MOZAMBIQUE LAND USE AND LAND USE CHANGE ASSESSMENT (2001-2020): MANGROVE FORESTS CASE STUDY

Assessment of the current Mangrove status in Mozambique and the changes occurred in the last 19 years (2001-2020) using augmented visual interpretation of very high-resolution satellite images.

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SECOSUD II Project is financed by the Italian Agency for Development Cooperation (AID 9695)

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Maputo, July 2021

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1. INTRODUCTION

Mangrove forests are among the most complex ecosystems on the planet (Smithsonian Institution 2018) and are the only forest located in the tropics and subtropics region found at the confluence between land and sea (Alongi 2002). Through specific physiological and morphological adaptations, such as aerial roots, viviparous embryos, tidal dispersal propagules and the ability to exclude and excrete salt, these plants are able to cope with the instability of the environment in which they live (Alongi 2002; Macamo 2018).

Estimating the mangrove forests cover in Mozambique still remains controversial (Macamo et al. 2016). According to Barbosa et al. (2001) 396 080 ha of mangroves occur in the Country, while this value ranges from around 225 995 ha to 318 000 ha according to other surveys (Shapiro 2018; Giri et al. 2011). Such differences in estimates may be due to the different assessment methodologies adopted, particularly important in the fluid scenario of the Mozambican coastline. Nevertheless, it is estimated that Mozambique hosts the second largest mangrove extension in Africa, after Nigeria, while globally it ranks 13th in mangrove coverage, accounting for about 2.3% of the global mangrove forest area (Stringer et al. 2015). The central region of Mozambique, characterized by organic muddy soils, alluvions and freshwater uptakes from several rivers flowing in the Indian Ocean, has the most extensive mangrove forest (Barbosa et al. 2001; Macamo 2018). Nine species belonging to nine genera of mangrove trees have been recorded in the Country, namely: *Acrostichum aureum* L., *Avicennia marina* (Forssk.) Vierh, *Bruguiera gymnorizha* (L.) Lam, *Ceriops tagal* (Perr.) C. B. Rob., *Heritiera littoralis* Aiton, *Lumnitzera racemosa* Wild., *Rhizophora mucronata* Poir., *Sonneratia alba* Sm. and *Xylocarpus granatum* J. Koenig (Macamo 2018). *Avicennia marina* and *Rhizophora mucronata* are the most diffuse species (Charrua et al. 2020).

Figure 1. Mangrove forest (*Rhizophora mucronata* and *Avicennia marina*) in Inhaca Island, southern Mozambique.

Mozambique population, around 31 million of people ("Instituto Nacional de Estatística - Moçambique. 1996 - 2021" n.d.) is afflicted by high level of poverty (Cabo Buján and Macandza 2017) and its subsistence is often supported by the use of natural resources (MITADER 2015), particularly in the rural areas. Mangroves contribute significantly to the livelihood of Mozambican communities (Macamo 2018), who benefit of their presence both directly and indirectly (Machava-António et al. 2020), through a number of ecosystem services which include food resources, economic income, medicine, cultural and recreational services (Macamo 2018). As direct use, their wood is utilized by communities as building material, firewood, and construction equipment; while ecologically mangroves represent an important fishing ground for several fish and crustacean of significant commercial value (Barbosa et al. 2001). In their indirect use, mangroves act as natural barrier, stabilize fine sediment and protect against coastal erosion, reduce the effects of storms and flooding, maintain the water quality, ensure the nutrient cycling, remove CO_2 from the atmosphere through photosynthesis and support the local wildlife (Vo et al. 2012), providing a sheltered nursery and feeding area for a highly diverse marine fauna (Costa and Ribeiro 2017).

Historically in Mozambique the major threats to mangroves have been human related, including conversion of mangrove forest for agriculture and salt production, over-exploitation of wood, urban expansion, coastal development, decreased flow of freshwater caused by construction of dams, and pollution (Barbosa 2001; Macamo 2018). Moreover, in the last decade, population growth, urban expansion and internal migration (both economic and climate change related) have put further pressure on lands already hosting a high-density population (Malatesta et al. 2019), such as coastal areas. Finally, natural causes such as floods, cyclones and erosion have been documented as one of the main factors in the degradation of mangrove forests in the Country (Bandeira and Balidy 2016; Macamo et al. 2016; Macamo 2018).
According to previous studies (Food and Agriculture Organization of the United Nations 2005; Malatesta et al. 2019) carried out with remote sensing methodology, the mangrove forest extension has suffered a decline from 396.080 ha in 1990 to 259.643 ha in 2016. Recently, between 2019 and 2020, the central region of the Country was hit by three severe cyclones, Idai, Kenneth and Eloise. The full impact of these cyclones on mangrove's cover has not been assessed yet.

This report estimates the current Mozambique mangrove forest cover and mangrove type distribution in the Country, aiming to identify the drivers of change and potential threats, and to determine the impact of the recent cyclones Idai and Kenneth through the application of a free access remote sensing technology. To this end, the County's mangrove forest between 2001 and 2020 was assessed applying various national and international classifications, using the free open-source software Open Foris – Collect Earth (CE) (Bey et al. 2015). This assessment was organised, coordinated, and conducted in strict collaboration with the Department of Biological Sciences, Eduardo Mondlane University – Mozambique, as part of the research activities developed by the SECOSUD II Project.

