RESEARCH ARTICLE

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Climate Change and Land Use Dynamics in Djirnda Commune (Fatick Region - Senegal): Remote Sensing Approach

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ABSTRACT

Climate change is one of the greatest challenges of our time. It is a real and rapid phenomenon which, perhaps, does not dramatically affect people today but will certainly have harmful effects on future generations. It has led to the weakening of ecosystems and accelerated the degradation of natural resources. This situation has prompted the scientific world to sound the alarm to warn of its environmental and socio-economic impacts.

This study seeks to analyze the dynamics of land use in Djirnda municipality in climate change. A pixel-based classification approach and the maximum likelihood algorithm were retained. The data used concerns Landsat images from 1986, 2000 and 2015. The post-classification comparison method is used to detect changes in the classified images. The overall accuracy of the classifications gives satisfactory results with 90 % for 1986, 89 % for 2000 and 91 % for 2015 and a respective Kappa coefficient of 89 %, 85 % and 90 %. The results of land use dynamics revealed an increase in mangroves (1553.13 ha) and salt lands (957.15 ha), and a regression in water surface (-458.64 ha) and mudflats (- 2051.64 ha).

Keywords: Climate change, dynamics, environment, land use, remote sensing.

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I. Introduction

Climate change is now one of the main natural physical factors contributing most to the fragility of the environment. Recent studies on climate (Servat *et al.,* 1998; GIEC, 2007; GIEC 2001; Bodian, 2014; Ndong, 2015; Faye *et al.,* 2018), based on models, observations or measurements, attest to its evolution and its serious consequences on ecosystems and economic activities. This is no longer evident in West African countries where the economy is essentially based on agricultural activities with very limited means of adaptation. The decline in rainfall in the 1970s and 1980s (Faye *et al.,* 2019; Descroix *et al.,* 2015) and harmful anthropogenic actions have favoured the dynamics of land use units and an imbalance in ecosystems (Tine *et al.,* 2020). The impacts of climate change are different in different environments and are manifested at several levels.

The long drought of the 1970s favoured the extension of bare, over-salted, hyper-acidified areas that are unsuitable for cultivation (Faye, 2018). These morphological and pedological changes, marked by strong salinization and soil acidification, have led to the gradual disappearance of the mangrove (Diéye *et al.,* 2013). This change in climate is likely to expose 20-30% of plant and animal species to an increased risk of extinction if the average global temperature increase exceeds 1.5-2 °C (UNEP, 2002). The IUCN Red List, which assesses the level of threat to plant and animal species, reveals that of the more than 19,500 species dependent on wetlands, a quarter, or 25%, are threatened with extinction (Convention de Ramsar sur les zones humides, 2018).

The commune of Djirnda, like the other communes of the Saloum Islands, is home to important forest formations dominated by mangroves, a very useful resource in the balance of coastal ecosystems. The mangrove offers abundant resources of wood, fish products and land for various agricultural and aquaculture activities (Diéye *et al.,* 2013; UICN, 2009; Bocquet, 2018). Mangrove forests play a protective role against coastal erosion and provide a natural defense against extreme weather events, such as hurricanes (Jadot, 2016). The break-up of the Sangomar spit in 1987 provided evidence of the protective function of mangroves against flooding in the Saloum islands. Apart from its role in protecting the coast against erosion, the mangrove provides essential nutrients for certain species of crustaceans and fish (shrimps, oysters etc.). It provides shelter, food and refuge for certain fish. In addition to its role in protecting the coastline, mangrove ecosystems have a great capacity to sequester greenhouse gases. On average, mangroves sequester about 1.4 Go tons of carbon per square kilometer per year (Jadot, 2016). This makes, Ndour *et al.,* (2011) say that mangroves have scientific, cultural, tourist and socio-economic values. They serve as reception areas, refuge, reproduction, nurseries, maintenance, and recycling of organic matter.

Nowadays, these resources are subject to numerous pressures, mainly due to high population growth, climatic variations, and land use systems. The people living in the mangrove forests derive important income from wood exploitation, fishing, rice cultivation, salt exploitation and other activities such as honey and medicinal plant harvesting. All these activities result in the clearing of mangrove forest for agriculture, firewood, and construction. This explains the importance of the stakes for their conservation and sustainability.

