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Study of the Risks of Overflow and Salinization of the Mbao Backwater: Impact on Local Populations

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ABSTRACT

The Mbao backwater, located in the Mbao forest in Dakar, plays an important role in income generation and flood prevention for the localities of Pikine, Keur Massar and Rufisque. Today, it is increasingly threatened with the risk of overflow due to the considerable reduction in its storage capacity and the arrival of large quantities of runoff water from the watersheds of which it is the outlet. In addition, its salinization is noted due to its proximity to the sea. The objective of this article is to present the results of the study of the risks of overflow and salinization of the Mbao backwater and their impacts on socio-economic activities. After modelling the volumes of water received by the backwater using the EPASWMM software and a study of its vulnerability to saline intrusion during high tides, It emerged that in the event of a decadal rainfall of the Desbordes type in the area, an overflow of 1,001,758 m^3 could be noted, causing flooding and inconvenience to the local populations. In addition, a connection between the waters of the sea and those of the backwater causes salinization of the latter, negatively impacting the market gardening activities carried out by local residents. A pumping system at 1,500 m^3/h could help prevent the backwater from overflowing, and the construction of a weir dam between the sea and the backwater would help control the salinization of the downstream part.

Keywords: risk, overflow, salinization, vulnerability, Mbao backwater

1. INTRODUCTION

Climate change is causing an increased manifestation of climate risks such as changes in air temperature, sea level rise, changes in the amount and distribution of precipitation. Precipitation is the most important factor in climate for both people and ecosystems. But over the past three decades, the evolution and consequences of floods in Africa have changed their are disastrous [1],[2].

Most African countries have experienced urban growth that is difficult to control. In West Africa, this population dynamic has accelerated with the creation of peri-urban areas that are sometimes undeveloped [3]. Urbanization, which has led people to settle in high-risk areas (lowlands, flood zones, swamps, riverbeds), is now a real problem. The expansion and multiplication of constructions (causing soil sealing) has led to increased runoff in watersheds as well as the accumulation of water following abundant rainfall. Senegal has been heavily affected by floods in recent decades. The new conditions created by an increase in rainfall, changes in land use, hydrogeological context, the dysfunction of the hydrographic network and the absence of a sanitation network are all factors that have contributed to this situation [4].

This situation is noticeable in the commune of Mbao, located in the peri-urban area of Dakar, which is no exception to this phenomenon. Since the beginning of the 1990s, marking "a recovery in rainfall" (Mballo, 2013), floods have become frequent in this peri-urban area. The Mbao watershed, a rainwater receptacle, drains a backwater during the winter after each rainy episode and significant perennial runoff. Thus, the backwater is threatened with overflow with the increasing inflows and its storage capacity which is reduced year after year with the solid inputs. Added to this is the salinization of the waters of the backwater due to its communication with the sea [5]. The objective of this study is to model the volume of water in the reservoir with the inputs from the watersheds to predict a possible overflow. It will also study the salinization aspect of the backwater, which is a key parameter in the quality of the water since it is used for market gardening in the area.

2. MATERIALS AND METHODS

2.1. Presentation of the study area

2.1.1. Geographical location

The Mbao Protected Forest is located in Senegal in the Dakar region. It is bounded to the north by the traditional villages of Boune, Darou Misseth and Medina Kell in the commune of Keur Massar North, to the south by Petit Mbao and Grand Mbao in the commune of Mbao, to the east by Kamb and Keur Mbaye Fall in the commune of Keur Massar Sud, and to the west by the National Road N°1 and the ramps of Petit Mbao and Fass Mbao starting with the commune of Diamagueune Sicap Mbao. Figure 1 shows the location of the Mbao Protected Forest [6],[7],[8].

