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# Socio-Ecological Resilience amongst Vulnerable Communities in the Senegal River Delta in the Face of Climate Change

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## Summary

The delta of the Senegal River is frequently subject to climate hazards such as floods, coastal erosion and drought, which expose inhabitants to various vulnerabilities.

This study aims, on the one hand, to analyse these environmental, socio-economic vulnerabilities and to study the perceptions of the population in the face of climate change in Saint-Louis (Senegal). On the other hand, it seeks to assess the resilience of its inhabitants.

For this purpose, we used remote sensing data and processing, and qualitative and quantitative household surveys.

The results indicate high coastline vulnerability, with a receding rate of 0.35 metres/year. Projected scenarios for rising sea levels, of 1.5/2 metres, would result in the flooding of 12% to 15% of the Langue de Barbarie area (199216 ha). The economic stakes associated with the coastal erosion hazards concern fishing and tourism activities, as well as housing. An analysis of land occupancy enabled us to establish that natural coastal land, without buildings, accounts for 42% of the total length of the Langue de Barbarie coast in Saint-Louis. The results also show low population resilience to climate change. The population has a good knowledge of the risks associated with climate change, but their adaptation strategies are not always appropriate for the "deflected delta" hydrological system.

**Keywords:** vulnerability, resilience, climate change, Senegal.

# Socio-Ecological Resilience amongst Vulnerable Communities in the Senegal River Delta in the Face of Climate Change

## Introduction

Natural disasters and climate change produce negative effects on populations, their means of subsistence and their environments. Studies show that 90% of these phenomena are linked to water (Heather, 2008). The delta of the Senegal River is frequently subject to climate hazards such as coastal erosion, flooding, drought, etc. Studies by Kane A. (1997), Diop (2004), Dumas & Mietton (2006), and Mietton et al. (2006) show that river flooding is recurrent. This has been confirmed by the work of Durand & Thomas (2010), who identified 18 major floods between 1827 and 1999 that affected the delta in Saint-Louis.

In contrast, the decades between 1960 and 1980 were marked by drought which affected the entire basin of the Senegal River (Demarée, 1990; Hubert, Carbonnel & Chaouche, 1989; Sircoulon, 1987) and led to the construction on the Senegal River of the Diama barrages in Senegal and the Manantali barrages in Mali, in 1986 and 1988 respectively.

However, these measures did not protect the delta from flooding throughout the 1990s, a decade marked by the return of humid conditions (Hubert, Bader & Bendjoudi, 2007). Indeed, partial flooding was observed as a result of high water levels in 1994, 1997, 1998, 1999 and 2003 (Diop, 2004).

Moreover, although the area has so far been protected from marine submersion, the fact remains that this is potentially the biggest risk in the context of climate change (Durand & Thomas, 2010). A large part of the city of Saint-Louis is located at, or below sea level. It is separated from the sea by a coastal peninsula commonly known as the Langue de Barbarie.

This natural barrier between the Senegal River and the Atlantic Ocean is currently weakened in several areas (Diakhaté, 2012). The opening of a 4 metre-wide relief duct (breach) in 2003 did prevent river flooding in Saint-Louis (Sy, Sy, & Bodian, 2015). However, it has since widened, reaching 5.5 kilometres in 2016 (Rey & Fanget, 2017). This has profoundly changed the hydrological functioning and is a threat to the entire Langue de Barbarie (Durand & Thomas, 2010; Wade & Rudand, 2007; Diakhaté, 2012).

Recently, in 2015, 2018 and 2019, surges from violent storms devastated dozens of houses in the Langue de Barbarie, forcing the authorities to relocate affected families to camps inland.

In light of these different events, it seems natural to ask whether the authorities and communities are in a position to anticipate these natural phenomena, and recover from them.

Our hypothesis is that the Langue de Barbarie is vulnerable to the impacts of the coastal dynamic and to climate change, and that its level of resilience is low.

To date, land use, urban planning and the socio-economic development of the Senegal River delta has been carried out with little regard for potential natural risks, and without taking their possible recurrence into account in the context of climate change.

In the same way, the high concentration of people in urban areas in the department of Saint-Louis, with 346,2 inhabitants/km$^2$ (ANSD, 2015), raises the question of community vulnerability. The socio-economic stakes associated with coastal hazards concern the vulnerability of infrastructures, including residential, commercial, service, heritage, road, and port infrastructures, and economic activities, namely fishing, market gardening, tourism and trade in fishery products.

Moreover, the residents' perceptions and traditional knowledge of the functioning of their natural environment are rarely taken into account as sources of information in scientific studies (Rodríguez del Amo & del Carmen, 2010) or in strategies of adaptation to climate change. In the context of accompanying coastal communities in the implementation of strategies to mitigate and adapt to environmental changes, it therefore seems essential to contribute to the improvement of knowledge by addressing major gaps with regard to building resilience for public authorities, local collectives and humanitarian organisations.

The aim of this study is therefore, on the one hand, to analyse the physical, ecological, and socio-economic vulnerabilities, and the perceptions of the populations on the Langue de Barbarie in Saint-Louis (Senegal). On the other hand, it aims to measure the inhabitants' resilience.

The scientific objective of this study is to contribute to improving the management of knowledge by documenting promising practices in matters of building resilience. This should contribute to the reinforcement of communities' immediate capacities for reaction, and to their sustainable recovery over the long term.

The social and humanitarian objectives are to ensure community participation by identifying and mobilising useful forms of traditional knowledge that help people to manage the variable climate and context of food insecurity. Community participation ought to facilitate the diversification of means of subsistence in response to real (and potential) shocks, on the basis of an in-depth risk assessment.

## Methodology

### *Area of study: the Langue de Barbarie in Saint-Louis, Senegal*

The city of Saint-Louis is located downstream of the Senegal River delta. It stretches over a territory that is made up of three entities: the Langue de Barbarie, the island of Saint-Louis and the neighbourhood of Sor.

The Langue de Barbarie is the result of the meeting between the Senegal River and the Atlantic Ocean. It is a sandy bar that stretches over 40 kilometres from the south of Saint-Louis to the mouth of the Senegal River (Figure 1). With a gradient of 3 to 4% and a width of 200 to 400 metres, this band of earth, which has an altitude of only 2 metres, is home to a number of residential areas that are exposed to climate hazards: flooding, storm surges, a rising water table, coastal erosion...

Figure 1: Localisation of the Langue de Barbarie in Saint-Louis, Senegal


It has a population of 45 875 inhabitants (ANSD, 2015), who make up roughly 20% of the population of the department of Saint-Louis in a densely populated area (one of the highest in the country).

The main economic activities in the Langue de Barbarie are fishing, market gardening and tourism.

