spawning grounds in addition to endangering the mangrove environment.

Following a mapping of the current extent of mangrove vegetation cover in South Asia from 2000 to 2012, the mangrove forest shift was noted [6]. In total, 1,187,476 ha of mangroves have been lost, which is equivalent to 7% of the world's total [7]. Conversion to other land uses, pollution, overharvesting, flooding, a decrease in the availability of freshwater, coastal erosion, a decrease in silt deposition, and disturbances from tropical cyclones and tsunamis are the main causes of deforestation in South Asia [8].

At a global level, loss of mangrove vegetation cover according to Hamilton et al. [9] was mainly due to population growth and coastal development. Jayakumar, [10] opined those specific factors to mangrove vegetation cover loss includes urbanization, aquaculture, conversion to agricultural activities such as rice cultivation, and vegetable gardening, road construction, and overexploitation for timber and fuel wood. Mangroves are highly protective ecosystem that provides numerous functions and services including food, spawning ground and refuge for numerous faunas, and a sink for contaminants, a trap for fine sediments, coastal sediments, coastal protection, and carbon sequestration [11].

The mangroves are widely distributed throughout the tropical world, making it challenging, time-consuming, and perhaps impossible to monitor these ecosystems through ground surveys. As a result, many remote sensing technologies and satellite imagery have been employed [12]. The MCL (maximum land cover) with NDVI approach was used to detect changes in mangrove density in Matang Forest, Malaysia. The findings suggest that the mangrove forest cover has decreased by roughly 8017.3 hectares. The causes of this loss were discovered to include erosion, tree harvesting, and illicit agricultural activities [13]. Using remote sensing technology and Landsat data, the extent and density of mangroves in Pongok, Indonesia, were mapped. In that study, Path/Row: 123/062 Landsat data that were collected on July 24th, 2019, were used. The density of mangroves was determined by utilising the NDVI formula, which uses a vegetation index approach and has a range of values from -1 to 1. The findings show that mangrove density can be divided into three classes: dense (NDVI range: 0.42-1; equal to 1,500 Trees/Ha), sparse (NDVI range: -1- 0.33; equal to 1,000 Trees/Ha), and moderate (NDVI range: 0.33-0.42; equal to 1,000 to 1,500 Trees/Ha) (Sabai, 2019). Supervised classification and Vegetation indexing approach has the potential to quantify mangrove extent and density within the area in temporal and spatial scale [14].

Mangrove control on the coast is essentially what the Indus Delta's coastal zone management is all about. Mangrove forests once covered the deltaic region entirely, having an indirect or direct impact on its fauna and vegetation [15-16]. The 600,000 acres of mangroves over a coastline of around 240 km were listed as the fifth or sixth largest arid climate mangroves. Their growth is rapid on islands and in the creeks, however mangroves are vanishing speedily due to extreme meddling of the environment, and overexploitation by man [17].

Several consultancy projects on mangroves occurred in The Gambia such as National Environment Agency's (NEA) assessment of mangrove dieback (NEA, 2014), and West African Bird Study Association's (WABSA) survey on mangrove restoration and identification of the different species of mangroves in The Gambia [18]. The extensive scientific study on mangrove vegetation in The Gambia was conducted on Tambi Wetland Forest. The research revealed that two main types of mangroves exist in the wetland, Avicenna germananes and rhizophora mangle [19]. Like in many parts of the globe, anthropogenic activities such as fishing, oyster collection, farming, tourism, and wood collection are reported as the major causes of mangrove forest depletion in The Gambia. In contrast to the late 1980s loss in mangrove cover, which was attributed to the 1960–1974 Sahelian droughts, Fent et al. [20] reported that mangrove vegetation cover had grown recently. The apparent decrease in mangrove vegetation cover may be the result of an imbalance between local resource demands and the ecosystem's ability to meet those demands. Mangroves must not only be maintained but also reforested in order to reap the many ecological benefits they provide in order to meet the Sustainable Development Goals (SDGs), particularly Goal 15 (Life on Land). It places a focus on managing forests sustainably, stopping deforestation, reversing land degradation, and preserving biodiversity. The wetlands in The Gambia, where mangroves are found has approximately 108 mammal species and over 540 bird species of which a third is palearctic migrants. The loss of these habitats will result in endangering this biodiversity. SDG 13 (Climate Action) is generally believed to be a hinderance to the achievement of the agenda 2030 due to increasing levels of global temperatures and its consequent effects on both living and non-living systems. SDG 13 emphasizes on an urgent action to combat climate change and its impacts. Achieving all other SDGs will be much more challenging without urgent climate action, including those related to poverty, hunger, access to water, terrestrial and marine ecosystems, health, gender equality and the empowerment of women and girls, among others. Floods, the most frequent hazard in The Gambia, can be decreased and habitats protected by the presence of mangroves. Floods are projected to increase in the coming years due to consequences of climate change, such as sea level rise [21]. REDD+ (Reducing Emission from Deforestation and Forest Degradation), which is based on Article 5 of the Paris Agreement, is really encouraged by SDG 15 [22] for countries to implement.

Monitoring and charting the amount of the mangrove cover is therefore essential for both restoration and gaining a thorough understanding of the mangrove ecosystem. The goal of this study is to do spatiotemporal monitoring and mapping in order to find changes in The Gambia's mangrove forest cover between 2000 and 2020. This study uses geospatial approaches to conduct exploratory research on the change analysis of mangrove cover. The main objectives of this paper are to determine the spatial extent of mangrove vegetation cover changes; compare these changes in the spatial extent of mangroves cover and evaluate the causes of these changes within the two decades.