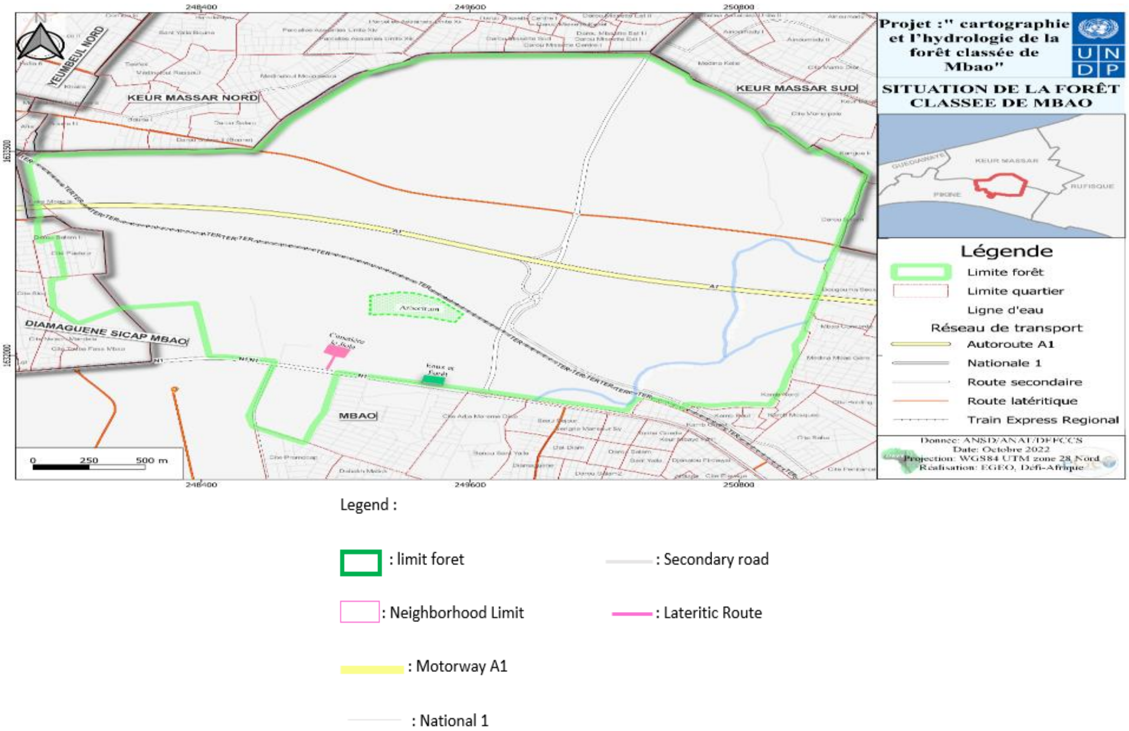
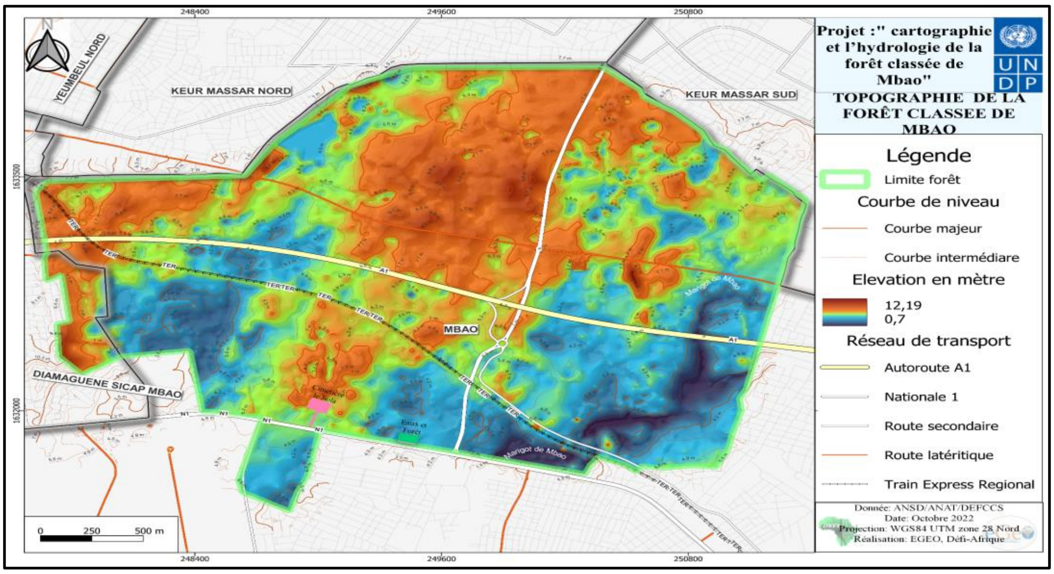