The objective of this work is to study the dynamics of land use between 1986 and 2015 in Djirnda because of climate change and to analyze the strategies developed for the preservation of the environment. Remote sensing mapping allows a better understanding of the evolution of land use units. The latter, considered as the description of space, represents the biophysical cover of the land (Lecerf, 2008; FAO, 2009; Noyola, 2009). The biophysical categories represent vegetation, built-up areas, wetlands, bare soil, etc. The biophysical categories represent vegetation, built-up areas, wetlands, bare soil, etc. They are distinct from land use, which corresponds to the different activities carried out by humans on the physical cover of the land surface (Buard, 2013).

Satellite imagery is nowadays the main source of information on the state of natural resources. With the possibilities offered by sensors and the frequency of image acquisition over very large areas, and the generalization and spatialization of results obtained from the ground, remote sensing has become essential for monitoring the state of our planet and the impact of our activities (FAO&CSE, 2003). These technological advantages make it possible to regularly monitor the dynamics of wetlands and to identify major changes in the land.

II. Presentation of the Environment

Djirnda is a commune belonging to the Saloum islands, more particularly to the northern part of the Saloum Delta called the Gandoul islands. Located between 13° 57' and 14° 20' North, and 16° 39' and 16° 27' West, it is crossed by the Saloum River and its tributaries (Fig 1). It is thus exposed to the various factors that control the dynamics of the coastline, making it a very fragile environment.

The climate of Djirnda is to be situated in that of the Fatick region, which is of the Sudanese and Sahelian type, marked by the alternation of a non-rainy season that lasts eight (8) months, from November to May, and a rainy season that stretches over four (4) months, from June to October. Annual rainfall volumes vary between 500 and 1,000 mm. The rainfall regime is unimodal with a maximum in August. Average annual temperatures are often above 28 °C (Faye *et al.,* 2021). The average annual rainfall pattern shows very contrasting variations as shown in Fig. 2.

The increase in rainfall, which began in the late 1960s, has greatly affected the volume of rainfall recorded in this part of Senegal. The analysis of rainfall data from the sites studied highlights this variability. The results of the standardized rainfall index showed that the rainy seasons of the 1950s and 1960s were wet (Fig 2). The 1970s and 1980s, coinciding with the great drought that hit the Sahel (Faye *et al.,* 2019), were marked by low rainfall volumes. This decline in rainfall lasted until the end of the 1990s, a period marked by an improvement in rainfall (Faye *et al.,* 2019; Bodian, 2011). The largest deficits were recorded in 1983 with an index of -2 in Foundiougne, and in 1996 and 2004 in Thiadiaye with an index of -1.75 and -2.2 respectively (Fig. 2).

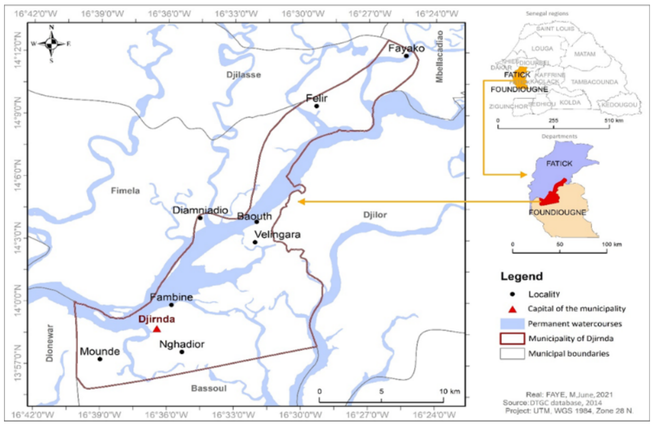

Fig. 1. Geographical location of the Commune of Djirnda.

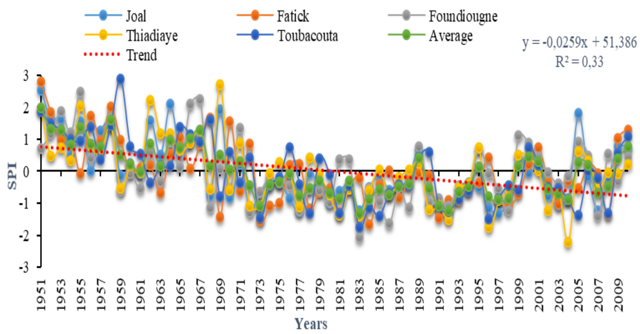

Fig. 2. Standardized Rainfall Index evolution for Joal, Fatick, Foundiougne, Thiadiaye and Toubacouta (1951-2010).