2. Study Area

The Gambia is located on the extreme west coast of Africa and extended from 13˚N to14˚N latitude and 13º to 17º West longitude. It has a total area of 11,295 km^2. The country has about 80 km coastline on the Atlantic Ocean. River Gambia is the main physical feature in the study area. It divides the country into north and south banks. The Gambia has a tropical climate with distinct dry and wet season. In the dry season, the temperatures are cool and dry varying from 70˚F(21˚C) to 80˚F (27˚C) and a relative humidity of 30% and 60%. The wet season starts in summer from June and October. Annual rainfall is between 800mm and 1000mm [23].

From the coast to about 250 km inland, the ocean salt water intrudes. It is on these banks where majority of the mangroves are found. Being halophytic, mangroves are found in the brackish waters along the banks and tributaries of the river, and the intertidal estuarine areas of the coast. Up to about 200 km inland, there is a continuous stretch of mangrove vegetation. Of the eight species of mangroves in Africa, seven are all found in The Gambia. The Gambia has three Ramsar sites comprised of mangroves: Bao Bolong Wetland Reserve, Tambi Wetland Complex, and Niumi National Park. The geographic location of the country and the presence of wetland systems support the diverse ecosystems for the several species of plants and animals [21].

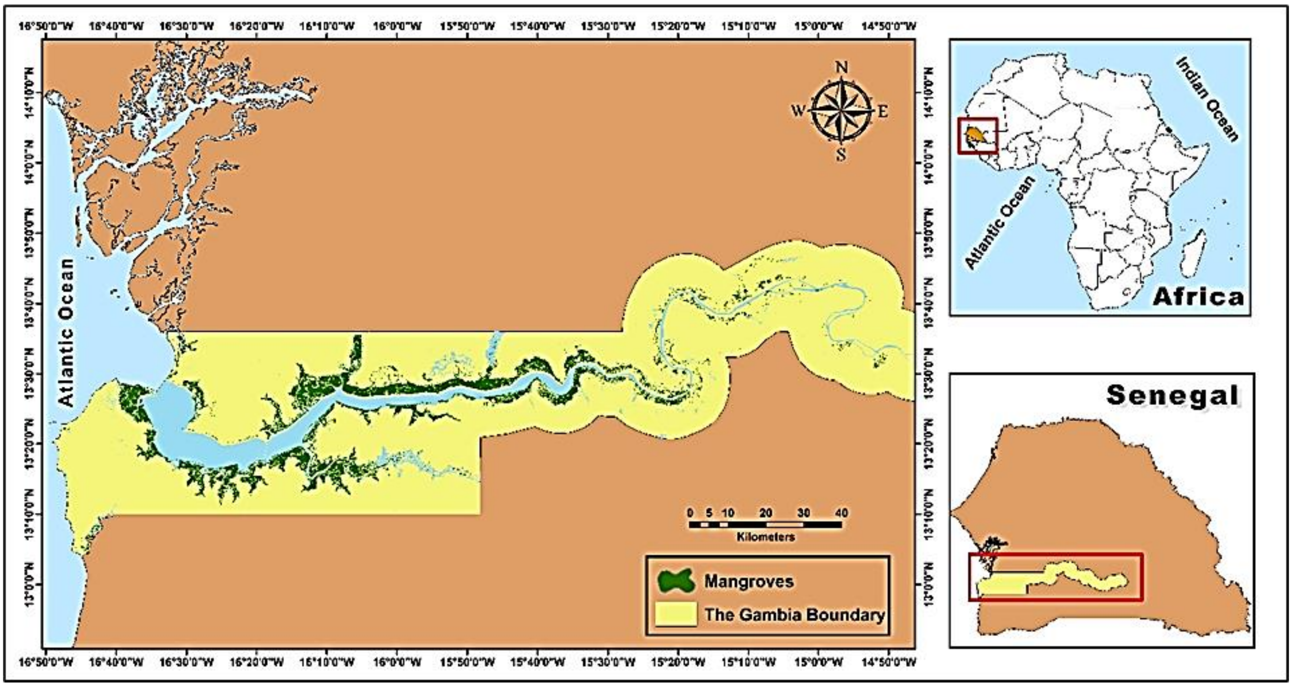

Figure 1. Representation of mangrove forest area in The Gambia

3. Material and Methods

The ideas behind change detection analysis are not new, but with the development of new imaging sensors and geospatial technologies, there is now a demand for image processing methods that can combine data from a range of sensors and datasets in order to map, detect, and monitor forest resources. The overall objective of this study was to map out and analyze the structural changes of mangrove forest cover using Landsat imageries of the study area. A supervised classification and CMRI index approach was performed on three multi-temporal satellite images.

3.1. Data Acquisition

Multispectral satellite images of the past twenty years (2000-2020) were downloaded for 2000, 2010 and 2020 with temporal resolution of 10 years from United States Geological Survey (USGS) [24] to geo-visualize mangrove cover changes in The Gambia. Specifications of the satellite data are given in Table 1.

