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Assessing the Impacts of Land Use and Climate Change on the Mesurado Wetland: A Case Study of the Peace Island Community Portion

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Abstract

Like many countries in the world, Liberia is one of those countries where wetlands exist and provide countless ecological, social, and economic benefits to communities near wetland areas. The area occupies 6 percent of Earth’s terrestrial land and exists in every continent except Antarctica. Regardless of their importance, wetlands face a significant threat from human activities and climate change impact. This study focuses on assessing the impact of land use and climate change on the Mesurado Wetland Peace Island portion. Additionally, considering temperature increase and human settlement as a driving force to the change in mangrove cover and wetland area has also led to some dis-function of the wetland's ecological services. This study has identified climate change as a major threat to the overall function of the Mesurado wetland Peace Island portion thereby reducing it in size and mangrove cover. With the findings of this paper, it has been established and statistically proven that There's a significant negative correlation between temperature and mangrove cover change (rho = -1), indicating that as temperature increases, mangrove cover decreases which validates that climate change has a direct impact on wetlands around the world by reducing their ecological services, wetland areas, mangrove cover and the Mesurado wetland in Liberia Peace Island portion is no exception. The study used a combination of data collection instruments - Geographic Information System (GIS) software and Meteoblue site. The GIS and remote sensing utilized satellite imageries to provide data on wetland area, (mangroves cover, and human settlement) changes over 4 years period (1991, 2001 2011, & 2023), identifying alterations due to both land use and climate factors. The climatic data (temperature and precipitation) was collected from Meteoblue. The publicly available precision of weather data for any area in the world is provided by this online platform. (https://www.meteoblue.com/en/climate-change/peace-island_liberia_8693108)

Keywords: *Climate Change, Land use, Mesurado Wetland, Peace Island.*

I. INTRODUCTION

The term "climate change" describes any alteration in the climate over a lengthy period brought on by either human activity or natural factors (Barros et al., 2014). Climate change results in altered temperature and precipitation patterns, which affect wetland physical and ecological processes and pose risks to ecosystems (Malekmohammadi et al. 2015). Increases in greenhouse gas emissions in the terrestrial atmosphere have recently been closely associated with climate change. Carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O), and water vapor (H_2O) are natural greenhouse gases in the atmosphere. These gases are responsible for controlling Earth's surface temperature. However, there is evidence that human activity has increased the concentration of some greenhouse gases, particularly CO_2, which is thought to have the strongest effect on global warming since the Industrial Revolution, particularly the burning of fossil fuels (coal, oil, and natural gas). Since the 1980s, climate change and global warming have been on the international agenda. To advance scientific understanding of the matter, in 1988, the United Nations Program for the Environment (UNEP) and the World

Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC), which is made up of well-known international scientists (Barros et al., 2014). Most of Africa has seen a 1-2-degree increase in temperature, according to the IPCC's Fourth Assessment Report from 2007. Changes in precipitation are also anticipated in terms of the amount and event type (IPCC, 2007). Rainfall episodes are expected to increase in severity and decrease in their frequency. Over the equatorial part of Africa, precipitation is expected to increase by up to 10–20%; however, precipitation is expected to drop by an equal or greater amount over mid-latitude regions and deserts. The surface water availability shifts as a result of these changes. Developing nations are more susceptible to climate change than developed nations, with African nations being the most susceptible because of their high reliance on natural resources, limited capacity for institutional and financial adaptation, low per capita gross domestic product (GDP), and high levels of poverty (Mitchell et al., 2013).

Wetlands are among the vital ecosystems worldwide because they contribute to ecological equilibrium and human livelihoods. Comprising only a tiny fraction of the earth's surface (ca. 6%, in comparison to terrestrial forests), wetlands are essential providers of water filtration, flood control, and carbon sequestration. They also contain an equally significant proportion of global biodiversity and offer multiple services vital for nature and human societies alike (Junk et al., 2013).

Wetlands face several consequences due to climate change namely, rising sea levels, changing water regimes, and more intense and frequent floods and droughts. Climate change-fueled modifications are especially dominant in the Mesurado Wetland of Liberia, more so, Peace Island which suffers dire consequences from these modifications. Changes in flooding patterns and saltwater intrusion will alter the species composition within the wetland decreasing its value in providing important services and escalating the already existing environmental and socio-economic problems of the area (Kim et al, 2022).

In 2006, the Mesurado Wetland was designated as one of Liberia's five Ramsar sites and incorporated into the Ramsar management network. This area, characterized by its thick mangrove forest, is situated between 06°19´ and 06°16´N latitude and 10°48´ and 10°42´W longitude and accounts for approximately 6,760 hectares. While the bulk of this forested region lies within the Mesurado Wetland, some portions extend approximately 6 km northward into the inland area. The mangrove wetland is a flat plain with a polymorphous shape extending east towards Paynesville. It offers a suitable habitat and feeding ground for various bird species, including the African spoonbill (Platalea alba), Common Pratincole (Glareola nuchaltis), and Curlew (Numenius arquata). The area is also home to several endangered crocodile species, including the African dwarf crocodile, Nile crocodile, and African sharp-nosed crocodile. Additionally, it serves a crucial function in stabilizing coastlines and capturing sediment and is significant for the preservation of three mangrove species: Rhizophora *harrisonii*, Rhizophora *mangle*, and Avicennia *Africana* (Olatunji & Charles, 2020).

Peace Island, situated within the Mesurado Wetland, offers a diverse array of ecological and socio-economic features, making it an ideal location for studying the impacts of land use and climate change on wetland ecosystems. The island's urban setting in Monrovia also subjects it to significant human-induced pressures. Furthermore, the area's varied biodiversity renders it particularly susceptible to environmental fluctuations, underscoring the importance of understanding how land use and climate change may affect this delicate ecosystem. (Bodelier & Dedysh 2013).

The intensification of human activities and urban development on Peace Island has led to substantial alterations in the wetland ecosystem over time. The expansion of residential areas and ongoing construction projects have resulted in deforestation, increased pollution, and disruption of natural water flow patterns, which have outweighed local conservation efforts. These environmental changes not only affect the natural habitat but also diminish the wetland's ability to provide essential services such as improving water quality and mitigating flood risks. (Li et al., 2022).

The Mesurado wetland ecosystem, especially Peace Island, vividly demonstrates the essential roles of wetlands in preserving different species and providing subsistence to people. Most importantly, however, such ecosystems are increasingly under threat due to climate change and anthropogenic activities. Tackling these issues demands that one considers the relationship between land use and climate change and wetlands health to create conservation strategies for these ecosystems.

- *Objective of the Study*

Generally, the study assesses the change in wetland area from 1991 to 2023 in the Peace Island’s portion of the Mesurado wetland due to climate change and land use.

- *Specific Objectives*

Specifically, this study aims to achieve the following objectives:

- To determine the change and trends in wetland, mangrove cover, and settlements in the Peace Island portion of the Mesurado wetland.
- To assess the trends in temperature and precipitation in the Peace Island portion of the Mesurado wetland.
- Examine the correlation between climate change (temperature and precipitation) and land use (wetland area, mangrove cover, and settlement).

II. METHODOLOGY

- *Data Collection Procedure*

The data-collection process involved two distinct procedures: GIS and climate data. GIS data collection constituted a three-step procedure involving data acquisition, image processing, and Land Use-Land Cover (LULC) classification, as described in **Table 1**. Temperature and precipitation data were collected from Meteoblue to show trends in precipitation and temperature over time in the Peace Island community.