III. Data

Landsat images were chosen for this study. This choice is based on the availability and free availability of the data. The dates selected are 1986, 2000 and 2015. The images are acquired during the dry season, notably between February and March (Table I). A series of corrections is applied to these

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images in order to increase the quality of the information and minimise the uncertainty in the data due to atmospheric disturbances, satellite movements in orbit and sometimes problems with the sensor. The choice of dry season images avoids confusion between vegetation and grass cover.

TABLE I: CHARACTERISTICS OF THE LANDSAT IMAGES USED

Sensors	Acquisition date	Bands	Wavelengths	Resolution
Tm	09/02/1986	1-Blue	0,45-0,52 µm	30 m
		2-Green	0,52-0,6 µm	
		3-Red	0,63-0,69 µm	
		4-PIR	0,76-0,9 µm	
		5-SWIR 1	1,55-1,75 µm	
		7-SWIR 2	2,08-2,35 µm	
ETM+	27/03/2000	1-Blue	0,45-0,52 µm	30 m
		2-Green	0,53-0,61 µm	
		3-Red	0,63-0,69 µm	
		4-PIR	0,78-0,9 µm	
		5-SWIR 1	1,55-1,75 µm	
		7-SWIR 2	2,09-2,35 µm	
OLI	13/03/2015	2-Blue	0,450-0,515 µm	30 m
		3-Green	0,525-0,600 µm	
		4-Red	0,630-0,680 µm	
		5-PIR	0,845-0,885 µm	
		6-SWIR 1	1,560-1,660 µm	
		7-SWIR 2	2,100-2,300 µm	

IV. METHODS

The supervised classification method is used in this work. This technique is used to identify similar areas on an image through the spectral signature. The first step is to identify training sites, samples that are fairly homogeneous on the image and representative of different types of surfaces. These samples are then used to define the spectral classes they represent (Tine *et al.,* 2020). Within supervised classification, there are several classification algorithms. However, for the purpose of this study, we have chosen the "maximum likelihood" classification. The latter is widely used in supervised classifications and is considered the most efficient in the production of thematic maps in the field of land use (Soro *et al.,* 2014). Maximum likelihood classification is based on Bayes rule:

$$Pr\{\mathrm{Ai}|B\} = \frac{\mathrm{Pr\{Ai\}}\cdot\mathrm{Pr\{B|Ai\}}}{\sum\mathrm{Pr\{Ai\}}\cdot\mathrm{Pr\{B|Ai\}}} \qquad (1)$$

Ai represents class i, B represents the response values of the pixel.

Pr {A|B} is the conditional probability that class Ai is the class where pixel B is placed.

For the detection of land cover changes, radiometric and atmospheric corrections were applied to the images. In addition to these corrections, other enhancement techniques such as normalization are applied to the images. The latter consists of using an image as a reference on which the radiometric properties of the image to be corrected are adjusted so that undesirable effects can be minimized or eliminated (Gueriniai, 2012). This technique makes it possible to compare, in terms of radiometric characteristics, images obtained by different sensors and on different dates. The ENVI 5.3 software allowed us to normalize the images with the Landsat ETM+ image from 2000 as a reference.

Post-classification comparison is used for change detection. It is the most obvious method which requires the comparison of independently produced classified images (Singh, 1989). It allowed us to detect changes during the time interval considered and to map the changes in land use in the commune of Djirnda. Fig. 3 illustrates the different processing steps carried out in this work.

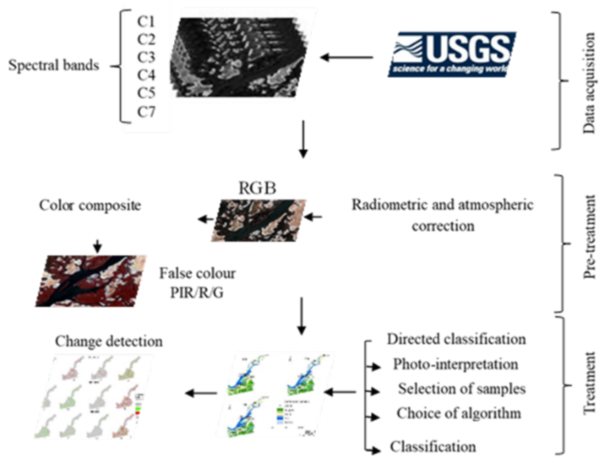

Fig. 3. Methodological flow chart for image processing.

