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Analysis of the dynamics of mangrove exploitation in the estuary of Sonfonia, Guinea

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Abstract

Mangroves, tropical forests typically found along coastlines and tidal rivers, play a vital role in conserving biodiversity. They are crucial feeding and nursery areas for many aquatic species. The objective of this study is to analyze the dynamics of the mangrove of Sonfonia between 2013 and 2023 and to identify the factors contributing to its degradation in order to implement a sustainable management strategy. The methodology adopted was as follows: a survey of mangrove users to better understand the causes of its degradation; then, a spatio-temporal mapping of the study area over ten years was carried out; finally, an in-depth analysis of the data collected was performed. The results reveal that human activities such as rice farming, urbanization, and logging are causing severe degradation of the mangrove of Sonfonia area. Fish habitats and nursery areas are being destroyed, leading to a decline in biodiversity and the migration of species to other areas. Between 2013 and 2023, mangrove forests lost 35% of their surface area, falling from 3,522.26 ha to 2,283.32 ha. At the same time, degraded areas increased by 759 ha, reaching 4,286.95 ha. The surface area of water channels decreased from 1,250.25 ha to 784.12 ha, while built-up areas increased by 431.69 ha, reaching 2,931.97 ha. The mudflat ecosystem also changed, increasing from 1,614.98 ha to 1,828.69 ha. If the unsustainable exploitation of the mangrove continues, the ecosystem of Sonfonia could be completely destroyed.

Keywords: Analysis; Dynamics; Exploitation; Mangrove; Estuary

1. Introduction

Mangrove forests, found along tropical and subtropical coastlines, play a crucial ecological and socioeconomical role. In addition to preserving biodiversity, mangroves absorb large amounts of carbon, thereby helping to mitigate the effects of climate change [1; 2]. They also act as a shield against coastal disturbances while providing a multitude of services such as the production of wood and non-wood forest products [3]. In urban areas, these forests serve as natural sponges, absorbing excess water that could cause flooding [4]. In addition, the abundance of fishery resources depends on the health and integrity of mangrove ecosystems, which serve as habitats and nursery and growth areas for marine resources such as crabs, shrimp, fish, and endangered species (manatees, Nile crocodiles, etc.). Despite these goods and services, mangroves are under numerous anthropogenic pressures that are causing their disappearance around the world [5].

With approximately 3.2 million hectares of mangroves, Africa is home to an exceptional wealth of biodiversity, nearly 70% of which is found in Nigeria, Mozambique, Madagascar, Guinea, and Cameroon [6]. However, this ecosystem is seriously threatened by various factors, including land conversion for agriculture and aquaculture, coastal urbanization, pollution, overexploitation of resources, and the impacts of climate change [7; 8]. As a result, nearly a quarter of mangroves have disappeared since the 1970s, and their natural regeneration capacity is increasingly compromised [9].

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In the Republic of Guinea, mangrove exploitation is a complex and crucial issue for the environment and local communities. Guinea's mangroves, which stretch along the coast and up to 40 km inland, are rich in biodiversity and play an essential role in protecting the coastline from erosion and flooding [10; 12; 13]. Several factors threaten this ecosystem and have led to a significant decline in mangrove areas over the years. In its summary report [14], the West Africa Mangrove Initiative project estimated the area of mangroves in Guinea at 400,000 ha in 1957 and 350,000 ha in 1965. Today, mangroves cover only 296,000 ha. Unfortunately, this ecosystem continues to suffer progressive degradation, threatening by local communities that depend on it for fishing and other livelihoods.

The Sonfonia estuary is a good example of these environmental issues. Once a sanctuary for biodiversity, this area is now severely degraded due to unsustainable practices, including logging, salt extraction, and uncontrolled urban expansion. The reduction in mangrove cover is seriously impacting the ecosystem services they provided, with a loss of habitat for fish species, accelerated silting of channels, and disruptions in aquatic food chains. he estuary of Sonfonia located near a rapidly growing population between Conakry and Dubréka, is a textbook case for analyzing the dynamics of its evolution between 2013 and 2023 and better understanding the factors contributing to the degradation of the fragile mangrove ecosystem, in order to develop and implement a sustainable management strategy for this area.

