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GOVERNMENT OF SENEGAL
- DEPARTMENT OF ENVIRONMENT AND CLASSIFIED ESTABLISHMENTS

WORLD BANK

Economic and Spatial Study of the Vulnerability and Adaptation to Climate Change of Coastal Areas in Senegal

Synthesis Report

Final Version



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egis International

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Acronyms and Abbreviations

ANSD	*Agence Nationale de la Statistique et de la Démographie* (National Statistics and Demography Agency)
ASECNA	*Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar* (Agency for the Safety of Aerial Navigation in Africa)
AV	Added Value
CC	Climate Change
CRODT	*Centre de Recherches Océanographiques de Dakar-Thiaroye* (Dakar-Thiaroye Oceanographic Research Center)
CSE	*Centre de Suivi Ecologique* (Ecological Monitoring Center)
DEEC	*Direction de l'Environnement et des Etablissements Classés* (Department of Environment and Classified Establishments)
DGPRE	*Direction de la Gestion et de la Planification des Ressources en Eau* (Department of Water Resource Management and Planning)
DIVA	Dynamic and Interactive Vulnerability Assessment
DTGC	*Direction des Travaux Géographiques et Cartographiques* (Department of Geographic and Cartographic Works)
DTM	Digital Terrain Model
DWS	Drinking Water Supply
EU	European Union
GCM	Global Climate Model
GDP	Gross Domestic Product
GFAF	Gross Fixed Asset Formation
GHG	Greenhouse Gas
GIS	Geographical Information System
GL	Geographic Leveling
GLCN	Global Land Cover Network
HZ	*Zéro Hydrographique* (Chart Datum)
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change

IRD	*Institut de Recherche pour le Développement* (Research Institute for Development)
ITF	Intertropical Front
IUCN	International Union for Conservation of Nature
KMS	Keur Momar Sarr
LCCS	Land Cover Classification System
LIDAR	Light Detection And Ranging
MAC	Mean Annual Cost
MSL	Mean Sea Level
NPC	Net Present Cost
OMVS	*Organisation pour la Mise en Valeur du fleuve Sénégal* (Senegal River Basin Organization)
ONERC	*Observatoire National des Effets du Changement Climatique* (National Observatory of Climate Change Impacts)
ORSTOM	*Office de la Recherche Scientifique et technique d'Outre-Mer* (Office of Overseas Scientific and Technical Research)
PDD	*Plan Directeur de Drainage* (Drainage Master Plan)
PEPAM	*Programme d'Eau Potable et d'Assainissement du Millénaire* (Millennium Drinking Water and Sanitation Programme)
POGR	*Programme d'Optimisation de la Gestion des Réservoirs* (Reservoir Management Optimization Programme)
SAPCO	*Société d'Aménagement et de Promotion des Côte et Zone Touristiques* (Agency for the Development and Promotion of the Tourist Coast and Area)
SDE	*Sénégalaise Des Eaux*
SHOM	*Service Hydrographique et Océanographique de la Marine* (Water and Ocean Department of the Navy)
SLR	Sea Level Rise
SONES	*Société Nationale des Eaux du Sénégal*
SRES	Special Report on Emissions Scenarios
TER	Third Evaluation Report
UEMOA	*Union Economique et Monétaire Ouest Africaine* (West African Economic and Monetary Union)
UNEP	United Nations Development Programme
UNEP	United Nations Environment Programme
WHO	World Health Organization

EXECUTIVE SUMMARY

A study which took place within a particularly sensitive context, thus requiring a close coordination with the other projects in progress

The African coastal countries are facing several **environmental and socio-economic challenges**, such as unplanned urban and economic development, fuelled by a growing rural exodus; non-functional and/or non-existent public infrastructures to handle the demographic growth along the coastline; air, water and soil pollution; and alteration of coastal ecosystems. West Africa, in particular, is facing severe land losses and major damage due to coastal erosion and shoreline loss. This situation impacts coastal communities, infrastructures and users, and hampers economic growth. The institutional, technical and financial capabilities at the regional, national and local scales are not sufficient to effectively meet these challenges. **The impacts of climate change will undoubtedly intensify those trends and induce accelerated coastal erosion, loss of land and assets, river or run-off floods, marine submersion, groundwater salinization and changes in the distribution and abundance of coastal and marine habitats and species.**

The Senegalese coastline is logically affected by the above trend. It stretches over 531 km, crossing 6 administrative regions of the country (Saint-Louis, Louga, Thiès, Dakar, Fatick and Ziguinchor) that are home to 60% of the Senegalese population (12.5 million inhabitants in 2010).

The **awareness** of the government of Senegal on the issue of coastal vulnerability to climate change is matched by a growing pressure from the public opinion. Authorities recently closed down two sand extraction quarries and are engaged in a major effort to implement the national coastal erosion prevention program – launched in 2006 – and the Coastal Law (*Loi Littorale*).

The World Bank's assistance

The World Bank, supported by the governments of Norway and Finland, assists the Senegalese government in developing its reforms program, in improving the country's technical and financial adaptability and in integrating climate resilience into the future development plans regarding the coastline of Senegal. Moreover, this study has been co-financed by the Global Facility for Disaster Reduction and Recovery (GFDRR).

A first limited analysis of the coastal areas' physical and economic vulnerability to climate change was carried out from October to December 2010 in Senegal and Gambia, using the DIVA model (Dynamic and Interactive Vulnerability Assessment) and funds from the World Bank.

In parallel, the World Bank carried out a preparatory mission, which included a broad consultation, in order to draft the terms of reference of this study, so as to fill the gaps in the fields of spatial and economic analysis of natural risks and climate change impacts.

This 2010 mission led to the recommendation that a study be performed in close cooperation with the initiative of the Ministry of Environment (financially supported by the European Union) that aimed at developing an **Integrated Coastal Zone Management Plan** (a project launched in January 2012), as well as with other initiatives (completed or in progress) regarding coastal erosion and adaptation to climate change.

Last, the competitive process to select the Consultant responsible for the performance of this study was completed at the end of June 2011 and led to the selection of **Egis International**. The study started in July 2011 and was completed at the end of 2012. The Consultant worked in close cooperation with the various national and local stakeholders, while the World Bank team responsible for the study cared for institutional relationships and facilitated exchanges.

This study thus meets a **strong demand from the government of Senegal**, represented by the Ministry of Environment, and was supported by the municipalities of the pilot sites where an

in-depth study was carried out. A technical committee, formed of representatives of all the administrations and agencies concerned by coastal planning, supervised and guided the design of the study. The Ecological Monitoring Center (*Centre de Suivi Ecologique* - CSE) played a major role in the provision of mapping data under the form of GIS.

A progressive, technical and structured approach

The main objective of the study was to carry out a **spatial and economic analysis of the coastal areas' vulnerability to climate change** and natural risks in Senegal, and to perform an economic analysis of different adaptation options in three pilot sites.

The operation was structured around two sub-objectives:

- spatial and **economic assessment**, over the coastal area, of the risks and vulnerabilities with regards to climate change, in particular those related to sea level rise;
- **assistance to decision-making** regarding investments and climate change adaptation actions, thanks to the evaluation of the costs and benefits and to the prioritization of actions and investments.

A long-term analysis
Four study horizons were considered: the situation in 1990 and today (2010), which enabled to determine the trends over the last 20 years; and the situation in 2030 and 2080, which correspond to medium- and long-term forecasts, the former following the current trends, the latter being more hypothetical but still enabling to draft a strategic vision of the issues that coastal territory planning will face with respect to natural risks and climate change.

The study comprised **four phases**:

1. Methodology development
2. Spatial analysis of the climate change vulnerability of the coastline of Senegal
3. Economic modelling and analysis of the adaptation options in three pilot sites
4. Consolidated recommendations to inform the development of an Integrated Coastal Zone Management Plan.

Hence, the study was first carried out **at the scale of the entire coastline of Senegal**, over a 10km-wide strip. **An in-depth analysis was done for the three pilot sites**. These were selected because of their established vulnerability to natural risks, especially those related to coastal erosion: Saint-Louis, at the mouth of the river Senegal; Rufisque-Bargny, at the junction of the peninsula of Cap-Vert and the shoreline of Petite-Côte; and Saly, on Petite-Côte.

Though no risk modelling was carried out, the study **made excellent use of the possibilities offered by the GISs** to assess vulnerabilities and simulate natural risks.

At its completion, the study had enabled to collect and assemble topographic, environmental and socio-economic data regarding the coastline, to analyse such data in view of climate change, and to assess this latter's impact in terms of economic value. Furthermore, it **provides the authorities in charge of spatial planning with a flexible and updatable decision-making economic model for the adaptation strategies**, which was lacking in the uncoordinated initiatives that had been previously implemented along the coastline.

A study at the scale of the entire coastline which highlights a strong increase in risks for the years to come

This study mainly **focused on urban areas**, which are considered as the most vulnerable to climate change along the coastline. In the years to come, such areas should grow spectacularly. **Over the 2005-2030 period, the study estimates that urbanized areas will grow by 16%** along the shoreline, to the detriment of agricultural and natural areas. Over the 1990-2080 period, the overall urbanization of the shoreline should have grown by one third. **The highest coastal urban growth should take place along the shoreline of Petite-Côte**, with +49% between 1999 and 2030. After that date, the extension of urban centers will mainly take place towards the hinterland, due to the lack of available space along the coast.

Major climate changes expected
On the Senegalese coast, the climate evolutions, as foreseen by global climate models, show that the mean annual temperature should increase by roughly 1.1-1.2°C by 2030 and 2.6-4°C by 2080. Precipitations do not evolve consistently according to all models. Overall, the models agree that precipitations should decrease in the broad North-West quarter of Senegal, thus increasing the current trend of moisture deficiency, notably in areas which are already less favored. The global temperature increase will lead to the dilatation of ocean masses and the melting of polar ice caps, leading to an acceleration of sea level rise. On the basis of a critical analysis of the IPCC's forecasts and of the latest evidence regarding that topic, this study considers that the global sea level will rise by 20 cm by 2030 and by 80 cm by 2080.

The respective evolutions of land occupation and of climate will combine and lead to an increase of natural risks:

- Whereas in the current situation, only 25% of the shoreline is deemed to be at high risk of erosion and shoreline loss, notably in the deltas and estuaries of the three main rivers, it is estimated that by 2080, because of sea level rise, **75% of the shoreline could become at high risk of erosion**. The main cause is sea level rise, which has already been significant over the last decades. However, sand extraction and beach-top urbanization accelerate erosion phenomena. At a local level, geological faults (such as the Kayar canyon) also restrict sediment transit.

- The risk levels related to marine submersion during storms show a limited evolution, mainly because they are currently already very high (> 50% of the coastline). However, by 2080, **two thirds of the shoreline could be facing a high risk of submersion**. Such risk is mainly high along the shoreline of Grande-Côte, where a breach in the dune ridge during a storm surge would lead to major and extended damage on adjacent agricultural land.

- The estuary of the Senegal river faces a **river flood risk that mainly concerns the city of Saint-Louis**. Since Saint-Louis had been selected as one of the pilot sites for this study, this issue has been further investigated (see below).

- **In the Dakar agglomeration, the flood risks are related to urban run-off**, notably because of the insufficient evacuation capability of the storm water network or the absence of network in the neighborhoods of **Pikine and Guediawaye**. The **Diaminar neighborhood, at the entrance of Saint-Louis**, faces similar risks. It should be noted that due to the difficulty to model exceptional precipitations, it was not possible to determine their long-term evolution.

- **The risks of water shortages** have been assessed by the water company *Société Nationale des Eaux du Sénégal* until 2025. For the **Dakar area**, the water deficits (withdrawals greater than natural replenishment) start as soon as 2011 and increase as

the needs grow, shifting from an average of 18,000 m³/day in 2011 to 195,800 m³/day in 2025. All the other urban areas of the coastline will face water deficit situations in the more or less short term.

- Finally, as regards the **risk of groundwater salinization**, the sea level rise and the decrease of mean annual precipitations will induce a shift of the saltwater wedge towards the hinterland, and thus a decrease of the groundwater resource. Without taking into account a possible positive evolution in terms of resource management (the groundwater balance already shows a major deficit, and this resource is already highly impacted by overexploitation due to pumping), **the impact of climate change will not be significant with regards to the impact of overexploitation**, whatever the horizon considered.

The above picture **strongly advocates for a 'climate proofing' of the sectorial investments along the Senegalese coastline.** The World Bank is already supporting the urban flood prevention project called PROGEP (*Projet de Gestion des Eaux Pluviales*) in Dakar. The integrated consideration of the climate change issue in the other sectors is key, with the support of the Government and the economic partners.

Three pilot sites for an in-depth analysis of natural risks and climate change

In the three pilot sites, the trends show an increase in vulnerabilities, with the urbanization of natural or agricultural areas and a densification of buildings in areas where urbanization is currently discontinuous. Whereas for the site of Saint-Louis, urban growth should mainly take the form of a densification of the existing urban fabric, on the sites of Rufisque and Saly, artificialized areas are expected to increase by 20-26% by 2080.

When refining climate forecasts using regional climate models, we see a North-South temperature gradient (greater warming in the northern part of the country), together with a trend inversion for pluviometry, according to the horizon considered. Hence, by 2030, we would more probably see an increase in mean rainfall, whereas by 2080, it would be the contrary, with here again a North-South gradient (the rainfall decrease would be three times greater in Saint-Louis than in Saly).

As regards natural risks and their evolution in the wake of climate change, the three pilot sites have the following distinguishing features:

- **The Saint-Louis agglomeration is mostly affected by the risk of river floods**. In the current situation, floods due to a 'relatively frequent' (10-year) flood of the Senegal river are already worrying and affect inhabited areas in the lowest neighborhoods. Regarding the future, major uncertainties affect the evolution of rainfall in the catchment area of the Senegal river; it is thus very difficult to determine whether floods will worsen or not. Nevertheless, sea level rise does worsen flooding conditions: irrespectively of rainfall evolution, at the 2030 horizon, over half of the city would be submerged during 'relatively frequent' floods. In 2080, the situation would become catastrophic, since 80% of the city would be submerged. With the sea level rise, which hampers the discharge of floods, **the 10-year floods in 2080** would be comparable to the current 50-year floods and **would affect 150,000 inhabitants**, instead of 54,000 in the current situation. It should also be noted that 1,000 dwellings and a population of 8,000 inhabitants living on the *Barbarie* spit of land could be affected in the long run by marine submersion during a 100-year storm.

- **At Rufisque-Bargny, the strong erosion** of the shoreline has led, since the 80s, to the construction of protection structures along the coastline of Rufisque. With the sea level

rise, the unprotected sectors, and more particularly the first lines of dwellings of Bargny, should disappear by 2080. This would impact **300 buildings, of which 250 dwellings housing a population of 2,250**. The sea level rise will hamper, or even impede, the discharge of storm water from the lower neighborhoods (without taking into account possible pumping systems).

- **At Saly**, **the shoreline is currently in strong recession,** a situation which is threatening the hotel activities and infrastructures, the second homes and the village. Such evolution has become a critical issue since the development of the tourist resort in the 80s, which led to a strong increase in land occupation, especially along the shore. Today, several groin-type structures and many longitudinal works made of riprap or gabions have been built. **By 2080, with just the forecast sea level rise, 60% of the current beaches could disappear**. At Saly, unlike at the two other sites, climate change could have an impact on groundwater resources, but the extent of this impact should be put into perspective, as it would represent approximately 1/10 of the current overexploitation.

The three pilot sites have formed the subject of proposed **adaptation measures** aiming at neutralizing the long-term risks of coastal erosion and marine submersion. However, it should be underlined that these measures **may only be considered as indicative** in the absence of more detailed specific studies:

- **The shoreline of Saint-Louis has been subdivided into three sections**, taking into account land uses and occupation, and adaptation proposals were made for each of these sections. At the level of the urbanized sector of the Barbarie spit of land, the recommended measure is a strategic retreat, together with the construction of heavy-weight maritime structures (groins, T-shaped groins) or a longitudinal beach-top structure (made of riprap). From the Fishermen's Cemetery to the Poles' Dike, beyond the solutions using heavy-weight structures, a massive recharging is also suggested. Finally, for the rest of the shoreline of the *Barbarie* spit of land, a beach reprofiling with protective devices would be sufficient.

- **At Rufisque-Bargny**, the coastline is already massively artificialized by longitudinal beach-top structures (riprap, concrete walls) that are heterogeneous and often not very effective due to their under-dimensioning. To face the effects of climate change, a strategic retreat of the entire urbanized shoreline would enable to retrieve the swell-dampening foreshore, but would be very costly (see below).

- **At Saly**, the creation of elevated artificial beaches, protected by a breakwater toe, would enable to maintain the site's attractiveness for beach front activities without having to implement a strategic retreat.

An economic cost related to natural risks and climate change that should not be underestimated

Up to now, the Senegalese shoreline had formed the subject of a certain number of studies regarding its vulnerability to climate change, but none of these had tackled the issue of the cost-benefit analysis of the adaptation measures in a structured and in-depth manner. Within the framework of this study, the economic analysis was thus carefully considered, and **one of the main objectives of the study was to draft an economic and financial model of the adaptation options at the pilot sites**. This model was submitted to the authorities, so that they may reuse it for other sites or update the economic analysis of this study. In this respect, a training program was offered to a certain number of technical managers of the Senegalese administration.

An analysis that takes into account many parameters
The economic analysis is based on the evaluation of direct and indirect costs (damage and economic losses, respectively) induced by natural risks and climate change. In order to take into account the probability of occurrence of natural risks, the damage and losses have been expressed in mean annual cost and summed up to obtain the net present cost (NPC) in 2080. Coefficients have been determined on the basis of the synthetic index of access to basic social services at the scale of the *Départements* so as to take into account social fragility.

This economic analysis was used **at each pilot site** and led to the following results:

- **At Saint-Louis, the net present cost in 2080 of floods would reach FCFA 818 billion (USD 1.636 billion), i.e. almost 13% of the national GDP for 2010**. The net present cost in 2080 due to marine submersion would amount to approximately FCFA 12.3 billion (USD 24.6 million). **The cost of the most favorable adaptation scenario** with respect to the marine submersion risk would amount to FCFA 7.76 billion (USD 15.52 million), thus leading to **a positive balance of FCFA 4.54 billion (USD 9.08 million), i.e. a benefit-cost ratio of 0.63**.

- **For Rufisque-Bargny, the net present cost in 2080 due to marine submersion and coastal erosion would amount to approximately FCFA 14.2 billion (USD 28.4 million). All the adaptation solutions proposed lead to an amount much higher than the cost of material damage and economic losses.** The cost-benefit balance of the least expensive solution would thus be negative by FCFA 8.5 billion (USD 17 million). In this case, warning system implementation, population information and the establishment of a fund for the relocation of victims of disasters seem to be a more appropriate solution, since it is much more cost-effective. It should be noted that the implementation of warning systems would be justified even if protection investments were to be selected.

- **At Saly, the net present value in 2080** caused by temporary or permanent marine submersion (due to storm sea rise or to sea level rise, respectively) **would amount to approximately FCFA 10 billion (USD 20 million)**. The creation of elevated artificial beaches would lead to a neutral economic balance (cost equal to the avoided damage).

The feedback obtained from the economic analysis carried out in Phase 3 at the pilot sites would enable to envisage certain types of **extrapolation to the entire Senegalese shoreline**. Another simulation was thus carried out, **on the basis of a macro-economic approach** and using demographic data as the main indicator, starting from a strong correlation between population and coastal vulnerabilities (human, material and economic challenges). The NPC in 2080 **for coastal erosion and marine submersion for 100-year events, when taking into account the sea level rise induced by climate change, is estimated to amount to FCFA 344 billion (USD 688 million)** and is mainly due to coastal erosion**. When excluding the city of Saint-Louis, the NPC in 2080 of coastal floods (due to rivers or run-off) for 10-year events amounts to approximately FCFA 389 billion (USD 778 million)** and is roughly equivalent to the NPC of coastal erosion and marine submersion. It should be reminded here that **the NPC of floods at Saint-Louis amounts to FCFA 818 billion (USD 1.636 billion)** and is thus twice the cost of coastal floods for the rest of the Senegalese shoreline. This seems consistent with the importance of the risks related to the floods of the Senegal river at Saint-Louis. **The amount for the main natural risks affecting the Senegalese coastline corresponds to a NPC in 2080 of approximately FCFA 1,500 billion (USD 3 billion).** The NPC of the damage and economic losses in the Senegalese coastal area **represents here almost one quarter of the GDP for 2010, and approximately 35% of the GDP of the coastal area for the same year**.

Health care cost of climate change
This study also tackled the cost of the climate change impact on health care. Indeed, the consequences of climate change on some diseases such as malnutrition, malaria and diarrheal conditions will be major risks for the future populations, particularly in low-income countries in the tropical and subtropical regions. An evaluation was proposed on the basis of a method developed by the World Health Organisation (WHO). This method is based on estimations of the Disease Adjusted Life Year (DALY). Thus, the net present cost in 2080 of the deterioration of the population's health condition in the coastal area due to climate change is estimated to amount to FCFA 1,200 billion (USD 2.4 billion). This cost is comparable to that of damage and losses caused by natural risks and climate change, thus highlighting the importance that should be given to health care issues in the adaptation to climate change. Moreover, it should be noted that these health care costs are only related to the impact of climate change, whereas the costs of damage and losses have been calculated by combining natural risks and climate change.

As regards the loss of ecosystem services, no evaluation was made, but the analysis shows that the effects of climate change, instead of inducing ecosystem services losses, lead to a recourse to indirect and induced services, and thus to an increase of the economic value of indirect uses (storm protection, flood retention and flow regulation, erosion control, water resource protection) in wetlands and forest areas. It is thus all the more important to protect such environments.

An intervention program that underlines the importance of urban planning and institutional measures

From the diagnosis of natural risks and their foreseeable evolution in the wake of climate change, and in the light of the economic analysis' results, an intervention program has been defined **to guide the Senegalese authorities regarding the adaptation measures to be considered for the coastal areas**, notably in view of the preparation of the Integrated Coastal Zone Management Plan. It should be specified here that **these are only recommendations, not an action plan**. Thus, it was not possible, within the framework of this study, to go further in the level of definition of the adaptation measures.

The actions that should be given priority with regards to the identified issues and to the expected benefits are mainly incumbent upon the urban planning and institutional sphere. Indeed, these actions cover all the natural risks (synergy effects), have a low cost, are of a 'no regret' or 'robust' nature and are flexible/reversible.

The measures that should be given priority and thus be scheduled within the next two years are the following:

- **In the institutional field**
  - Strengthening of institutional coordination (improvement of the efficacy of the command chain and of the knowledge-study-technical decision process);
  - Rationalization of the natural risk management procedures (substantial simplification of the procedures and reduction of the number of institutional interlocutors);
  - Readjustment and implementation of the reference texts: Coastal Law, National Coastal Erosion Prevention Program and National Action Plan for Climate Change Adaptation;

- **In the field of operational preparation**
  - Implementation or strengthening of the early surveillance and warning systems, through a set of cultural actions, in order to contribute to the improvement of the preparedness and response potential at national and local level;
  - Preparation and self-protection against fast-evolving phenomena, coupled with the implementation of emergency plans at various scales (notably in Saint-Louis);
  - Accompaniment measures for the implementation of urban planning regulations (implementation of a dissuasive/repressive administrative police activity; follow-up of land occupation using satellite images, combined with information/awareness-raising of citizens);
  - Implementation of a budget policy for climate change adaptation, integrating new financing solutions, additional economic and financial analyses, and a production and operation account for each project;
- **As regards training**
  - Awareness-raising program focusing on self-protection, with a particular focus on communication methods and on the technological means to be implemented;
  - Information regarding natural risks, to be offered to the population, the economic stakeholders (industries, businesses, services) and the administrations;
- **As regards urban planning and regulation**
  - Control of the strict ban on sand collection along the coastline;
  - Run-off management for new neighborhoods or urban rehabilitation operations (planning laws imposing a non-aggravation of the downstream flow rates);
  - Assessment of the subsidence phenomena at Saint-Louis (in view of their integration into a natural risk prevention plan);
  - Drafting of master plans for sanitation, taking into account the new pluviometry and sea level assumptions; implementation of waste collection in order to improve the efficiency of the storm water drainage network.
- **As regards follow-up measures**
  - Regular bathymetric follow-up and dredging operations aiming at maintaining a sufficient flow cross-section downstream from Saint-Louis and at the outlet;
  - Monitoring the evolution of the position of river Senegal's mouth, with a view to possibly recreating an artificial breach;

It should be noted that **no heavy-investment river flood or coastal protection measures are proposed for the short term**, as their feasibility and efficacy strongly depends on the effective implementation of the aforementioned actions. In this respect, it is recommended to combine

every development or protection project/program of the coastal territory with a cross-sectorial analysis in the wake of the teachings of this study.

The implementation of these measures **requires the mobilization of several government stakeholders and local authorities**. These stakeholders must thus all take ownership of the issues identified in this study. A broad dissemination process regarding the study results will be performed in this respect, with the support of the Word Bank, as a follow-up to the study.

An exploratory approach which has limits...

This study is a first for Senegal, and even for the entire West African region, due to its topic and the way it was handled. The main elements which make this an original approach are, among others, the level of detail of the study, the 'multi-risk' approach, the horizons considered (2030 and 2080), the recourse to field surveys, the implementation of a two-tier economic evaluation (local and national), the taking into account of the social fragility of the populations exposed to climate disasters, the performance of sensitivity tests to analyse the robustness of the economic analysis' results, the performance of a cost-benefit analysis regarding the adaptation measures, the design of an economic decision-making tool, and the proposal of a program covering all the intervention fields (institutional, operational preparation, training, urban planning, regulation, infrastructures, technical measures, ...).

The innovative nature of the approach has induced **certain drawbacks, regarding the methodology** (initial assumptions not always verified) and due to the unavailability or the **lack of precision of some data sets**. To these are to be added, quite logically, the **limits of the approach itself**, which did not aim at providing precise technical and economical evaluations, but rather a first idea of the cost induced by natural risks and climate change on the Senegalese coastline.

... but which may be replicated in other coastal areas

The risk evaluation and economic analysis methodology, designed and implemented within this study, **aims at being replicated particularly in other West African coastal areas.** However, to ensure the optimal replicability of the approach used here, a few limits should be underlined. To that end, **a certain number of tips are described below**:

- Perform **topographic and bathymetric measurements using the LIDAR technique** (Light Detection And Ranging), which enables to cover long sections of coastline for a moderate cost;
- Carry out a **longitudinal analysis of the shoreline evolution** using aerial photographs;
- **Refine the climate forecasts and trends** by homogenizing the observation series and downscaling the climate forecasts;
- **Characterize the beaches** (foreshore width, altimetry, nature and granulometry of sediments, available sand layer) and their evolution in function of the hydrodynamic conditions;
- Improve the **hydrological and hydraulic knowledge** regarding coastal rivers;
- Analyse coastal vulnerabilities on the basis of a precise enough classification of land occupation (approximately 40 classes);
- Perform the **territorial prospective exercises** by involving the local and national authorities in order to validate or specify the areas that are likely to face urban development or changes;

- Implement **specific studies regarding the evaluation of damage and losses** related to natural risks, notably with the economic valuation of the various land occupation classes; Indeed, the quality of the results produced by the economic analysis depends on the efforts made to best depict the specificities of the studied territory. The necessity to make an in-depth study of the impact of climate change on the fishing industry, which has a great social and economic importance in Senegal, should also be underlined.

RESUME EXECUTIF

Une étude s'inscrivant dans un contexte particulièrement sensible, nécessitant une étroite coordination avec les autres démarches en cours

Les pays côtiers africains sont confrontés **à plusieurs défis environnementaux et socio-économiques** tels que le développement urbain et économique non contrôlé, alimenté par un exode rural croissant, des infrastructures publiques non fonctionnelles et/ou inexistantes pour absorber la croissance démographique sur le littoral, la pollution de l'air, de l'eau, des sols et une altération des écosystèmes côtiers. L'Afrique de l'Ouest, en particulier, doit faire face à de sévères pertes de terres et d'importants dommages dus à l'érosion côtière et au recul du rivage. Cette situation impacte les communautés côtières, les infrastructures et les usagers, et freine la croissance économique. Les capacités institutionnelles, techniques et financières au niveau régional, national et local sont insuffisantes pour faire face de manière efficace à ces défis. **Les impacts du changement climatique ne feront qu'exacerber ces tendances et induire une érosion côtière accélérée, une perte des terres et des biens, des inondations fluviales ou par ruissellement, des submersions marines, une salinisation des nappes et des changements dans la distribution et l'abondance des habitats et espèces côtiers et marins**.

Le littoral Sénégalais s'inscrit dans cette tendance. Il s'étend sur 531 km, traversant 6 régions administratives du pays (Saint-Louis, Louga, Thiès, Dakar, Fatick et Ziguinchor), abritant 60% de la population sénégalaise (12,5 millions d'habitants en 2010).

La **prise de conscience** du Gouvernement du Sénégal sur la question de la vulnérabilité côtière aux changements climatiques va de pair avec une pression croissante de l'opinion publique. Les autorités ont récemment fermé deux carrières d'extraction de sable, et se sont engagées dans un effort important pour mettre en œuvre le programme national de lutte contre l'érosion côtière – lancé en 2006 – et la Loi littorale.

L'assistance de la Banque Mondiale
La Banque mondiale avec l'aide des Gouvernements de la Norvège et de la Finlande assiste le Gouvernement sénégalais pour développer son programme de réformes, améliorer la capacité technique et financière d'adaptation du pays et intégrer la résilience climatique dans les futurs plans de développement des zones côtières au Sénégal. La présente étude est par ailleurs cofinancée par le GFDRR (Global Facility for Disaster Reduction and Recovery). Une première analyse restreinte de la vulnérabilité physique et économique des zones côtières aux impacts du changement climatique à travers le modèle DIVA (Dynamic and Interactive Vulnerability Assessment) a été réalisée d'octobre à décembre 2010 pour le Sénégal et la Gambie sur financement de la Banque Mondiale. En parallèle, la Banque Mondiale a mené une mission préparatoire, incluant une large concertation, pour ébaucher les termes de références de la présente étude, afin de combler les lacunes dans les domaines de l'analyse spatiale et économique des risques naturels et des effets du changement climatique.

Lors de cette mission en 2010, il a été recommandé que l'étude soit menée en étroite collaboration avec l'initiative du Ministère en charge de l'Environnement avec l'appui financier de l'Union européenne, visant à développer un **Plan de Gestion Intégrée des Zones Côtières** (démarche démarrée en janvier 2012), ainsi qu'avec d'autres initiatives en cours ou finalisées relatives à l'érosion côtière et à l'adaptation au changement climatique.

Finalement, la sélection compétitive du Consultant chargé de la réalisation de la présente étude s'est achevée fin juin 2011, et la société **Egis International** a été retenue. L'étude a démarré en juillet 2011, pour un achèvement de l'étude fin 2012. Le bureau d'étude a travaillé en étroite collaboration avec les différents acteurs nationaux et locaux, tandis que l'équipe de la Banque

Mondiale responsable de l'étude maintenait les rapports institutionnels et se chargeait de la facilitation des échanges.

La présente étude répond donc à une **demande forte du Gouvernement du Sénégal**, représenté par le Ministère de l'Environnement, avec l'appui des Municipalités des sites pilotes sur lesquels l'étude a été approfondie. Un comité technique composé de l'ensemble des administrations et agences concernées par l'aménagement du littoral a suivi et guidé l'élaboration de l'étude. Le Centre de Suivi Ecologique (CSE) a joué un rôle important dans la transmission de données cartographiques sous SIG.

Une démarche progressive, technique et structurée

L'objectif principal de l'étude était de procéder à une **analyse spatiale et économique de la vulnérabilité de la zone côtière aux changements climatiques** et aux risques naturels au Sénégal, et de mener une analyse économique de différentes options d'adaptation dans trois sites pilotes.

L'opération s'est articulée autour de **deux sous-objectifs** :

- **l'évaluation économique** et spatiale sur l'espace du littoral des risques et des vulnérabilités liés au changement climatique, notamment ceux liés à l'élévation du niveau de la mer ;
- **l'aide à la prise de décision** pour les investissements et les actions d'adaptation aux changements climatiques grâce à l'estimation des coûts et bénéfices et la priorisation des actions et investissements.

Une analyse sur le long terme
Quatre horizons d'étude ont été considérés : la situation 1990 et la situation actuelle (2010), qui permettent de déterminer les tendances évolutives sur ces 20 dernières années ; la situation 2030 et la situation 2080, qui correspondent à des projections à moyen et long terme, la première s'inscrivant dans les tendances actuelles, la seconde étant de nature plus hypothétique, mais permettant d'esquisser une vision stratégique des problématiques d'aménagement du territoire côtier face aux risques naturels et au changement climatique.

L'étude comportait **quatre phases** :

5. Développement de la méthodologie
6. Analyse spatiale de la vulnérabilité aux changements climatiques de la zone côtière du Sénégal
7. Modélisation économique et analyse des options d'adaptation dans trois sites pilotes
8. Recommandations consolidées pour renseigner le développement d'un Plan de Gestion Intégré de la Zone Côtière

L'étude a donc d'abord été menée **à l'échelle de l'ensemble de la zone côtière** sénégalaise, sur une bande de 10 km de largeur, **puis approfondie sur trois sites** retenus en fonction de leur vulnérabilité déjà établie aux risques naturels, et notamment les risques d'érosion côtière : Saint-Louis à l'embouchure du fleuve Sénégal, Rufisque-Bargny à la jonction de la presqu'île du Cap Vert et de la Petite Côte, et Saly sur la Petite Côte.

Si aucune modélisation des risques n'a pu être réalisée, l'étude a néanmoins **fait largement appel aux potentialités offertes par les SIG** pour l'évaluation des vulnérabilités et la simulation des risques naturels.

Au terme de la démarche, l'étude a permis de collecter et d'assembler les données topographiques, environnementales et socioéconomique de la zone côtière, de les analyser au

regard du changement climatique et d'évaluer son impact en termes de valeur économique. En outre, elle **apporte aux autorités en charge de l'aménagement du territoire un modèle économique souple et actualisable d'aide à la décision pour les stratégies d'adaptation**, ce qui manquait aux démarches peu coordonnées mises en œuvre jusqu'ici sur le littoral.

Une étude à l'échelle de l'ensemble de la zone côtière mettant en évidence une forte augmentation des risques dans les années à venir

La présente étude s'est essentiellement **concentrée sur les espaces urbains**, considérés comme les plus vulnérables au changement climatique sur la bande côtière. Or dans les années à venir ces espaces sont amenés à s'étendre de façon spectaculaire. **Sur la période 2005-2030 l'étude estime à 16 % la croissance du linéaire urbanisé** le long du littoral, au détriment des zones agricoles et naturelles. Sur la période 1990-2080, l'urbanisation globale du littoral devrait avoir progressé d'un tiers. **La plus forte croissance urbaine littorale devrait concerner la Petite Côte**, soit + 49 % entre 1990 et 2030. Au-delà, l'expansion des centres urbains s'effectuera essentiellement vers l'intérieur des terres, faute d'espace sur le littoral.

D'importants changements climatiques attendus
Les évolutions climatiques, telles que prévues par les modèles climatiques globaux, indiquent une augmentation de la température moyenne annuelle sur les côtes sénégalaises, de l'ordre de 1,1-1,2°C à l'horizon 2030, 2,6 à 4°C à l'horizon 2080. Les précipitations n'évoluent pas dans le même sens pour tous les modèles. Globalement, ils s'accordent sur des projections de précipitations à la baisse dans le grand quart Nord-Ouest du Sénégal, renforçant ainsi la tendance déjà observée d'assèchement du climat, notamment dans les zones déjà actuellement les moins favorisées. L'augmentation globale de température entraine une dilatation des masses océaniques et la fonte des calottes glaciaires, se traduisant par une élévation accélérée du niveau marin. Sur la base d'une analyse critique des projections du GIEC et des dernières références bibliographiques sur ce sujet, la présente étude considère une élévation globale du niveau marin de 20 cm à l'horizon 2030 et 80 cm à l'horizon 2080.

L'évolution de l'occupation des sols et celle du climat vont se combiner pour donner lieu à une augmentation des risques naturels :

- Alors qu'en situation actuelle seulement un quart du linéaire côtier est jugé en risque fort d'érosion et de recul du rivage, notamment les deltas et estuaires des trois grands fleuves, d'ici 2080 du fait de l'élévation du niveau marin, **les trois quarts du littoral devraient passer en risque fort d'érosion**. La principale cause est l'élévation du niveau marin, déjà significative ces dernières décennies. Cependant, les prélèvements de sable et l'urbanisation du haut de plage accélèrent les phénomènes d'érosion. Localement, des accidents géologiques (comme le canyon de Kayar) limitent également le transit de sédiments.

- Les niveaux de risques de submersion marine au moment des tempêtes évoluent dans une moindre mesure, surtout parce qu'ils sont déjà très élevés en situation actuelle (> 50 % du littoral). Cependant, à l'horizon 2080, **les deux tiers du littoral devraient être concernés par un risque fort de submersion**. Ce risque est surtout important le long de la Grande Côte, où la rupture du cordon dunaire en période de surcote marine exceptionnelle entrainerait des dégâts importants et très étendus sur les terres agricoles adjacentes.

- L'estuaire du Sénégal est soumis à un **risque d'inondation fluviale qui concerne essentiellement la ville de Saint-Louis**. Saint-Louis étant un des sites pilotes de la présente étude, cette problématique a été approfondie (voir ci-après).

- **Sur l'agglomération dakaroise, les risques d'inondation sont liés au ruissellement urbain**, notamment en raison des capacités d'évacuation insuffisantes du réseau d'eaux pluviales ou par l'absence de réseau sur les **quartiers de Pikine et Guediawaye**. Notons que le **quartier Diaminar à l'entrée de St Louis** présente des risques similaires. Notons que la difficulté de modélisation des précipitations exceptionnelles ne permet pas de cerner leur évolution sur le long terme.

- **Les risques de pénurie d'eau** ont été évalués par la Société Nationale des Eaux du Sénégal jusqu'à l'horizon 2025. Pour la **zone de Dakar**, les déficits (prélèvements supérieurs aux apports naturels) commencent dès 2011, et s'accentuent avec l'accroissement des besoins : ils passent de 18 000 m3/jour en moyenne en 2011 à 195 800 m3/jour en moyenne en 2025. Toutes les autres zones urbaines du littoral connaitront des situations de déficit de la ressource en eau à plus ou moins court terme.

- Enfin, en ce qui concerne le **risque de salinisation des nappes**, la hausse du niveau marin et la baisse des précipitations moyennes annuelles vont aller dans le sens d'une progression du biseau salé dans l'intérieur des terres et donc d'une diminution de la ressource souterraine. Hors évolution positive dans la gestion de la ressource (le bilan des eaux souterraines est déjà très déficitaire et cette ressource est déjà très affectée par la surexploitation par pompage), **l'impact du changement climatique ne sera globalement pas significatif au regard de l'impact de la surexploitation**, quel que soit l'horizon considéré.

Le tableau dressé ci-dessus **milite fortement en faveur d'un « climate proofing » des investissements sectoriels sur le littoral sénégalais**. La Banque Mondiale apporte déjà son soutien à la lutte contre les inondations urbaines à Dakar (PROGEP - Projet de Gestion des Eaux Pluviales). La prise en compte intégrée de la problématique du changement climatique sur les autres secteurs est essentielle, avec l'appui du Gouvernement et des partenaires économiques.

