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Change detection analysis of mangrove ecosystems in the Mesurado Wetland, Montserrado County, Liberia

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ABSTRACT

Worldwide, there has been a drastic decline in mangrove ecosystems; hence, there is a need for information on the spatiotemporal characteristics of mangrove ecosystems to inform sustainability efforts. This study sought to provide information to bridge the knowledge gaps on spatiotemporal mangrove distribution in the Mesurado Wetland by analyzing three distinct years (1986, 1998 and 2020). Landsat 8 and Landsat 5 for supervised classification to classify mangrove forest cover within the region of interest (ROIs) were employed to achieve the study goal. The classification done on the three distinct years had an accuracy of 84.83, 93.27, and 92.01% and kappa coefficient of 0.80, 0.92, and 0.88, respectively. The analysis indicated a continuous decline in the mangrove forest cover overall for the thirty-four years (1986-2020) studied-a loss of 10.83% (1986 and 1998) and 24.73% (1998 and 2020); however, most of the decline was experienced from patches within other zones surrounding the Mesurado wetland. Consequently, a total mangrove forest loss amounting to 32.88% at an extrapolated decline rate of 0.96% yr^{-1} was recorded for the study period (1986-2020). Three of the ten zones, including Central Monrovia, Clara Town, and Old road losing 100% of the mangrove patches between 1986 and 2020, with the rest still experiencing a continuous decline. This study's findings can be used as the basis for policy development, sustainability planning, and restoration activities for the mangrove forest cover in the county.

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INTRODUCTION

Mangroves ecosystems are among the most productive ecosystems on earth and occur in the intertidal zone (Naidoo, 2009) of tropical and subtropical coastal rivers, estuaries and bays of the world (Zhou et al., 2010) where they may receive organic materials from estuarine or oceanic ecosystems (Ellison, 2000). This ecosystem has received increasing attention from not only coastal and land managers but also academia and conservation communities (Li et al., 2013; Fickert, 2018) due to its essential ecological and societal functions (Wang et al., 2004; Giri and Muhlhausen, 2008), such as providing food and breeding areas as well as nursing grounds for many faunas, reducing pollution, precipitating fine sediments, protecting coastlines, and storing carbon, among other functions (Aheto et al., 2016; Blankespoor et al., 2017; Dahdouh-Guebas et al., 2005; Granek and Ruttenberg, 2008).

Mangroves cover up to 75% of the world's tropical

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coastlines with an estimated coverage of 180,000 km², distributed in 112 countries and territories in the tropics (Vaiphasa et al., 2006; Aheto et al., 2011). Africa contains extraordinary vast and rich mangrove assemblages among the diversity of coastal habitats, including sandy beaches, coastal dunes, coral reefs, estuaries, bays, seagrass, and meadows (Hoguane, 2007). Within this region, 17 mangrove species are recorded with eight species uniquely in West and Central Africa, while nine species are unique to the Eastern African Coasts. Mangroves have undergone rapid spatiotemporal variation worldwide, especially in developing areas (Giri and Muhlhausen, 2008). The integrity of this ecosystem has changed at an alarming rate due to natural and anthropogenic influences (for example, extreme weather events, relative sea-level rise, absence of appropriate legislation, deforestation for fish smoking, the proliferation of invasive species, installation of shrimp and fish ponds, agro-industrial chemicals, petroleum, and gas exploitation). Studies (Ajonina and Usongo, 2001; Ajonina et al., 2014; Donato et al., 2011) have reported that the global area of mangrove forests has declined by 30–50% with about over 20–30% recorded for West and Central Africa over the past half-century.

Like other parts of the world, the greatest threat to mangrove ecosystems in the Mesurado Wetland is land degradation due to urbanization, infrastructure development, and other intense anthropogenic activities (FAO, 2007). Overuse and overexploitation of natural resources practices such as of hunting, firewood collection, charcoal production, and timber extraction, pollution of the water, air, and soil from chemicals released from agricultural pursuits, oil exploration, mining, and the effects of climate change also contribute to the loss of mangroves in this wetland. The species richness and ecological function of mangroves have been significantly degraded. Therefore, monitoring the spatiotemporal characteristics and discovering the driving forces that may cause changes in the mangrove distribution have become attractive to many researchers. They are of considerable significance to ecological conservation.