The question is: how the mangrove of Sonfonia is exploited? and what impact would have the sustainable management? To answer this question, to answer these questions, this study aims to identify and describe the factors contributing to the degradation of the mangrove of the estuary of Sonfonia in order to analyze their evolution between 2013 and 2023 with a view to implementing a sustainable management strategy. It will be based on a spatio-temporal mapping of the study area over a decade to highlight the changes observed and discuss the extent of the factors contributing to the degradation of this mangrove ecosystem.

2. Methodology

2.1. Presentation of the study area

Covering an area of 62 km^2, the estuary of Sonfonia is located to northwest of the city of Conakry, in the municipality of Ratoma (Figure 1), which has a population of 716,770 inhabitants, with a high average density of 11,560 inhabitants per km^2 [15]. The study area includes an estuary of approximately 6 km long, which is one of the four major waterways leading into Sangaréyah Bay [16].

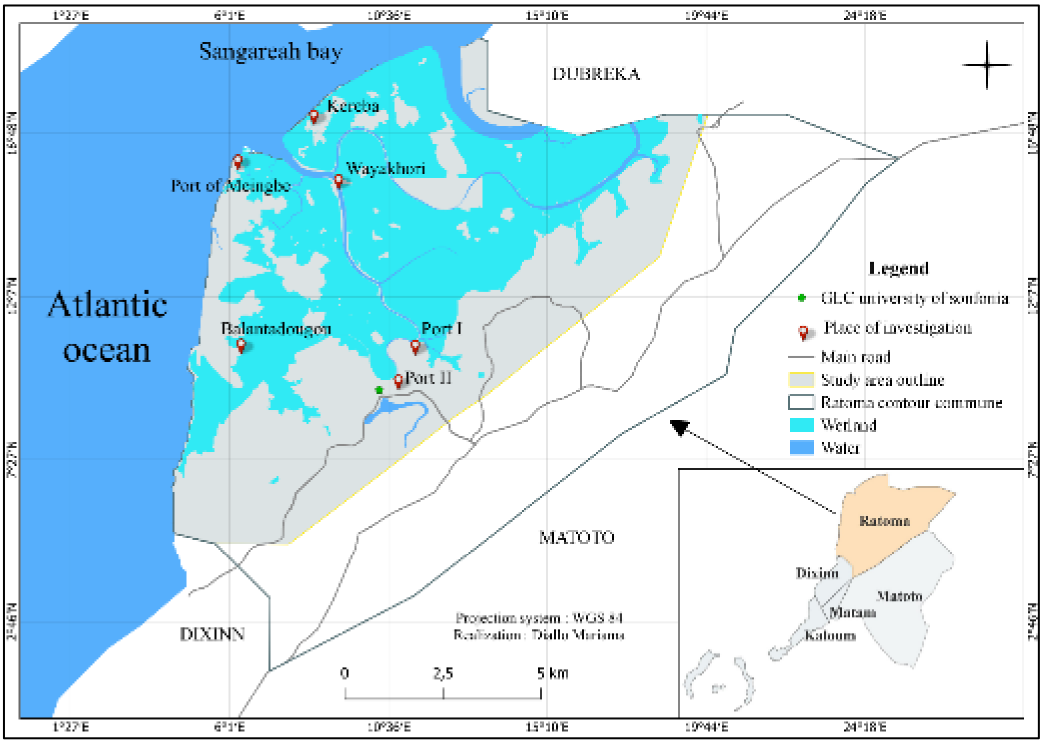

Figure 1 Location map of the estuary of Sonfonia

The study area, located in Ratoma, is bordered to the north by the Prefecture of Dubréka and to the south by the municipality of Dixinn.

2.2. Method

The methodology adopted for this study is based on three main components. First, socio-economic surveys were conducted among the various stakeholders involved in mangrove exploitation. These surveys aimed to identify the factors linked to the degradation of this ecosystem and concerned data on the socio-professional stakeholders interested to the resource, exploitation practices, perceived impacts, and socio-economic constraints.

After conducting a preliminary survey with local authorities on the characteristics of the socio-professional actors who exploit these ecosystems of mangrove, a sample of representative groups of actors, including loggers, rice farmers, fishermen, and willow growers, was targeted for more in-depth focus groups.

