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# Dynamics Analysis and Factors in Landscape Units' Evolution in Senegal River Delta Ecosystems

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author MAT designed the study, wrote the protocol, wrote the first draft of the manuscript and collected the necessary data for this study. Authors VBT and MLN managed the literature researchs, analyses of the study, did the figures (map) and traced the graphs. Authors GF and BC completed the first draft of the manuscript. Authors AN and CTW read, corrected and approved the final manuscript.*

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## ABSTRACT

Nowadays, the dynamics of the Senegal river delta ecosystem has attracted the attention of the authorities because of the profound changes which it is subject. This study aims to analyze the relationship between the dynamics of land use units and natural and anthropogenic factors. It is performed by means of remote sensing and GIS data. Landsat images, acquired in 1977, 1988, 1999, 2006 and 2014 are chosen for this purpose. Supervised classification by maximum likelihood on neo-channel (ACP and NDVI), has allowed making the evolution of landscape units cards. These results are coupled with field data and statistics obtained in the state structures. The analysis

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showed that the natural and human factors are causing mutations noted in the Senegal delta ecosystems. Supervised classification has to show an expansion rate of vegetation cover (64%) crop areas (6.77%), surface water (4%) and regression of salted areas (74.69%) and dune (15.62%) between 1977 and 2014. The significant increases are due mainly to irrigation schemes, population growth and protection policies and conservation of natural resources while regressions observed, are related to the development of the agricultural sector in recent years and the importance of rainfall limiting biophysical processes. The results of this study can serve as capacity strengthening tools for actors in the field, to the understanding of the mechanisms and processes of degradation of delta ecosystems to consider adaptation measures on the rational management of space natural.

*Keywords: Remote sensing; anthropic ecosystems; dynamic occupations; natural factors; Senegal River delta.*

## 1. INTRODUCTION

Ecosystem dynamics analysis has become a topical issue in recent decades at world scale. It takes relatively large proportions in Senegal, particularly in the Senegal River Delta in the north. It is located downstream of the lower valley of the Senegal River, spreads Dagana at the mouth south of the city of Saint Louis and it is shared by Senegal and Mauritania (Fig. 1). Senegal River Delta covers an area of 5000 km$^2$ (4000 km$^2$ in Senegal; 1000 km² in Mauritania). In this study, the limits of the delta range from the town of Richard-Toll specifically at the junction of Taouey channel and the Senegal River at KP 143 (North-east) to the town of Gandon in southwest. Indeed, it is a vast floodplain topography almost flat and monotonous over 73.83% of the medium [1]. This floodplain closes the Transboundary Biosphere Reserve of the Senegal River delta, the latter includes the National Parks of birds Djoudji and the Langue de Barbarie; the sylvopastoral Reserve Mpal-Mérinaguène; Classified Forests to Mpal, Maka-Diama, Tilène, Naéré and Rao. It is crossed by the Senegal River and includes Lake Guiers, Ndiael of depression and many wetlands. The delta is a very dynamic space. Indeed, it knows many hydraulic structures and irrigation. Delta ecosystem through its varied habitats attracts many tourists and is a rapidly expanding middle [2]. Delta belongs to the Sahelian climate field [3], characterized by a highly variable rainfall characterized by large deficits which are most marked at the origin of the great drought recorded during the late 1960s and early 1970 [4]. The demographic point of view, the delta as the entire Sahel is growing. This growing population is putting increasing pressure on the environment's natural resources (water, soil, vegetation, wildlife, etc.). These changes are associated with climate dynamics, socio-economic and environmental observed, to a lesser extent, across the delta of Senegal. Today, the recovery of the ecosystem dynamics of general way, is called the Remote Sensing [5-11]. It is currently an effective and efficient means to meet the need without increasing desist related to inventory, monitoring and management of the ecosystems of the planet. Land use is a fundamental variable for regional planning and for the study and understanding of the environment [12]. Remote sensing provides indeed tools of observation and monitoring of the continental biosphere by means of measuring instruments [13]. Using satellite images, it is possible to map the vegetation cover, water resources and farmlands to time scales and varied space [11,13-15]. To this end, monitoring plant areas in arid and semi-arid in Senegal has become a priority for policymakers and scientists alike since the widespread drought in the Sahel region (1970-1980), which followed a wetter period (1950-1969) [16]. Knowledge of the dynamics of land cover requires an identification and understanding of the mechanisms associated with this dynamic, to better base the analysis on the changing state of the environment. In the Senegal River delta, ecosystem dynamics is under the influence of natural factors through the climate and anthropogenic variability with rapid population growth, deforestation and especially hydroelectric and irrigation schemes [17]. The peculiarity of the delta outside its geographical feature, reads through its wealth of natural resources (water, vegetation) but also its dynamism from an economic point of view (an agricultural area, fishing and trade) [18]. Under the influence of these factors, accelerating the transformation of ecosystems through soil salinization, recurring floods, the development of aquatic plants, accelerated coastal erosion is observed in this medium. This dynamic is