V. RESULTS

A. Land Use Dynamics

The diachronic mapping of the 1986, 2000 and 2015 Landsat images allowed us to understand the spatial and temporal dynamics of the land cover units in the commune of Djirnda. Statistics from the 1986, 2000 and 2015 land cover maps (Fig. 4) highlight the spatial and temporal dynamics of each thematic class (Table II).

In 1986, salt lands and mudflats were more representative in the commune. They occupied 7663.41 ha (30.9%) and 6537.06 ha (26.4%) respectively. The predominance of these two units can be explained by the decrease in rainfall noted during this period (Fig. 2) and the low water inflow upstream of the estuary. The mangrove, the third most important unit, covered an area of 5926.23 ha, or 23.9% of the total area of the study area in 1986.

In 2000, mudflats were more important in the municipality with 7344.81 ha. They increased from 26% in 1986 to 29% in 2000, followed by mangroves with 28% in 2000. On the other hand, salt lands and water surface have experienced a regression in their extent. They represented respectively 24% (6036 ha) and 17% (4275 ha), as 4% and 1% less than in 1986.

TABLE II: LAND USE STATISTICS BETWEEN 1986, 2000 AND 2015

	1986		2000		2015	
Classes	Area (ha)	Proportion (ha)	Area (ha)	Proportion (ha)	Area (ha)	Proportion (ha)
Mangrove	5926,23	23,9	7116,57	28,7	7479,36	30,2
Salt lands	7663,41	30,9	6036,84	24,4	8620,56	34,8
Water	4647,42	18,8	4275,9	17,3	4188,78	16,9
Mudflats	6537,06	26,4	7344,81	29,6	4485,42	18,1

A strong advance of saline land was observed in 2015. The salt lands increased from 6036 ha (24%) in 2000 to 8620 ha (34%) in 2015, an increase of 10%. This extension can be linked to the climatic variability observed through the SPI (Fig. 1). Mangrove increased slightly (30%). water Surface and mudflats areas have decreased. They decreased from 17 and 29% respectively in 2000 to 16 and 18% in 2015. Indeed, the major changes are more marked in tidal flats and mudflats between 2000 and 2015.

The salt lands have increased in the municipality, while the mudflats have decreased considerably. These two land-use units are more marked in the north of Djirnda, particularly in the villages of Felir and Fayako (Fig. 4). The mangrove is mainly represented in the south of the municipality.

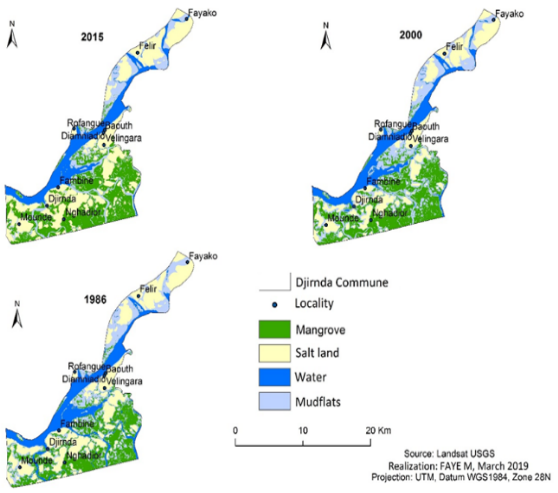

Fig. 4. Land use in Djirnda municipality in 1986, 2000 and 2015.

B. *Detection of Land Use Changes*

The landscape of Djirnda has undergone changes often related to the salinization process and the hydrological Delta system. The tides and the regular submergence of the low areas influence the hydrological regime. The latter is one of the most remarkable types of salt input. The low freshwater inflow, rising temperatures and evaporation, and the capillary rise of the salt water table constitute a dynamic system that generates changes (modification or conversion) of land use units in Djirnda.

The land cover maps are crossed in pairs to generate change maps (Fig. 5) and statistical tables that reflect the evolution of the different thematic classes between dates. In order to detect the changes that occurred between two dates and to allow the visualization of the areas that have evolved, we proceeded to a recording of the different themes on the classifications. Indeed, the analysis of changes is based on three levels: modification, conversion, and stability (Fig 5). Modification refers to changes within the same land use category, such as mudflat becoming a salt land (Tine, *et al.,* 2020; Sarr, 2007). While conversion is the change from one land use category to another. The no-change zones refer to all classes that have remained stable between two dates.