Subsequently, a spatio-temporal map of the mangrove of Sonfonia was developed, covering a ten-year period (2013-2023). The data used came from Google Earth Pro satellite images and OSM data, which were integrated and analyzed using QGIS v3.28 software. This step made it possible to visualize changes in land use and quantify transformations in the mangrove landscape, such as the loss of mangrove area and the expansion of urbanized areas. Finally, the cartographic data was combined with information from surveys for in-depth analysis. The indicators selected include the area of degraded mangroves, changes in land cover, and changes in land use dynamics. The results were analyzed using statistical analysis tools (Microsoft Excel 2021) and presented in tables to illustrate trends.

2.2.1. Factors contributing to mangrove degradation

Observations were made at various sites in the study area, such as artisanal fishing ports, salt farming areas, rice fields, and mangrove cutting areas, to better understand the impacts of mangrove exploitation. These observations made it possible to assess the state of degradation of coastal ecosystems along the coastline and estuary, focusing on parameters such as the extent of land clearing and the intensity of human activities. The sites were selected to cover the entire study area and represent the diversity of activities and pressures on the mangrove. The dynamics of socio-professional activities were also analyzed through individual interviews and semi-structured focus groups involving a representative sample of local users (loggers, willow growers, rice farmers, and fishermen). These discussions provided qualitative information on exploitation practices, motivation of stakeholders, and perceived impacts. The data was supplemented by structured questionnaires on degradation factors, the extent of destructive activities, and their ecological impacts.

2.2.2. Spatio-temporal mapping of the study area

Although automated detection studies using pixel classification of high-resolution satellite images (Landsat or Sentinel) exist, acquiring these data synchronously (same date for the entire area) represents a significant financial cost. However, free alternatives are available, notably Google Earth Pro, which offers free, very high spatial resolution covering the entire study area, temporal synchronization, and update frequency [17]. The mapping was therefore carried out using free tools and data. As result, recent images (dated 2013 and 2023) were used for the entire study area. The Google Earth Pro satellite images were interpreted using photo interpretation, a visual analysis process that identifies, interprets, and digitally delineates the landscape features of an area using dedicated GIS software. This interpretation is visual, and the delineation is done manually using digitalization tools. However, this approach has some limitations.

Although Google Earth data is of high resolution, it sometimes lacks spectral accuracy for specific analyses (such as infrared to detect the type of vegetations). In addition, the manual photo interpretation method, although accessible, remains subject to operator interpretation. To overcome these limitations, a verification visit was carried out in the field to ensure the accuracy of the mapping data. The mangrove of Sonfonia was mapped using images corresponding to the dry season for the years 2013 and 2023, in order to ensure data consistency.

2.2.3. Production of land cover maps

Following the example of [18], the land cover maps were produced in two stages. First, Google Earth Pro was used to obtain two satellite images of the study area, one dated 2013 and the other 2023. These images, with a resolution of less than or equal to two (2) meters, were used to identify the main land cover groups, including formation of mangrove, water surfaces, bare soil (degraded areas), inhabited sites (built-up areas), and mudflats. Each land cover class was digitalized, and the data was exported to km^2 format to ensure compatibility with various geospatial software. The vector layers resulting from the digitalization were then imported into QGIS, where they were assembled, validated, and corrected to minimize potential errors. The layers were highly imposed according to the principle of spatial hierarchy (point, line, polygon), labeled with symbols appropriate to the land use groups, and then integrated into a coherent map layout. The final maps produced provide an accurate visual representation of land use areas in the study area between 2013 and 2023.

2.2.4. Analysis of cartographic data

Following the production of land cover maps, an in-depth analysis of the changes that occurred during the study period (2013-2023) was carried out using QGIS and Excel 2021. These tools were selected for their ability to combine geospatial analysis (QGIS) and statistical calculations (Excel), ensuring an accurate and reproducible assessment of observed dynamics. The QGIS field calculator was used to calculate the area of each land cover group for each map. The analysis was based on a comparison of the spatio-temporal dynamics of the areas of the different land cover classes identified for the two periods (2013 and 2023), across the entire site and within the study area. To measure the change and percentage change in the different classes, we used the method described by [19], using the following mathematical formula:

$$Pe = [(S_2 - S_1) / S_1] \times 100$$

Where, Pe = percentage change (%); S_1 = Area of the class in 2013; S_2 = Area of the class in 2023.

