Assessment of the Spatial Evolution of the Mussulo and Samba Pequena Bay Wetlands Using Geotechnologies and Implications for the Ramsar Convention

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Key words: Mussulo Peninsula, Wetlands, Geotechnologies, Coastal dynamics, Ramsar Convention.

SUMMARY

The first Conference of the Parties to the Convention on Biological Diversity recommended the classification of Ilhéu dos Pássaros as an Integral Nature Reserve, while the Ramsar Convention provides guidelines for the protection of marine wetlands with depths of up to six metres. The Mussulo peninsula, Mussulo Bay, its islands and Samba Pequena Bay form a dynamic coastal system increasingly affected by human occupation. Although Angola is a signatory of several environmental conventions, it still lacks officially protected marine or coastal areas, making Mussulo a strong candidate for classification. To assess the spatial and environmental evolution of the area, historical maps and satellite image time series were analysed using geotechnologies and geographic information systems. The analysis revealed shoreline advance, expansion of island areas, emergence of new islands and a progressive reduction in both flooded area and bay depth, mainly associated with increased sedimentation from the Cambamba river basin and the Samba coastal zone. Formerly submerged areas have also been occupied by buildings, increasing environmental and social risks. Without effective management and protection measures, environmental degradation is likely to intensify. This study provides scientific support for monitoring coastal dynamics and for classifying the Mussulo area as a protected zone under the Ramsar Convention, contributing to the conservation of wetlands and mangroves.

RESUMO

A primeira das partes da convenção sobre a Diversidade Biológica recomenda o Ilhéu dos Pássaros como reserva e a Convenção de Ramsar foca em zonas húmidas até seis metros. O sistema Mussulo-Samba Pequena enfrenta forte pressão antrópica e carece de proteção oficial em Angola. Análises baseadas em series históricas de mapas e imagens de satélite, geotecnologias e Sistemas de informação geográfica revelaram o avanço da linha de costa, novas ilhas e redução da profundidade devido à sedimentação. Este estudo fundamenta cientificamente a monitorização costeira e a urgência de classificar o Mussulo como área protegida de Ramsar, essencial para a conservação de mangais e da biodiversidade local.

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1. INTRODUCTION

Coastal wetlands are ecosystems of high biological productivity and ecological complexity, essential for maintaining biodiversity, regulating biogeochemical cycles and protecting the coastline. According to the Ramsar Convention, they include marshes, ponds, lagoons, mangroves and shallow marine waters, whether natural or artificial, permanent or temporary, with a depth of less than six metres at low tide (Ramsar, 1971; ICNB, 2008).

These ecosystems provide important environmental services, such as sediment and nutrient retention, coastal erosion mitigation, carbon sequestration and the provision of critical habitats for waterbirds and marine species, as well as supporting relevant socio-economic activities such as artisanal fishing, tourism and recreation, especially in urbanized coastal areas (Smith et al., 2024).

Despite their high ecological importance, coastal wetlands are among the most threatened ecosystems globally due to increased anthropogenic pressures, such as urbanization, industrialization, pollution, agricultural expansion, and disorderly coastal occupation, which cause significant changes in their structure and functioning (Pacheco e Silva, 2014; Marine Development, 2024). The spatial dynamics of coastal zones result from the interaction between natural processes and human interventions, such as dredging, infrastructure works and vegetation removal, modifying the coastline and increasing vulnerability to environmental risks, including erosion, flooding and excessive sedimentation (Gianuca and Tagliani, 2012; Martínez Piedra et al., 2001).

Given the high complexity of these systems, integrated planning and management approaches are necessary, such as Integrated Coastal Management, which seeks to reconcile economic development, environmental protection and social well-being, with a view to Marine Spatial Planning (MSP), which spatially organises human activities, reduces conflicts of use and promotes the conservation of ecosystems (Gianuca and Tagliani, 2012; Portz et al., 2014; GNC-OEM, 2019). Under the Benguela Current Convention, MSP has been promoted as an essential tool for the sustainable governance of marine resources in Angola, including the identification of EBSAs such as the Mussulo–Barra do Kwanza–Cabo Ledo complex (GNCOEM, 2017).

