

**DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA**

Ministry of Higher Education and Scientific Research

University of Tlemcen

جامعة أبو بكر بلقايد  
UNIVERSITÉ DE TLEMCCEN



**Pan African University**  
**Institute of Water  
and Energy Sciences**

**PAN AFRICAN UNIVERSITY**

Institute for Water and Energy Sciences (Incl. Climate  
Change)

**Climate Change Effects and Anthropically Induced Wetland  
Degradation: A Case Study of the Urban Natural Reserve of  
the Great Niaye of Pikine (Technopole)**

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**Date: 20/04/2024**

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**Examiner 1:**

*Academic Year: 2023-2024*

## **DEDICATION**

To our kind and beloved Prophet (PBUH)

To my dear parents Mamadou Alhousseynou LY and Coumba Hawoly Baro

To my dear brothers, sisters, half brothers and sisters, Moussa, Fatoumata, Aïssata, Oumar, Daha, Thierno, Khadidiatou, Amina, and Bebe Faty

To Pr Samehahmed KANTOUSH, Pr Assane BEYE, Dr Mbayang THIAM, Dr KhagendraPralhad BHARAMBE and Dr BinhQuang NGUYEN

To my DAMCP Family Colonel Assane NDOYE, major Bintou BA, Technopole manager Abdoulaye TOURE, Lieutenant Racine TOURE, Lieutenant Aminata DIA, Lieutenant Penda Gueye, Sergeant Mayacine, Sergeant Wally NIANG, the President Bassirou Ndiaye...

To my ISFAR ex ENCR Bambey Lecturers Dr Papa Babacar THIONE, Dr Cheikh Omar SAMB and Mr Birahim FALL

To My Apex Family My Uncle Amadou Tidiane DIA

To my colleague at ISFAR, especially Papa Diene, Maodo Malick NDAO, Seydina DIOP, Adama DIAO, Alioune Badara DIOP and Abdou Lahat SALL

To my PAUWES friends Adji Billo NIANG, Mor Kane DIOUF, Racky DIALLO, Salifou DOUMBIA, Abdoulai Osman KOROMA, Maimuna DRAMMEH and Jainaba TRAWALLY

To all my Algerian Friends

## **DECLARATION**

I, Aliousseyni LY, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here have been fully cited and referenced in accordance with the relevant academic rules and ethics.

## ABSTRACT

Senegal, like other coastal African countries, is home to some very important wetlands. These wetlands regulate flooding and help to reduce water deficits during periods of drought, as is the case in the Technopole reserve. In the Dakar region, the Technopole nature reserve plays a crucial role in the ecological balance and is of considerable economic and environmental importance.

This study examines the impact of climate variability and human activities on the degradation of wetlands at Technopole. An analysis of precipitation, maximum temperature and evaporation parameters was carried out alongside analyses of climatic indices, including flood and drought risks (SPI analysis), and lake water levels. In addition, field surveys and land use studies (from 1993 to 2023) were carried out, along with water quality analyses to measure levels of degradation.

Our studies indicate the influence of rainfall variability on the Technopole's lakes, leading to drought scenarios from the 1970s onwards. These scenarios posed challenges in terms of water renewal, fluctuating water levels, rising salinity levels and the risk of flooding in 2003 and 2013. In addition, the land use results show human pressure on these wetlands through the conversion of natural vegetation and bare land (304.59 Ha and 15.8 Ha, respectively) into buildings, farmland and water bodies, with values of 133 Ha, 109.87 Ha and 77.88 Ha respectively between 1993 and 2023. Agricultural and craft practices continue to pollute the environment and water through the use of chemicals. Water analyses reveal high levels of salinity in the five Technopole lakes and high levels of faecal coliforms in the two Maristes lakes, preventing the normal development of marine flora and fauna.

These results were used in the study to propose a sustainable development plan. This plan consists of concrete actions to combat the degradation and regression of the wetlands, such as taking into account land pressure and implementing integrated management of the reserves between political decision-makers and communities.

**Key words :** Wetlands, Climate change, degradation, anthropogenic induced.

## RESUME

Le Sénégal, comme d'autres pays côtiers africains, abrite des zones humides très importantes. Ces zones humides régulent les inondations et contribuent à réduire les déficits hydriques en période de sécheresse, comme c'est le cas dans la réserve de Technopole. Dans la région de Dakar, la réserve naturelle de Technopole joue un rôle crucial dans l'équilibre écologique et revêt une importance économique et environnementale considérable. Cette étude examine l'impact de la variabilité climatique et des activités humaines sur la dégradation des zones humides de Technopole. Une analyse des paramètres de précipitations, de température maximale et d'évaporation a été réalisée en parallèle avec des analyses d'indices climatiques, y compris les risques d'inondation et de sécheresse (analyse SPI), ainsi que les niveaux d'eau des lacs. En outre, des enquêtes de terrain et des études sur l'utilisation des terres (de 1993 à 2023) ont été réalisées, ainsi que des analyses de la qualité de l'eau pour mesurer les niveaux de dégradation.