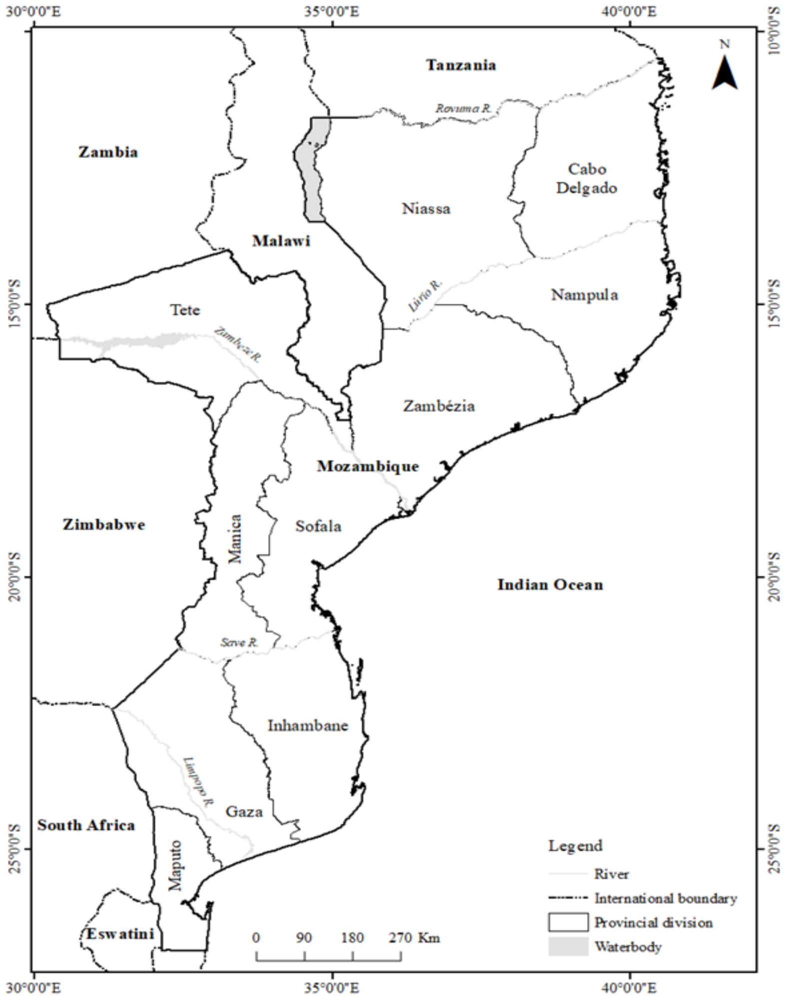
2. MATERIAL AND METHODOLOGY

2.1. Study area

Mozambique is located in southeast of Africa, between latitudes 10° 27' S to 26° 52' S and longitudes 40° 51' E to 30° 12' E, bordered by Tanzania in the North, Indian Ocean in the East, Zambia in the Northwest, Malawi, Zimbabwe and Swaziland in the West and South Africa in the South. The Country has a total surface area of 799 380 km^2 (Instituto National de Estatística 2020) and its coastline extends from about 2770 KM, hosting a variety of rich biodiversity ecosystems (Charrua et al. 2020). The Country's climate is tropical, or subtropical in the south, with a warm and wet summer from November to March, and a cooler dry season from April to October (Charrua et al. 2020). The coastline is the wettest part of the Country, receiving about 800-900 mm of rain per year, with some areas receiving up to 1400 mm per year (Food and Agriculture Organization of the United Nations 2005).

The coastal area can be divided in three main regions characterized by different morphologies. The coralline coast in the North, dominated by shallow reefs, with mangrove forests in bays and sheltered areas, such as river estuaries. The estuarine and swampy coast in the Centre, dominated by mud rich in organic matter, has the most extensive mangrove formations, an almost continuous mangrove forest from the Zambezi River to Beira and further south to the Save River estuary. In fact, according to previous studies, mangrove forest is most abundant in Zambézia and Sofala provinces (Malatesta et al. 2019; Shapiro 2018). The South presents a sandy coastline, characterized by beaches and dunes, with a few mangrove formations, mostly sheltered in bays and estuaries (Barbosa et al.2001; Macamo 2018; Charrua et al. 2020).

Figure 2. Mozambique geographic location and its provinces.



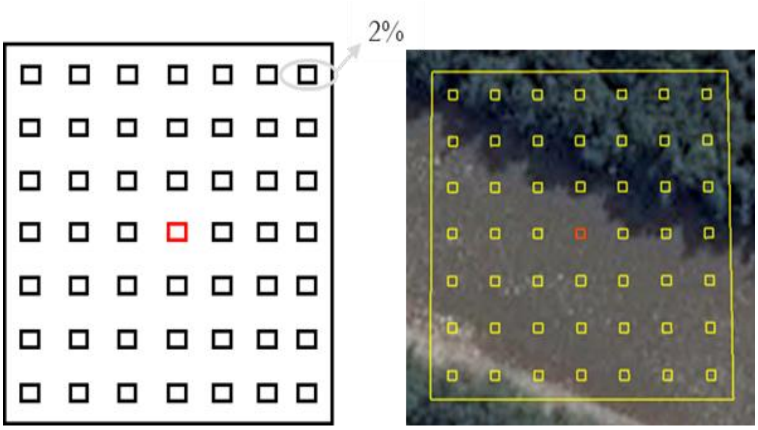
2.2. Data collection

The assessment of mangrove forest cover between 2001 and 2020 was performed using the CE 1.5.1. software ("Open Foris – Collect Earth. Augmented Visual Interpretation for Land Monitoring" n.d.), a free open-source software for land monitoring developed by the Food Agriculture Organization of United Nations (FAO). CE was used as a tool for augmented visual interpretation of Very High-Resolution (VHR) satellite images, allowing the access to freely available archives, which include: VHR satellite images provided by Google Earth and Bing Maps; high resolution satellites imagery, gathered by Landsat 7 and Landsat 8 satellites and provided by Google Earth Engine; vegetation indices such as NDVI, NDWI and EVI, derived from Landsat 7, Landsat 8 and MODIS, elaborated through Google Earth Engine Code Editor (Bey et al. 2016). Through CE it is also possible to access the historical photo database of Google Earth, allowing to perform the augmented visual interpretation of the same plot at different times, thus providing an easy inference of Land Use changes through time.