This study seeks to explore mangroves distribution over the past thirty-four years, from 1986 to 2020, and to discover the spatiotemporal variation pattern of mangrove distribution in Montserrado county. It attempts to provide referable information to aid in coastal management and mangrove protection. Findings from this study can serve useful for environmental managers and agencies and other stakeholders wishing to initiate effective and sustainable management on Liberian mangroves in the future.

MATERIALS AND METHODS

Study area

The Mesurado Wetland is geographically located in Montserrado county, one of the fifteen counties in Liberia. Demographically, the county is the smallest in the country, yet has approximately 33% of Liberia's total population. The county's population density is estimated to be 599.7 inhabitants per square kilometer, which makes it the highest in Liberia. The mangrove forest cover is surrounded by ten zonal administrative boundaries including Central Monrovia, Clara town, Congo Town, Gardnersville, Lakpazee, Logan town, New Georgia, Paynesville Old road and Sinkor (Figure 1), which are however highly urbanized constituting intense anthropogenic activities including industrial and commercial operations.

The Mesurado Wetland is one of the five Ramsar sites that was commissioned in Liberia and included under the Ramsar management network in 2006. The dense mangrove forest cover is located between latitudes 06°19´ and 06°16´N and longitudes 10°48´ and 10°42´W with major component falling within the Mesurado Wetland, and few patches extending about 6 km north inland. The mangrove wetland can be described as a flat plain constituting a polymorphous shape stretching east towards Paynesville. It provides a favorable habitat and feeding ground for several species of birds, including the African *spoonbill* Platalea *alba,* Common Pratincole Glareola *nuchaltis*, and Curlew Numenius *arquata*.

It also hosts the vulnerable African dwarf crocodile, the Nile crocodile, and the African sharp-nosed crocodile and plays a vital role in shoreline stabilization and sediment trapping.

Data collection

The process and analysis of the classification of non-mangrove and mangrove land cover were implemented with 3 Landsat satellite images, consisting of Landsat 8 OLI/TIS and Landsat 4-5 TM. These images mainly concentrated on one scene (path 200, Row 56) and covered three distinct years, which include explicitly 1986, 1998, and 2020 (Table 1). The images were acquired from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov). The selection of these images was predicated upon the quality, particularly for those with limited to no cloud cover (Table 1).

Image preprocessing

The images were subjected to WGS_84 datum geo-reference and Universal Transverse Mercator (UTM) Zone 29 N coordinate system and radiometric correction to convert the raw digital number (DN) format to reflectance value using the radiometric calibration tool from the ENVI software. Afterward, change detection was analyzed