Nos études indiquent l'influence de la variabilité des précipitations sur les lacs de la Technopole, conduisant à des scénarios de sécheresse à partir des années 1970. Ces scénarios ont posé des défis en termes de renouvellement de l'eau, de fluctuation des niveaux d'eau, d'augmentation des niveaux de salinité et de risque d'inondation en 2003 et 2013.

A cela s'ajoutent les résultats de l'occupation des sols qui montrent la pression humaine sur ces zones humides à travers la conversion de zones de végétation naturelle et de terrains nus (304,59 Ha et 15,8 Ha) en bâtiments, terres agricoles et plans d'eau avec des valeurs respectives de 133 Ha, 109,87 Ha et 77. 88 entre 1993 et 2023 et des pratiques agricoles et artisanales qui continuent à polluer l'environnement et l'eau par l'utilisation de produits chimiques, ainsi que des analyses d'eau révélant des niveaux de salinité dans les 5 lacs technopolitains et des charges de coliformes fécaux dans les deux lacs des Maristes, empêchant le développement normal de la flore et de la faune marines. Ces résultats ont été utilisés dans cette étude pour proposer un plan de développement durable. Ce plan consiste en des actions concrètes pour lutter contre la dégradation et la régression des zones humides, telles que la pression foncière, et la gestion intégrée de la réserve entre les décideurs politiques et les communautés.

**Mots clés :** Zones humides, changements climatiques, dégradation, activité anthropique

## ACKNOWLEDGMENT

- ✓ I give thanks to ALLAH, the Almighty, the Most Merciful, for granting me life and health so that I may successfully pursue this course. May blessings and peace be upon the Prophet Muhammad, the Servant of Allah.
- ✓ Our thanks go to the African Union for the opportunities for study and cultural enrichment at PAUWES.
- ✓ To Pr. Samerhahmed KANTOUSH, my supervisor, for his insightful guidance. It is difficult for me to find the words to express my gratitude and admiration for him. He generously shared his knowledge with me and followed the various stages of this work regularly. Thank you for his assistance, advice, relevant suggestions, and patience.
- ✓ To Dr. Mbayang THIAM, for her determination in work and commitment to training at WASCAL-UCAD and for agreeing to be my co-supervisor. I am grateful for her multiple services.
- ✓ To Mr. Pape Babacar THIOUNE, Lecturer-Researcher at ISFAR ex ENCR, for his unwavering support and availability.
- ✓ To Prof. Assane BEYE for welcoming me to WASCAL-UCAD.
- ✓ We thank Dr. KhagendraPralhad BHARAMBE and Dr. Binh Quang NGUYEN for their great technical support.
- ✓ To all the Pan-African professors at PAUWES.
- ✓ To the host country, Algeria, for its openness.
- ✓ We thank the Directorate of Community Marine Protected Areas and the Technopole Reserve Team for their unfailing support.
- ✓ To all those who have contributed, directly or indirectly, to the success of this work.

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## **LIST OF ACRONYMS AND ABREVIATION**

- **ADIE:** Sénégal Numérique SA (Numerical senegaleese)
- **ANACIM:** National Agency for Civil Aviation and Meteorology
- **CBD:** Convention on Biological Diversity
- **DAMCP:** Direction des Aires Marine Communautaire Protégée (Department of Community Marine Protected Areas)
- **BOD:** Biochemical Oxygen Demand
- **COD:** Chemical Oxygen Demand
- **FAO:** Food and Agriculture Organization of the United Nations
- **NDWI:** Normalized Difference Water Index
- **RAMSAR:** Ramsar Convention
- **SOGED:** Schéma d'organisation et de Gestion des Déchets (Waste Organization and Management Scheme)
- **SONATEL:** Societe Nationale de Telecommunication
- **SPEI:** Standarized Precipitation and Evaporation Index
- **SPI:** Standarized Precipitation Index
- **UNRGNPD:** Urban Natural Reserve of Great Niaye of Pikine and Dependance
- **USGS:** United States Geological Survey
- **UCAD:** Cheikh Anta Diop University

# I INTRODUCTION

In West Africa, particularly in the Sahelian regions often described as arid or semiarid, wetlands perform essential environmental functions (Zwarts et al., 2009). Senegal is a Sahelian country located in the western part of the African continent (Faye & Solly, 2019). It is subdivided into six ecogeographical zones (Groundnut basin, Senegal river valley, ferlo sylvo-pastoral zone, niayes zone, eastern senegal zone, southern forest zone), each home to several coastal, continental, and artificial wetlands. They are characterized by an almost permanent presence of water and migratory birds (Gardner et al., 2015).