Table 1. Characteristics of Acquired Satellite Images

Satellite Data	Year of acquisition	Number of Bands	Spatial Resolution	Month
L7 ETM+	2000	8		
L7 ETM+	2010	8	30m	October
L8 OLI/TIRS	2020	11		

3.2. Image Pre-processing

Satellite image pre-processing before change detection phenomenon is very important. The satellite data will be imported into ERDAS imagine software for stacking, mosaicking, extraction of AOI and for geometric correction.

3.3. Data Analysis and Techniques

Geographic Information System (GIS) techniques such as Supervised Classification and Combined Mangrove Recognition Index (CMRI) were performed to analyze changes in mangrove forest cover in the past 20 years.

3.4. Supervised Classification

The maximum likelihood algorithm was used to perform supervised classification on the images. It is a sort of image classification where the analyst itself controls the majority of the process by choosing the pixels that best represent the targeted classes. As images were spectrally strong and with ground truth information it was easy to do visual interpretation of all categorized classes. Targeted object texture, tone, color made it more precise to determine required classes like Agriculture cover represents less thickness as compared to mangrove cover. Also, field survey and indigenous knowledge of study area help analyst to select samples more accurately. Built-up Area, Agriculture, Mangrove Cover, Water Body, Dry Fields, and Barren Land were the categories that were defined. Each class was given a distinct identity and given a specific color to help them stand out from one another. Training samples were chosen for each of the preset land cover/use types. The pixels contained by these polygons were used to record the spectral signatures for the various land cover types that were obtained from the satellite data.

3.5. Combined Mangrove Recognition Index

The Combined Mangrove Recognition Index (CMRI) incorporates three bands (Red Band, Green Band, and Near Infra-Red Band) for evaluating solely the mangrove forest cover utilizing information like greenness and water content (succulence).

MRI (Mangrove Recognition Index) was applied in Beilunhekou (National Nature Reserve Area of China) for differentiating mangrove vegetation cover from non-mangrove cover area. Changes are observed in spectral values during conditions like both high and low tides, that's why this index used green and wet values of satellite images. The need for an index that is not dependent on such variables arises from the fact that factors like tides, salinity, and the variety of nearby vegetation cover vary globally. In compared to other vegetation indexes, CMRI index offers much improved results because it is primarily utilized to identify mangrove forest cover. In our study, mangrove vegetation cover was identified using CMRI. The formula of Combined Mangrove Recognition Index is shown in Equation 1.

$$\textbf{CMRI} = [(NIR-RED) / (NIR+RED)] - [(GREEN-NIR) / (GREEN+NIR)] \tag{1}$$

3.6. Accuracy assessment

Accuracy assessment is an important step for the validation of image classification process. In this research, accuracy of user, producer, and O A (overall accuracy) was done through Equation 2.

$$OA = \frac{Correctly\ classified\ no.of\ sampling\ classes}{No.of\ reference\ sampling\ classes} \tag{2}$$

Precision of classified image or validity with reference information is measured by kappa (K) values. Numerical statement of kappa (K) is stated in Equation 3.

$$K = \frac{Observed\ Accuracy - Chance\ Assessment}{1 - Chance\ Agreement} \tag{3}$$

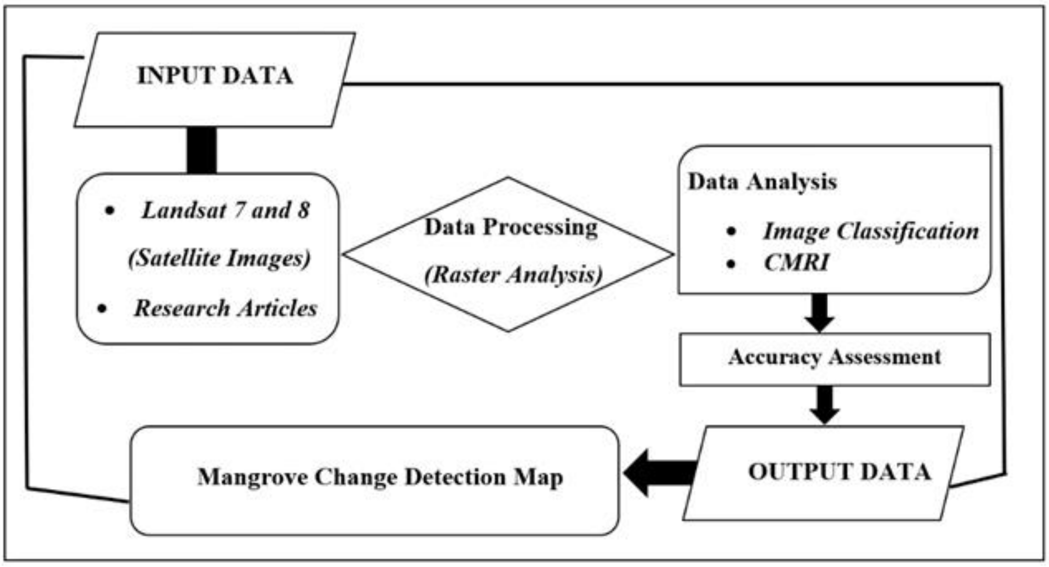

Figure 2. Research Methodology

4. Results and Discussion

4.1. Image Classification

The analysis of mangrove cover change done using supervised classification and CMRI techniques on satellite images from 2000 to 2020. In green cover most of the area is covered by mangrove and significant decline has been observed in the past two decades.