Trois sites pilotes, pour une analyse fine des risques naturels et du changement climatique

Sur les trois sites pilotes la tendance est à l'augmentation des vulnérabilités, avec une urbanisation d'espaces naturels ou agricoles et une densification du bâti sur des secteurs actuellement urbanisés de façon discontinue. Alors que sur le site de Saint-Louis, la croissance urbaine se ferait essentiellement par densification du tissu urbain existant, sur les sites de Rufisque et de Saly est prévue une augmentation de 20 à 26% des surfaces artificialisées à l'horizon 2080.

En affinant les projections climatiques par l'utilisation des résultats de modèles climatiques régionaux, on constate un gradient de température Nord-Sud (réchauffement climatique plus fort dans le Nord du pays), mais aussi une inversion de tendance pour la pluviométrie, en fonction de l'horizon considéré. Ainsi, à l'horizon 2030, on assisterait plutôt à une augmentation des précipitations moyennes, alors qu'en 2080 ce serait l'inverse, avec là aussi un gradient Nord-Sud (la diminution de précipitations serait trois fois plus importante à Saint-Louis qu'à Saly).

Au regard des risques naturels et de leur évolution dans une situation de changement climatique, les trois sites pilotes présentent les particularités suivantes :

- **L'agglomération de Saint-Louis est surtout marquée par le risque d'inondations fluviales**. En situation actuelle, les inondations en cas de crue « courante » (fréquence décennale) du fleuve Sénégal sont déjà préoccupantes, et touchent des zones habitées

dans les quartiers les plus bas. En situation future, de fortes incertitudes pèsent sur l'évolution des précipitations sur le bassin du fleuve Sénégal, et il est très difficile de se prononcer sur une aggravation éventuelle des crues. Par contre, l'élévation du niveau marin aggrave les conditions d'inondation : sans préjuger de l'évolution des précipitations, à l'horizon 2030 plus de la moitié de la ville serait inondée pour des crues courantes. A l'horizon 2080, la situation serait catastrophique, 80% de la ville étant inondée. Avec l'élévation du niveau marin, qui gêne l'écoulement des crues, **les inondations d'occurrence décennale en 2080** seraient comparables à des inondations d'occurrence cinquantennale en situation actuelle, et **pourraient affecter 150 000 habitants**, contre 54 000 en situation actuelle. Notons également que 1 000 logements et une population de 8000 habitants pourraient être affectés à long terme sur la langue de barbarie par des submersions marines pour une tempête de fréquence centennale.

- **Sur Rufisque-Bargny, la forte érosion** de la ligne de rivage s'est traduite depuis les années 80 par la construction d'ouvrages de protection le long du littoral de Rufisque. Avec l'élévation du niveau marin, les secteurs non protégés, et notamment les premières lignes d'habitations de Bargny, devraient disparaitre d'ici 2080. Ce sont près de **300 bâtiments, dont environ 250 logements pour une population de 2 250 habitants qui seraient touchés** à cet horizon. La montée des eaux marines rendra difficile, voire impossible l'évacuation des eaux pluviales des quartiers bas, hors dispositifs de pompage.

- **A Saly**, **le littoral est actuellement en forte régression** ce qui menace les activités et les infrastructures hôtelières, résidences secondaires et village. Cette évolution est devenue sensible à compter du développement de la station touristique dans les années 80, qui s'est traduit par une forte augmentation de l'occupation du sol, en particulier en bordure du rivage. Aujourd'hui, de nombreux ouvrages de type épis mais également ouvrages longitudinaux en enrochements ou en gabions ont été réalisés. **En 2080, rien qu'avec l'élévation projetée du niveau marin, 60% des plages actuelles pourraient disparaitre**. Contrairement aux deux autres sites, à Saly le changement climatique pourrait avoir une incidence sur les ressources en eaux souterraines, mais il convient cependant de relativiser l'ampleur de cet impact, de l'ordre de 1/10 de la surexploitation aujourd'hui observée.

Les trois sites pilotes ont fait l'objet de propositions de **mesures d'adaptation** visant à neutraliser les risques d'érosion côtière et de submersion marine à long terme. Soulignons cependant que celles-ci **ne peuvent être qu'indicatives** en l'absence d'études spécifiques plus détaillées :

- **Le littoral de Saint Louis a été découpé en trois parties**, compte tenu des usages et de l'occupation du sol, pour lesquelles des propositions d'adaptation ont été émises. Au droit du secteur urbanisé de la langue de Barbarie, le recul stratégique est prôné ainsi que des solutions par ouvrages maritimes lourds (épis, épis en T) ou un ouvrage longitudinal de haut de plage (en enrochements). Du cimetière des pêcheurs à la digue des polonais, outre les solutions par ouvrage lourds, un rechargement massif est également proposé. Enfin sur le reste du littoral de la langue de Barbarie, un reprofilage de la plage avec mise en défend serait suffisant.

- **A Rufisque-Bargny**, le littoral est déjà massivement artificialisé par des ouvrages longitudinaux de haut de plage disparates (enrochements, murs béton) et souvent peu efficaces car sous dimensionnés. Pour répondre aux effets du changement climatique, un

recul stratégique sur l'ensemble du linéaire urbanisé permettrait de reconquérir l'estran disparu amortisseur de la houle, mais s'avèrerait coûteux (voir ci-après).

- **Sur Saly**, la création de plages artificielles surélevées, protégées par une butée de pied, permettrait de maintenir l'attractivité du site pour les activités balnéaires sans avoir à mettre en œuvre de recul stratégique.

Un coût économique des risques naturels et du changement climatique à ne pas sous-estimer

Le littoral sénégalais avait jusqu'ici fait l'objet d'un certain nombre d'études au regard de sa vulnérabilité au changement climatique, mais aucune n'avait abordé la question de l'analyse coût-bénéfice des mesures d'adaptation de façon structurée et approfondie. Dans le cadre de la présente étude, l'analyse économique a donc fait l'objet d'une attention particulière, et **l'un des principaux objectifs de l'étude a été d'élaborer un modèle économique et financier des options d'adaptation dans les sites pilotes**. Ce modèle a été remis aux autorités locales en vue de sa réutilisation ultérieure sur d'autres sites ou pour actualiser l'analyse économique de la présente étude. A ce titre, **une formation a été organisée**, au bénéfice d'un certain nombre de responsables techniques de l'administration sénégalaise.

Une analyse intégrant de nombreux paramètres
L'analyse économique repose sur l'évaluation des coûts directs (dommages) et indirects (pertes économiques) liés aux risques naturels et au changement climatique. Pour rendre compte de la probabilité d'occurrence des risques naturels, les dommages et pertes ont été exprimés en coût moyen annuel, puis additionnés pour obtenir le coût total actualisé (CTA) à l'horizon 2080. Des coefficients ont été construits sur la base de l'indice synthétique d'accès aux services sociaux de base à l'échelle des Départements pour prendre en compte la fragilité sociale.

Cette analyse économique a été mise en œuvre **sur chaque site pilote**, avec les résultats suivants :

- **Sur Saint-Louis, le coût total actualisé des inondations à l'horizon 2080 s'élèverait à 818 milliards de FCFA, soit presque 13 % du PIB national de l'année 2010**. Le coût total actualisé à l'horizon 2080 causé par la submersion marine s'élèverait à environ 12,3 milliards de FCFA. **Le coût du scénario d'adaptation** au risque de submersion marine le plus avantageux s'élèverait à 7,76 milliards de FCFA, dégageant **un bilan positif de 4,54 milliards de FCFA, soit un ratio bénéfice/coût de 0,63**.

- **Pour Rufisque-Bargny, le coût total actualisé à l'horizon 2080 causé par la submersion marine et l'érosion côtière s'élèverait à environ 14,2 milliards de FCFA. Toutes les solutions d'adaptation proposées présentent un montant beaucoup plus élevé que les coûts des dommages matériels et pertes économiques**. La balance Coûts/Bénéfices de la solution la moins couteuse serait ainsi négative de 8,5 milliards de FCFA. Dans ce cas de figure, la mise en place de système d'alerte, l'information des populations et la création d'un fonds de relogement des sinistrés semble une solution plus appropriée, car nettement moins onéreuse. Notons que la mise en place de système d'alerte s'avère justifiée, même si des investissements de protection sont néanmoins décidés.

- **A Saly, le coût total actualisé à l'horizon 2080** causé par la submersion marine temporaire (surcote de tempête) ou permanente (élévation du niveau marin) **s'élèverait à environ 10 milliards de FCFA**. La création de plages artificielles surélevées présenterait un **bilan économique neutre** (coût d'égale importance aux dommages évités).

Le retour d'expérience obtenu avec l'analyse économique réalisée en Phase 3 sur les sites pilotes permettait d'envisager certaines formes d'**extrapolation à l'ensemble du littoral sénégalais**. Une simulation a ainsi été réalisée, **basée sur une logique macroéconomique**, et utilisant les données démographiques comme principal indicateur, partant d'une forte corrélation population / vulnérabilités côtières (enjeux humains, matériels et économiques). le CTA à l'horizon 2080 **de l'érosion côtière et de la submersion marine pour des évènements de fréquence centennale, en tenant compte de l'élévation du niveau marin lié au changement climatiques est évalué à 344 milliards FCFA**, et est essentiellement lié à l'érosion côtière. **Hors ville de Saint-Louis, le CTA à l'horizon 2080 des inondations côtières (d'origine fluviale ou par ruissellement) pour des évènements de fréquence décennale est d'environ 389 milliards FCFA**, et est donc du même ordre de grandeur que le CTA lié à l'érosion côtière et aux submersions marines. Rappelons que **le CTA des inondations sur Saint Louis s'élève à 818 milliards de FCFA** et est donc deux fois plus élevé que le coût des inondations côtières sur le reste du littoral sénégalais. Cela semble cohérent au vu de l'importance des risques liés aux crues du fleuve Sénégal sur Saint-Louis. **La somme des principaux risques naturels affectant le littoral sénégalais correspond à un CTA à l'horizon 2080 d'environ 1 550 milliards de FCFA.** Le CTA des pertes et dommages économiques sur la zone côtière sénégalaise **représente près d'un quart du PIB de l'année 2010 et environ 35 % du PIB de la zone côtière pour la même année**.

Le coût sanitaire du changement climatique
La présente étude a également abordé le coût de l'impact sanitaire du changement climatique. En effet, les conséquences du changement climatique sur certaines maladies comme la malnutrition, la malaria et les maladies diarrhéiques constitueront des risques importants pour les populations futures, particulièrement dans les pays à faible revenus dans les régions tropicales et subtropicales. Une évaluation a été proposée à partir d'une méthode développée par l'Organisation Mondiale de la Santé (OMS). Cette méthode est basée sur des estimations du nombre d'années de vie corrigée du facteur d'invalidité (*Disease Adjusted Life Year* ou DALY). Ainsi, le coût total actualisé à l'horizon 2080 de la dégradation de l'état de santé de la population de la zone côtière du fait du changement climatique est estimé à 1 200 milliards de FCFA. Ce coût s'inscrit à un niveau comparable à celui des pertes et dommages causés par les risques naturels et le changement climatique, mettant ainsi en exergue l'importance à accorder aux aspects sanitaires dans l'adaptation au changement climatique. Notons par ailleurs que ces coûts sanitaires relèvent uniquement de l'impact du changement climatique, alors que les coûts des pertes et dommages ont été calculés risques naturels et changement climatiques confondus.

En ce qui concerne les pertes de services écosystémiques, aucune évaluation n'a pu être apportée, mais l'analyse montre que les effets du changement climatique, au lieu de générer des pertes de services écosystémiques, augmentent le recours aux services indirects et induits, donc une augmentation de la valeur économique des usages indirects (protection contre les tempêtes, rétention des crues et régulation des flux, contrôle de l'érosion, protection de la ressource en eau) des zones humides et forestière. Il est donc d'autant plus important de protéger ces milieux.

Un programme d'intervention soulignant l'importance des mesures institutionnelles et de planification urbaine

A partir du diagnostic des risques naturels et de leur évolution prévisible avec le changement climatique, et à l'aune des résultats de l'analyse économique, un programme d'intervention a été défini **pour guider les autorités sénégalaises sur les mesures d'adaptation à prendre en compte pour les zones côtières**, notamment dans le cadre de l'élaboration du Plan de Gestion Intégrée des Zones Côtières. Précisons qu'**il s'agit de simples recommandations et non pas d'un plan d'action**. Il n'était ainsi pas possible, dans le cadre de la présente étude, d'aller plus loin dans le niveau de définition des mesures d'adaptation.

Les actions jugées prioritaires au regard des enjeux identifiés et des bénéfices attendus relèvent essentiellement de la sphère institutionnelle et de la planification urbaine. En

effet, ce sont des actions couvrant l'ensemble des risques naturels (effets de synergie), à faible coût, de type « sans regret » ou « robuste », et flexibles/réversibles.

Les mesures jugées prioritaires et donc à programmer dans les deux années à venir sont les suivantes :

- **Dans le domaine institutionnel**
    - Renforcement de la coordination institutionnelle (améliorer l'efficacité de la chaine de commandement et la filière connaissance-étude-décision technique) ;
    - Rationalisation des procédures de gestion des risques naturels (simplification substantielle des procédures et réduction du nombre d'interlocuteurs institutionnels) ;
    - Recadrage et mise en application des textes de référence : Loi littorale, Programme national contre l'érosion côtière, et Plan d'Action National pour l'Adaptation aux changements climatiques ;
- **Dans le domaine de la préparation opérationnelle**
    - Mise en place ou renforcement des systèmes de surveillance et d'alerte précoce, au travers d'un jeu d'actions structurelles, pour contribuer à améliorer la préparation et le potentiel de réponse au niveau national ;
    - Préparation et autoprotection contre les phénomènes à déroulement rapide, couplée à la mise en place de plans de secours à différentes échelles (notamment à Saint-Louis) ;
    - Mesures d'accompagnement pour l'application des réglementations d'urbanisme (mise en œuvre d'une activité dissuasive/répressive de police administrative, et suivi de l'occupation des sols à partir d'images satellitaires, couplée à une information-sensibilisation des citoyens) ;
    - Mise en place d'une politique budgétaire d'adaptation au CC, intégrant de nouvelles pistes de financement, des analyses complémentaires en termes économiques et financiers et un compte de production et d'exploitation pour chaque projet ;
- **En matière de formation**
    - Programme de sensibilisation axé sur l'autoprotection, en apportant un soin particulier aux modalités de communication et aux moyens technologiques à mettre en œuvre ;
    - Information sur les risques naturels à mettre en place auprès de la population, des acteurs économiques (industries, commerces, services) et des administrations ;
- **En matière de réglementation et de planification urbaine**
    - Contrôle de l'interdiction stricte de prélèvement de sable sur le littoral ;

- o Gestion du ruissellement pour les nouveaux quartiers ou les opérations de réhabilitation urbaine (réglementation d'urbanisme imposant une non-aggravation des débits à l'aval) ;
- o Evaluer les phénomènes de subsidence sur Saint-Louis (en vue d'une intégration dans un plan de prévention des risques naturels) ;
- o Réalisation de plans directeurs d'assainissement, prenant en compte les nouvelles hypothèses de pluviométrie et de niveau marin ; mise en place de collecte des déchets pour améliorer l'efficacité du réseau de drainage pluvial.

- **En ce qui concerne les mesures de suivi**
  - o Suivi bathymétrique régulier et dragages visant à maintenir une section d'écoulement suffisante en aval de Saint-Louis et à l'exutoire ;
  - o Suivre l'évolution de la position de l'embouchure du fleuve Sénégal, dans la perspective d'une décision éventuelle de recréer une brèche artificielle ;

Notons qu'**aucune mesure d'investissements lourds de protection côtière ou contre les inondations fluviales n'est proposée à court terme**, car leur faisabilité et leur efficacité dépend beaucoup de la mise en œuvre effective des actions amont listées ci-dessus. A cet égard, il est recommandé d'assortir tout projet / programme d'aménagement ou de protection du territoire côtier d'une analyse cross-sectorielle au regard des enseignements de la présente étude.

La mise en œuvre de ces mesures **implique la mobilisation de nombreux acteurs gouvernementaux et autorités locales**. Il convient donc que l'ensemble de ces acteurs s'approprient les enjeux identifiés dans le cadre de cette étude. Un large processus de dissémination des résultats de l'étude sera engagé à cet effet, avec l'appui de la Banque Mondiale, dans le prolongement de l'étude.

Une démarche exploratoire présentant certaines limites…

La présente étude représente une « première », au Sénégal, voire pour l'ensemble de l'Afrique de l'Ouest de par la thématique et le traitement dont elle a fait l'objet. **Les principaux éléments qui font l'originalité de la démarche** sont notamment le niveau de détail de l'étude, le caractère « multirisques » de l'approche, les horizons considérés (2030 et 2080), le recours à des enquêtes de terrain, la mise en œuvre d'une évaluation économique à deux échelles (locale et nationale), la prise en compte de la fragilité sociale des populations exposées aux catastrophes climatiques, la réalisation de tests de sensibilité pour analyser la robustesse des résultats de l'évaluation économique, la réalisation d'une analyse coût-bénéfice des mesures d'adaptation, la construction d'un modèle économique d'aide à la décision, et la proposition d'un programme couvrant l'ensemble des domaines d'intervention (institutionnel, préparation opérationnelle, formation, urbanisme, réglementation, infrastructures, mesures techniques, …).

Le caractère innovant de la démarche présente **certains inconvénients, d'ordre méthodologique** (hypothèses de départ non forcément vérifiées) et tenant également à l'indisponibilité ou au **manque de précision de certaines données**. Il convient évidemment d'ajouter les **limites mêmes de l'exercice**, qui n'était pas destiné à fournir des évaluations technico-économiques précises, mais une première approche du coût des risques naturels et du changement climatique sur la zone côtière sénégalaise.

… mais réplicable à d'autre zones côtières

La méthodologie d'évaluation des risques et d'analyse économique, développée et mise en œuvre dans le cadre de la présente étude, a **vocation à être réutilisée sur d'autres zones côtières d'Afrique de l'Ouest ou d'ailleurs**. Pour garantir une réplicabilité optimale de la démarche mis en œuvre ici, il convient cependant de lever certaines limites de l'exercice. Un certain nombre de **conseils sont apportés à cette fin** :

- Réaliser des **levers topographiques et bathymétriques par la technique LIDAR** (Light Detection And Ranging), permettant de couvrir des linéaires importants de zone côtière à des coûts modérés ;
- Faire une **analyse diachronique de l'évolution du trait de côte** à partir de photographies aériennes ;
- **Affiner les tendances et projections climatiques** en homogénéisant les séries d'observations et en effectuant des descentes d'échelles des projections climatiques ;
- **Caractériser les plages** (largeur de l'estran, altimétrie, nature et granulométrie des sédiments, épaisseur de sable disponible) et leur évolution en fonction des conditions hydrodynamiques ;
- Améliorer les **connaissances hydrologiques et hydrauliques** des fleuves côtiers ;
- Analyser les vulnérabilités côtières à partir d'une **classification de l'occupation des sols suffisamment fine** (environ 40 classes) ;
- Réaliser les **exercices de prospective territoriale** en impliquant les autorités locales et nationales pour valider ou préciser les zones susceptibles de s'urbaniser ou d'évoluer ;
- Mettre en œuvre des **études spécifiques pour l'évaluation des dommages et des pertes** liés aux risques naturels, incluant notamment la valorisation économique des différentes classes d'occupation des sols. En effet, la qualité des résultats produits par l'analyse économique réside dans l'effort fourni pour refléter au mieux les spécificités du territoire étudié. Soulignons également la nécessité d'approfondir la réflexion sur l'impact du changement climatique sur le secteur de la pêche, en raison de son importance sociale et économique au Sénégal.

1. INTRODUCTION

Take-away messages

- The coastal areas of West Africa are subject to many types of environmental damage, of which shoreline erosion.
- Climate change is likely to aggravate this situation, in particular with the acceleration of sea level rise.
- The Senegalese coastline is logically affected by the above trend.
- Senegalese authorities have become aware of the issue and have already launched a number of actions.
- With the World Bank's support, they launched in 2011 this study regarding the economic and spatial analysis of the vulnerability and adaptation to climate change of coastal areas.
- This study analyses the impacts of climate change at different horizons (2030 and 2080) and at various geographical scales (entire Senegalese coast + 3 pilot sites) and provides the authorities with a flexible and updatable decision-making model for adaptation strategies.
- This study complements the Integrated Coastal Zone Management Plan, which is currently being drafted.

1.1. CONTEXT OF THE STUDY

The African coastal countries are facing **several environmental and socio- economic challenges,** such as unplanned urban and economic development, fuelled by a growing rural exodus; non-functional and/or non-existent public infrastructures to handle the demographic growth along the coastline; air, water and soil pollution; and alteration of coastal ecosystems. West Africa, in particular, is facing severe land losses and major damage due to coastal erosion and shoreline loss (cf. UEOMA study on shoreline follow-up and Coastline Master Plan for West Africa, completed in 2010). This situation impacts coastal communities, infrastructures and users, and hampers economic growth. The institutional, technical and financial capabilities at the regional, national and local scales are not sufficient to effectively meet these challenges. **The impacts of climate change will undoubtedly intensify those trends** and induce accelerated coastal erosion, loss of land and assets, floods, marine submersion, groundwater salinization and changes in the distribution and abundance of coastal and marine habitats and species.

The Senegalese coastline logically follows the above trends. It stretches over 531 km and crosses 6 administrative regions of the country (Saint-Louis, Louga, Thiès, Dakar, Fatick and Ziguinchor). This key socio-economic driver is threatened by various hazards[1] related to climate change, which expose both urban and rural areas to various forms of vulnerability. Along this coastline, the major urban centers and the deltas are particularly vulnerable. Coastal erosion is taking place in both urban areas (e.g.: Saint-Louis, Cambérene, Yoff, Dakar, Rufisque, Saly/Mbour, Joal and Ile de Gorée) and rural zones (Côte Nord, Petite-Côte, delta of the Saloum river, Basse Casamance, etc.).

This **coastal erosion** results from the combination of natural events and anthropic pressure. This latter is materialized by a form of coastal development that is considered as non-

[1] A hazard might be defined as a phenomenon or a natural event that is likely to affect a given area (environment, infrastructures, dwellings, individuals). The hazard has the notion of probability (or susceptibility, if the probability may not be calculated). Thus, the hazard is often defined as the 'frequency (probability) / intensity (impact level)' combination of an event.

sustainable. Coastline development is facing rapid changes that are taking place in the absence of a consistent territorial development plan.

The awareness of the Government on the issue of coastal vulnerability to climate change and the pressure of the public opinion are both growing. The Government recently closed down two sand extraction quarries and is engaged in a major effort to implement the national coastal erosion prevention program and the Coastal Law (*Loi Littorale*). In the main universities of Senegal, research programmes on these issues are being launched, thus offering a real possibility of generating information and data on such topics and of making them available for consultation and circulation.

The World Bank, supported by the governments of Norway and Finland, is assisting the Senegalese government in the development of its reforms program, in the improvement of the country's technical and financial adaptability and in the integration of climate resilience into the future development plans regarding the Senegalese coastline. Moreover, this study has been co-financed by the Global Facility for Disaster Reduction and Recovery (GFDRR).

A first limited assessment of the physical and economic vulnerability to climate change of the coastline was carried out from October to December 2010 in Senegal and Gambia, using **the DIVA model** (Dynamic and Interactive Vulnerability Assessment) and funds from the World Bank[2].

In parallel, the World Bank has carried out a **preparatory mission,** which included a broad consultation, in order to draft the terms of reference of this study, so as to fill the gaps in the fields of spatial and economic analysis of natural risks and climate change impacts. This 2010 mission led to the recommendation that a study be performed in close cooperation with the initiative led by the Ministry of Environment (financially supported by the European Union) in order to develop an **Integrated Coastal Zone Management Plan,** as well as with other initiatives (completed or in progress) regarding coastal erosion and adaptation to climate change.

Last, the competitive process to select the Consultant in charge of performing this study was completed at the end of June 2011 and led to the selection of **the company Egis International**. The study started in July 2011 and was completed at the end of 2012. The Consultant worked in close cooperation with the various national and local stakeholders, while the World Bank team responsible for the study cared for institutional relationships and worked at facilitating exchanges. A steering committee composed of representatives of the various stakeholders involved in coastal development and protection was set up and met at the end of each phase of the study. The reports for each phase have thus been reviewed, discussed and approved by the steering committee. At the end of the study, a training program was organized to raise the awareness of the main public administrations and institutions regarding the interest and the use of the economic model developed within this study.

1.2. STUDY OBJECTIVES AND APPROACH

The main objective of the study was to carry out a spatial and economic analysis of the coastal areas' vulnerability to climate change and variability **and to** natural risks in Senegal, and to perform an economic analysis of different adaptation options in three pilot sites.

The results of this study will contribute to **integrating climate resilience into the local and national development plans** for the coastal areas of Senegal - particularly in view of the preparation of the Integrated Coastal Zone Management Plan initiated by the Ministry of Environment with the support of the European Union - and to **strengthening the Government's capability** in this field. The operation, carried out in close synergy with the

[2] Integrated Assessment of Coastal Vulnerability of Senegal and Gambia with the DIVA model, Jochen Hinkel, December 22, 2010, Report submitted to the World Bank

projects currently executed or planned by the Government and the development partners, has **two main sub-objectives**:

- spatial and economic assessment, over the coastal area, of the risks and vulnerabilities related to climate change, in particular those linked to sea level rise;
- assistance to decision-making regarding investments and climate change adaptation actions, thanks to the evaluation of the costs and benefits and to the prioritization of actions and investments.

Four study horizons have been considered: the situation in 1990 and today (2010), which enabled to determine the trends over the last 20 years; and the situation in 2030 and 2080, which correspond to medium- and long-term forecasts, the former following the current trends, the latter being more hypothetical but still enabling to draft a strategic vision of the issues that coastal territorial planning will face with respect to natural risks and climate change.

The study comprises **four phases**:

1. Methodology development
2. Spatial analysis of the vulnerability to climate change of the coastline of Senegal
3. Economic modelling and analysis of the adaptation options in three pilot sites
4. Consolidated recommendations to inform the development of an Integrated Coastal Zone Management Plan.

This document is the synthesis report of the study.

1.3. CONTENT OF THIS REPORT

This main aim of this report is to **describe the main results and lessons of the study.** Its broad target audience comprises technical staff and decision-makers, to whom it provides the main methodological elements, the basic data, the precise results and other decision-making elements.

After the introduction **(Chapter 1),** the report gives an overview of the natural risks and climate change impacts faced by the entire Senegalese coastal strip **(Chapter 2).** An in-depth analysis is then carried out at three pilot sites **(Chapter 3),** for which adaptation measures are determined. The cost of such measures is compared to the costs induced by natural risks and climate change **(Chapter 4),** in order to define an intervention programme **(Chapter 5).** The added value and the limits of the study are reminded **(Chapter 6).** Finally, recommendations are made in view of a possible replication of the study in other coastal areas **(Chapter 7).**

This report has been prepared by **Egis International.** The authors bear full responsibility for the content of this report.

2. NATURAL RISKS AND CLIMATE CHANGE ON THE SENEGALESE COASTLINE

Take-away messages

- ☞ The Senegalese coastline stretches over 531 km of coast (or even 700 km with the estuaries).
- ☞ The main vulnerabilities and issues related to climate change correspond to the urban areas. The coastline is home to 60% of the Senegalese population.
- ☞ These urban zones are expected to grow by 16% (on average) along the shoreline by 2030, with the highest growth foreseen in the Petite-Côte area.
- ☞ Climate change will take the form of a major temperature increase, which could reach 4°C at the 2080 horizon, and a sea level rise of approximately 80 cm at the same horizon. The evolution of rainfall is much less predictable, but climate aridity should increase.
- ☞ The respective evolutions of land occupation and of climate will combine and lead to an increase in natural risks.
- ☞ By 2080, sea level rise will place three fourths of the coastline at high risk of coastal erosion, against one fourth in the current situation. The entire Grande-Côte coastline and almost all of the Cap Vert peninsula and of the Petit-Côte coastline would be concerned.
- ☞ The risk of marine submersion during storms, already high in the current situation (>50% of the coastline being at high risk), would affect two thirds of the coastline in 2080. Such risk is mostly important along the Grande-Côte coastline.
- ☞ Only the estuary of the Senegal river faces a significant river flood risk, which mainly concerns the city of Saint-Louis.
- ☞ The risk of run-off floods mainly applies to the Dakar and Saint-Louis agglomerations.
- ☞ The growing dryness of the climate is inducing a risk of water deficit in the more or less short term for all the other urban areas of the coastline.
- ☞ Sea level rise and drought will contribute to reducing coastal water resources, but overall, such impact is not significant when compared to the current overexploitation.

2.1. A COASTLINE SEGMENTATION BASED ON LAND OCCUPATION

The figure below illustrates the study area. It consists in a **10 km-wide strip** that stretches along the coastline and extends by 50 km towards the hinterland at the outlet of the main rivers. This map also illustrates the location of the pilot sites for which an in-depth analysis has been carried out.

Figure 1: Study area

Source : Egis Eau

In this coastal strip, **land occupation** has been recorded under the form of a GIS (Geographical Information System), by means of a semi-automated processing of LANDSAT satellite images by the Global Land Cover Network (GLCN), in partnership with the CSE. This land cover has been used for the horizons of 1990 and 2010. For the future horizons (2030 and 2080), in the absence of territorial prospective information, it was only possible to

characterize and map the evolution of urbanization by extrapolating the 1990-2005 trend to 2030 and by adding a slight slowdown of urban growth thereafter.

Five categories of land occupation have been considered: urban area; rural or agrosilvopastoral area; wetland vegetation (mangrove, gonakie, etc.); natural land vegetation (forest, savannah, etc.); and bare soil, dune and sand. Other land use elements did form the subject of a qualitative assessment, but they were not used in the definition of coastal risks. Such elements are the protected areas and the current and future tourist resorts.

Due to the extent of the study area (which covers approximately 8,000 sq km for some 530 km of shoreline), **the overall analysis scale of the coastline is relatively coarse (1:500,000).**

The Senegalese coastline was first subdivided into **4 large geographic areas,** which represent the territorial units for the cartographic representation of the issues[3], hazards and risks: **Grande-Côte, Cap Vert, Petite-Côte and Casamance.**

It was then subdivided according to the vulnerabilities (issues) that are present in the coastal strip, defined according to their **economic sensitivity** to the various hazards:

- **High-importance issues**: artificialized areas
- **Medium-importance issues**: agricultural areas
- **Low-importance issues**: vegetation and bare soil

It should be noted that the fact of awarding the highest level of issue to artificialized areas does not mean that agricultural areas and natural environments deserve no attention, since other criteria than economic sensitivity to hazards might be considered.

The coastline segmentation was thus determined by this classification, taking into account the dominant land use type. For instance, between Dakar and Saint-Louis, the main issue identified is agriculture, which prevails behind the beach and the beefwood line. It represents a medium-importance issue as regards hazards. When a relatively urban area (such as Kayar, Fas Boue or Dogo) was present, the issues became of high importance.

2.2. A COASTLINE CHARACERIZED BY A STRONG GROWTH OF URBAN VULNERABILITIES

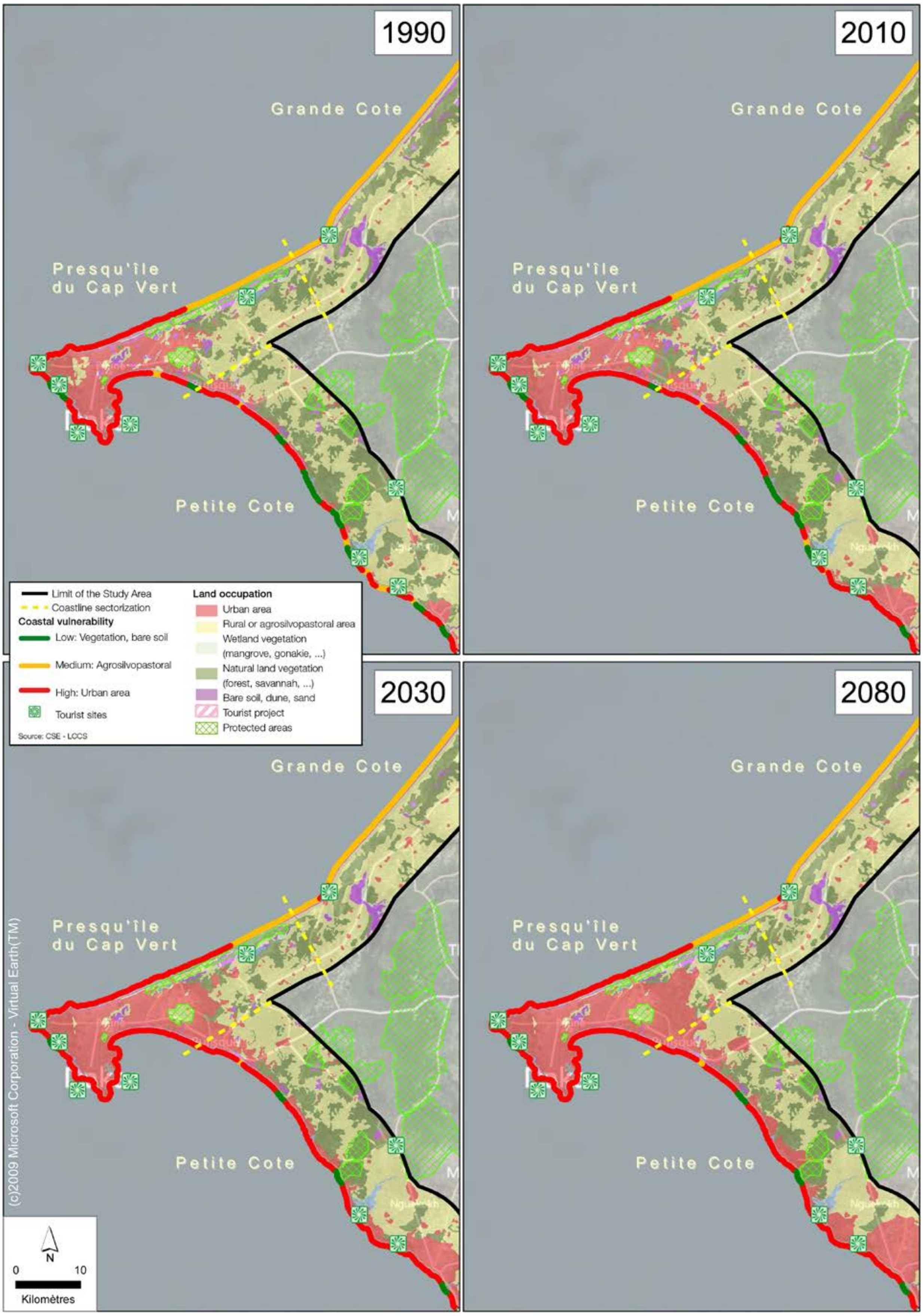
The Senegalese coastline, already morphologically fragile, is also facing **the effects of an almost anarchic use and operation of space,** combined with coastal erosion phenomena. This induces a process that deteriorates and destroys hotel infrastructures or dwellings, diminishes agricultural and halieutic productions, induces beach erosion or losses, and disrupts mangroves and natural habitats.

This study mainly focused on urban areas, which are considered as the most vulnerable to climate change on the coastline. In the years to come, such areas are due to extend. **Over the 2005-2030 period, the study estimates that coastal vulnerabilities of the urbanized area type will grow by 16%,** to the detriment of agricultural and natural areas. This is significant, all the more since this is just a forecast of the urban growth along the coastline, which does not take into account urbanization towards the hinterland. Furthermore, the Senegalese coastline is already quite urbanized (25.7% of the shoreline in 2005-2010).

The figure on the following page illustrates the evolution of vulnerabilities **under the form of maps,** taking the example of the Cap Vert area.

[3] Here, the concept of issue is related to that of vulnerability, defined as the combination of the following factors: exposure, sensitivity to climatic risk, and adaptability.

Figure 2: Cartographic illustration of coastal vulnerabilities in the Cap Vert area



The tables below present an overview of how the vulnerabilities **of the Senegalese coastline will evolve between 1990 and 2080, by large coastal sector:**

Table 1: Evolution of coastal vulnerabilities with respect to the baseline situation

Vulnerability	Evolution of vulnerabilities with respect to the baseline situation (in km of shoreline and in % of increase vs. 1990)									
	1990 (km)	2005 (km)	Diff.	1990-2005 (%)	2030 (km)	diff	1990-2030 (%)	2080 (km)	Diff.	1990-2080 (%)
Urban	127.0	143.3	16.3	13%	166.5	39.5	31%	168.4	41.4	33%
Agricultural	260.8	249.0	-11.9	-5%	236.4	-24.5	-9%	234.5	-26.3	-10%
Natural	126.7	122.3	-4.4	-3%	111.7	-15.0	-12%	111.7	-15.0	-12%

Table 2: Evolution of urban vulnerabilities with respect to the baseline situation

Coastal sector	Evolution of urban vulnerabilities with respect to the baseline situation (in km and in % of increase vs. 1990)						
	1990 (km)	2005 (km)	1990-2005 (%)	2030 (km)	1990-2030 (%)	2080 (km)	1990-2080 (%)
Grande-Côte	11.6	12.1	4%	15.1	29%	15.4	32%
Cap Vert	63.5	70.0	10%	76.6	21%	76.6	21%
Petite-Côte	46.5	55.8	20%	69.5	49%	71.0	53%
Casamance	5.3	5.3	0%	5.3	0%	5.3	0%

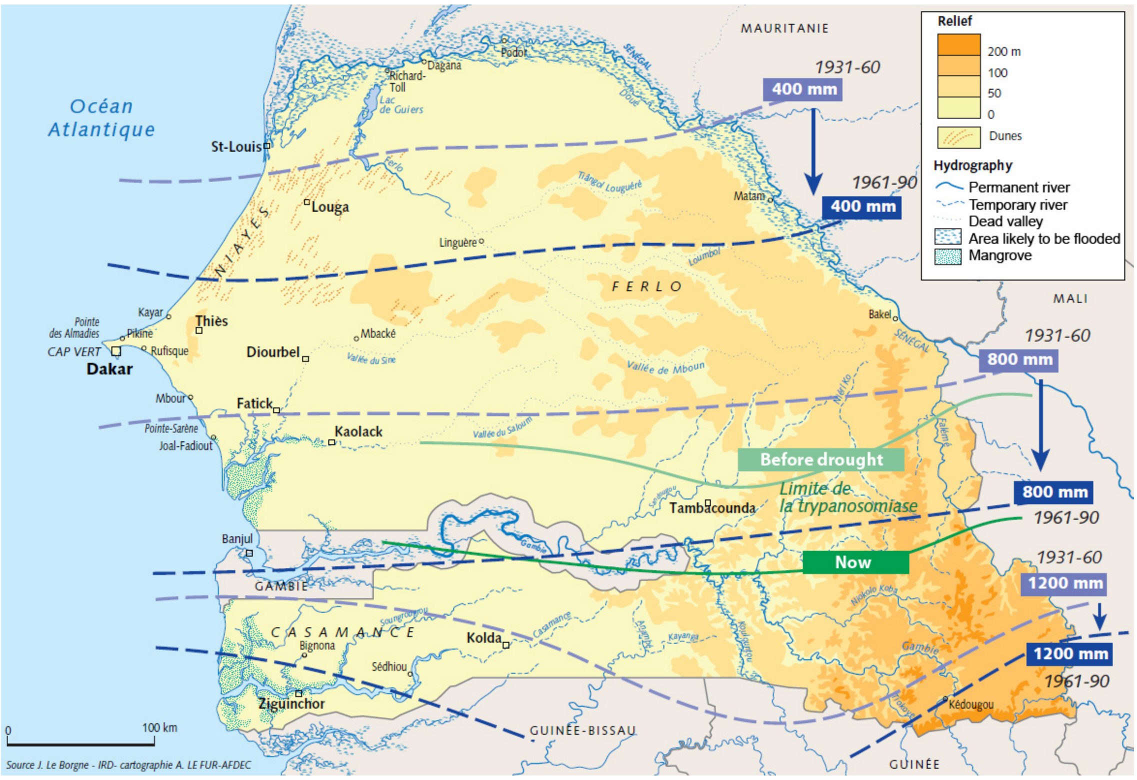
With the assumptions used in this study, this statistical analysis shows that urbanized coastal areas will strongly grow between 1990 and 2080 (from 30% to more than 50%), to the detriment of agricultural and natural areas. **The highest coastal urban growth concerns Petite-Côte,** which should grow by +49% between 1990 and 2030 before slowing down. The extension of existing urban centers (such as Rufisque, Bargny, Saly, Mbour, etc.) between 2030 and 2080 will take place towards the hinterland, due to the lack of available space on the coastline. And since the Cap Vert coastline is already densely urbanized, the growth rate of urban vulnerabilities is relatively low. But it is logically the sector which has the highest decline of agricultural and natural areas (-48% and -68%, respectively) between 1990 and 2030. It should be noted that we assumed an absence of major changes in land occupation in Casamance, although a few development projects should densify the existing tourist areas.