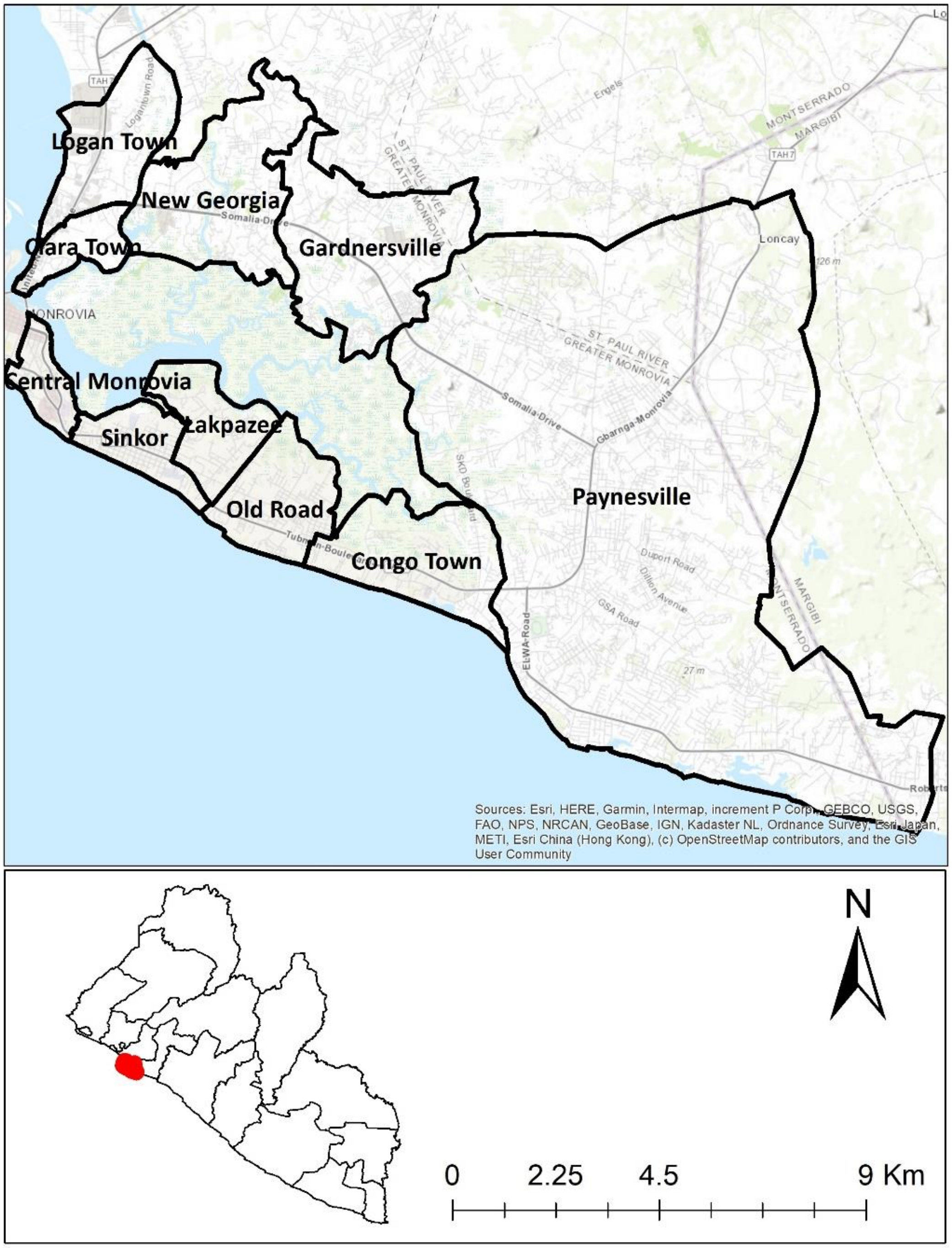

Figure 1. Study area geographic location.

Table 1. Details of acquired satellite images.

Year	Satellite ID	Sensor ID	Path\Row	Acquisition date	Spatial resolution
1986	Landsat 5	TM	200\56	Jan 21, 1986	30
1998	Landsat 5	TM	200\56	Feb 23, 1998	30
2016	Landsat 8	OLI\TR	200\56	Jan 01, 2020	30

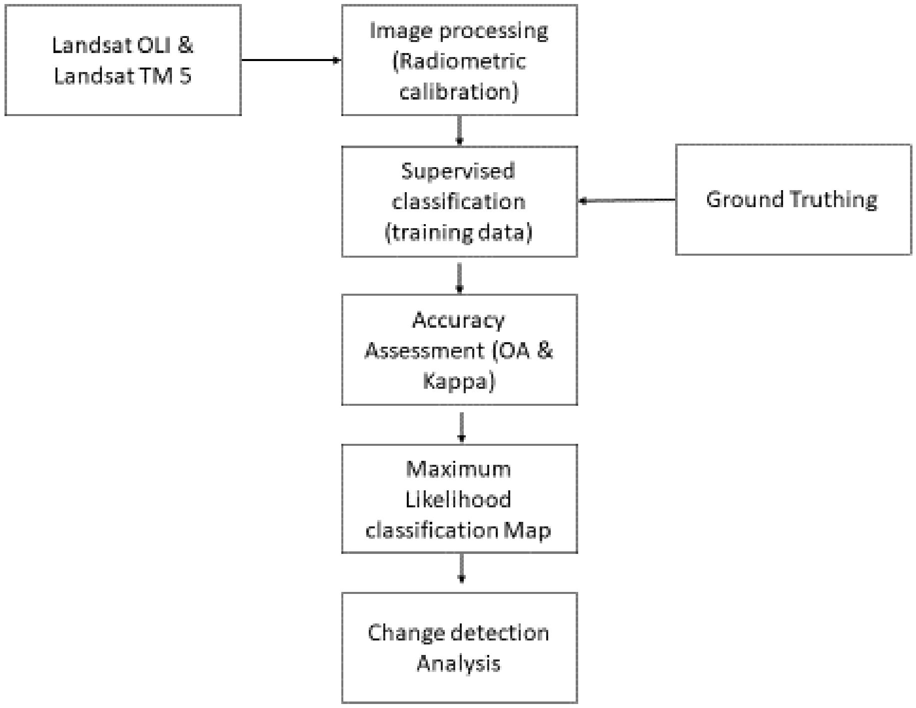

Figure 2. Change detection analysis methodological framework.