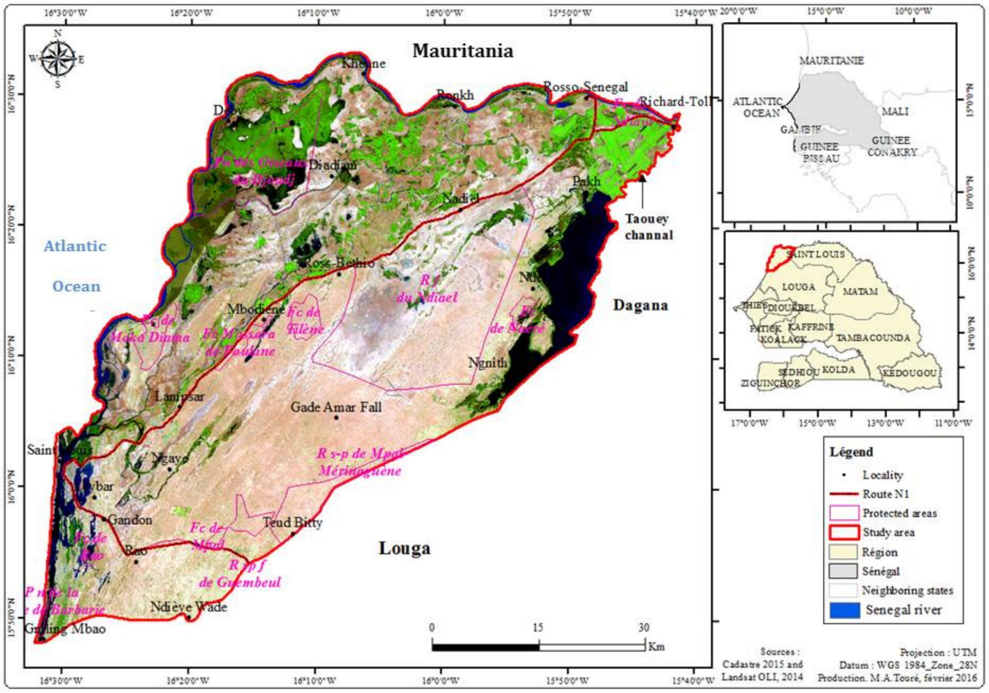


**Fig. 1. Location of the Senegal River delta**

manifested either by a gain area (progression) or a loss of area (regression) and those in favor of or against a unit [10]. Thus, the dynamics of landscape units has impacts on the environment of environmentally and socio-economic. The objective of this study is to jointly analyze the dynamics of occupation of the Senegal River delta units with natural and anthropogenic factors, on a 38-year period. For this, we used the Landsat image data acquired in 1977 (MSS) in 1984 and 1988 (TM) in 1999 and 2006 (ETM) and 2014 (OLI), coupled to the data collected in the field. Our main motivation through this paper is to make capacity strengthening tools for actors in the field, to the understanding of the mechanisms and processes of degradation of delta ecosystems to consider adaptation measures on the rational management of space natural.

## 2. MATERIALS AND METHODS

### 2.1 Data

The study establishes the period from 1970 to 2010. For the monitoring of land cover units around the Senegal River delta, we increased our choice on Landsat images. The Landsat directory offers the longest continuous record of satellite earth observation data [19]. Indeed, it allows to benefit from a large body of data available since the early 1970s and allowing for a regular monitoring on the last 40 years [14]. Selected images from the sensors, Multi Spectral Scanner (MSS) for 1977, Thematic Mapper (TM) for 1984 and 1988, ETM for 1999 and 2006 and Operational Land Imager (OLI) for the year 2014. This data is acquired the same period, in September. This logic keeps the consistency of spectral signatures of different landscape units, minimizing the effects of the atmosphere, soil moisture differences and the difference due to the variation of the solar angle [20].

### 2.2 Image Preprocessing

The images have been geometrically corrected to overcome the distortions caused by the rotation of the earth [21]. USGS provides orthorectified Landsat images already corrected and the appropriate coordinate system [22]. However, have performed a correction about Landsat imagery to minimize the mean square error (RMS), which is generally below ½ pixel. They will then be projected into the overall system WGS 1984 UTM Zone 28 N. Correction radiometric images were appropriate. Detection and characterization of the changing landscape using multiple temporal imaging satellites requires atmospheric correction of the image to be used [22]. These conversions provide a standardized basis for comparison of data in a single scene or between images acquired at different dates or by different sensors [19]. The DN value of the image has been converted to radiance, then spectral reflectance. The technique of global contrast enhancement applied to the set of strips Landsat imagery. This technique is indeed to make a histogram expansion, selecting two thresholds Smin and Smax, which will be respectively assigned to the values 0 and 255 when the screen image display [23]. It is applied to all preset Landsat images. It was followed by the creation of neo-channels including the ACP and the NDVI. The vegetation index used to increase the contrast soil-vegetation. The principal component analysis reduces multispectral images redundancy effect generally, by selecting the first 03 components (ACP-1, ACP-2 and ACP-3) for the tri-color composition. The image operating process is presented in Fig. 2.

