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Integrated coastal management strategy for the Saint-Louis region, Senegal

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Abstract:
The city of Saint-Louis (Senegal) and its region are particularly prone to river flooding in the lower river delta area and to coastal flooding and erosion along the waterfront.
To avoid a major flooding in 2003 in the city of Saint-Louis, Senegal, the authorities decided to evacuate excess river discharge by creating an artificial breach 7 km south of the city, across the sandy strip of the Langue de Barbarie (LdB).
This measure prevented flooding of the city, but the breach expanded uncontrollably over the years, migrated to the south, and strongly affected populations, economic activities, and the ecosystem, without definitively resolving the flood risks in the area.
A long-term sustainable management strategy for the lower river delta (PROGEP project) and the waterfront of the city of Saint-Louis (SERRP project) has been developed.
This paper focusses on the PROGEP project, for which the multi-thematic analysis carried out enabled several types of solution to be distinguished and compared in depth.
Finally, it is recommended to maintain the natural functioning of the lower delta, while attenuating the negative impact of the southward migrating river mouth, by a package of urgent protection measures. To avoid inundation of Saint-Louis after horizon 2050, whenever a peak (≥ 1/10-year) river discharge is recorded upstream, an artificial breach should be created through the sand-spit a few kilometers south of the town of Degouniaye.
This "Building with nature" scenario could be compatible with a future harbor, as aspired by the organization OMVS, although an artificial sediment by-pass would in that case be necessary to avoid breaching of the sand spit, and several other challenges remain.

Keywords:
Coastal engineering, ICZM, Maritime hydraulics, Beach nourishment, Sand spit, Coastal ecosystems, Lagoon, Estuary, Nature based solutions, Cost-benefit analysis, MCA.

1. Introduction

The region's capital city Saint-Louis is located in the low delta of the Senegal river, on the northern part of the Langue de Barbarie (LdB) sand spit, between the river and the sea (Figure 1). This UNESCO heritage site is estimated to have about 250,000 inhabitants in 2020 of which about 55,000 are living on the LdB. Mostly fishermen's neighbourhoods are present there, together with tourist infrastructure on its southern part. The history of the city is marked by the recurrence of floods, the more recent being of 1994, 1999 and 2003. The vulnerability of the city to flooding is primarily related to its low topography, mostly lying below 1.50 m IGN, anarchic urbanisation, and poor river-dike protection.

Figure 1. Saint-Louis, a territory between river and ocean.

To avoid a major flood in 2003, the authorities decided to expel excess water from the river by creating an artificial breach 7 km south of the city, across the LdB (Figure 2). This measure prevented widespread flooding, but the breach expanded uncontrollably over the following years and became the new mouth of the river, migrating to the south at an average rate of 500m/yr. This sudden change in environmental conditions and the progressive displacement of the mouth towards the south is having numerous impacts on local villages, fishing activities, agriculture and delta's ecosystem, without definitively resolving the flood risks, to which 180,000 inhabitants could be exposed by 2050.

Against this backdrop, the Government of Senegal has drawn up, with the assistance of the Egis-Deltares consortium, a sustainable and long-term management strategy for the lower Senegal River delta, as part of the PROGEP project (Projet de Gestion des Eaux Pluviales et d'adaptation au changement climatique), funded through the WorldBank (WB) program, through a grant from the Nordic Development Fund (NDF).

As a complement to PROGEP, the SERRP project (Saint-Louis Emergency Recovery and Resilience Project), was designed initially to provide a solution for the populations of the Langue de Barbarie exposed to repeated destructive floods from the sea (freeing up a 20m coastal strip and relocating the populations concerned), but also to offer a sustainable protection solution against coastal flooding, erosion and rainfall flooding.

Figure 2. Evolution of the width of the breach (left: onsite; right: satellite images).

During the course of these two projects, in-depth technical analyses have been carried out to understand and predict future evolution of the complex dynamics of this coastal area. These studies, conducted alongside stakeholder, social, economic, financial and environmental analyses, have enabled several management strategies for the study area to be developed and evaluated, incorporating hard and soft, nature-based, solutions.
This paper focusses on the PROGEP project, describing the challenges of the low delta area and the evaluated management strategies.

2. Lower delta dynamics

The sediment dynamics of the Senegal river mouth is strongly dependent on the wave climate and river flow. Ocean waves from the northwest induce a strong southward directed sediment transport along the coast. Net annual transport rate in the study area is estimated to be between 0.8 to 1.2 million m^3/yr. Under this strong littoral drift, the sand spit extends further southwards over time, forcing the river mouth to migrate with it at an average rate close to 500 m/yr.
The natural morphodynamics of the LdB is dominated by breaches, which are the result of the combination of both fluvial and marine dynamics; they occur mainly during periods of high-water discharge, at narrow, low lying sections (SY *et al*., 2015). The spit was affected by 7 breaches between 1850 and 1900, and by 13 breaches between 1900 and 1973, all natural (SADIO *et al.*, 2017). When a new breach formed north of the existing river mouth, this often became the new river mouth, and migrated southward over time. This is a cyclical process, with a period of about 10 to 20 years on average over the last few centuries (NIANG & KANE, 2011). It is interesting to note that between the beginning of the 20th century and the artificial opening in 2003, the river mouth was always located at least 15 km south of Saint-Louis. This can (partly) be explained by the fixation of the sand spit by plantation of filaos trees, undertaken in the first two decades of the 20th century.