The quantity and quality of wetlands are declining worldwide (Gardner et al., 2015). The services provided by wetlands (revive biodiversity, store carbon, improve livelihood, enhance well-being, replenish and filter water supply) continue to degrade either because of a lack of understanding or because of short-term economic gains (Finlayson & Rea, 1999). Darwin (1998) estimated that over half of the wetlands in semiarid South Africa have been destroyed through commercial agriculture, mining practices, and urban development.

In Senegal, several studies have been carried out on the state of wetlands at the regional and national levels. However, fewer studies have addressed them specifically and at local scales (De.Grande et al., 2023). Nevertheless, studies of land-use change point to a gradual degradation of Senegal's wetlands, in line with those of West Africa (Adama, 2011). The fourth national report on the Convention on Biological Diversity (CBD) implementation highlights that Senegal's wetlands are experiencing regressive dynamics (Senegal republic et al., 2010). Some wetlands are experiencing immense pressure from human activities, the most critical being drainage for agriculture and settlement, excessive exploitation by local communities, and improperly planned development activities (Kabii, 1996). Those of Pikine are the largest and are located in the heart of the urban agglomeration (Ndao, 2012). The dry periods of the 1970s, 1980s and 1990s were marked by a decrease in rainfall (Ndao, 2012). During this period, the spatiotemporal evolution of Niayes (Pikine) is characterized by a reduction in the surface area of wetlands, particularly by the disappearance of permanently flooded areas in favor of a spatial extension of soils with partial hydromorphy and partial hydromorphy with salinity (Ndao, 2012). Such environmental changes are the result of persistent drought whose intensity, duration and extent have been unique in the climatic records of the last fifty years (Ndao, 2012).

The conservation of the natural Reserve of Pikine is a real challenge due to the rapid growth of the city, which has resulted in increasing urban pressure (Berger, 2022).

Chemical analyses have shown that wastewater contains high levels of Mest, Dco and Dbo before and after treatment and does not comply with the Senegalese, Fao and WHO standards(Faye, 2019).

Moreover, a high number and amount of pesticides, including pesticides prohibited by international regulations, are used in an uncontrolled way in the market gardening zones of the Niayes peri-urban area(Tarentaise et al., 2020).

Indeed, in the technopole area, as in other wetland regions, road infrastructure, residential places and public facilities have been built, and agricultural land has been converted to residential areas(Berger, 2022).

Wetlands worldwide are experiencing tremendous changes due to various drivers from climate and human interventions(Ndao, 2012). Wetlands are susceptible to the hydrological responses of the catchment and the flow regime(Acreman & Bullock, 2003). The deterioration of the ecosystem and water quality eutrophication, among other factors, are the leading causes of wetland ecological degradation (Ansari et al., 2011). These wetlands are highly threatened by human and natural drivers (Sylla, 2021). This situation has led to an ecological imbalance, resulting in the disappearance of species that depend on certain wetlands and a decline in natural wetlands in favor of artificial wetlands (SOGED, 2019). Despite the importance of wetland systems and their crucial contributions to ecosystem services, minimal research has been conducted to analyze the coupled impacts of climate and human activities(Ricaurte et al., 2017). Climate change-driven natural disasters greatly affect economic development and threaten human lives, especially in developing countries such as Senegal. This kind of research is very important for Africa and Senegal in particular since it can be used to understand and establish appropriate strategies and precaution measures to reduce damage caused by human-induced and climate-related changes.

Wetlands, as essential ecosystems, face a significant threat of extinction resulting from various natural and human factors. Climatic variability, characterized by prolonged fluctuations in precipitation and maximum temperatures, has detrimental effects on the Pikine Natural Reserve. This study aimed to analyze the impact of climate change and anthropogenic effects on wetland degradation in the Urban Natural Reserve of Great Niayes of Pikine and Dependence (UNRGNPD) and to recommend measures to address these various environmental problems.

The specific objectives of this study are to assess:

1. Assess climate parameters and the hydrological response to wetland degradation

2. Analyze the anthropogenic effects on wetland degradation
3. Propose alternatives and management plans for natural reserve conservation

### **Research Questions**

For this study, the following questions were asked:

- ✓ what is the evolutionary trend of the Somone mangrove?
- ✓ what is the impact of climatic and anthropogenic factors on the evolution of wetlands?
- ✓ can effective lake management planning lead to sustainable management?