Analysis of the change values revealed cases of progression (indicated by positive values) and cases of regression (negative values). These results highlighted the impact of human activities on the area of the mangrove of Sonfonia.

3. Results

3.1. Distribution of respondents by survey site

The results obtained on the distribution of respondents by site are presented in Figure 2.

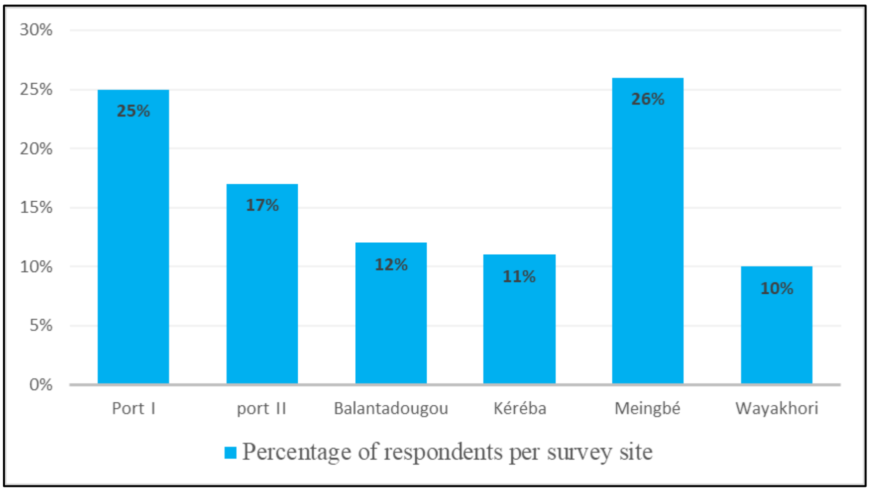

Figure 2 Percentage of respondents by survey site

The sites of Meyengbe and Port I in Sonfonia, with 26% and 25% of respondents respectively, are the areas where the most active players in terms of mangrove resource exploitation are found; these sectors are strategic locations for these activities. Port II in Sonfonia, with 17% of respondents, shows relatively sustained activity, although less concentrated than Port I. Its role as a relay port, due to the decrease in the frequency of rising tides, which no longer allow docking at Port I as often, could explain this position. The sites of Balantadougou (specializing in salt farming) and Kereba (a mangrove cutting area), with 12% and 11% respectively, have relatively lower rates of respondents, indicating that these areas are less frequented or have more limited exploitation. The Wayakhori site, with 10%, is the area with the fewest respondents. This may mean that its exploitation potential is lower or that its resources are less abundant. The results show that mangrove resource users are more concentrated in Mèyingbé and Port I, while the other areas have more moderate levels of activity. This distribution could help to guide sustainable management strategies.

3.2. Distribution of respondents according to activity

Four main activities were identified that exert anthropogenic pressure on the mangroves of the estuary of Sonfonia. The results of the distribution of respondents according to activity in the mangrove are shown in Figure 3.