3. Existing challenges

The current position of the river mouth of the Senegal River is associated with numerous socio-economic and environmental interests and challenges, which are often conflicting:
a) *Reduce the risk of flooding of the city of Saint-Louis by the Senegal River* - The closer the river mouth is to Saint-Louis, the lower the risk of flooding;
b) *Limit coastal erosion at the villages in the Gandiolais region* - The inner delta is exposed by the southward migration of the new mouth of the river;
c) *Preserve agricultural activity in the Gandiolais* - The farther the river mouth, the lower the salinity in the estuary, and thus the saltwater intrusion;
d) *Improve fishing activities at Langue de Barbarie and the Gandiolais* - By securing (ideally stabilizing) the access to the sea from the river and the beach;
e) *Preserve environmentally important zones* – Sensitive areas are, exposed by the southward migration of the new mouth of the river (e.g. mangroves, "Birds island");
f) *Provide a maritime outlet for the Senegal River navigation project* - By securing the mouth of the river near Saint-Louis with dikes and a sand bypass system;
g) *Prevent the formation of new breaches* – New breaches could have devastating effects.

4. Technical approach

The analysis of the coastal system is essential for the development of effective and sustainable intervention measures. Three vast geophysical and hydrodynamic measurement campaigns (SBES, LiDAR, ADCP, drifting buoys, river discharge, water levels, CTD, sediments) were realized, over a coastal zone of about 35 km, between Diama dam and the former river mouth in Potou, to obtain detailed knowledge of the natural system and to provide input and calibration data for numerical modelling, as well as to identify potential sand sources for nourishments.
Various state-of-the-art numerical (morpho)dynamic models (Infoworks, SWAN, Delft3D-FM, ShorelineS, Unibest-CL+, XBeach) of river and coastal areas have been set-up to evaluate various scenarios and help in the preparation of an integrated action plan.
In the view of defining a sustainable strategy in a long-term perspective, three climate change scenarios for SLR, wave climate and river flow, were considered.

5. Evaluated management strategies for the lower river delta

5.1. Baseline scenarios and first technical evaluation

Four baseline scenarios were studied over the coming decades, namely:

- Scenario 1: "No intervention on the river mouth",
- Scenario 2: "Distant river mouth to the south of Saint-Louis",
- Scenario 3: "Controlled river mouth near Saint-Louis",
- Scenario 4: "Partial diversion of the Senegal River north of Saint-Louis".

In the first scenario, the sand spit will continue its migration southward, and a risk of natural breach of the LdB will stay present at low-lying places (Figure 3; left). In scenario 2, a solution is sought that would allow the river mouth to be positioned further away from Saint-Louis, to protect the Gandiolais and maintain a natural system in the south end with cyclic formation of breaches (Figure 3; centre). In scenario 3, the river mouth is artificially fixed to the immediate south of Saint-Louis, to seek synergy with the OMVS port project (Figure 3; right). Scenario 4 involves the partial diversion of the Senegal River upstream of Saint-Louis. Its main objective is to limit the risk of flooding in the city of Saint-Louis and the Gandiolais region.

Meetings and interviews conducted with stakeholders have helped to identify additional options that could improve the efficiency of the baseline scenarios. These additional developments are included in the form of variants to the baseline scenarios:

- Scenario 2-1: Overflow weir to the south of Saint-Louis
- Scenario 2-2: Flood-risk reduction actions around Saint-Louis
- Scenario 2-3: Permanent river-sea link at location of river mouth in 2003
- Scenario 2-4: Fishing wharf
- Scenario 3-1: Flood-risk reduction actions around Saint-Louis