### **Hypothesis**

The research aims to validate the general hypothesis that historical factors, both climatic and anthropogenic, play an important role in the sustainable management of UNRGNPD lakes and mangroves. To test this hypothesis, four specific hypotheses are proposed:

- **Hypothesis 1** : Overall, from 1993 to the present day, the Technopole's lakes are in decline. Diachronic mapping between 1993 and 2023 could shed light on this point;
- **Hypothesis 2**: Climatic variability influences the evolution of Technopole wetlands. Rainfall deficits and rising temperatures, leading to water evaporation and salt accumulation, increase the mortality of marine species, while the return of precipitation causes water masses to advance. To test this hypothesis, a Mann-Kendall and Sen slope test, drought analyses using the SPI index, flood risk analyses and lake fluctuation levels will be carried out to observe their influence on these wetlands;
- **Hypothesis 3** : Wetland degradation is also attributable to human activities. To test this hypothesis, land use maps from 1993, 2003, 2013 and 2023 will be produced to demonstrate when lakes have regressed or progressed due to human pressure. Water quality analyses will also be carried out, along with field observations, to quantify the damage caused by human activities;
- **Hypothesis 4** : The development of inclusive strategies through a management plan will ensure sustainable management. Effective management requires an effective management plan.

# CHAPTER I: STATE OF THE STUDY AREA

## II.1.1 Location

The Grande Niaye de Pikine is the largest horticultural production area in Greater Dakar. It is essentially made up of farms of less than 1 hectare. Market gardening is practiced year-round in depressions and on blunt dunes. The Great Niaye of Pikine, an urban nature reserve, is commonly called Technopole (Berger, 2022).

The Pikine Basin is surrounded by the urban areas of Guédiawaye, Pikine and Dakar. Along with Rufisque, these are the four communes of the Dakar region. Pikine lies to the east of the commune of Dakar, to the west of Rufisque and to the south of the commune of Guédiawaye. Guédiawaye is separated from Pikine by its erection as a commune under decree no. 90-1134 of October 8, 1990 (Ndione et al., 2009). Pikine is the most densely populated city in the Dakar region, with 1,000,000 inhabitants and 10,000 per km<sup>2</sup>. It has developed largely in the Niayes, particularly the Grande Niaye de Pikine (Sarre et al., 2018).

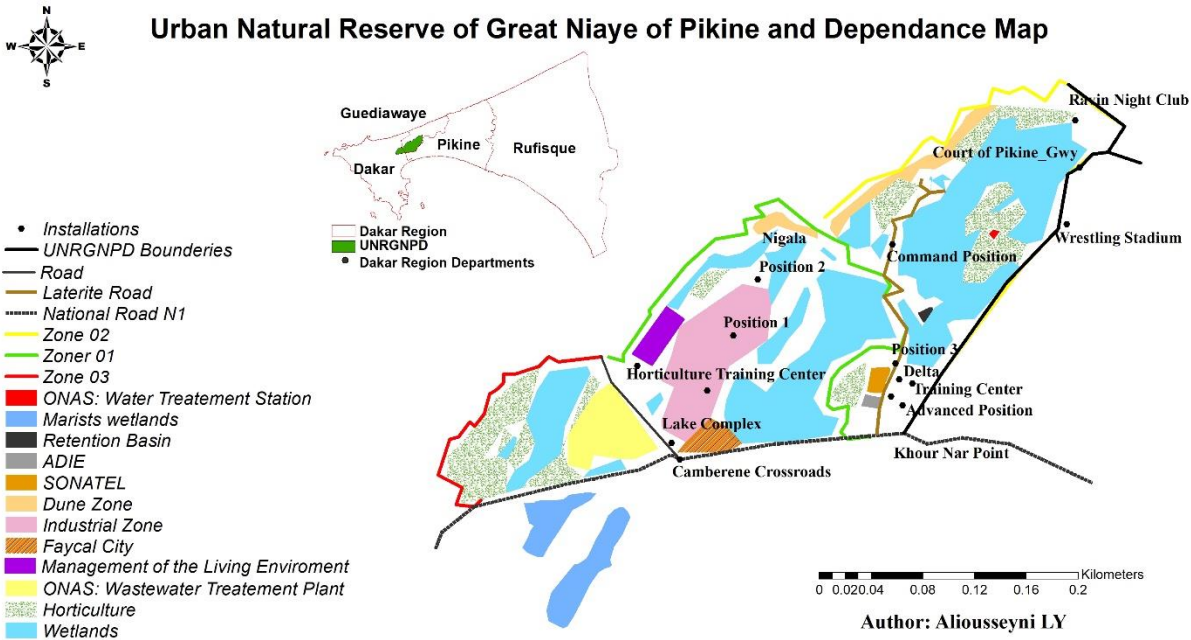


Figure 1: Location Map of Technopole

## II.1.2 Technopole Delineation

The foundational data for this map were sourced from 12.5 m digital elevation model (DEM), which provides detailed elevation values and was analyzed in ArcGIS.

The delineation process began by importing the processed DEM into ArcGIS. A fill operation was performed to remove sinks and ensure an uninterrupted flow surface. Flow direction and accumulation were then calculated to establish the potential path of water through the terrain. Using these calculations, stream networks were identified based on a defined flow accumulation threshold. Finally, the watershed boundaries were delineated using flow direction data to determine the areas contributing to each stream segment.