### 2.2.1 Classification and measurement images

Supervised classification based maximum likelihood algorithm is applied to all images and was used to map the land use in the Senegal delta. The training plots are defined on the field database from a field mission. The selected classes are: continental vegetation, aquatic vegetation, areas of culture, surface water, salty lands and dune areas. The results of the classification are validated using the confusion matrix to evaluate the classification accuracy using field data. Overall, the classifications are considered excellent in terms of values of higher Kappa around 0.90.

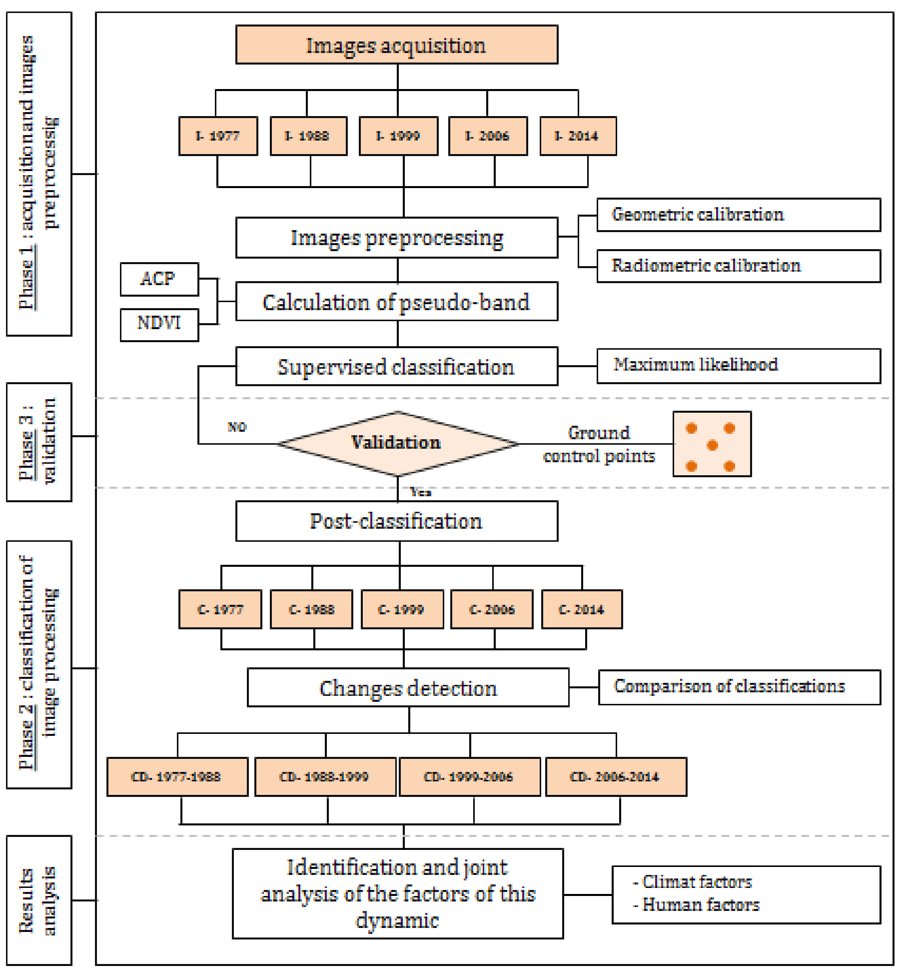


**Fig. 2. Flowchart of the methodology of processing and analysis of Landsat images**

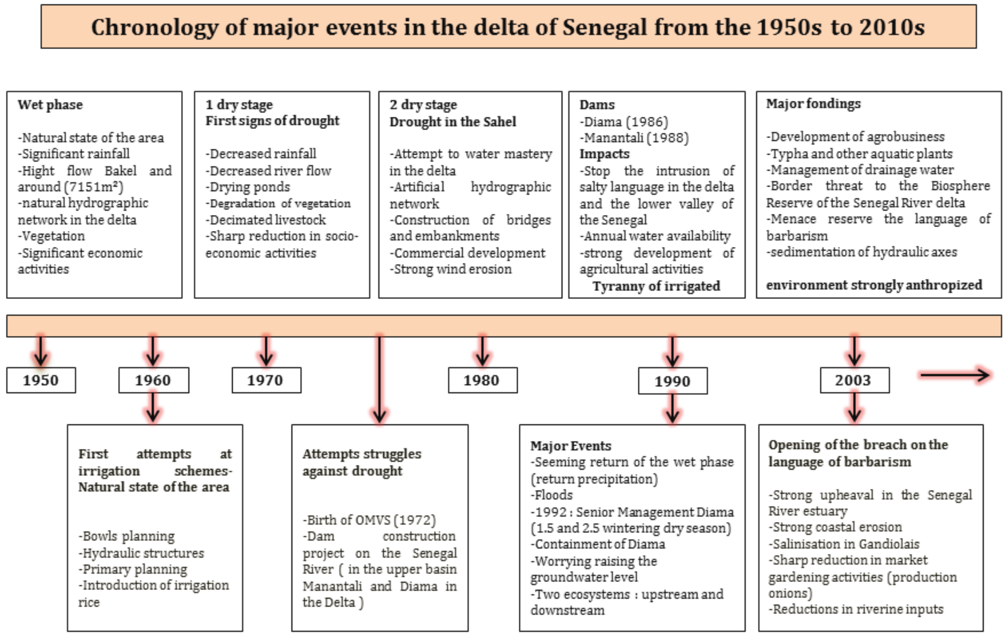


**Fig. 3. Chronology of major events in the Delta**

#### 2.2.2 Evaluation of land use dynamic

This calculation allows to understand the evolution of the occupation units of ground between the dates: 1977-1988; 1988-1999; 1999-2006; 2006-2014. In order to show the evolution of each land use class over time, we used a series of set transformations; the relationship between the class on two different dates, we can extract the "stable" areas, "regression" and "progression" of this class [10]. To map these changes, we used the equation proposed by [24].

$$\Delta U = U2 - U1$$

**U1** is the set of pixels at time 1, **U2** all pixels on the date 2 and **∆U** the variation of a pixel of a land occupation of any unit between **U1** and **U2** dates.
**∆U = 0**, reflects the state of **stability** (no change);
**∆U < 0**, translated **regression** (reduction, loss, etc.);
**∆U> 0** reflects the **progression** (expansion, gain, etc.).

### 2.3 The Factors of the Dynamics of Land Use

Regarding the identification of factors of the dynamics of soil, we have been using field data on the climate (rainfall, temperature, ...), the Senegal River flow rate in the resorts of Bakel Richard Toll, Diama Upstream and St. Louis, types of hydro-agricultural development (dams, agricultural bins, ...), but also the bibliography on the zone. Thus, the chronology of events that took place in the delta is synthesized through the figure above (Fig. 3).

## 3. RESULTS AND DISCUSSION

### 3.1 Dynamics Analysis of Land Cover Units between 1977 and 2014

Any ecosystem known mutations from one year to another. But these are compounded by natural changes and / or anthropogenic phenomena can lead to great extents that may be irreversible. The development areas under the various Delta biotope units is manifested by the expansion or shrinkage of the area occupied by the portion of habitats (Fig. 4). To measure the spatiotemporal evolution of the land use class, we have used a series of binary transformation, i.e., the relationship between the same classes of two different dates. This allows bettering understanding the changes occurred during the considered time interval. Through these changes we have identified the regression areas, "progress" and "stable" areas. Figs. 5 and 6 illustrated the evolution of different land use units in the Senegal river delta from 1977 to 2014.