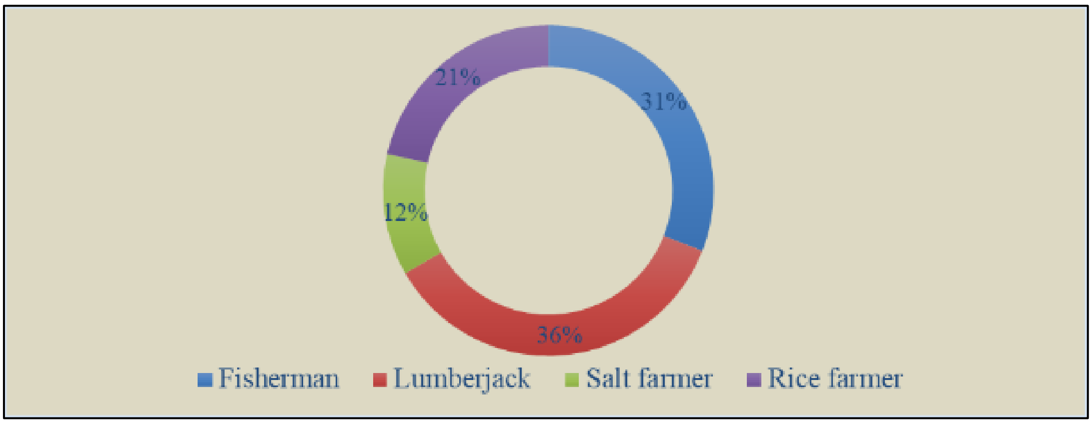

Figure 3 Breakdown of respondents by activity

The figure shows that the mangrove of the estuary of Sonfonia is exploited in a variety of ways, with a marked concentration of logging (36%) and fishing (31%) activities. This raises questions about the management and conservation of fishery resources and reveals their dependence on the mangrove as a nursery area. Rice farmers, accounting for 21% of those surveyed, clear the mangrove to practice flooded rice cultivation. Their presence suggests an adaptation of agricultural practices to the specific conditions of this ecosystem. Salt farmers, accounting for 12%, are the smallest group. Their activity remains essential for the production of cooking salt.

3.3. Breakdown of respondents by gender

Figure 4 shows the results of the breakdown of respondents by gender.

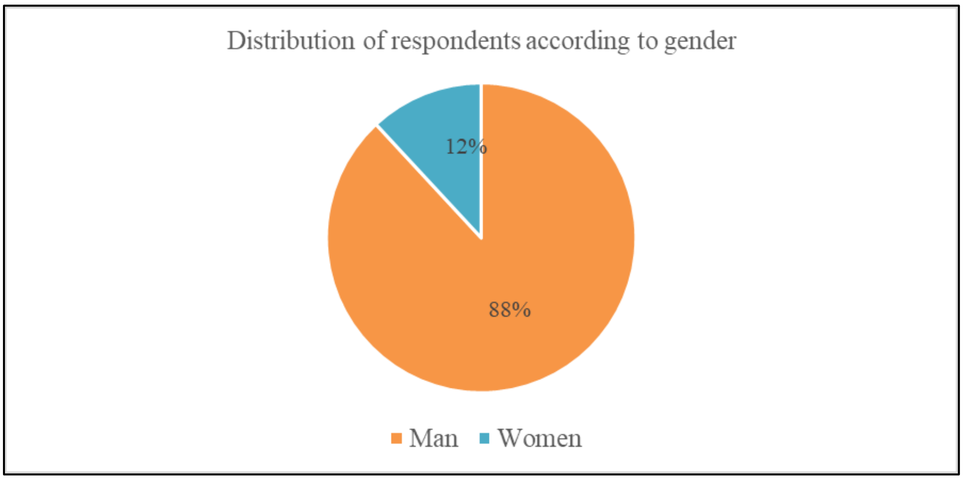

Figure 4 Distribution of respondents by gender

With 88% of respondents, there is more male predominance in mangrove exploitation in Sonfonia. This can be attributed to the nature of the jobs practiced in the mangroves, which are often physical and intensive, and to some socio-cultural constraints. Otherwise, women, who account for 12% of respondents, are more represented in activities that are more often focused on shore fishing, the processing and marketing of mangrove products, and the production of cooking salt. This low female participation could be linked to social barriers. Thus, the low proportion of women in these activities could open discussions on issues of inclusion, access to economic opportunities, and gender dynamics in the exploitation of mangroves in Sonfonia.

3.4. Perception of respondents to factors contributing to mangrove degradation

While most stakeholders acknowledged that mangroves have undergone significant decline in recent years, a survey was conducted among them to better identify the factors contributing to this decline. The results are shown in the following figure 5.