The protection of coastal wetlands is supported by international instruments, notably the Ramsar Convention, which defines criteria for the identification and conservation of wetlands of international importance, with a view to maintaining biodiversity, ecological integrity and the rational use of natural resources (Ramsar, 1971; ICNB, 2008). However, the formal creation of protected areas alone does not guarantee their conservation. It is essential to implement effective environmental management practices, enforcement and involvement of local communities, challenges that in developing countries such as Angola are often exacerbated by institutional, technical and financial constraints (Oliveira, Oliveira and Pinheiro, 2016).

Advances in geotechnologies have revolutionized the analysis and management of coastal areas, enabling the integration and processing of large volumes of georeferenced data from multiple sources, such as historical maps, satellite images, GNSS surveys and environmental data (Niu et al., 2005; Braz et al., 2013). Geographic Information Systems (GIS) are fundamental tools for spatial analysis, enabling the visualization, cross-referencing and modelling of environmental, social and economic information. Its application in coastal areas allows monitoring changes in the coastline, assessing the evolution of flooded and emerged areas, identifying areas of land use conflict, and supporting decision-making in integrated coastal management (Portz et al., 2014; Ahamed, 2024).

Recent studies show that combining GIS with high-resolution remote sensing significantly improves the accuracy of wetland mapping and the analysis of their spatiotemporal dynamics, providing robust technical support for environmental planning and conservation (Anokye and Hashemi-Beni, 2025). The Luanda coastal system, including Mussulo Bay and Samba Pequena Bay, fits perfectly into the theoretical framework presented, characterized as a complex of highly dynamic coastal wetlands subject to intense anthropogenic pressures and natural processes of sedimentation and erosion. The presence of sandbanks, mangroves, islets and shallow waters gives the area high ecological importance, but also increases its environmental vulnerability.

In this context, the application of geotechnologies and GIS, combined with the principles of Integrated Coastal Management and Marine Spatial Planning, constitutes an appropriate methodological approach to understand the spatial evolution of the system, assess the dynamics of flooded areas and provide reliable scientific information to support strategies for the conservation, planning and sustainable use of these coastal ecosystems.

2. Characterization of the Study Area – Mussulo Peninsula, Mussulo Bay and Samba Pequena Bay

The Ramsar Convention reveals disparities between CPLP countries, with Brazil standing out as having the largest classified area, while Angola has no recognized sites. This situation highlights the need to identify wetlands of high ecological value in the country. In this context, the Mussulo Peninsula, Mussulo Bay, Ilhéu dos Pássaros and Samba Pequena Bay were selected because they have characteristics that are compatible with the criteria of the Ramsar Convention.

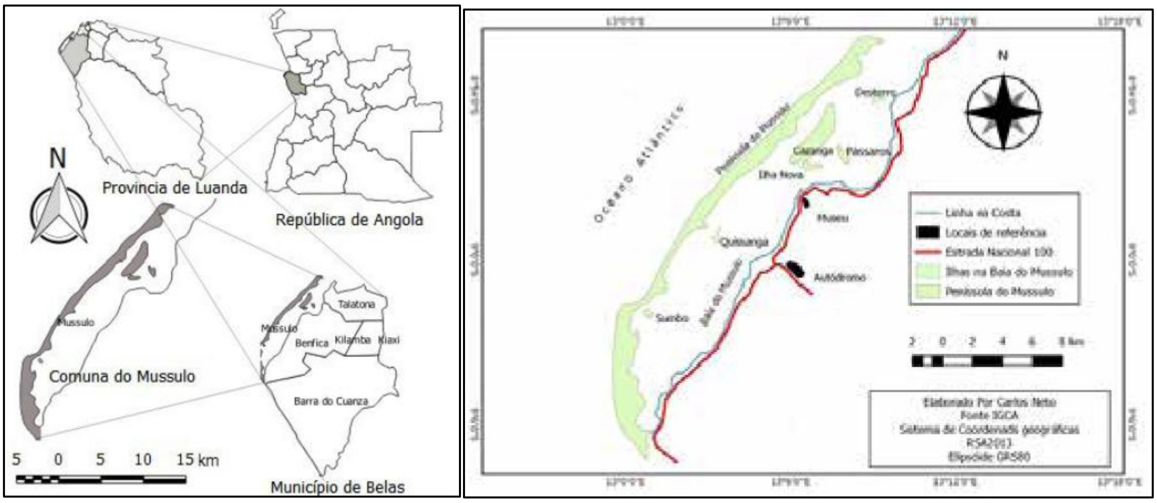

Figure 1 - Location of the study area

The study area is located in the south-west of Luanda and is administratively part of the municipality of Belas. The delimitation was based on official cartography and geographical coordinates, covering the Mussulo Peninsula, Samba Pequena Bay, Mussulo Bay and the associated islands, namely Cazanga Island, Pássaros Island, Desterro Island and Quissanga Island, as can be seen in the figure 1 . The analysis also considered the spatial and temporal evolution of the islands, including the disappearance and emergence of new islands over the analyzed periods.