2.3. A CLIMATE MARKED BY DROUGHT AND MAJOR UNCERTAINTIES FOR THE FUTURE

In Senegal, the type of climate ranges from Sahelian (in the North) to Sub-Guinean (in the South) and is characterized by the alternation of a dry season (from November to May) and a rainy season (from June to October). The mean annual rainfall follows an increasing gradient from the North to the South of the country. It goes **from 300 mm in the semi-desert North to 1,200 mm in the South,** with major variations from one year to the other. On the other hand, **the presence of a maritime front induces climate differences between the coastal areas and the hinterland.** For instance, the Dakar region, with its advanced location in the Atlantic ocean, benefits from a coastal microclimate. This latter is strongly influenced by maritime trade winds and monsoon, which are present from November to June and July to October, respectively, in the N-NW and S-SE directions.

A careful observation of the climate trend leads us to identify a **climate change over the past 50 years,** with a period of severe drought, as soon as 1968-1969. Such climate deterioration has been characterized by an interannual irregularity of rainfall, but also by a decrease in rainfall volumes, which led to a noticeable southward shift of the isohyets (see figure below). This drought is one of the major causes of the environmental deterioration and of the greater mobility of the Senegalese population (rural exodus).

Figure 3: Isohyets of the 1931-1960 and 1961-1990 periods

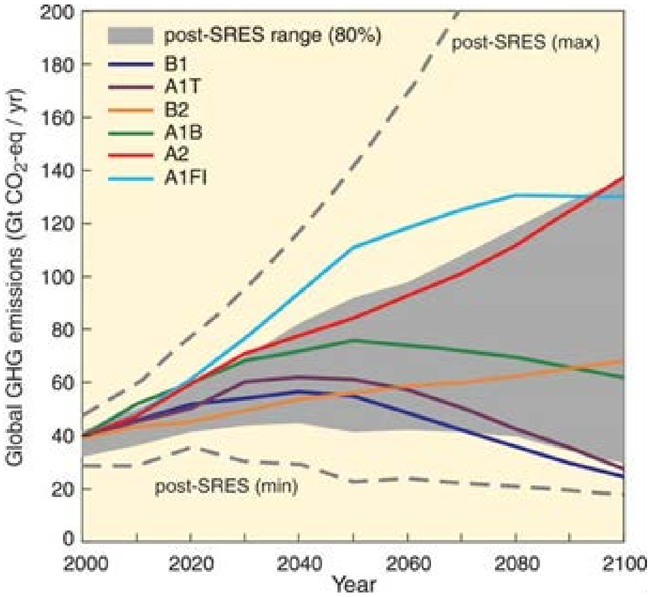


Source: Institut de Recherche et Développement (http://www.cartographie.ird.fr/SenegalFIG/secheresse.html

The forecasts of the climate models presented in the latest report published by the IPCC (2007) show that **the global mean surface air temperature is likely to further increase by 1.1 to 6.4°C during the 21st century.** The differences between the forecasts are related to the use of models which have different sensitivities to GHG concentrations and different assessed values for future emissions. The situation in Senegal logically follows that trend. The forecasts for the horizons of 2030 (2010-2039) and 2080 (2070-2099) have been estimated using data coming from **three global climate models (obtained from the IPCC Data Center) and from SRES scenarios A1B and A2** (see figure below). Changes have been calculated with respect to the baseline period (1961-1990).

Selection of the climate models for the study
Nineteen global climate models have been developed by various research centers. They are all **coupled atmosphere-ocean models** that make a dynamic link between the detailed ocean models and the atmospheric models. For each model, the results are available at the IPCC Data Distribution Center. The selection of global models was logically the same as for the World Bank study carried out in 2011 regarding adaptation to climate change and natural disasters of coastal cities of North Africa: ECHAM5 (developed in Germany), CNCM3 (France) and HADCM3 (GB). Furthermore, the selection of these global models was based on **four selection criteria** suggested by Smith and Hulme (1998): - date of the model: simulations based on recent models are more reliable; - resolution: a high spatial resolution gives a better climate representation; - validation: selection of models that best simulate the current climate, in the hope that these models might be able to produce a reliable representation of the future climate. It should however be noted that this relative performance of the models depends on the size and location of the region studied and on the variables analyzed; - representativeness of the results: according to the model, major differences might exist in the evaluation of changes in the regional climate. It should be noted that for Phase 3 of the study, we used modelling results downscaled to the pilot sites, i.e. with regional climate models that have a finer resolution (50 km).

Figure 4: Evolution of emissions according to the IPCC emission scenarios



Source: Fourth IPCC Report.

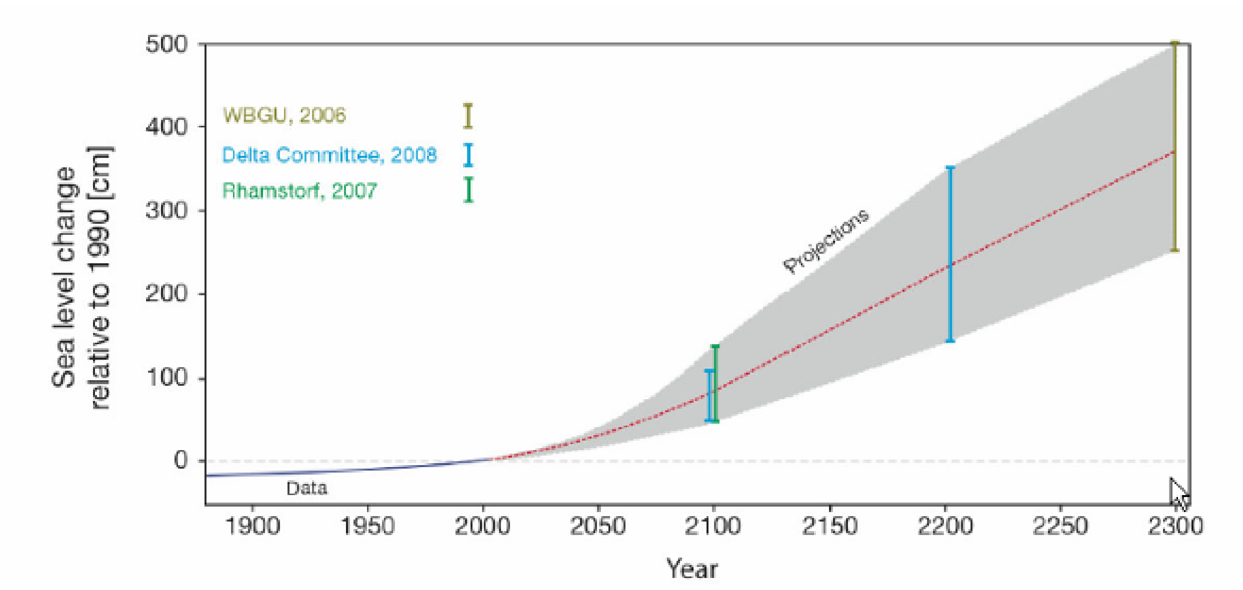
The mean annual temperature on the Senegalese coastline at the 2030 horizon increases by 1,12 to 1,23°C with the three models and the two scenarios. The increase at the 2080 horizon is 2.65 to 4°C in coastal areas, with a North-South temperature gradient along the Senegal river which ranges from 5.18 to 5.6°C for scenario A2.

Precipitations do not evolve consistently according to all models. The uncertainty is related to both amplitudes and variability. Variation forecasts between the current situation and the future periods (2030 and 2080 horizons) for climate scenario A1B in the North-West quarter of Senegal vary from -4.5% to -19% in 2030 and from -15% to -55% in 2080. For the same horizon, but with a more pessimistic climate scenario, the rainfall decrease on the Senegalese coastline would be twice the above values. For instance, it would move from -20% in scenario A1B to -40% in scenario A2.

The temperature and rainfall evolution was calculated with respect to a baseline period that includes the greatest drought faced by Senegal over the last century. Since the forecasts show a continuation of global warming and a decrease of mean annual rainfall during the 21st century, **years of tougher droughts should be expected**.

Furthermore, the global temperature increase leads to the dilatation of ocean masses and the melting of polar ice caps. On the basis of a critical analysis of the IPCC's forecasts and of the latest evidence regarding such topic, we have considered, for this study, that **the global sea level will have risen by 20 cm and 80 cm at the 2030 and 2080 horizons, respectively**. It should be noted that these are high hypotheses, as shown on the figure below. Indeed, we can clearly see the 'runaway' effect related to climate change (+17 cm for the 20th century), which has led to the concept of 'accelerated' sea level rise.

Figure 5: Forecast of sea level rise



Historical data are from Church and White (2006); forecasts, from Rahmstorf (2007), WBGU (2006) and the 'Delta Committee' of Vellinga et al, 2008

2.4. A COASTLINE SEVERELY THREATENED BY NATURAL AND CLIMATE-RELATED HAZARDS

The natural hazards studied within this report are coastal erosion (shoreline recession), marine submersion (floods due to storm surges), river or run-off floods, water shortages and groundwater salinization. Such hazards have been analyzed for the current situation and for the 1990, 2030 and 2080 horizons, by taking into account the potential effects of climate change. Although it was not possible to give quantified evaluations, broad trends have been identified and hazard categories have been defined and mapped. It should also be reminded that a more quantitative approach of the hazards has then been implemented at the pilot sites.

As shown by the figure below, **the Senegalese coastline shows generalized erosion,** but the intensity of this phenomenon is still low for more than half of the coastline. **The areas most sensitive to this hazard are the deltas and the estuaries** of the three major rivers, since sediments supplied are far from compensating erosion losses in these low zones. And since such zones are of great ecological importance, erosion might lead to significant biodiversity losses. Generally, erosion speeds do no exceed 2 meters per year, but locally, some beaches might lose more than 10 meters per year (e.g., Pointe Sarène beach).

Ranking the causes of shoreline recession is a very difficult task. But the first cause is likely to be mainly related to the lack of 'new' sediments since the last marine transgression that had enabled to create sediment stocks that have been distributed along the coastline. More recently, during the development of coastal urbanization, very large volumes of sand have been extracted from the beaches, thus contributing to the decrease in sand stocks available for sediment transport. It is likely that such extraction has been the first cause of erosion over the last decades. Massive extractions are now forbidden, although some kind of activity can still be observed in a few places, but with a much lower impact on the coastline. **The continued shoreline recession is now more related to anthropic activities** which exacerbate erosion: river structures (dams, impoundments) which stop sand supply; major coastal infrastructures (ports, dikes, etc.) which stop coastal transit and enhance downstream erosion; and leveling of the dunes which supply materials to coastal areas upon storms. When noticed, these losses have led to the **construction of protective structures, which in turn have a negative impact** on coastal beaches (for instance, beach-top structures built parallel to the shoreline). Indeed, beach recession is then increased when powerful storms are combined with high water levels (astronomical tide + barometric tide), since beach tops might then be reached. The last cause of shoreline recession is linked to **sea level rise induced by climate change**, which has a mechanical effect on beach recession, according to their slope. This accelerated sea level rise is **likely to become the main cause of erosion in the years to come**.

The **following box** describes a few additional points regarding the main causes of erosion.

Figure 6: Erosion of the sand shoreline since the 1950s according to bibliographic data (Source: I. FAYE)

Main causes of coastal erosion

Coastal erosion is a **natural phenomenon**, mainly related to the action of wind and of swell (with the currents this latter induces), to sea level variations (climate change, storms), to the quantity of sediments supplied by coastal rivers and to the local geological and morphological characteristics. In addition to these natural causes, we often have **anthropic factors** (coastal artificialization, dams that decrease sediment supply, anarchic sand extraction from beaches) that can strongly aggravate this phenomenon.

The Senegalese coastline is no exception to the rule and is affected by these causes, individually or jointly.

During **exceptional sea storms**, the water table rise (surge: setup, surfbeat, run-up) and the greater energy of swells accelerate erosion. Such phenomenon is exacerbated when dune ridges have been leveled, and the various issues (human, economic and environmental) then become more vulnerable to marine submersion. For relatively frequent storms, the changes in the beach profile might be compensated during low swell periods, when sediments are thrown back onto the beach.

Sea level rise induced by climate change, although not yet of a great magnitude, is leading, on low-sloped beaches, to a 'mechanical' shoreline recession which intensifies the erosion phenomenon during storms. In the long run, sea level rise will have an even greater impact on sand beaches, but also on shores bordered with cliffs, where recession will further increase.

Another important point is the presence, to the south of Grande-Côte, of the **Kayar canyon**, a geological fault likely to have a major influence on sediment transit between the northern and southern parts of the coastline. Indeed, scientists think that the canyon is trapping a great share of sand sediments carried by the longshore drift, thus inducing some level of sediment deficit to the south (in particular along Petite-Côte). To the north of the canyon, sediment transit could amount 200,000 to 1,500,000 m³ per year (Barusseau, 1980), but south of Cap Vert, there would only be a few tens of thousand cubic meters per year.

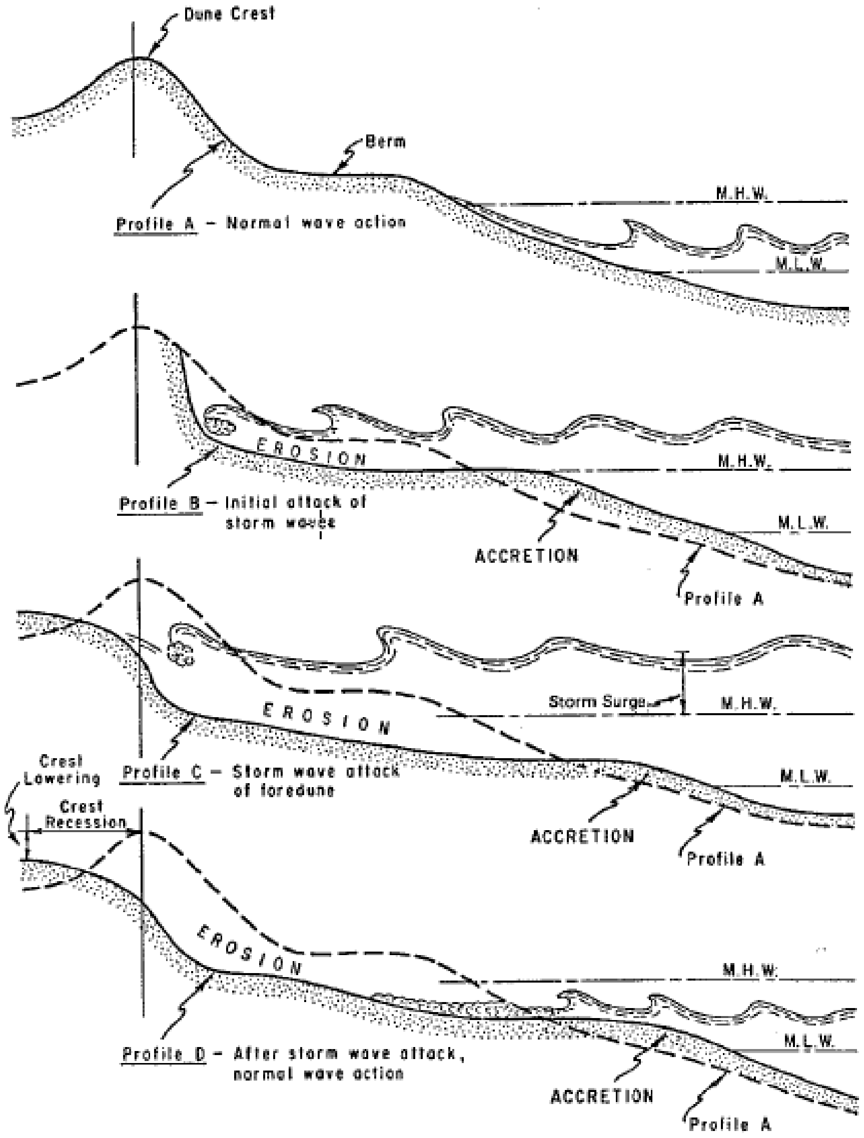
Amongst the **anthropic actions**, those that mainly affect the Senegalese coastline are the following:

- **Sand extractions** from beaches (e.g. in Yoff or Bargny) lead to a decrease in the sand volume carried by coastal transit or present in the beach profile (mainly during high swell and storms), while the attack and transport capacity of the sea remains unchanged. Sand is thus directly extracted from the shore and can no longer reload the beach later during nice weather. Field surveys carried out within this study show that local populations are fully aware of the issue and are in favor of a total ban on such activity. On the other hand, there is no alternative, and this activity continues in order to satisfy individual needs. The awareness-raising campaign launched by the Ministry of Environment does not seem to have produced the expected results yet. However, it should be noted that industrial extraction would have stopped.
- **Maritime protection structures** increase the erosion phenomena:
  - ☞ Beach-top longitudinal structures, like in Rufisque and Saint-Louis, induce at their foot, when struck by the sea, a doubling of the swell amplitude. This leads to the lowering of the beach profile and, eventually, to the disappearance of the beach, such as in Rufisque.
  - ☞ Groins, as those built in Saly, lead to the erosion of the shoreline downstream of the transit due to the lack of sand supply by coastal transit when these structures are not saturated by the upstream transit (sector between Teranga hotel and Filaos residence).

A last factor, which is difficult to quantify today, is the **decrease in rainfall**, due to the natural variability of the climate or to climate change induced by human activities. This would lead to a decrease in solid sediments supplied to the shore (for instance, by the Senegal river), and thus, an aggravation of coastal erosion. Such decrease in sediment supply could also be intensified by the presence of dams on the river (e.g.: the Manantali dam), which block coarse particles.

The impact of sea level rise is likely to be low in 2030, but it could become significant at the 2080 horizon due to the sandy nature of the coastline. Foreshore recession should take place on natural beaches, and the beach profiles should drop. In fact, **more than 60% of the coastline could move to a high hazard category at that horizon, against less then 5% today.**

Figure 7: Schematic diagram of storm wave attack on beach and dune



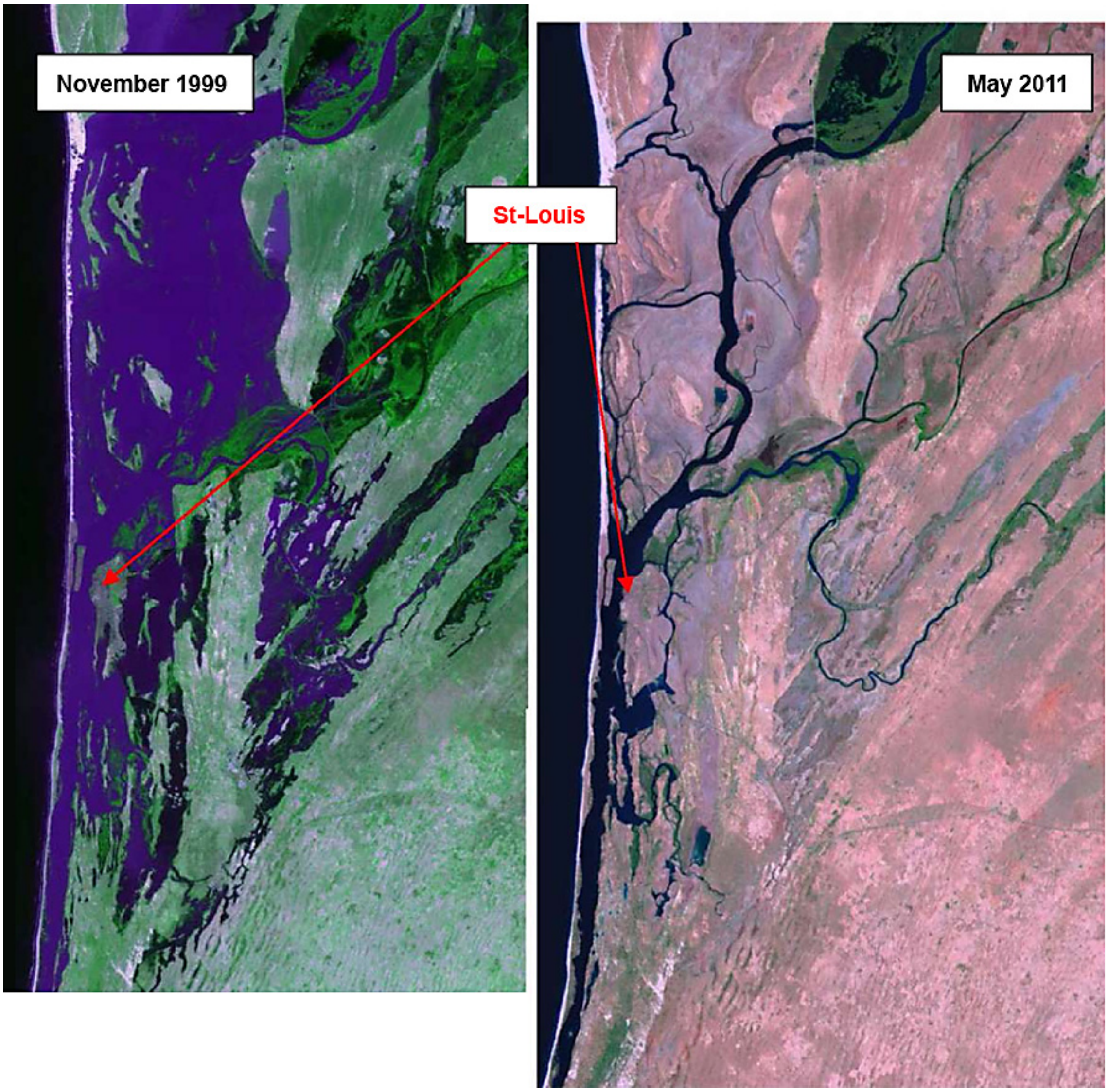
Source: Shore Protection Manual, Vol. 1, Coastal engineering research, 1984

During storms, the zones that are most sensitive to the **submersion hazard** are again the estuarial areas and the low-sloped sandy shores. For a 100-year storm, marine submersion might affect all the coastal areas located below the elevation of 1.5 m with respect to the mean sea level (and even 1.8 m at Grande-Côte). This hazard is already considered as high in the current situation for more than 70% of the Senegalese coastline. In the future, the impact will

be proportional to the amplitude of sea level rise. Storm surges will increase the extension of flooded areas in the lower zones, the attack of dune systems and the floods behind the beach-top (see Figure 7). **At the 2080 horizon, more than 90% of the coastline would be facing a high marine submersion hazard.**

The flooding hazard for the studied area regards two different types of floods: river floods and run-off floods. Such floods are induced by weather phenomena that are different in nature: river floods caused by cumulative rainfall during the rainy season, and urban floods caused by short but intense rain on sealed surfaces. In coastal areas, sea level might be an aggravating factor. The **floods of the Senegal river** are by far the main concern as regards river floods. The figure below shows the extent of such floods (comparison between the 1999 floods and the low water level of 2011). At the mouth of the river, we can see that discharge conditions are the main cause of floods, much more than the flow rate of the river. This explains why a breach was made in 2003 at the Barbarie spit of land.

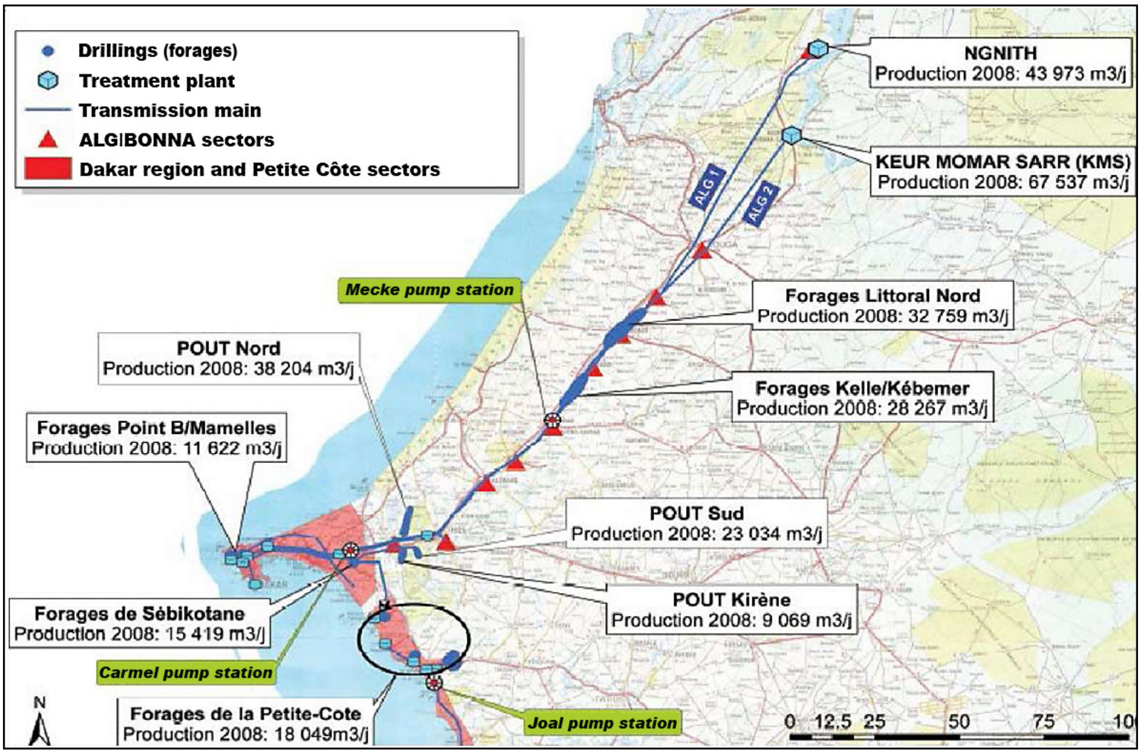
Figure 8: Satellite photos of the estuary of the Senegal river



In the future, the high variability of the results provided by the climate change model scenarios makes it difficult to forecast rainfall evolution, and thus flood levels. Temperature increase coupled to a decrease in rainfall should minimize flooding risks, but even if rainfall would increase, the flooding conditions in the downstream part of the river will continue to be determined by the flowing conditions at the river mouth. As regards run-off floods, the **urban area of Dakar** is the most exposed area. It should be noted that the city of Saint-Louis is exposed to both river and run-off risks.

At the other end of the water hazard scale is the **water shortage hazard,** during dryness periods. When focusing on the water supply issue of the **city of Dakar,** we can see that half of the agglomeration's supply comes from surface water channeled from Lake Guiers (which is itself supplied by the Senegal river), and that the other half is supplied from boreholes (see figure below).

Figure 9: Water supply system for the Dakar area and production figures for 2008 (Source: SONES)

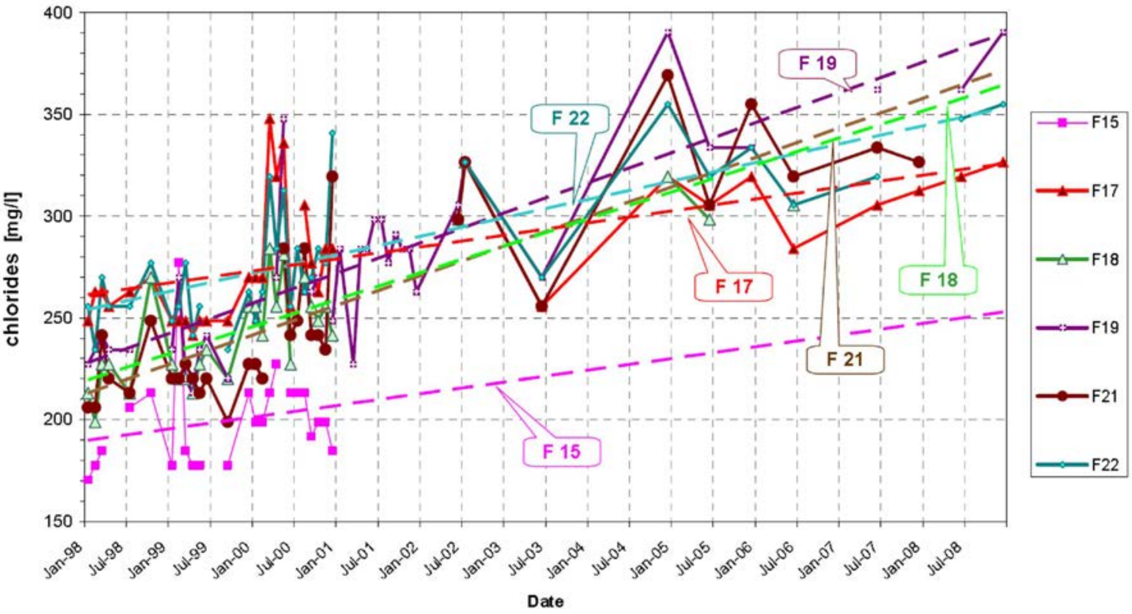


As regards **surface water,** the flow rate withdrawn is negligible with respect to evaporation from the lake surface, which represents twice the volume of all the water uses of the impoundment (in particular, irrigation) and 20 times the flow rates withdrawn for the water supply of the city of Dakar. Today, water supply to the Dakar agglomeration is not posing any difficulty. However, rainfall decrease in the upper catchment area of the Senegal river, combined to a temperature rise that will increase evaporation, could lead to much more demanding conditions for the management of Lake Guiers, which will require choices to be made between the various uses and a management method more adapted to seasonal variations. The management conditions of the Manantali dam must also be added to the reflection process regarding the management of Lake Guiers. As regards **groundwater,** the study of the supply area of the Dakar agglomeration shows that the hydrological balance of all the water tables is currently in a deficit situation and has been so since the 1960s. Such situation, combined to a deterioration in the quality of the surface water table, has led to progressively shifting the water supply of the city of

Dakar from groundwater to the waters of Lake Guiers. Nevertheless, such decrease in groundwater withdrawals has not been sufficient to balance the aquifer system. The combination of rainfall decrease and temperature rise would lead to an additional decrease in the groundwater resource, but this would have a low impact with respect to the other overexploitation issues observed today. Furthermore, it should be noted that only the surface water tables (of the Terminal Complex) are directly recharged by the infiltration of rainwater.

Groundwater salinization is one of the consequences of their overexploitation (see figure below). Indeed, when the fresh water load decreases, the saltwater wedge coming from the marine environment moves towards the hinterland.

Figure 10: Evolution of chlorides sampled from SONES boreholes located in the quaternary sands of the Thiaroye area over the past 10 years



Two hazards related to climate change might further aggravate the situation: **sea level rise,** which will increase the hydraulic load of sea water and shift the saltwater wedge towards the hinterland; and the **decrease in recharge,** which will increase the difference between refill and withdrawals, leading to a lowering of the fresh water level and ultimately, to a further hinterland shift of the saltwater wedge. Though decrease in refill remains uncertain, sea level rise seems unavoidable.

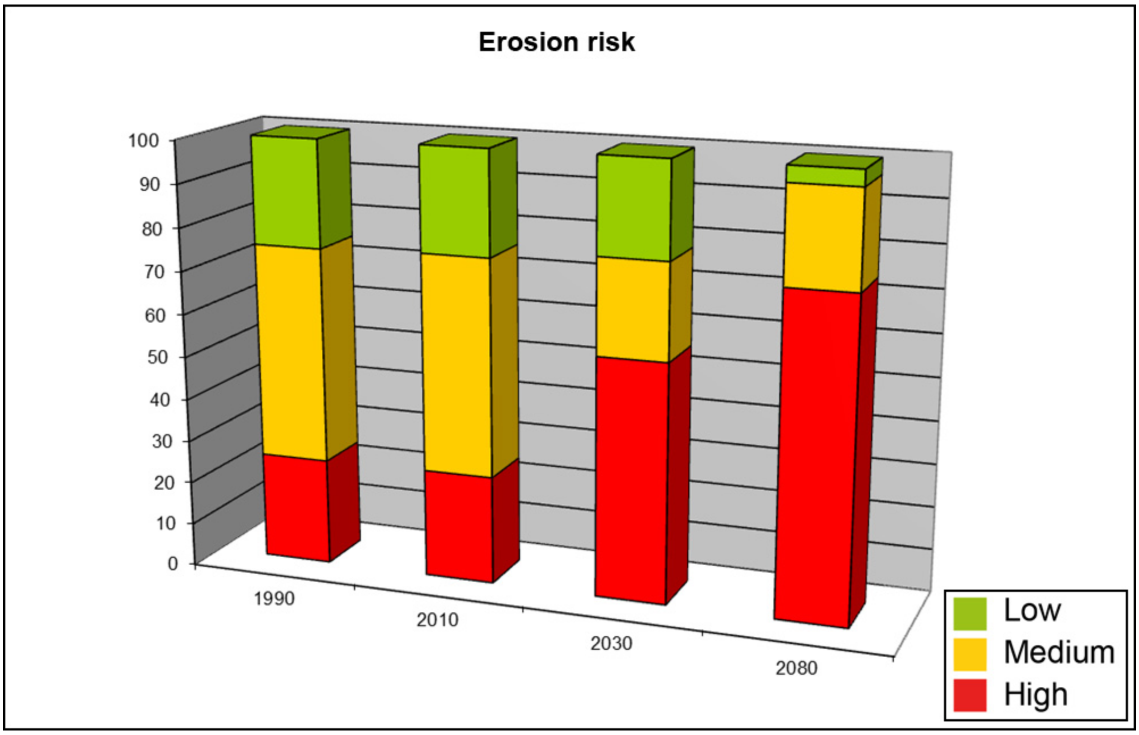
2.5. AGGRAVATION OF RISKS DUE TO CLIMATE EVOLUTION

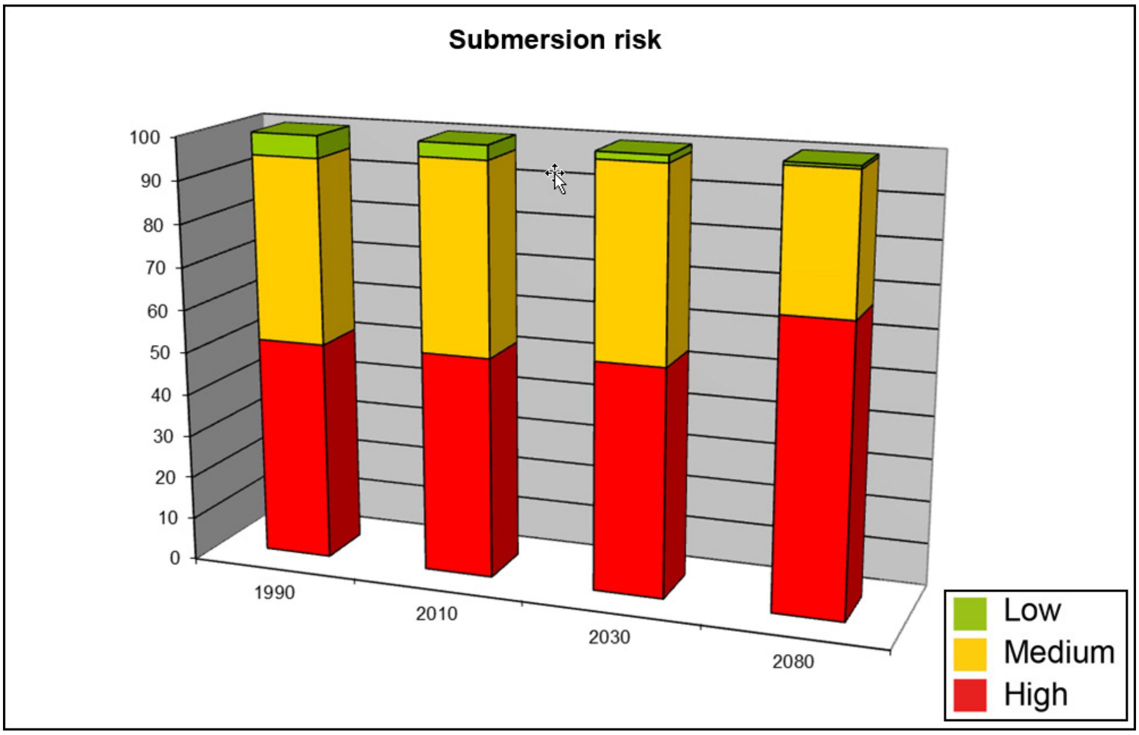
The **crossing of hazard and vulnerability** enables to determine the risk. Hazard and vulnerability levels might be used to determine corresponding risk levels. Risk assessment enables to identify and locate which of the sensitive components (vulnerabilities) of the coastline are exposed to hazards, and to what hazard level. This work was mainly carried out in a cartographic manner for the main risks studied.

While the erosion risk levels are almost unchanged between 1990 and 2010 (in fact, 2005), with one fourth of the coastline at high risk, **more than half of the coastline would be at high risk in 2030, and approximately three quarters in 2080.** Such evolution is mainly due to the erosion hazard that increases proportionally to sea level rise, which should reach +80 cm by 2080.

Risk levels related to marine submersion show a limited evolution, mainly because they are currently already very high (> 50% of the coastline). The situation shows no major changes at the 2030 horizon, which is relatively close, but **at the 2080 horizon, two thirds of the coastline will be facing a high submersion risk.** The figures below illustrate such evolutions.

Figure 11: Level and variability over time of the risk of coastal erosion and marine submersion





The main sensitive elements of the coastline are urban areas, the extent of which will increase by more than 30% between 1990 and 2080. Of particular concern are Saint-Louis, Kayar, some areas of the Dakar agglomeration, Rufisque, Saly, Somone, Nianing, etc. In 2080, the entire Grande-Côte coastline and almost all the Cap Vert peninsula and Petite-Côte coastline become at high risk of erosion. **The submersion risk is mainly high along the shoreline of Grande-Côte,** where a breach in the dune ridge during a storm surge would lead to major and extended damage on adjacent agricultural land.

The estuary of the Senegal river faces a river flood risk that mainly concerns the city of Saint-Louis. Although it is currently impossible to quantify such risk, it should be noted that the flood levels observed have remained much lower than the warning level since the creation of the breach at the Barbarie spit of land in 2003. However, two situations could lead to a high risk situation in Saint-Louis: the combination of a storm (storm surge) and a river flood; or the occurrence of an extremely intense flood that could not be controlled enough by the Manantali dam (return period of 50 years or more). The extension of the occupation of the lower areas of Saint-Louis, combined with the feeling of protection induced by the commissioning of dams, has probably increased the vulnerability to flood risk. **With climate change, a possible rainfall increase could aggravate the situation**, but an optimized management of the Manantali dam could enable to offset this impact.