The satellite images for the study were obtained from 1991 to 2023 at 10-year intervals for the years 1991, 2001, 2011, and 2023 as base years to evaluate and interpret LULC changes. Cloud-free Landsat 4 TM (1991), Landsat 7 ETM+ (2001 and 2011), and Landsat 8 OLI (2023) images of the Greater Monrovia District, with paths 200 and 56, were obtained from the USGS website. The acquired data with WGS_1984 were projected onto UTM projections specific to Liberia (WGS_1984_UTM_Zone_29N). **Table 1** summarizes the satellite imagery acquired for the classification. Notably, data acquisition is mostly dependent on data availability, suitability, and quality.

Table 1 Satellite Imagery Acquired in the Study

Landsat Sensor	Acquisition Date	LUCL Band	Thermal Band
Landsat 4 TM	11/1/1991	4(NIR), 3(Red), 3(Green)	6TIR
Landsat 7 ETM+	7/2/2001	4(NIR), 3(Red), 3(Green)	6TIR
Landsat 7 ETM+	2/1/2011	4(NIR), 3(Red), 3(Green)	6TIR
Landsat 8 OLI	01/03/2020	4(NIR), 3(Red), 3(Green)	10TIR

➢ *The GIS Data Collection Method is Illustrated in **Figure 1**.*

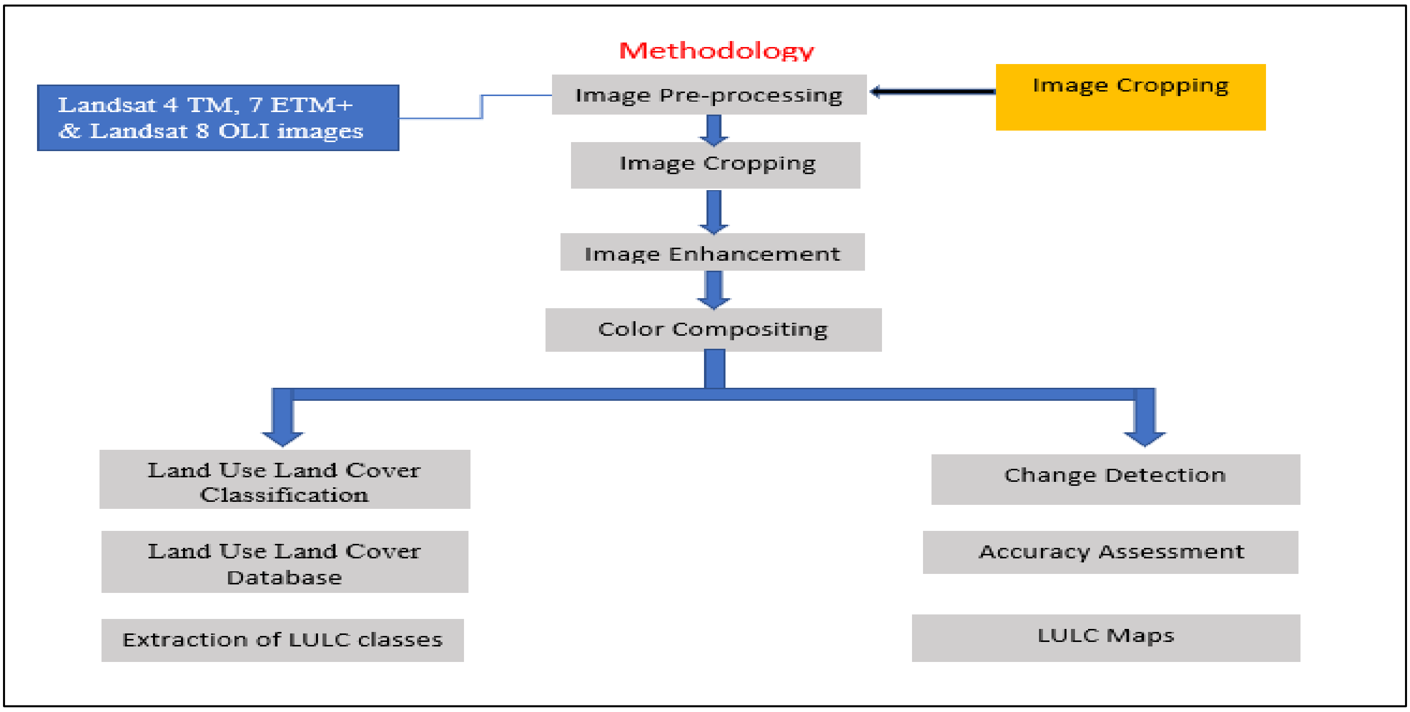

Fig 1 Methodology for the GIS Data Collection

In addition, GIS data were supplemented by climate (temperature and precipitation) data from the Meteoblue platform (https://www.meteoblue.com/en/climate-change/peace-island_liberia_8693108).

➢ *Data Analysis Procedure*

The data analysis involved the following steps as outlined thus:

The downloaded images were cropped to limit the scope of spatial analysis to the Area of Interest (AOI). Thereafter, they were pre-processed for atmospheric and geometric corrections. The images were then enhanced to improve visual contrast, and color compositing was performed using a geoprocessing tool that generated Red, Green, and Blue (RGB) raster datasets from a multiband raster dataset. A supervised classification approach entailing the creation of training sites defined by a six-classification system, including settlement, waterbodies, bare land, mangroves, grassland, and mangrove degraded, was applied. Images from Landsat 4 TM, Landsat 7 ETM+, and Landsat 8 OLI were used to obtain land use and surface characteristics for each year from 1991 to 2023. ArcGIS software was utilized to classify land use and detect changes using a combination of near-infrared, red, and green bands. The supervised classification approach determined the total area in hectares (ha) for each land class and tracked changes in land use. To ensure the efficient classification of pixels into the correct land cover classes, the number of correctly classified pixels was divided by the total number of validations set in each class. Finally, an LULC map was generated.

This study used interpolation to create a uniform time-series dataset to have a minimum data count for the correlation. Descriptive statistics were computed for each variable to understand its central tendency, variability, and distribution characteristics. Summary statistics and histograms were used to visually depict the frequency distributions of variables. Additionally, correlation analysis was conducted to explore the relationships between climate variables and mangrove cover changes. Normality assumptions were verified using the Shapiro-Wilk test, and Pearson's correlation coefficient or Spearman's rank correlation coefficient was computed. Simple linear regression models were used to investigate the individual effects of environmental factors on mangrove cover. The least squares method was used to fit the models, and model diagnostics were used to evaluate the significance and reliability of the relationships. Finally, visualizations were used throughout the methodology to facilitate data exploration and interpretation. Line plots visualized the temporal trends of environmental variables over the study period, while scatter plots with regression lines illustrated the relationships between predictor variables and mangrove cover change.

III. RESULTS

➢ *GIS Result*

This section provides the results from the GIS and statistical analysis. **Table 2** presents the changes in land use from the GIS analysis and covers six categories—Settlement, Mangrove Degraded, Bareland, Waterbodies, Grassland, and Mangrove—over four years: 1991, 2001, 2011, and 2023.