The dynamics of the area are conditioned by the Samba River basin, which flows into Mussulo Bay and Samba Pequena Bay, transporting water and sediments, especially during the rainy season. The hot and humid climate, combined with high rainfall variability, influences the morphology and environmental conditions, with vegetation dominated by mangroves and sandbanks. Of particular note is Ilhéu dos Pássaros, a protected area of high ecological value that requires continuous monitoring due to pressure on biodiversity.

3. MATERIALS AND METHODS

For the production of geospatial information and to form the basis for assessing the evolution and dynamics of the Mussulo Peninsula and its bay, the adjacent areas including Samba Pequena Bay, as well as the spatial analysis of the variation between areas occupied by water and islands, different sources of cartographic data and satellite images were collected and integrated. Historical maps of the area, published by the Geographic and Cadastral Institute of Angola (IGCA), were used, as well as time series of satellite images, complemented by a specialized bibliographic review and analysis of the applicable legislation.

This approach was reinforced by the author's experience gained through his participation in the Marine Spatial Planning project in Angola, developed in the context of the MARISMA project, which is part of the Benguela Cold Current Convention, a consortium of the Governments of

Angola, South Africa and Namibia, whose main objective is to determine marine areas of ecological and biological importance and establish conservation areas, Thematic maps were produced reflecting the existing situation along the coast, enabling integrated spatial analysis, the results of which are contained in the technical reports on Marine Spatial Planning (MSP) in Angola, reinforced by Presidential Decree No. 177/22.

In the first stage of the work, field visits were carried out with the aim of visually assessing the main aspects of the landscape, the anthropic activities carried out in the area, new constructions, vegetation cover and the consequent intensification of erosion processes. The behaviour of the coastline was also observed, particularly in the areas of Mussulo Bay and Samba Pequena Bay. For the spatial assessment of the existing situation at different times, maps of the study area published by IGCA were collected, as well as satellite images that allowed for the analysis of the evolution of the coastline, the islands and the configuration of the bays. Considering the long period without systematic updating of the cartography, historical series of satellite images were used to complement the analysis of the morphological evolution of the coastline of Mussulo Bay, the associated islands and Samba Pequena Bay.

Thus, topographic maps covering the entire work area were used. With a view to spatial harmonization of data and comparability between different sources, the transformation parameters defined by the Interministerial Commission for the Delimitation and Demarcation of Angola's Maritime Spaces (CIDDEMA) were introduced, obtained as part of the project to extend the Continental Shelf beyond 200 nautical miles, developed under the supervision of IGCA and the Faculty of Sciences of Agostinho Neto University in 2015.

Thus, all cartographic information used — historical maps and satellite images — was referenced to the WGS 84 geodetic system, with UTM projection, zone 33 South. The spatial coincidence of previously selected notable points was evaluated using QGIS software, and the cartographic information was subsequently vectorized using AutoCAD Land Survey Civil 3D software.

Files in DXF format containing all the vectorized information were created, from which the areas of the Mussulo Peninsula, the associated islands, Mussulo Bay, Samba Pequena Bay and the areas covered by water were determined. The areas were determined for each season on both the historical maps and the satellite images.

The areas of the islands and islets were determined by vectorizing their visible contours in satellite images. In the case of the Mussulo Peninsula, its boundaries were defined by the land contour up to the intersection with the meridian 13°00'50" E, including the corresponding section of that meridian. For Mussulo Bay, the entire coastal outline was vectorized from the intersection with the parallel 8°51'36" S, following the coastline and the inner outline of the respective bays until returning to the starting point. For Samba Pequena Bay, the entire coastal outline was vectorized.