Table 2. Accuracy assessment tables.

Year	Overall accuracy (%)	Kappa coefficient
1986	84.83	0.80
1998	93.21	0.92
2020	92.01	0.88

(Figure 2).

Image classification

The supervised classification algorithm employed for this study is the Maximum Likelihood Classification of ENVI. This algorithm is among the most popular and commonly used supervised classification. It utilizes training data as a class and calculates the probability of each pixel belonging to a specific category. The documentation of Maximum Likelihood Classification in ENVI states that the discriminant of each pixel is calculated based on the equation of Richards and Richards (1999).

$$g_i(x) = 1np(\omega_i) - {}^1/_2\, 1n|\Sigma_i| - {}^1/_2\, (x - m_i)^T \Sigma_i^{-1} (x - m_i)$$

Where, I, Class; x, n-dimensional data (where n is the number of bands); p(ωi), probability that class ωi occurs in the image and is assumed the same for all classes; |Σi|, determinant of the covariance matrix of the data in class ωi; Σi-1, its inverse matrix; mi, mean vector.

Accuracy assessment

A major component of the image classification process is assessing accuracy (Rwanga and Ndambuki, 2017). This exercise defines the map's quality generated from the remotely sensed data (Foody, 2002). Confusion Matrix is commonly employed for the accuracy assessment imagery classification. This approach equates data acquired by referenced sites to the classified image's data for some of the sample area.

Accuracy assessment was performed for the three images classified for the distinct years, 1986, 1998, and 2020 (Table 2). The study used the Confusion Matrix Using Ground Truth Image tool to conduct the assessment. A minimum of 10 random points was generated per class employing the stratified random sampling technique to enhance the accuracy assessment. The conforming reference class for the Mangrove and non-mangrove land use and land cover types were acquired from 3 different sources, including data from field visits, raw image, and google earth pro. The field visit was done to authenticate the points generated from the google earth and raw model for the 2020 vision and had discussions with elders in the region of interest to establish ground-truthing points for 1986 and 1998 image.

RESULTS AND DISCUSSION

Classification accuracy

The overall accuracy of the three distinct years was 84.83, 93.27, and 92.01%, with the Kappa coefficient of 0.80, 0.92, and 0.88, respectively. A similar study was done by (Rwanga and Ndambuki, 2017) and got an overall accuracy of 81.7% and 0.72 kappa. This result simply illustrates that the image classification has performed satisfactorily and therefore deems it fit for the determination of the spatial-temporal change of mangrove forest cover in Montserrado County.

Spatial-temporal change

The overall spatiotemporal changes in the mangrove patches of the ten zones and the Mesurado Wetland dense mangrove forest in Montserrado County over the past thirty-four years is illustrated in Table 3 and Figure 3.

The pattern of mangrove distribution in other zones in Montserrado County

Generally, the wetland mangrove cover showed a reduced pattern continuously from 1986, 1998 to 2020, in the order of 3282.5, 2926.9, and 2203 ha, respectively. Furthermore, the continuous loss observed was not uniform; therefore, a decline of 355.58 ha or 10.83% of mangrove cover between 1986 and 1998 and further decline of 723.89 ha or 24.73% between 1998-2020 was recorded; thus, the highest drop occurred in the later period, constituting 22 years. Hence in the 34 years between 1986 and 2020, the total mangrove loss within the wetland is 32.88% at 1076.47 ha at an average of 31.65 ha or 0.96% yr^{-1}. Based on an extrapolated decline rate, if the Business, as usual, should continue, the mangrove will be lost by 2089.

A significant hectare of mangrove cover was detected in the administrative zones considered for this study; the distribution of mangroves amongst these zones for the past thirty-four years is vividly shown in Table 3. In terms of mangrove distribution, the Paynesville zone had the highest cover, followed by New Georgia and Congo town, respectively.