Table 2 Change in Peace Island's Wetland Area Over the Period 1991-2023

No.	Variables names	Area in hectares per year				
		1991	**2001**	**2011**	**2023**	**Total**
1	Settlement	0 ha	0 ha	47 ha	62 ha	62 ha
4	Mangrove Degraded	0 ha	0 ha	0 ha	36 ha	36 ha
6	Bareland	2 ha	4 ha	0 ha	0 ha	0 ha
2	Waterbodies	4 ha	5 ha	4 ha	7 ha	7 ha
3	Grassland	46 ha	41 ha	0 ha	0 ha	0 ha
5	Mangrove	94 ha	93 ha	93 ha	39 ha	39 ha

Settlement expanded from 0 hectares (ha) in 1991 and 2001 to 62 ha by 2023, indicating significant urbanization. Mangrove Degraded had no recorded area until 2023, when 36 hectares were classified as degraded, reflecting environmental stress. Bareland decreased from two hectares in 1991 and four hectares in 2001 to zero hectares by 2011, indicating reclamation or conversion to other uses. Waterbodies have increased from four hectares in 1991 to seven hectares in 2023, indicating either natural expansion or artificial intervention. Grassland declined from 46 hectares in 1991 to 0 hectares in 2011, likely due to land conversion for other purposes. The mangrove area has shrunk significantly from 94 hectares in 1991 to 39 hectares in 2023, highlighting substantial ecosystem loss. Overall, the data show considerable land-use changes driven by urbanization, environmental degradation, and possibly climate change.

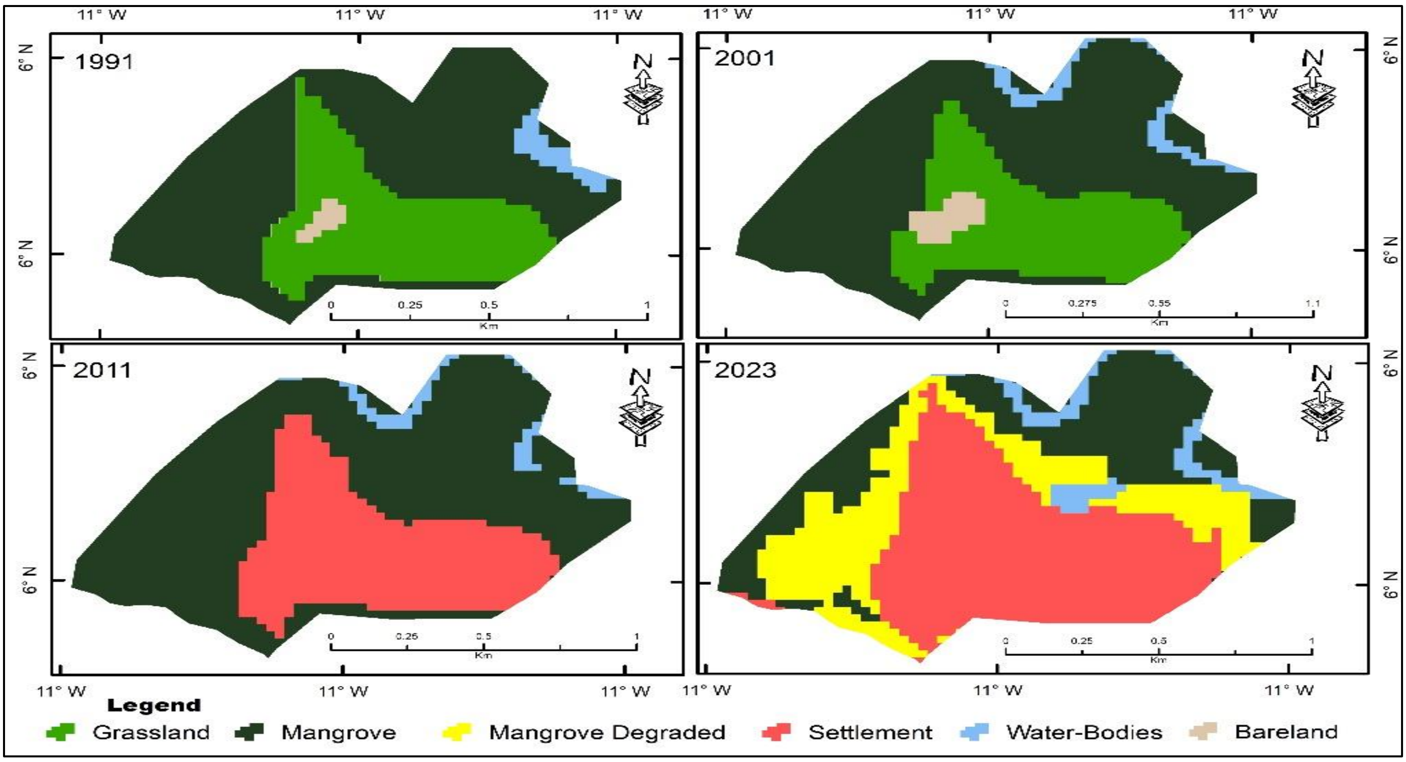

Fig 2 Change in Peace Island's Wetland Area Over the Period 1991-2023

➢ *Statistical Results*

- *Descriptive Statistics*

The median temperature, precipitation, and settlement trend in Peace Island from 1991-2023 were 25.94°C (IQR: 25.66-26.27°C), 3560mm (IQR: 3469-3568mm), and 28.20 hectares (IQR: 0.00-52.00 hectares), respectively. The median mangrove degraded area was 0.0 hectares (IQR: 0.0-12.0 hectares) with a maximum of 36.0 hectares, while the median mangrove cover change was 93.00 hectares (IQR: 75.00-93.20 hectares). This is illustrated in **Figure 3** below.