This procedure was repeated for the topographic map and satellite images from 1981* (1984 for Samba), 2001, 2005* (2006 for Samba), 2010, 2015, 2020 and 2025* (2024 for Samba). The results are illustrated in Figures 3, 4, 5 and 6, which show the images corresponding to each period analysed for both Mussulo and Samba. For Mussulo Bay, based on the vectorised information, the areas of the peninsula, the entire bay and each of the islands were determined. the flooded area was calculated considering the difference between the area of the entire bay and the sum of the areas of each of the islands contained therein.

The areas obtained for each season were subsequently transferred to Microsoft Excel software, where tables containing the area values and respective reference years were organized. Temporal correlations were established, as can be seen in the figure 2, with a view to analyzing the spatial dynamics of the areas and obtaining correlation equations, which were used to predict the future evolution of the flooded areas, assuming similar assessment conditions.

4. RESULTS

The on-site assessment revealed that the area continues to reveal significant changes, with the emergence of new buildings and economic and tourist activity, mainly in the area around the slavery museum. As a result, the area continues to lose native vegetation, and this loss of vegetation exacerbates the erosion process and alters environmental conditions in the area. In addition, there has been an increase in solid waste and water discoloration, indicating sedimentation at various points in the area, judging by the colour of the water, which indicates small areas with great depths and many with reduced depths.

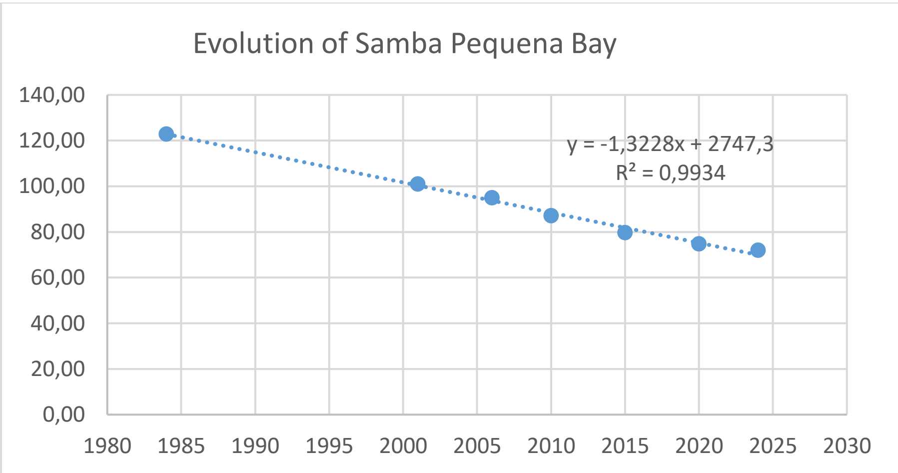

Figure 2 – Evolution of Samba Pequena Bay wetland area.

Topographic maps on a scale of 1:100,000 as shown in the figure 3, were acquired and used in the work, as the larger scale topographic maps available for Luanda (1: 2000 and 1/5000, do not cover the entire work area and were only used in Samba Pequena Bay as shown in the figure 6, hence the difference between 1984 and 1981 marked with an asterisk in Table 1. Thus, from the evaluation of the maps acquired, a small part near Ilhéu dos Pássaros with mangroves can be seen, and the depth does not exceed 9 metres in the deepest areas, with depths not exceeding 6 metres between each of the islands. Between the northern tip of Mussulo and Samba Pequena Bay, the depth does not exceed 27 meters at the time the maps were produced.