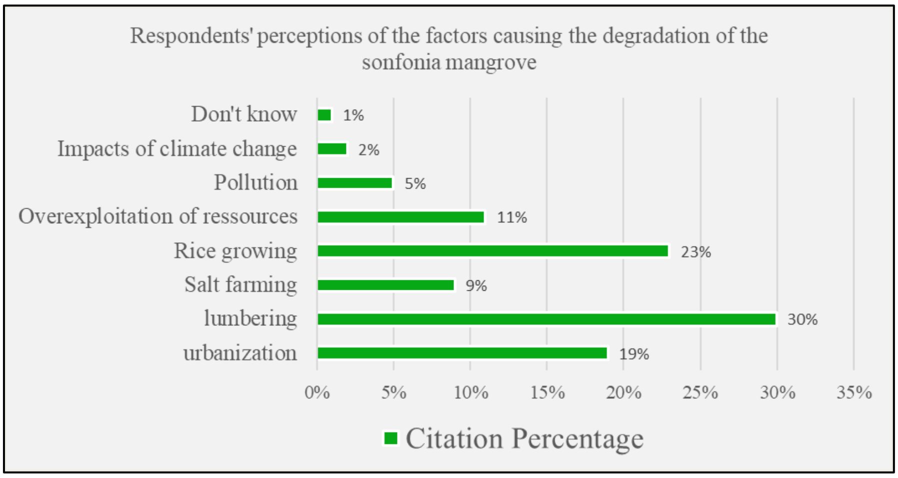

Figure 5 Factors contributing to degradation of the mangroves of Sonfonia

Analysis of this figure reveals that mangrove degradation is mainly attributed to anthropogenic factors, with relatively less mention of climate change, despite its increasingly noticeable effects through frequent flooding, rising sea levels, coastal erosion, etc. At 30%, logging is identified as the main factor in the degradation of the Sonfonia mangroves. This perception among respondents reflects the pressure exerted by the cutting of mangrove wood, which is mainly used as firewood and for construction. Rice cultivation, at 23%, ranks second, suggesting that the conversion of mangrove land to agricultural areas contributes significantly to the loss of this natural habitat. At 19%, urbanization also represents a significant threat. With urban population pressure coupled with the rapid expansion of the city of Conakry, the rice fields of Sonfonia are not excluded to be converted into urban land, thus accelerating the disappearance of mangroves.

The pressure exerted by the overexploitation of fishery resources (11%) and salt farming (9%) is also significant and affects the natural regeneration of mangroves. On the other hand, pollution, cited by 5% of respondents, and the impacts of climate change, cited by 2%, are less frequently mentioned. This may be due to a lower awareness of their effects on this fragile ecosystem or to a lack of awareness of the effects of global warming on mangroves. A sustainable management approach must be considered to limit these effects and preserve this essential ecosystem.

3.5. Spatio-temporal mapping of the study area

The results of the spatio-temporal mapping of the study area in 2013 and 2023 are presented in Figure 6 and 7.