Between 1986 and 2000, we note a great change in the mangroves and salt lands (Table III and IV). The area occupied by mangroves increased (1190.34 ha), while the salt lands showed a regression (1626.57 ha) in their area. At the same time, water surface and mudflats have evolved slightly. The former showed a decrease of 371 ha, while the latter showed an increase of 47 ha.

For the period 2000-2015, the major changes were observed on tidal flats and mudflats (Table III and IV). Mudflats have registered a regression of 2859.39 ha to the benefit of mangroves and tidal flats. The most important progression is noted on the salt lands with 2578.68 ha. This extension of the salt lands can be explained by the marine intrusion into the Saloum Delta following the rupture of the Sangomar spit in 1987, a situation that favours a high level of salinity from upstream to downstream in the estuary. The mangrove, on the other hand, has changed little (367.83 ha) in contrast to the previous period.

Long time periods are crucial in the study of land use dynamics. Between 1986 and 2015 (30 years), we observe a great change in the mangrove and mudflats (Table III and IV; Fig 5). The newly forested area of mangroves is estimated at 1553.13 ha. Mudflats have decreased in area (2051.64 ha) in favour of mangroves (1553.13 ha) and salt lands (957.15 ha). Indeed, the increase in the area of mangroves is due to reforestation campaigns initiated by the State, NGOs and the local population. The actions of the wind and man (salt exploitation) favour the extension of the salt lands through the transport and deposition of salt particles on the non-salted land. As a result, with the return of rainfall since the 2000s, we note a reduction in salt lands in Djirnda. On previously bare and salty soils, halophilic species are growing, giving rise to a grassy salt lands.

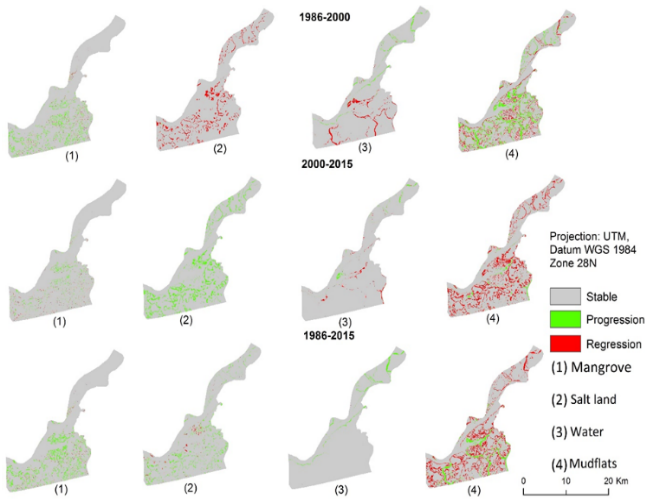

Fig. 5. Changes in land use units between 1986-2000, 2000-2015 and 1986-2015.

TABLE III: CHANGE DETECTION STATISTICS OF LAND USE UNITS IN HA

		1986-2000	2000-2015	1986-2015
Mangrove	Regression	174,15	178,29	188,55
	Stable	5752,08	6938,28	5737,68
	Progression	1364,49	546,12	1741,68
Salt lands	Regression	1639,89	3,6	163,71
	Stable	6023,52	6033,24	7499,7
	Progression	13,32	2582,28	1120,86
Water	Regression	760,5	276,93	911,7
	Stable	3886,92	3998,97	3735,72
	Progression	388,98	189,81	453,06
Mudflats	Regression	1756,35	3218,58	3279,6
	Stable	4780,71	4126,23	3257,46
	Progression	1803,69	359,19	1227,96

TABLE IV: CHANGE DETECTION EVOLUTION OF LAND USE UNITS IN HA

		1986-2000	2000-2015	1986-2015
Mangrove	Regression	-	-	-
	Progression	1190,34	367,83	1553,13
Salt lands	Regression	1626,57	-	-
	Progression	-	2578,68	957,15
Water	Regression	371,52	87,12	458,64
	Progression	-	-	-
Mudflats	Regression	-	2859,39	2051,64
	Progression	47,34	-	-

C. Strategies to combat environmental degradation.

Faced with the combined effects of climate change and human activities, Senegal State, supported by NGOs, has developed strategies to combat pressure on the mangrove, coastal erosion and salinization in the Gandoul islands, particularly in the island villages or those bordering the oblongs.