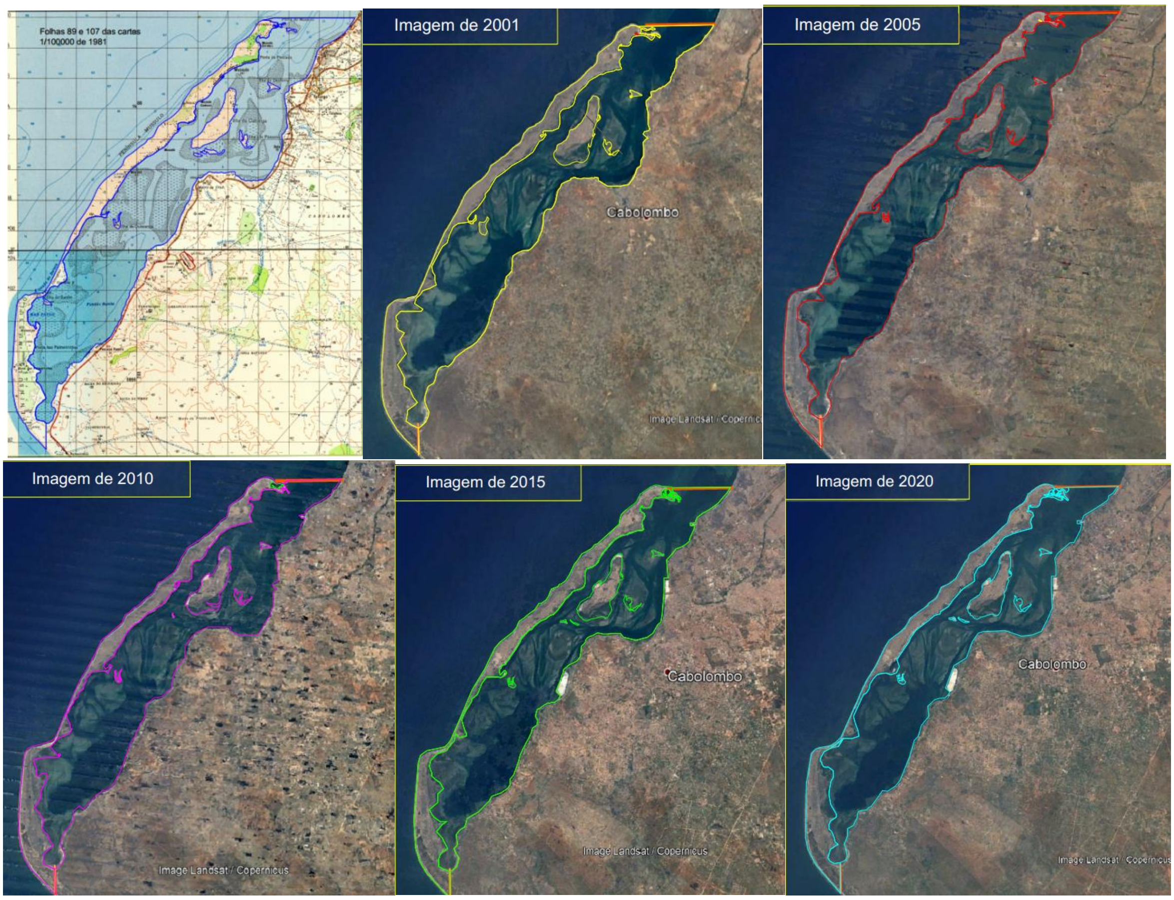

Figure 3 - Extracts from maps and satellite images and vectorization of the areas assessed

Taking into account the depths verified, it is necessary to carry out bathymetric surveys to determine the current depths and assess the level of sedimentation in the area, as well as the areas measured in situ, using classical or photogrammetric survey methods, and to verify the possibility of making as protected area and, based on the depths measured, to verify whether the area meets the requirements for a RAMSAR area, although some areas clearly indicate that they have depths of up to 6 meters.

The bathymetry of the area shows that, from Quissanga Island, the depths gradually decrease towards the coast, the Mussulo Peninsula and the neighbouring islands, with a central zone marked by a bathymetry of 10 metres and extensive shallow areas with steep slopes. In addition, between Quissanga Island and Desterro Island, depths of less than 6 metres predominate, with the exception of a specific depression near the coast, close to Morro da Cruz, an area sensitive to intense construction activity and sediment transport due to erosion. The presence of defined channels and the colour of the water confirm the high degree of sedimentation throughout the region.