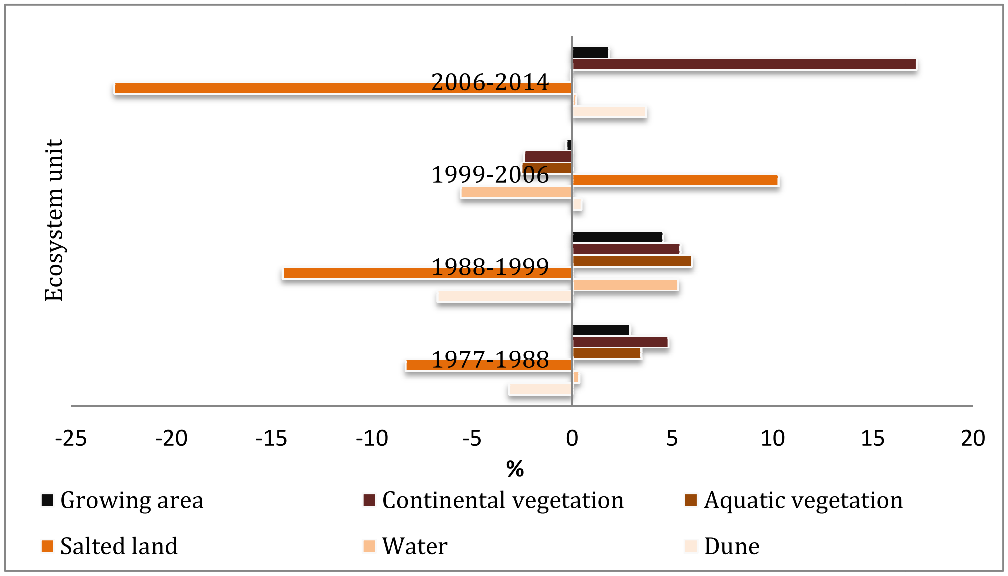


**Fig. 4. Dynamic of land use areas between 1977 and 2014**

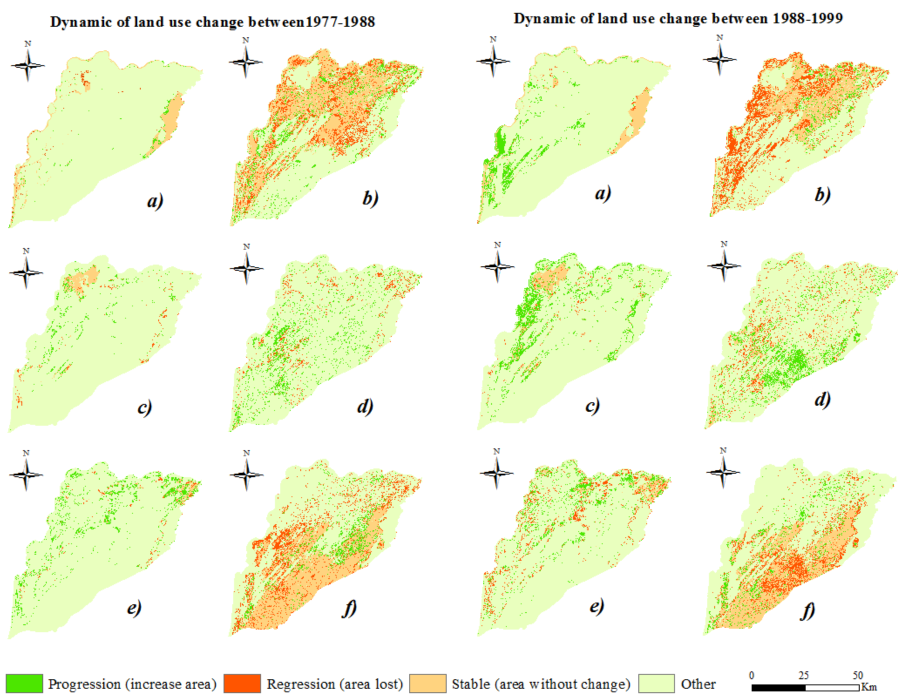


**Fig. 5. Dynamics of land use between 1977 to 1988 and from 1988 to 1999: a) "water" ; b) "salt land" ; c) "aquatic vegetation" ; d) "continental vegetation" ; e) "crowing area"; f) "dune"**

### 3.1.1 Dynamics analysis of surface water

The evolution of surface water is characterized, on one hand, by an extension of the periods 1977-1988, 1988-1999 and 2016-2014 and, secondly, by a withdrawal between 1999-2006. The trend is a generally favorable to the increase in the area of surface water. It is 5% (1347.2 ha) between 1977 to 1988, 75% (28806.8 ha) between 1988 to 1999 and 3% (742.0 ha) between 2006-2014 (Fig. 4). This increase is dependent on rainfall and water projects observed in the area. Despite the improvement in rainfall in 1988 compared in 1977, 1988 belongs to the long sequence of drought (1970-1997) whose average is less than that of the series (1970-201) and the sequence (1998 -2014) (Fig. 7). The increase in total rainfall is felt at the average ratings of the river. But even more by the commissioning of the dam Diama and Manantali. Nevertheless, the Bakel station is not in our study environment, but changing the dimension of the Senegal River at this level affects the stations of the delta (Fig. 8). It is representative of the flows from the upper basin. At this station, Senegal is already joined by all its tributaries [25]. The water extension is visible around Lake Guiers, three backwaters (Djeuss, Lampsar), the basin of Djoudji (Figs. 5 and 6). Over the years, the transition to the wet phase has affected the flow of rivers. Indeed, the monthly average ratings of the river Senegal Bakel stations, Richard-Toll, Diama Upstream and St. Louis showed an increase, with deviation reaching 129.6 cm in Bakel (Fig. 8). The increase in the volume of water in addition to the importance of rainfall is reinforced by the dams, and containment system made the turn of the Senegal River at Rosso Diama. These works are not adjusted to a more abundant rainfall have led to the middle of the phenomena of recurrent flooding. The water expansion is much higher in the estuary where it overflows the riverbed covering the lower parts. It is also developed around three backwaters, the bowl Ndiael and that of Djoudji. The expansion is also visible around Lake Guiers.

### 3.1.2 Dynamics of salted lands

The dynamics of salted lands or "tanned" is marked by a downward trend between 1977 to 2014. Indeed, the decline in the area of salted lands is estimated at 18% (32,756.2 ha) between 1977-1988, 37% (56,973.8 ha) between 1988-1999 and 66% (90,056.3 ha) between 2006 -2014. By against an increase of 42% (40,615.2 ha) is recorded between 1999-2006 (Fig. 4). The evolution of saline land is highly dependent on climate variability, particularly under the effect of temperature rainfall and evapotranspiration. Higher rainfall has led the desalination of salted lands. The importance of salty soil in 1977 is related to the rise of the salty language on the riverbed up to 200 km from the mouth.