The resulting map features clear delineations of stream networks and watershed boundaries. The gradient of values, from high (34) to low (-16), likely represents a parameter such as elevation or flow accumulation, which is integral to understanding watershed characteristics.

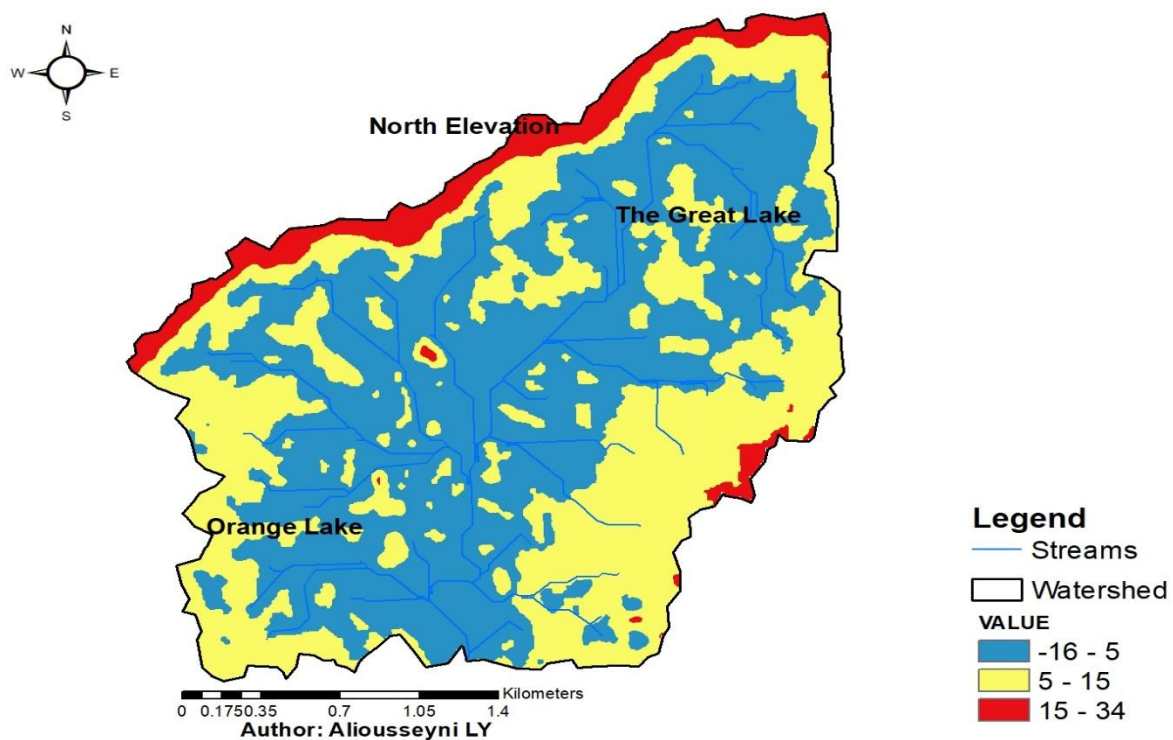


Figure 2: Technopole delineation map

#### II.1.4 Natural drivers in the Dakar Region and Technopole

The Dakar region, as in the West African Sahel more generally, experiences high interannual seasonal variability with respect to rainfall. The region largely recovered from the devastating droughts of the late 1970s through the 1980s, although it did not return to predrought rainfall levels of the mid-20th century (Sy et al., 2013).

Statistical analysis of rainfall data from the city of Dakar shows that heavy rainfall events sufficient to trigger flooding have a return period of 6 years for Dakar. The 156 mm of rain recorded in Dakar on 26 August 2012 represented a greater than 1 in the 30-year return period (Ozer et al., 2003).

Since 2005, despite a relative decrease in rainfall in 2006 and 2007, the situation has never improved. Moreover, it became more pronounced, particularly in 2008 and 2010, years in which rainfall totals were also in surplus (Ndiaye et al., 2014).

Three types of hazards have been observed in Dakar: flooding, coastal erosion and rising sea levels. The occurrence of floods in the Dakar metropolitan region has increased in recent years for climatic and anthropogenic reasons and constitutes a major threat (IAGU, 2009).

Flooding is one of the most serious threats to Dakar and has become a frequent and enduring reality in recent years. The underlying causes are complex and include not only the recent increase in rainfall but also, in particular, the whole socioeconomic process of an uncontrolled urban explosion (IAGU, 2009).

Since 2005, Pikine, the most densely populated town in Greater Dakar, has been suffering from serious environmental problems linked to recurrent flooding, which has completely disarticulated the structure of its urban fabric (Ndiaye et al., 2014).

The catchment area of Grande Niaye in Pikine is subject to a number of threats. These phenomena tend to modify surface conditions and make the soil more impermeable, sometimes leading to recurrent flooding, as observed in 2005, 2009 and 2012 (Amoikon, 2019). These changes are becoming more widespread, especially with climate change, where we are seeing very high intensities of rainfall (Mertz et al., 2011).