4.2. Spatial Analysis of Mangrove Cover Change

The mangrove vegetation occupied roughly 1181 square kilometers (16 %) of the total land area in 2000. 1381kilometer squares (or 12 %) was made up of agricultural land, whereas 1.4 % was occupied by built-up areas. There were more dry fields and barren ground than anything else, making up 35% and 27% of the total area, respectively. A total of 571 km^2 of built-up land can be seen in the 2010 image (5 %). In 2010, there was 4.2 % agricultural land, down from 12 % in 2000. This decrease is reflected in both built-up and bare land, which increased from 4036 (36%) in 2000 to 6567 (58%) in 2010. Mangrove cover, however, saw a reduction in forestry from 16 to 13 %. According to an analysis of 2020 imagery, the area covered by barren land is 33 %, the greatest percentage among the other classes, including dry fields (8 %), built-up areas (15 %), and mangrove cover (7 %).

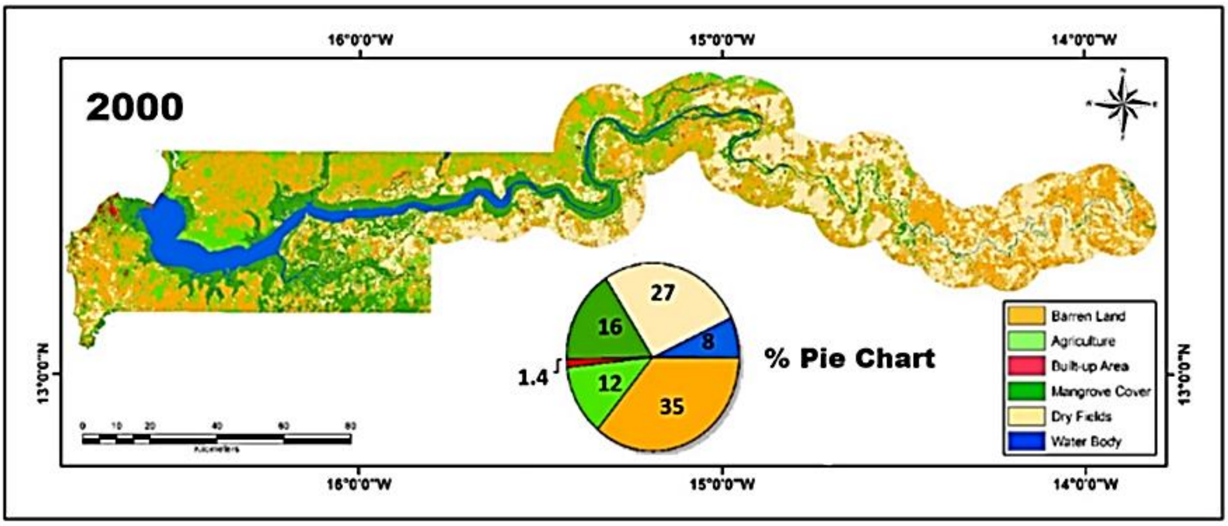

Figure 3. Classification of 2000

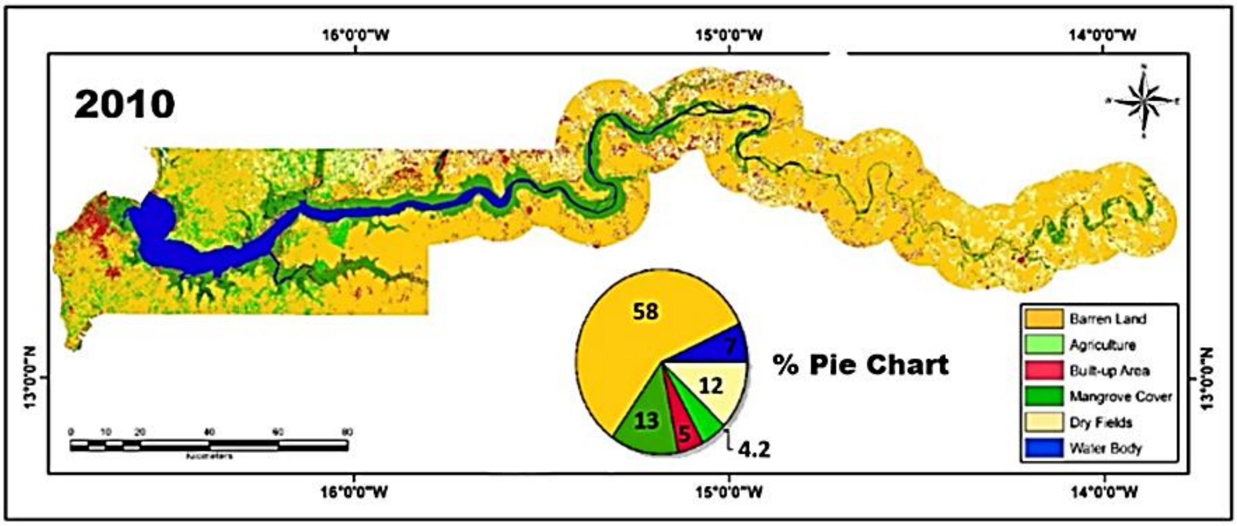

Figure 4. Classification of 2010

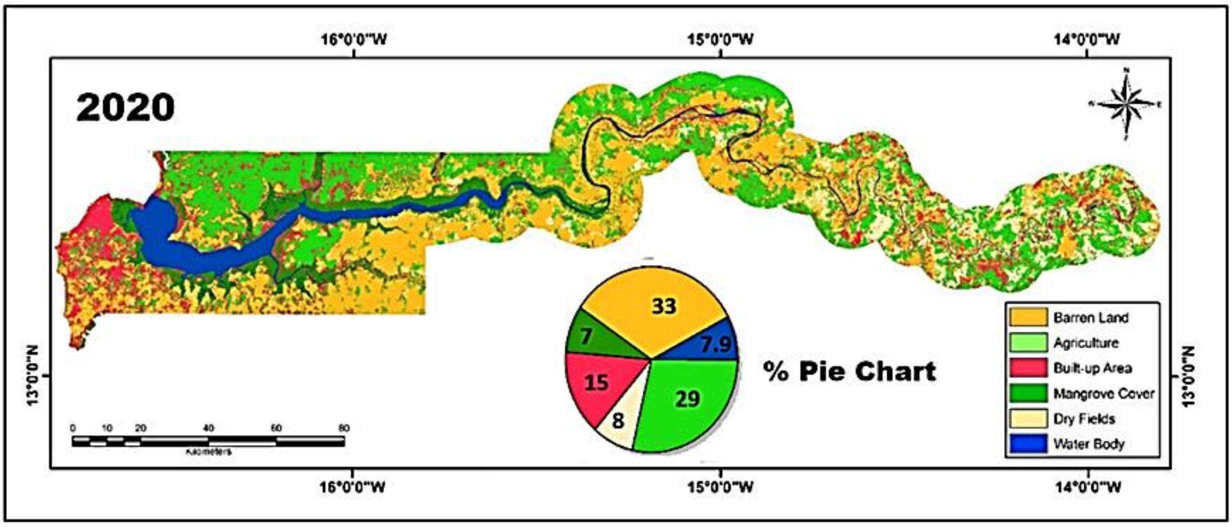

Figure 5. Classification of 2020

4.3. Combined Mangrove Recognition Index Changes

The extent of the mangrove cover pattern may be readily detected from the images analysis carried out utilizing CMRI technology. On the banks of the river Gambia and its tributaries, the mangrove cover is depicted as a dark green color. Compared to the 2000 image, the 2020 photographs revealed a considerable reduction in mangrove cover (853 km^2) (1811 km^2). This explains a decrease of mangrove vegetation cover of 958 km^2 (more than 100%) during a period of 20 years. Between 2000 and 2020, there was a rising trajectory in the built-up area. The expansion of the built-up area clearly has a deleterious impact on both the mangrove cover and other land uses. Due to a variety of circumstances, including the temperature, closeness to the sea, concentrated government facilities and services, private enterprises, urbanization, and others, this is particularly pronounced in the western region of the country. The accompanying figure clearly highlights variations in mangrove forest cover and displays the spatiotemporal scope of the mangrove cover pattern.

In 2020, the built-up area and agricultural land areas are seen to grow the most. The degradation of mangroves is mostly brought about by these two anthropogenic factors. On New Jeshwang, Tallinding, and Faji Kunda, one can see vegetable and rice farms being grown. The construction and expansion of the West Field-Banjul Highway has caused the degeneration of the mangrove cover along this area and further attracted the construction of buildings along the highway.

Mangroves across the entire country were the subject of this study. Hence detailed matters such as major deforested areas may not be highlighted. An area-specific study and field observations can help one gain a better knowledge of the situation by revealing the facts on the ground and helping to pinpoint areas where the mangrove vegetation cover is increasing or decreasing.