To assess the effect of the cyclone's impact on all the mangrove's typologies in the Country (including dispersed and low-density patch), the study area considered for the analysis has been increased to include the zones of fringe coverage surrounding the main forests. A unique shapefile of 395 254.15 ha of maximum mangrove occurrence area was derived from two different mangrove extent shapefiles; one developed by World Wildlife Fund – Mozambique and the other from the Department of Biological Sciences of Eduardo Mondlane University, both created through an automatic classification of High-Resolution satellite images. To achieve an effective spatial coverage of the survey area, including possible missing areas in the initial shapefile and examine the possible drivers of land cover changes surrounding the mangrove forests, a buffer zone of 455 767.76 ha was added, totalizing a survey area of 851 021.91 ha. A random grid of 4 306 points was created over the shapefile with a minimum distance of 100 m.

To facilitate the visual interpretation of the land cover in the satellite imagery, each plot was subdivided in 49 (7x7) subplots, each representing ~2% of the plot area. The extent of each cover type in the plot was measured assessing the number of control points falling over specific elements of each land cover type considered in the survey. Each control point accounted for ~2% cover of that element type (*Figure 3*).

Figure 3. Plot Layout



In this work, a classification system based on the Intergovernmental Panel on Climate Change (IPCC) land use standard (Penman et al. 2015) was adopted. According to IPCC Land Use Categories, 6 categories of main land use (*Table 1*) were assessed. The threshold of 20% was adopted to define the land use categories, following an "anthropic impact" hierarchical order: Settlement > Cropland > Forest Land > Grassland > Wetland > Other land. According to the IPCC classification system, mangroves are one of the 11 different forest types existing in Mozambique (Malatesta et al. 2019).

Table 1. Land use categories of the Intergovernmental Panel on Climate Change

Category	Definition
Forest	This category includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but *in situ* could potentially reach the threshold values used by a country to define the Forest Land category.
Cropland	This category includes cropped land, including rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.
Grassland	This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastoral systems, consistent with national definitions.
Wetlands	This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.
Settlement	This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. *This should be consistent with national definitions*.
Other land	This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories.

In our assessment, five mangrove vegetation categories were considered: fringe, riverine, dwarf, overwashed and basin (Macamo et al. 2016, Lugo and Snedaker 1974). The definitions for the categories are as follow:

- *fringe mangrove* – mangroves that grow relatively close to the sea, along the fringe of protected shoreline or directly exposed to tides and sea waves;
- *riverine mangrove* – floodplains mangrove forests growing along flowing waters, such as creeks, and flushed by the daily tides;
- *dwarf mangrove* – adult mangrove with height between 1m and 1.5 m, usually occurs along flat coastal fringe or in arid environment;
- *overwashed mangrove* – small and narrow mangroves, occurring in low-islands and land masses in shallow bays and estuaries, frequently washed over by tides. Their position, obstructing the tidal flow, limits the abundance of organic matter in these forests;
- *basin mangrove* – mangrove forests mainly occurring in inland areas along drainage depressions, regularly flooded during the wet season.

Based on canopy cover, we also classified the mangrove formations as follows: (i) dense adult mangrove (canopy cover ≥ 80%), (ii) medium adult mangrove (80% <canopy cover≥ 50%), (iii) dispersed adult mangrove (canopy cover <50%) and (iv) juvenile/short adult mangroves (canopy cover <50%, individual growth still occurring or limited by environmental factors). Factors of land use change and potential threats to mangrove areas, such as crop encroachment, constructions, fires and natural disaster (cyclones and floods) were assessed as well.

2.3 Quality control

To establish the assessment protocol, a preliminary data collection phase was conducted in synergy by 2 operators on about 1.5% of the total plots.

To reduce random errors and systematic bias due to operator's interpretation, such as misinterpretation of land cover, wrong input in the survey form or overvaluation of a land use category, a quality control was conducted on about 5% of the total plots, randomly selected. Such control plots were duplicated and reassessed independently by the operators. Subsequently, the control plots were compared and analysed, identifying and measuring any possible inconsistencies.

2.4. Data analysis

Land cover for each class was obtained through the following formula: $A_i = N_i * E_f$, where: A_i is the latest (2020) national area (ha) for each i land use category, N_i is the total number of plots assessed for each land use category, and E_f is the expansion factor, resulting from the ratio of the total surveyed area A (851 021.91 ha) and the total plots assessed N (4 306 plots). The expansion factor represents the representative area value of a single plot, expressed in ha (Malatesta et al. 2019). In this assessment, the expansion factor is 197.63 ha. Using such value, we can provide the extent areas for mangrove forest cover, other land uses cover, changes in land uses, loss of land cover, and assess the extent of forest coverage loss.

Qualitative information on the driver of land cover changes can be as well obtained from the direct observation of the satellite images.

Table 2. Random distribution of assessed plots within the country

	Plot count		
Province	**Mangal**	**Buffer**	**Total**
Cabo Delgado	197	243	440
Gaza	2	24	26
Inhambane	154	142	296
Maputo	60	117	177
Nampula	292	423	715
Sofala	534	428	962
Zambézia	788	902	1 690
Total	2 027	2 279	**4 306**

3. RESULTS

3.1. Quality assessment

The performed quality control analysis has detected an error level of approximately 7% for the identification of mangrove forest. This value in partly due to a different interpretation by the operators of the canopy cover uniformity in some analysed plots. Therefore, it does not lead to a significant underestimation of national mangrove forest extent, but only to an acceptable level of uncertainty over the correct extension of some classes of mangrove forest.