## *Data collection and analysis techniques*

### *Data collection*

Two kinds of data were collected: environmental and socio-economic.

Environmental data collection was based on a geomatic procedure consisting of collecting and processing satellite images (from Landsat 7 ETM+, Google Earth Pro and data from the Digital Terrain Model (DTM) of the area of study). The reference timescale for the Landsat 7 ETM+ images was fixed at 10 years, but varied according to the available data.

Socio-economic data collection was carried out over ten days (in January 2019) in the area of study. It was based on the collection of data from qualitative studies (individual interviews, a focus group, and direct observation in the field), and quantitative studies (521 questionnaires) with a sample group of 10% of households in the Langue de Barbarie, for a total of 5227 households.

Table 1: Profile of respondents

| **GENDER M/F** | Number | % |
|---|---|---|
| Male | 299 | 57.4% |
| Female | 222 | 42.6% |
| Total | 521 | 100.0% |
| **Age** | | |
| Average = | 47.03 | |
| Median = | 46.00 | |
| Min = 18 Max = 85 | Min = 18 | Max = 85 |
| | Nb | % cit. |
| Under 20 | 5 | 1.0% |
| From 20 to 29 | 57 | 10.9% |
| From 30 to 39 | 120 | 23.0% |
| From 40 to 49 | 111 | 21.3% |
| From 50 to 59 | 106 | 20.3% |
| 60 and over | 122 | 23.4% |
| Total | **52**1 | 100.0% |
| **Number of people in the household** | | |
| Average = | 13.80 | |
| Median = | 13.00 | |
| Min = 2 Max = 37 | | |

**Interviews with key interviewees**

The chosen respondents were administrative, community, local and traditional authorities. These included the Prefect of the Department of Saint-Louis, heads and directors of regional fishing, environmental, education, and health services, the deputy mayor, neighbourhood chiefs, representatives of fishermen's and fishmongers' associations, the imam, etc. These served as key interviewees with regard to the components of resilience linked to governance, risk assessment, knowledge and education, risk management and the reduction of vulnerabilities, and preparedness and response. The questions requiring their participation were asked separately prior to the attribution of a level of resilience.

**Individual interviews**

The individual interviews targeted the heads of households (521 households). The questionnaire was designed to provide an analysis of vulnerabilities. The aim was to identify vulnerable groups and gather information about the main risks of climate change facing the community, and to gain an appreciation of their perceptions of climate change.

Sampling was carried out according to household size in six target neighbourhoods in the Langue de Barbarie (Dakk Guet Ndar, Lodo Guet Ndar, Bas Ndar Toute, Haut Ndar Toute, Goxu Mbathie, Hydrobase).

**The focus group**

The focus group was composed of displaced people from Goxu Mbathie and Guet Ndar in the Khar Yalla camp. There were 13 participants. The group was made up of the neighbourhood chief, the camp imam and his deputy, two womens' representatives, one youth representative, community leaders and some public figures. This composition was relatively representative of the different sectors of the community and allowed us to gain insight into a broad range of opinions, attitudes and points of view.

The questionnaire and data processing were carried out using the SPHINX programme.

*Analysis techniques*

**Analysis of physical and ecological vulnerabilities**

This analysis was based on a diachronic analysis of Landsat 7 ETM+ images to study the evolution of the coastline in the area of study. To this end, three images from 2000, 2010 and 2018 were downloaded and analysed with the help of the ArcGis programme. This analysis was completed by a transect of the coastline (over 15 kilometres) to characterise the type of coast, its condition, and the kind of artificiality that was present.

To analyse the risks of sea water intrusion, an analysis of scenarios of rising sea levels was carried out using data from the Digital Terrain Model (DTM) (30m) of the area of study. To this end, we considered four scenarios of rising sea levels: 0.5m; 1.5m; 2m and 5m.

These scenarios were selected on the basis of studies on climate projections and sea level rises in Senegal by 2035. We calculated the total area affected by the rise in sea levels for each scenario.

**Analysis of socio-economic vulnerabilities**

The analysis of socio-economic vulnerabilities was based on the analysis of studies and research documenting the socio-economic profiles and demographics of the community on the Langue de Barbarie (main means of subsistence, state of health, etc). It also focused on the identification of vulnerable groups and information about the main risks of climate change, but especially on economic issues and the potential economic impacts of climate change.

**Assessment of community resilience**

Resilience is generally considered to be "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change." (IPCC, 2008).

Nevertheless, basing themselves on new knowledge about climate change, Folke et al. (2010) note that resilience means "acting to convert communities and economies to configurations that work better in the conditions of a new, dynamic climate regime".

This approach enables an analysis of resilience that takes into account several components and the anticipation of social and ecological systems' responses to the hazards of climate change.

This was the approach that we used for this study. In order to measure population resilience in the face of climate change, we used "GOAL and Resilience: a Guide Note" (GOAL, 2015), which we adapted to the context of the Langue de Barbarie. This tool is designed to measure community resilience to disasters by means of a wide range of components of resilience. These components cover five key thematic domains: governance, risk assessment, knowledge and education, risk management and the reduction of vulnerabilities, and preparedness and response (Table 3).

The tool has been applied in a number of regions throughout the world, amongst both rural and urban communities. In Africa, it has been applied in Malawi and in Ethiopia in rural areas subject to flooding and droughts.

In the context of the Langue de Barbarie, consultation questions were submitted to key interviewees. They were developed to explore the characteristics of resilience for each component, on the basis of a ranking scale. Each of the five potential answers refers to one characteristic of resilience, which corresponds to an attributed "level of resilience", from 1 to 5 (1 indicating minimal resilience and 5 indicating high resilience). The recorded answers illustrate community resilience for each component. To determine the category of resilience in the domain, the median of the different domain components was used (Table 2).

Table 2: Scale for resilience assessment

| % | Scale | CATEGORY | DESCRIPTION |
|---|---|---|---|
| **0-20** | **1** | **Minimal resilience** | Little awareness of the problem(s) or little motivation to address them. Limited action in response to crises |
| **21-40** | **2** | **Low Resilience** | Awareness of the problem(s) and willingness to address them. Limited capacity for action (knowledge and competence, human, material and other resources). Interventions tend to be one-off, piecemeal and short-term. |
| **41-60** | **3** | **Average resilience** | Development and implementation of solutions. Improvement of the capacity for action, which remains significant. Interventions are more numerous and developed for the long-term. |
| **61-80** | **4** | **Resilience** | Coherence and integration. Interventions are extensive and cover all the main aspects of the problem, and they are linked together as part of a coherent, long-term strategy. |
| **81-100** | **5** | **High resilience** | All actors have a "culture of security" integrating the reduction of climate risks as well as the relevant components of policy, planning, implementation, attitudes and behaviours. |

## Results

### *Physical and ecological vulnerability*

The results indicate a receding coastline between 2000 and 2018 in the Langue de Barbarie. Figures 1 and 2 show the movement of the coastline. The average erosion rate, calculated by linear regression, is 0.35 metres/year over all measuring points between 2000 and 2018. However, in the Hydrobase sector in Guet Ndar, the results show a continuous erosion of the coastline since 2000, with an average rate of 0.61 metres/year. In the sector between Guet Ndar and Goxu Mbathie, this rate is 0.69 metres/year.