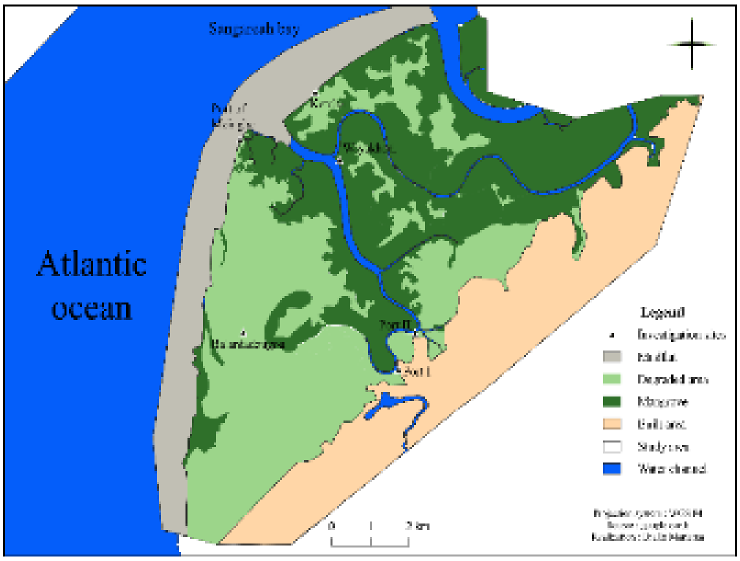

Figure 6 Land use map of Sonfonia in 2013

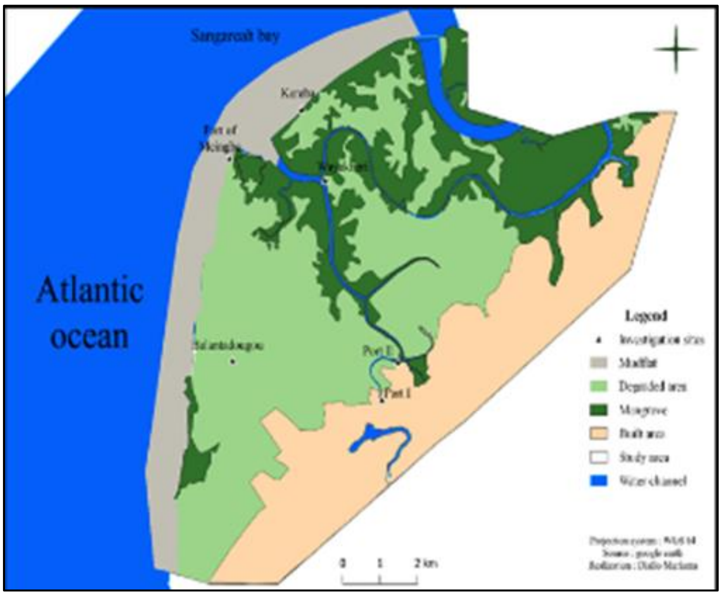

Figure 7 Land use map of Sonfonia in 2023

3.6. Analysis of cartographic data

The areas of land use classes are shown in the following table.

Table 1 Results of land use class areas for 2013 and 2023

Land use class	Area (ha)		Evolution (ha)	Percentage change
	2013	2023		
Mangroves	3522,26	2283,32	-1238,94	35%
Degraded area	3527,95	4286,95	+759	22%
Mudflat	1614,98	1828,69	+213,71	12%
Built-up area	2500,28	2931,97	+431,69	17%
Water channel	1250,25	784,12	-466,13	37%

This table shows that mangrove and water body areas have declined by 35% and 37% respectively. Mangrove coverage has fallen from 3,522.26 ha in 2013 to 2,283.32 ha, representing a loss of 1,238.94 ha, or 35% of its total area. This decline is mainly due to rapid urbanization and overexploitation of resources. The consequences of this decline in mangroves are a significant increase in degraded areas, characterized by depleted soils and loss of biodiversity. These areas increased from 3,527.95 ha in 2013 to 4,286.95 ha in 2023, an increase of 759 ha (+22%).

Channels and other bodies of water have also undergone a significant reduction in surface area, from 1,250.25 ha in 2013 to 784.12 ha in 2023, a decline of 466.13 ha. This decrease directly affects aquatic ecosystems and fishery resources, which are essential for local populations living near estuaries. In addition, built-up areas have increased from 2,500.28 ha in 2013 to 2,931.97 ha in 2023, an increase of 431.69 ha (+17%). This expansion illustrates the accelerated urbanization of the area, but raises the question of sustainable infrastructure management and its environmental impact. These phenomena have led to the gradual silting up of the study area, where the mudflat ecosystem has grown from 1,614.98 ha in 2013 to 1,828.69 ha in 2023, an increase of 13%.

4. Discussions

4.1. Factors contributing to mangrove degradation

The perceptions of local stakeholders surveyed on the factors contributing to degradation in the Sonfonia area revealed that mangrove degradation is mainly attributed to anthropogenic factors, while environmental causes remain relatively unidentified. Logging is identified as the main factor in degradation, confirming the work of [20], who showed that the exploitation of mangrove wood leads to accelerated deforestation, compromising natural regeneration and reducing essential ecosystem services. The conversion of mangrove land to rice fields also profoundly affects biodiversity and disrupts hydrological balances, as shown by studies by [21] in Guinea-Bissau. Urbanization is a growing threat, exacerbated by population pressure and the expansion of urban infrastructure. This corroborates the work of [22], who showed that the conversion of rice fields to urban land accelerates the disappearance of mangroves and reduces their ability to protect coastlines from coastal erosion and flooding. On the other hand, pollution and the impacts of climate change are less perceived as factors of degradation. However, the work of [23] shows that sea level rise and changes in hydrological regimes influence the resilience of mangroves. This difference can be explained either by a lack of awareness or insufficient awareness of the effects of global warming on the mangroves of Sonfonia.