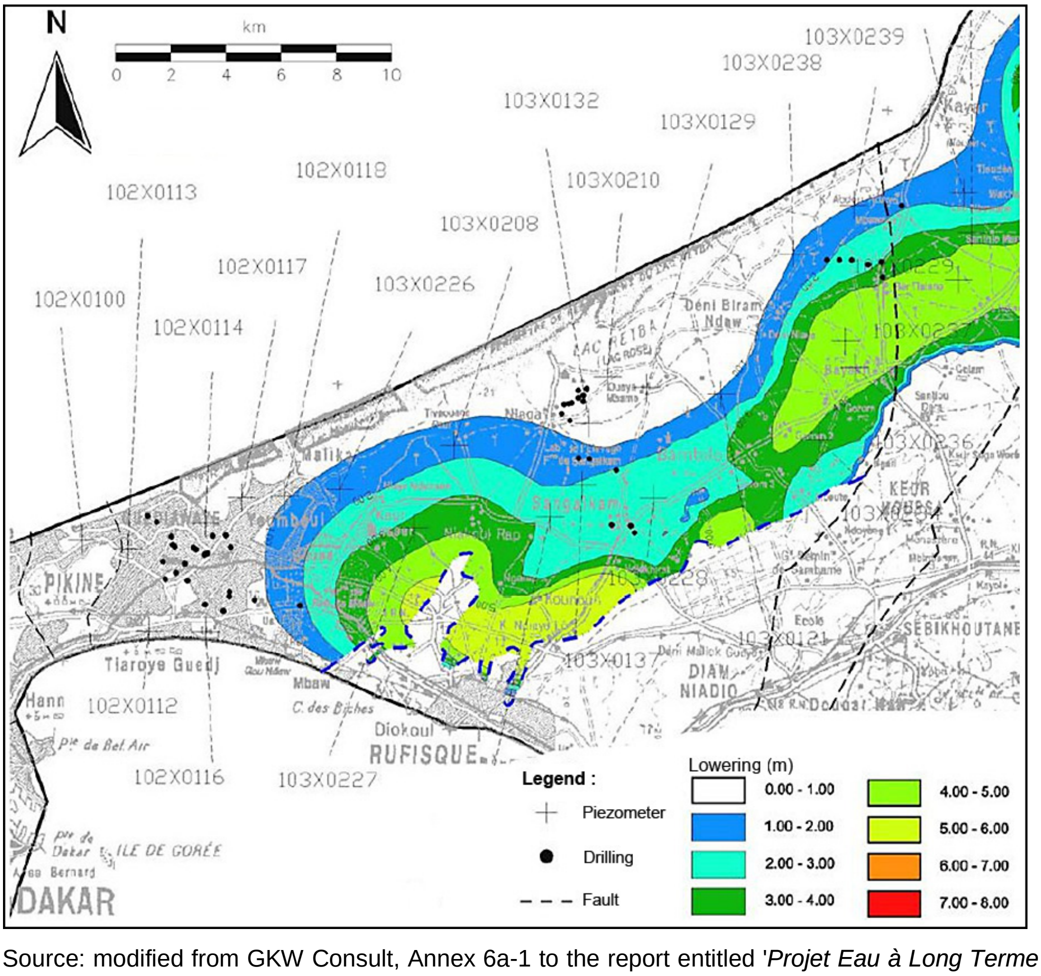
Photo 1: Floods at the Saint-Louis island during the high water level of 2003 (NE part of the island, 2 October 2003)

In the Dakar agglomeration, the flood risks are related to urban run-off, notably because of the insufficient evacuation capability of the storm water network or the absence of network in the **neighbourhoods of Pikine and Guediawaye.** It should be noted that the **Diaminar neighbourhood, at the entrance of Saint-Louis,** faces similar risks of run-off floods.

The water shortage risks have been assessed by SONES until the 2025 horizon. **For the Dakar area,** , with the progressive decrease in groundwater withdrawals and the current level of withdrawals from Lake Guiers, **the water deficits** (withdrawals greater than natural replenishment) **start as soon as 2011 and increase as the needs grow,** shifting from an average of 18,000 m³/day in 2011 to 195,800 m³/day in 2025. All the other urban areas of the coastline will face water deficit situations in the more or less short term.

As regards the **risk of groundwater salinization,** the sea level rise and the decrease in mean annual rainfall will induce a shift of the saltwater wedge towards the hinterland, and thus a decrease of the groundwater resource and the invasion of production infrastructures (mainly drinking water boreholes) by sea water. Yet, along the Senegalese coastline, the groundwater balance already shows a major deficit, and this resource is already highly affected by overexploitation due to pumping. Without taking into account a possible positive evolution in terms of resource management (in fact, on the contrary, indicators show an increase in overexploitation), **the impact of climate change will not be significant with regards to the impact of overexploitation,** whatever the horizon considered. **The only exception regards two small areas located west of Mekhé and to the immediate north of Rufisque** (see figure below), where the 'rainfall decrease' hazard will have the highest impact.

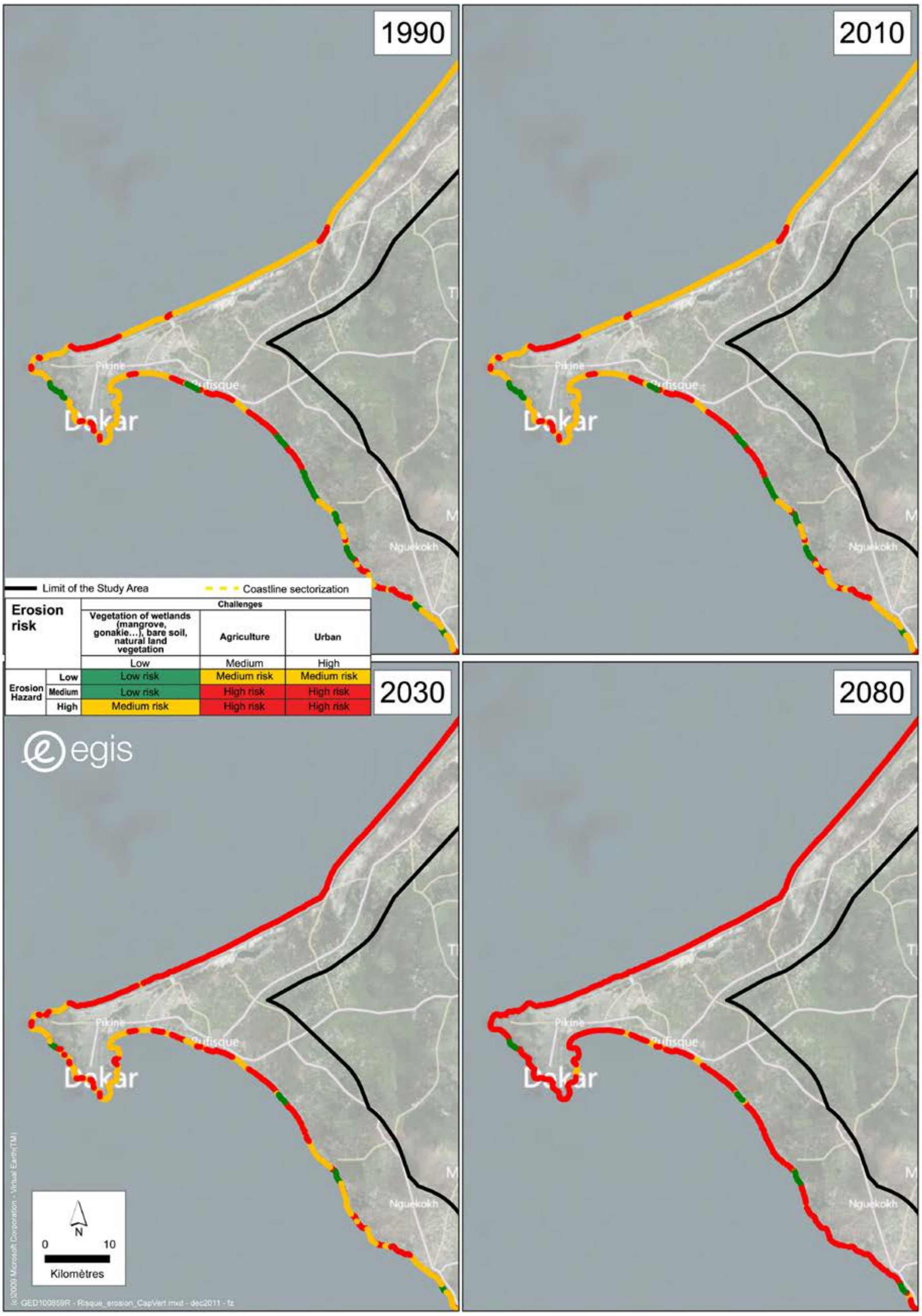
Figure 12: Lowering of the upper aquifer (Thiaroye sands - Cap Vert) caused by rainfall decrease, without taking into account the impact of withdrawals



Source: modified from GKW Consult, Annex 6a-1 to the report entitled '*Projet Eau à Long Terme - Etudes Hydrogéologiques Complémentaires, Phase 4 Lot 1b Modélisation numérique*'

The figure below illustrates the evolution of risks under the form of maps, taking the example of the Cap Vert area and the erosion risk.

Figure 13: Cartographic illustration of coastal erosion risks in the Cap Vert area



3. IN-DEPTH STUDY AT THREE PILOT SITES

Take-away messages

- ☞ The study has been carried out in depth at three predominantly urban pilot sites: Saint-Louis, at the mouth of the Senegal river; Rufisque-Bargny, at the junction of the Cap-Vert peninsula and the shoreline of Petite-Côte; and Saly, on Petite-Côte.
- ☞ In these three sites, the trends show an increase in vulnerabilities, with the urbanization of natural or agricultural areas and a densification of buildings.
- ☞ The Saint-Louis agglomeration is mostly affected by the risk of river floods. Sea level rise worsens the flooding conditions: at the 2030 horizon, more than half of the city would be submerged during relatively frequent floods. At the 2080 horizon, the situation would become catastrophic, since 80% of the city would be submerged.
- ☞ The site of Rufisque-Bargny is mainly threatened by coastal erosion, and some 300 buildings could be destroyed because of shoreline recession by 2080, despite the existing protection structures.
- ☞ In the case of Saly, a site which has been developed for seaside tourism, the means that have been built and that should be reinforced in the years to come are likely to be sufficient to protect the buildings, but not the beach, which is the main tourist attraction.
- ☞ For each site, adaptation measures aiming at neutralizing the risks of long-term marine submersion and coastal erosion are proposed and defined, both technically and financially: strategic retreat (displacement of populations); protective structures built at sea or on the beach-top; beach recharging; reprofiling, etc.

3.1. SELECTION OF THE THREE PILOT SITES

To go further in the analysis, three pilot sites were selected **to form the subject of an in-depth study.** The selection process involved two steps: at first, consultation with the various stakeholders met at the beginning of the study; then, taking into account of data availability and geographical and technical criteria. The objective was to select sites that were highly exposed to coastal risks, in different geographical areas and with different land use situations, i.e. sites representative of the main coastal issues currently faced. **Data availability played an important role**: it would have been useless to select a site for which no assessment of the risks and their economic impact could have been made. In this respect, a parameter soon proved to be essential: the existence of topographic data that were recent and fine enough to simulate future erosion and submersion conditions.

In fine, the three pilot sites selected were the following:

- **The Saint-Louis agglomeration** on Grande-Côte (10 km of shoreline, plus the Senegal river estuary), because of its exposure to a variety of risks: coastal erosion, coastal submersion, and floods due to the Senegal river. It would have been interesting to extend the study area to the Gandiolais district so as to include an agricultural sector into the analysis, but the topographic data available for that area proved to be insufficient. Nevertheless, the vulnerability of that sector to an evolution of groundwater salinization has been discussed.
- **The Rufisque-Bargny area** (12 km of shoreline), at the outskirts of Dakar, an area which has already greatly suffered from coastal erosion. This dense urban sector is home to populations with low income, and thus with less capacity to adapt to natural risks. It is often presented as THE area most emblematic of coastal issues in Senegal.
- **The Saly sector** on Petite-Côte (7.5 km of shoreline), and more particularly the tourist area of Saly, which regroups Senegal's largest number of tourist infrastructures and seaside activities. Besides a few fishermen's villages, local populations are thus mostly wealthy, and the issue here is more to maintain an economic activity that is of importance for the country.

The **maps on the following pages** show the boundaries of the study areas on each site and the detail of land use now and at the 2030 and 2080 horizons).

3.2. SITES SHOWING HIGH VULNERABILITIES RELATED TO URBANIZATION, AND INCREASING OVER TIME

In the three pilot sites, **the trends show an increase in vulnerabilities, with the urbanization of natural or agricultural areas and a densification of buildings** in areas where urbanization is currently discontinuous. Nevertheless, the evolution is different according to the sites.

In **Saint-Louis,** the lack of space induces a limited evolution of urban spaces. We would mainly see a densification of urban areas. The tourist resort of **Saly** has faced a major urban evolution, but would still continue to progress and densify. Due to the tourist purpose of this sector, the areas that should develop the most are located close to the shoreline, in particular in the western part of the site.

Figure 14: Evolution of land use in Saint-Louis between 2011 and 2080

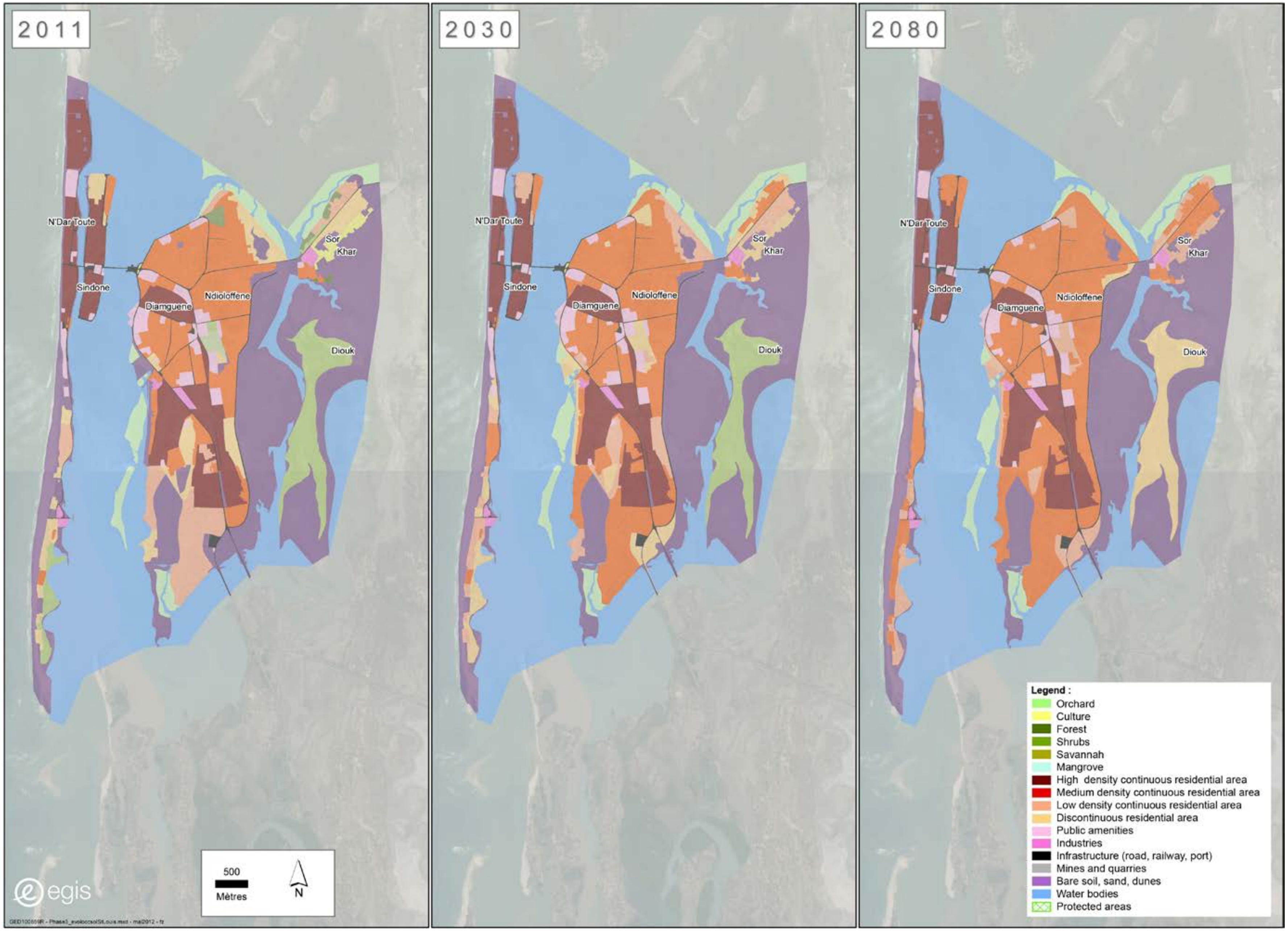


Figure 15: Evolution of land use in Rufisque-Bargny between 2011 and 2080

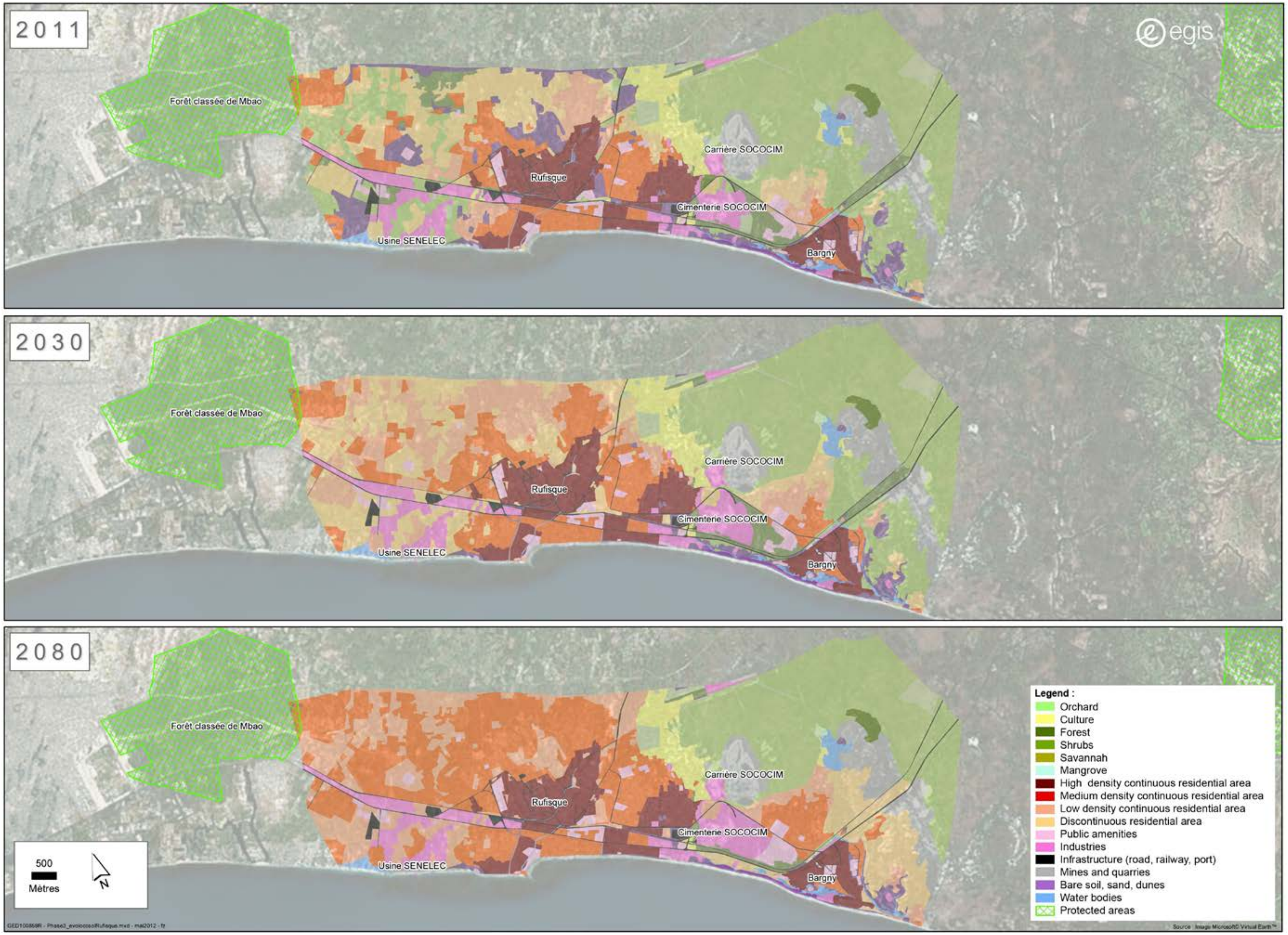
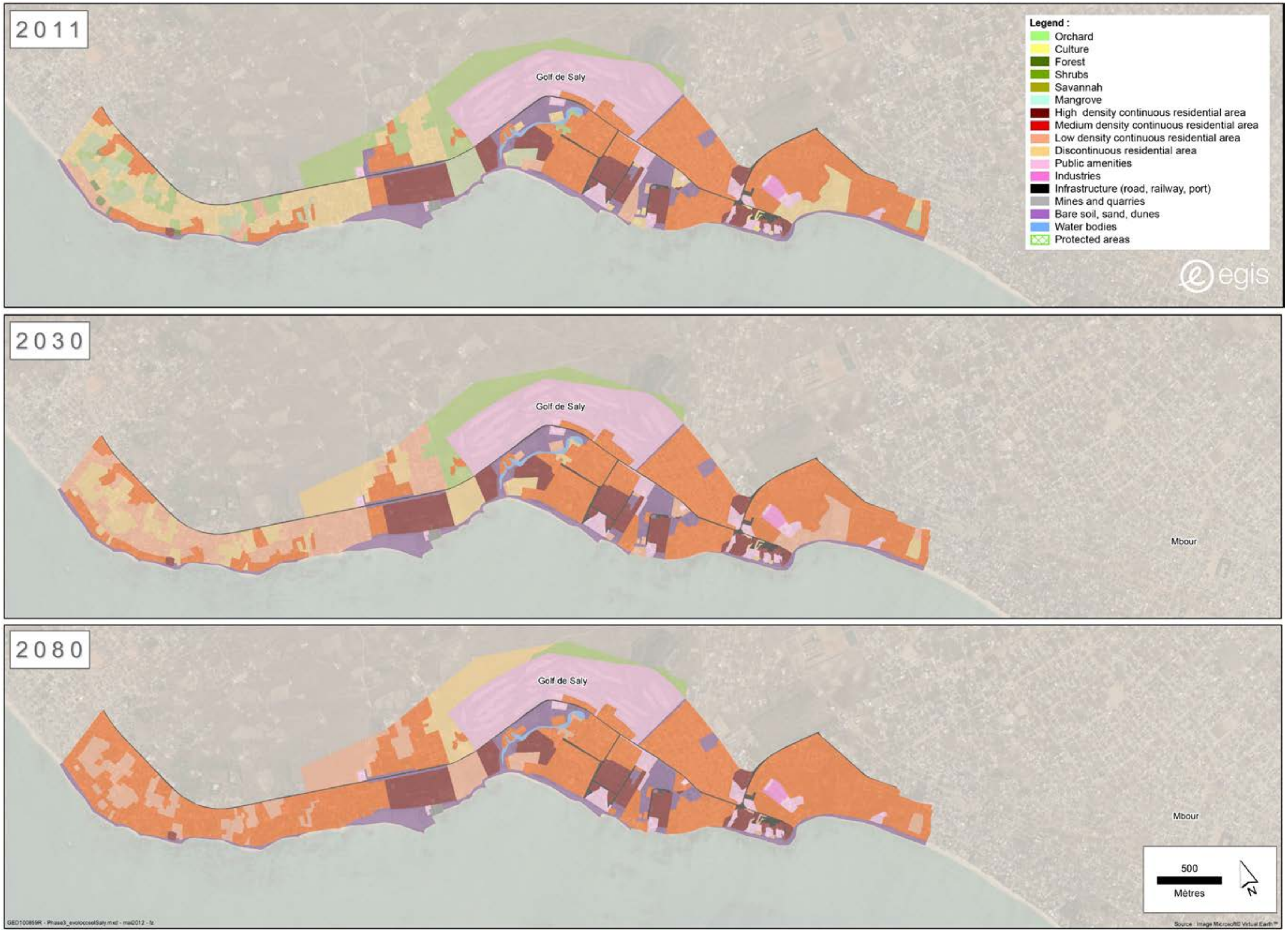


Figure 16: Evolution of land use in Saly between 2011 and 2080



The site of **Rufisque-Bargny** is the sector where vulnerabilities should increase the most, notably because of the proximity to the capital city Dakar, of the growing dynamics of those two urban centers and of the availability of natural areas (savannah, forests, etc.).

At the pilot sites of Rufisque and Saly, artificialized surfaces are expected to increase by 20 to 26% **at the 2080 horizon with respect to today, with a major densification of the current built environment**.

3.3. POPULATIONS THREATENED, ON VARIOUS ACCOUNTS, BY THE ENCROACHMENT OF THE MARINE ENVIRONMENT

Field surveys carried out within the framework of this study highlight socio-economic challenges related to the evolution regarding land use and the risks to which populations are exposed, in particular due to shoreline recession. These surveys have been taken into account to refine the assessment of vulnerabilities and damage.

In the **Saint-Louis area,** consultations were organized, in particular in the Guet Ndar neighborhood, on the Dounbaba Diéye island and in the Gandiol area (village of Mouit). In Saint-Louis, and more particularly in the Get Ndar neighborhood, 2011 was characterized by a very strong sea encroachment with respect to the previous years. Dwellings were flooded by the sea. Sea-food processing sites located along the coastline were also affected, with the loss of many production workshops (drying rack, oven, cooking pot, etc.). The opening of the breach at the Barbarie spit of land in October 2003 led, according to the populations, to a reduction in mangrove surfaces in the Gandiolais area and to land losses in Dounbaba Dieye. Flood recession agriculture in the flood plains of the Gandiol river is facing a strong decrease due to the progressive salinization of land and surface water following the opening of the diversion canal.

On the site of **Rufisque/Bargny,** land use is mostly characterized by the presence of traditional neighborhoods, which were first occupied by the Lebou people (fishermen). Consultations with the populations showed that sea encroachment has been present for many years but that it has greatly intensified over the past decade. It is characterized by sea level rise and a rough sea with waves of more than 2 meters that destroy all the buildings located on the seafront. At Rufisque, the neighborhoods of Keury Kaw and Keury Souf are the most affected by coastal erosion. This phenomenon also led to a decrease in the number of landings and of fishermen (migration towards other fishing areas or reconversion to other activities). Run-off floods are very frequent during the rainy season. On the municipal territory of Bargny, according to the populations, three mosques and three cemeteries have been flooded. Many houses have been damaged, and others threatened by waves. Several public squares (Penc) have been invaded by the sea.

Along the **Popenguine/Saly road,** sea encroachment is worrying all the people who work or live on the seafront. Many dwellings and hotels are being destroyed or damaged, as well as restaurants, businesses, etc. Landings are also being destroyed, and others strongly reduced because of sea encroachment. According to the inhabitants, sea encroachment has intensified over the last two years, in particular since 2011 with the construction of the protection dike at the level of the presidential residence of Popenguine. In order to protect their asset, some hotel owners have built protection dikes in front of their establishment. This has induced a deviation and an intensification of the phenomenon in other areas. Marine sand extraction from certain beaches, notably in Ngaparou, would also contribute to sea encroachment.

Photo 2: Sea shell sellers (Cap des Biche, Rufisque)

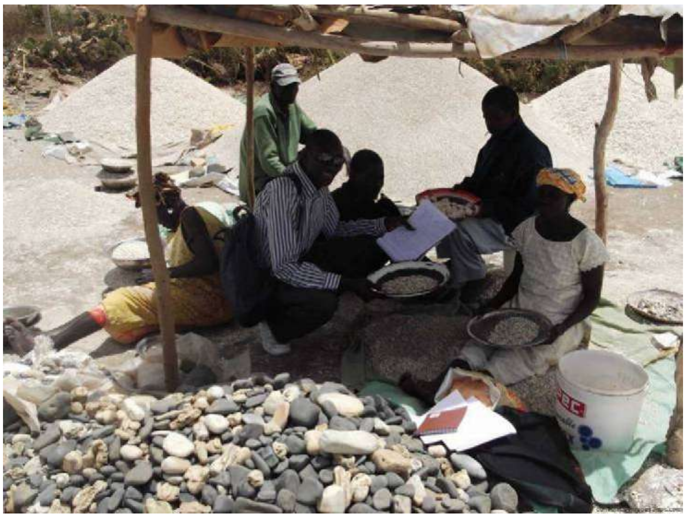


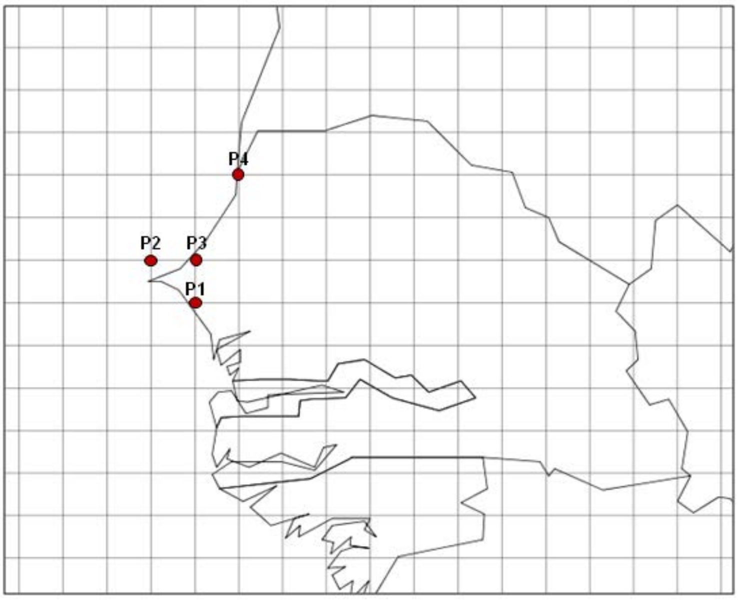
Photo 3: Fish drying workshop in Saly

Photo 4: Sand extraction

3.4. CLIMATE FORECASTS SHOWING A NORTH-SOUTH GRADIENT, WITH POSSIBLE TREND REVERSALS

In Phase 3, forecasts at the 2030 and 2080 horizons have been assessed by means of four **regional climate models** obtained from the data center of the ENSEMBLES project, with scenario A1B. The grid points of the models used for the pilot sites are illustrated below.

Figure 17: Grid of the regional climate models



The mean annual temperature along the Senegalese coastline increases by approximately 1°C at the 2030 horizon. Such increase continues at the 2080 horizon and would reach 2.28 to almost 3°C to the north of the country (Saint-Louis), with a higher North-South temperature gradient at the 2080 horizon.

Precipitations do not evolve consistently at all the sites. At the 2030 horizon, a temperature increase in the north-western part of Senegal would lead to an increase in rainfall. Overall, we can see a South-North gradient where rainfall would increase by 0 to +5.74% in Saly and by +11.37 to +25% in Saint-Louis. At the 2080 horizon, the trends reverses, and the less rainy North-West regions face the highest rainfall decrease. Such decrease would be three times greater in Saint-Louis (-13%) than in Saly (-4%).

3.5. GROUNDWATER RESOURCES MAINLY THREATENED BY HUMAN ACTIVITIES, BUT A POTENTIAL IMPACT OF CLIMATE CHANGE IN SALY

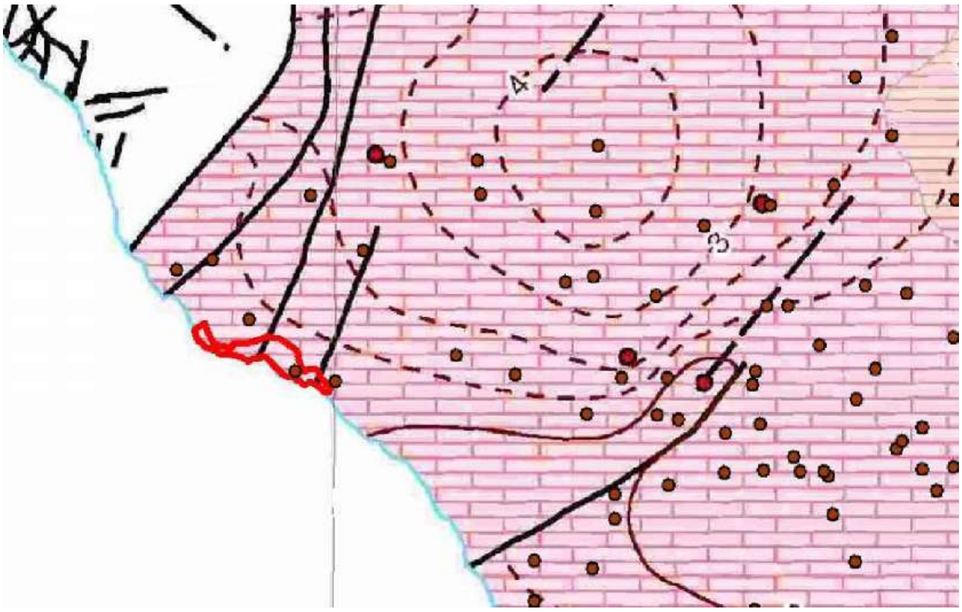
At the northern edge of the site of **Rufisque,** the likely decrease in mean rainfall will induce a decrease in the fresh water resource located in the quaternary sands by 1 to 2 meters at the 2080 horizon. Though it is a significant decrease, it will have no direct consequence on the pilot zone since this resource is not exploited, nor intended to be exploited, as it is already overexploited in the surroundings. Thus, at the pilot sites of both **Saint-Louis** and Rufisque, in the absence of significant groundwater resource and of groundwater production infrastructures, we should not expect a significant impact of sea level rise and rainfall decrease.

The impact of climate change related hazards on groundwater resource is becoming more and more perceptible at the pilot site of Saly, with the AEP boreholes of Saly Portudal.

These boreholes pump from the Maastrichtian aquifer, which is however less impacted than the overlying Terminal Complex or Paleocene water tables. This aquifer is mainly affected by an intense overexploitation, which should have an impact (i.e. a level decrease by 0.5 m per year) much higher than the expected impact due to climate change (i.e. a level decrease lower than 0.05 m per year), with thus a ratio of 1 to 10.

This site is also home to several private boreholes pumping from the outcropping Paleocene water table, which will be directly affected by these hazards, as they already are by level decrease and salinization induced by overexploitation.

Figure 18: Piezometry (brown dotted line) of the Paleocene aquifer in the area of the pilot site of Saly (red line).



Note: from the cartographic work published by GEOTER SA in 2009. The dots indicate the boreholes and piezometers connected to the Paleocene water table (some are also connected to the underlying Maastrichtian table).

3.6. RIVER FLOODS THREATENING THE ENTIRE SAINT-LOUIS AGGLOMERATION IN THE FUTURE

From the three pilot sites studied, the site of **Saint-Louis** clearly stands out due the importance of flooding issues related to the river Senegal. For the rest of this chapter, because of the strong uncertainties regarding how rainfall will evolve with climate change, we have only considered sea level rise.

For relatively frequent floods (return period of some 10 years), we can see in the current situation that the lowest areas are flooded and that 37% of the urban areas and 17% of the equipment and infrastructure zones are affected. The most affected neighborhoods are located both to the South (Pikine and Djaminar) and to the North (Darou, Balaco and Khor). The north of the N'Dar island (Saint-Louis island) is also affected. At the 2030 horizon, we obtain a major increase in the flooded artificialized areas: 53% of the urban fabric and 32% of the other artificialized sectors are affected.