Figure 2: Sector A: Movement of the coastline between 2000 and 2018: from Goxu Mbathie to the southern border of Santhiaba

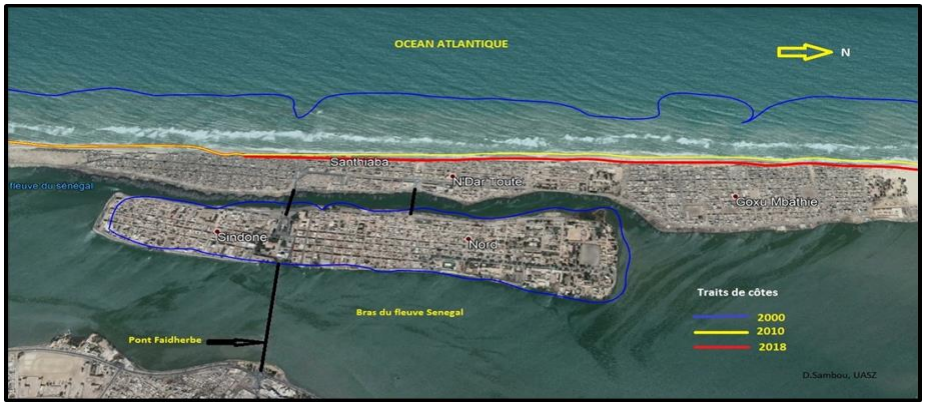
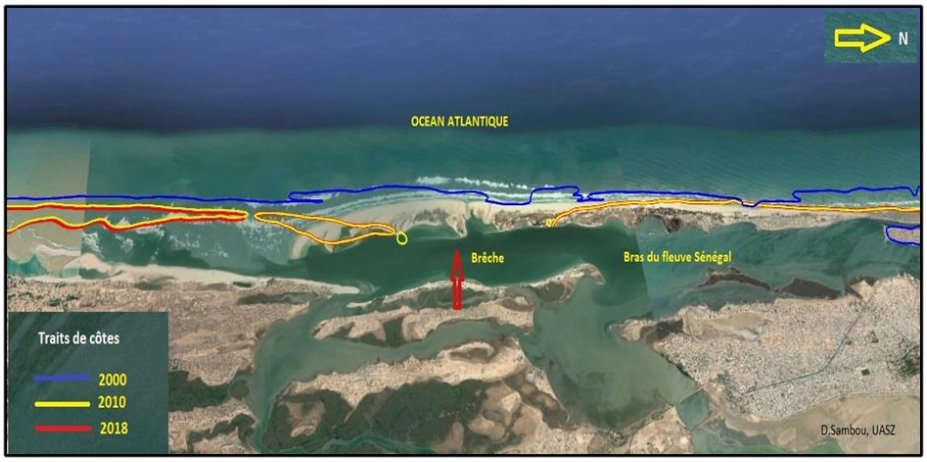
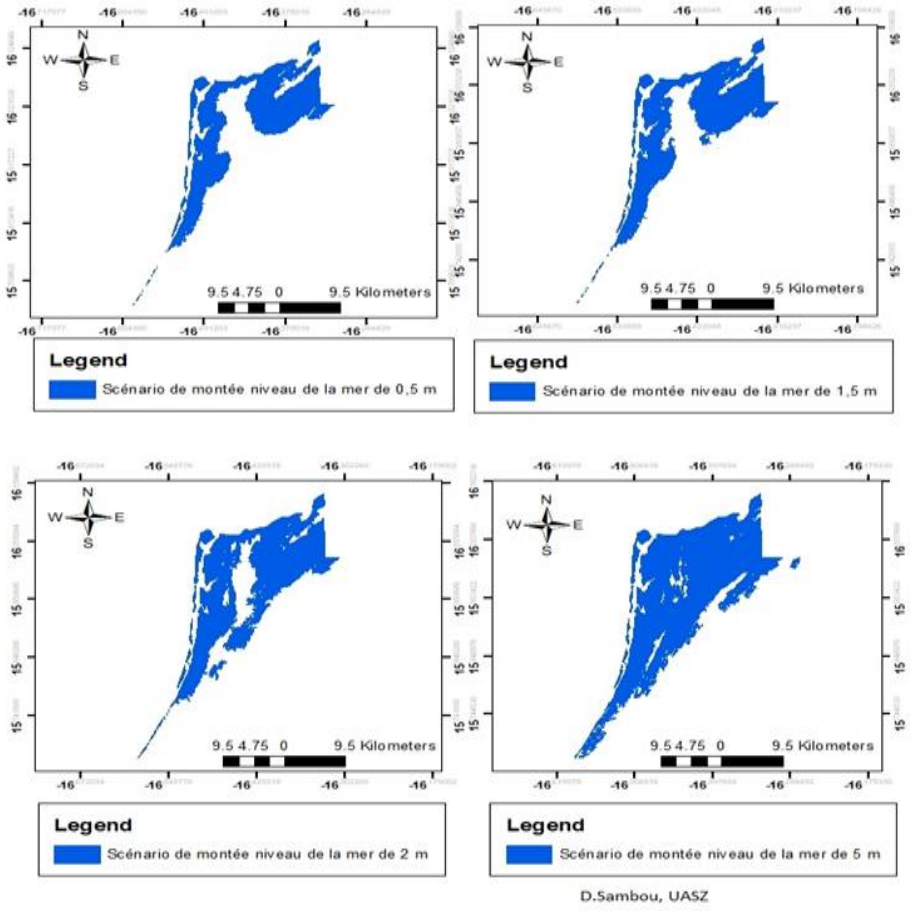



Figure 3: Sector B: Movement of the coastline between 2000 and 2018. From Santhiaba, by way of the Hydrobase beach, to the south of the breach




Scenarios of rises in sea levels indicate that for a rise of 0.5 metres, 11% (199.216 hectares) of the Langue de Barbarie would be flooded. The sizes of floodable areas for scenarios involving rises of 1.5 metres, 2 metres, and 5 metres are, respectively, 24.248 hectares; 29.14 8 hectares and 40.254 hectares (Figure 4).

igure 4: Scenarios of rises in sea levels and floodable areas




### *Socio-economic vulnerability*

The most significant economic issues in the Langue de Barbarie concern the activities of fishing and tourism, as well as housing.