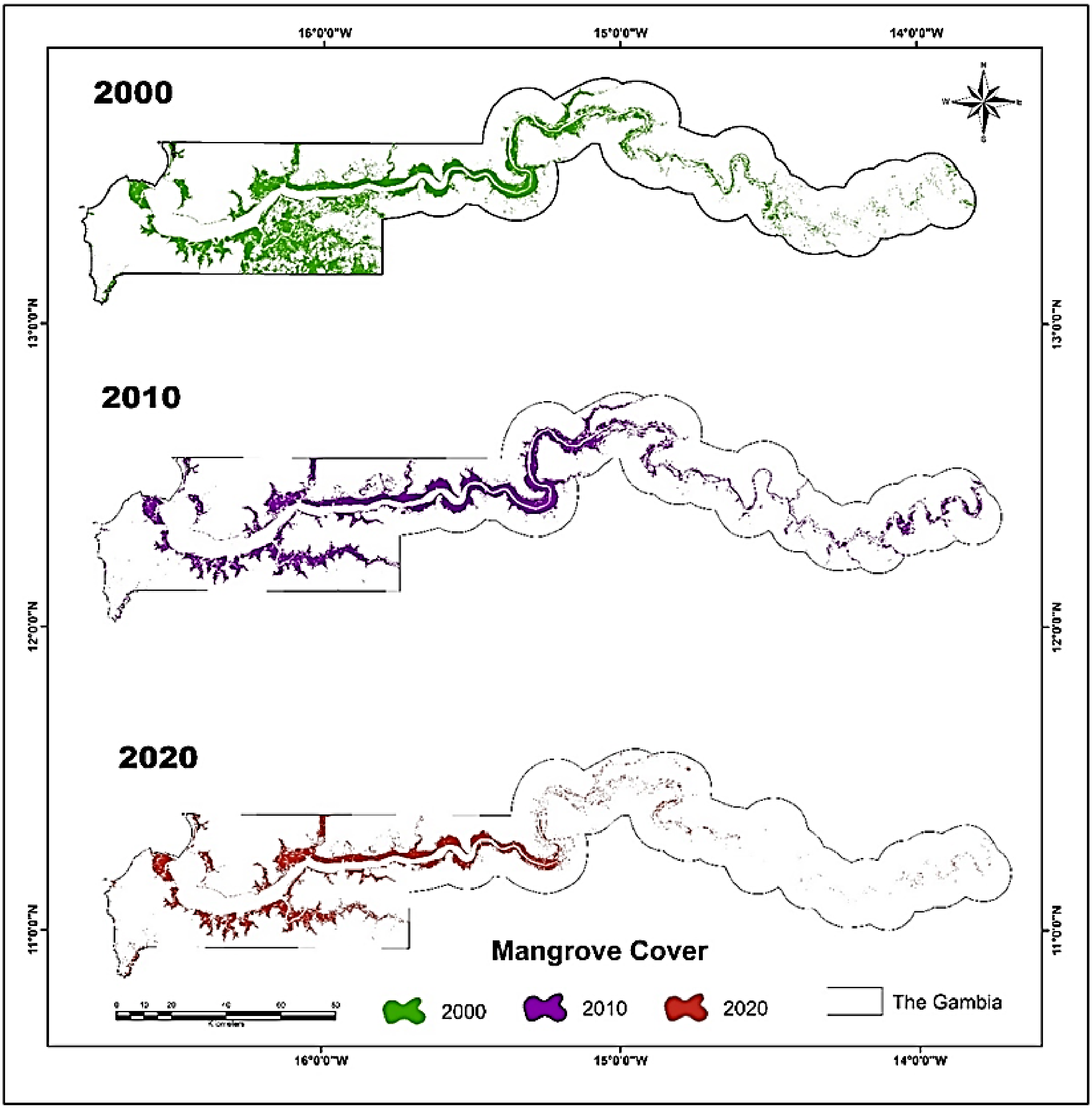

Figure 6. Change Detection of Mangrove Cover

4.4. Temporal Analysis of Mangrove Cover Change

Figure 5. presents abrupt change in built-up area which is 1664 km2 from 159 km^2 area and barren land is approximately decreased from 4036 km^2 to 3688 km^2 in 20 years. In this research, mangrove forest cover decline has been found to be approximately from 1811 km2 to 853 km^2 between 2000 and 2020 as shown in Table 2.

Table 2. Area Statistics of the land use land cover units from 2000 to 2020 of The Gambia

Categories	2000		2010		2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Built up Area	159	1.4	571	5	1664	15
Mangrove Cover	1811	16	1418	13	853	7
Barren Land	4036	36	6567	58	3688	33
Dry Fields	3042	27	1396	12	928	8
Agriculture	1381	12	479	4.2	3258	29
Water body	763	7	762	7	803	8

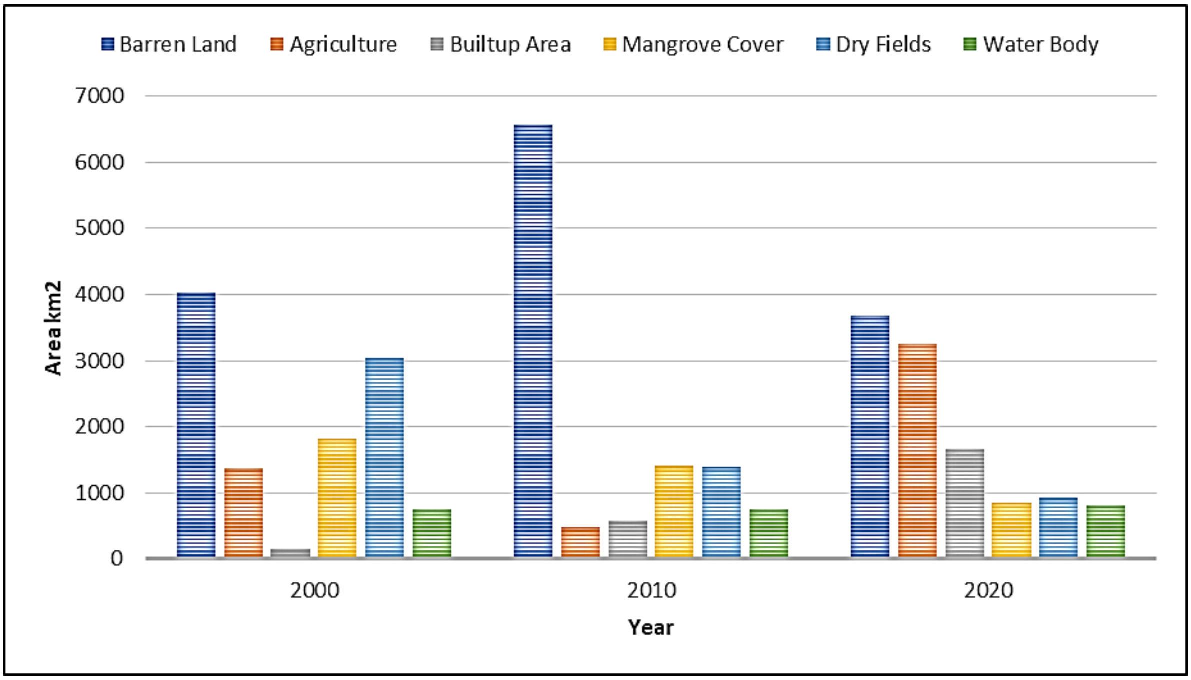

Figure 7. Temporal Analysis of Mangrove Cover Change

4.5. Accuracy assessment

K (kappa) values along with user's and producer's accuracy of delineated classes for the years 2000, 2010 and 2020 are shown in Table 3.