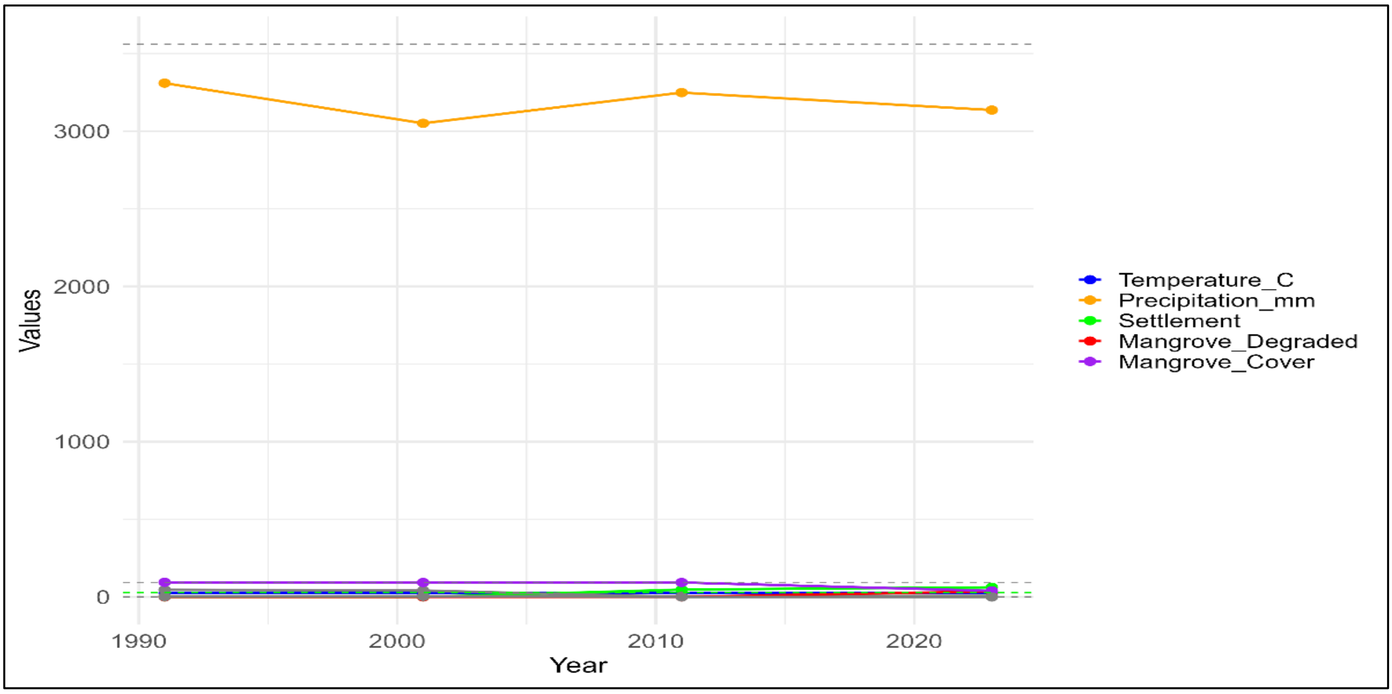

Fig 3 Descriptive Statistics Showing Median Values

➢ *Correlation Results*

- *Temperature and Mangrove Cover Change*

The correlation test revealed a significant negative relationship between temperature and mangrove cover, with a Spearman's rho of -1, indicating a perfect negative monotonic relationship. The p-value of 0.01 leads to rejecting the null hypothesis, confirming a strong negative correlation: as temperature increases, mangrove cover decreases in the study area. **Figure 4** visualizes this relationship.

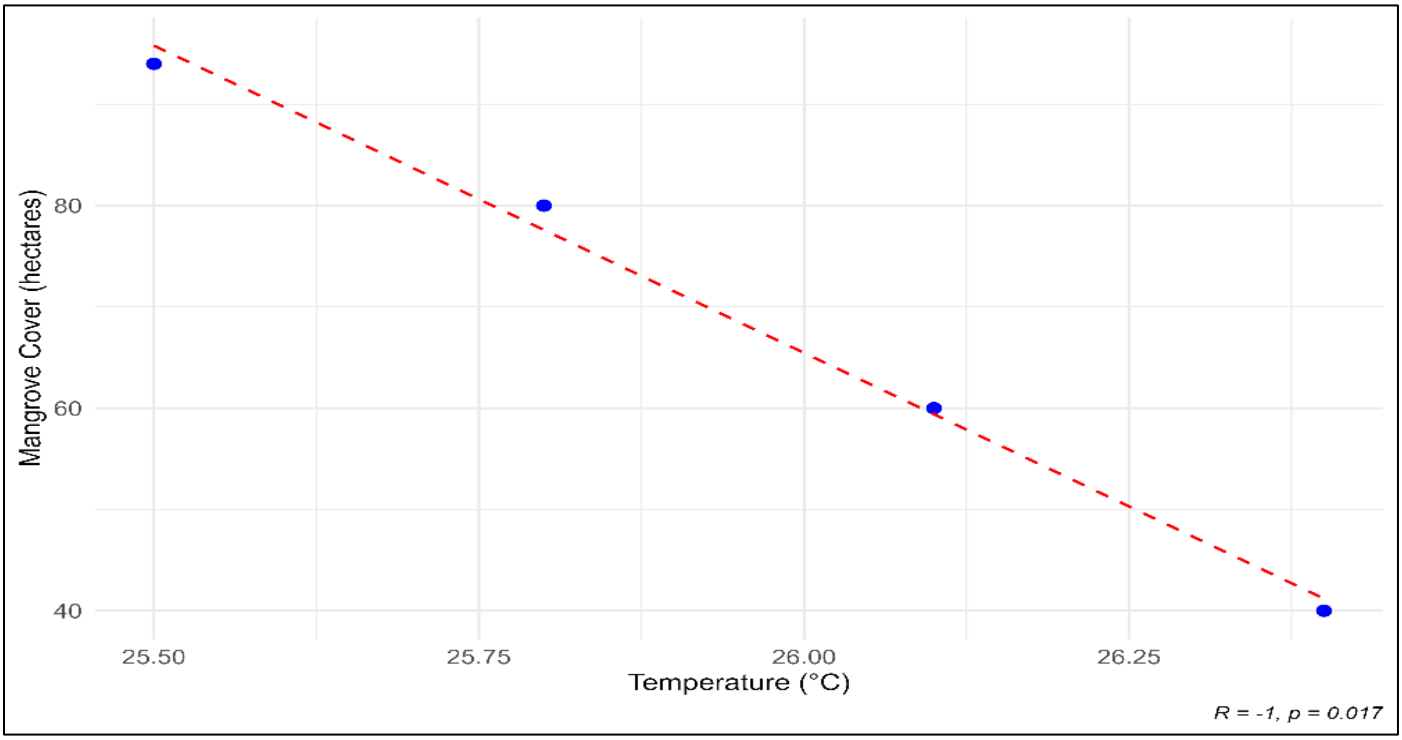

Fig 4 Correlation Between Temperature and Mangrove Cover

- *Precipitation and Mangrove Cover Change*

The correlation test shows a moderately strong negative relationship (rho = -0.7) between precipitation and mangrove cover change, suggesting that mangrove cover decreases as precipitation increases. However, the p-value (0.2333) exceeds the 0.05 threshold, indicating that this correlation is not statistically significant. Thus, we fail to reject the null hypothesis, concluding no statistically significant correlation exists between precipitation and mangrove cover change. This is illustrated in **Figure 5**.