71% of respondents declared that their economic activities are exposed to, or already affected by, climate change. Figure 5 shows that the most exposed/affected economic activities are fishing (91%), and trade in fishery products (77%), mainly involving women who transform fishery products.

Figure 5: the most affected economic activities

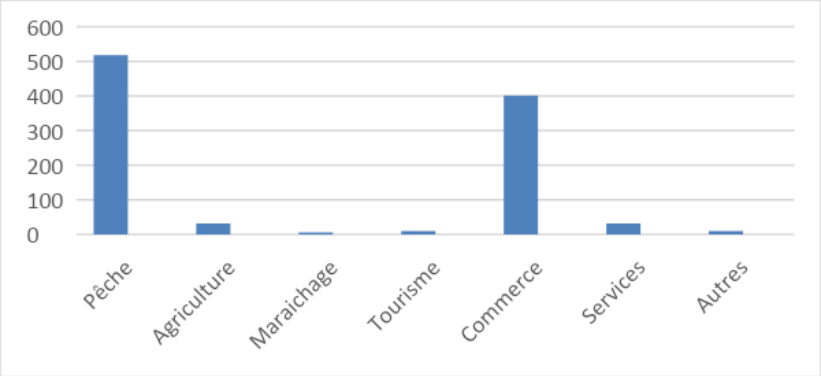



Chart legend:

- Fishing
- Agriculture
- Market gardening
- Tourism
- Trade
- Services
- Other

Tourist activity is also very vulnerable. Interviews with tourism professionals revealed a reduction in their revenues. The erosion of the Langue de Barbarie has also led to the closure of three tourist camps. The analysis of the territory enabled us to establish that the natural coastal territory, without buildings, accounts for 42% of the total length of the coastline (40 kilometres). According to the respondents, the most exposed and affected infrastructures and equipment are housing (95%), dugouts (91%), and equipment/infrastructures for the transformation and conservation of fishery products (43%).

Figure 6: The most exposed/affected infrastructures and equipment

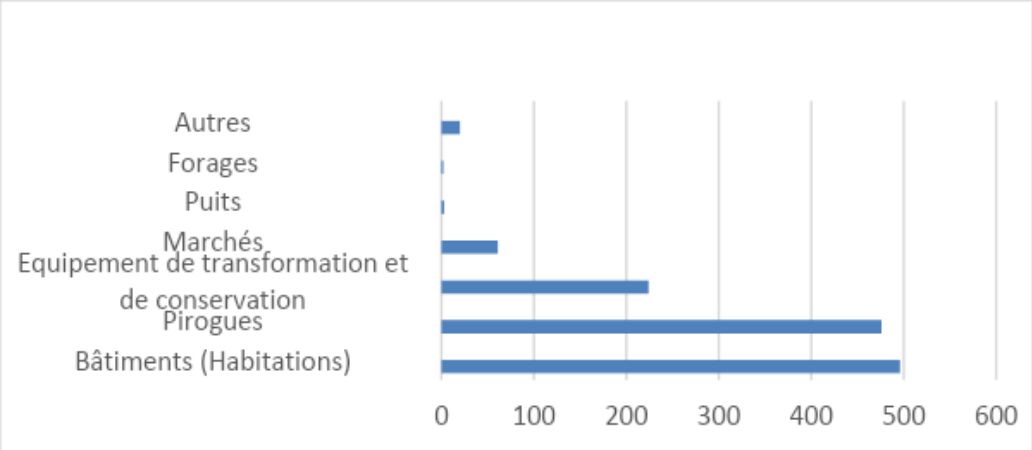


Chart legend:

- Other
- Drilling sites
- Wells
- Markets
- Transformation and conservation equipment
- Dugouts
- Buildings (housing)

The identification of the most vulnerable socio-professional categories shows that fishermen are the group most affected/threatened by climate change (97%), followed by women who work in the sector of fishery transformation and conservation (44%) and the sale of fishery products (40%).

Figure 7: Most vulnerable socio-professional categories

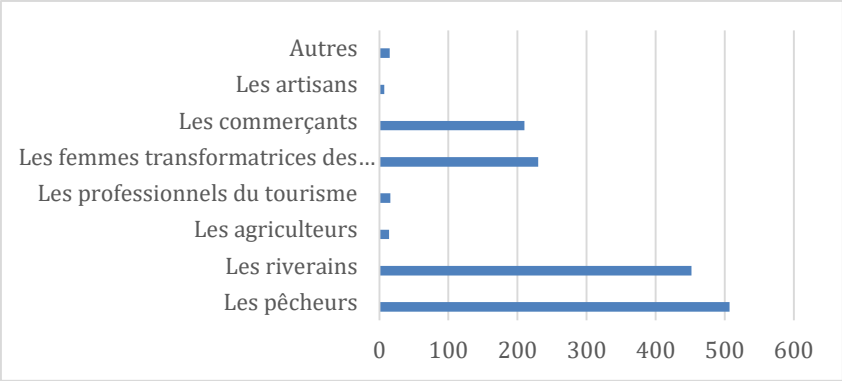



**Chart legend:**

- Other
- Artisans
- Merchants
- Women involved in fish processing
- Tourism professionals
- Peasants
- Residents
- Fishers

### *Residents' perceptions and adaptive measures with regard to coastal erosion*

The analysis of residents' perceptions enabled us to observe that respondents have a good understanding of the risks linked to climate change. Indeed, the vast majority of respondents identified the advance of the sea, river flooding, the scarcity/disappearance of certain fish species and coastal erosion as major risks in the context of climate change.

Figure 8: Identified risks

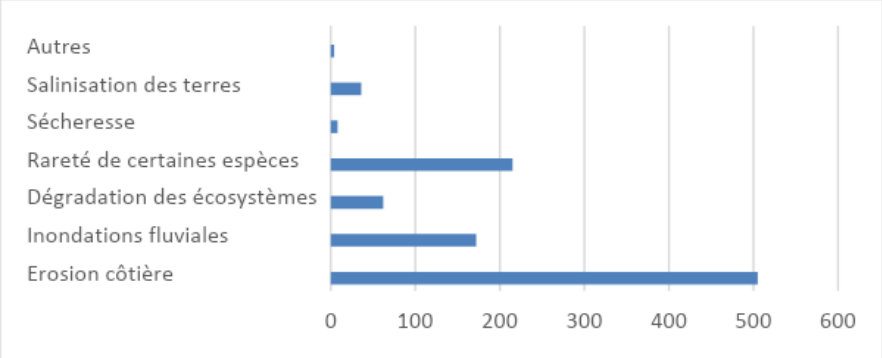



**Chart legend:**

- Other
- Land salinisation
- Drought
- Scarcity of certain species
- Degradation of ecosystems
- River flooding
- Coastal erosion

Moreover, 42% and 45% respectively declared that these phenomena have serious impacts (that is, the observed loss of human life), and high impacts (that is, fatal even if no loss of human life has yet been recorded).