Figure 19: Flood risk in Saint-Louis for 10-year floods at the 2011, 2030 and 2080 horizons

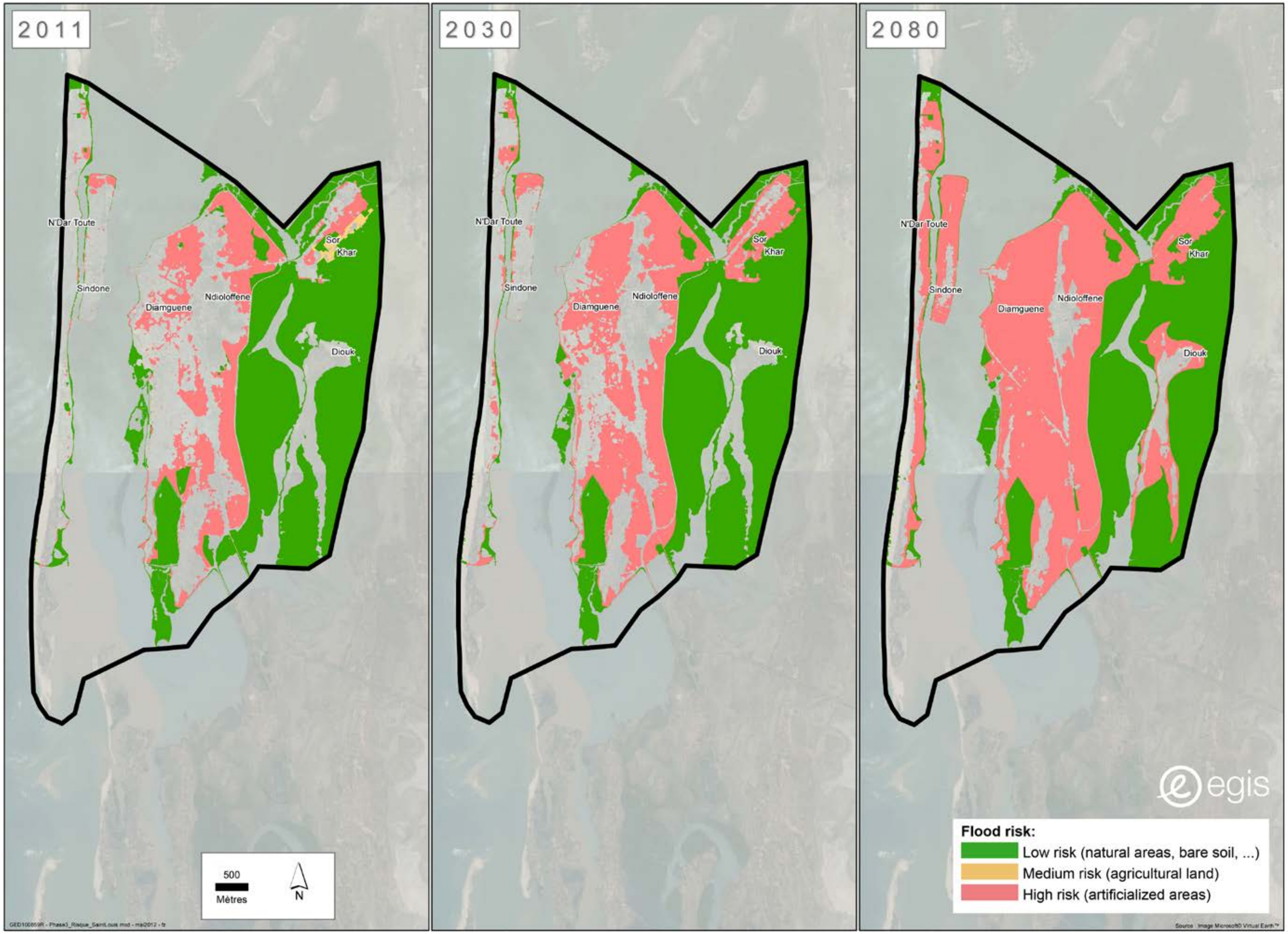
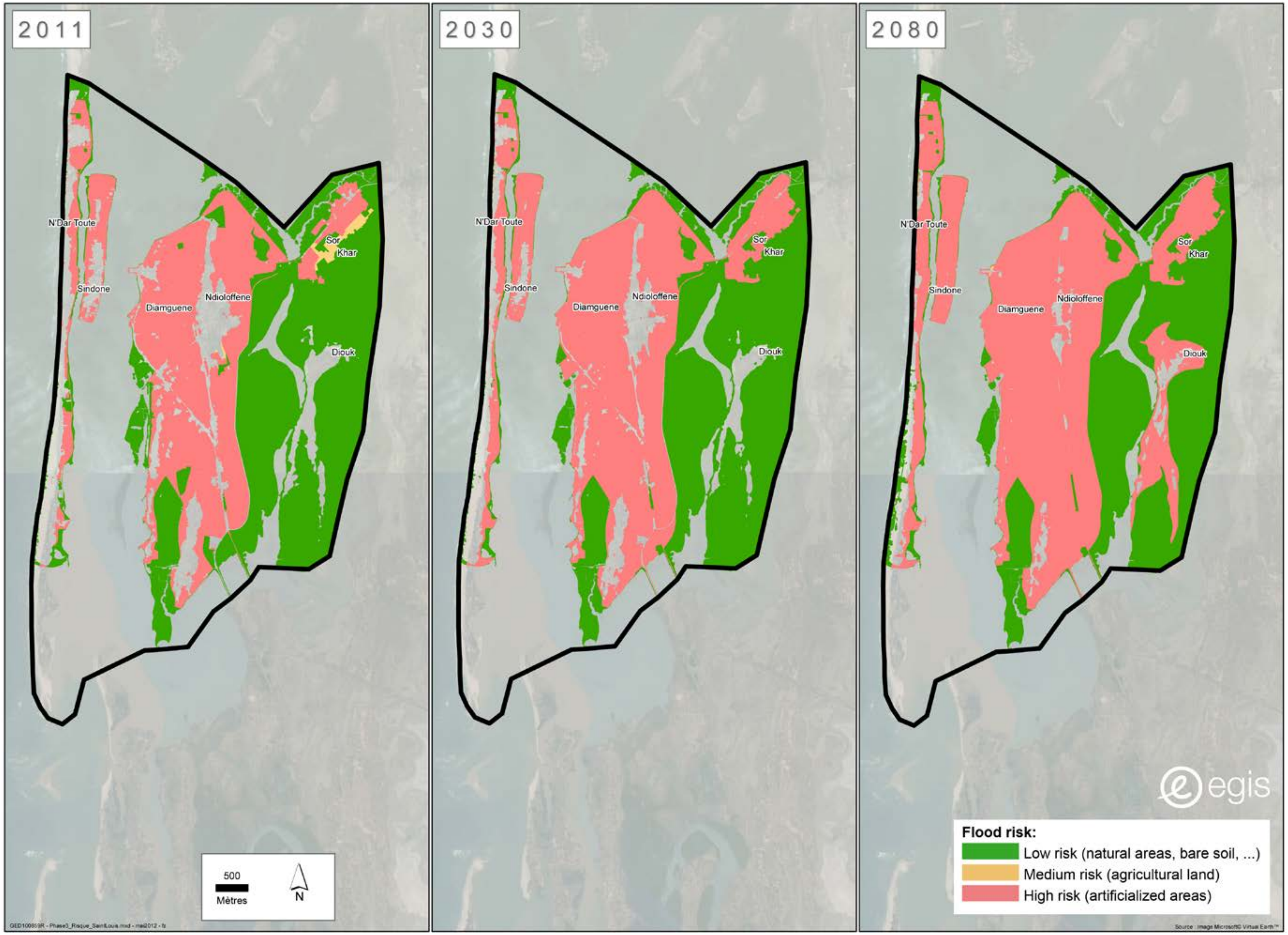


Figure 20: Flood risk in Saint-Louis for 50-year floods at the 2011, 2030 and 2080 horizons



At the 2080 horizon, most of the urban area is flooded (80%), and only few older neighbourhoods stay out of the water (for instance, Ndiolofene). Most of the N'Dar island is flooded. The eastern side of the Barbarie spit of land, along the river, is also flooded.

For exceptional floods (return period of some 50 years), the current situation is similar to that obtained for 10-year floods at the 2080 horizon, with most of the city being flooded (77% of the urban fabric and 62% of the other artificialized areas). At the 2030 horizon, we see a moderate increase in the flooded surface area, which is already high at the 2011 horizon. 83% of the urban fabric is flooded. At the 2080 horizon, floods almost cover the entire city (92%), including the older neighbourhoods. The entire N'Dar island is flooded.

In the current situation, floods due to a 'relatively frequent' (10-year) flood are already worrying and affect inhabited areas in the lowest neighbourhoods. Sea level rise worsens the flooding conditions: at the 2030 horizon, over half of the city is submerged during 'relatively frequent' floods. At the 2080 horizon, the situation becomes catastrophic, since most of the city is submerged.

In that context and given the long flooding duration when a flood arises, the main action proposed aims at reducing the flood flows passing through Saint-Louis, so as to make sure that levels remain acceptable despite sea level rise, while maintaining the presence of the river at the level of Saint-Louis. Hydraulic developments could enable to reach such objective: creation of **flood spillways** (lateral spillways) to over-flood some of the existing flood expansion areas; **rewatering of some of the former arms,** or even of ancient outlets located north of Saint-Louis. The technical and economic assessment of these options will require additional studies.

At **Rufisque and Bargny,** the flooding issue is only related to rainfall (run-off and overflow of systems). Two parameters must be considered when analyzing the impact of climate change on floods: rainfall and sea level. At Rufisque, in 2030, the Western canal will be permanently flooded by the sea until the main road (RN1). In 2080, certain areas bordering the canal will be permanently flooded. Therefore, this canal will no longer be able to effectively play its storm water discharge role in its current configuration, i.e. by gravity. At Bargny, in 2080, the areas located below water level will have become permanent lagoons or sea-covered areas. Coastal configuration will be modified, with the likely continuation of shoreline recession. The bed of the Bargny backwater will be permanently flooded almost from the RN1 road. Some of the neighbourhoods located along the backwater will also be flooded. During rainy periods, an extension of flooded areas in the Bargny neighbourhoods located south of the RN1 road is thus foreseeable, in combination with sea level rise.

Currently, the discharge capacity of the existing canals is unknown, and in particular the protection level. Frequent floods are observed during the rainy season. Urban development is one of the factors that certainly contributed the most to flood aggravation and to the issues related to waste collection. The **adaptation actions** that may be envisaged are the following: preservation of the flowing and drainage channels, in particular the bed of the Bargny backwater; implementation of a waste collection scheme to improve the efficacy of the storm water drainage system; continuation of the wastewater collection and wastewater/storm water segregation programmes; taking into account of storm water drainage constraints in the development of new neighbourhoods; continuation and intensification of the canal cleaning programme before and after the rainy season; drafting of a sewerage master plan taking into account the new assumptions regarding rainfall and sea level, etc. Inasmuch as possible, priority should be given to solutions enabling gravity flow, but the installation of pumps must be foreseen as sea level rises, due to the low altimetry of the part of the town that is the closest to the coastline.

Photo 5: Drainage canal in Rufisque, cluttered with deposits (sand, refuse, waste water)

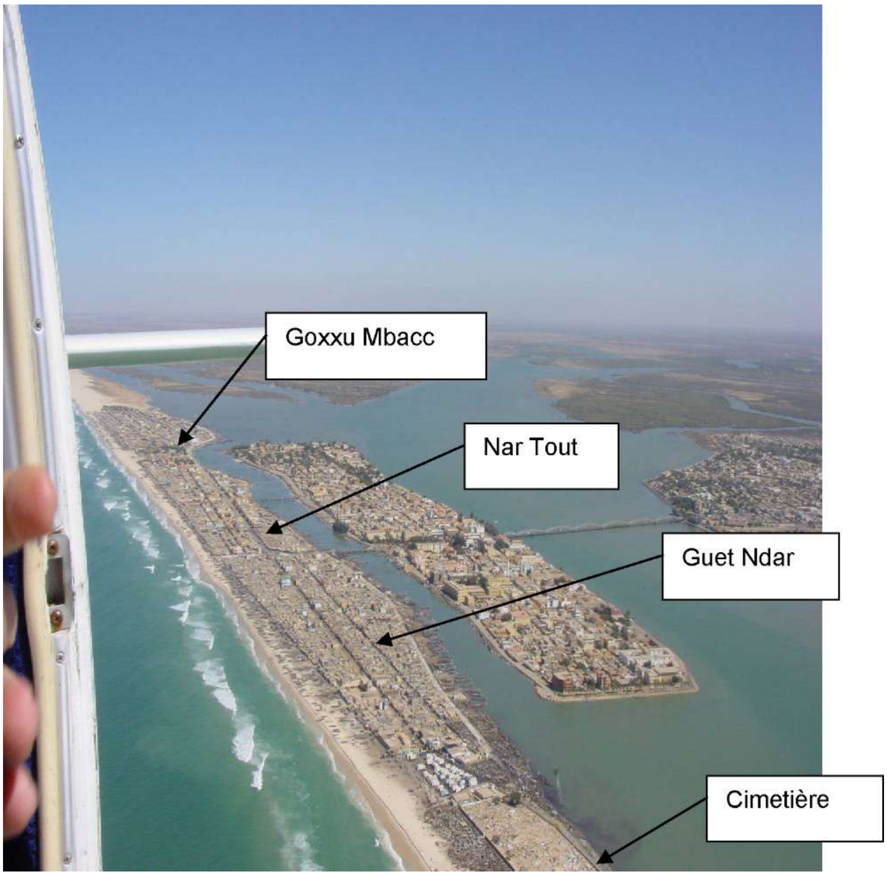
Last, in the **tourist resort of Saly,** floods due to storm water run-off are not currently a priority concern compared to the impact of shoreline recession and to the risks of marine submersion. However, the existing backwater is facing a worrying situation since its bed is progressively narrowing due to urbanization. Sea level rise and the increase in heavy rain frequency could lead to floods in both the lower and the most densely urbanized sectors. The adaptation measures are the following: restoration and preservation of the backwater's bed; taking into account of climate change parameters in the master plans for storm water drainage; construction of systems aiming at avoiding the concentration of flows; building prescriptions enabling to reduce the buildings' vulnerability to floods in the lowest sectors.

3.7. MARINE SUBMERSION RISKS ALSO WORRYING AT SAINT-LOUIS, THE OTHER SITES BEING MOSTLY CONCERNED BY EROSION RISKS

The situation at the three sites studied shows the following trends. In **Saint-Louis,** shoreline evolution at the Barbarie spit of land has formed the subject of many diagnosis studies, and numerous recent and older observations show that **the overall trend in the distal part of the Barbarie spit of land is erosion.** The seafront side of the neighborhoods of Saint-Louis is currently experiencing severe damage during exceptional storms combined with high sea level. And though it is difficult to say if these storms are more frequent today than before because of climate change, their impact is felt more severely on the backshore since the anthropic developments (houses, walls, fishing quays) are now being hit by the waves, thus simultaneously leading to an increased beach erosion (beach profile decrease by reflection) and the destruction of dwellings. The three urbanized neighborhoods are alternatively affected by storm swell, but it has not yet been possible to correlate the hydrodynamic conditions during storms and the neighborhood affected. The most recent storm (March 2010) had more affected the neighborhoods of Guet Ndar and Goxxu Mbacc, whereas in April 2008, it had only been Goxxu Mbacc. To the south of Guet Ndar, although the sea might entirely invade the uncovered beach during exceptional storms associated to high sea level, it seems that the beach is wide

enough to absorb the action of swell. Existing infrastructures (*Hydrobase* housing development, cemetery, hotels, etc.) have no negative impact on shoreline evolution. There is no obvious sign of shoreline recession in that sector: a dynamic beach balance seems to continue.

Photo 6: View of the northern part of the Barbarie spit of land and of the Ndar island (Source: DEEC)



The **impact of the diversion canal** of the Senegal river (breach created in 2003) on shoreline evolution is obvious. However, this raises two issues, which are of importance for coastal erosion in the southern part of the Barbarie spit of land, but for which is it difficult to give final answers: will the breach continue to widen? Will it continue to migrate southwards? Whatever happens, though this evolution of the mouth of the Senegal river influences shoreline evolution at the Barbarie spit of land, south of the breach, it has no significant impact on the northern shore of the spit of land since hydrodynamic conditions favor a positive balance of sediment transit going from North to South.

Cartographic elements taken from various studies of coastal evolution in Saint-Louis show a **chaotic variation of the shoreline.** Though it is undeniable that today, shoreline is undergoing recession in urbanized areas after each major storm (subsidence and dwelling destructions testify to that - see Photo 7), it is not possible to precisely quantify such recession.

Photo 7: Damage caused by a storm in the Gokhou Mbathie neighbourhood in 2008 (Source: DEEC)

As regards submersion, the sea level rise induced by climate change, estimated to be of 20 cm at the 2030 horizon, will have no impact on the shoreline due to the altimetry of the backshore. Only the lowest areas on the left side of the Senegal river will be more impacted than in the current situation if the existing roads fail to block water propagation. The estimated mean sea level rise of 80 cm at the 2080 horizon could lead, at extreme water levels, to water flowing over a part of the low area located north of Goxxu Mbacc. Besides, at the level of urbanized areas, a major width of uncovered beach would be under water. Further south, from the Fishermen's Cemetery, the beach widens and sea level rise has almost no impact. On the other hand, in the Senegal river, this 80 cm rise would lead to a significant increase in the flooded areas if roads fail to block water propagation.

During storms, the flooding effects of a 100-year storm surge at the 2030 horizon, which would lead to a water level of +2.02 m MSL (excluding run-up), seem more or less intense. The possible impact it might have on the Goxxu Mbacc neighbourhood, where local overflows could favor the submersion of the lower areas at the back, should be highlighted. **In 2080,** with a water level of +2.62 m MSL (excluding run-up) **for a 100-year storm, the largest part of the urbanized coastline (Goxxu Mbacc, Ndar Tout and Guet Ndar) would *a priori* be flooded** (see Figure 21).

Figure 21: Submersion hazard at the 2080 horizon for a 100-year storm on the coastal section of Saint-Louis locate at the level of the highly urbanized area

At **Rufisque/Bargny,** the erosion speed seems particularly high, in the region of 1 m per year. This evolution is related to a deficit in sediment supply in the coastal area, to anthropic actions and to sea level rise. Such evolution of the shoreline has led, since the 80s, to the construction of **protective structures** along the coastline of Rufisque.

Photo 8: Protection dike in Rufisque

In the long term (2080 horizon), west of Rufisque, shoreline recession will mostly affect sandy shores, and not so much coastal developments. However, it can be noted that the southern edge of the land plot occupied by the thermal power plant will face a certain recession if no protection measures are implemented. Erosion on the eastern and western sides of the Muslim cemetery of Diokoul and a few dwellings back of the current protection granted by the vertical wall will be very clear and will thus have a greater impact on current developments. Due to shoreline recession, the grounding areas of the small boats of Keuris Souf should disappear, leading to a major issue for that traditional activity. East of the Thiawlène cemetery, shoreline erosion will be higher. This will have a major impact on the land plot of the Bata plant (if no adaptation measures are implemented) and then, on the adjoining land plots further south. In this respect, the wetlands between the Bata plant and Bargny would become 'marine' because of their altimetry. And it is likely that the new shoreline will be further inland, very close to the road. **At Bargny, on the contrary, shoreline recession will have a great impact:** a major line of houses located in Bargny and isolated houses further East, built at the top of the current beach, would disappear.

Figure 22: Erosion hazard area on the shore of Bargny at the 2030 and 2080 horizons (in yellow and red, respectively)

As regards submersion, the effects of a 100-year storm surge at the 2030 horizon are *a priori* very limited. The impact remains relatively low at the 2080 horizon for a water level of +2.32 m MSL (excluding run-up). Along the coastline, which is protected by longitudinal obstacles, water does not submerge the structures. And along the sandy shorelines, the sea floods the uncovered sections of the beach, but not the backshore (except temporarily if run-up enables overflows, but it is not possible to determine this globally). Only the backwaters of Bargny seem to be flooded by sea waters flowing over the barrier beach, since overflow points are not precisely defined. We also note that only waterways or storm water discharge canals might be invaded by sea water moving up their beds.

Last, **at Saly, the shoreline is currently undergoing major recession,** a situation which is threatening the hotel infrastructures and activities, the second homes and the village. Such evolution has become a critical issue since the development of the tourist resort in the 80s, which led to a strong increase in land use, especially along the shore. Today, several groin-type structures and many longitudinal works made of riprap or gabions have been built. A shoreline protection project involving submerged breakwaters is in progress.

Photo 9: View of the coastline in front of the Téranga hotel in Saly. The beach has disappeared and the beach-top is protected by a riprap dike

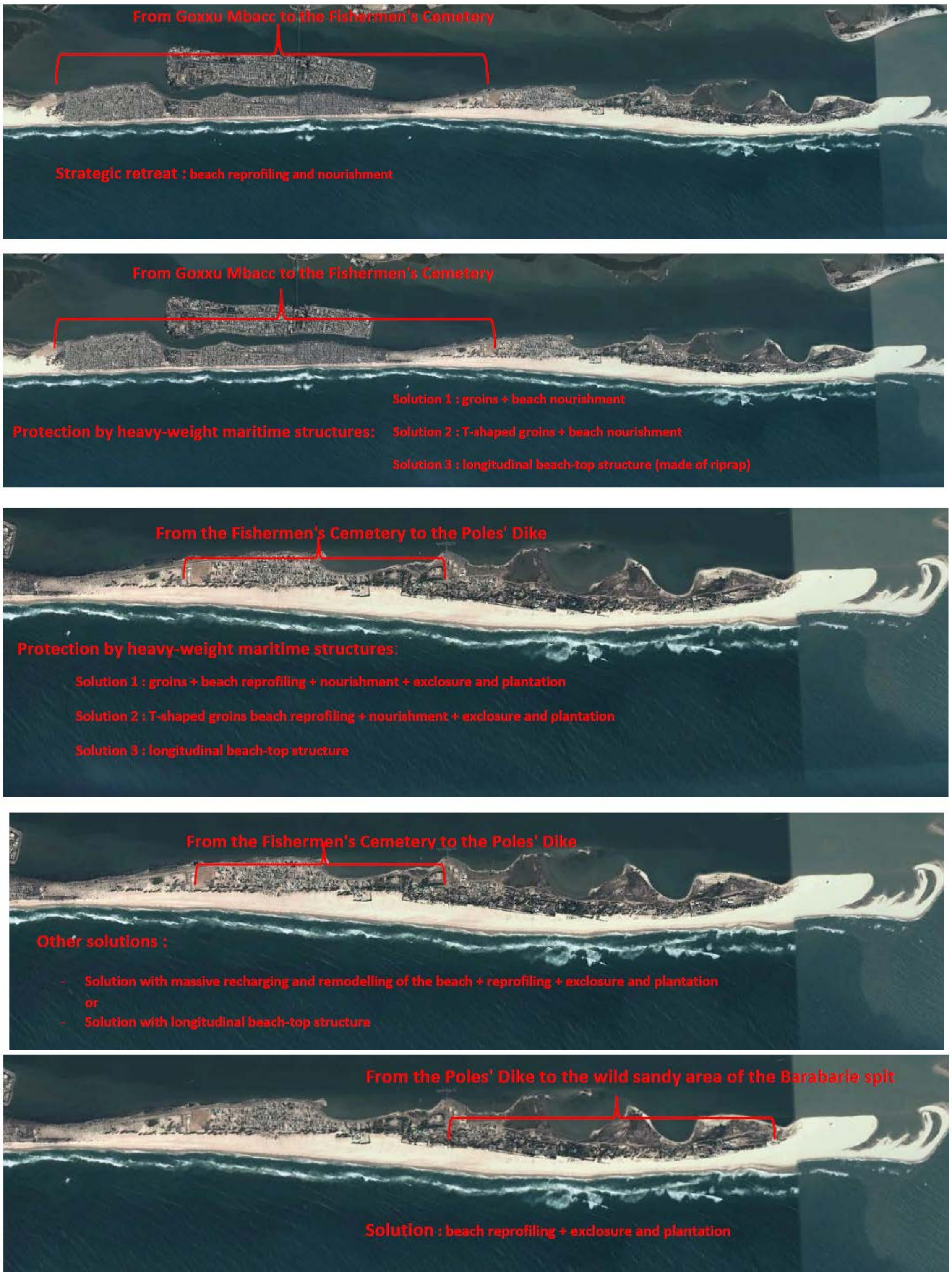
3.8. VARIOUS POSSIBLE SCENARIOS FOR COASTAL PROTECTION

For the three pilot sites, **adaptation measures have been proposed.** The analysis of the future trends of the respective shoreline of each site, stemming from the diagnosis analysis of the coastal evolution, has enabled to determine the coastline's sensitivity to hazards at the 2030 and 2080 horizons. With regards to the future trends of the shoreline, to the sensitivity of the coastline to erosion and submersion hazards and to coastal morphology, **protection and/or development proposals were made, bearing in mind that these are only indicative and their cost approximative** in the absence of specific detailed studies regarding the local hydrodynamic, sedimentological and morphological parameters. Furthermore, it should be noted that the purpose of this report is first and foremost to assess the investments that should be foreseen in terms of protection against natural risks and climate change, so as to use them in the economic analysis. Nevertheless, 'soft' measures, which have a low or negligible cost, such as regulatory, urban planning or institutional measures, have been discussed in Phase 4 of the study.

The shoreline of Saint-Louis has been subdivided into three sections, taking into account land uses and occupation. Adaptation proposals were made for each of these sections. At the level of the urbanized sector of the Barbarie spit of land, the recommended measure is a **strategic retreat**, together with the construction of **heavy-weight maritime structures** (groins,

T-shaped groins) or a **longitudinal beach-top structure** (made of riprap). Along the commercial/fishing shoreline (from the Fishermen's Cemetery to the Poles' Dike), in addition to the heavy-weight structures (groins, T-shaped groins), a **massive recharging** is also suggested. Finally, for the rest of the 'used' shoreline of the Barbarie spit of land, a **beach reprofiling with protective devices** is proposed. The figure below presents the various protection options studied.

Figure 23: Protection options for the coastline of Saint-Louis



At Rufisque, the coastline is almost entirely artificialized by longitudinal beach-top structures (riprap, concrete walls) that are heterogeneous and often not very effective due to their under-dimensioning. To face the effects of climate change, a **strategic retreat** of the entire urbanized shoreline would enable to retrieve the swell-dampening foreshore. The creation of an **artificial beach** through massive recharging and the construction of a breakwater toe would also enable to regain the coastal beach. The **restoration of the existing structures** and the homogenization of the protective structures, after a dimensioning adapted to the future situations, are also among the possible solutions. The figure below presents the various protection options studied.

Figure 24: **Protection options for the coastline of Rufisque-Bargny**

At Bargny, the coastline has no protection structure, except at the extreme south of the municipal territory, where a few hundred meters of artificial and/or natural longitudinal protective structures can be found in areas that have now returned to a natural state; **new constructions must be banned** in that area. At the level of the urbanized area built directly on the backshore, a **strategic retreat** would enable to respond to sea level rise but would lead to the destruction of the closest dwellings. Solid structures (**breakwater or longitudinal beach-top walls**) would enable to respond to the impacts of sea level rise by maintaining the dwellings, but they would artificialize the site and would require regular maintenance and sand recharging. In the rest of the urbanized area, further away from the shoreline, **backshore modelling and sand recharging** might offer short- and medium-term protection against sea level rise, in particular during storms. At the extreme south of the study area, since the very close sea has already destroyed a certain number of dwellings, which are not numerous along the shoreline, the construction of protection solutions is not justified. The only solution is a strategic retreat. The figure above presents the various protection options studied.

For the municipal territory of Saly, adaptation solutions range from **massive sand recharging** in the sectors where beaches have entirely disappeared due to the maritime structures built over the past years (groins in transit upstream), to the construction of **heavy-weight groins or breakwaters** combined with sand recharging in the sectors that are most affected by erosion, or to the **creation of elevated artificial beaches**. A proposed solution is also to readapt, after a careful follow-up to assess its efficacy, the submerged breakwater that is due to be built in 2012/2013 along 1,500 meters of shore.

Figure 25: Protection options for the coastline of Saly

The three pilot sites have very different purposes, and more particularly Saly. Saly has a strong tourist vocation characterized by the presence of a great number of hotels along the shoreline. The coastline is characterized, on the one hand, by a few groin-type structures built to limit North-South coastal transit, and on the other hand, by gabions intended to minimize sand losses perpendicularly to the shore. At Saint-Louis, between Goxxu Mbacc to the North and the Fishermen's Cemetery to the South, and at Rufisque, urbanization is very dense next to the shoreline. But today, at Rufisque, the uncovered beach has almost disappeared from the urbanized coastline following the construction of 'solid' structures that are blocking the coastline, whereas at Saint-Louis, except for a very short section, the shoreline might further recess to the detriment of dwellings which will eventually collapse, once their foundations will have been undermined.

However, **a review of the various adaptation solutions proposed to control the effects of climate change shows that, in fact, they are identical**: strategic retreat, massive recharging, construction of heavy-weight maritime structures (groins, T-shaped groins, breakwaters, breakwater toe) and longitudinal beach-top structure. The choice of a given solution is first and foremost political and not financial, though this latter criterion is also important to rank solutions that are equivalent in terms of protection objectives. It should also be noted that, except for strategic retreat (which requires population displacement), the field surveys carried out within this study show the **good social acceptability** of the proposed measures, desired by the main populations concerned.

Beyond the recommendations specific to the pilot sites identified within this study, it should be reminded that - generally speaking - when facing erosion and/or marine submersion risk, **four options must be analyzed** according to land occupation and use:

- respecting natural evolution where issues do not justify any action, as for instance at Grande-Côte, between Kayar and the former mouth of the Senegal river;
- limited intervention in order to direct natural processes - for instance, flexible control of the evolution of coastal dunes through a reduction of wind action with several techniques (plantings, wind-shields, cover). Example of target area: southern part of the little-urbanized Barbarie spit of land;
- organizing the retreat of existing buildings behind a new natural or developed defence line (strategic retreat), as for instance on the coastline of Bargny (Miname neighborhood) or in Saint-Louis (1st line neighborhood such as Goxxu Mbacc);
- maintaining the shoreline (using solid or soft techniques): at Rufisque, in front of the hotels in Saly, for the cliffs in Dakar.

3.9. SUMMARY FOR EACH SITE

To complete the thematic analysis delivered above, it seemed appropriate to propose a summary for each pilot site, in order to have an **overview, for each site,** of the hazards, vulnerabilities, risks, protection measures and cost-benefit analysis of such measures. This information is presented **in the following tables.** The elements regarding the economic analysis are detailed in the next chapter.

A brief comparative analysis of the three sites is also proposed in Table 6.

Table 3: Summary for the pilot site of Saint-Louis

Characteristics of the studied territory	The studied territory covers 33.5 sq km and has 10 km of shoreline. In terms of land use, it corresponds to the **current agglomeration area**, and as such, it mainly comprises urban areas, plus a few remnants of agricultural land and mangroves. Since the city is located at the mouth of the Senegal river, water surfaces and foreshores submerged by the tides account for more than 60% of the study area. Saint-Louis has approximately 172,000 inhabitants. The main economic activity of the coastal area is fishing (in front of the urban area) and vegetable crop growing (in the Gandiolais area).
Hazards	At the 2030 horizon, **climate change** should lead to a mean temperature increase of approximately 1°C and to an increase in rainfall. In 2080, mean temperature rise could reach 3°C, but with a decrease in rainfall. **Sea level rise** due to climate change should be of 20 cm and 80 cm at the 2030 and 2080 horizons, respectively. Considering this accelerated sea level rise, we could reach a water level of +2.62 m MSL (excluding run-up) for a 100-year storm in 2080. In the absence of clear and consistent elements regarding the hydrological evolution of the Senegal river, we have considered that flood level at Saint-Louis will mainly depend on the evolution of sea level. For 'relatively frequent' floods (return period of some 10 years), the flood level mark could rise from 1.2 to 2 m NGS by 2080. For 'exceptional' floods (return period of some 50 years), the flood level mark could rise from 1.8 to 2.6 m NGS by 2080.
Evolution of urban vulnerabilities	The development of urban areas is limited by geographical constraints imposed by the Senegal river and the ocean. Hence, urban growth will mainly take the form of densification.
Risks	In the absence of a significant underground resource and of groundwater production infrastructures in the Saint-Louis sector, sea level rise and rainfall decrease should have no significant impact on water resources. The city of Saint-Louis is, by far, the main agglomeration threatened by river floods in Senegal. In the current situation, floods due to a 'relatively frequent' (10-year) flood are already worrying and affect inhabited areas in the lowest neighborhoods. Sea level rise worsens the flooding conditions: at the 2030 horizon, over half of the city is submerged during 'relatively frequent' floods. At the 2080 horizon, the situation is catastrophic, since 80% of the city is submerged. With sea level rise, which hampers the discharge of floods, **the 10-year floods in 2080** will be comparable to the current 50-year floods and **could affect 150,000 inhabitants**, instead of 54,000 in the current situation. The seafront side of the neighborhoods of Saint-Louis (Goxxu Mbacc, Ndar Tout and Guet Ndar) is currently experiencing **severe damage during exceptional storms** combined with a high sea level. And though it is difficult so say if these storms are more frequent today than before because of climate change, their impact is felt more severely on the backshore since the anthropic developments (houses, walls, fishing quays) are now being hit by the waves, thus leading simultaneously to an **increased beach erosion** (beach profile lowering by reflection) and the destruction of dwellings. The effect of the diversion canal made on the Senegal river (breach created

	in 2003) on shoreline evolution is obvious, but it has no significant impact on the northern shore of the spit of land since hydrodynamic conditions favor a positive balance of sediment transit going from North to South. **In terms of submersion**, sea level rise due to climate change could lead, in times of high water, to the overflow of a section of the low area located to the north of Goxxu Mbacc in 2080. During storms, the effects of a 100-year storm surge at the 2080 horizon would lead to the flooding of most of the urbanized coastline, affecting **approximately 1,000 dwellings and 8,000 inhabitants**.
Proposed measures	The main measures proposed aim at **reducing the flood flows passing through Saint-Louis**, to make sure that levels remain acceptable despite sea level rise. Reaching such objective will require the creation of flood spillways (lateral spillways) to over-flood some of the existing flood expansion areas; the rewatering of some of the former arms, or even of some ancient outlets located north of Saint-Louis. As regards the measures to control coastal erosion and marine submersion, **the coastline of Saint-Louis has been subdivided into three sections**, according to land occupation and uses. At the level of the urbanized sector of the Barbarie spit of land, the recommended measure is a strategic retreat, together with the construction of heavy-weight maritime structures (groins, T-shaped groins) or a longitudinal beach-top structure (made of riprap). Along the tourist/fishing shoreline (from the Fishermen's Cemetery to the Poles' Dike), in addition to the heavy-weight structures (groins, T-shaped groins), a massive recharging is also suggested. Finally, for the rest of the 'used' shoreline of the Barbarie spit of land, a beach reprofiling with protective devices is proposed.
Cost-benefit analysis	**The economic analysis only concerns coastal protection measures**, since those related to the floods of the Senegal river are impossible to evaluate without in-depth studies. The net present costs in 2080 due to marine submersion for the municipal territory of Saint-Louis amount to approximately FCFA 12.3 billion (USD 24.6 million). The cost of the most favorable adaptation scenario amounts to FCFA 7.76 billion (USD 15.52 million), thus leading to **a positive balance of FCFA 4.54 billion (USD 9.08 million), i.e. a benefit-cost ratio of 0.63**.

Table 4: Summary for the pilot site of Rufisque-Bargny

Characteristics of the studied territory	The site of Rufisque-Bargny **covers some 45 sq km**, with 12 km of shoreline, and is located at the outskirts of Dakar. Since it is close to the capital city, it is a highly urbanized site, with 238,000 inhabitants, but large areas remain natural further away from the shoreline. The site is also characterized by a large vegetable crop growing activity and a few **industrial plants**. Along the shoreline, we can also see traditional neighborhood which were first inhabited by the Lebou people (fishermen).
Hazards	At the 2030 horizon, **climate change** should lead to a mean temperature increase of approximately 1°C and to a slight increase in rainfall. In 2080, mean temperature would rise by 2 to 2.5°C, but with a decrease in rainfall. At the northern edge of the site, due to the likely decrease in mean rainfall, the **fresh water resource** located in the quaternary sands could decrease by 1 to 2 meters at the 2080 horizon. **Coastal erosion** speed seems particularly high, in the region of 1 m per year. Considering this accelerated sea level rise, we could reach a water level of +2.32 m MSL (excluding run-up) for a 100-year storm at the 2080 horizon.
Evolution of urban vulnerabilities	This pilot site is the one **where vulnerabilities should increase the most** (57% growth of the residential urban fabric between 2011 and 2080), notably because of the proximity to the capital city, of the growing dynamics of those two urban centers and of the availability of natural areas (savannah, forests, etc.) to absorb such growth. And since the coastal strip is almost entirely urbanized, such growth will mainly move towards the hinterland.
Risks	The likely lowering of the water table in the long term, in connection with rainfall decrease, will have no direct consequence on the pilot zone since this resource is not exploited, nor intended to be exploited, as it is already overexploited in the surroundings. Here, the flooding issue is only related to rainfall (run-off and overflow of systems). At Rufisque, in 2030, the Western canal will be permanently flooded by the sea until the main road (RN1). Therefore, it will no longer be able to effectively play its storm water discharge role by gravity. At Bargny, in 2080, the areas located below water level will have become permanent lagoons or sea-covered areas. Some of the neighborhoods located along the backwater will also be flooded. During rainy periods, an extension of flooded areas in the neighborhoods of Bargny located south of the RN1 road is thus foreseeable. **The major erosion** of the shoreline has led, since the 80s, to the construction of protective structures along the coastline of Rufisque. The unprotected sectors, and more particularly **the first lines of dwellings of Bargny, should disappear by 2080**. This would affect some 300 buildings, of which 250 dwellings housing a population of 2,250, at that horizon. **In terms of submersion**, on the basis of simulations carried out from available DTMs, the effects of a 100-year storm surge at the 2030 horizon are *a priori* very low. The impact remains relatively **low at the 2080 horizon**. Only the backwaters of Bargny seem to be flooded by sea water flowing over the barrier beach.
Proposed measures	The control of run-off floods is mainly based on the preservation of the flowing and drainage channels (in particular, the bed of the Bargny

	backwater), on the implementation of a waste collection scheme to improve the efficacy of the storm water drainage system, and on the continuation of the wastewater collection and wastewater/storm water segregation programmes. The installation of pumping systems for water discharge must be foreseen as sea level rises. To face the effects of sea level rise, a **strategic retreat of the entire urbanized shoreline** would enable to retrieve the swell-dampening foreshore. The creation of an artificial beach through massive recharging and the construction of a breakwater toe would also enable to regain the coastal beach. At Rufisque, the restoration of the existing structures and the homogenization of the protective structures, after a dimensioning adapted to the future situations, are also among the possible solutions.
Cost-benefit analysis	The net present costs in 2080 due to marine submersion and coastal erosion at Rufisque-Bargny amount to approximately FCFA 14.2 billion (USD 28.4 million). **All the adaptation solutions proposed lead to an amount much higher than the cost of material damage and economic losses.** The cost-benefit balance of the least expensive solution is thus negative by FCFA 8.5 billion (USD 17 million). In that case, warning system implementation, population information and the provisioning of funds for the relocation of victims of disasters seem to be a more appropriate solution, since it is much more cost-effective.

Table 5: Summary for the pilot site of Saly

Characteristics of the studied territory	The site of Saly covers **some 4.5 sq km**, with 7.5 km of shoreline, and is located to the north-west of Mbour. This site is mainly **a beach resort**, comprising beachfront hotels and residential areas. But the fishing village persists.
Hazards	At the 2030 horizon, **climate change** would lead to a mean temperature rise slightly higher than on the other sites, but still of approximately 1°C. On the other hand, rainfall would very slightly increase. In 2080, mean temperatures would increase by 2 to 2.5°C, with a rainfall decrease *a priori* lower than at the other sites. **Water table lowering** due to climate change could be in the region of 0.05 m/year. **Coastal erosion** speed is very high, in the region of 6 m/year, in the most exposed sectors. Considering this accelerated sea level rise, we could reach a water level of +2.32 m MSL (excluding run-up) for a 100-year storm at the 2080 horizon.
Evolution of urban vulnerabilities	This tourist site **has seen a very strong urban evolution**, which is likely to continue and densify (+15% of artificialized surfaces at the 2080 horizon). Due to the tourist purpose of this sector, the areas that should develop the most are located close to the shoreline, in particular in the western part of the site.
Risks	Unlike at the other sites, **the impact of climate change on groundwater resource becomes perceptible at Saly**, which is supplied by the boreholes of Saly Portudal. However, the extent of such impact should be relativized, since it would be in the region of one tenth of the current overexploitation.

	The risk of storm run-off floods is currently low. However, the existing backwater is facing a worrying situation, since its bed is progressively narrowing due to urbanization. **The shoreline is currently undergoing major recession**, a situation which is threatening the hotel activities and infrastructures, the second homes and the village. Such evolution has become a critical issue since the development of the tourist resort in the 80s, which led to a strong increase in land use, especially along the shore. Today, several groin-type structures and many longitudinal works made of riprap or gabions have been built. A shoreline protection project involving submerged breakwaters is in progress. **By 2080, with just the forecast sea level rise, 60% of the current beaches could disappear**.
Proposed measures	To prevent run-off flooding issues, it is advised **to restore and protect the bed of the backwater**, to take into account climate change in the drainage master plan, and to avoid flow concentration in the future developed areas. The **adaptation solutions to sea level rise** range from massive sand recharging in sectors where beaches have entirely disappeared to the construction of heavy-weight structures such as groins or breakwaters combined to sand recharging in the sectors most affected by erosion. But only the creation of artificial beaches elevated with respect to the current shore, to take into account a sea level rise of 80 cm by 2080, will enable to preserve the current beaches, and thus to balance all the losses and damage induced by such rise.
Cost-benefit analysis	The net present costs in 2080 caused by temporary or permanent marine submersion (due to storm surge or to sea level rise, respectively) amount to approximately FCFA 10 billion (USD 20 million). The **creation of elevated artificial beaches** leads to a neutral economic balance (cost equal to the avoided damage).