3.2. Mangrove forest cover

Overall, 4 306 plots were assessed. Based on our analysis, the current national mangrove cover area was estimated at 386 507 ha, including the areas of dispersed or very dispersed mangroves (50%> canopy cover > 20%). Concerning its distribution (*Table 3.*), the largest mangrove forest cover was found in Zambézia (38.99% of national mangrove forest cover), followed by Sofala (26.98%), Nampula (14.36%) and Cabo Delgado (10.48%). Lower coverages were found in the Inhambane, Maputo and Gaza provinces, representing 6.44%, 2.61% and 0.10% of the national mangrove forest, respectively.

Table 3. Mangrove forest cover at national and provincial level

	National mangrove forest	
Province	**Mangrove (ha)**	**fr (%)**
Cabo Delgado	40 508	10.48
Gaza	395	0.10
Inhambane	24 898	6.44
Maputo	10 078	2.61
Nampula	55 526	14.36
Sofala	104 333	26.98
Zambézia	150 769	38.99
Total	**386 507**	**100**

3.3. Mangrove forest categories

Mangrove forest has been classified in five categories, following Macamo et al. (2016) methodology: basin, fringe, riverine, dwarf and overwashed mangrove (*Figure 4*). Basin mangroves were found to be the dominant type of mangroves (39.11%, 151 164 ha), particularly abundant in the Zambézia province (88 327 ha), followed by fringe (36.55%, 141 284 ha), predominant in Sofala province (39 915 ha), and dwarf (21.17%, 81 806 ha). Riverine and overwashed types were less common, representing 1.84% and 1.33% of the national mangrove forest. The distribution of mangrove forest types is shown in *Table 4*.

Figure 4. Mozambican mangrove forest categories

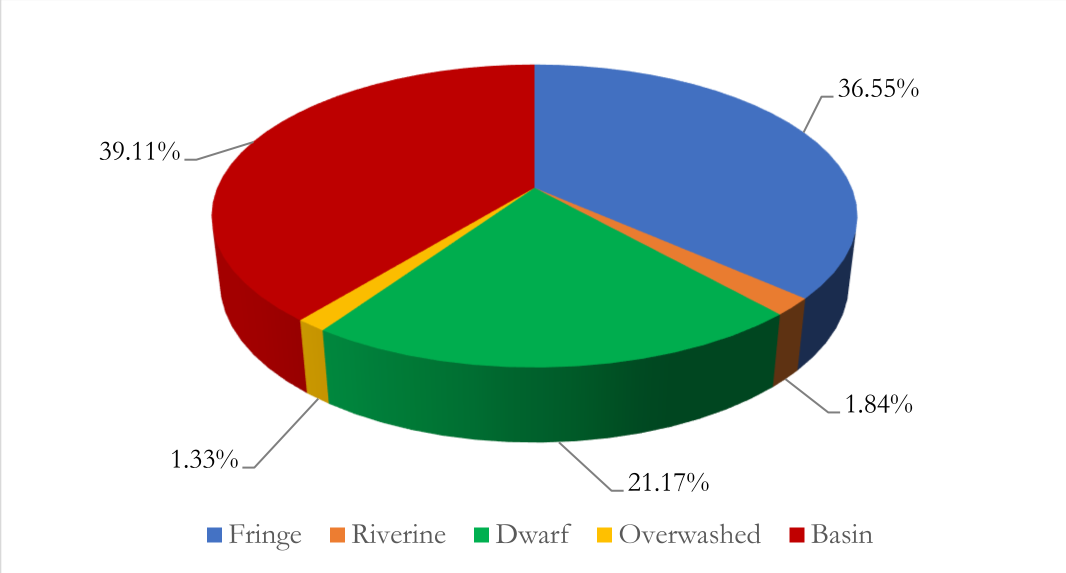


Table 4. Mozambican mangrove forest categories and its national distribution

Province	Mangrove forest categories					Total
	Basin	**Riverine**	**Fringe**	**Overwashed**	**Dwarf**	
Cabo Delgado	9 485	988	25 095	988	3 952	40 706
Gaza	0	395	0	0	0	395
Inhambane	3 557	0	15 018	198	6 125	24 898
Maputo	2 569	593	3 557	198	3162	10 078
Nampula	11 658	593	28 454	1 581	13 239	55 526
Sofala	35 568	988	39 915	988	26 874	104 333
Zambézia	88 327	3 557	29 245	1 186	28 454	150 571
Total	**151 164**	**7 114**	**141 284**	**5 139**	**81 806**	**386 506**
Fr (%)	**39.11**	**1.84**	**36.55**	**1.33**	**21.17**	**100**

3.4. Mangrove canopy cover

About half of Mozambique's mangrove forests (46.06%) consists of dense adults growing in closed patches, with a forest canopy cover denser than 80%. Juvenile/short adult represent 30.83% of the remaining mangrove forest, while the medium adults and dispersed adult categories cover respectively 12.22% and 10.89% (*Figure 5*). The distribution of mangrove canopy cover within the country is shown in *Table 5*.