Figure 1 : Geographical location of the Mbao Protected Forest [9]

2.1.2. Topography

The forest has a low topography with a maximum altitude of 12.19 m at PK 111 at the Keur Massar bridge and a minimum altitude of 0.7 m at the Marigot de Mbao. It is located in the Niayes area, which is characterized by a succession of inter-dune depressions that allow the water table to outcrop [10]. Figure 2 shows the topography of the area



Legend :

: Forest boundary : Elevation in metres

Figure 2 : Carte topographique de la forêt classée de Mbao [11]

2.1.3. Rainfall

The annual rainfall of the study area, with large variations of up to 3 multiplicative factors from one year to the next, also experienced a significant downward trend from the 1970s to the early 2000s. An upward trend in annual rainfall has been noted since the early 2000s. The average values of the annual rainfall are, depending on the period:

- 1896-1969 : The annual average is 550 mm
- 1970-2004 : The annual average drops to 340 mm
- 2005-2016 : The annual average is 479 mm.

Figure 3 below shows the evolution of annual rainfall in Dakar from 1970 to 2020.

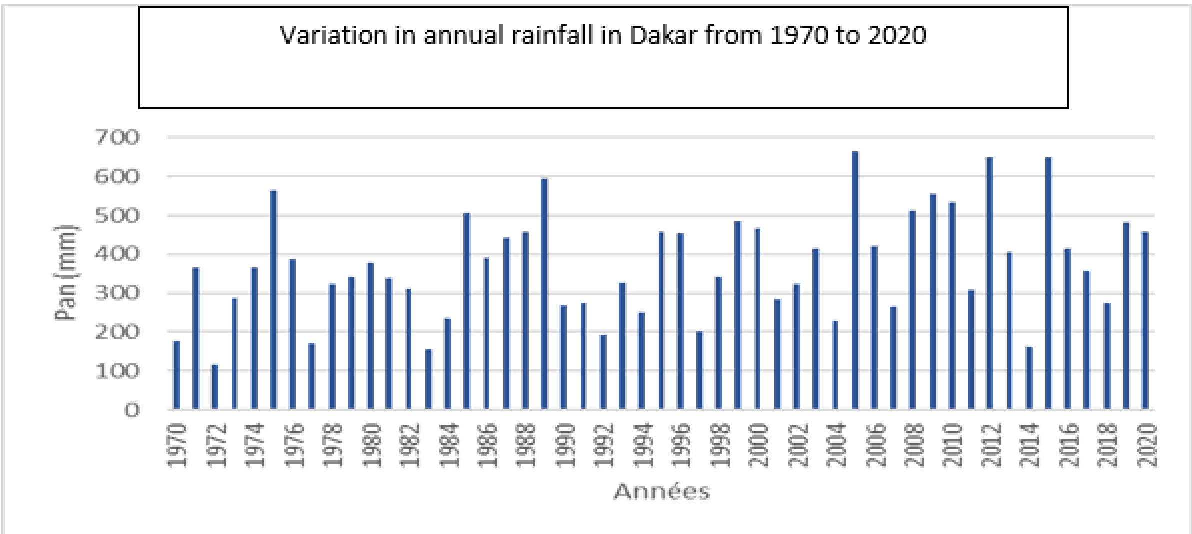


Figure 3 : Variation in rainfall in Dakar from 1970 to 2020 [12]

2.2 Overview of the Global Mapper software

Global Mapper is a mapping software developed by BLUE MARBBLE GEOGRAPHICS to produce maps with digital elevation models (DEMs), flow simulations, zoning maps, and watershed and subwatershed boundaries of a given location.