Figure 9: Characterisation of impacts

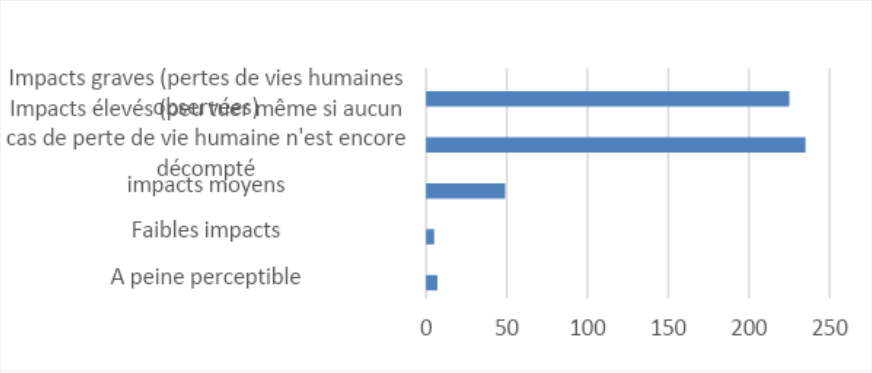


**Chart legend:**

- Serious impacts (loss of human life)
- High impacts (fatal even if no loss of human life has yet been recorded)
- Average impacts
- Low impacts
- Barely noticeable

Similarly, they consider that the most exposed/affected natural resources are the coastlines (77%), the beaches (69%), and the Langue de Barbarie National Park (79%). Also, 95% of respondents declared that the most exposed/affected infrastructures are the houses. Coastal erosion is the most marked environmental change that they observed. The vast majority of respondents declared that they had already been affected by coastal erosion. 81% of respondents declared having been affected, or having a close family member who was affected.

Figure 10: Climate hazards and their effects

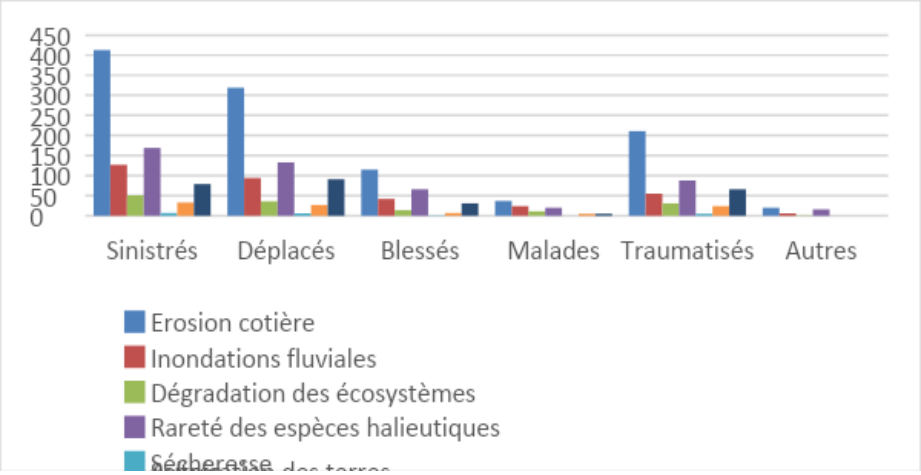



**Chart legend:**

**Horizontal**

- Victims
- Displaced persons
- Injured parties
- Sick people
- Traumatised people
- Other

**Vertical**

- Coastal erosion
- River flooding
- Ecosystem degradation
- Decline of fish species
- Drought

To date, residents' preferred actions to protect themselves from and adapt to coastal hazards have essentially involved building wooden or stone walls, sandbanks, and planting vegetation. Most believe that heavy, rigid structures, such as rip-rap and steel or concrete walls, are the best solution to counter coastal erosion. According to the majority of respondents, these actions, which entail significant costs, should be carried out by the Senegalese state.

### *Assessment of resilience*

Generally speaking, the results of the assessment of the different components of resilience, divided into five domains (governance, risk assessment, knowledge and education, risk management and the reduction of vulnerabilities, and preparedness and response) indicate a low level of resilience amongst populations on the Langue de Barbarie in the face of climate change.

Figure 11: Level of resilience of populations on the Langue de Barbarie according to the five domains

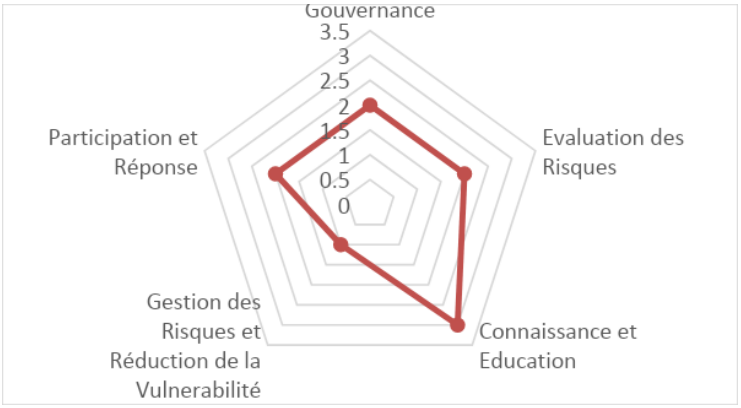



**Chart legend:**

- Governance
- Risk Assessment
- Knowledge and Education
- Risk Management and the Reduction of Vulnerabilities
- Preparedness and Response

Nevertheless, this result masks disparities between the different domains and components. Table 2 shows the results of the assessment of resilience. The level of resilience is low in the domains of governance, risk assessment and preparedness and response. However, it is average in the domain of knowledge and education, and minimal in the domain of risk management and the reduction of vulnerabilities.