Table 6: Brief comparison of the three pilot sites

Site	Nature of long-term hazards (2080)	Risk assessment	Proposed measures	Cost-benefit analysis *
Saint-Louis	**Temperature increase** (+3°C) and decrease in annual rainfall. **Sea level rise** by 80 cm and storm surge of +2.62 m MSL for a 100-year storm, aggravating the coastal erosion and marine submersion phenomena. In the absence of clear trends regarding the evolution of floods, water level at Saint-Louis mainly aggravated by sea level rise. No expected decrease in the level of the water tables linked to the Senegal river.	Main risk: **aggravation of river floods** because of sea level rise (10-year flood in 2080 equivalent to a current 50-year flood). Barbarie spit of land highly threatened by **coastal erosion and marine submersion**, in particular the neighborhoods of Goxxu Mbacc, Ndar Tout and Guet Ndar.	Reduction of the flood flows passing through Saint-Louis by means of upstream water retention or water diversion. Option proposed for the **protection of the Barbarie spit of land**: protection groins + sand recharging in the northern section; ibid. + beach reprofiling in the central section; beach reprofiling and protective devices in the southern section.	The option proposed is the most cost-effective, with a **benefit/cost ratio of 0.63**. A strategic retreat (displacement of exposed neighborhoods) would be preferable, but much less cost-effective.
Rufisque-Bargny	**Same overall trends as for Saint-Louis**, but with a lower temperature increase (between 2 and 2.5°C). Storm surge for a 100-year storm lower that at Saint-Louis, but still considerable (+2.32 m MSL). No river issue, but storm water drainage issues aggravated by sea level rise.	Main risk: **coastal erosion, especially at Bargny**, where the first lines of dwellings would disappear. **river floods** due to the overflow of systems in several neighborhoods. No risk associated to the lowering of the water table, since it is no longer exploited nor intended to be exploited.	**Three coastal protection options**: strategic retreat, heavy-weight maritime structures, and adaptation of the existing beach-top structures. For the **improvement of storm water drainage**: preservation of the flowing and drainage channels; implementation of a waste collection scheme;	**None of the proposed options has a positive economic balance**, and the strategic retreat is the most expensive.

	Likely decrease by 1 to 2 meters of the fresh water resource located in the quaternary sands.		continuation of the wastewater collection and wastewater/storm water segregation programmes.	
Saly	**Same overall trend as at the two other sites**, with a temperature increase comparable to that of Rufisque-Bargny. Generally speaking, hazards similar to that of the Rufisque-Bargny site, due to the geographic proximity. However, water table lowering could be twice higher.	Main risk: **coastal erosion, all the more since the current beaches are used by the tourism industry.** 60% of those beaches, which had already experienced recession over the past years, could disappear at the 2080 horizon. Low risk of river flood. Tangible impact of climate change on the water resource, but still low compared to the current overexploitation.	Adaptation solutions to sea level rise ranging from massive sand recharging in sectors where beaches have entirely disappeared, to the construction of heavy-weight structures such as groins or breakwaters combined to sand recharging in the sectors most affected by erosion. Recommended option: **creation of elevated artificial beaches with breakwater toe.**	The recommended option has a **neutral economic balance** (cost equal to the avoided damage).

* Regards only measures to protect the coastline against coastal erosion and marine submersion.

4. ECONOMIC ANALYSIS OF NATURAL RISKS AND CLIMATE CHANGE

Take-away messages

- This study proposes a structured and in-depth cost-benefit analysis of the options for climate change adaptation. This analysis was used to calibrate an economic model provided to the authorities so as to enable them to replicate and update the results of this study and to use the analysis method at other sites.
- The economic analysis is based on the evaluation of direct and indirect costs (damage and economic losses, respectively) induced by natural risks and climate change. In order to take into account the probability of occurrence of natural risks, the damage and losses have been expressed in mean annual cost and summed up to obtain the net present cost (NPC) in 2080.
- At Saint-Louis, the net present cost in 2080 of river floods would reach FCFA 818 billion (USD 1.636 billion), i.e. almost 13% of the national GDP for 2010.
- Always at Saint-Louis, the net present cost in 2080 due to marine submersion would amount to approximately FCFA 12.3 billion (USD 24.6 million). The cost of the most favorable adaptation scenario with respect to the marine submersion risk would amount to FCFA 7.76 billion (USD 15.52 million), thus leading to a positive balance of FCFA 4.54 billion (USD 9.08 million).
- For Rufisque-Bargny, the net present cost in 2080 due to marine submersion and coastal erosion would amount to approximately FCFA 14.2 billion (USD 28.4 million). All the adaptation solutions proposed have a total cost much higher than the costs of material damage and economic losses, because of the low economic value of the assets they aim at protecting.
- At Saly, the net present cost in 2080 due to marine submersion would amount to approximately FCFA 10 billion (USD 20 million). The recommended adaptation option (creation of elevated artificial beaches) would lead to a neutral economic balance (cost equal to the avoided damage).
- If we extrapolate to the entire coastline the results of the economic analyses carried out at the pilot sites, we can obtain an estimate of FCFA 1,550 billion (USD 3.1 billion) for the total cost of the main natural risks affecting the Senegalese coastline (coastal erosion, marine submersion, river floods), expressed in net present cost in 2080, i.e. the equivalent of one fourth of the GDP of 2010 and approximately 35% of the GDP of the coastal area for the same year.
- The health cost of climate change on the coastline (malnutrition, malaria, diarrheal diseases, etc.) would be in the same order of magnitude.

Up to now, the Senegalese shoreline had formed the subject of a certain number of studies regarding its vulnerability to climate change, but none of these had tackled the issue of the cost-benefit analysis of the adaptation measures in a structured and in-depth manner. This part was thus performed with the greatest care, and **one of the main objectives of the study was to design an economic and financial model of the adaptation options at the pilot sites.** This model was submitted to the authorities (Department of Environment and Classified Establishments of the Ministry of Environment), so that they may reuse it at other sites or update the economic analysis of this study. This economic model mainly aims at being used by the Ministry of Environment to guide and inform the other decision-making stakeholders at the local and national scale regarding their coastal planning and investment decisions. In this respect, **a training program** has been offered to a certain number of technical managers of the

Senegalese administration.[4]. This section discusses some of the educational elements, before describing the results of the study.

It should be emphasized here that the economic model designed has a double objective**:**

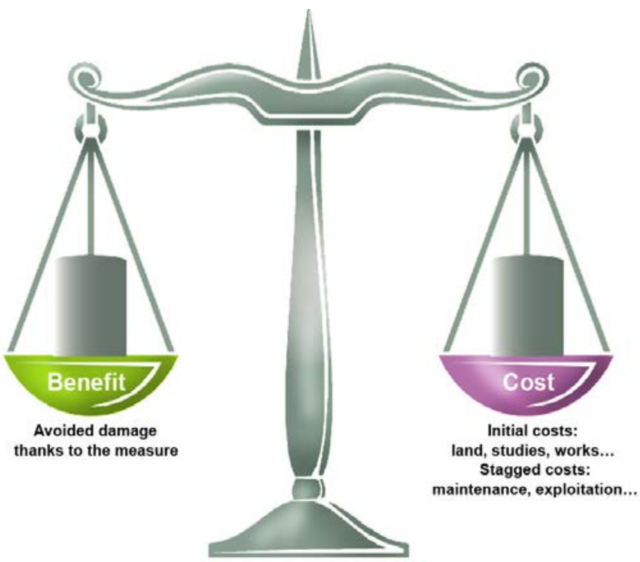
- To enable **the cost-benefit analysis** of the measures intended for climate change adaptation and for protection against natural risks;
- To provide the Senegalese authorities with a **multicriteria modelling tool** in order to prioritize future investments.

To serve this second objective, the economic model has been further developed and the main analysis parameters have been detailed, thus enabling potential users to prioritize certain criteria or use different input data.

4.1. PRINCIPLES AND OBJECTIVES OF THE COST-BENEFIT ANALYSIS

The measures already implemented by public authorities to reduce the risk of flooding, marine submersion or erosion enable to avoid a certain number of negative consequences when such events occur. Each of these measures, by reducing or eliminating potential damage, is thus likely to induce benefits for the wider society. These benefits can be expressed as **'avoided damage'** for the territory on which the measure has been implemented.

Figure 26: Principles of the CBA



On the other hand, such risk reduction measures always have a **financial cost**: study cost, investment cost, maintenance cost, etc., which might extend over long periods of time.

The analysis, which consists in comparing over time the benefits generated by a risk reduction measure and its implementation cost, sheds an important light on its economic relevance. This is the purpose of the **Cost-Benefit Analysis** (CBA).

Generally speaking, the CBA applied to risk reduction enables to evaluate the economic interest of risk reduction measures. The contractor may wish to benefit from an economic perspective regarding a specific measure or to compare several measures or variants of a given measure.

The CBA enables:

- **To better understand the exposure of the territory to the risk,** and the diversity and extent of the damaging consequences of potential disasters;
- **To feed consultation**: the CBA provides socio-economic data for discussions regarding vulnerability and implementation of a risk management measure;
- **To inform political decisions,** to support and promote the choices made: the CBA sheds an essential light which enables to better justify and improve transparency on decisions made.

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[4] Such training session was held on 11 and 12 December 2012 and gathered approximately twenty participants coming from some ten different public institutions and administrations.

- **To assist in the construction of a natural risk management strategy**: the CBA offer the possibility to compare several natural risk management measures and to assign priorities with respect to their respective preserved issues, avoided damage and economic relevance.

The performance of a CBA requires the design of physical models for the evaluation of hazards (natural phenomena likely to cause damage) and of an **economic model,** for the evaluation of damage and losses. The rest of this chapter describes the design principles of the economic model.

4.2. DESIGN OF THE ECONOMIC MODEL

4.2.1. General information regarding the design of the economic model

Five key principles govern the design of the economic model:

Money as a comparison tool: The CBA consists in evaluating the difference between the cost of a measure and the benefits it is likely to generate. A common unit of value is thus necessary. This unit is the currency, here FCFA. Therefore, the CBA is only able to give economic relevance information from data that might be evaluated in a monetary form. Different valuation methods might be used to assign a value to the damage and losses induced by the risks under consideration.

The comparison of two situations: with and without the adaptation measure. The benefit of a measure corresponds to the damage which is likely to be avoided if the measure is implemented. The evaluation of such benefit thus requires to consider two situations: an initial condition (without the measure) and a projected condition (with the measure that has been implemented). Ultimately, the benefit of the measure is the difference between the potential damage sustained by the territory in the projected condition and those sustained in the initial condition.

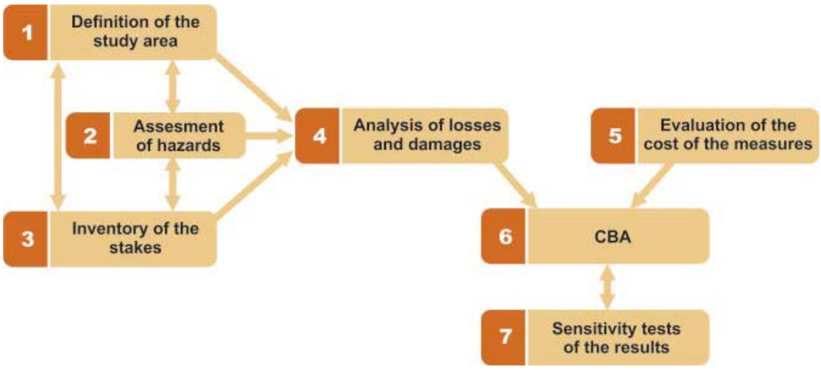
Multiple events to be taken into consideration: The cost-benefit comparison is all the more relevant if all possible situations are considered. For instance, it is preferable not to only take into account the specific flood for which the protection measure has been dimensioned, but also the case of more frequent and less frequent floods. Furthermore, the evolution in the characteristics of the hazards because of climate change has been integrated into the modelling of the various flood events.

An evaluation over time: A measure is (in general) intended to have effects over time. In such case, the benefits that might be expected are distributed over years or decades. The same applies to the costs of the measures (repair, maintenance, etc.). The CBA takes into account this spreading of costs and benefits. Their evaluation is performed over a strictly defined time period. This time period determines the 'time horizon' of the economic analysis. In this study, the time horizon is the year 2080. This principle requires to update the value of costs and benefits, because a CFA Franc of today does not have the same monetary value as in ten years. This discount operation consists in expressing all the various costs and benefits that are occurring at different dates in the monetary value of the same reference year.

A basic assumption regarding the evolution of the territory. Often, when performing a CBA, the territory is considered as invariable, i.e. it is assumed that the issues exposed to the risk do not evolve over time. The modelling performed within this study includes a territory evolution scenario designed on the basis of a projection of the current trends. In particular, this scenario includes the evolution forecasts regarding urbanization, built assets value and economic activity.

4.2.2. General information regarding the design of the economic model

Figure 27: The various steps of the model



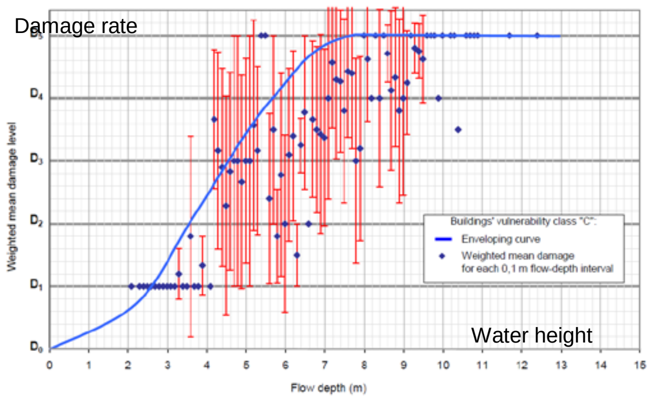
To perform the CBA on the study areas that have been defined **(1), the hazards considered were first modeled (2)** by taking into account the physical characteristics of the coastal areas and the influence of climate change. Such modelling was mainly based on simulations of the marine submersion or river flood levels, using the digital terrain models available for the three pilot sites (Saint-Louis, Rufisque-Bargny, Saly).

In parallel, **the issues and vulnerabilities present on every territory were mapped (3) ;** the study area was subdivided into large land use categories (urban fabric, cultivation, forest, etc.). A detailed study was performed to determine their geographic location. The review of already available data was complemented by a field survey intended to strengthen the knowledge of the exposed territory.

The crossing of the results of these two steps (determination of hazards, then identification and location of issues) enabled to highlight the **level of exposure** of the various issues (vulnerabilities) present at the three pilot sites. Notably, it enabled to assess the situation in terms of hydraulic parameters (water height, in particular). Such crossing was made using a geographical information system (GIS).

It is necessary to **express the impact of an event (e.g. flood) in monetary terms (4)** (for instance, estimating the material impact of a flood in a house or a company in FCFA). We call **direct damage or cost** the monetary expression of a negative impact on the assets. Such damage has also a clear negative impact on the economic activity of the area. We call **indirect losses or damage** the economic impacts induced by the damage.

Figure 28: Example of a damage curve



In a CBA, damage assessment requires the application of '**damage (or damaging) functions**'. These are functions defined for each issue, which associate to a specific event (e.g.: a 10-year flood) a damage amount and/or a damaging coefficient.

Damage or damaging functions are very diverse. Their application **first requires to collect certain characteristics associated with each issue** (e.g.: structural

characteristics of the built environment, nature of agricultural productions, etc.). The definition of such functions is a delicate and central task in the design of the economic model. The choice of damage or damaging functions is performed according to the information available. Within this study, functions have been designed for each land use category studied.

The investment and operating costs of the risk control measures have then been evaluated **(5).** The cost-benefit analysis has been performed by comparing such costs to the amounts of losses and damage avoided by the implementation of such measures **(6).** Given the uncertainties inherent to such type of evaluation, a review of the model has been carried out by means of sensitivity tests on the results **(7).**

The following table gives the elements required to take into account the damage functions according to the type of event considered.

Table 7: Main parameters of the risk evaluation for coastal natural risks

Elements of the total economic value	Marine submersion	Coastal erosion
Growing (vegetable crops)	Loss of annual productive value of the agricultural land and deterioration of the land improvements.	Loss of annual productive value of the area and destruction of the land plot.
Forestry or fruit tree planting	Loss of productive potential in the subsequent years due to soil salinization.	Cost for transferring the activity to another area. Loss of destroyed land and cost for the acquisition of the same surface of land.
Tree forest **Bush forest** **Savannah**	Total loss of vegetation and ecosystem services provided	Total loss of vegetation Loss of land
Mangrove	Partial loss of vegetation and loss of part of the ecosystem services provided	Total loss of vegetation
Bare soil, sand, dune	No damage	Loss of beach surface area
Water surface area	No damage	No damage
Residential urban fabric continuous and dense moderate density low density discontinuous	Partial damage to real estate assets and to light collective infrastructures Associated loss of economic activity	Total destruction of assets Associated loss of economic activity Loss of land
Equipment		
Road, rail, port or airport **infrastructure**		
Industrial plant		

4.3. ECONOMIC ANALYSIS OF THE THREE PILOT SITES

4.3.1. Methodological framework and assumptions made

Erosion, submersion and flooding phenomena are already present on the entire Senegalese territory. **The only effect of climate change is to increase the intensity or the frequency of such events.** All things being equal, the costs related to climate change can thus be estimated as corresponding to the difference between the current cost of the events considered within this study and their future cost.

The economic analysis of the vulnerability of the coastline is based on **the evaluation of direct and indirect costs (damage and economic losses, respectively)** induced by natural risks and climate change. The evaluation includes the spatialization of the economic sectors on the coastal area, the change in the economic structure of the various sectors and the modification of the spatial distribution of land use (urban and rural).

To illustrate the probability of occurrence of natural risks, damage is expressed as a **mean annual cost** (MAC), corresponding to the weighted sum of costs, taking into account a discount rate for the forecasts. An updated sum is then made to obtain the NPC (net present cost).

Forecasts at the 2030 horizon are based on the data provided by the ANSD and the IMF regarding population and economic growth, respectively. The extension of time series at the 2080 horizon is very uncertain. It has been agreed to consider the SRES scenarios established for the IPPC until the 2100 horizon.

The Senegalese experience shows that areas submerged by the ocean during 'storms' are more or less destroyed. **The absolute value of a surface unit is estimated by taking into account the assets present on the area and the associated economic activity. Damaging functions are then identified.** The valuation methods are based first and foremost, inasmuch as possible, on an **analysis of the data specific to the Senegalese cases.** Literature is often used to compare the results obtained with the existing frame of reference.

For the various natural risks considered, the **low valuation assumptions** were always selected. Cost evaluation is thus at a minimum level.

When we consider a given climate event (whatever its return period), the further in time it occurs, the higher its cost (in terms of damage and losses) will be. Such differences are due to the taking into account of **numerous parameters that tend to increase the cost of such events in the years to come.** Among such parameters, the most significant are the following:

- Sea level rise (which induces an increase in submerged areas, an increase in coastal erosion and a more difficult discharge of continental water levels during floods);
- Increase in, and densification of, land use;
- Economic growth.

However, it should be noted that the cost increase that will take place in the future will increase at a slower rate than the discount rate selected for our calculations. Indeed, **when the discount factor is applied, the future costs are lower than the present cost.** This is all the more true since the discount rate is high.

We can estimate that for a developing country such as Senegal, the **discount rate** selected for the calculations performed is low. Indeed, the cost for financing public capital is higher than in developed countries. The discount rate selected is generally at least as high as the expected return on investment. Furthermore, the country's economic situation leads to increasing the preference for present, thus leading to an increase in the discount rate used in economic calculations. Nonetheless, the evaluation of climate change impacts is an approach that is in essence turned towards the future.

The time factor is central in that type of cost-benefit analysis. On the one hand, costs (adaptation measures) focus on the short term. On the other hand, benefits (elimination of losses and damage) occur in a longer term, at a time when impacts without adaptation are the greatest. Assigning a probability of occurrence to marine submersion events is a real issue, since many uncertainties prevail and since it has a strong impact on the NPCs.

The NPC is calculated as a 2010 value for a period of time ending in 2080. The **discount rate** used is the rate recommended in the Lebègue report (4% during the first 30 years, then gradual decrease in the subsequent years).

The most deprived communities not only have a direct sensitivity to climate events, but they also have relatively low post-disaster resilience capabilities. Coefficients have thus been determined on the basis of the Synthetic index of access to basic social services, at the scale of the *Départements*, so as to take into account this **social fragility** by overvaluing the estimated costs. The Synthetic index of access to basic social services is based on 5 access indicators: access to a drinking water outlet; access to a primary school; access to a health center; access to a trading venue; and access to a road. Such overvaluation can lead to a doubling of the estimated costs.

Sensitivity tests have been carried out on the results of the economic analysis so as to evaluate the impact of the variability of the model's input factors on the output variable(s). Practically, this consisted in analyzing the consequences on the NPC related to natural risks and climate change of the variability of the 'building damage rate' and 'discount rate' parameters. Such tests demonstrated the sensitivity of the results presented below to the parameters considered, and thus their close dependence to the assumptions used.

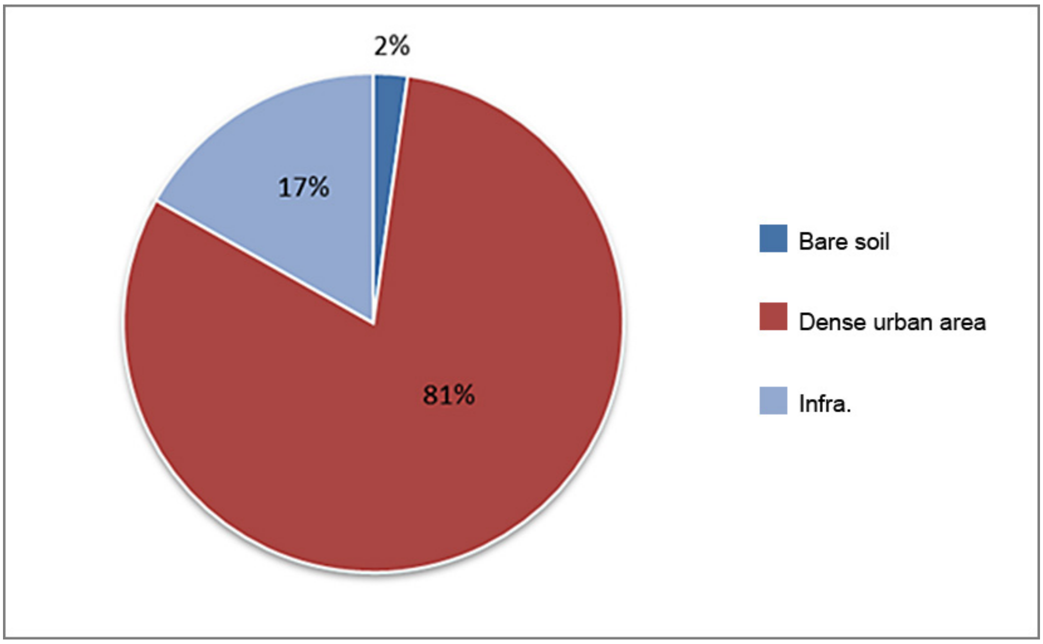
Last, as already mentioned above, **the entire evaluation of the impacts of natural risks has been carried out on the basis of conservative assumptions**. In other words, the values chosen to perform the calculations always tend to minimize the costs of losses and damage due to the hazards considered. Such variables regard the values assigned to the various types of land use and to the damage rates suffered in the event of submersion or flood. Indeed, the sensitivity analysis shows the effects of less conservative assumptions on the results. Furthermore, for some of the issues at stake, such as human lives or cultural heritage, it was not possible to make a monetary evaluation, although they are severely exposed. Taking into account all these elements, **we must therefore consider that the results presented correspond to the low end of the range for the costs related to natural risks and climate change, and that such costs could be twice as high**.

4.3.2. At Saint-Louis

As regards coastal risks, the analysis focuses on **marine submersions.** Indeed, it should be reminded that the cartographic elements taken from the various studies of coastal evolution in Saint-Louis show a chaotic variation of the shoreline. Though it is undeniable that today, shoreline is undergoing recession in urbanized areas after each major storm (subsidence and dwelling destructions testify to that - see Photo 7), it is not possible to precisely quantify such recession.

According to estimations, **30% of the urban areas of the Barbarie spit of land are submerged at the 2080 horizon for a 100-year event.** These areas mainly have a high urban density (see figure below). The **net present costs** in 2080 due to marine submersion for the municipal territory of Saint-Louis amount to approximately **FCFA 12.3 billion (USD 24.6 million).** The estimated cost for that event in 2030 is approximately **FCFA 31 billion (USD 62 million),** and in 2080, this cost amounts to **FCFA 95 billion (USD 190 million).** Almost**1,000 dwellings and 8,000 inhabitants** are likely to be affected by that event.

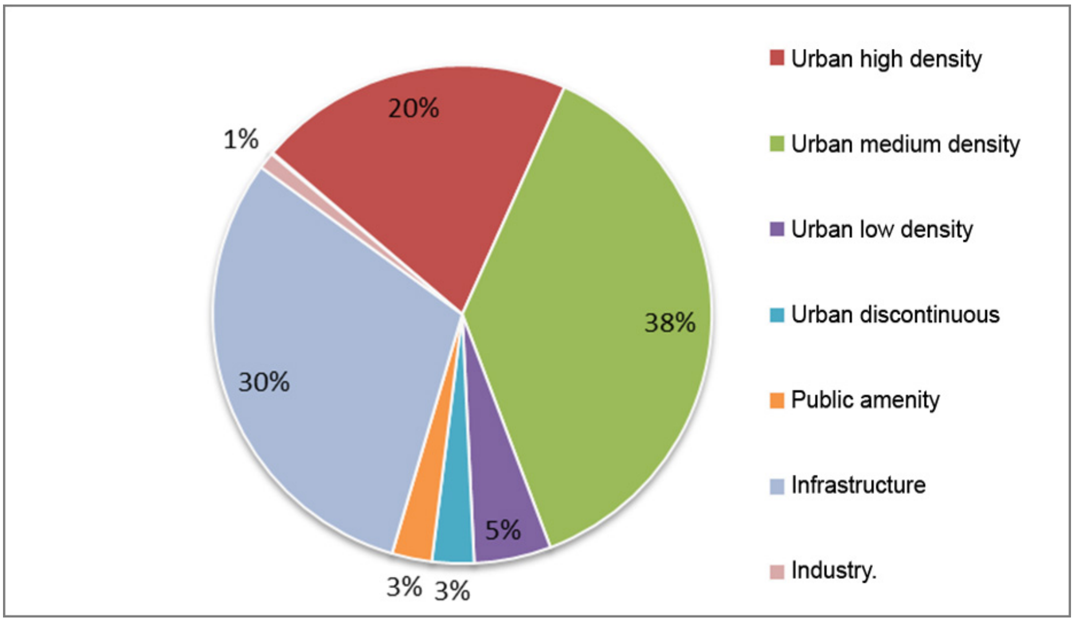
Figure 29: Breakdown of net present costs induced by a 100-year submersion - Saint-Louis



Regarding the flood hazard induced by the Senegal river, the consequences of two types of events have been modeled: floodings caused by floods occurring every 10 to 30 years, and floodings caused by 50-year floods. Regarding the **hazard occurring every 10 to 30 years,** the total flooded surface area for such an event at the 2080 horizon is 1,696 ha. The net present cost of such event amounts to more than **FCFA 707 billion (USD 1.414 billion).** At the 2080 horizon, such event would affect **18,900 dwellings, i.e. some 150,000 inhabitants.** If the event considered here (10-year return period) would occur in **2030,** its cost (damage and losses for that year) would amount to almost FCFA 179 billion (USD 358 million), i.e. 1.4% of the GDP of the coastal area **for that year. Should that event occur in 2080, its cost would be of approximately** FCFA 1,033 billion (USD 2.066 billion), i.e. 1.3% of the coastal GDP of that year.

Regarding the **hazard occurring every 50 years,** the total flooded surface area for such an event at the 2080 horizon is estimated to be 1,768 ha. The net present cost of such event amounts to more than FCFA 225 billion (USD 450 million). Such event would affect 21,600 dwellings, i.e. approximately 170,000 inhabitants. For that type of event, which is less frequent (this explains why its NPC is lower than the NPC calculated for 10-year floods) but more violent, the share of infrastructures in the cost breakdown is higher. Should that event occur in 2030, its cost would be of approximately FCFA 360 billion (USD 720 million), i.e. 2.7 % of the coastal GDP of that year.

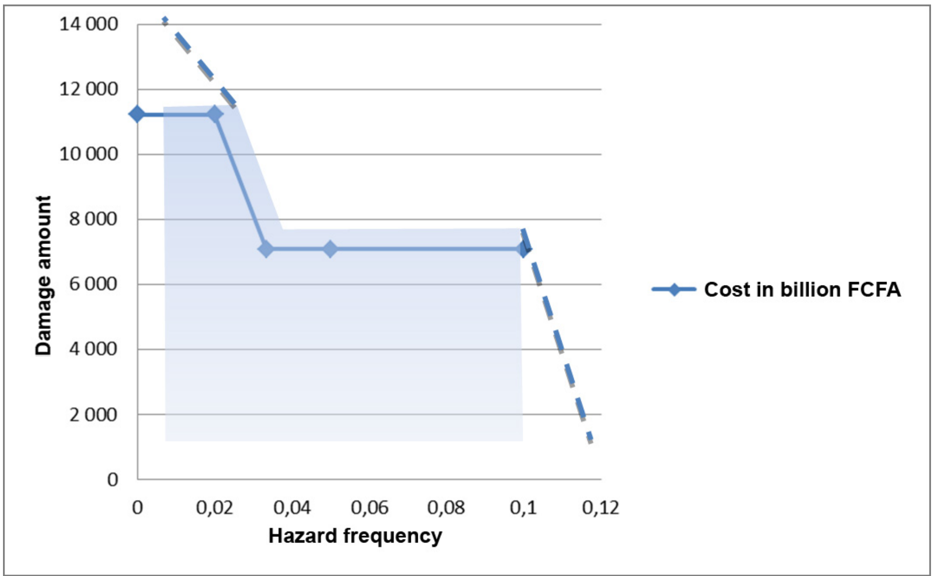
Figure 30: Breakdown of net present costs induced by a 50-year flood - Saint-Louis



For that type of event, which is less frequent but more violent, the share of infrastructures in the cost breakdown is higher.

Since we have the evaluation of costs for various return periods, it is possible to calculate the **mean net present cost** (MNPC) of floods. This MNPC value expresses the mean cost, over the entire period of time, of all floods that are likely to occur.

Figure 31: Breakdown of the mean net present cost of floods



The MNPC value corresponds to the area of the blue surface on the above graph. It is a minimum MNPC since the areas located below the dotted segments should also be taken into account. However, no estimation is possible for those two extremes.

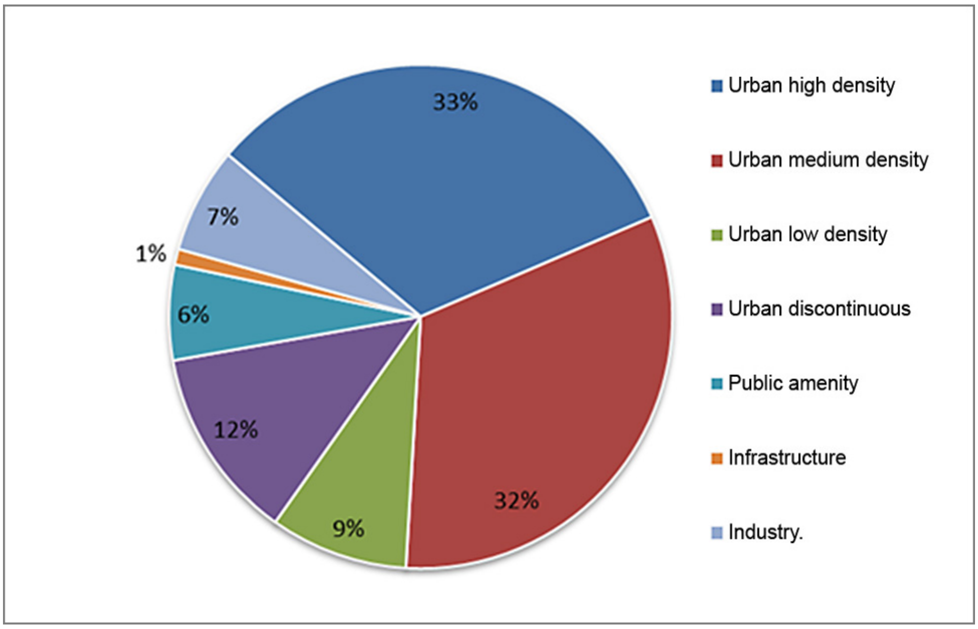
The MNPC of floods in the municipal territory of Saint-Louis amounts to FCFA 818 billion (USD 1.636 billion), i.e. almost 13% of the national GDP for the year 2010.

The adaptation solutions presented here only concern the marine erosion and submersion risk of the Barbarie spit of land. Indeed, the study regarding the protection of Saint-Louis against the floods of the Senegal river is too complex to be carried out within this study. Various combinations of adaptation solutions have been studied. From these comparisons, **one scenario stands out, with a positive cost-benefit balance of FCFA 4.54 billion (USD 9.08 million).**

4.3.3. At Rufisque-Bargny

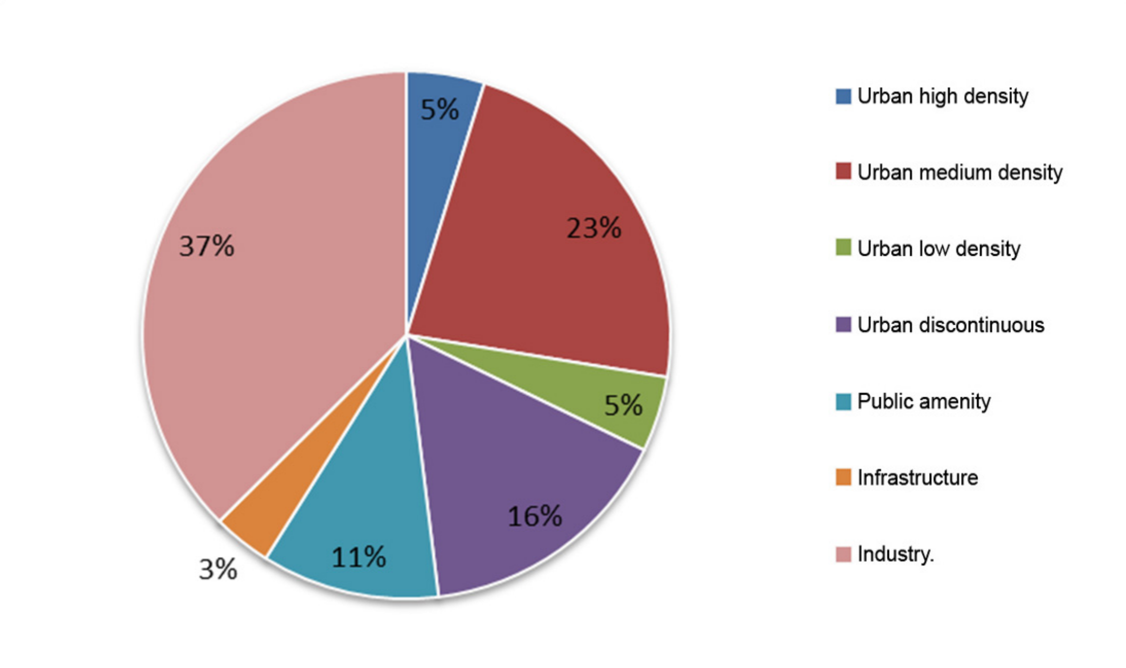
The net present costs at the 2080 horizon caused by the 100-year marine submersion in the municipal territories of Rufisque-Bargny amount to almost **FCFA 440 million (USD 0.88 million).** This relatively low amount is due to the various assumptions used and to methodological biases. If the event considered here (100-year return period) would occur **in 2030,** its cost (damage and losses for that year) would amount to almost **FCFA 360 million (USD 0.72 million).** Should that event occur in 2080, its cost would be of approximately **FCFA 11 billion (USD 22 million).** This increase is explained not only by an intensification of the submersion phenomenon, but also by an increase in the urban issues (densification of habitat and economic development).

Figure 32: Breakdown of net present costs induced by a 100-year submersion - Rufisque-Bargny



The net present costs in 2080 due to coastal erosion at Rufisque-Bargny amount to approximately **FCFA 10.5 billion (USD 21 million).** At the 2080 horizon, some 300 buildings, of which approximately **250 dwellings,** will have been destroyed. Knowing that an average household comprises 9 people, **2,250 inhabitants** of Rufisque-Bargny are likely to be affected.

Figure 33: Breakdown of net present costs induced by coastal erosion - Rufisque-Bargny



Among the hypotheses considered for hazard evaluation, it has been assumed that the current protective structures are maintained in an operating condition until the end of the study period. Therefore, to the cost of damage and losses, we must add this **cost for the consolidation and maintenance of these existing structures,** whose NPC is estimated to amount to FCFA 3.21 billion (USD 6.42 million).

Hence, the net present costs at the 2080 horizon caused by the 100-year marine submersion and coastal erosion at Rufisque-Bargny, when taking into account the maintenance costs of the existing structures, amount to almost **FCFA 14.2 billion (USD 28.4 million), i.e. 0.3% of the coastal GDP for 2010.**

All adaptation solutions proposed for Rufisque-Bargny have a cost that is higher than the evaluated damage. The cost-benefit balance of the least expensive solution is negative by FCFA 8.5 billion (USD 17 million). This situation can be explained by the relatively low level of the costs of damage and losses in the baseline situation. It should also be underlined that the economic modelling does not take into account the costs related to the possible loss of human lives, to the loss of places with a high heritage value (such as places of worship and cemeteries), and to the disappearance of grounding areas for fishing boats. In that case, the implementation of a warning system to protect human lives, the information of population and the provisioning of funds for the relocation of victims of disasters seem to be the most appropriate solution.

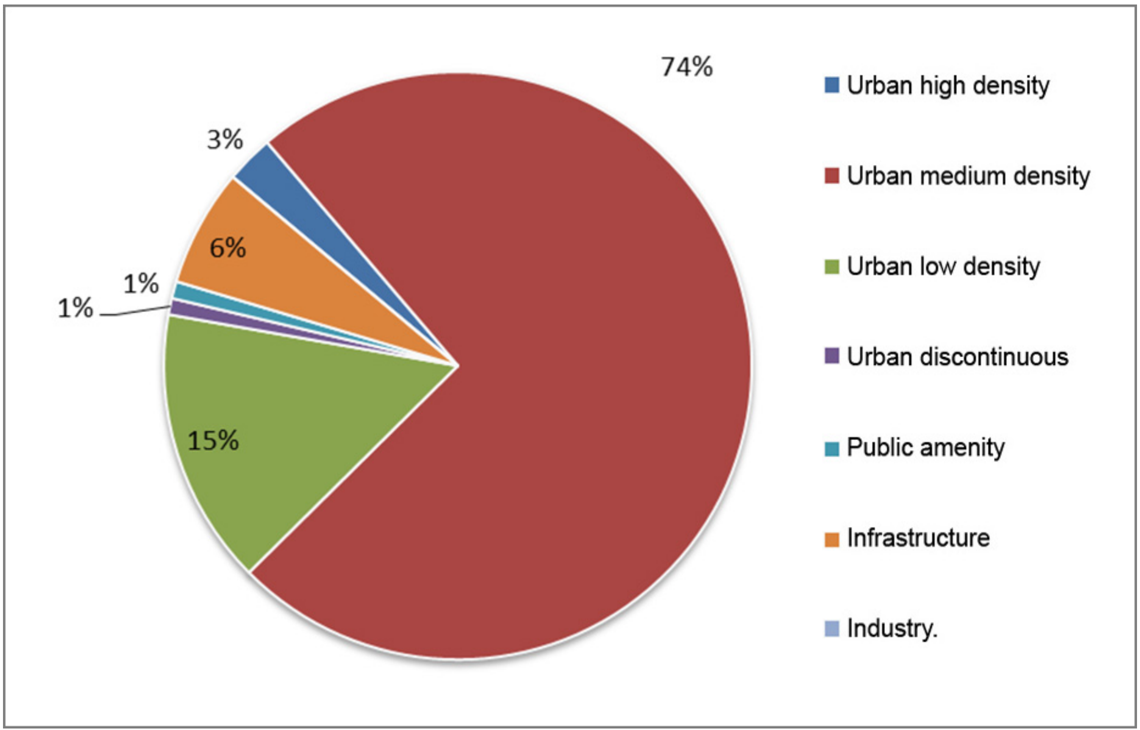
4.3.4. At Saly

The NPC of the 100-year submersion, as calculated from the DTM provided by the DTGC, amounts to approximately **FCFA 209 million (USD 0.418 million).** This low amount is explained by the small size of the flooded area for that event at the 2080 horizon: only 16 ha, of which 12 ha of beach. It should be reminded no economic cost is induced by this temporary submersion of the beach, unlike its erosion or its permanent submersion due to sea level rise.