Over the past two decades, Dakar has faced recurrent flooding problems, which are linked to rapid urban growth and changing land-use patterns. Flood risks are likely to increase in the future given the potential for increased frequency of high-intensity rainfall events associated with climate change in combination with land use changes. The land around and within the Niaye Depression is being rapidly converted from permeable surfaces, many of which support agriculture, to impermeable surfaces to meet housing and other urban infrastructure needs (Khouma, 2013).

This basin, which was once the green lung of Dakar (containing the large and the small Niayes), is now under threat from the advancing urban front and numerous urban developments. These phenomena tend to modify the surface conditions and make the soil more impermeable, sometimes leading to recurrent flooding, as observed in 2005, 2009 and 2012 (Amoikon, 2019). These changes are becoming more widespread, especially with climate change, where we are seeing very high intensities of rainfall (Mertz et al., 2011).

Sea-level rise presents an additional threat to the city's infrastructure and to the coastal lakes and agricultural areas of the low-lying Niayes, which are particularly at risk for saltwater intrusion. Given Dakar's peninsular location, the city is highly vulnerable to sea-level rise

resulting from global warming. A sea-level rise of 0.5 m, well within the realm of likelihood for the second half of this century, could substantially worsen saltwater intrusion into the already stressed aquifers that provide water for Dakar, including its large UPA sector (Khouma, 2013).

As a result, risk is an interface concept that refers as much to physical reality, through the nature of the hazard, as to society, through its vulnerability and its multiple, evolving responses over time. A flood hazard is a physical process linked to atmospheric and terrestrial dynamics and is influenced by human development. Today, the main agent triggering flooding, especially in Dakar, is the development of populations in at-risk areas, such as the Niayes (Ndao, 2012).

Urban flooding, which uses streets to reoccupy former urbanized beds, as in the case of Nîmes in 1988 and the urbanized Niayes of Dakar since the 2000s: flooding of Dakar's main thoroughfares. These floods are the result of difficulties in evacuating run-off water and the increase in the volume of water run-off from impermeable surfaces. According to Literak et al., (2009), they are the result of a lack of infiltration in urban areas subject to precipitation, whether the accidental accumulation conditions are geomorphological, hydrological, topographical, anthropogenic or meteorological.

Dakars is affected by both lowland and urban flooding. The Dakar region is a very low-lying peninsula, with an average elevation of 20 m above sea level, and several watersheds, most of which have been filled for construction purposes (Ndao, 2012). The settlements of Pikine, Guédiawaye and Thiaroye were built on a large watershed of 87 km<sup>2</sup> (CSE, 2006), with a highly developed and complex surface and underground hydrographic network, combined with the proximity of the sea. Almost all of these territories are located in the alluvial plain of the former dried-up watercourse (the niayes). The major riverbeds in this area are well developed and difficult to locate, and a large part of Pikine lies on the water table. In the past, the water table was very low, but now that the rains are back, the water has returned to its former level. Five minutes of rain is enough to flood Dakar (Ndao, 2012).

### **II.1.5 Human drivers in Technopole**

The advance of the urban front is out of all proportions and currently affects peri-urban wetlands. Between 1978 and 2017, this wetland was considerably swallowed by the urbanization process. According to Diaouma (2018), the population of Dakar increased by 79.8% between 1955 and 1961. In the same period, the city recorded an influx of thirty thousand people per year (Diaouma, 2018).

Ndong (1990) noted that between 1973 and 1980, urbanization conquered an average of 74.6 hectares each year. The wetlands underwent major changes as a result of development carried out by the beneficiaries of leases, land titles and precarious occupancy permits. Horticultural areas have been converted into residential zones. Road infrastructure and public facilities are built in or near wetlands. The construction of the national arena (7 hectares) in Pikine's Great Niaye is a case in point (Diaouma, 2018).