With Global Mapper, nine (09) sub-watersheds (SBVs) that feed the Mbao backwater have been identified (Figure 4). Global Mapper also made it possible to have the physical characteristics of these SBVs presented in the results section (Table 1) [13].

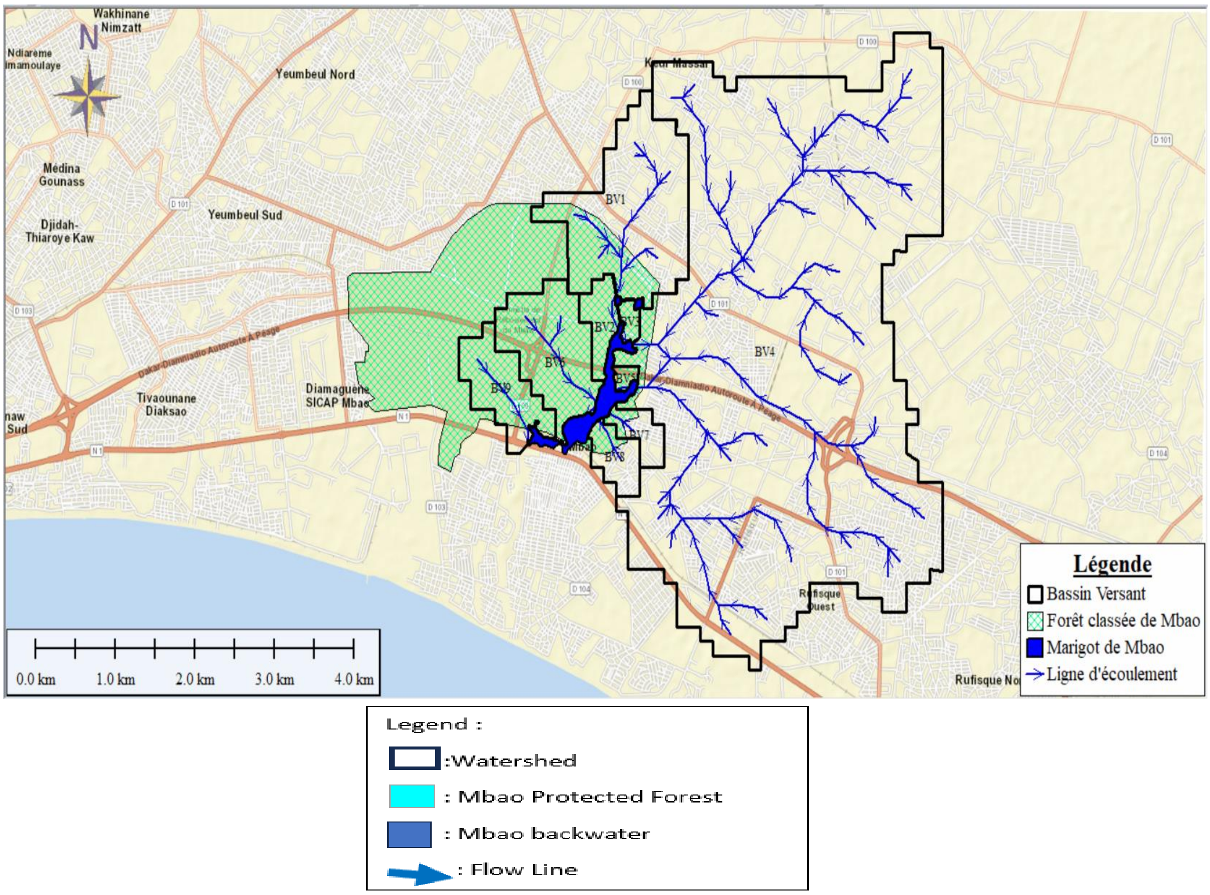


Figure 4 : Watershed map with street map imagery

2.3 Overview of EPA SWMM Software

EPA SWMM (Storm Water Management Model) software is software geared towards precipitation or flow during a single or continuous event. quantity and quality of flow, mainly in urban areas. This software was created in 1971 and has since seen many improvements. Today, it is used all over the world. Indeed, because of the physical parameters it requires and which do not oppose the location of the basin to be studied, it is now widely used in Senegal. Version 5 is produced by the U.S. Environmental Protection Agency with the assistance of a consulting firm. In addition, EPA SWMM uses hydrological models such as Horton, Green Ampt, Curve Number, etc.

The input parameters are existing data that allow us, once entered into the software, to make a flow calculation, to simulate the runoff in the watershed and to have the runoff volumes and volumes for a given infiltrated rain (EPA SWMM, 1971), (Lavabre et al., 1997), (Sakar et al., 2006). These parameters are project rainfall which is defined by a synthetic hyetogram and which is statistically equivalent to the actual rainfall ever observed (Halff et al., 1993), (Folland et al., 1986), (Le Barbe et al., 2002), (Lebel et al., 2003). In the DP, the return period of design storms T = 10 years was defined. We use them to diagnose the network. There are five (5) of them and they are as follows: four (4) short rains, elaborated according to the double delta method, characterized by their intense periods: DESBORDES type rains 15, 30, 60 and 120 minutes.

2.4 Salinity study method

Salinity measurement is carried out on the Mbao backwater (forest and non-forest part), on irrigation wells or ceanes. These measurements are coupled with soil sampling in the cultivated plots and in the vicinity of the backwater (the major bed) on both sides of the highway in order to determine the conservation relationship of the soils in the cultivated plots. The lack of baseline studies on salinity in the forest does not allow