Should the event considered here occur **in 2030,** its cost (damage and losses for that year) would amount to almost **FCFA 211 million (USD 0.422 million)**. Should that event occur

in 2080, its cost would be of approximately **FCFA 5 billion (USD 10 million), i.e. 0.1% of the coastal GDP for 2010.**

Figure 34: Breakdown of net present costs induced by a 100-year submersion – Saly



Due to the lack of precision of the DTM used and to the economic importance that seaside activities have at Saly **because of the width and the quality of its sandy beaches, it seemed necessary to complement the analysis with an** evaluation 'according to expert' of the potential impact of sea level rise at the 2030 and 2080 horizons on the future of those beaches.

In the absence of topographic profiles of the beaches in the current situation, and on the basis of a field survey carried out at the Saly beaches and of existing photographic documents, we noted that the mere static sea level rise of 20 cm **in 2030** could induce a **20% loss of the overall surface area of the beach,** a value that could even **reach 60% at the 2080 horizon** with a sea level rise of some 80 cm.

With this hypothesis, slightly less than 130 ha of beach would disappear at the 2080 horizon; **the NPC of the permanent submersion of the Saly beaches amounts to approximately FCFA 6.5 billion (USD 13 million).** This amount is high because the economic valuation of this site's beaches includes their high contribution to the creation of local added value. Indeed, the beaches represent a major asset for the tourism industry.

Among the hypotheses considered for hazard evaluation, it has been assumed that **the current erosion control structures are maintained** in an operating condition until the end of the study period. Therefore, to the cost of damage and losses, we must add this cost for the consolidation and maintenance of these existing structures, as well as the cost for regular beach recharging.

Thus, the net present costs in 2080 caused by the 100-year marine submersion **(conservative hypothesis of a loss of 60% of beaches at the 2080 horizon)** in the municipal territory of Saly, when taking into account the maintenance costs for the existing structures, amount to approximately FCFA 10 billion (USD 20 million).

Most adaptation solutions proposed for the site of Saly have a cost which is lower than the baseline situation (without adaptation), whose NPC amounts to FCFA 10 billion (USD 20 million). It should be reminded here that the NPC amount of the baseline situation is based on an evaluation 'according to expert' of the submersion hazard. Nevertheless, for the calculation, we have used the low simulation value. However, only the **creation of artificial beaches elevated** with respect to the current shore, so as to take into account a sea level rise of 80 cm by 2080, will enable to preserve the current beaches, and thus to balance all the losses and damage induced by such rise. The recommended option has a neutral economic balance (cost equal to the avoided damage).

4.3.5. Budget considerations

Although these three sites can not, alone, represent all the issues related to the disasters caused or aggravated by climate change along the Senegalese coastline, they are particularly significant and **might be considered as priority sites in terms of public intervention**. Due to the investment amounts at stake (evaluation of FCFA 33.15 billion - USD 66.3 million), it is estimated that such investments could be spread over 4 years (i.e. FCFA 8.28 billion - USD 16.56 million per year). For the subsequent years, maintenance costs are estimated at approximately 1% of the investment costs.

To measure the weight of such investments, we can compare them to the national annual public investment. In 2009, public investment amounted to FCFA 401 billion (USD 802 million) (Gross Fixed Asset Formation = GFAF). Over the first four years of programming, the aforementioned adaptation investments would thus account for slightly less than **2% of public GFAF** for that reference year. It should be reminded here that such investments will enable to protect both private property and public infrastructures. Thus, future investments related to the repair of public assets might be avoided thanks to this anticipatory investment. In the subsequent years, the maintenance costs of these structures (coming under the 'investment' budget line of public accounts) are relatively low with respect to the annual budget allowances.

As regards the intermediate consumption required for such investments, some 20% (corresponding to the multidisciplinary engineering studies) are likely to be imported due to the complexity and extent of the tasks. The rest of the costs is broken down between the building work force and the construction materials and equipment. Due to the nature of the works, this intermediate consumption should be available locally. Finally, thanks to the volume of works and to the low share of imports required, these projects would have **positive impacts on the local economy in terms of direct and indirect job creations**.

4.4. A MACROECONOMIC APPROACH OF COASTAL RISKS OVER THE ENTIRE SENEGALESE COASTLINE

4.4.1. An extrapolation based on a macroeconomic logic

The feedback obtained from the economic analysis carried out in Phase 3 at the pilot sites enabled to envisage certain types of extrapolation to the entire Senegalese coastline.

To that end, it was necessary to use macroeconomic indicators that could be representative, reliable and available at the scale of the coastal regions. It was also necessary to separately deal with the issue of river floods and coastal hazards at Saint-Louis, which represents a specific case (unique in Senegal) that can not be extrapolated to other coastal areas. After having reviewed a certain number of macroeconomic indicators (national accounting, GDP, population density, etc.), we observed that one of the indicators that best reflected the sensitivity of coastal areas to natural risks and climate change was **the population count** of the regions concerned. Furthermore, it is the only 'macro' indicator (at the scale of a region) that might be compared to values available for the pilot sites. Indeed, no macroeconomic data are available at the scale of the pilot sites. For all these reasons, this variable was selected.

The underlying assumption is that the populations of coastal regions are concentrated along the shoreline, and that there is thus a strong correlation between population count and coastal vulnerabilities, all the more since the location of populations is perfectly correlated with the location of material issues and economic activities. In addition to the demographic criterion, we have assumed that vulnerabilities were evenly distributed along the coastline. **The population of coastal regions amounts to 7,261,181 inhabitants (according to the 2009 census) and is distributed as follows:**

Table 8: Population of the coastal regions (figures of 2009)

	Average size of households (number of persons)	Population 2009
Dakar	7.3	2 536 959
Fatick	9.6	722 343
Louga	10.3	831 309
Saint-Louis	8.6	865 058
Thiès	9.9	1 610 052
Ziguinchor	7.4	694 460

The costs related to the coastal erosion and marine submersion phenomena are extrapolated from the case study performed at Rufisque-Bargny. Indeed, out of the three pilot sites, it is the site that is most representative of the coastal issues faced by the Senegalese coastline. Indeed, the site of Saly is too specific as it is currently the only tourist resort of the coastline. As for Saint-Louis, as recalled above, it is also a specific case. The Barbarie spit of land, located at the mouth of the Senegal river, is constantly changing since erosion and accretion follow each other in a more or less cyclic manner at the same location of the shoreline . Furthermore, within the framework of this study, the coastal erosion and marine submersion risks there have been studied in a less detailed manner that at Rufisque-Bargny (better resolution of the DTM at this latter site).

Table 9: Extrapolation of the erosion and submersion risks to the entire coastline

Population of Rufisque-Bargny in 2009	NPC at the 2080 horizon of coastal erosion at Rufisque-Bargny	NPC at the 2080 horizon of submersion at Rufisque-Bargny
238,000	FCFA 10.5 billion (USD 21 million).	FCFA 440 billion (USD 880 million).
Population of the coastal regions in 2009	NPC at the 2080 horizon of coastal erosion over the entire coastline	NPC at the 2080 horizon of submersion over the entire coastline
7,261,181	FCFA 320 billion (USD 640 million).	FCFA 14 billion (USD 28 million).

Excluding the site of Saint-Louis, the net present cost in 2080 of coastal erosion and marine submersion for 100-year events, **when taking into account sea level rise related to climate change, thus amounts to FCFA 334 billion (USD 668 million), and is** mainly related to coastal erosion. **When adding the site of Saint-Louis,** this cost amounts to FCFA 344 billion (USD 688 million).

The costs related to coastal flooding (river or run-off floods) are extrapolated from the case study performed at Saint-Louis. Indeed, of the three pilot sites, it is the only site which is really affected by that risk. We have considered the costs related to 10-year floods, which are the most damaging over the 2010-2080 period because of their high frequency. The total cost of floods in 2009 is used here as a baseline for the introduction of the climate change effects in terms of progressive risk increase.

Table 10: Extrapolation of the flood risks to the entire coastline

Cost of a 10-year flood at Saint-Louis in 2010	NPC at the 2080 horizon of 10-year floods at Saint Louis
FCFA 81 billion (USD 162 million).	FCFA 707.6 billion (USD 1.4512 billion).
Total cost of the 2009 flood	NPC at the 2080 horizon of floods over the entire coastline
FCFA 44.5 billion (USD 89 million).	FCFA 388.6 billion (USD 777.2 million).

Excluding the site of Saint-Louis, the net present cost in 2080 of coastal floods**(due to rivers or run-off)** for 10-year events **thus** amounts to approximately FCFA 389 billion (USD 778 million). We note that it has the same order of magnitude as the NPC related to coastal erosion and marine submersion. It should be reminded here that the NPC of floods **at Saint Louis** amounts to FCFA 818 billion (USD 1.636 billion) and is thus **twice the cost of coastal floods for the rest of the Senegalese shoreline.** This seems consistent with the importance of the risks related to the floods of the Senegal river at Saint-Louis. When taking into account the Saint-Louis agglomeration, the NPC would thus reach **FCFA 1,207 billion (USD 2.414 billion).**

The amount for the main natural risks affecting the Senegalese coastline corresponds to **an NPC in 2080 of approximately FCFA 1,550 billion (USD 3.1 billion)**. The NPC of the economic losses and damage on the Senegalese coastline at the 2080 horizon thus represents **almost one quarter of the GDP for 2010, and approximately 35% of the GDP of the coastline** for that same year.

It should be underlined that this is a **high hypothesis,** which takes into account an overestimation of the affected population, an average household size identical to the current situation, and double counts (at Saint-Louis). However, in view of the detailed results of the economic analysis performed at the pilot sites, this seems consistent.

4.4.2. Additional evaluations

This study also tackles the cost of the climate change impact **on health care.** Indeed, the consequences of climate change on some diseases such as malnutrition, malaria and diarrheal conditions will be major risks for the future populations, particularly in low-income countries in the tropical and subtropical regions.

An evaluation was proposed on the basis of a method developed by the World Health Organisation (WHO). This method is based on estimations of the Disease Adjusted Life Year (DALY). The evaluation is based on the crossing of WHO data regarding the increase in health expenditure with the GDP growth forecasts (which include health expenditure). Though the GDP growth forecasts take into account the economic evolution of the country, they do not specify the evolution of the social and sanitary context. **Thus, the net present cost in 2080 of the deterioration of the population's health condition on the coastline due to climate change is estimated to amount to FCFA 1,200 billion (USD 2.4 billion)[5].** This cost is comparable to that of damage and losses caused by natural risks and climate change, thus highlighting the importance that should be given to health care issues in adaptation to climate change. Moreover, it should be noted that these health care costs are only related to the impact of climate change, whereas the costs of damage and losses have been calculated by combining natural risks and climate change.

As regards the **loss of ecosystem services,** no evaluation was made, but the analysis shows that the effects of climate change, instead of inducing ecosystem services losses, lead to a recourse to indirect and induced services, and thus to an increase in the economic value of indirect uses (storm protection, flood retention and flow regulation, erosion control, water resource protection) in wetlands and forest areas. It is thus all the more important to protect such environments.

4.4.3. Comparison of the study results with the DIVA model results

Before this economic analysis, a first limited assessment (based on existing data) of the physical and economic vulnerability to climate change of the coastline was carried out from October to December 2010 in Senegal and Gambia, using **the DIVA model** (Dynamic and Interactive Vulnerability Assessment) and funds from the World Bank. DIVA is an integrated and global model for coastal systems, which analyses the biophysical and socio-economic consequences of sea level rise and the socio-economic development. The impacts taken into account include coastal erosion, coastal floods, wetland losses and salinization with or without adaptation measure (only 'hard' adaptation options are evaluated, i.e. beach recharging and dike reinforcement/construction).

To compare the results obtained within this study and the results of the DIVA study, it was **first necessary to identify the values which could be compared.** Indeed, while this study aims at giving a present value to all the future costs, the results presented by the DIVA study are non-actualized total annual costs.

The amount which we deemed most relevant to compare is the total annual cost of climate change without adaptation for the year 2080. According to the DIVA model, such cost amounts to approximately USD 210 million, i.e. approximately FCFA 107 billion.

[5] Finally, it should be noted that this evaluation does not take into account the possible socio-economic evolutions at that horizon.

According to our calculations, this cost amounts to approximately FCFA 380 billion (USD 760 million). This value is more than three times higher than the results obtained by the DIVA model for that same year.

For the year 2030, the results of this study are more than 5 times higher that the evaluation obtained within the DIVA study. This shows two major differences in the methodological approach: the model implemented here takes into account a much higher vulnerability of the coastal area than the DIVA model, but a lower increase in vulnerability over time.

Regarding global cost evaluation, the main factors that could explain why our model leads to much higher results are a higher valuation of land use and a higher intensity of the hazards studied. The lower annual increase in costs of our model can be explained with several parameters. Unfortunately, we do not know the socio-economic assumptions (development of urbanization, economic growth and increase in the value of the buildings) used in the DIVA model. This latter might use lower assumptions regarding such elements. Another explanation lies in the hazard increase assumptions. The DIVA model seems to be based on a less progressive increase in submersion and flood phenomena, and a strong increase during the last years.

Nevertheless, overall, the estimation of coastline vulnerability is very similar as regards the structure of the costs deriving from the models. The weight of each type of risk in the total costs is very similar, with a clear preponderance of floods. However, it should be noted that in the DIVA model, no difference is made between river floods and coastal submersion.

Anyway, **in the absence of clear methodological elements regarding the DIVA modelling, any direct comparison of the results of both studies would be highly uncertain.** To give an example, in the methodological elements of the DIVA model, the study report does not specify if the probability of occurrence of the climate hazards considered is taken into account in the cost calculations for a given year. In other words, the question regarding the interpretation of the results is the following: do the costs indicated for a given year correspond to a situation with exceptional weather events or to an average situation of all possible conditions (with or without exceptional events, plus all the intermediate conditions)?

Anyhow, **this economic analysis has been carried out using elements that are much more detailed and reliable than the DIVA modelling**. Indeed, it is based on the extrapolation to the entire coastline of results obtained at pilot sites ('bottom-up approach'), whereas the DIVA model uses a 'top-down' approach based on macroeconomic elements which have not been verified or correlated at the local scale.

5. PROPOSAL OF INTERVENTION PROGRAMME

Take-away messages

- An intervention programme has been drafted to guide the Senegalese authorities regarding the adaptation measures to be considered for the coastal areas.
- The actions that should be given priority with regards to the identified issues and to the expected benefits are mainly incumbent upon the urban planning and institutional spheres.
- No heavy-investment measure for coastal protection or river flood control is proposed for the short term, as their feasibility and efficacy strongly depends on the effective implementation of the urban planning and institutional measures.
- Whatever the protection investments envisaged, they must be complemented with early surveillance and warning systems regarding river floods or coastal submersion.
- The implementation of such measures requires the mobilization of numerous government stakeholders and local authorities.

This chapter aims at proposing **priority recommendations** in order to guide Senegalese authorities regarding the adaptation measures to be implemented in coastal areas, in particular within the framework of the Integrated Coastal Zone Management Plan. Such recommendations are obviously based on the conclusions of the various phases of the study, but also on the experience acquired by the Consultant on other projects.

It should be specified here that **these are only recommendations, not an action plan.** Thus, it is not possible, within the framework of this study, to go further in the level of definition of the adaptation measures. Nevertheless, we have tried to be as precise as possible and are thus able to provide cost elements for some of the recommendations.

The **programming elements** of such recommendations are proposed at the end of this section.

5.1. INTERVENTION LOGIC

To tackle the risks and vulnerabilities identified during the previous study phases, we have drafted a set of recommendations that can be subdivided into four categories:

1. Recommendations regarding **investments and other technical measures** that will be required to ensure the protection of the main vulnerabilities of the coastline.
2. Recommendations regarding **regulatory and territorial planning measures** intended to reduce the exposure to the risk of the main vulnerabilities of the coastline. Such recommendations refer to the current land use and to the urban development forecasts at the 2030 horizon.
3. Recommendations regarding **institutional aspects** to be taken into account for an effective implementation of the adaptation actions. This category also includes organisational measures that would enable a better management of disaster risks.
4. Recommendations regarding **training and awareness-raising,** for populations and decision-makers alike.

It should be noted that the three last fields of intervention correspond to strategic priorities, which tackle risks rather globally and horizontally. The first is related to a more thematic and relatively technical approach to risks and vulnerabilities. Besides, the institutional aspects and the training element are mostly focusing on '**risk preparedness**', whereas urban planning is more related to a '**prevention**' approach and investments and technical measures mainly aim at the '**protection**' of assets and people.

5.2. INVESTMENTS AND OTHER TECHNICAL MEASURES

In order to define the investments that are needed to protect the Senegalese coastline against natural risks and climate change, **it is first necessary to improve the knowledge of the hazards and vulnerabilities of the coastline.** As we have observed during this study, such knowledge is still too partial and incomplete. In particular, the characteristics of the beaches and their evolution according to the hydrodynamic conditions are currently little known. A better knowledge of the morphological evolutions and of the hydrodynamic characteristics along the coastline would enable to better adapt the protection solutions that could be required if sea level rise continues. A better knowledge of the river or run-off floods in the most vulnerable sectors must also be acquired. Finally, the analysis of vulnerabilities must be refined.

Beyond this necessity of additional information, a certain number of **practical measures** are recommended:

- Protection of the shoreline by means of structures (dikes, groins, breakwaters) and of beach recharging in the areas where the issues justify it and where the situation enables so (e.g.: on the Barbarie spit of land and at Saly);
- Demolition of the most exposed buildings and displacement of population in the areas where protective structures would not be economically justified and/or where the current situation as regards the erosion or submersion risks does not enable to envisage other options (e.g.: at Rufisque-Bargny).
- Drafting of a sewerage master plan, taking into account the new assumptions regarding rainfall and sea level;
- Implementation of a waste collection scheme to improve the efficacy of the storm water drainage system;
- Continuation of the wastewater collection and wastewater/storm water segregation programmes;
- Continuation and intensification of the canal cleaning programme before and after the rainy season;
- Improvement of the drainage in the lower neighborhoods, densification of the system;
- Preservation of the natural drainage and flowing channels;
- Construction of devices aiming at avoiding the concentration of flows: discharge of run-off water into ditches (shallow, large-width trenches), expansion areas (that can be used as leisure or green spaces);
- Taking into account of storm water drainage constraints in the development of new neighborhoods; measures aiming at not aggravating the downstream flows rates (notably, retention basins).

In view of the socio-economic issues, such protective measures **must be accompanied by institutional and urban planning measures** that aim at reducing vulnerability.

For the **city of Saint-Louis,** which is particularly exposed to floods caused by the Senegal river and to sea level rise related to climate change, the following intervention programme is recommended.

Table 11: Flood control programme at Saint-Louis

Priority	Objective	Action	Implementation deadline
Improvement of the flood discharge conditions	Maintaining a sufficient discharge cross-section downstream from Saint-Louis and at the river outlet	Regular bathymetric follow-up Dredging	To be implemented within the next 12 months
	Monitoring and managing the position of the river mouth	Following the evolution of the position of the river mouth. Possibly deciding to recreate an artificial breach to the north of the river mouth when its position becomes too detrimental in terms of flood levels reached at Saint-Louis.	Follow-up to be implemented within the next 12 months
	Reducing the flood flow rates passing through Saint-Louis	Favoring the expansion of floods in the valley upstream from Saint-Louis: creation of lateral spillways, temporary rewatering of some of the former arms, temporary reopening of former sea outlets, etc.	Requires in-depth studies over several years: hydraulic studies, environmental impact studies, socio-economic studies, agreements between riparian countries - mainly Senegal-Mauritania (cf. dam management by the OMVS)
Reduction of vulnerability	Reducing the vulnerability of the built environment, the equipment and the infrastructures	Establishing diagnoses, blocking water contact with expensive equipment (both individual and collective), tight systems, displacement of certain equipment or buildings to less vulnerable areas, stilt constructions, etc.	To be scheduled in the short term (< 5 years)
	Enhancing storm water discharge during floods	Implementation of pumping devices for run-off water that can not be discharged when the river is too high (collection, storage, pumping)	To be scheduled in the short term (< 5 years), with an extension of the devices as sea level rises
Prevention and warning	Regulating urban development	Releasing some of the lower areas that are being illegally occupied, with associated rehousing programmes	To be scheduled in the short term (< 5 years)
	Informing population and companies	Information campaigns, training of trainers: building technicians, school pupils	To be implemented within the next 12 months
	Warning in advance of the near occurrence of a damaging flood	Warning and forecasting system regarding flood levels at Saint-Louis	To be scheduled in the short term (< 5 years)
	Taking people and assets to shelter	Municipal safeguarding and crisis management plan	To be implemented within the next 12 months

5.3. REGULATORY AND TERRITORIAL PLANNING MEASURES

This section describes a few **common sense rules,** reflecting the state of the art in developed countries as regards urban planning and regulations aiming at the prevention of natural risks.

- **Zoning and urban planning regulations** aiming at avoiding risk exposure. A strict regulation, such as the 'Natural Risk Prevention Plan' (PPRN) implemented in France, should be implemented to regulate urban development in the areas where natural risks are high, in particular at Saint-Louis. According to the risk level, a given development might be forbidden, or authorized with a certain number of constraints. The objective is to avoid increasing vulnerability and, if possible, to reduce it. The high uncertainties related to climate change should be integrated into the required safety margins, in particular for areas that are not yet urbanized.

- **De-densification of the urban fabric and habitat network** aiming at reducing hazards. This is a key element of a city/environment rebalancing approach. This network reconnects, at the scale of the urban territory, the areas to be safeguarded from urbanization because of their role in flood control, flood reduction, protection against the warm prevailing winds, protection against marine submersion (dune-dike) and maintenance of biodiversity.

- **Run-off management for new neighborhoods or urban rehabilitation operations.** Urban development without measures to avoid aggravating the downstream run-off flow rates will ineluctably lead to a strong reduction, or even a total cancellation, of the effect of the protection developments implemented. An urban planning regulation imposing a non-aggravation of downstream flow rates should thus be implemented. At the scale of large projects, such as new neighborhoods, it is indispensable to integrate storm water sewerage in the development project, in particular by providing for areas capable of storing storm water.

- **Assessing subsidence phenomena at Saint-Louis.** Indeed, the Saint-Louis agglomeration is built on loose sedimentary soils, which are highly likely to have significant compaction movements. This natural subsidence of soils, generally aggravated by urbanization, can progress at speeds of approximately one centimeter per year. This phenomenon would double the speed of sea level rise in the sectors concerned. Once the subsidence risks have been evaluated, they can be used for a zoning integrated to the Natural Risk Prevention Plan.

- **Delimiting the Maritime Public Domain,** so that the Coastal Law (*Loi Littorale*) might become enforceable as soon as possible. *In fine,* the objective is to implement rules regarding the interdiction of building over a certain width, behind the beach-top. On the one hand, such rules enable to protect the existing natural spaces against urbanization, and on the other hand, they allow the shore to retreat without 'obstacles'. This retreat possibility thus enables to avoid, in a more or less long term, the construction of protections against retreat, which sometimes become an aggravating factor of shoreline recession. Furthermore, this might enable to leave 'green' internals between urbanized areas.

5.4. INSTITUTIONAL ASPECTS

This study was mainly focusing on technical and economic aspects. The Consultant did not have the mandate to study institutional aspects. This is perfectly understandable, since it is an important element of the ICZM plan currently being drafted under the auspices of the Ministry of Environment. Therefore, this chapter only makes **general recommendations,** mainly on the basis of the experience acquired within the framework of similar studies carried out in North Africa and of proposals made by the institutional partners of this study.

Such recommendations are expressed in view of their further development and their integration into the reflection process initiated in parallel to the drafting of the ICZM plan.

- **Strengthening of institutional coordination** to counter natural risks and adapt to climate change. The aim is essentially to improve the efficacy of the command chain for the management of sudden-impact natural risks (torrential rain, coastal submersion) and of the chain of knowledge-study-technical decision-making for risks related to climate change.

- **Advanced planning, operational response and rationalization of natural risk management procedures.** In coordination with the previous action, the short-term operational efficacy, especially when dealing with hazards whose return periods are measured in centuries, could gain from substantially simplifying procedures and reducing the number of institutional interlocutors. Decentralisation of part of the response chain is recommended.

- **Strengthening of the early surveillance and warning systems,** through a set of cultural actions, in order to contribute to the improvement of the preparedness and response potential at national and local level. An increased capability in territorial monitoring, modelling and short-term forecasting of natural disasters is considered as the principal route for controlling the effects of climate change. Indeed, it is recalled that no protective measure is totally reliable, and that early warning is still the most efficient and cost-effective way of preventing disasters. Besides, early warning systems are indispensable for preparedness and self-protection, as discussed below.

- **Preparedness and self-protection against fast-evolving phenomena.** The aim is to prepare individuals and families to naturally perform the safeguarding actions required during situations of imminent danger or natural disaster. To make the system work, State services must provide - in appropriate times and through adequate communication means - the information regarding the risk scenario in progress.

- **Flood surveillance and warning system at Saint-Louis.** This system includes the implementation of a warning and forecasting system for a maximum anticipation of floods and the preparation of rescue actions, the information of both population and companies exposed to the flood risk (see next chapter), and the implementation of emergency plans at various scales, including specific plans for buildings open to the public.

- **Accompanying measures for the enforcement of urban planning regulations.** This study has confirmed the existence of difficulties as regards the control of compliance to urban plans, underlining the need for precise and substantial controls regarding planimetry and altimetry to face the issues related to sea level rise and to flow and run-off changes in the urban sewerage systems. Since the issue of legal compliance is associated with both the virtuous behaviour of Citizens and the implementation of a dissuasive/repressive

administrative police activity (at the level of the cadastral register), the most appropriate response could be a follow-up of land occupation using high-resolution satellite images, combined with the information and awareness-raising of citizens (see next chapter).

- Implementation of a **budget policy for climate change adaptation**, integrating new financing solutions, additional economic and financial analyses, and a production and operation account for each project. The amounts likely to be lost in damage and losses related to natural risks and climate change could usefully be set aside to feed a self-insurance system against floods.

All those measures seem to be a priority, with a short-term programming (2 years), possibly to the exception of the flood surveillance and warning system at Saint-Louis, which requires a certain number of investments and whose efficacy mostly depends on the implementation of the other measures.

5.5. TRAINING AND AWARENESS-RAISING

This chapter complements the previous one since institutional actions are generally supported by training and awareness-raising measures. In our view, the training and awareness-raising actions should be carried out in priority along the following three lines:

- Civic education intended to avoid aggravating risk exposure
- Awareness-raising programme focusing on self-protection
- Information regarding natural risks

5.5.1. Civic education intended to avoid aggravating risk exposure

First, it is absolutely necessary to make sure that populations understand the risks they are facing and the responsibility they have in the possible aggravation of such risks. The most striking example in Senegal is certainly **the habit of considering storm water sewerage systems as a dumping place for household waste.** Indeed, beyond the sanitary risks, this hinders the free flow of water and prevents the systems from correctly playing their role. Another example regards **the extraction of sand from the beach and its use as a building material.** Such extractions aggravate coastal erosion mechanisms.

It is thus highly recommended to implement a **civic education action,** so as to enable the Citizen of the future to visualize - in the strict meaning of the term: (1) the daily evolution of his or her immediate environment; (2) the places or structures that have been subject to unauthorized modifications or have suffered deterioration; (3) the cascading effects of abuses on urban development and land deterioration (floods, erosion, submersion, etc.). This typology of information is well adapted to post-elementary school grades, with of course different levels of complexity.

5.5.2. Awareness-raising programme focusing on self-protection

Experience shows that**talking about recent disasters is not an effective way** of triggering a 'useful' awareness of the risk and the 'adequate' self-protection mechanisms. Indeed, these events are **often perceived as generic and external** since they concern extremely different and/or far-away populations.

It thus seems necessary that every technical protective measure against natural risks be supported by the implementation of an **awareness-raising programme, focusing on the development of self-protection,** organized at the level of individuals and their family

nucleuses. The programme would aim at bridging the existing gap between the information computed by the geophysical surveillance systems and the understanding of its content by the weakest link of the risk chain: 'the man in the street'. Information sheets should be prepared and should include the main recommendations to follow in the event of a natural disaster (Quick Reaction sheet).

The efficacy of the programme could be improved by means of a **prior reflection regarding the communication strategies and the technological means to be implemented.** The nature of the programme suggests that its management should not necessarily be entrusted to technical stakeholders (e.g.: the scientists managing the warning systems), but that it could be shared with a single government representative and maximum local interaction levels, such as municipalities, for instance.

5.5.3. Information regarding natural risks

In connection with the previous measure, it is obviously necessary to develop the information regarding natural risks that should be offered **to the population, the economic stakeholders (industries, businesses, services) and the administrations.** Such information requires the knowledge of the hazards for various levels of event frequency, represented in a cartographic manner, and of the vulnerability of the populations concerned.

5.6. PROGRAMMING ELEMENTS

This section aims at giving an **overview** of the recommendations. The tables summarize the recommendations made and propose a **schedule.** Whenever possible, **cost elements** are presented.

5.6.1. Identification of priorities

Recommendations scheduled in a very short term **correspond to priority actions, i.e.** actions deemed to be the most effective and actions whose implementation conditions the efficacy or the feasibility of other actions **(upstream actions).**

The actions that should be given priority with regards to the issues identified and to the expected benefits are mainly incumbent upon the **urban planning and institutional spheres.** Indeed, these actions cover all natural risks (synergy effects), have a low cost, are of a 'no regret' or 'robust' nature and are flexible/reversible.

5.6.2. Programming table

The recommendations are presented under the form of a **summary table** which highlights:

- **The type of action, with reference to the intervention spheres**: Infra = Infrastructure / Technical measure; Urba = Urban planning / Regulation; Prépa = Institutional/operational preparation[6]; Forma = Training / Awareness-raising. It is reminded that though recommendations are classified under one of the four spheres, some might be simultaneously concerned by 2, or even 3, spheres.

[6] Institutional preparation corresponds to structural or organizational strengthening actions, having a relatively general and horizontal scope, to improve the efficacy of natural risk prevention and preparation; operational preparation includes measures that are technical - often, they complement the aforementioned measures - and that can be applied locally. These are prevention measures, unlike the protection measures presented in the 'Infra' category.

- **The scale of intervention**: local (at the level of one of the pilot sites) or national.
- **the issue level** (risk) associated with these actions, as identified during the diagnosis phase of the study,
- **the efficiency** (cost-benefit ratio) of these actions, as it might have been estimated within the framework of the economic analysis,
- **the scheduling** proposed for the programming of these actions, knowing that none of them has been scheduled so far,
- **the initial investment cost** and the annual maintenance or follow-up costs to be borne for the duration of the programme, for the recommendations for which an economic analysis has been carried out within the framework of this study.

☞ **Comments regarding the programming table**

- Recommendations are ranked by intervention priority. But a ranking by type of risk would also be relevant.
- Efficiency is based on expertise and on the cost-benefit ratio, with a preference given to the actions coming under a multi-risk approach. Evaluation is qualitative, on a scale that comprises three classes: +, ++, +++.
- The programming period concerns the works to be performed, unless the recommendation only includes studies. These latter should all be carried out in the short term. In the first programming phase, a distinction is made between actions considered as urgent, i.e. that should be initiated during the first two years of the programme (XX), and actions that might be postponed at a 3- to 5-year horizon (X).
- Cost: the indication '= 0' means that the cost is zero or negligible; '?' means that it has not been possible to determine the cost within the framework of this study. Specific studies should be carried out, in the continuation of this study, so as to assess their cost.

Table 12: Intervention programme

Recommendations	Type of action	Scale of intervention	Level of issue	Efficiency	Programming		Cost (FCFA x 10^6)	
					< 5 years	< 2030	initial	annual
Strengthening of institutional coordination (improvement of the efficacy of the command chain and of the chain of knowledge-study-technical decision-making)	Insti prepa	National	Very high	+++	XX		= 0	= 0
Rationalization of the natural risk management procedures (substantial simplification of the procedures and reduction of the number of institutional interlocutors);	Insti prepa	National	Very high	+++	XX		= 0	= 0
Readjustment and implementation of the reference texts: Coastal Law (*Loi Littorale*), National Coastal Erosion Prevention Program, and National Action Plan for Climate Change Adaptation	Insti prepa	National	Very high	+++	XX		?	?
Implementation or strengthening of the early surveillance and warning systems, through a set of cultural actions, in order to contribute to the improvement of the preparedness and response potential at national and local level	Opera prepa	National	Very high	+++	XX		?	?
Preparation and self-protection against fast-evolving phenomena, coupled with the implementation of emergency plans at various scales (notably in Saint-Louis)	Opera prepa	Local	Very high	+++	XX		= 0	= 0
Accompanying measures for the implementation of urban planning regulations (implementation of a dissuasive/repressive administrative police activity; follow-up of land occupation using satellite images, combined with information/awareness-raising of citizens);	Opera prepa	Local	Very high	+++	XX		?	?

Implementation of a budget policy for climate change adaptation, integrating new financing solutions, additional economic and financial analyses, and a production and operation account for each project	Opera prepa	National	Very high	+++	XX		= 0	= 0
Awareness-raising programme focusing on self-protection, with a particular focus on communication methods and on the technological means to be implemented	Training	Local	Very high	+++	XX		?	?
Information regarding natural risks, to be offered to the population, the economic stakeholders (industries, businesses, services) and the administrations	Training	Local	Very high	+++	XX		?	?
Control of the strict ban on sand collection along the coastline	Urba	National	Very high	+++	XX		= 0	= 0
Run-off management for new neighborhoods or urban rehabilitation operations (urban planning laws imposing a non-aggravation of the downstream flow rates)	Urba	National	Very high	+++	XX		= 0	= 0
Assessing subsidence phenomena at Saint-Louis (zoning to be integrated to the PPRN)	Urba	Local	Very high	+++	XX		40	5
Regular bathymetric follow-up and dredging operations aiming at maintaining a sufficient flow cross-section downstream from Saint-Louis and at the river outlet	Infra	Local	Very high	+++	XX		?	?
Monitoring the evolution of the position of the Senegal river mouth, with a view to possibly recreating an artificial breach	Infra	Local	Very high	+++	XX		?	?
Drafting of sewerage master plans, taking into account the new rainfall and sea level assumptions; implementation of a waste collection scheme in order to improve the effectiveness of the storm water drainage system	Urba	Local	Very high	+++	XX		?	?

Warning and forecasting system for the flood level in Saint-Louis, to inform with anticipation of the occurrence of a damaging flood	Opera prepa	Local	Very high	+++	X		?	?
Civic education intended to avoid aggravating risk exposure, to be incorporated into school cycles	Training	National	High	++	X		= 0	= 0
Zoning and urban planning regulations aiming at avoiding risk exposure (binding regulation of a PPRN type)	Urba	Local	Very high	++	X		?	?
Delimiting the Maritime Public Domain, so that the Coastal Law (*Loi Littorale*) might become enforceable	Urba	National	Very high	+++	X		?	?
Reducing the vulnerability of the built environment, the equipment and the infrastructures at Saint-Louis: establishing diagnoses, blocking water contact with expensive equipment (both individual and collective), tight systems, etc.	Infra	Local	Very high	++	X		?	?
Implementation of run-off pumping systems to facilitate storm water discharge at Saint-Louis during the floods caused by the Senegal river	Infra	Local	Very high	+++	X		?	?
Releasing some of the lower areas of Saint-Louis that are being illegally occupied, with associated rehousing programmes	Urba	Local	Very high	+++	X		?	?
De-densification of the urban fabric and ecological mesh aiming at reducing hazards (city/environment rebalancing)	Urba	Local	High	++		X	?	?
Protection of the Barbarie spit of land against coastal erosion and marine submersion (groins, beach recharging and reprofiling)	Infra	Local	High	++		X	1200	150
Protection of Saly against coastal erosion and marine submersion (creation of artificial beaches)	Infra	Local	High	++		X	9200	92

Reinforcement of the existing coastal protections at Rufisque-Bargny and strategic retreat for the most exposed sectors	Infra	Local	Very high	+		X	28500	15
Favoring the expansion of floods in the valley upstream from Saint-Louis: creation of lateral spillways, temporary rewatering of some of the former arms, temporary reopening of former sea outlets, etc.	Infra	Local	Very high	+		X	?	?

5.7. IMPLEMENTATION CONDITIONS

The various recommendations listed in this report come under the responsibility of various State departments and public institutions. To manage the approach and follow the implementation of the various actions recommended here and of those that will be developed within the ICZMP, it would be **advisable to appoint a coordinating entity.** It is clear that the selection of such an entity is incumbent on the Government and that the national agency which coordinated this study will not necessarily be in charge of its implementation. However, it should be noted that the various national institutions that got involved within the framework of this study have cumulated knowledge and an institutional commitment that could be very useful in the next phase of the decision-making process. It is also recommended that the representatives of local authorities (notably Saint-Louis) be more directly involved in the preparation of the implementation phase, so as to ensure an additional local ownership and a support to adaptation and resilience action plans.

The coordinating entity should liaise with the Ministry of International Cooperation to draft the **financing package** for the recommendations programme. It is indeed very unlikely that the Government will be able to finance all these actions on its own funds; therefore, international aid should be requested. The multilateral development agencies and the main economic partners could be contacted. First, such partners would be called upon in order to launch and finance the additional studies required for the implementation of an action plan at the pilot sites (drafting of terms of reference, launching of calls for tenders, selection and steering of consulting agencies) and for the improvement of knowledge on the other potentially vulnerable sites of the coastline.

The coordinating entity could be supported by a **steering committee** composed of representatives of the financial partners and of the main authorities concerned by the action plan. *A priori,* such steering committee could replicate the structure of the committee established in January 2011 for coastal protection activities, i.e.:

- The representative of the ME / MEPN
- The Director of the Department of Environment and Classified Establishments
- A representative of the Prime Minister
- A representative of the Minister of Infrastructures
- A representative of the Minister of Economy and Finances
- A representative of the Minister of Maritime Economy
- A representative of the Minister of Urban Planning
- A representative of the Minister of Tourism
- A representative of the Minister of Mines
- A representative of the Association of Local Elected Officials
- A representative of the Research and Training institutes and schools
- A representative of the UNDP, of the European Union, of Japan, of UEMOA and of USAID.

It would also be interesting to further extend the steering committee to representatives of the civil society and of the private sector (e.g.: consular chambers).