Table 3: The characterisation and assessment of resilience according to its different components

| Themes | Components of resilience | Score | Level of resilience |
|---|---|---|---|
| **Governance** | Community leadership | 4 | **2** |
| | Awareness of rights and advocacy | 2 | |
| | Integration with development planning | 2 | |
| | Access to funding and partnerships | 1 | |
| | Inclusion of vulnerable groups | 2 | |
| | Involvement of women | 4 | |
| | | | |
| **Risk Assessment** | Analysis/assessment of hazards | 2 | **2** |
| | Vulnerability and Capacity Assessment (VCA) | 1 | |
| | Local and scientific methods for raising awareness with regard to risks | 4 | |
| | | | |
| **Knowledge and Education** | Public awareness and knowledge | 3 | **3** |
| | Dissemination of knowledge related to climate change | 3 | |
| | Cultural attitudes and values | 4 | |
| | | | |
| **Risk Management and the Reduction of Vulnerabilities** | Sustainable environmental management | 1 | 1. |
| | Access to health care in emergency situations | 1 | |
| | Access to health services under normal circumstances | 3 | |
| | Disaster-resistant livelihood practices | 2 | |
| | Social protection | 2 | |
| | Access to financial services | 1 | |
| | Protection of basic infrastructures and services | 1 | |
| | Land occupation and planning | 2 | |
| | | | |
| **Preparedness and Response** | Preparedness and response capacity | 2 | **2** |
| | Early warning system | 4 | |
| | Emergency planning/ORSEC Plan | 2 | |
| | Emergency response and recovery | 2 | |
| | Volunteering and accountability | 2 | |
| | | | |
| **General level of resilience** | **2** | | |

## Discussion

This study showed the vulnerability of the natural and socio-economic system on the Langue de Barbarie in Saint-Louis, Senegal, in the face of climate change. It also revealed limited population resilience.

The results of the study of environmental vulnerabilities showed that the coastline receded by 0.35 metres/year between 2000 and 2018, and that there is a risk of marine submersion with a rise in sea levels of at least 2.5 metres. This illustrates the highly sensitive nature of the coastal peninsula in the Senegal River delta, referred to by geomorphologists (Bhattacharya & Giosan, 2003) as a "deflected delta" because of the dominance of powerful northern sea currents over river currents. Several studies (Kane C., 2010; Durand & Thomas, 2010; Wade & Rudand, 2007; Diakhaté, 2012) have highlighted the sensitive nature of this (fragile) environment that moves according to the hydrological systems. Other studies (Sy, 2010; Varcin, 2018) have even considered the risk of the Langue de Barbarie disappearing altogether. These studies focused on the dynamic of the breach on the Langue de Barbarie. Its opening in 2003 created an instability and an imbalance of the forces in action (Diakhaté, 2012), and, after rapid coastal erosion, led to the disappearance/abandonment of the village of Doub Baba Dieye in 2012. Several other coastal villages on the Langue de Barbarie, as well as urban neighbourhoods including Guet Ndar and Goxu Mbathie, are also under threat from this coastal erosion.

On the other hand, other studies (Rey & Fanget, 2017) show that the displacement and lengthening of the coastal peninsula towards the south has made the coastal sector of Doun Baba Dieye less vulnerable to the hazards of marine weather. They also consider that a process of self-organisation is underway between the breach and the bank of the river opposite. The movement of the river mouth will contribute to the protection of the bank, thereby enabling a progradation and accretion of the beaches (Rey & Fanget, 2017). These new sedimentary conditions in Doun Baba Dieye would appear to amount to a form of coastal resilience.

Uncertainties with regard to climate trends and hydrological and geomorphological dynamics on the Langue de Barbarie therefore require more attention and precautions in terms of coastal management.

The human impact on these coastal areas contributes to reducing coastal resilience to projected climate changes. Offshore platforms are scheduled to be installed, following the recent discovery of hydrocarbon deposits 50 kilometres off the coast of Saint-Louis. The official studies on the impact on the sea bed and sea currents conclude that their impact will not be an aggravating factor in coastal erosion. Yet it is reasonable to ask whether these installations will effectively increase the risk level in the Langue de Barbarie.

In terms of socio-economic vulnerability, an analysis of the potential economic impacts of climate change revealed the vulnerability of the Langue de Barbarie. The most significant economic stakes in the Langue de Barbarie concern fishing and tourism activities, as well as housing.

The fishing sector is the most vulnerable to coastal erosion and climate change. Respondents declared that up until the year 2000, hundreds of fishing dugouts between 60 and 100 metres long berthed on the beach, but now the sea has engulfed everything, and they currently berth on the river, entering by the river mouth.

Fishermen are also the first victims of the effects of the breach. Recurring accidents at the river mouth often lead to the loss of dugouts and human lives. This is compounded by the halieutical issue of the decline in fish resources, caused by overfishing and changes on the seafloor. This situation compels fishermen to fish far out at sea, towards the Mauritanian coast, which often leads to conflict. It has also led to a depletion of family economies, which are largely dependent on the women who work in the transformation, conservation and distribution of fish.

With regard to tourism, Saint-Louis' bodies of water, beaches and rich colonial history, together with the Langue de Barbarie National Park (PNLB), mean that it is one of the country's main tourist centres. The erosion of the beaches has consequences for tourism: reduction of revenue, destruction of tourist camps, unemployment, etc.

Some businesses linked to the tourist industry are also very vulnerable, particularly in the Hydrobase sector (recreational and tourist area). The diminishing width of the beaches also affects tourism. With the rise in sea levels, these extreme events are likely to become more frequent.

The analysis of socio-economic vulnerabilities did not take into account the value of infrastructures and the costs of repairing damages caused by climate hazards in the Langue de Barbarie.

With regard to housing, residents of the Langue de Barbarie who regularly watch, helpless, as violent storm surges destroy their goods and houses, are torn between staying and going. Whilst some inhabitants have no intention of leaving the area, others would consider being relocated inland. The question then arises of investment and compensation. Does the Senegalese state have the means to implement such a policy?

Our interviews with displaced people in the Khar Yalla camp showed that their needs and expectations with regard to the State primarily concern the acquisition of land and compensation. These questions mask those relating to the restoration of sustainable means of subsistence (Harild, Vinck, Vedsted & Berry, 2013), and to the process of restoring socio-economic conditions (Warner et al., 2013), crucial to any process of "environmental" migration, which is accompanied by the risk of impoverishment (Cernea, 2003).

Photo 1: Coastal erosion and its effects in Guet Ndar 2019 - Sambou D


Photo 2: Khar Yalla camp for displaced persons - Sambou D. 01/2019

Photo 3: Focus group with displaced persons in the Khar Yalla camp - Sambou D. 01/2019

The study of perceptions showed that the inhabitants of the Langue de Barbarie have a good knowledge of the risks linked to climate change. They identified coastal erosion as being the most marked environmental change that they had observed.

Nevertheless, morpho-dynamic and environmental processes are not so visible for coastal communities. It is likely that respondents' perceptions are influenced by recent events in the Langue de Barbarie, namely the storm surges in 2018 and 2019, which caused significant material damage. Another visible event was the case of the breach, whose consequences have made navigation around the river mouth mortally dangerous. Since its opening in 2003, there have been 350 recorded deaths of fishermen as a result of accidents (Sy, Sy, & Bodian, 2015). These different events can explain the fact that a majority of respondents in the Langue de Barbarie perceived an increase in these phenomena.