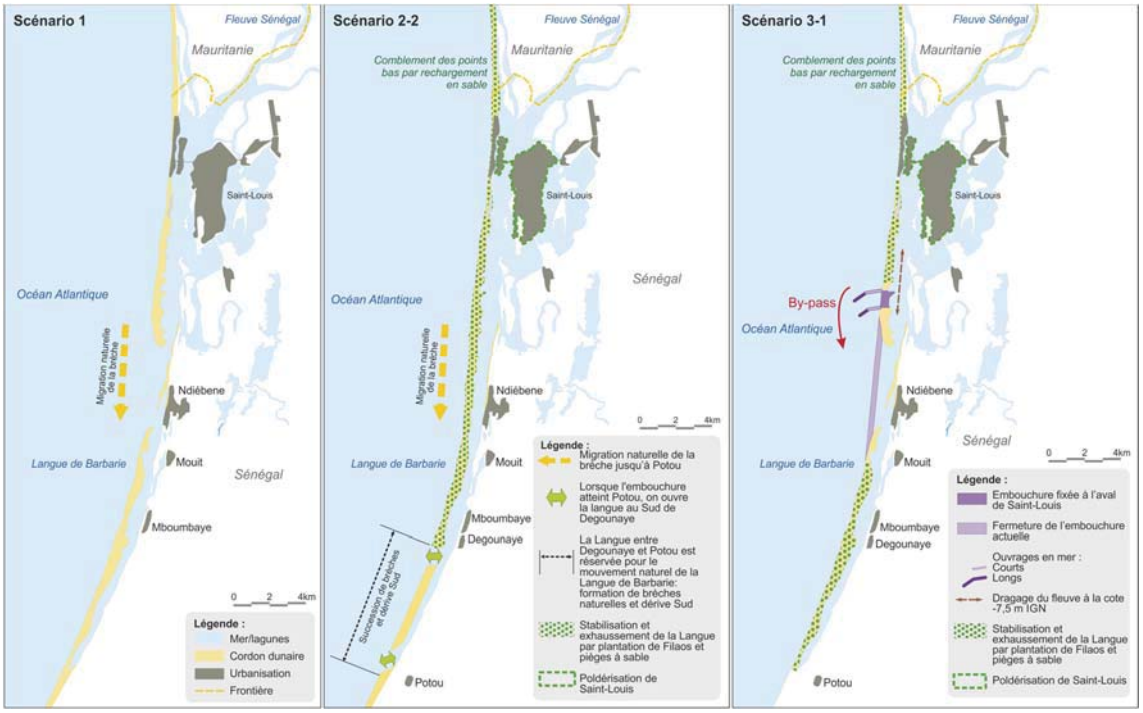

Figure 3. From left to right, Scenario 1 with a natural evolution of the system, Scenario 2.2 natural evolution plus natural cyclic behavior between Degouniaye and Potou, and Scenario 3.1. a closed system with a harbor.

After technical evaluation of the scenario's and their subvariants, several have been discarded from further socio-economic analyses, namely Sc 4 (interesting in the short

term only, with a risk of formation of a breach north of Saint-Louis, and requiring an intervention in Mauritania), Sc 2-1 (limited hydraulic interest, fixed structure at risk of erosion), Sc 2-3 (high-risk for river flooding of the city Saint-Louis, risk of inoperative infrastructure and destruction in case of a natural breach occurring upstream), Sc 2-4 (partial answer only to the concerns of fishermen, risk of sediment transport perturbation, although limited, potentially leading to a new breach).
Finally, a fifth (optimized) scenario is defined, that builds further on scenario 2-2, and in combination with a package of "no-regret" protection measures: Scenario 5: "Building with nature". This optimized scenario is based on the natural migration of the river mouth towards the south, and includes the reinforcement of the river-dikes around the city to 2mIGN. However, with the natural southward migration of the river mouth, the risk of flooding in Saint-Louis will nonetheless increase, particularly after horizon 2050. To avoid flooding of Saint-Louis, Scenario 5 proposes the cyclical creation of an artificial breach a few kilometres south of Degouniaye. Whenever a large river discharge (>1/10 year return period) is measured upstream at the hydrological station of Bakel, there will be a delay of 45 to 50 days before the flood peak will reach Saint-Louis. This delay makes it possible to initiate a breach in the Langue de Barbarie, which will expand naturally by river and tidal currents, allowing thereby the surplus of river water to drain quickly into the sea. This implies the reinforcement of the sand spit down to Degouniaye, to ensure that no natural breaches will occur upstream. Natural behavior of the LdB is then only allowed between Degouniaye and Potou. The elevation of the coastal area is here higher than +2.5 mIGN and few villages only are present on this part of the old riverbank, so that coastal erosion will have less impact.