mineralization to be assessed prior to current measurements. The data presented are therefore baseline values. For the in situ observations, the method consisted of measuring the salinity from the ocean to the point of the biodiversity pond constituting about a 4 km path with a branching in the inhabited part (outside the park). Points are taken at intervals of about 250 m.

Electrical conductivity (EC) values are given in millisiemens per centimeter (mS/cm) which we have converted to microsiemens per centimeter (µs/cm) to facilitate the calculation of the overall mineralization and interpretations. From the conductivity values, the overall mineralization was determined and allows the dissolved salt content in the water to be assessed. The equivalence method of RICHARD and VAN CU (RODIER, 1984) was used to observe the amount of dissolved salts. It assigns an equivalence coefficient to each EC value observed according to the defined intervals (Table 1) (EDE Senegal, 2017).

Table 1 : Equivalence coefficients in the RICHARD and VAN CU method

CE (µs/cm)	EQUIVALENCY
<50	1,365
50-166	0,948
166-333	0,77
333-833	0,716
833-10000	0,759
>10000	0,85

3. RESULTS AND DISCUSSIONS

3.1 Physical characteristics of watersheds

The fairly low altitudes confirm the proximity of the area to the sea. However, the slopes of the land are not very significant, which shows that the significant runoff is rather due to the waterproofing of the area due to urbanization. The specific differences in altitude observed (Ds < 10 m) show a fairly low relief of the area.

Table 2 : Physical characteristics of watersheds

Watershed	Surface A (km²)	Perimeter P (km)	Medium slope (%)	Max Altitude (m)	Outlet Altitude (m)	Elevation gain D (m)	Max Length Lmax (km)	Compactness index Icomp	Rect length eq Léq (km)	Overall slope index Ig (m/km)	Specific elevation gain Ds (m)
BV1	2.513	8.923	0.79	15	5	10	1.884	1.58	3.762	2.66	4.21
BV2	0.335	3.085	0.72	10	5	5	0.405	1.49	1.268	3.94	2.28
BV3	0.099	1.420	0.42	8	6	2	0.126	1.26	0.512	3.91	1.23
BV4	19.230	27.811	0.90	30	5	25	4.970	1.78	12.235	2.04	8.96
BV5	0.067	1.162	0.78	8	5	3	0.170	1.26	0.418	7.18	1.85
BV6	1.300	6.207	0.74	11	2	9	1.449	1.52	2.577	3.49	3.98
BV7	0.276	2.810	0.97	12	3	9	0.365	1.50	1.156	7.78	4.09
BV8	0.358	2.890	0.93	12	3	9	0.522	1.35	1.113	8.09	4.84
BV9	0.811	5.579	0.70	11	3	8	1.159	1.73	2.437	3.28	2.96