It should be noted that we do not have statistical data on specific strategies to the commune of Djirnda. The strategies presented in this study relate to all the islands of the Saloum, including the study area.

The strategies developed revolve around the protection of certain areas (Table V), the revaluation of salt lands, the reforestation of mangroves, the construction of dykes, and the fight against the salinization of land (Fig. 6). This allows for better management of natural resources and ensures the balance of ecosystems (Convention de Ramsar sur les zones humides, 2018). Mangrove restoration initiatives have been developed by the West African Association for Marine Environment (WAAME), the International Union for Conservation of Nature (IUCN), the Oceanium, the World Wide Fund for Nature (WWF), Wetlands International Africa (WIA), Gembloux Development Aid (GDA), etc. over the last two decades. The development of protected areas enables the authorities to deal with the various harmful anthropic actions on the Saloum Delta mangrove (Table V).

TABLE V: THE DIFFERENT PROTECTION STATUSES ATTRIBUTED TO THE SALOUM DELTA MANGROVE (BOCQUET, 2018)

Type of protection status	Area (ha)	Creation date
Saloum Delta National Park (SDNP)	76 000	1976
Saloum Delta Biosphere Reserve (SDBR)	334 000	1981
RAMSAR site	73 000	1984
Bamboung Marine Protected Area	7 000	2004
UNESCO World Heritage Cultural Site	145 811	2011
Gandoul Marine Protected Area	15 732	2014
Sangomar Marine Protected Area	87 437	2014

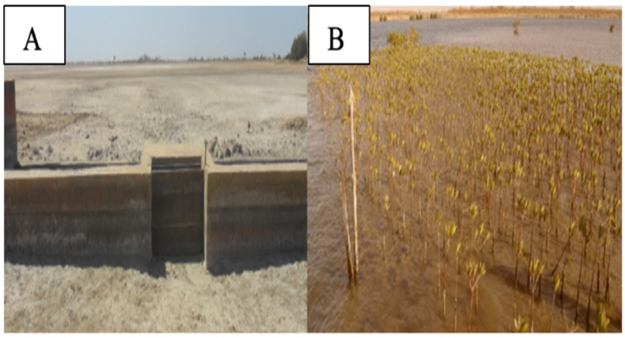

Fig. 6. Dyke installation to combat salt advance (A) and mangrove reforestation (B) for the revitalization of mangrove forests in the Saloum islands.

The populations, in collaboration with NGOs and donors, have also carried out conservation, restoration and alternative production actions (UICN, 2003). Thanks to the technical and financial support of NGOs such as WAAME, CAREM, FIOD, IUCN, PAGERNA, etc., reforestation actions were developed in several villages and on the Saloum islands between 1995 and 2002. The NGO CAREM, supported by IUCN, planted between 1995 and 2002 about 1000 ha of mangrove and mobilised 19 villages, the NGO WAAME supervised 27 villages and planted 70 ha from 1998 to 2001, while FIOD encourages the populations that participate in the mangrove reforestation effort by providing them with assistance in kind. Thus, the total area planted by the villages supervised by FIOD amounted to 240 ha between 1998 and 2001.

VI. DISCUSSION

The severe drought noted during the 1970s continued until the 1980s affecting rainfall volumes in the region (Faye *et al.,* 2021; Niasse, 2004). The time series analysis (Fig. 2) showed an acute drought during the decades 1971-1980 and 1981-1990. The decrease in rainfall, the drought and the tidal phenomena reinforced by the rupture of the Sangomar spit, constitute the major factors of the dynamics of the morphological units of the commune of Djirnda. The degradation process is carried out through erosion, salinization, and deforestation (Tine, 2020). The decrease in rainfall has been accompanied by an increase in temperature and evaporation. The resulting drying of the soil has facilitated the deflation of fine particles, the spread of salt lands, the lowering of the water table and the advance of the salt wedge (Faye, 2018).

This climate variability has had influences on the dynamics of the land use units. The mangrove is in an advanced state of degradation, even though we have noted an increase in the area occupied by it in recent years. It has become increasingly scarce in some places (the north of the study area). The degradation process is also marked by the phenomenon of tides, which has become more acute since the rupture of the Sangomar spit (Diéye *et al.,* 2013; Faye, 2016). These tides, by their duration and speed, contribute to the extension of the salty land. The period 1986-2015 is marked by an extension of more than 900 ha of tidal flats. Indeed, the most pronounced extension was noted between 2000 and 2015 with more than 2578 ha.