Figure 5. Mozambican mangrove canopy cover

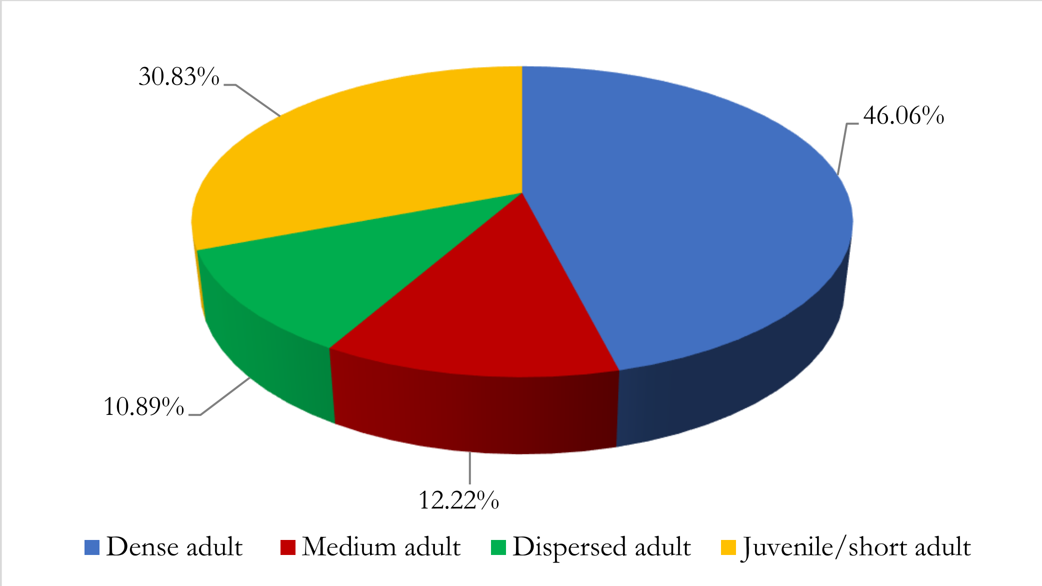


Table 5. Mozambican mangrove canopy cover and its national distribution

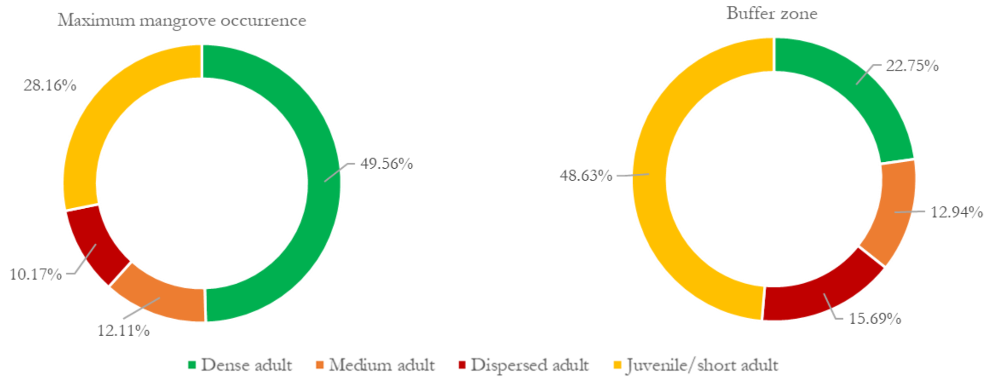
Province	Mangrove canopy cover (ha)				Total
	Dense adult	**Medium adult**	**Dispersed adult**	**Juvenile/short adult**	
Cabo Delgado	24 502	4 347	4 347	7 311	40 507
Gaza	0	198	198	0	396
Inhambane	7 904	3 754	3 162	10 078	24 898
Maputo	2 371	2 371	1 186	4 150	10 078
Nampula	21 736	7 904	7 904	17 982	55 526
Sofala	41 101	12 449	10 868	39 915	104 333
Zambézia	80 423	16 203	14 425	39 718	150 769
Total	**178 037**	**47 226**	**42 090**	**119 154**	**386 507**
Fr (%)	**46.06**	**12.22**	**10.89**	**30.83**	**100**

Analysing the geographical distribution of the mangrove cover, we found a significant difference between the mangrove canopy cover in the core survey area defined as “maximum mangrove occurrence” (the initial merged shapefile) and the buffer zone added around it in this work. Juvenile/short adult mangroves (canopy cover <50%, individual growth still occurring) are the dominant category in the buffer zone, accounting for 48.63% of the forest in the area, while occurring only in 28.16% of the core area. Dispersed adult mangroves represent 15.69% of the buffer zone mangroves and 10.17% of the core area. Conversely, dense adult mangrove is the most abundant category in the “maximum mangrove occurrence area” (49.56%) while sharply decreasing in the buffer area (22.75%) (*Table 6* and *Figure 6*).

Table 6. Different distribution of mangroves in the "maximum mangrove occurrence area" and in the buffer zone

Mangrove canopy cover classes	Maximum mangrove occurrence	Buffer zone
Dense adult	49,56%	22,75%
Medium adult	12,11%	12,94%
Dispersed adult	10,17%	15,69%
Juvenile/short adult	28,16%	48,63%

Figure 6. Graphical representation of the different distribution of mangrove in the "maximum mangrove occurrence area" and in the buffer zone



3.5. Mangrove forest dynamic between 2001 and 2020

From 2001 to 2020, 7 114 ha of Mozambican mangrove forest (1.84% of the total) have been lost (*Table 7)*, mainly due to conversion to Wetlands (88.88%). Such conversion is partially explainable due to the normal shifting of sand banks in rivers' estuaries, but it is noticeable a strong effect of the winds and floods associated with the cyclones Idai and Kenneth, which affected the Country in 2019. A relevant conversion to Salt pans (8.34%) was recorded in Zambézia, while a conversion to Settlement (2.78%) was recorded only in Maputo City.