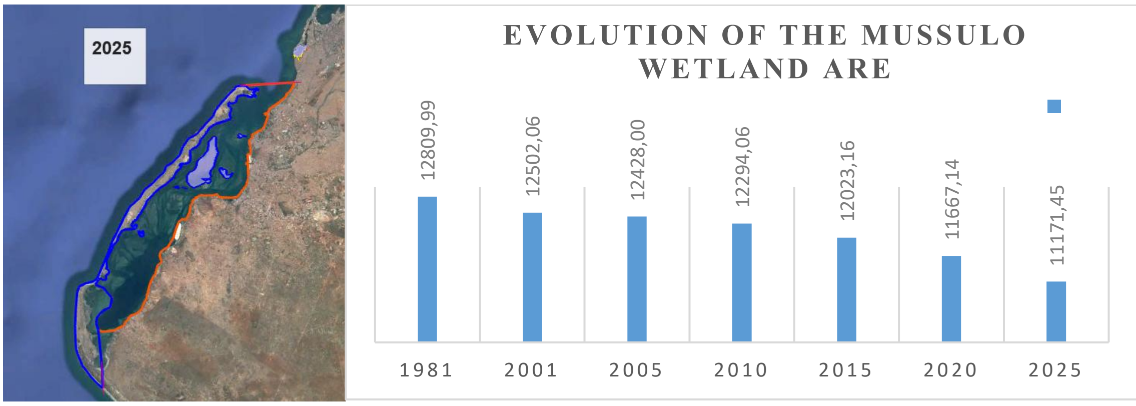

Figure 4 – Satellite image with vectorized areas of 2025 and the Evolution of Mussulo wetland

The distance from the coast to the tip of Mussulo is 1.9 km, with depths ranging from 10 to 27 meters and all the islands have sparse forests and narrow strips of shrubs, new forests and mangroves and on the coast, there are also some mangroves, shrubs and a few trees, as well as many buildings and structures along the coast, also, from a visual assessment of the images, The results indicate that vegetation in the area is sparse and sedimentation is evident, judging by the difference in colours in the part covered by water, where the more yellowish indicates sedimented areas and the darker blue areas corresponding to deeper zones can be seen, as also confirmed by the bathymetry shown on the map used.

The areas of the islands were assessed and there has been an increase in the areas of the Mussulo peninsula, Cazanga Island and Ilhéu dos Pássaros, a reduction in the areas of Ilha do Desterro, the flooded area in the bay and the total area of the bay, while Quissanga Island decreased from 2001 to 2005, since 2005 its area has been increasing, with a tendency to connect with the Mussulo Peninsula, as happened with Sumbo Island.

The first signs noticed in the 2010 images, probably with the reduction in depth, are noticeable in the 2020 images, where The results indicate that the sum of the areas of the new islands is slightly smaller than that of the islands of Desterro and Quissanga, which are currently experiencing a reduction in area, unlike the new islands, which are rapidly increasing in area and are expected that they will exceed the areas of the aforementioned islands in the next years if the pace continues.

Data	Mussulo		Islands						Wetland	
	Peninsula	Bay	Desterro	Pássaros	Cazanga	Quissanga	New	Total	Mussulo	Samba
1981*	3187.63	13367.17	19.56	36.95	479.53	21.14	0.00	557.17	12809.99	122.87
2001	3326.98	13219.05	18.54	38.39	645.11	14.95	0.00	716.99	12502.06	101.00
2005	3504.82	13129.12	17.63	40.02	629.34	14.14	0.00	701.13	12428.00	95.00
2010	3549.90	13015.63	17.43	41.24	643.58	16.74	2.57	721.57	12294.06	87.10
2015	3585.64	12782.15	17.40	42.19	669.78	19.47	10.14	758.99	12023.16	79.70
2020	3720.32	12459.73	16.88	44.71	693.85	21.00	16.16	792.59	11667.14	74.70
2025	4343.46	11973.31	16.22	56.48	703.79	17.77	7.60	801.86	11171.45	71.90

Table 1 – Results of the assessment of areas obtained from maps and satellite images by season.

The reduction in the area of the bay tends to increase rapidly with the emergence of new islands, as can be seen in Figure 4, and with the tendency for their areas to increase. It should be noted that from 2015 to 2020, new islands increased by 59%, having decreased in 2025, probably due to the redistribution of sediments that can be verified with bathymetric surveys, the other islands have continuously increased in area, and this development may exacerbate the reduction in the flooded area, which represents a danger to the area and to species. The rate of reduction in the area of the bay is on average 31.68 hectares per year. All results are included in the table 1.

In the sedimented places, the emergence of new islands is observed as a recent and dynamic process evidenced by images since 2005 with greater clarity from 2010 onwards, when a new island emerged south of Cazanga Island as shown in the figures 3 e 5, also in the table 1, with an area of 2.57 ha, expanding to 10.14 ha in 2015 and reaching 16.16 ha in 2020, with dimensions comparable to the islands of Quissanga and Desterro, which reinforces the need for its official designation.