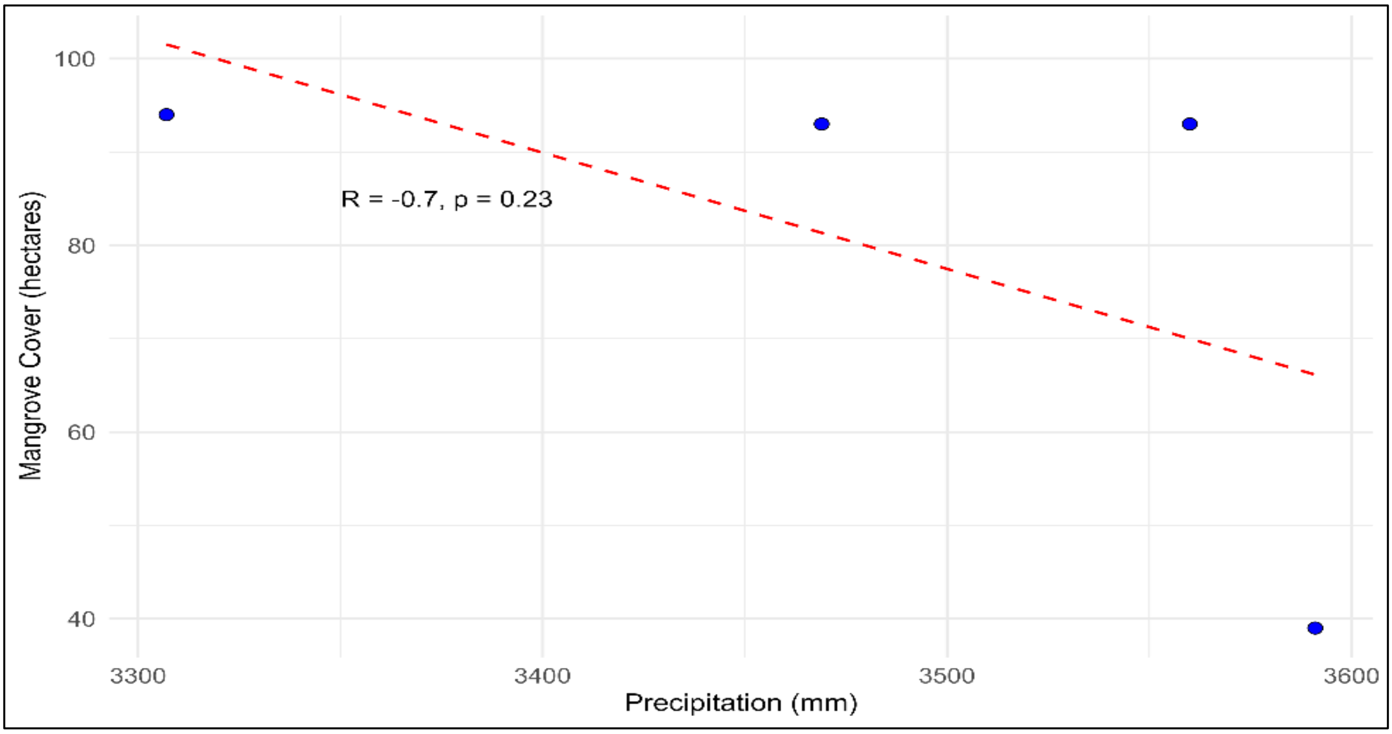

Fig 5 Correlation Between Precipitation and Mangrove Cover Change

- *Settlement and Mangrove Cover Change*

The correlation test shows a strong negative relationship between settlement and mangrove cover change, with a Spearman's rho of -0.975, indicating a sharp decrease in mangrove cover as settlement increases. The p-value of 0.004818 leads us to reject the null hypothesis, confirming a significant negative correlation. This suggests that increased settlement is associated with decreased mangrove cover in the Peace Island Community. See **Figure 6**.

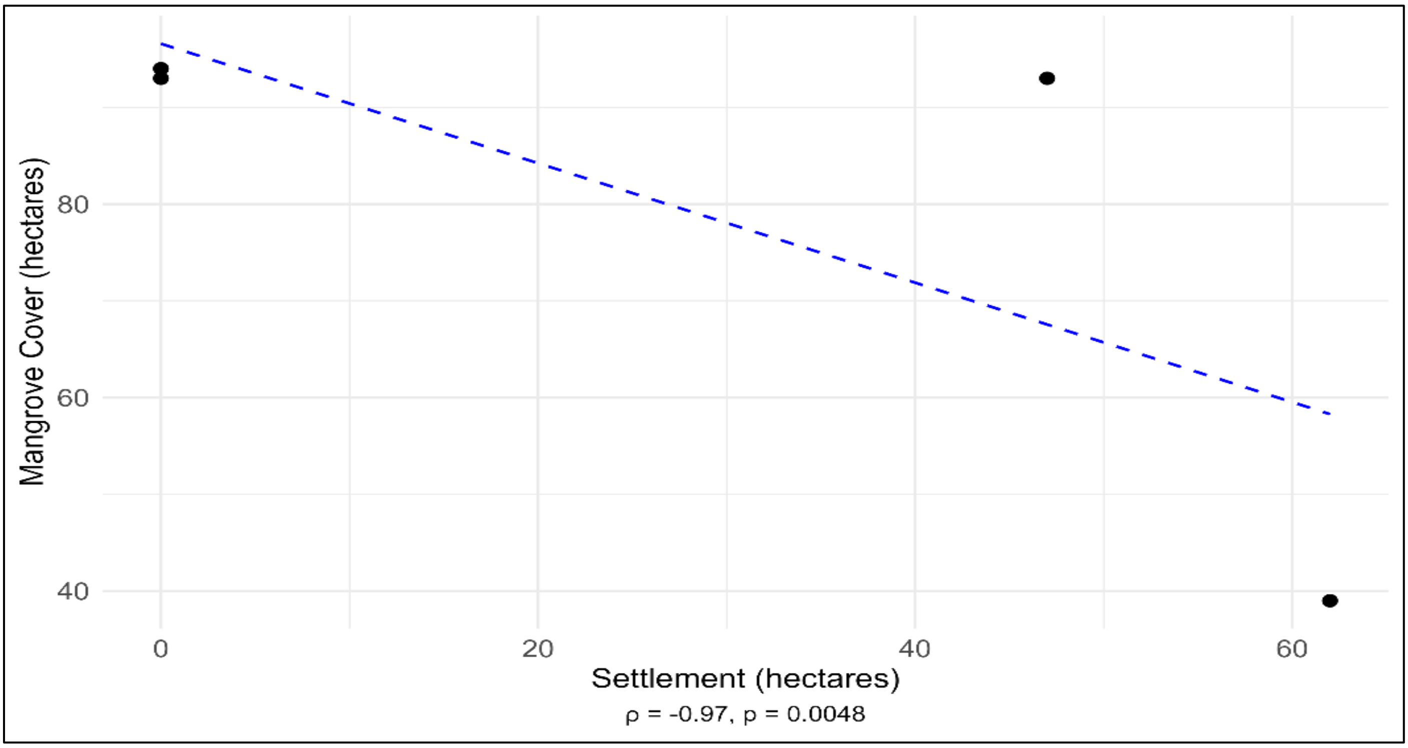

Fig 6 Correlation Between Settlement and Mangrove Cover Change

➢ *Linear Regression Result*

- *Temperature and Mangrove Cover*

The linear regression analysis reveals a significant negative relationship between temperature and mangrove cover, with a slope of -47.79 ($p = 0.0354$). This suggests that for each 1°C increase in temperature, mangrove cover decreases by approximately 47.79 hectares. The model explains 81.65% of the variance in mangrove cover (Adjusted R-squared = 0.7553). Both the intercept (1321.18, $p = 0.0302$) and the temperature coefficient are statistically significant. The F-statistic (13.35, $p = 0.03541$) confirms the model's overall significance, highlighting temperature as a key factor in mangrove decline. See **Figure 7**.