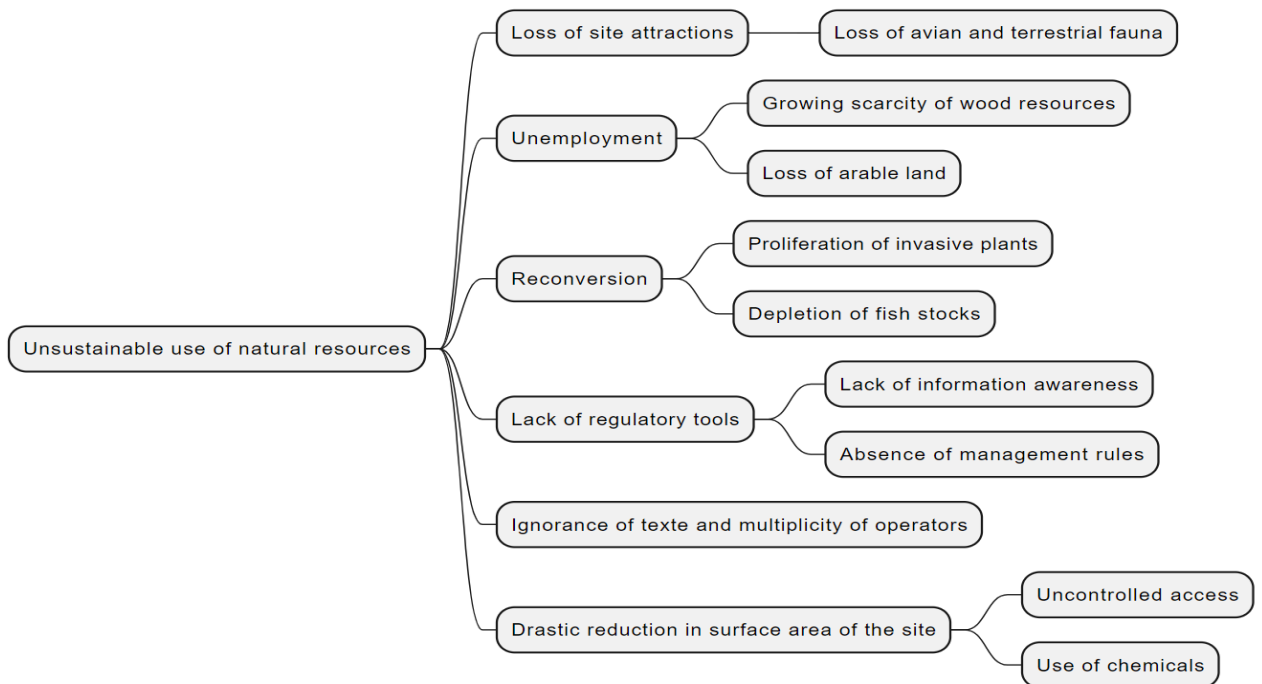
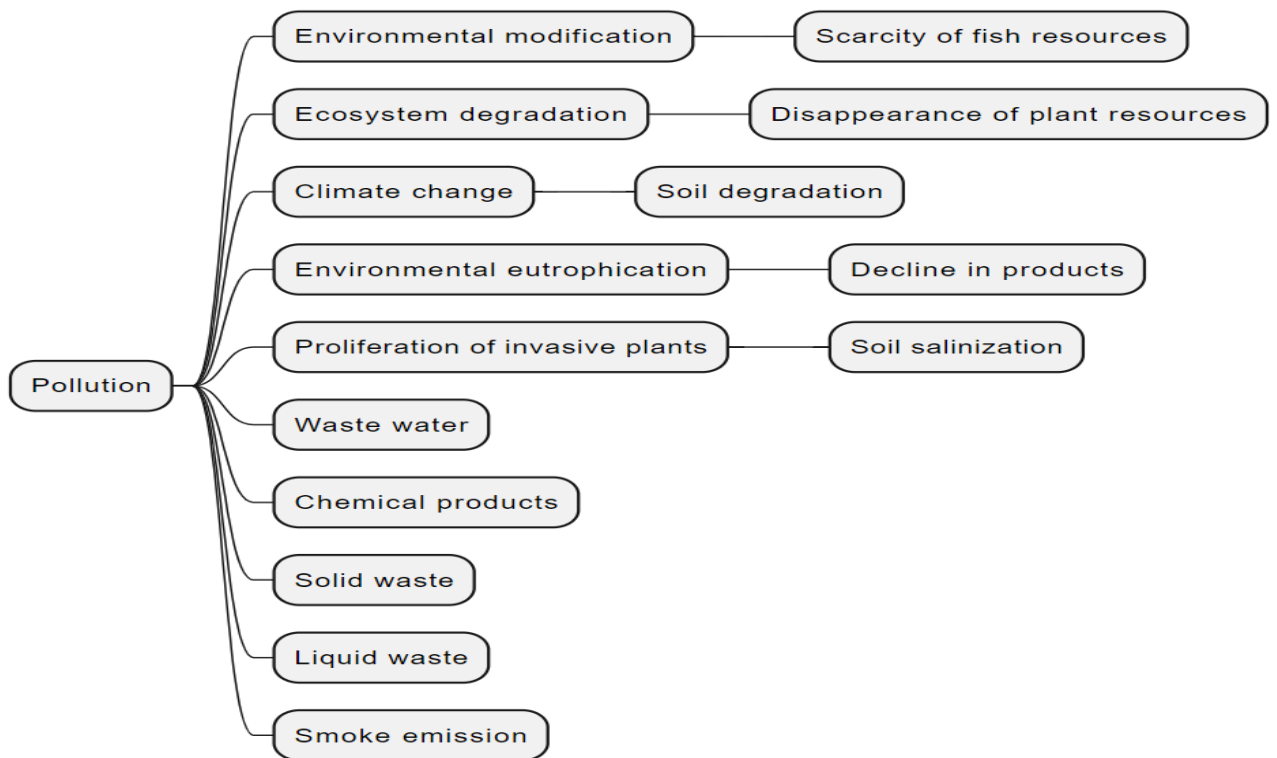
The results of this study showed that these waters (groundwater, lake, and treated wastewater) at certain points do not meet Senegalese standards for use in agriculture and fishing. In addition, the concentrations of the physicochemical and microbiological parameters of wastewater treated by the STEP and used for irrigation far exceeded the standards for reuse in agriculture (Gueye et al., 2023).