At the same time, images from 2020 indicate the submersion of approximately 16.157 ha in areas that already require attention from the authorities, due to the advance of residential occupation in risk zones, as well as the occurrence of coastal landfills associated with construction works, dredging and natural sedimentation, especially in Samba Bay and west of Cazanga Island as shown in Figure 3 and reinforced in the 2010 image, which already shows the new island, making visible the white spot that contributes in part to the reduction of the flooded area.

Figure 5 – Emergence and growing evolution of new islands in Mussulo Bay since 2005

With regard to the evolution of the areas of the Peninsula and Mussulo Bay, including the islands they contain, Table 1 shows that the peninsula is steadily increasing in area while the area of the bay is constantly decreasing, indicating constant sedimentation and an advance of the coastline and a worrying dynamic for the wetland area, as there is a risk of its disappearance. The results indicate that the area covered by water (flooded zone) in Samba Pequena (figure 6) and Mussulo Bay (figure 4) is also constantly shrinking, which can be confirmed both by the increase in the area of the islands it contains and by the advance of the coastline.

Here, a considerable reduction can be observed, which, according to the assessment, shows a linear variation that correlates very well with each of the seasons, indicating that there is a loss of flooded area that is worrying given the importance of water for the subsistence of species and the conservation of the place. The equation obtained shows that there is a trend towards a reduction in the area covered by water, which reached 7% of the area by 2020 and could reach 15% by 2065 if measures are not taken to reverse the situation.

In general, it was possible to assess the situation in the area with the appearance of buildings and areas with ongoing land subdivision projects, a possible reduction in depth judging by the water color and the emergence of new islands, in addition to verifying that, with the exception of Desterro Island, which is reducing in size, all the islands are increasing in size, including Mussulo Island, but there is a reduction in the bay in general and a marked loss of the area covered by water (wetland area).