6. ADDED VALUE AND LIMITS OF THE STUDY

Take-away messages

- This study is a 'first' for Senegal, and even for the entire West African region, due to its topic and the way it was handled.
- The originality of the approach is particularly related to the following elements: level of detail of the study; 'multi-risk' nature of the approach; horizons considered (2030 and 2080); recourse to field surveys; implementation of a dual-scale economic evaluation (local and national); consideration of the social fragility of populations exposed to climate disasters; etc.
- The innovative nature of the approach has induced drawbacks, regarding the methodology (initial assumptions not always verified) and due to the unavailability or the lack of precision of some data sets.
- With respect to the study performed by the World Bank in 2011 on the coastal cities of North Africa, which was itself a pilot study, this study provides an overview of the impacts of climate change at the 2080 horizon and an economic model to assist decision-making.

In many ways, this study is an exploratory approach. But this very exploratory nature induces a certain number of limits. These two aspects are the main points discussed in this section. The chapter then closes with a comparison with a study performed on the same topic in North Africa.

6.1. AN EXPLORATORY APPROACH

This study is a 'first' for Senegal, and even for the entire West African region, due to its topic and the way it was handled. The following paragraphs describe **the main elements that give its originality to the approach**:

- The **level of detail** of the study. Up to now (cf. UEMOA study, DIVA modelling), studies conducted on the topic of climate change at a national level had been performed at much larger scales, with cartographic restitutions that did not exceed 1:500,000. Within the framework of this study, the mapping of hazards and vulnerabilities at the level of the pilot sites has been performed against a background of high-resolution satellite images taken in 2011, at a working scale of 1:5,000.
- A **multi-risk approach.** Although it focuses on coastal erosion and marine submersion issues, this study also discusses hazards and risks related to river or run-off floods and issues pertaining to water resource and salinization. This global and horizontal approach enables notably to highlight the cumulative impacts of marine submersion events and river or run-off floods.
- The **horizons** of the study. The reflection initiated within the framework of this study focuses on the very long term (2080 horizon), with an intermediate horizon (2030). It has thus been necessary to perform territorial prospective assessments, especially in terms of urban development and growth, which had not been made until now.
- A **field survey** has been carried out at the level of the pilot sites to evaluate how populations and local stakeholders perceive the issues related to natural risks and climate change. Such survey was performed using the 'focus group' method. This enabled to cross the technical analysis of the experts working on this study with the comments and 'feelings' of the populations.

- An **evaluation of the costs** of natural risks and climate change, not only at the pilot sites, but also **over the entire Senegalese coastline.** The overall economic evaluation was performed by extrapolating the results obtained at the pilot sites using two distinct methods ('bottom-up' approach). The results obtained were then compared to those deriving from a prior study (DIVA modelling) based on a 'top-down' approach.
- The **consideration of the social fragility of populations** exposed to climate disasters. The most deprived communities not only have a direct sensitivity to climate events, but they also have relatively low post-disaster resilience capabilities. Coefficients have thus been determined on the basis of the Synthetic index of access to basic social services, at the scale of the *Départements*, so as to take into account this **social fragility** by overvaluing the estimated costs.
- Sensitivity tests have been carried out on the results of the economic analysis so as to evaluate the impact of the variability of the model's input factors on the output variable(s). Practically, this consisted in analyzing the consequences on the NPC related to natural risks and climate change of the variability of the 'building damage rate' and 'discount rate' parameters.
- A **cost-benefit analysis** of the adaptation measures. The level of detail of the study at the pilot sites has enabled to estimate both the costs (losses and damage) related to natural risks and climate change and the investment and operating costs of the adaptation measures to coastal erosion and marine submersion risks, which in turn enabled to perform a cost-benefit analysis.
- An **economic model** to assist decision-making. One of the main deliverables of this study is the design of an economic model capable of evaluating the cost of natural risks and climate change, which is simple to use and intended for local authorities. Indeed, the utmost care has been given to the design of a robust, structured and transparent tool, in which all the methodological steps and assumptions used are explained (in particular, the economic valuation of each type of land use).
- A **programme** covering all intervention fields (institutional, operational preparation, training, urban planning, regulation, infrastructures, technical measures, etc.) and providing cost estimates for the main protection investments that should be made at the pilot sites. Such programme describes priorities and implementation times, and aims at contributing to the preparation of the future Integrated Coastal Zone Management Plan for the Senegalese coastline.

6.2. THE LIMITS OF THE STUDY

As stated in the introduction, the innovative nature of the approach has induced drawbacks, **regarding the methodology** (initial assumptions not always verified) and due to the unavailability or the **lack of precision of some data sets.** To these are to be added, quite logically, the **limits of the approach itself,** which did not aim at providing precise technical and economical evaluations, but rather a first approximation of the cost induced by natural risks and climate change on the Senegalese coastline.

6.2.1. Uncertainties on topographic data

Initially, the segmentation of the coastline was meant to be based on geomorphological and, most of all, topographic criteria. **The absence of a digital terrain model (DTM) with a high enough resolution** at the scale of the entire coastline did not enable such task to be performed. This is the **main technical limit of this study.**

The **three pilot sites** which have formed the subject of a more detailed study (Saint-Louis, Rufisque- Bargny, Saly) were selected because of the **existence of specific DTMs**.

Nonetheless, the low density of spot elevations in these DTMs (two points might be located more than 100 meters away from each other), the recourse to interpolations between each reference point and the uncertainty regarding the correspondence between the NGS (General Leveling of Senegal) and the MSL (Mean Sea Level) systems require to be cautious when interpreting the results. The mapping of hazards and risks related to river floods (Saint-Louis), coastal erosion (Rufisque-Bargny) and marine submersion (three sites), **is only indicative and does not aim at being used as a reference for any risk zoning serving a regulatory purpose.**

6.2.2. Uncertainties on climate forecasts

Climate forecasting is not an exact science. The numerous uncertainties related to the selected greenhouse gas emission scenarios and to the technical limits of the simulation models are such that specialists often use the concept of **'cascading pyramids of uncertainties'.**

In particular, it should be underlined that **climate models are still little reliable in the forecasting of exceptional climate events,** such as extreme rainfall. This is reflected in the great variability of the results obtained for that type of events in the model-scenario pairs studied here. This explains why climatologists are currently very cautious regarding the evolution of intense rainfall. Today, this phenomenon is the most difficult hazard to study since it takes place at a small scale, which even the 25 or 50 km models are unable to perfectly describe. Due to the uncertainty attached to such forecasts, it has been deemed necessary, within the framework of this study, to use the precautionary principle and work with the most pessimistic forecasts.

It is also necessary to discuss **the role played by the natural variability** of the climate in the results. This role might be considered as predominant for relatively close horizons, such as 2030. At that horizon, the uncertainty regarding the emission scenario is not a real issue; its impact is only felt at the end of the century.

Finally, rigorously speaking, **the use of homogeneous observation data over the baseline period would be more reliable** for comparisons and conclusions. However, few homogeneous data sets are available for Senegal, in particular data coming from coastal resorts. Unfortunately, most data available are heterogeneous and have discontinuities, especially in those countries where means are often lacking. The data used might contain errors related to equipment, site change, sensor change, instrument shelter change or poor observation. Such errors make the data set more or less homogeneous.

6.2.3. Uncertainties on hazard evaluation

Even for the hazards that have formed the subject of the most detailed analysis (i.e. coastal erosion and marine submersion), uncertainties are high. Thus, **the cartographic results for the 'erosion' and 'submersion' hazards should be considered with caution.**

It was not possible to use a DTM over the entire **coastline,** in particular to evaluate submerged areas. Indeed, the DTM available for the entire coastline (SRTM 3) has a clearly insufficient precision. At most, it enables to highlight the coastline's areas of vulnerability to submersion, but it does not enable to make a quantitative evaluation of such vulnerability. The evaluation in terms of high, medium or low hazard was thus highly subjective and is based on the sole appreciation of the expert with regards to the various parameters taken into account.

At the **pilot sites,** the elaborated maps clearly show the submersible areas and their limits. However, the lack of precision of the DTMs gives little reliability to such delimitation.

Furthermore, when analyzing the impact of marine submersion on the coastline, one should bear in mind that the value of extreme water levels is calculated with the exceptional spring tide level (tidal coefficient of 120). Yet, such a water level is only maintained for a short time during high tide (from a few tens of minutes to one hour, according to weather conditions). Besides, the storm surge value used corresponds to an assumption that has not been verified by

measures or observations. **Thus, the water level values should also be considered with caution.**

It should also be noted that the storms generating the surge taken into account (70 cm) are likely to have a relatively short duration (from half a day to a full day, as a maximum). Therefore, the storm surge value taken into consideration is also limited in time. The addition of the various values of 'extreme' water levels thus leads to a high value, but with a limited duration. Nevertheless, this surge value is enough to cause noticeable damage on the coastline.

Last, we also noted the lack of bibliographic data regarding shoreline evolution and the absence of precise data on coastal bathymetry, local hydrodynamic conditions and sedimentology.

In the end, **the protection and adaptation solutions proposed within the time frame of this study are only indicative, and the estimation of their costs, approximate.** Detailed studies would be required to fine-tune these solutions and provide all the elements required to select the most appropriate solution(s) for the more or less long term.

6.2.4. Uncertainties on the economic analysis

The evaluation of hazards gives different results according to the territories studied (pilot sites). Likewise, the analysis of land use (issues, vulnerabilities) is specific to the territory at stake. **The use of the economic model thus requires the collection of numerous data that characterize the physical, environmental and socio-economic situation of the area studied.** The overall precision of the economic analysis model of the vulnerability to natural risks depends notably on the precision in the treatment of each type of land use for the areas exposed to such risks.

Generally speaking, the limits of the cost-benefit analysis correspond:

- **to the level of quality of the data** used in the analysis. Error sources, approximations during collection or lack of data are likely to affect the results of the analysis. Uncertainties might also be hydraulic, hydrological, geographical, economic, etc.;
- **to the non-consideration of intangible damage** (i.e. whose monetary value is difficult to assess). Since the comparison of costs and benefits uses a monetary unit, very often, only tangible damage is included in the analysis. The following damage is rarely considered, and when so, the results are weakened by numerous uncertainties: human mortality, psychological trauma, environmental impacts, deterioration of architectural heritage, impact on the image of a tourist resort, etc. This category might also include the impact of climate change on the fishing industry (fish resources and activities);
- **to the lack of exhaustiveness in the consideration of tangible damage.** Though indirect damage might be considerable, it is not always spontaneously taken into account in an economic analysis. In this respect, the CBA, when taken as an approach and not merely as a tool generating a result regarding the economic interest of a given measure, should enable to induce, on the occasion of technical and steering meetings, a reflection regarding avoided damage that is not being considered in the analysis (damaged networks, cost for the relocation of victims of disasters, cost of public service dysfunction, etc.);
- **to the static nature of the analysis,** which considers that the development of the studied territory is frozen over several decades (maximum 50 years). It is necessary to take into account the inevitable evolution of territorial development. Indeed, it is very likely that the areas where human activities are performed will evolve over time in terms of extension or vulnerability.

6.3. COMPARATIVE ANALYSIS WITH THE STUDY REGARDING COASTAL CITIES OF NORTH AFRICA

In 2011, the World Bank carried out a study on climate change adaptation and natural disasters preparedness in the main coastal cities of three countries of North Africa. The cities concerned were Alexandria, Tunis and Casablanca. The study also discussed the development project of the Bouregreg Valley, in Morocco.

The topic of that study was very similar to the one covered by this study: evaluating the impact of natural risks and climate change on the territories concerned, and proposing an adaptation plan. But the similarities stop there. Indeed, **both studies differ greatly in their content**.

First, the differences relate to **the territories studied**. Those of the North Africa study corresponded to the agglomerations of the capital cities, whereas this study concerns, on the one hand, the entire coastline, and on the other hand, urban sites of lesser importance (the pilot sites). As a direct consequence of this difference in the territorial approach, the **analysis scales** were also different: the scale of the North Africa study is located at an intermediate level, between the relatively coarse scale of the study performed over the entire Senegalese coastline and the detailed scale used to study the pilot sites. Finally, **the themes** were not totally identical. Whereas this study is focusing on coastal risks, the North Africa study paid a greater attention to other categories of natural risks, some of which had no relationship with climate change, such as seismic risk. Furthermore, the North Africa study comprised an institutional part, and the economic analysis was much less detailed.

The originality of this study and its added value with respect to the study performed on the coastal cities of North Africa, which was itself a pilot study, are mainly related to the following elements:

- **An overview of the impacts of climate change at the 2080 horizon**, whereas the North Africa study was limited to the 2030 horizon. Such point is essential, because if it is true that the impacts of climate change at the 2030 horizon are already relevant, they are by far lower than the impacts expected at the end of this century. The fact of having worked on those two horizons within the framework of this study enables to measure this evolution and the adaptation efforts in the more or less long term.
- **The design of an economic model to assist decision-making.** While for the North African cities, the economic analysis was based on a 'mere' expert assessment, of which only the results were published, within the framework of this study, a major effort has been dedicated to the description of the various methodological steps and of the assumptions considered. This is notably linked to the fact that one of the main objectives of this study was the design of an economic model to evaluate the cost of natural risks and climate change, that is simple to use and intended for local authorities.

7. RECOMMENDATIONS IN VIEW OF A REPLICATION TO OTHER COASTAL AREAS

Take-away messages

☞ The risk evaluation and economic analysis methodology, designed and implemented within the framework of this study, aims at being replicated particularly in other West African coastal areas.

☞ Recommendations are made so as to overcome the limits described in the previous chapter, improve the results of this study and enable to replicate the methodological approach at other coastal areas.

The risk evaluation and economic analysis methodology, designed and implemented within the framework of this study, **aims at being replicated particularly in other West African coastal areas.** This explains why this synthesis report closes with a chapter that includes recommendations in view of the replication of the tool at other coastal areas. Besides, the points discussed below echo the limits of the study described in the previous chapter. The aim is to describe the **elements that are required for a correct technical and economic evaluation of natural risks and climate change.**

7.1. EVALUATION OF HAZARDS

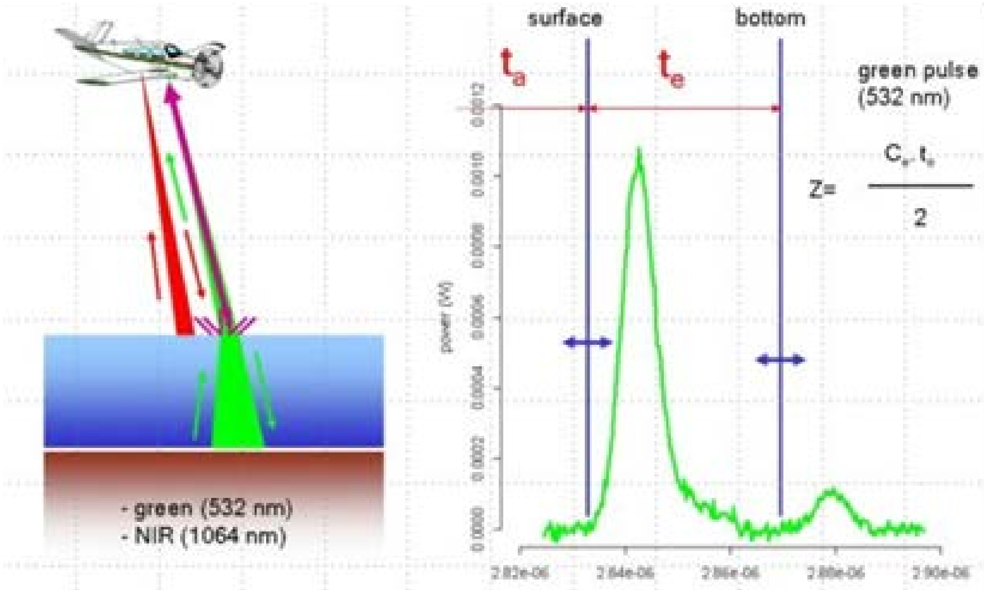
7.1.1. Topographic knowledge

Within the framework of this study, **marine submersion** was evaluated and discussed. But the spatialization of marine surges was performed on the basis of more or less precise topographic data.

The possibility of a **LIDAR topographic survey** over the entire Senegalese coastline has been envisaged but could not be completed within the time frame of this study. Nonetheless, this tool is now becoming unavoidable whenever a precise topo-bathymetric analysis of long stretches of coastline is required. LIDAR mapping is an emerging remote sensing technology which is able to quickly generate a high density of georeferenced 3D points. The accuracy of the points is equivalent to that of traditional field surveys, but the collection and processing times are much faster than traditional aerial methods (photogrammetry). The LIDAR mapping system uses a combination of three proven technologies:

- a compact and robust laser telemeter (LiDAR: Light Detection And Ranging),
- an inertial reference system (IMU: Inertial Measuring Unit),
- a satellite positioning system (GPS: Global Positioning System).

Figure 35: Schematic diagram of the airborne bathymetric LIDAR system



The integration of these three subsystems into one simple instrument, installed in an airplane or a helicopter, enables to quickly generate precise digital 3D topographic maps of the terrain. Certain airborne laser bathymetric systems are also able to precisely determine water depths by measuring the travel time of two laser pulses of different wavelengths: the infra-red is back-scattered by the sea surface while the other pulse (generally, the green beam at 532 nm) crosses the water-air interface and is reflected by the sea bottom. The LIDAR technology **thus enables to simultaneously make topographic and bathymetric surveys along the coastline.**

Erosion could only be quantified at the pilot site of Rufisque. Research enabled to calculate the mean annual recession by means of a **diachronic analysis.** We then used the data obtained to extrapolate until 2030 and 2080, and thus to produce a zoning of the erosion hazard. This enabled us to obtain a precise economic analysis for that hazard at that site. To do the same analysis over the rest of the Senegalese coastline or at other coastal areas, the diachronic analysis can make use of several documents: satellite images, aerial photographs, etc. In the 40s-50s, many African countries formed the subject of **aerial photography campaigns;** some photographs are available at the photographic library of the IGN. They could be digitized and georeferenced to evaluate shoreline evolution between the date of the photograph and today, i.e. more than 60 years. Below is an example of diachronic analysis using aerial photographs.

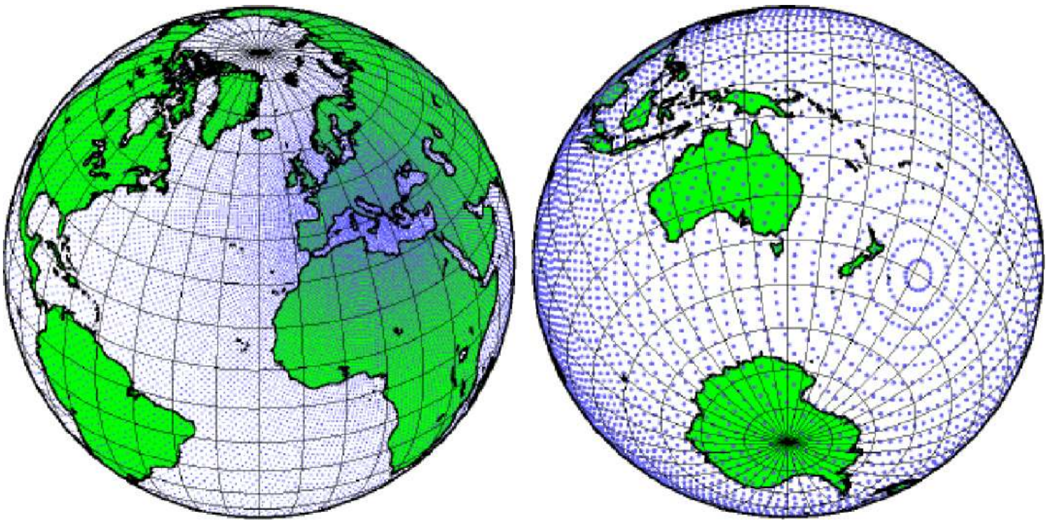
Figure 36: Example of an analysis of shoreline evolution by diachronic analysis using aerial photographs (coastal area of Tunis)

7.1.2. Climate knowledge

Though the climate situation of most countries is relatively well known, reliable climate forecasts are still lacking in some countries. To better take into account the impacts of climate change, it is thus indispensable to **fine-tune forecasts.** This mainly regards two lines of work:

- **Homogenizing observation series.** Existing data might contain errors related to equipment, site change, sensor change, instrument shelter change or poor observation. Such errors make the data sets more or less homogeneous. Despite its long and tedious nature, such homogenization work is essential to confirm the climate trends observed and to enable their use for climate forecasts at more or less long term.
- **Performing fine-mesh climate forecasts over the entire coastline.** Little work has been done on downscaling the forecasts of global climate models (GCM) in developing countries. Local meteorological authorities should be given the IT means to do so (modelling requires powerful processors). The objective is to fine-tune the outputs of the IPCC's global models for 25 km meshes.

Figure 37: **Example of downscaling based on a variable-mesh GCM (ARPEGE-Climat, Météo France)**



7.1.3. Oceanographic and sedimentological knowledge

The **characteristics of beaches** (foreshore width, altimetry, nature and granulometry of sediments, available sand layer) and their evolution in function of the hydrodynamic conditions, are often little or partially known. Yet, such elements are **central in the evaluation of coastal erosion and marine submersion risks.**

Besides, a thorough knowledge **of the morphological evolutions and of the hydrodynamic characteristics** along the coastline enables to better adapt the protection solutions that will be required because of sea level rise.

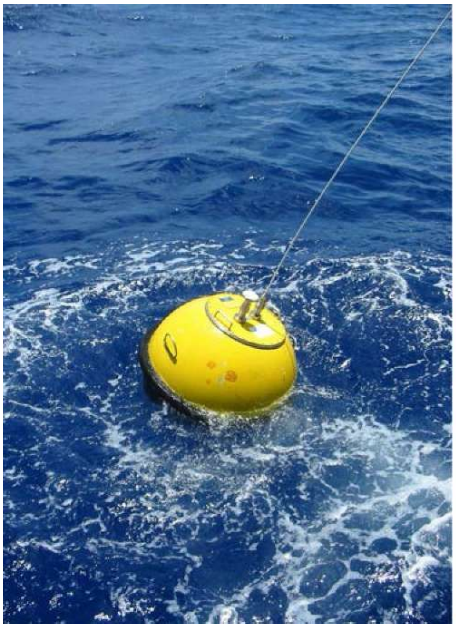
Hence, the **implementation of a follow-up scheme** comprising the performance, at least between the beach-top limit and the -10m sea bottom, of the campaigns described below will enable to give adapted responses in the future:

- yearly topo-bathymetric beach profiles at the end of the summer and winter seasons, with a profile every 100 to 500 m according to the beach configuration and length;

- sediment sampling and analyses: three on the shore and four at sea along the topo-bathymetric profiles every 10 years, unless if an exceptional event occurs;
- Very High Resolution seismic profile survey to determine the usable sand thickness.

Furthermore, the scheme should be complemented with **marigraphic data**, regularly processed (once a year), so as to establish in the coming years statistics regarding water level evolution: levels related to tides, surge levels, return period, etc. Such data would also be complemented with the collection of offshore swell data, by means of directional wave recorders. Swell measurement (direction, amplitude, period) might be performed by means of buoys floating on the water surface or by systems resting on the sea bottom.

Photo 10: Swell measurement devices



DATAWELL buoy (Source: IXSURVEY)

Current profiler and directional swell sensor resting on the sea bottom, with concrete ballast (Source: IXSURVEY)

7.1.4. Hydrological and hydraulic knowledge

Coastal sites located at the mouth of a river, such as Saint-Louis, are often most vulnerable and most exposed to natural risks and climate change since they are under the dual influence of marine and river levels.

The oceanographic and sedimentological knowledge described above must then be complemented with hydrological and hydraulic data. In particular, it is **important to determine, at the level of the river mouth, the relationship between the levels and the flow rates of the river**, according to the combination of the bathymetry conditions of the river until its mouth, the position of the mouth and the sea level. Abacuses might thus be built in order to provide answers to questions such as: what is the river flow rate that will generate a maximum level of 1.20 m if the river mouth is located 10 km away from the city to be protected, the sectional area of flow is 3,000 sq m and the sea level is 20 cm above the current level?

7.2. EVALUATION OF VULNERABILITIES

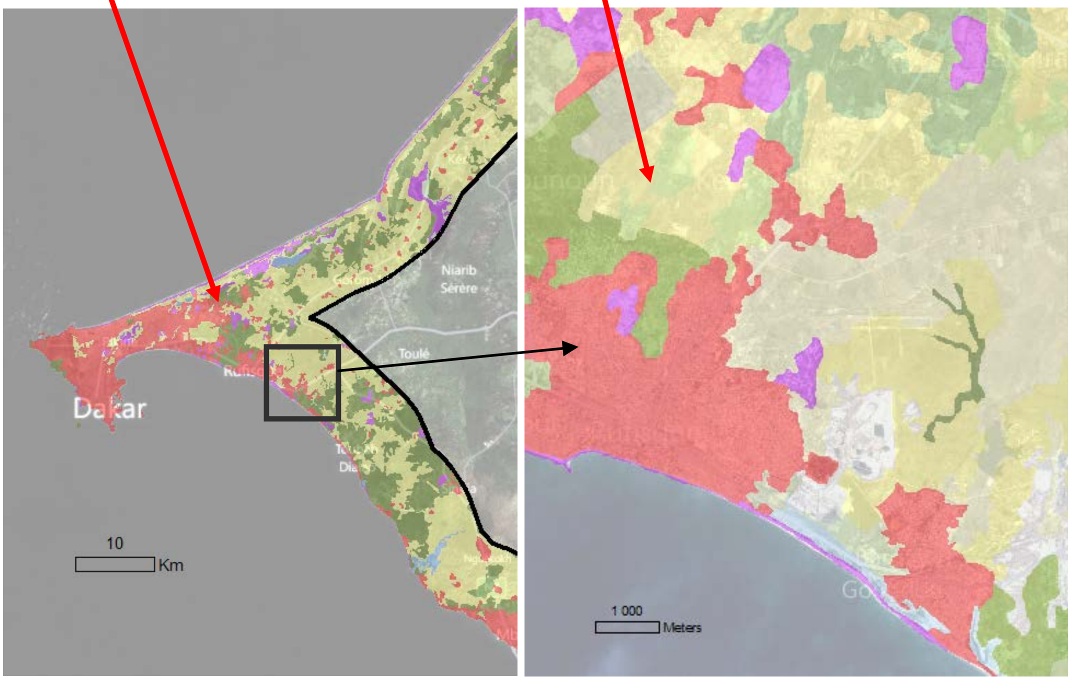
7.2.1. Land use knowledge

Figure 38: Nomenclature defined to characterize land use at various scales (left: 1:500,000 - right: 1:50,000)

Etude économique et spatiale de la vulnérabilité et de l'adaptation des zones côtières aux changements climatiques au Sénégal

Classification de l'occupation du sol

1 Agriculture	1.1	Arboriculture	1.1.1	Plantations forestières
			1.1.2	Plantations irriguées d'arbustes fruitiers, vergers tels que banane
			1.1.3	Plantations d'arbres fruitiers, verger d'orangers, de manguiers
	1.2	Culture	1.2.1	Culture irriguée herbacée (Canne à Sucre)
			1.2.2	Culture pluviale herbacée annuelle (arachide, mil, mais, sorgho, niébé, etc.)
			1.2.3	Cultures de décrues
			1.2.4	Riziculture
2 Végétation naturelle terrestre	2.1	Forêt	2.1.1	Forêt d'arbres
			2.1.2	Forêt d'arbustes
	2.2	Savane	2.2.1	Savane boisée
			2.2.2	Savane herbeuse
			2.2.3	Savane arborée et arbustive
3 Végétation de zones humides	3.1	Végétation ligneuse	3.1.1	Arbustes de mangroves
			3.1.2	Arbustes
			3.1.3	Gonakie
	3.2	Végétation herbacée	3.2.1	Herbacées d'eau douce inondées en permanence
			3.2.2	Herbacées d'eau salée inondées en permanence
			3.2.3	Herbacées d'eau douce inondées saisonnièrement
4 Surfaces artificialisees	4.1	Zone urbaine	4.1.1	Tissu urbain résidentiel continu dense
			4.1.2	Tissu urbain résidentiel continu moyennement dense
			4.1.3	Tissu urbain résidentiel continu peu dense
			4.1.4	Tissu urbain résidentiel discontinu
			4.1.5	Equipements
	4.2	Infrastructures et réseaux de communication	4.2.1	Aéroport
			4.2.2	Port
			4.2.3	Infrastructures routières et ferroviaires
			4.2.4	Mines et carrieres
5 Sols nus	5.1	Sable	5.1.1	Dune
			5.1.2	Sable nu
	5.2	Sol	5.2.1	Sol nu
			5.2.2	Sol nu érodé
	5.3	Sols nues hydromorphes	5.3.1	Sols nus inondés en permanence
			5.3.2	Sols nus inondés saisonnièrement ou temporairement
6 Surfaces en eau	6.1	Eau douce	6.1.1	Cours d'eau
			6.1.2	Lac d'eau douce
	6.2	Eau salée	6.2.2	Lac salé
			6.2.3	Zones d'extraction de Sel
7 Aires protégées	7	Aires protégées	7	Aires protégées



As shown on Figure 38, when studying coastal vulnerabilities at a **global scale**(in the region of 1:500,000), a nomenclature comprising 5 land use classes is sufficient. On the contrary, for an in-depth analysis of specific sites (as the three pilot sites of our study), a **smaller scale** (minimum 1:50,000) is required, as well as a much more detailed nomenclature with some forty land use classes.

7.2.2. Territorial prospective

The evolution of land use, and thus of vulnerabilities, proposed in the long term (2030 and 2080) within the framework of this study, has been estimated very approximately. It would be necessary to **involve local planning institutions so as to confirm or identify the areas that are likely to be urbanized or to change in the future.** Indeed, the local scale is where the vision of medium-term development is the most reliable, since territorial changes and major orientations are decided or implemented at the local level.

Furthermore, this study mainly focused on the evolution of urban classes. It would be **interesting to evaluate the agricultural and natural changes** foreseen by the territorial stakeholders (for instance, crops envisaged for the future, possibility to diversify the land purpose with renewable energies, biofuels, etc., which will have an impact on the economic value of such areas).

7.2.3. Economic evaluation

☞ **Consideration of damage (direct costs)**

For certain material assets, it is difficult to obtain local values accepted by everyone. **Specific studies** should be carried out. The crossing of **opinions of various experts** might also be a robust information source. The calibration of damage functions would require to have **a feedback** regarding situations that are comparable to those studied here.

☞ **Consideration of losses (indirect costs)**

Within the framework of the study at the pilot sites, the analysis of national accounts was only partially useful. Indeed, in Senegal, the breakdown of accounts is only done at the national level. The existence of accounts at a smaller scale, such as **regional accounts,** would enable a better approximation of the spatial distribution of activities by sector.

☞ **Improvement possibilities by land use type**

For each type of land use, a possibility for improving the results of the economic evaluation is directly related to the **quality of the inputs.** Here, in the absence of local data that are precise, verified and shared by all stakeholders, estimations often had to be made using more general data, i.e. less relevant for the specific case on which the evaluation was focusing.

The table below describes the source data that could enable to improve the economic analysis and facilitate its replication.

Table 13: Elements that could improve the economic analysis of vulnerabilities

Type of land use	Improvement possibilities for the evaluation
Agricultural areas	Precise breakdown of the local agricultural mix (production). For each type of crop, productive value of a surface unit. Mean value of equipment per surface unit.
Natural areas	Necessity to evaluate the ecosystem services provided by tree forests, bush forests and savannah, and most of all by wetlands (mangroves). But this type of study is quite expensive (contingent evaluation method or choice-based experimentation method), and several statistic biases might reduce the relevance of the data produced. This type of evaluation could be performed at a larger scale than the pilot sites.
Urban areas	The main improvement possibility regards the values (FCFA/m²) used for built land (single-family houses or multi-family buildings) and raw land. Instead of using averaged values based on the regulation, it would be more relevant to use the market prices observed in real estate transactions (matching of offer and demand). It should be noted that an evaluation based on a price valuation made by the occupants or the owners would undoubtedly lead to an overvaluation of prices. Another important improvement possibility regards the evaluation of the proportion of multi-family and single-family dwellings, for each urban density category identified (high density, moderate density, low density, discontinuous). To build the damage functions, it would also be necessary to have a description of the various building structures and to know their statistical distribution within the urban fabric. Indeed, the damaging curves available in the literature can only be used in a relevant manner if the vulnerability of the built environment considered is known. The best solution would be to have damaging curves built from the feedback regarding the areas studied. What damage rate, for what water height, for what type of built environment?
Road, rail and port infrastructures	Local costs per surface unit should be available from municipal authorities. A feedback on local damage rates for such infrastructures (as above) would also enable to more precisely determine the damaging functions.
Industrial plant	Companies are rarely transparent as regards the value of their fixed assets, equipment and stocks (semi-finished and finished products). It is thus illusory to believe that such data could be obtained. Nevertheless, a census of the types of activities present in the study area could enable to more precisely determine the value of damage and losses.

☞ Replicability of the economic model

The damage or damaging functions of the economic model developed within the framework of this study have quite general structures, but **the calculation parameters are specific to the territories studied.** It is thus impossible to envisage applying them 'as is' to another zone. The structure of the functions might be reused, but the local costs must be analyzed to calibrate the functions with respect to the new territories. This comment is particularly true for the prices of land and buildings, the identification of the agricultural production mix and the average selling price of productions. An analysis specific to the territory studied will lead to the building of a damage function that best translates the local situation.

For some topics, it is very difficult to build specific functions. It is then possible to use the reference values available in the literature. This is notably the case for the consideration of ecosystem service losses. Studies regarding the economic valuation of ecosystem services provided by the various types of natural habitats are rare. It is often difficult to find a reference value that exactly matches the type of natural environment of the area studied. Furthermore, the valuation of these ecosystem services also depends on the associated socio-ecosystem. When confronted to difficult choices for the valuation of certain damage, it might seem preferable to take into account these costs than to ignore them, but **low assumptions are then required when choosing the reference values, so as to avoid the risk of overvaluation.**

This study might be used as an example **and a basis for reflection to carry out similar studies, but it should not be considered as a catalogue of economic data or functions.** The quality of the results produced by the economic analysis depends on the efforts made to best depict the specificities of the territory studied.

7.2.4. Specific case of the fishing industry

The coastal areas of Senegal are part of the **Canary Current Large Marine Ecosystem**, fueled by the cold current of the Canary islands, which flows from North to South, with coastal water upwellings that are relatively cold and rich in nutrients. This ecosystem has major fish resources. Marketable fish include cephalopods, tuna, hake, etc. More than half of the commercial catches are represented by small pelagic Clupeidae (herrings, sardines and anchovies).

At an economic and social level, **the fishing industry plays a major role in Senegal**. Indeed, its contribution to the national GDP amounts to approximately 2.5%. In 2007, the commercial value of the products reached FCFA 185 billion (USD 370 million). This sector generates more than 600,000 direct and indirect jobs (17% of the active population), and 1.6 to 2 million people are dependent on marine fishery. With more than 500,000 tonnes of fish, molluscs and crustaceans landed every year, the fishing industry contributes 70% of animal protein intake, is the main source of currency, accounts for one fourth of the State budget and makes 60% of its sales from exports. The main fishing centers are located in Saint-Louis, Kayar, Dakar, Mbour, Joal, Kafountine and Cap Skirring.

The impact of climate change on the fishing industry in Senegal covers two aspects:

- Impact **on the resource**. The warming of ocean waters might lead to a change in marine currents and a displacement of the distribution areas of species. This phenomenon has already a practical consequence: the Senegalese sole, a species with an interesting commercial potential, has migrated northwards and has durably settled in the Mediterranean Sea. The deterioration of corals (bleaching) and mangroves, which are both the habitat and the reproductive sites of numerous species, has also a particularly negative impact on the availability of such resources. Ocean acidification related to greenhouse gas release might lead to the loss of species that are more sensitive or that are not able to migrate (sedentary species like molluscs will no longer be able to build their shell because of the higher acidity). Furthermore, it is known that sea temperature increase has a negative influence on ocean productivity and on the dynamics of currents such as the deep current flowing up from the Antarctic, which carries towards Senegal and the other countries of the sub-region nutrient salts that are present in the upwellings. We can also note a decrease in the power of trade winds, which could have a direct impact on the force of upwellings, and thus on the productivity of fisheries and of the wider marine environment. Last, the temperature increase could lead to the development of toxic agents in marine animals (mainly molluscs and fish).
- Impact **on the fishing activity and the fishermen communities**. Fishermen communities are installed on the beachfront and are thus the first affected by the effects of accelerated sea level rise, in terms of coastal erosion and marine submersion. Both the dwellings and the fishing installations and equipment are threatened.

With its impact on agricultural resources, the climate also plays a non-negligible role in the development of the Senegalese artisanal fishing sector. Indeed, numerous recent and older examples confirm the idea that fishing and shell harvesting have contributed to alleviating food crises caused by poor rainfall. Even today, the deterioration of climate conditions significantly contributes to the partial or total reconversion of social groups in professional fishing. Indeed, the development of fishing (both estuary and marine) within local communities of rice growers, breeders and farmer-fishermen is unquestionably one of the most striking social phenomena of the past twenty years.

It should thus be noted that, whatever the impact of climate change on the fishing industry, the main deterioration factor of the activity is, and will very likely remain, overfishing. Although

foreign industrial fishing fleets, accused of plundering the fishery resource off the Senegalese coasts, have had their authorizations withdrawn, this does not solve the problem. A recent study carried out by the CRODT (Dakar-Thiaroye Oceanographic Research Center) and the IRD (Research Institute for Development, France) points the finger at **artisanal overfishing**. Quadrupling in thirty years of the number of pirogues (partly fueled by the reconversion phenomenon described above), modern equipment to track groupers (GPS, sounding machines, etc.), increase in grouper prices, increase in demand, subsidies, etc. All these elements are contributing to the depletion of 'thiof' (local name for groupers) off the Senegalese coasts. And according the the CRODT, other species will follow. This phenomenon is causing a **deep crisis** in the entire industry. One after the other, fish processing plants (canneries, freezing facilities, etc.) are closing down, for lack of fish. Those that persist are running at a third of their capacity.

The other deterioration factors of the fishing industry are industrial development and the strong growth of the urban population over a narrow coastal strip (approximately 50% of the population is living less than 100 km from the shoreline). The deterioration of water quality is particularly severe around the large cities. The use of the terrestrial environment (leading to soil erosion and deforestation) has led to a massive sediment supply in coastal areas, inducing very often a deterioration of coastal habitats and a decrease in water quality.

Within the framework of this study, **the impossibility to more precisely evaluate the impacts of climate hazards on this activity** is not related to a lack of information regarding professional fishermen or the added value generated by this sector (including fish processing and selling). In fact, the evaluation difficulty is more related to the nature of the impacts. What needs to be evaluated is the cost induced by working conditions that have become more difficult. The costs to take into account are for instance the displacement of the boat grounding areas, of the repair areas for pirogues and fishing nets, and of the fish processing and selling sites. The activity must thus migrate according to the space available on the coastline. The reduction in the number of sea access points is another issue. To state things simply: either beaches are disappearing because of coastal erosion, or sea access is blocked due to the implementation of structures to protect the shoreline against coastal erosion or marine submersion. *In fine,* the task is to evaluate the adaptation cost of this sector to much more constrained land availability and sea access.

Nonetheless, while fishermen might have the adaptation capability to cope with these more difficult conditions, the heart of the issue for the fishing activity is undoubtedly the depletion of fish resources. Even if all fishermen could continue practicing their activity without any constraints (of land availability and sea access), competition at sea is growing fast due to the depletion of resources.

In any case, it is strongly recommended to continue this reflection in all the studies related to climate change adaptation of coastal zones, notably at Saint-Louis where fishing is the main economic activity.