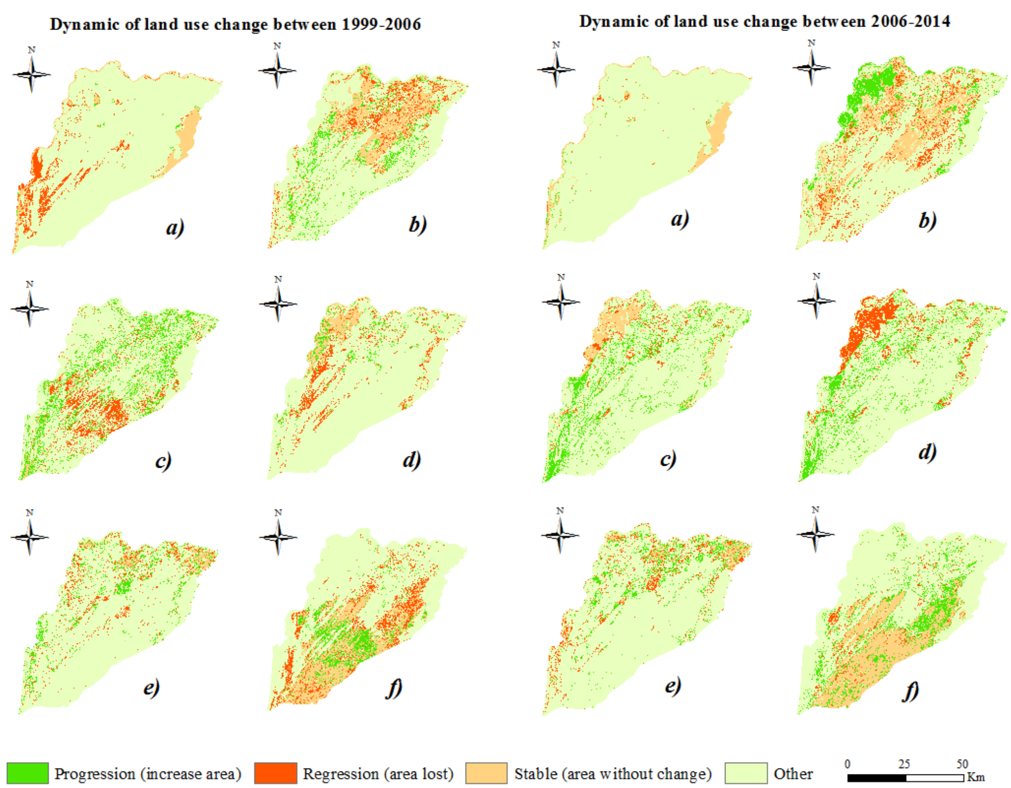


**Fig. 6. Dynamics of land use between 1999 to 2006 and from 2006 to 2014: a) "water" ; b) "salt land" ; c) "aquatic vegetation" ; d) "continental vegetation" ; e) "crowing area" ; f) "dune"**