Scientific studies must recognise coastal communities' knowledge as a source (Stervinou, Mayrand, Chouinard, & Nadège Thiombiano, 2013), since it can help to identify events that have had significant impacts on coastal systems (Bernatchez P. et al., 2008). Their knowledge helps to define the thresholds beyond which natural phenomena have an effect on the coast, and consequently on coastal communities.

With regard to the fight against coastal erosion, individual and community initiatives by residents to protect themselves from and adapt to coastal hazards have mainly consisted of building wooden or stone walls, making seawalls with sandbags, and planting vegetation.

Mitigation and adaptation actions on behalf of the Senegalese state have included placing sandbags (1.5 cubic metres) along the river bank, to break the energy of the waves. They have also recharged the sediment on the beach. These measures, undertaken after the disaster in the village of Doun Baba Dieye, were financed by the Ministry of the Environment for 525 000 euros (Rey & Fanget, 2017). Nevertheless, they did not produce the desired results. Since then, rip-rap and stone walls have been the preferred solutions in certain urban coastal sectors such as Goxu Mbathie and Santhiaba. These works are underway and have required 37 million euros in financing - 15 million from France and 22 million from the World Bank (Varcin, 2018).

Photo 4: Rip rap on the coast at Guet Ndar. Sambou D. 01/2019

Photo 5: Vegetation on the coast at Hydrobase. Sambou D. 01/2019

Photo 6: Seawall protection with sandbags, destroyed after a surge. Sambou D. 01/2019

Photo 7: Protection work (rip rap and wall) at Goxu Mbathie. Sambou D. 01/2019

But are these structures adapted to the coastal system on the Langue de Barbarie? Do they not exacerbate coastal erosion? What are their potential impacts?

Some respondents believed that these structures had negative impacts on the beaches and the coasts, and that they exacerbated coastal erosion. Research by Bernatchez, Fraser & Lefaivre (2008) showed that on the low-lying, sandy coastal areas, rigid protective structures do reduce the rate of receding coastlines in the short-term, but they increase the risk of submersion. Other studies (Rey & Fanget, 2017) have shown that the "fixed" approach does not always yield good results because coastal temporalities do not correspond to the temporalities of societal decision-making and action.

It therefore remains necessary to raise awareness amongst residents of coastal environments regarding the different coastal risks, and especially regarding different adaptation measures.

Finally, population resilience on the Langue de Barbarie was evaluated by means of 25 components grouped into five domains (Table 3). It was attributed a level 2, on a scale of 1 to 5, that is, low resilience. Nevertheless, this result masks disparities between the different domains.

In terms of governance, the low level of resilience can be explained by the multi-scalar management approach, and the plurality of stakeholders (Rey & Fanget, 2017) in the management of coastal risks. Our interviews with our key interviewees and with displaced persons in the Khar Yalla camp enabled us to observe the diversity of stakeholders (private and institutional) whose interests and concerns are divergent and prevent the good management of issues surrounding coastal erosion.

Moreover, Senegal has developed a number of tools that bear witness to its commitment to taking the dimension of climate change into account in its policies for socio-economic development. Yet inadequacies prevent the implementation of the National Adaptation Plan for Action (PANA). These include the financing of projects and programmes in favour of the adaptation of the main socio-economic sectors (Gaye, Lo, Djimbira, Fall, & Ndiaye, 2015).

In the domain of education and knowledge, resilience is average. This bears witness to the level of implication on behalf of populations on the Langue de Barbarie in a dialogue about potential risks. The key component of this dialogue is the degree of impact of representations and cultural/religious values on communities' understanding of risk, and on their capacity to adapt and recover. This dialogue must be pursued through formal and informal methods of community communication.

Resilience in terms of risk management and the reduction of vulnerabilities is minimal on the Langue de Barbarie. Indeed, the policies and programmes developed by the State of Senegal to reduce population exposure to coastal risks are accounted for in official documents, but their implementation remains problematic. Respondents believe that these policies and programmes do not prioritise measures against the losses and interruptions of revenue which affect fisherman and women in fishery-derived activities in the wake of disasters.

Finally, the results indicate a low level of resilience in the domain of preparedness and response to disasters. The authorities' and communities' limited capacity to anticipate events, manage the victims and recover from the shocks have been all too apparent in the wake of the different natural disasters affecting the Langue de Barbarie.

## Conclusion

Ultimately, the analyses undertaken in the Langue de Barbarie show its physical, ecological and socio-economic vulnerability. They also reveal that the system and the population have low levels of resilience in the face of climate change.

The issue of reducing vulnerabilities and building resilience is therefore paramount. Aside from the Senegalese state, this question also needs to be addressed by local communities, humanitarian organisations and development partners.

The answers must be based on an in-depth analysis of public and private strategies for the implementation of policies of adaptation to climate change. From this perspective, research directions could include:

- Links between governance and climate resilience

The quality of governance noticeably contributes to resilience. What is the role of institutions implementing national adaptation policies? The issue of financial resources and resilience infrastructures might also be explored.

- Strategies and costs of resilience in coastal areas

It would be interesting to study strategies that mobilise human, natural and social capital to encourage resilience dynamics in coastal areas, and which priority needs, in terms of infrastructure building, might contribute to this resilience. It would also be useful to evaluate the costs of building these infrastructures.

## Bibliography

(ANSD), A. N. (2015). *Situation économique et sociale régionale 2012 .* Saint-Louis.

Bernatchez, P., Fraser, C., & Lefaivre, D. (2008, Mai 20-24). Effets des structures rigides de protection sur la dynamique des risques naturels côtiers: érosion et submersion. *Conférence canadienne sur les géorisques*(4).

Bernatchez, P., Fraser, C., Friesinger, S., Jolivet, Y., Dugas, S., Drejza, S., & Morissette, A. (2008). *Sensibilité des côtes et vulnérabilité des communautés du golfe du Saint-Laurent aux impacts des changements climatiques.* UQAR. Rimouski: Laboratoire de dynamique et de gestion intégrée des zones côtières, UQAR.

Bhattacharya, J., & Giosan, L. (2003). Wave-influenced deltas: geomorphological implications. *Sedimentology, 50*, 187-210.

Cernea, M. (2003). Pour une nouvelle économie de la réinstallation : critique sociologique du principe de compensation. *Revue internationale des sciences sociales*, 39-48. doi:https://doi.org/10.3917/riss.175.0039

Demarée, G. (1990). An indication of climatic change as seen from the rainfall data of a Mauritanian station. *Theor. Appl. Clim 42*, 139-147.