From Table 3, the ten zones hosting the mangrove patches, the highest patch was recorded in the Paynesville area with 405.05, 311.82, and 215.68 ha for 1986, 1998, and 2020, respectively. Next was New Georgia, with 234.33, 133.43, 30.93 ha, and Congo Town 227.64, 217.14, and 143.94 ha zones, in 1986, 1998, and 2020. It can be seen that in 1986 these represented a total of 65.37% of mangroves patches in the ten zones of Montserrado County, separately having 30.54, 17.67, and 17.16% in the baseline year respectively. From the baseline year to 2020, Paynesville, New Georgia, and Congo Town zones had significantly lost 189.37, 203.40, and 83.70 ha at the annual rate of 5.56, 5.98, and 2.46 $yr^{-1.}$ The result indicates that in all of the zones, Paynesville and New Georgia had the highest hectares of mangrove loss of the ten zones, with New Georgia having the highest loss and Lakpazee being the third in mangrove cover loss at 87.19% total loss in the thirty-four years.

The least mangrove patch within zones was observed in Central Monrovia (11.85, 2.17, and 0.00 ha), Sinkor (20.07, 13.59, and 2.47 ha), Old Road (97.95, 75.76, and 0.00 ha), and Clara Town (37.61, 28.55, and 0.00 ha) for 1986, 1998, and 2020. Three zones, including Central Monrovia, Clara Town, and Old Road, have lost 100% of the mangrove patches between 1998 and 2020, which accounts for 11.85, 37.61 and 97.95 ha, respectively. The Old Road zone has shown to experience the highest loss of mangrove forest cover among the three zones.

The mangrove estimates in Mesurado Wetland for 1986, 1998, 2020, were 1956.18 ha, 1926.38 ha, and 1750.72 ha, respectively, accounting for about 59.60, 65.82, and 79.47% of the total mangrove area in these years for Montserrado County (Figure 4).

The classification results indicate that the distribution of mangrove forests did not display similar patterns over the past thirty-four years. This result shows that most of the pressure on the mangrove forest covers are found within the zones that host the mangrove patches, mainly from New Georgia, Payneville, Lakpazee, and Old Road the total loss of 203.40, 189.37, 109.53, and 97.95 ha respectively. As compared to the dense mangrove forest in the Mesurado Wetland, the patches that fall within the administrative boundaries of the zones are smaller in land area but still depicts the consecutive decline in the three distinct study years, with the overall values of about 1326.29, 1000.51, and 452.29 ha in 1986, 1998, and 2020, respectively, accounting for approximately 40.41, 34.18, and 20.53% of the total mangrove area for Montserrado County for those years (Figure 5).

Most of the drivers of change that influence the mangrove forest cover in the county are occurring within