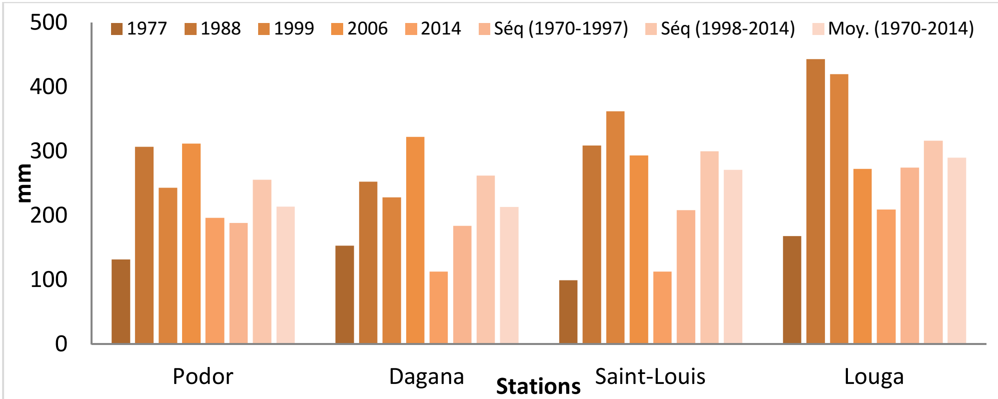


**Fig. 7. Evolution of total rainfall in the delta rainygauge between 1970 and 2014**

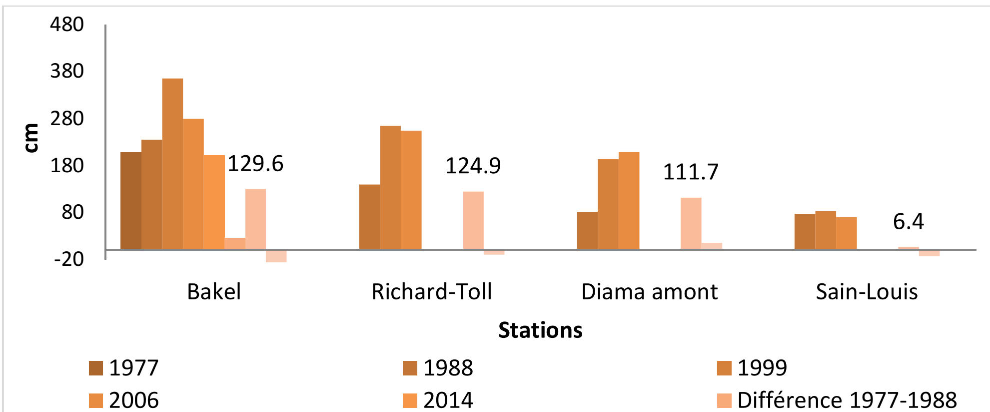


**Fig. 8. Evolution of annual average depth of the Senegal River from 1977 to 2014**

Thus, the gradual replacement of river water by those of the sea aggravates land salinization. In 1977, antisel Diama dam was not built. However, its creation in 1986 stopped the salt water downstream of Diama leading, lower saline lands. Also, adds rainy pockets during periods of dry spells and return to the rainfall recorded during the last decades. Indeed, abundant rainfall leads desalination land leaching. Desalinated areas are occupied by crops, aquatic vegetation where by water. The regression of this unit is more pronounced in the bowl of Ndiael, space irrigated areas, north of the town of Deby and estuary (Figs. 5 and 6). By cons, the increase of the area of saline lands is linked to several factors. Indeed, in the Delta, the evaporative water losses are greater than the amount precipitated [17]. Which is a factor of the extension of salty soil. Also, development of land depends on the progress of salted bevels. The latter is especially dependent on river flow during low water, itself based on the size of the previous flood [26]. Rainfall drop causes the river flow. Thus it promotes the progression of salted bevels far into the river. During the non-rainy season, drying up during the high evaporation promotes the deposition of dissolved salts on the surface. Delta also is covered by a salty groundwater whose level is close to 0 m [26,27]. This sheet is flush in all basins, their depletion causes salinization. The infrastructure development in the delta also involve extension of saline lands. The development of irrigated areas is a good example of the dissolution of buried salt and deposition surface.

### 3.1.3 Dynamics of aquatic vegetation

We are witnessing the proliferation of aquatic vegetation in the delta between 1977 and 2014. Figs. 5 and 6 highlight two general trends of the dynamics of this unit. The increase was 78% (13,540.2 ha) between 1977-1988 and 76% (23,513.6 ha) between 1988-1999 (Fig. 4). These changes are due to the desalination of the lands colonized thereafter regularly in submerged aquatic vegetation parties. This is due to the desalination freshwater continuously upstream of the Diama dam. The aquatic vegetation in this part consists in dominance by Tipha australis, Fragmites bulgaris, Salvinia molesta (water fern) and Pistia stratiotes (water lettuce). In the estuary, it consists of mangrove, also in part by the Freshwater tiphaie. The regression of aquatic vegetation is estimated at 18% (9988.7 ha) between 1999-2006 and 1% (257.6 ha) between 2006-204. It is explained by the decrease in water recorded during 2006 and the extension of saline lands. But also the destruction of the vegetation, which is in fact made up of invasive plants.