5.2. "No-regret" protection measures

The so-called "no regret" protection measures, mostly nature-based, are not sensitive to existing scientific uncertainties or the final choice of development scenario. They are listed below, from the short term (actions *a* to *e*) to middle term (2035; actions *e* and *f*):

a. *Protection of the natural environment*: Bird Island relocation. Due to the southward migration of the river mouth, the bird island, an iconic bird reproduction area of the National Park will soon be at risk. It is recommended to relocate it immediately.
b. *Improvement of the artisanal fishing activity of Saint-Louis*: Navigation safety improvement. It is recommended to implement channel buoys in the river mouth and update them every 2 months. A large sand nourishment in front of the waterfront of Saint-Louis, as planned in the context of the SERRP project, would also support the fishing activity along the city waterfront, and limit the traffic through the river mouth.
c. *Fresh water availability*: The extension of an existing irrigation channel would provide a short-term solution to the availability of water for agricultural activity in the Gandiolais.

d. *Reinforcement of the LdB*: To avoid the formation of a natural breach, sand nourishments are recommended at three critical locations (850 000 m³), together with the pursuing of stabilization's actions initiated by the Protected Marine Area, and involving local communities, *i.e.* installing ganivelles locally made of invasive plants, planting of Filaos trees and mangroves (Figure 4).
e. *Protection of the coastal villages of Gandiolais*: preventive sand nourishments are recommended to mitigate the impact of the future passage of the river mouth (1 Mm³).
f. *Flood protection of the city of Saint-Louis*: It is recommended to increase to 2 mIGN the level of protection of the inhabited areas of Saint-Louis (8.9 km of quays / dikes). This latter action will be necessary regardless of the development scenario selected.

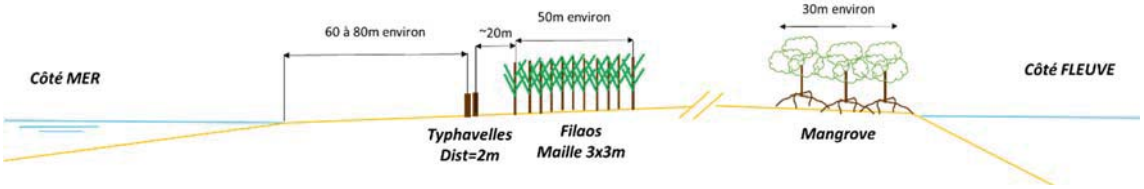

Figure 4. Cross-section of the surface works retained for the reinforcement of the sand spit Langue de Barbarie.

5.3. Scenarios retained for detailed technical and socio-economic analysis

In total four scenarios were selected for technical and detailed socio-economic analyses, namely scenarios 1, 2-2, 3-1 and 5. The cost-benefit analysis (CBA) shows that flood is the main hazard contributing to the direct damages, far away from coastal flooding and erosion. The inhabitants are the most exposed issue, before agricultural areas.

From the CBA and multi-criteria analysis (MCA), scenarios 1 and 2-2 were the least effective in resolving the existing challenges in the region. Scenario 3-1 and 5 emerged as the most promising and the most satisfactory among stakeholders.

a. *Scenario 3-1 "Controlled river mouth near Saint-Louis"* presents positive impacts for sea fishing activity, tourism, commercial development (harbor), the Gandiolais region (erosion prevented), and for the inhabitants of the city, protected from flooding. Negative impacts concern mainly agriculture in the Gandiolais region (salinity), and the marine protected area, directly impacted by the port construction. Not to mention the very high cost of the Scenario 3-1, it also includes the implementation of a sand bypass system to restore sediment transport. This sand bypass is an absolute necessity and must be maintained indefinitely, otherwise, in case of failure, the port access structures could be rapidly destroyed, and a new breach would occur in the LdB to the south of the port.
b. *Scenario 5 – "Building with nature"* allows to respond to the current problems for most of the issues. On the basis of the indicators produced as part of the CBA, scenario 5 is the scenario offering the best collective profitability. It brings a clear improvement on the protection against flooding, coastal erosion and risks of breach

formation. The fishing activity also benefits. On the other hand, the agricultural activity remains strongly affected, on the one hand by the current location of the river mouth, but towards the end of the century, also by climate change. The river fishing activity will also be affected. This scenario does not foresee the construction of a port.

6. Conclusions

The Senegal lower-river delta is vulnerable to inundation, salt intrusion and coastal erosion and flooding. These hazards are associated with numerous, often conflicting, socio-economic and environmental interests and challenges. They moreover rapidly vary in time and space, due to the rapid southward migration of the river mouth. In the context of the PROGEP study, several short to long-term management scenarios for the Senegal lower-river delta have been studied in depth. The technical and socio-economic analyses (CBA/MCA) carried out led out to recommend maintaining the natural functioning of the lower delta, while attenuating the negative impact of the southward migrating river mouth, by a package of urgent, "no-regret" protection measures. To avoid inundation of Saint-Louis after horizon 2050, whenever a critical river discharge is recorded upstream, an artificial breach should be created through the sand-spit a few kilometers south of the town of Degouniaye. This "Building with nature" scenario could be compatible with a future harbor, as aspired by the international organization OMVS, although an artificial sediment by-pass would in that case be necessary to avoid breaching of the sand spit, destruction of the entrance dikes, and several other challenges remain. It has therefore been retained by the Government of Senegal to initiate as soon as possible the proposed "no-regret" measures foreseen in this scenario as well as an early warning system.

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