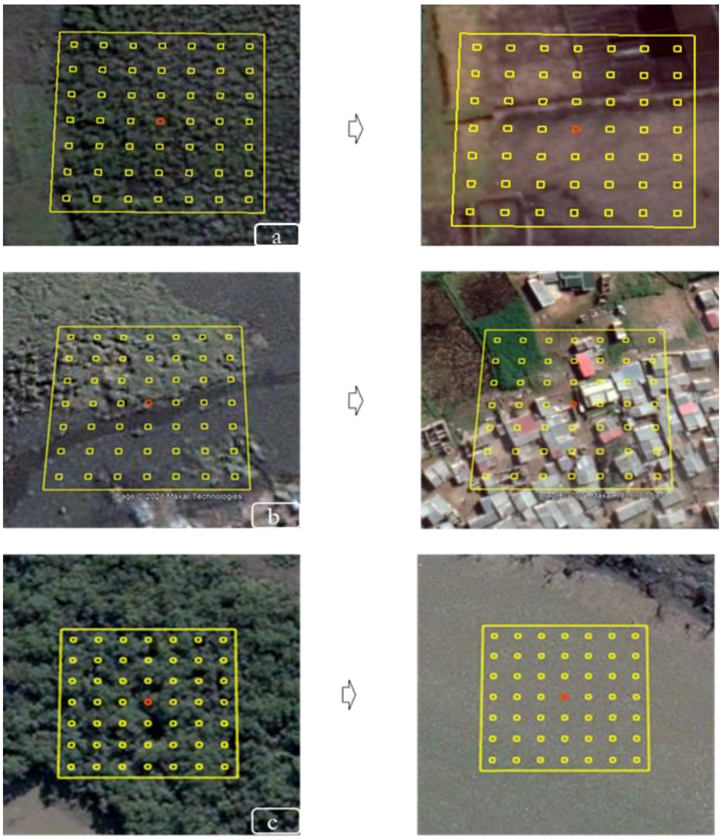
Table 7. Mozambican mangrove loss and conversion per province (2001-2020)

Province	Mangrove forest loss(ha) Settlement	Wetland	Salt pans	Total	Fr (%)
Cabo Delgado	0	593	0	593	8.34
Inhambane	0	395	0	395	5.55
Maputo	198	0	0	198	2.78
Nampula	0	790	0	790	11.10
Sofala	0	1 581	0	1 581	22.22
Zambézia	0	2 964	593	3 557	50.00
Total	**198**	**6 323**	**593**	**7 114**	**100**
Fr (%)	**2.78**	**88.88**	**8.34**	**100**	

The largest mangrove forest loss occurred in Zambézia province (50.00%), followed by Sofala (22.22%) province. Minor losses were recorded in Nampula (11.10%), Cabo Delgado (8.34%), in Inhambane (5.55%) and Maputo province (2.78%). No losses were recorded in Gaza province.

Figure 7 shows three examples of mangrove forest conversion to salt pans (*a*), settlement (*b*) and wetland (*c*), occurred in Mozambique during the investigated temporal range.

Figure 7. Mangrove forest conversion to salt pans (a), settlement (b) and wetland (c)



During the last 20 years, new mangrove forests have been recorded in all the country with a total growth of 2 768 ha (*Table 8*). Such gain is generally due to the conversion from Wetlands into mangrove forest (92.85%), mainly in Zambézia (28.58%) and Maputo (28.54%) provinces, followed by Nampula (14.27%). A lower conversion rate occurred in Cabo Delgado, Gaza, Inhambane and Sofala provinces, each accounting for 7.15% of the total rate of conversion. A smaller gain in the national mangrove coverage has been accounted form the conversion of Cropland into mangrove forest (7.15%), only recorded in Zambézia province.

Table 8. Mangrove gain per province

Province	Forest of mangrove gain (ha)		Total	Fr (%)
	Cropland	Wetland		
Cabo Delgado	0	198	198	7.15
Gaza	0	198	198	7.15
Inhambane	0	198	198	7.15
Maputo	0	790	790	28.54
Nampula	0	395	395	14.27
Sofala	0	198	198	7.15
Zambézia	198	593	791	28.58
Total	**198**	**2570**	**2768**	**100**

3.6. Disturbance factors in current mangrove forest

About 23 318 ha (6.03% of the total) of the current mangrove forest area has been subject to disturbances. Natural causes, such as wind and floods, are the single largest disturbance factor (53.39%) (*Figure 8*). Conversion to salt pans (23.72%), shifting agriculture (9.33%), and fire (11.02%) represent other relevant disturbances. Paths (occurrence of human or livestock pathways in the forest cover) seems to have the smallest disturbance impact (2.54%), only occurring in Cabo Delgado province. Overall, Zambézia (43.22%) and Sofala (42.37%) are the provinces with the highest active disturbance recorded, whereas the mangrove of Gaza province remains intact. The distribution of the disturbance factors within the country is shown in *Table 9*.