#### 3.1.4 Dynamics of the continental vegetation

The kinetics of the continental vegetation occurs by extending or narrowing of its area. These changes depend on the contribution of water resources (in the form of rain or water body) and human activities. The general trend is the increase of the area of the continental vegetation, which is 231% (19,917.4 ha) between 1977-1988, 78% (21,247.8 ha) between 1988-1999 and 74% (67,778.4 ha) between 2006-2014 (Fig. 4). The dynamics of the continental vegetation is more pronounced towards the south and is the turn of localities Gade Amar Fall and Ngnith. It colonizes the training ogoliennes dunes. It develops timidly toward the west near Maka-Diama and Mbodiène-Lampsar-Ngaye sector. The increase of the vegetation is attributed to an increase in annual rainfall, which is characterized by the increase in their total in 1988 compared to that of 1977. The vegetation is dominated by the formation of Acacia nilotica, it is in the form settlements in the depressions between. This development of the continental vegetation is also observed in the irrigated areas north of the study environment and northeast of the town of Diama. It is also noted in the estuary and around the backwaters and Lake Guiers. However, the regression of vegetation between 1999-2006 is attributed to the decline of water resources, due to the decrease in rainfall and high pressure noted on the resource (drinking water supply and irrigation).

#### 3.1.5 Dynamics of growing areas

The availability of water in the delta has allowed the development of irrigated agriculture. Indeed, the table below shows the status of the dynamic areas occupied by crops over the years. This dynamic is usually marked by a rapid expansion with the irrigated areas in the north and in lesser extent on rain south. It depends largely on rainfall justifies the cultivated areas. Thus, areas of crops have a tendency to increase their surface area. They recorded an increase of 95% (13,353.0 ha) between 1977-1988, 77% (17,859.6 ha) between 1988-1999 and 18% (7247.6 ha) between 2006-2014. A decrease of 3% (1172.4 ha) is noted between 1999-2006 (Fig. 4). The cultural space in the delta is mainly represented by the irrigated agriculture, crop monitoring under rain in the north and north-east. Irrigated crops are dominated by rice (Fig. 9). The extension of cropland is rated south of Lake Guiers, in the resort of Teud Bitty and Fass Ngom, but also in the northern part between Ronkh, Diama and Ndiael and also Ross-Béthio to Mbodiène (Figs. 5 and 6). Increased cultivation extended also reflects the improvement in rainfall but also to the decrease in salinity. The reduction of crop land between 1999-2006 is related to the decline in rainfall, reducing runoff and soil salinization. Indeed, rice occupying 18,190 ha in 1999 performs reduction - 4190 ha in 2006 (14 000 ha). It is the same for crops cowpea and millet with respective reductions - 2353 ha - 1117 ha between 1999 and 2006. However, the cultivation of groundnuts accuses an increase in its extent with an increase of 4430 ha (Fig. 9). This is explained by the fact that the peanut is a culture in which rain is formed in the dunes of the localities of Fass Ngom, Teud Bitty, etc. Thus, the map shows a clear trend extended culture between 1999 and 2006.The responses from the field surveys demonstrates the practice of peanut farming in this part.