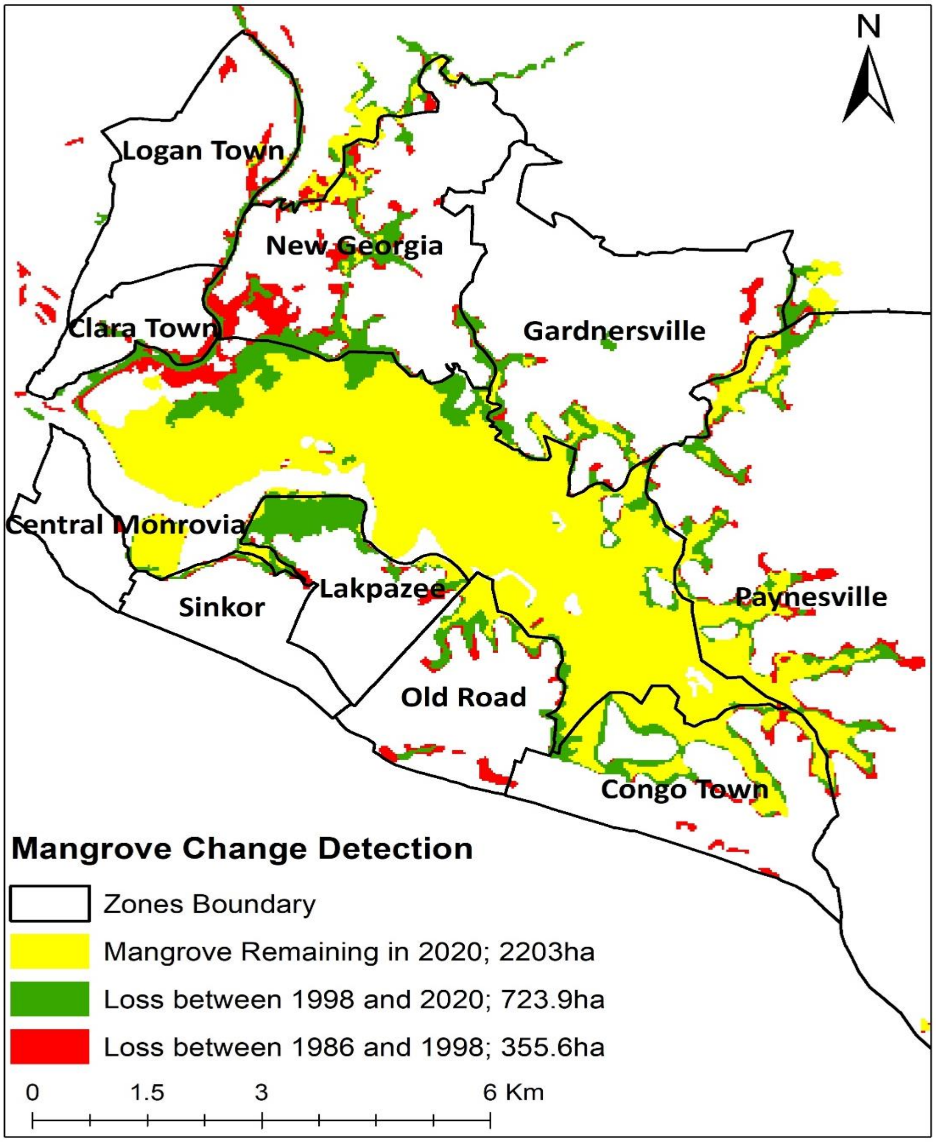

Figure 3. Mangrove change detection map of Montserrado County.

Table 3. Mangrove forest cover change detection data for other zones in Montserrado County.

Zones	1986	1998	2020	Total decline 1986-2020	Mangrove decline per year	Final decline year (BAU)
Central Monrovia	11.85	2.17	0.00	11.85	0.00	-
Clara Town	37.61	28.55	0.00	25.61	0.00	-
Congo Town	227.64	217.14	143.94	83.70	2.46	2078
Gardnersville	126.27	85.84	39.61	86.66	2.54	2036
Lakpazee	125.62	112.94	16.09	109.53	3.22	2025
Logan Town	39.90	19.27	3.56	36.34	1.07	2023
New Georgia	234.33	133.43	30.93	203.40	5.98	2025
Paynesville	405.05	311.82	215.68	189.37	5.56	2039
Old road	97.95	75.76	0.00	97.95	0.00	-
Sinkor	20.07	13.59	2.47	17.60	0.51	2025

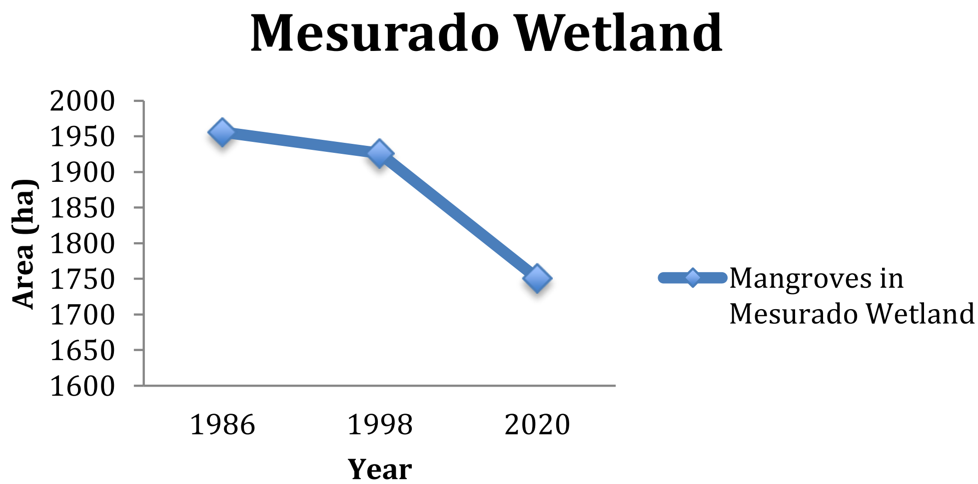

Figure 4. Pattern of mangrove distribution in Mesurado Wetland.