3.2 Study of the overflow of the backwater

An overflow is observed for rains of 15, 30, 60 and 120 minutes. We will just present the overflow of the extreme rain (120 mns) for the sake of brevity.

For this rainfall event, the volume of water expected to receive from the backwater is 1,797,010 m3, exceeding the storage capacity of the backwater which is 795,251.4 m3. There will then be an overflow of 1,001,758.6 m3 of water.

Figure 6 shows the variation in flow for a 4-hour rain of the DESBORDES type with an intense duration: 120 min.

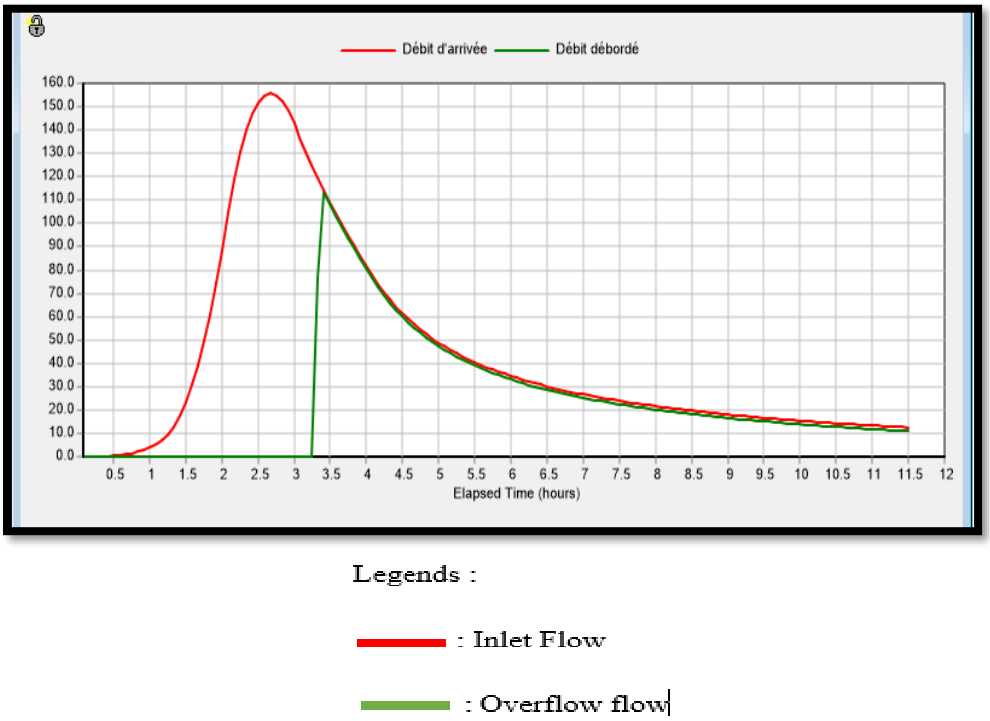


Figure 6: Variation in flows for a Desbordes-type rainfall; Intense duration: 120 min

The analysis of the different types of project rainfall shows that the volumes of runoff water far exceed the storage capacity of the backwater. Pumping is then a solution to consider to avoid overflow. Thus, for a rainfall of 120 minutes with a pumping of 1,500 m3/h, we would have the appearance of the curve presented in Figure 7.