#### 3.1.6 Dynamics of the dune

Dune areas are declining between periods 1977-1988 and 1988-1999 in this order with the rate of 9% (12,401.6 ha) and 20% (26,454.0 ha) (Fig. 4). This decrease is explained by the increase in rainfall recorded during this period, thus promoting the development of the continental vegetation on the dunes, particularly in the south of the study area. The dunes are also experiencing an increase in their area during the past two decades, or 2% (1815.5 ha) between 1999-2006 and 14% (14,521.4 ha) between 2006-2014. This extension is visible south of the middle turn of the locality of Gade Amar Fall, north of Fass Ngom and common Diama. She also developed east of the basin of Ndiael (Figs. 5 and 6). The information collected on the ground show that the presence of wind erosion very marked in the delta, and causing siltation basins, where the progress of the dune.

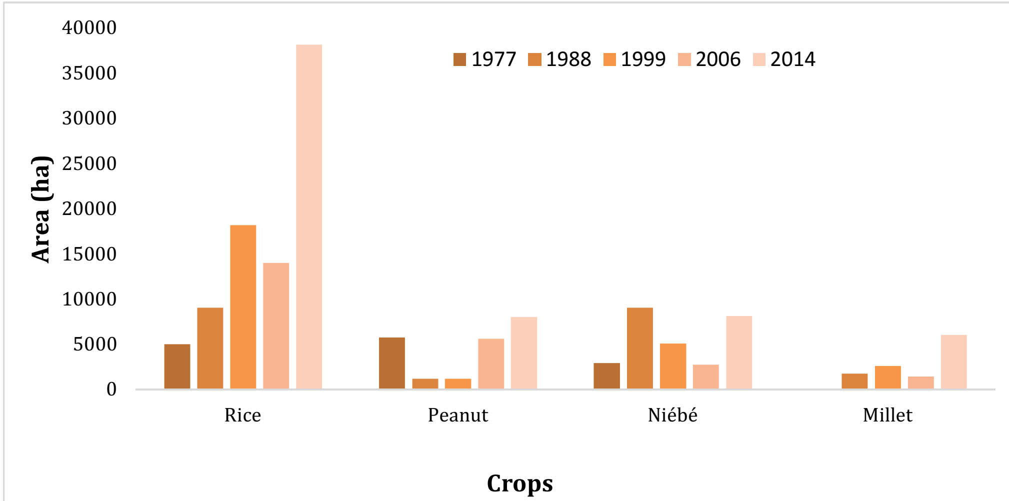


**Fig. 9. Evolution of cultivated areas from 1977 to 2014 (Dagana and St. Louis) 4.2.6**

## 4. CONCLUSION

The joint analysis of the dynamics and factors of land use in the Senegal River delta, showed significant changes noted in the landscape units between 1977 and 2014, under the effect of climate variability (temperature and precipitation), population growth, the development of agriculture (irrigated and rainfed) and irrigation schemes. In general, there is a rising trend of surface water, aquatic and land plants and growing areas, and vice versa for classes, dunes and saline lands. The chronology of events that took place in the Senegal delta, indicates that between 1977 and 2014, the area experienced a rainfall variability, marked by alternating dry and wet phases phases. Facing the long drought of the 1970s in the Sahel, facilities for mastering water resources are made on the Senegal River (Manantali in 1988) and the delta in particular (Diama 1985), Rosso of embankments at Diama (finalized in 1992) and the establishment of dikes and dams in many bridge backwaters of the delta. These achievements have driven off the ascent of the saline tongue, development of irrigated agriculture, animal husbandry and the navigability of the Senegal River from St. Louis to Kayes. Indeed, there is thus an artificial hydrological regime of the normal course of the river and its distributaries, leading to changes in natural ecosystems. Also, these works are not adjusted to a more abundant rainfall situation. Therefore, the improvement in rainfall between 1998-2014, produced recurrent floods in the delta. The severity of the impacts of this phenomenon pushes the authorities to implement emergency solutions, in this case the opening of the spade on the Langue de Barbarie in the south of the city of St. Louis in 2003. The opening this load shedding channel achieved its goal, which is to evacuate the excess floodwaters from the river to the sea. However, the river regime in the downstream estuary of Diama dam is completely changed and the environment too.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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