In addition to these natural factors favouring the degradation of the environment, human activities are not to be outdone (Ministère de l'Environnement et du Développement Durable, 2014; Andrieu &Alexandre, 2011). The use of Rhizophora wood for cooking, firewood, processing of fishery products, roofing of houses, fencing, as well as harvesting oysters (Fig. 7) have considerably contributed to the mutation of mangrove forests and favoured the advance of salt lands (Diéye *et al.,* 2022; Sow *et al.*, 2019; Solly *et al.,* 2018). In addition to the rise of the sea, the dynamics of the salt wedge, the exploitation of salt further contributes to the increase of salty land through the deposition of salt particles on healthy land.

Fig. 7. Mangrove wood exploitation (A and B) for the processing of fish products (C and D) in Mounde village.

Faced with this situation, several actions have been carried out over the last two decades to preserve the environment. These actions essentially revolve around the conservation of the mangrove and the fight against the expansion or recovery of salt lands (Faye, 2018; UICN, 2003; Faye, 2016; WIACO, 2019). In this respect, Wetlands International has played a leading role in the safeguarding and restoration of mangrove ecosystems. In 2019, its actions based on "Assisted Natural Regeneration" enabled the restoration of 195 hectares of mangroves (ha), (WIACO, 2019). In addition to this, funding and technical support is provided to the population to promote the natural recovery of the mangrove. The implementation of microfinance programs such as the Savings Group and Credit for Mangrove Conservation (GECCOM), has been decisive in the conservation and restoration of mangroves in the Saloum Delta. This microfinance initiative, an indirect strategy for mangrove conservation, has enabled the establishment of 20 GECCOMs, thus enrolling more than 500 women. The GECCOMs, in addition to developing a savings culture, give beneficiaries the opportunity to acquire the capital needed to invest in alternative activities that reduce the pressure on mangrove resources. In terms of savings, the portfolio of the 20 GECCOMs is valued at more than 24 million CFA francs or more than 36,000 Euros. This has also enabled 63 vulnerable people to be assisted with a sum of 1,403,000 CFA francs (or more than 2,000 Euros) (WIACO, 2019).

With regard to the dynamics of salinization, attempts to recover salt land have been initiated by the state through its technical services, including the National Institute of Pedology (INP) and the Senegalese Institute of Agricultural Research (ISRA). These include the introduction of species such as Melaleuca sp, Eucalyptus sp, and Acacias such as *Acacia holosericea*, *Acacia trachicarpa*, *Acacia bivenosa*, *Acacia lumida*, etc., activities initiated mainly by the Centre National de Recherches Forestières (CNRF), which became the Senegalese Institute for Agricultural Research (ISRA) (Faye, 2018). In addition to reforestation activities, dykes have been set up by partners and the State's technical services to fight against the salinization of the land. Despite these techniques, land salinization is increasingly dynamic in Djirnda. Agriculture is poorly practiced, due to the lack of healthy land. Bare and herbaceous salt lands are replacing mudflats and continental vegetation.

Overall, we can say that the commune of Djirnda has undergone profound socio-environmental changes between the 1980s and 2010, thus impacting the ecosystems of the area. Climate change, which has been identified as a trigger factor for the dynamics of land use units, has been amplified by human activities.

VII. Conclusion

This study has enabled us to understand the spatial evolution of the different land use units in the commune of Djirnda, under the combined effect of climatic and anthropic factors. Two main trends were observed in the land use units between 1986 and 2015. These are a regression of water surface (458 ha) and mudflats (2051 ha) and an increase or progression of mangrove areas (1553 ha) and salt lands (957 ha). Indeed, the dynamics of the different soil entities are not homogeneous. The mudflats and salt lands are more accentuated in the north of the municipality. The mangrove, on the other hand, is concentrated in the centre and the south.

Contrary to the work of (Sow *et al.,* 2019; Diop *et al.,* 2013), the mangrove area increased between the 1980s and 2000, even if it is disparate. This is consistent with the results of Diéye *et al.,* (2013), which state that there was an evolutionary trend in the mangrove during this period. Decreased freshwater inflow due to reduced rainfall and marine intrusions contributed to increased salinity, salt lands extension and degradation of the vegetation cover. The increase in mangrove areas is the result of the combined actions of the state, NGOs, and the local population.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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