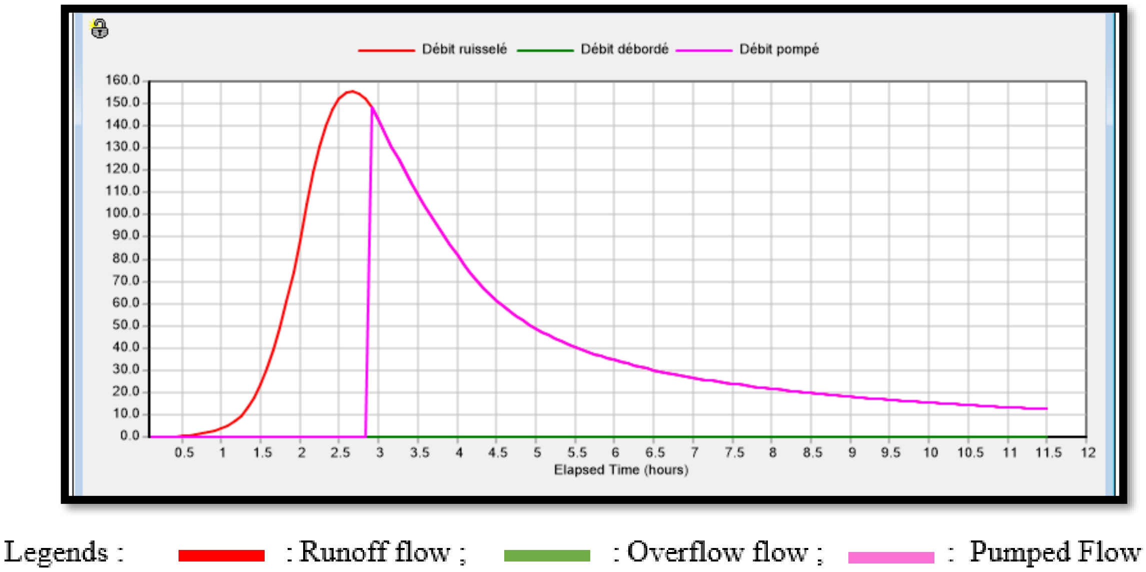


Figure 7: Variation of flow rates for a Desbordes rain, duration 120 min with pumping of 1500 m3/h

We observe that there is no longer an overflow and that pumping starts towards the end of the second hour until the end of the simulation. The capacity of the backwater is maintained at 534,800 m^3. A pump of 1500 m^3/h is then sufficient to prevent the backwater from overflowing.
In addition, a reduction in the capacity of the backwater over the years is caused by the solids during runoff water inputs. Thus, a regular reprofiling of the bottom of the backwater would be a way to maintain its capacity more or less constant over time.

3.3 Study of the salinity of the backwater

The main consequences of rising sea levels and their advance on the continent are:

- the invasion of land and water by salt, which mainly leads to a reduction in land suitable for agriculture
- the loss of some homes and infrastructure located by the sea and in low-lying areas.

The first phenomenon has been the subject of specific field investigations based on the analysis of water samples from the backwater of the wells and ceanes of the backwater, which has given results illustrated by the following map (Figure 8) which shows that along the Mbao backwater:

- the salinity of the water is excessive from the sea to beyond the railway line
- then it drops to remain very strong (between 1.5 and 3 g/l).

High salinity values (0.5 to 1.5 g/l) are observed on structures located relatively far from the backwater and to the east of the forest. These structures should certainly be located in the vicinity of the tributaries of the backwater, which are also affected by the upwelling of the sea.