Figure 8. Disturbance factors in current mangrove forest

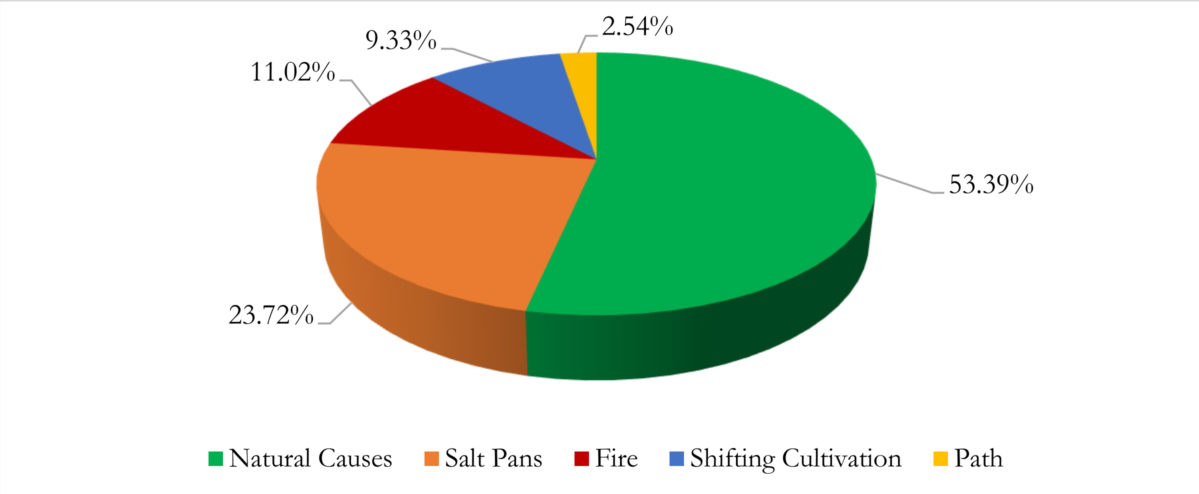


Table 9. Disturbance factors in current Mozambican mangrove forests

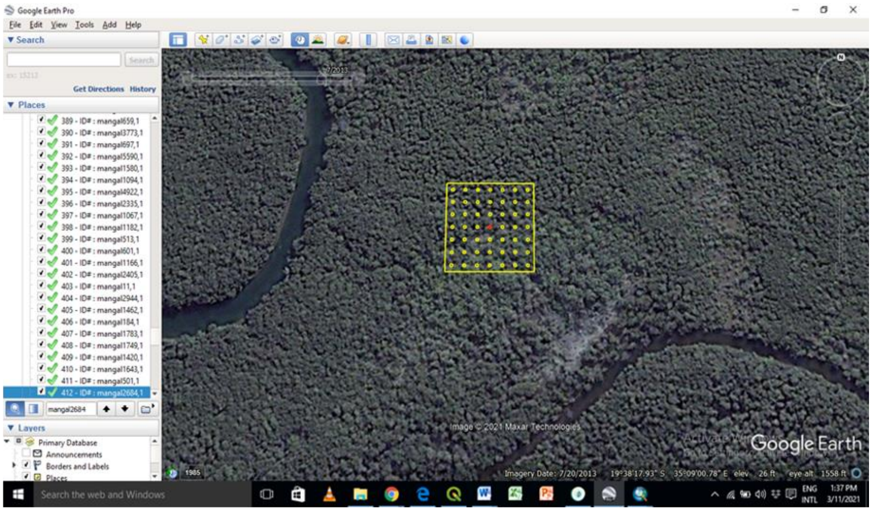
Province	Disturbance factor (ha)					Total	Fr (%)
	Nat. Causes	Salt pans	Shift. Agri.	Fire	Path		
Cabo Delgado	198	395	0	198	198	989	4.24
Inhambane	198	198	198	0	0	594	2.55
Maputo	0	395	0	0	0	395	1.69
Nampula	395	790	198	0	0	1 383	5.93
Sofala	6 323	2371	198	988	0	9 880	42.37
Zambézia	5 335	1 383	1 581	1 383	395	10 077	43.22
Total	**12 449**	**5 532**	**2 175**	**2 569**	**593**	**23 318**	**100**
Fr (%)	**53.39**	**23.72**	**9.33**	**11.02**	**2.54**	**100**	

3.7. Cyclones and floods impact on mangrove

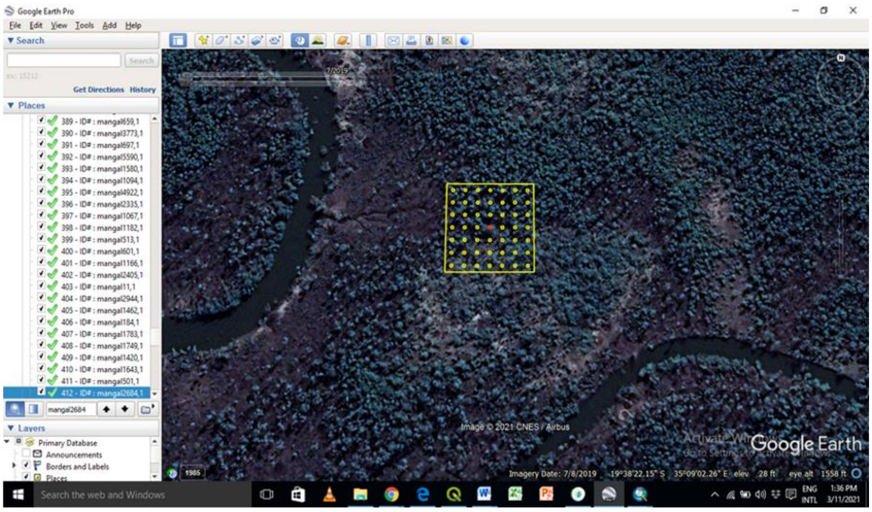
Cyclone Idai effects have been recorded mainly in Sofala and Zambézia provinces, affecting a total of 10 473 ha of mangrove forest. Along the coast of Sofala, 6 521 ha of mangrove were degraded due to the strong winds (93.1%) and riverbank erosion (6.9%) related to the flood and/or cyclone

(*Figure 9*). Along the Zambezi River delta in Zambézia, 3 162 ha of mangrove were damaged in the floods (81.2%), possibly connected to extreme weather events, and riverbank erosion (18.8%).