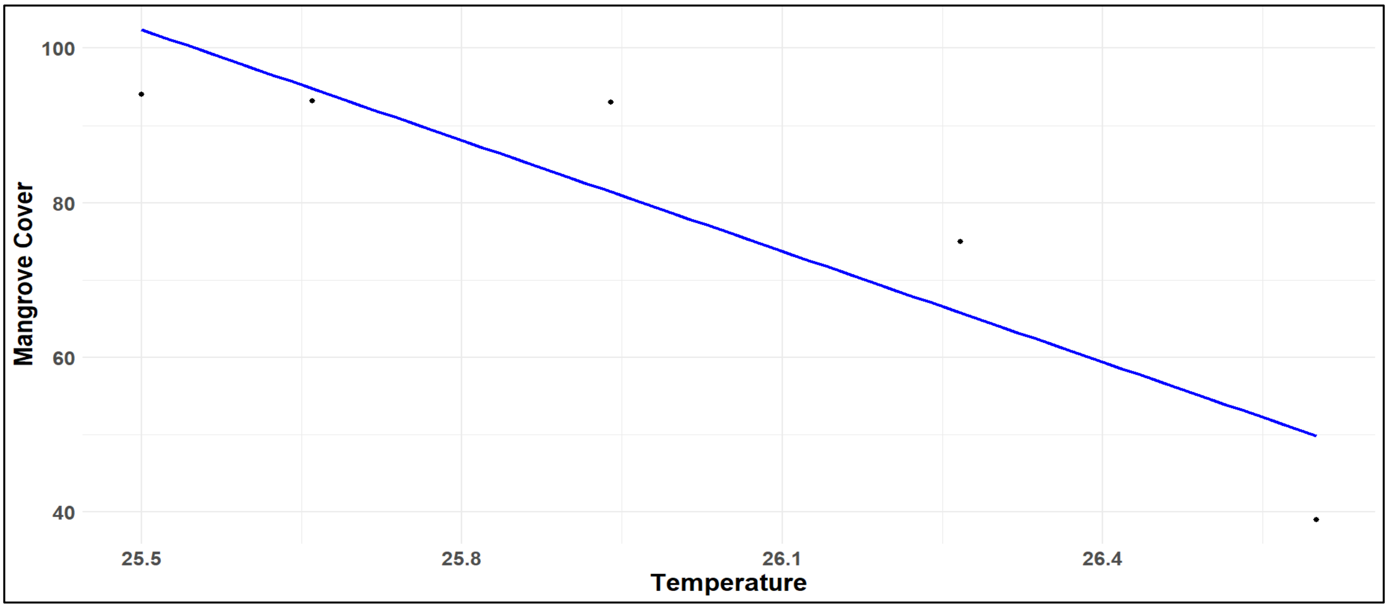

Fig 7 Temperature and Mangrove Cover

- *Precipitation and Mangrove Cover*

The coefficient for precipitation which is -0.09433 indicates that for each unit increase in precipitation, the mangrove cover decreases by approximately 0.09433 hectares (p<value 0.429). given the significance of 0.429 which is greater than our threshold of 0.05, we conclude that precipitation is not a statistically significant predictor of mangrove cover change. See **Figure 8**.

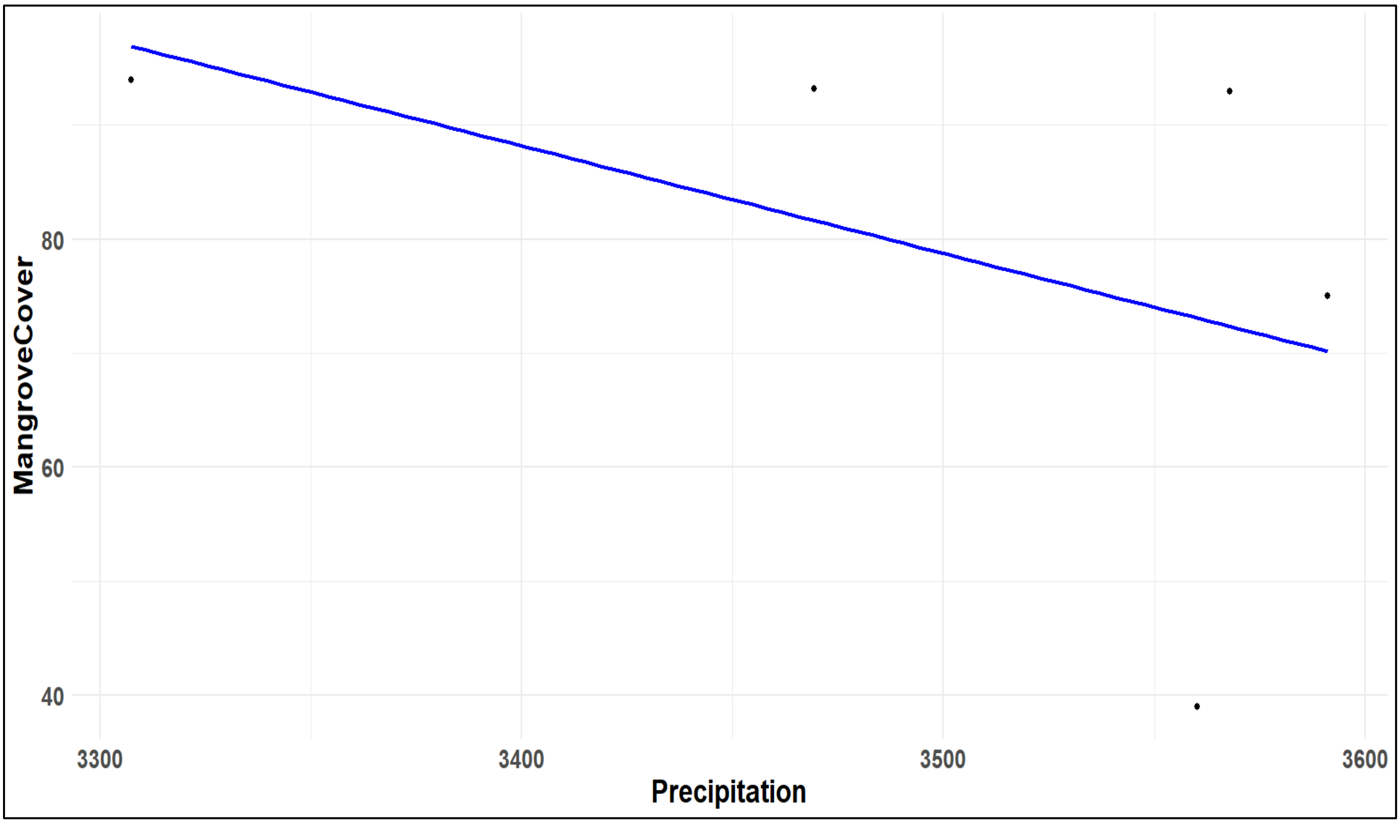

Fig 8 Precipitation and Mangrove Cover

- *Settlement and Mangrove Cover*

The coefficient for settlement is -0.6882 indicating that for each unit increase in settlement, the mangrove cover decreases by approximately 0.6882 hectares ($p< 0.07810$). With the intercept ($p< 0.00224$) being a statistically significant predictor and the settlement coefficient being marginally significant, we can conclude that Settlement is marginally statistically significant in predicting mangrove cover, but its significance is not strong. See **Figure 9**.