Table 3. Summation of producer's and user's accuracy and kappa (K) coefficients

Classes	Producer's Accuracy (%)							User's Accuracy (%)							Overall Accuracy	K
	1	2	3	4	5	6	Avg.	1	2	3	4	5	6	Avg.		
2000	89	86.7	84.6	80.2	83.1	80.4	88.1	87.8	88	86	86.7	83.6	86.4	88.5	0.83	0.80
2010	90.4	91.3	87	89.1	84	83	89.5	89.8	90	83.7	84.2	86.2	84.7	89.9	0.88	0.85
2020	87.7	95.5	88.2	87.4	86	87	87.4	84.7	82.5	84.7	85.5	86.8	85.8	87.6	0.86	0.82

The map makers (producer) accuracy is the accurateness of the map while the accuracy of users is the accuracy from the perspective of map user not mapmaker. The two accuracies in our data were within a reasonable extent, indicating less mistakes in findings.

4.6. Mangrove Deforestation and Challenges

Mangrove deforestation has global significance because very few mangrove ecosystems are surviving and fighting anthropogenic actions. There are numerous environmental problems and a depletion of natural resources in The Gambia. Extreme forest degradation and soil degradation are the two main problems. According to reports, the percentage of mangrove forests has decreased from 16 to 7%. Without a doubt, this loss will make areas more susceptible to hydrometeorological hazards.

The Gambia is divided into two different Representative Territorial Units (RTUs). In contrast to the North Bank Region, which is rural and dependent on subsistence agriculture, the Greater Banjul Area is located in the western coastal regions and is more developed and urbanized.

The North Bank RTU is mainly affected by deforestation and soil erosion. Being an agrarian region, these hazards have a negative consequence on food security and livelihood activities. The Greater Banjul Area is confronted mainly by coastal erosion, flood, and deforestation. Deforestation is more severe in The Kanifing Municipality as commercial and industrial activities and urbanization have increase demand for land. Coastal erosion is another major environmental hazard in GBA. In some areas, the beach is retreating at a rate of 1-2 meters annually. Sectors such as tourism (second major contributor to the economy of The Gambia), artisanal fisheries and other livelihoods will be affected due to sea level rise and other hydrometeorological events.

The main vegetation being deforested in Greater Banjul Area is mangroves. This impact has significantly increased the vulnerability of residents to flash floods after heavy rainfalls especially in towns like Serrekunda, Tallinding, Bundung, New Jeshwang and even the Capital City, Banjul. Over 35,000 people, 2,371 houses and unaccounted food and cash crops were damaged by flash floods in 2010 rainy season alone.

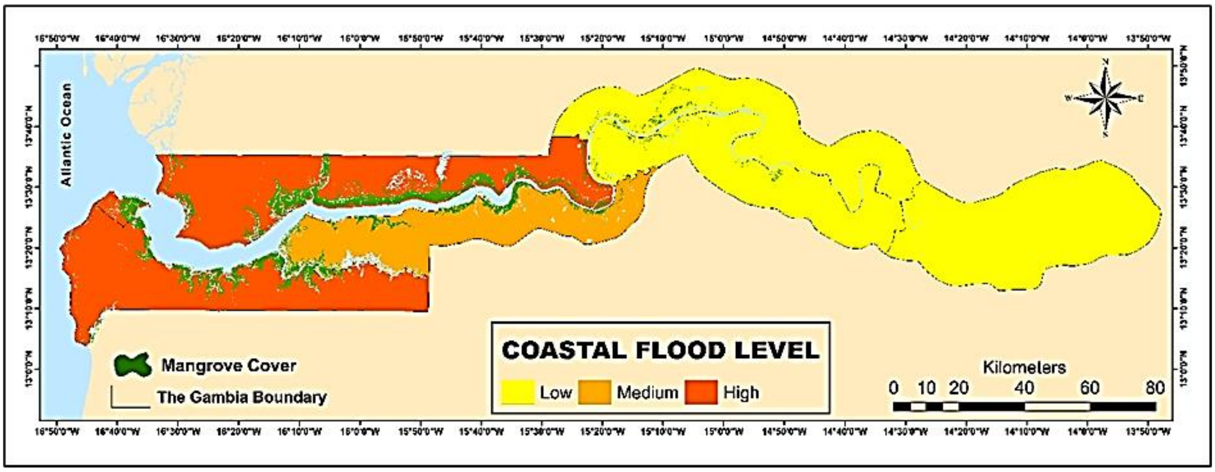

Figure 8. Zonation of Coastal flood-Hazard Level (Source: Mapbox)

Mangroves have both environmental and societal impacts. The effectiveness of mangroves in hydrometeorological risk reduction has been well documented in coastal setting where they exist. Mangrove belts are effective in attenuating storm surges during cyclones (typhoons/ hurricanes) hence, protecting lives and properties. For example, the 2004 Indian Ocean tsunami, hamlets in the Indian Tamil Nadu region did not lose a single life attributed mainly to the impact of mangroves. Another impact is that mangroves have the potentials to reduce flood extent in low-lying areas as it serves as a buffer between marine and terrestrial ecosystems. Mangrove roots bind the soil, reducing erosion and carbon storage. This accretion acts as a carbon sink and helps to reduce coastal erosion. Deforestation reduces the potential of mangroves in these environmental impacts. Mangroves have the potential to increase community resilience to hydrometeorological impacts [25].