4.2. Spatio-temporal changes in Sonfonia's ecosystems

4.2.1. The decline of mangroves

Between 2013 and 2023, the mangroves of Sonfonia have lost 1,238.94 ha, or 35% of their total area, mainly due to urban expansion and excessive mangrove logging. This decline has led to a significant deterioration in ecosystem services [24]. Our findings also corroborate those of [13], who show that Guinea currently has just over 2,000 square kilometers of mangrove forests, compared to 2,992 in 1980, mainly due to unsustainable harvesting of mangroves. Over the years, the role of mangroves in coastal protection and carbon storage has been severely compromised, exacerbating the vulnerability of coastal areas to climate risks.

4.2.2. The expansion of built-up areas

The increase in built-up areas of 431.69 ha (i.e., +17%) reflects rapid urbanization at the expense of natural ecosystems. Although this expansion is essential to meet population growth, it poses challenges in terms of sustainability and responsible mangrove management. This phenomenon is also documented by [25], who show that cutting mangroves for port infrastructure leads to serious ecological impacts, including biodiversity loss and coastal erosion. Furthermore, the findings of [25] Subhendu et al. (2023) corroborate this trend, indicating a 32% reduction in mangrove area in Guinea since 1980.

5. Conclusion

At the end of this study, it is clear that the Sonfonia mangroves are under increasing anthropogenic pressure at an alarming rate. Since the 1992 mangrove project, no concrete initiatives aimed at limiting the degradation and overexploitation of this ecosystem have been observed in the field. The pressure on mangroves is due to commercial exploitation, unplanned urbanization, and unregulated exploitation of resources at a rate that far exceeds the natural regeneration capacity of mangroves. he impacts of this pressure are visible, and field surveys and observations have identified the main factors responsible for this degradation. Spatio-temporal analysis has revealed a significant reduction in mangrove areas and water channels, as well as an alarming increase in mudflats due to coastal erosion and sea level rise, which is particularly visible in Meyingbe. These phenomena compromise the vital functions of mangroves, which are essential to biodiversity, local human activities, and carbon sequestration. Finally, the results highlight the urgent need for sustainable and proactive management. Without concrete measures to protect and enhance the mangrove of Sonfonia, this ecosystem is expected to disappear completely within the next 30 years, jeopardizing the ecological services it provides and the local environmental balance.

For sustainable management of the mangrove forest of Sonfonia, conservation of this fragile ecosystem must be based on a participatory or co-management approach, involving local communities and stakeholders who depend on it.

In light of our findings, which are quite worrying for the future of the mangroves in the Sonfonia area, and given the threat of their disappearance, we recommend:

To the public authorities

- To introduce appropriate legislation on mangroves;
- Reforest degraded mangrove areas;
- Support NGOs working to restore and maintain the mangrove ecosystem;
- Establish specific regulatory frameworks to regulate the exploitation of mangroves, including exploitation quotas and seasonal bans;
- Promote participatory management involving local communities, authorities, and stakeholders in decision-making;
- Establish a monitoring system to track the condition of mangroves and exploitation activities;
- Provide mangrove managers with sufficient financial and logistical resources.

To mangrove managers

- Conduct awareness campaigns among operators and local populations on the importance of mangroves and the long-term economic benefits of sustainable management.
- Reforest degraded areas and strengthen community monitoring.
- Support sustainable alternative livelihoods for local communities to reduce pressure on mangroves.
- Develop solar salt pans on abandoned rice fields and salt extraction areas.
- Enforce rules and regulations on mangrove forest management;
- Regularly assess progress and adjust management strategies based on results.

To mangrove operators

- Adopt sustainable harvesting methods such as selective harvesting, taking only mature mangroves and leaving young trees to grow to ensure the natural regeneration of the mangrove;
- Stop using chainsaws and gillnets in the mangrove forest;
- Contribute to reforestation and support the natural regeneration of mangroves
- Avoid catching immature fish (juveniles);
- Comply with regulations put in place to maintain and preserve the mangrove ecosystem.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflicts of interest.

Statement of informed consent

The informed consent of all patients to participate in the study was acquired and confidentiality was observed throughout the data collection process. The results were used for strictly scientific purposes.

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