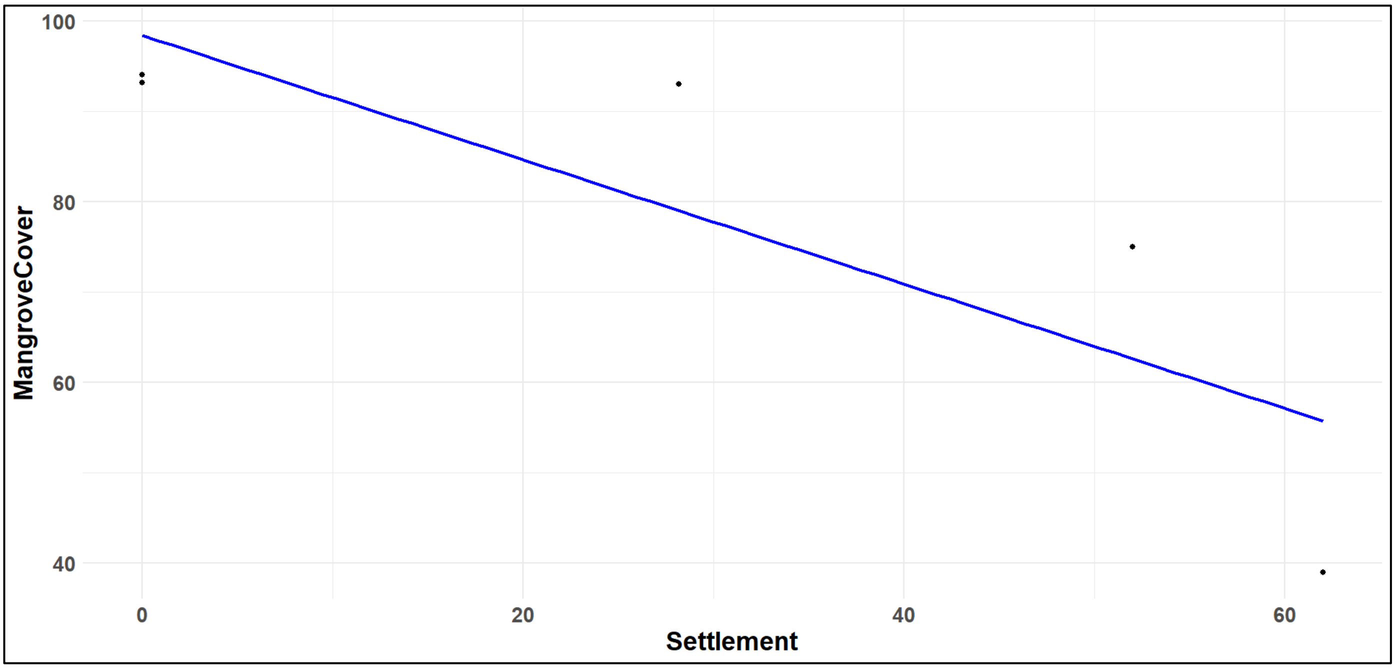

Fig 9 Settlement and Mangrove Cover

- *Mangrove Degradation and Mangrove Cover*

For each unit increase in mangrove degradation, the mangrove cover decreases by approximately 1.51176 hectares ($p<0.001$). Given the highly significant level, we can conclude that mangrove degradation is a higher statistically significant predictor of mangrove cover, and the model fits the data extremely well. **Figure 10**.

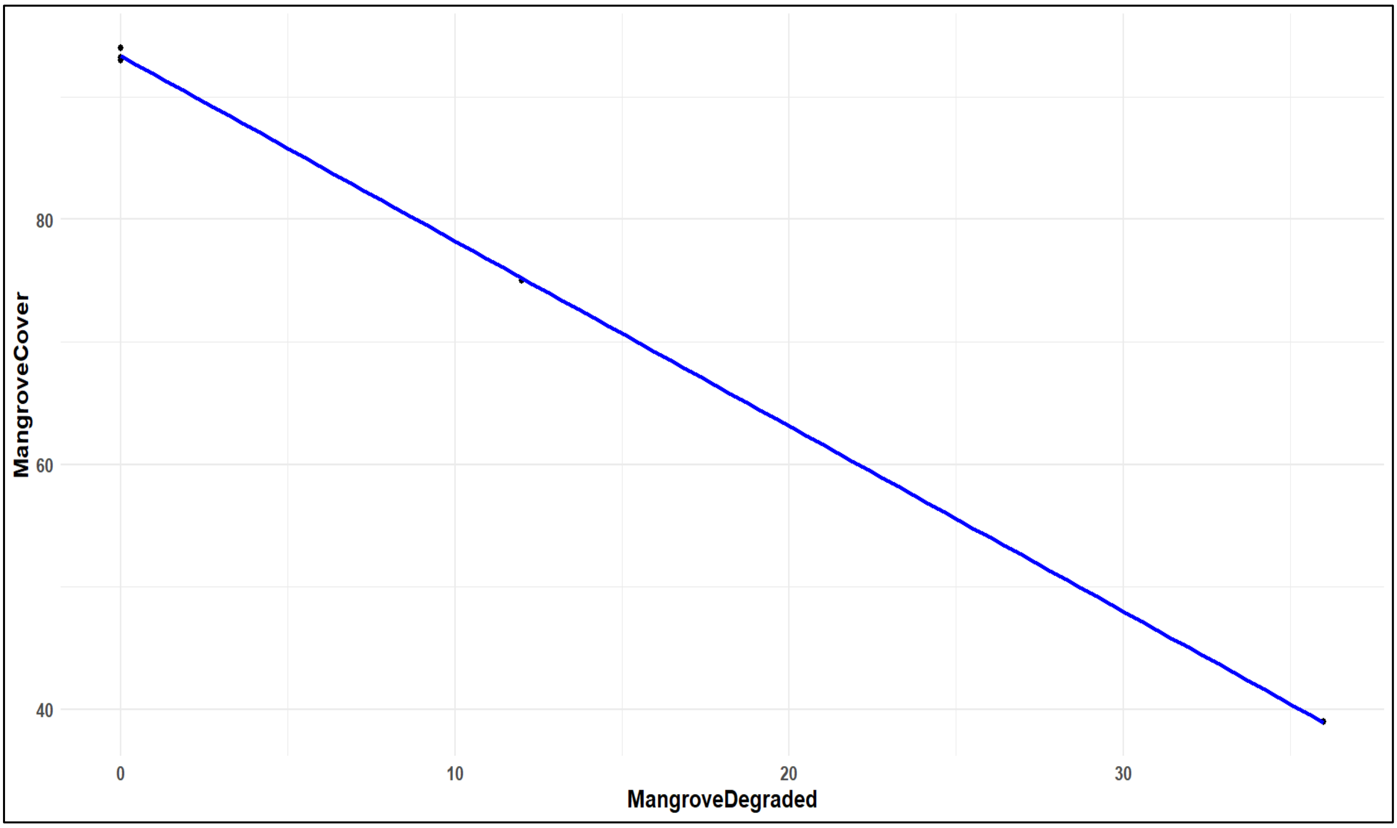

Fig 10 Mangrove Degradation and Mangrove Cover

IV. DISCUSSION

The impacts of land use and climate change remain evident on the Mesurado wetland as a contributing factor that has led to several declines in the ecological values of the area. This study has established from the correlation result that the temperature in the Peace Island community has increased over time with a median temperature between 1991-2023 at 25.94°C, with an IQR of 25.66-26.27°C indicating that as temperature increases, mangrove cover decreases. It can be deduced that the temperature rise has contributed significantly to the decrease in mangrove cover. The median settlement trend in the Peace Island community between 1991-2023 indicates that the area lost 62 hectares of land to human settlement, hugely linked to wetland degradation and mangrove depletion. The study also shows that the area was rich in mangrove cover between 1991-2011 covering an area of 94 hectares in 1991, 93 hectares in 2001, and 93 hectares in 2011, experiencing a drastic decline between 2012-2023 reducing it to 36 hectares. This study has statistically proven that an increase in temperature in the study area has led to the decline in mangrove cover aiding us to understand variables that are significant to the change in mangrove cover. This can be further explained as, for each unit increase in temperature, mangrove cover decreases by approximately 47.79 hectares, making up a maximum degraded area of 36.0 hectares. Moreover, settlement is another variable that is marginally statistically significant in predicting mangrove cover change, with each unit increase in settlement, it is associated with a decrease in mangrove cover by approximately 0.6882 hectares.

V. CONCLUSION

This study highlights the significant impacts of land use and climate change on the Mesurado wetland, particularly in the Peace Island community. Human activities like deforestation and settlement, along with climate change factors such as altered rainfall patterns and rising temperatures, have significantly altered the wetland. Given the wetland's critical ecological, economic, and social services, there is an urgent need for a comprehensive conservation and management plan involving communities, NGOs, and government institutions. The findings offer valuable insights for future research and inform policymaking to promote wetland resilience and sustainability.