Socially, as highlighted in previous chapters mangrove forests serve as a good source of livelihood to locals in the forms of fishing, crap, oyster and wood collection, herb, medicinal purposes and recreation functions. The absence of mangroves will severely affect these livelihood services.

Due to the Greater Banjul and North Bank regions' vulnerability to climate-related dangers, mangrove belt restoration and afforestation are essential. In some places of the world, increasing mangrove forest cover has been accomplished through public awareness campaigns, replanting, reforestation, and even legal action. This would lessen The Gambia's vulnerability to climate-related disasters and enhance its ability to adapt.

The United Nation Environment Program (UNEP) office Banjul has launched “Gambia Ecosystem-based Adaptation 2017-2023” in line with SDG 15 (Life on Land) where it targets the rehabilitation of 10,400 ha of degraded forest, savanna and mangroves and an additional 3000 ha of farmland. According to UNEP (nd), it has already planted 10million mangrove propagules within the first 2 years. These mangroves are expected to serve as a buffer against storm surges to protect coastal settlements and also provide habitat for many fish species. In line with SDG 1 (No Poverty), the project also targets increasing the income of 11,550 household through horticulture and vegetable gardening. This will reduce the overdependence of inhabitants on the forest on which they get fuelwood and wood for income generation. The significant function of mangroves in carbon sequestration, preventing soil erosion, controlling the effects of sea level rise can be very instrumental in attaining SDG 13 (Climate Action). As argued by [23] that the need to participate in the production of knowledge in order to achieve Goal 15 of the Sustainable Development Goals on the preservation and restoration of terrestrial ecosystems, monitoring of changes in vegetation cover is necessary.

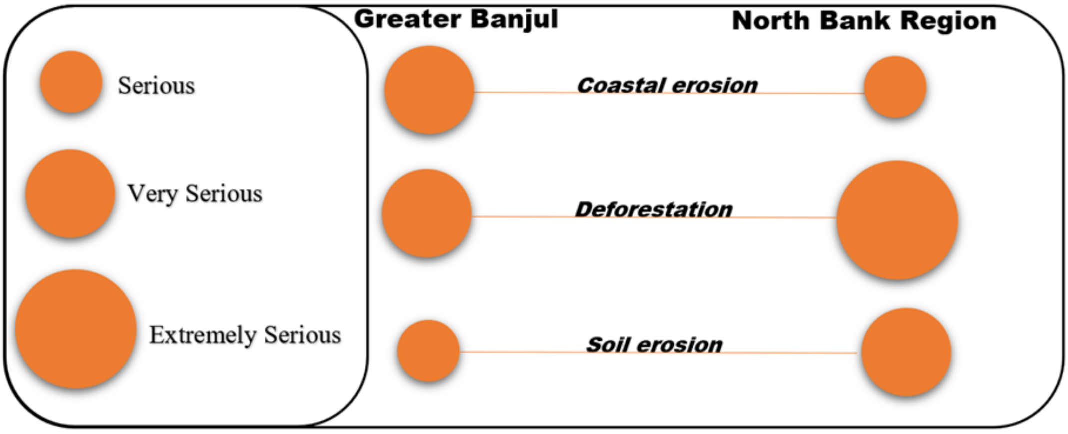

Figure 9. Challenges in Greater Banjul Area and North Bank Region (Source: DARA)

5. Conclusion

Mangrove forest are decreasing due to rapid deforestation. The main causes of these are attributed to both anthropogenic factors such as urbanization and agriculture/aquaculture activities, wood collection, etc. and natural factors such as cyclones, rising sea levels, and climate changes impacts. In The Gambia, the main cause of mangrove degradation is attributed to anthropogenic activities mainly farming, oyster collection, wood collection, urbanization, and damming of distributaries which prevent water reaching some areas. Natural factors such as drought and increasing salinity are the main causes of mangroves dieback.

The importance of mangroves in both coastal protection and ecological services cannot be over emphasized. This research found that, The Gambia has experienced a significant decrease of mangrove cover within two decades. Therefore, there is a need to curb the deforestation trend to benefit from mangrove vegetation functions. Tambi Wetland Reserve and areas along the Bintang Creek need more protection and restoration activities respectively. Mangroves in the Tambi Wetland Reserve are exposed to urban expansion effects while those along the Bintang Creek suffer from local wood collection and dieback due to climate change impact. Mangrove forests should be protected through public awareness campaigns and, where possible, through litigation. Indeed, for sustainable management, mangrove vegetation healthiness and cover should be constantly monitored, not only to maintain existing ones but also to increase the area covered by mangroves.

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Author contributions

Bambo Bayo: Conceptualization, Analysis, Geo-visualization **Warda Habib: Analysis:** Preparation of manuscript. **Shakeel Mahmood:** Methodology, writing, reviewing and editing.

Conflicts of interest

The authors declare no conflicts of interest.

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