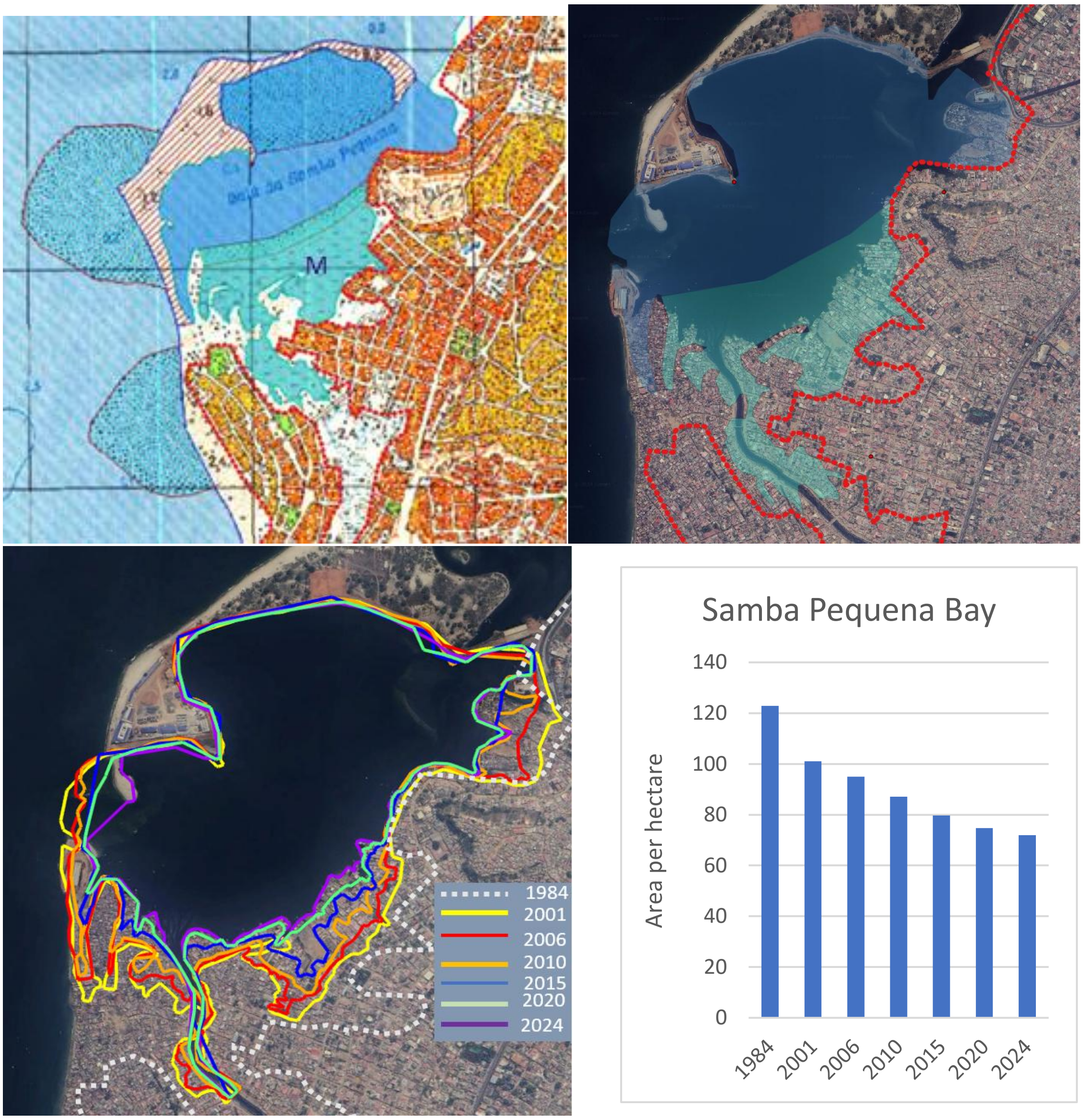

Figure 6 – Wetland area evolution and current condition from topographic map to imagery.

Throughout the period analyzed, Samba Pequena Bay underwent significant changes to its coastline, as can be seen in the upper left side of Figure 6, where the mangrove area marked with the letter M initially covered around 32 hectares and was home of a wide variety of species, has been replaced by buildings and partially covered by water. In 23 years, 32.45 hectares of mangrove forest and 30.97 hectares of aquatic area were lost, mainly due to the advance of coastal occupation. The continuous reduction in the area of the bay allowed to establish a correlation presented in Figure 2, whose equation allowed to predict its future evolution, indicating that if the situation persists, by 2077 the bay could be reduced to only 0.16 hectares, practically disappearing.

5. CONCLUSIONS

Although Angola is a signatory to several international conventions and has legislation and initiatives in the environmental field, the country still does not have formally protected maritime or coastal areas. The results of this study show that the Mussulo Peninsula, Mussulo Bay and Samba Pequena Bay have the natural and ecological conditions that qualify them as strong candidates for classification as wetlands of international importance under the Ramsar Convention, given their shallow depths, the presence of mangroves, high biodiversity and intense pressure from natural processes and human activity.

The application of geotechnologies, including Geographic Information Systems, multi-temporal satellite imagery and bathymetric data, proved to be fundamental for the spatial and temporal assessment of the coastal dynamics of the area. These tools made it possible to analyse the evolution of the coastline, islands and bays, identify the emergence of new islands, quantify variations in their areas and provide robust technical information to support decision-making in the areas of spatial planning, coastal management and the creation of protected areas.

The results show a progressive increase in the area of the Mussulo peninsula and several islands, as well as the emergence of new island formations, accompanied by an advance of the coastline and the growing occupation of land reclaimed from the sea. Of particular note is the tendency for the island of Quissanga to connect to the Mussulo peninsula, a phenomenon similar to what previously occurred with the island of Sumbo, reflecting an advanced process of sedimentation and morphological alteration of the coastal system.

There has also been a continuous and significant reduction in the flooded area in both Mussulo Bay and Samba Pequena Bay, with worrying average rates of loss and projections indicating that this trend will worsen if mitigation measures are not taken. The loss of mangroves, the decrease in depths and the degradation of environmental quality jeopardise biodiversity, ecosystem services and the sustainability of associated socio-economic activities. Given this scenario, it is urgent to implement Integrated Coastal Management measures, carry out regular bathymetric surveys, control human occupation and adopt a legal protection status, namely under the Ramsar Convention, in order to safeguard these coastal ecosystems that are strategic for Angola.

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BIOGRAPHICAL NOTES

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