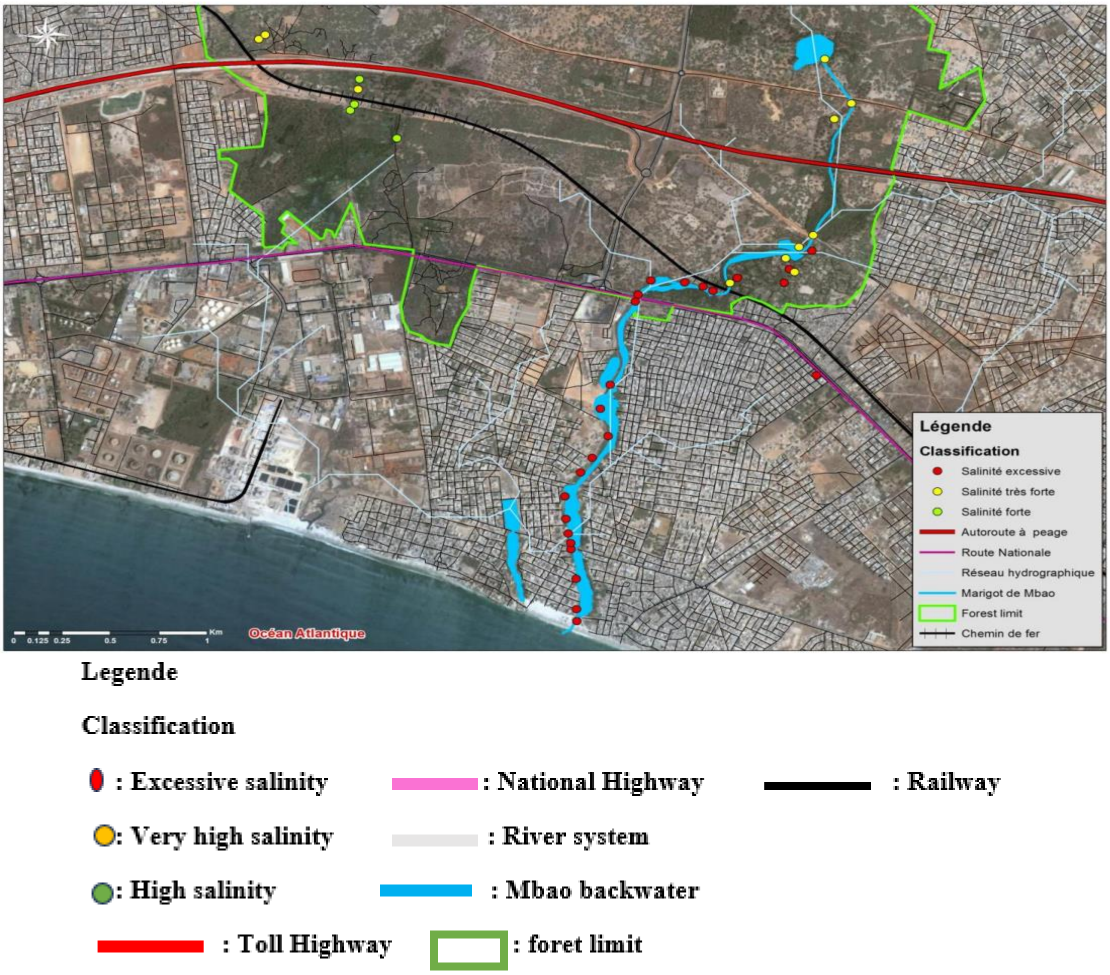


Figure 8: Variation in the salinity of the backwater in space

The solution to this advance of the sea would be a that would perform the following functions:

- block the advance of the sea, the level of which can rise to the coast + 2m;
- allow the flow of the Mbao backwater and the solid deposits carried by runoff water to pass through during normal periods.

CONCLUSION

In a context of climate change accentuated by an increasingly marked deforestation of forests, nature reserves, classified forests, parks, etc. have become key issues in the protection of the planet's biodiversity. The protected forest of Mbao is also more so because it is located in an area in full urbanization and is thus the green lung of Dakar.

Studies on the risk of overflow and water salinity are important elements in the management of the protected forest. Like these studies, studies of the vulnerability of the area's water table, hydrogeological prospecting studies, soil studies, etc. are all actions to be carried out to identify the physical environment and facilitate the implementation of management strategies. This is all the more essential as the agricultural activities of market gardening in the area depend on the water resource that constitutes the Mbao backwater.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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