REFERENCES

[1]. Adeeyo, A. O., Ndlovu, S. S., Ngwagwe, L. M., Mudau, M., Alabi, M. A., & Edokpayi, J. N. (2022). Wetland resources in South Africa: threats and metadata study. Resources, 11(6), 54.

[2]. Ajibola, M. O., Adewale, B. A., & Ijasan, K. C. (2012). Effects of urbanization on Lagos wetlands. International Journal of Business and Social Science, 3(17), 310-318.

[3]. Bailey, V., Brinton, R., Snowden, S., & White, A. (2022). Yellowstone Ecological Forecasting II: Assessing Change in Aspen Extent in Northern Yellowstone National Park.

[4]. Barros, D. F., & Albernaz, A. L. M. (2014). Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon. Brazilian Journal of Biology, 74, 810-820.

[5]. Barros, D. F., & Albernaz, A. L. M. (2014). Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon. Brazilian Journal of Biology, 74, 810-820.

[6]. Barros, D. F., & Albernaz, A. L. M. (2014). Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon. Brazilian Journal of Biology, 74, 810-820.

[7]. Bassi, N., Kumar, M. D., Sharma, A., & Pardha-Saradhi, P. (2014). Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. *Journal of Hydrology: Regional Studies*, *2*, 1-19.

[8]. Berkessa, Y. W., Bulto, T. W., Moisa, M. B., Gurmessa, M. M., Werku, B. C., Juta, G. Y., ... & Gemeda, D. O. (2023). Impacts of urban land use and land cover change on wetland dynamics in Jimma City, southwestern Ethiopia. Journal of Water and Climate Change, 14(7), 2397-2415.

[9]. Bodelier, P. L., & Dedysh, S. N. (2013). Microbiology of wetlands. *Frontiers in microbiology*, *4*, 79.

[10]. Carter, S., Peterson, J., Lipton, D., Rubenstein, M. A., Weiskopf, S. R., Crozier, L., ... & Lipton, D. Ecosystems, Ecosystem Services, and Biodiversity.

[11]. Curtis, E. A., Comiskey, C., & Dempsey, O. (2016). Importance and use of correlational research. Nurse researcher, 23(6).

[12]. Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research, 65(10), 934-941.

[13]. Desta, H., Lemma, B., & Fetene, A. (2012). Aspects of climate change and its associated impacts on wetland ecosystem functions: A review. Journal of American Science, 8(10), 582-596.

[14]. Di Napoli, C., McGushin, A., Romanello, M., Ayeb-Karlsson, S., Cai, W., Chambers, J., ... & Robinson, E. J. (2022). Tracking the impacts of climate change on human health via indicators: lessons from the Lancet Countdown. BMC Public Health, 22(1), 663.

[15]. Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology and Management*, *17*(1), 71-84.

[16]. Garnell, A. (2022). Effects of Climate Change on Wetlands in the Boreal Region: Impacts on species composition and greenhouse gas fluxes.

[17]. Hardy, J. T. (2003). Climate change: causes, effects, and solutions. John Wiley & Sons.

[18]. Junk, W. J., An, S., Finlayson, C. M., Gopal, B., Květ, J., Mitchell, S. A., ... & Robarts, R. D. (2013).

Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. *Aquatic sciences*, *75*, 151-167.

[19]. Kabii, T. (1996). An overview of African wetlands.

[20]. Kim, B., Lee, J., & Park, J. (2022). Role of small wetlands on the regime shift of ecological network in a wetlandscape. *Environmental Research Communications*, *4*(4), 041006.

[21]. Kogure, K., & Takasaki, Y. (2019). GIS for empirical research design: An illustration with georeferenced point data. PloS one, 14(3), e0212316.

[22]. Lee, S. Y., Dunn, R. J. K., Young, R. A., Connolly, R. M., Dale, P. E. R., Dehayr, R., ... & Welsh, D. T. (2006). Impact of urbanization on coastal wetland structure and function. *Austral Ecology*, *31*(2), 149-163.

[23]. Lhamo, P. (2019). *Assessing the influence of human settlements on the plant diversity in wetlands of Phobji and Gangtey, Bhutan* (Doctoral dissertation, Submitted by: Pema Lhamo).

[24]. Li, Z., Ma, L., Gou, D., Hong, Q., Fai, L., & Xiong, B. (2022). The impact of urban development on wetland conservation. *Sustainability*, *14*(21), 13747.

[25]. Lloréns, J. L. P. (2008). Impacts of climate change on wetland ecosystems. *Water supply*, *7*(2.117), 8.

[26]. Malekmohammadi, B., Blouchi, L. R., Ghehi, N. K., & Shakib, F. J. (2015, March). Investigating the Effects of Climate Change on Wetlands Using Risk Assessment and Remote Sensing (Case Study: Choghakhor Wetland, Iran). In *Symposium Committee* (p. 138).

[27]. Meng, L., Roulet, N., Zhuang, Q., Christensen, T. R., & Frolking, S. (2016). Focus on the impact of climate change on wetland ecosystems and carbon dynamics. *Environmental Research Letters*, *11*(10), 100201.

[28]. Mitchell, S. A. (2013). The status of wetlands, threats and the predicted effect of global climate change: the situation in Sub-Saharan Africa. *Aquatic sciences*, *75*(1), 95-112.

[29]. Mitra, S., Wassmann, R., & Vlek, P. L. (2003). Global inventory of wetlands and their role in the carbon cycle.

[30]. Olatunji, E. T., & Charles, J. (2020). Change detection analysis of mangrove ecosystems in the Mesurado Wetland, Montserrado County, Liberia. *International Journal of research in environmental studies*, *7*, 17-24.

[31]. Salimi, S., Almuktar, S. A., & Scholz, M. (2021). Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. *Journal of Environmental Management*, *286*, 112160.

[32]. Sica, Y. V., Quintana, R. D., Radeloff, V. C., & Gavier-Pizarro, G. I. (2016). Wetland loss due to land use change in the Lower Paraná River Delta, Argentina. *Science of the Total Environment*, *568*, 967-978.

[33]. Solomon, S. (Ed.). (2007). *Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge university press.

[34]. Urama, K. C., & Ozor, N. (2010). Impacts of climate change on water resources in Africa: the role of adaptation. *African Technology Policy Studies Network*, *29*(1), 1-29.

[35]. Walker, J. E. (2021). *Effects of Climate Change on Coastal Wetland Ecosystems and the Implications for Their Future Management* (Doctoral dissertation, University of Florida).

[36]. Xu, T., Weng, B., Yan, D., Wang, K., Li, X., Bi, W., ... & Liu, Y. (2019). Wetlands of international importance: Status, threats, and future protection. *International journal of environmental research and public health*, *16*(10), 1818.

[37]. Young, J., Parr, T., Heip, C., & Watt, A. D. (2005). Climate change and biodiversity conservation: knowledge needed to support development of integrated adaptation strategies. Report of an e-conference, September 2005.

[38]. Zhang, Y., Jin, R., Zhu, W., Zhang, D., & Zhang, X. (2020). Impacts of land use changes on wetland ecosystem services in the Tumen River Basin. *Sustainability*, *12*(23), 9821.

[39]. Zorrilla-Miras, P., Palomo, I., Gómez-Baggethun, E., Martín-López, B., Lomas, P. L., & Montes, C. (2014). Effects of land-use change on wetland ecosystem services: A case study in the Doñana marshes (SW Spain). *Landscape and Urban Planning*, *122*, 160-174.