Diakhaté, M. (2012, Décembre). Dynamique naturelle et processus de modélisation de la «brèche» ouverte sur la Langue de Barbarie à Saint-Louis : problématique et préalables méthodologiques» . *Revue de Géographie du Laboratoire Leïdi –ISSN0851-2515*(10).

Diop, I. (2004). Canal de délestage de la crue de 2003 : impacts et perspectives. *Communication à L'Académie des Sciences du Sénégal* . Dakar, Senegal.

Dumas, D., & Mietton, M. (2006). Fonctionnement des hydrosystèmes et gestion de l'eau dans le bas delta du fleuve Sénégal : ruptures et adaptations. La Baule.

Durand, B., & Thomas, Y. (2010). L'impact de l'ouverture de la brèche dans la langue de Barbarie à Saint-Louis du Sénégal en 2003 : un changement de nature de l'aléa inondation ? *Cybergeo : European Journal of Geography; Environnement, Nature, Paysage*. Accessed at: http://journals.openedition.org/cybergeo/23017 ; DOI : 10.4000/cybergeo.23017

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society, 15*(4). Accessed at: http://www.ecologyandsociety.org/vol15/iss4/art20/

Gaye, A. T., Lo, H. M., Djimbira, S., Fall, M., & Ndiaye, I. (2015). *Sénégal: Revue du contexte socioéconomique, politique et environnemental.* Dakar.

GOAL. (2015). *Outils pour mesurer la résilience des communautés aux désastres.* Accessed at: https://www.goalglobal.org/images/GOAL_Toolkit_Disaster_Resilience_Guidance_Manual_FRENCH_May_2015.compressed.pdf

Harild, N., Vinck, P., Vedsted, S., & Berry, P. (2013). *Forced displacement of and Potential solutions for IDPs and refugees in Sahel-Burkina Faso, Chad, Mali, Mauritania and Niger.* Washington DC: World Bank. doi:http://wwwwds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/08/12/000470435_2

Heather, A. (2008). Réduire les risques de catastrophe associés aux conditions climatiques et à leur évolution. *Bulletin de l'OMM (2)*, 57. Accessed at: https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/article_bulletin/related_docs/Bul_57_2_auld_fr.pdf?LealLylzKdjIzS5WLv5V.Z1rTg.PvYT

Hubert , P., Bader , J., & Bendjoudi, H. (2007). Un siècle de débits annuels du fleuve Sénégal. *Hydrological Sciences Journal, 52*(1), 68-73. doi:10.1623/hysj.52.1.68

Hubert, P., Carbonnel, J., & Chaouche, A. (1989). Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest. *Journal of Hydrology*, 349-367.

IPCC. (2008). 2007 Climate Change Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change. Geneva: [Main drafting team, Pachauri, R.K. and Reisinger, A. (published under the direction of~)]. Accessed at: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_fr.pdf

Kane, A. (1997). L'après-barrage dans la vallée du fleuve Sénégal : Modifications hydrologiques, géochimiques et sédimentologiques. Conséquences sur le milieu naturel et les aménagements hydroagricoles. *L'après-barrage dans la vallée du fleuve Sénégal : Modifications hydrologiques, géochimiques et sédimentologiques. Conséquences sur le milieu naturel et les aménagements hydroagricoles*, 551. Dakar, Senegal: doctoral thesis, Univ. Dakar.

Kane, C. (2010). Vulnérabilité socio-environnementale en domaine sahélien : l'exemple de l'estuaire du fleuve Sénégal. *Thèse de doctorat en géographie. Strasbourg*, 318. Strasbourg, France: Université de Strasbourg.

Mietton , M., Dumas, D., Hamerlynck, O., Kane, A., Coly, A., Duvail, S., . . . Daddah, M. (2006). Le delta du fleuve Sénégal. Une gestion de l'eau dans l'incertitude chronique. *Actes du Colloque international « Incertitudes et Environnement- mesures, modèles, gestion*, (p. 12). Arles.

Nick, S. (1998, Septembre). Importance de la pêche au Sénégal et le rôle primordial des femmes dans cette activité. *Congrès du Collectif National des Pêcheurs Artisanaux du Sénégal (CNPS*. doi:http://base.d-p-h.info/fr/fiches/premierdph/fiche-premierdph-5549.html

Rey, T., & Fanget, C. (2017). L'inadéquation entre les temporalités côtières et le temps des décisions et des actions au Sénégal : l'exemple de la brèche de Barbarie. *Territoires d'Afrique*(10).

Rodríguez, S., del Amo, M., & del Carmen , V.-T. (2010). Reflections on the social learning process for community work in rural areas of Mexico. *International Journal of Biodiversity Science, Ecosystem Services and Management, 3*, 31-45. doi:10.1080/17451590709618160

Sircoulon, J. (1987). Variation des débits des cours d'eau et des niveaux des lacs en Afrique de l'Ouest depuis le début du 20e siècle. (M. B. IAHS Solomon S.L., Éd.) *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources.*(168), 13-25.

Stervinou, V., Mayrand, E., Chouinard, O., & Nadège Thiombiano, A. (2013). La perception des changements environnementaux : le cas de la collectivité côtière de Shippagan (Nouveau-Brunswick, Canada). *Vertigo, 13*(1).

Sy, B. A. (2010). L’histoire morpho dynamique de Doun Baba Dièye du Sénégal. *1*(1), 21.

Sy, B. A., Sy, A. A., & Bodian, A. (2015). *"Brèche" ouverte sur la langue de Barbarie à Saint-Louis: Esquisse de bilan d'un aménagement précipité.* Saint-Louis: Harmattan. doi:ISBN : 978-2-343-06975-3

Varcin, A. (2018). *klima.ong.* Accessed at “Klima entre terre et mer”: https://www.klima.ong/varcin-saint-louis-du-senegal/

Wade, S., & Rudand, J. (2007). Gestion des catastrophes naturelles par télédétection et SIG :Application à l’étude hydrologique du fleuve Sénégal et à la gestion des risques d’inondation de la ville de Saint-Louis. *Programme CORUS, Laboratoire de télédétection appliquée, Institut des Sciences de la Terre, Université Cheikh Anta Diop, Dakar*, 94.

Warner, K., Afifi, T., Kälin, W., Leckie, S., Ferris, B., Martin, S., & Wrathall, D. (2013). *Changing climates, moving people: Framing migration, displacement and planned relocation.* Policy Brief 8, United Nations University / Institute for Environment and Human (UNU-EHS), Bonn. Accessed at: http://www.ehs.unu.edu/article/read/changing-climate-moving-people-framingmigration-displacement