Figure 9. The impact of Cyclone Idai along the banks of Búzi River, Sofala Province. Note the density reduction and the loss of canopy cover



(a) Before Idai Cyclone (2019)



(b) After Idai Cyclone (2019)

The impact of Cyclone Kenneth, characterized by less flooding and weaker winds, seems to have impacted the mangrove forest cover only in Pemba, Cabo Delgado province, where the lost area was estimated in around 198 ha.

The cyclones had no significant impact on the mangrove cover of the other provinces. Therefore, our analysis tends to exclude the cyclones in the forest loss due to natural causes which affected Inhambane and Nampula provinces.

4. CONCLUSION REMARKS

This assessment provides an updated analysis of the status of mangrove forests in Mozambique. Applying our survey methodology to an ample study area, obtained by merging two shapefiles with the most up to date mangrove area measurements and adding a buffer zone to include any undetected area of mangrove presence, the extent of mangrove forest in the Country has been estimated at 386 507 ha, higher than most of the current assessments but lower than Barbosa et al. (2001) which reports 396 080 ha. The high value of our result is partially explained by the difference in the analysis tool, as our approach was based on an augmented visual interpretation protocol instead of an automatic satellite images classificator. As our findings are based on visual interpretation from a human operator, we were able to include types of mangrove cover that are harder to detect through spectral signature analysis, assessing also the extent of juvenile, short adult and dispersed mangrove, 161 244 ha of the national cover. These categories are less represented using an automatic classificator analysis, as confirmed in chapter 3.4. To notice, the sum of the classes with a higher canopy cover (dense and medium mangrove forests) reaches an area of 225 263 ha, virtually identical (99.68%) to Shapiro (2018).

Unsurprisingly, the highest extents of mangrove forest have been found in the Zambézia and Sofala provinces, which together account for 66% of the Country's mangrove cover. More interestingly, these two provinces are different in the mangroves categories that characterize their forests. While the mangroves in Sofala provinces are almost evenly distributed between three categories (26% dwarf, 34% basin and 38% fringe), in Zambezia the basin category is predominant, accounting for 59% of the provincial cover (representing about the 23% of the national cover, almost one mangrove tree out of four has been classified as basin in Zambezia). This difference, probably due to the structure of the Zambezi River delta, could be an additional factor in the diverse impact of cyclone Idai on the two provinces' forest covers, as Sofala showed an area of degradation almost double compared to Zambezia. Further studies on the recovery capabilities of different mangrove categories may be needed to shed light on this possibility.

Between 2001 and 2020, Mozambique has lost 7 114 ha mangrove areas. Such loss has been mainly caused by the conversion of mangrove forest into wetlands, predominantly in Sofala and Zambézia provinces. The mangrove forests of these two central provinces have lost respectively 1.5% and 2.4% of their mangrove coverage in the last 20 years. Considering the importance of mangrove ecosystems services for the livelihood of local populations (Himes-Cornell et al. 2018) such loss may represent a dangerous trend in the area. Unfortunately, only 11.12% of these losses are directly

connected to human activities [salt pans (8.34%) and settlement (2.78%)] and can therefore be directly addressed with a local policy change.
A minor growth of mangrove forest coverage has been reported in the assessment, particularly in Maputo City. Gaza province has almost doubled its mangrove cover in the last 20 years, but on a very small scale (198 to 395 ha); while Maputo's coverage has increased by almost 800 ha, partially due to the conservation efforts in Maputo Bay. The overall growth of new mangrove forests in the country (2 768 ha) represents only a 0.72% gain against a 1.84% of total decrease, with a net loss of 1.12% (around 4 300 ha) coverage at national level.

This assessment has provided an estimate of the latest forest cover degradation, affecting 23 318 ha only in the recent years. A high percentage of damage to the mangrove extent has been connected to natural causes and to the harshening of extreme weather events due to climate change. Extreme natural phenomena, including cyclones and floods, have been identified as the main disturbance factor, having affected a total of 12 449 ha of mangrove forest (53.38% of the total). On the other hand, the direct and indirect anthropic impacts (causing overall 46.62% of the mangrove forest degradation) still remain an issue to be faced. To note, the analysis of the types of degradation has two caveats: a) the total number of plots assessed was determined to ensure a proper area representation of the mangrove extent in the country. To solidify the results obtained regarding each class of forest degradation, a further increase in the plots assessed would be required. b) it has to be noted that small amounts of timber harvesting, a common practice in most coastal communities, are not clearly identifiable from satellite images and therefore have been not included in this analysis. Forest degradation caused by timber harvesting activities should not be underestimated based on this report.

Through the Collect Earth analysis, a proxy measure of the cyclones Idai and Kenneth was recorded. Idai mainly affected the centre of Country, causing a degradation of respectively of 6.25% and 2.10% of mangrove forests in Sofala and Zambézia provinces. Kenneth had a weaker impact on the Country's mangrove cover, with a limited effect on Cabo Delgado province. The data collected offer a proxy measure of these two cyclones' impact on the Mozambican mangrove forests, identifying key areas to plan management and recover strategies, and pre- and post- disaster studies. As highlighted by the data presented in this report, mangrove forests in Mozambique are subject to different types of disturbance and threats, suffering a prolonged reduction in extent. To plan the management and protection of these habitats and their ecological services, continuous monitoring aimed to assess their status and their recovery is essential.

The augmented visual interpretation of satellite images methodology applied using Open Foris – Collect Earth has proved to be a reliable approach to assess the extent of mangrove forests in Mozambique and could become a valuable monitoring tool. To allow further analysis and studies of the land use and land cover of these habitats, we attach to this report the final CSV file obtained from the Collect Earth assessment.

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