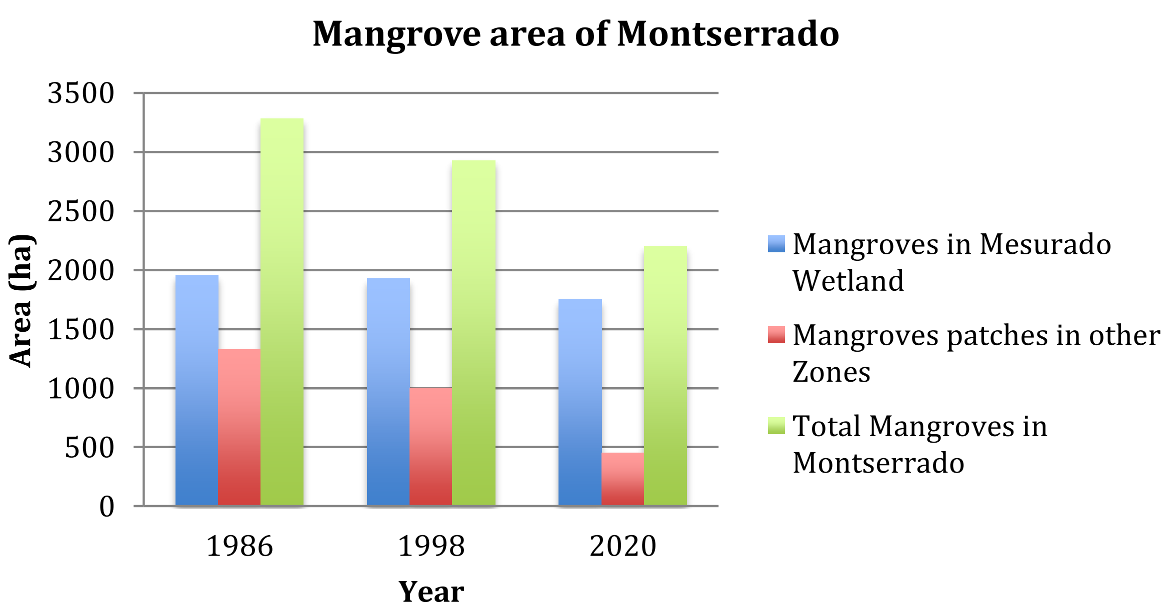

Figure 5. Total area of mangrove in Montserrado County during the period from 1986 to 2020.

the zones. This claim can be supported by the (UNEP, 2007) report, whereas, drivers of change to the mangrove in Liberia was attributed to civil unrest which started at the rural parts of the country and forced the rural community dwellers to the capital city, which happens to be along the coast. However, because the capital could no longer hold the displaced occupants, they settled in the surrounding mangrove areas. This finding is significantly similar to (Mondal et al., 2017), where mangrove along the Sierra Leone coast reduce by 25% in size between 1990 and 2016, with the lowest lower loss occurring in 2000, during the period of their civil war (1991–2002).

Conclusion

The urgency of an intervention is established by the information presented in this study. Therefore, it is recommended that immediate management interventions, most importantly within the zones before it reached the dense forest in the Mesurado Wetland. Some of the responses may include the establishment of nature reserves to promote an increase in the mangrove area; economic valuation of the mangrove forest cover and integration of scientific and traditional ecological knowledge to formulation policies for the mangrove forest cover should be initiated; rehabilitation programs in the mangrove denuded ecosystems should be undertaken, and future studies should be conducted to other mangroves ecosystem around the country to establish the spatiotemporal distribution identify drivers of change.

The finding of the study on the present status and rate of change of the Mesurado Wetland mangrove forest cover will be valuable to policymakers, researchers, conservationists, natural resource managers, and other stakeholders on the management, conservation, and restoration of the mangrove ecosystem. The information gathered on the mangrove forest cover has enhanced our understanding of the temporal variation, established the rate of deforestation, and set the basis for further research to determine the driver of change of the mangrove ecosystem. This is paramount to the decision-making on the national level regarding mainstreaming mangrove conservation and restoration into the national budget and other inter-sectoral agendas.

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