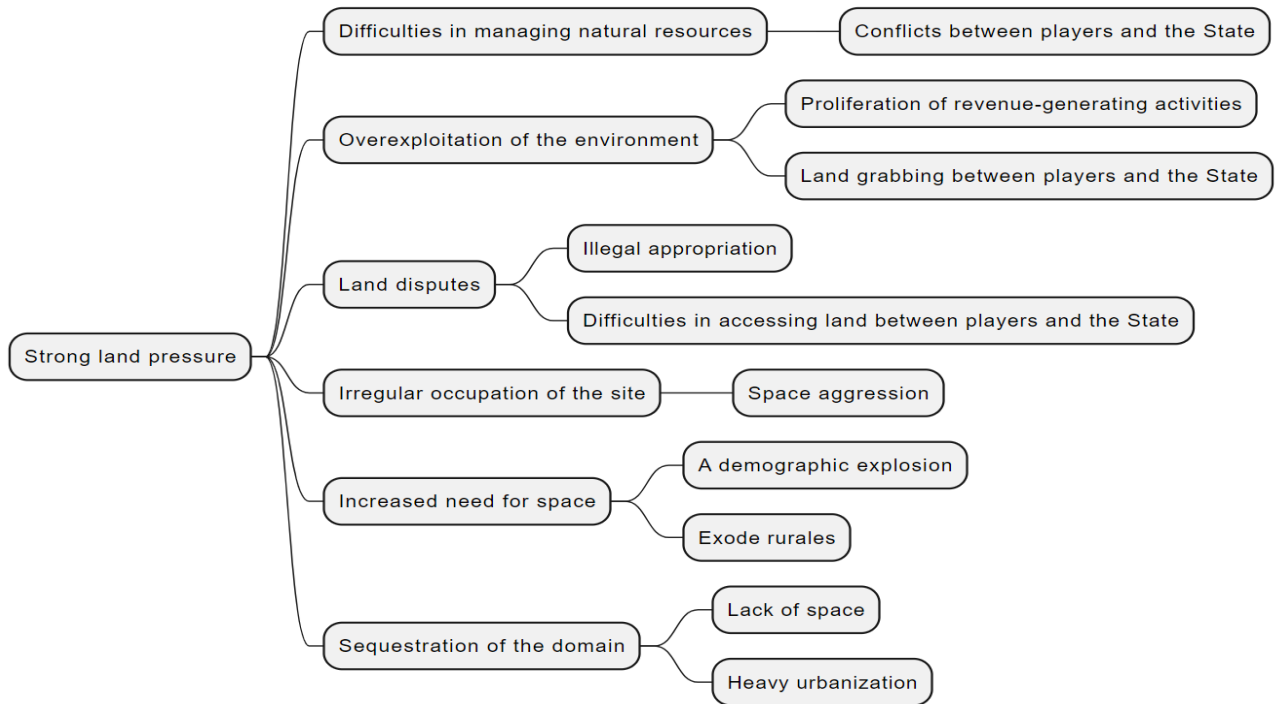
High concentrations of suspended solids (85.9 mg/L), chemical oxygen demand (1789 mg/L), and total nitrogen (67.6 mg/L) contribute to a decrease in dissolved oxygen and thus degrade the biodiversity of aquatic ecosystems. In addition, the concentrations of the physicochemical and microbiological parameters of wastewater treated by WWTPs and used for irrigation far exceeded the standards for reuse in agriculture (Gueye et al., 2023).

Changing climatic conditions have stimulated the mobility of rural populations and contributed to increased urbanization. For the Sahelian region, Senegal experienced a complete upheaval in its climatic norms in the mid-1960s, when a long period (1950-67) of surplus rainfall caused rapid growth in the total population and an increase in the density of the rural population (World Bank, 2009). The capital, Dakar, was the main destination of the rural exodus and the main site for observing the most serious problems caused by this migration and accelerated urbanization. The development of Dakar has itself been marked by rapid spatial expansion resulting from intrinsic demographic dynamism and migratory flows from inland regions. Dakar conurbation, with a population currently estimated at approximately 4 million, is thus the most important place of socialization and invention in Senegalese society (World Bank, 2009).



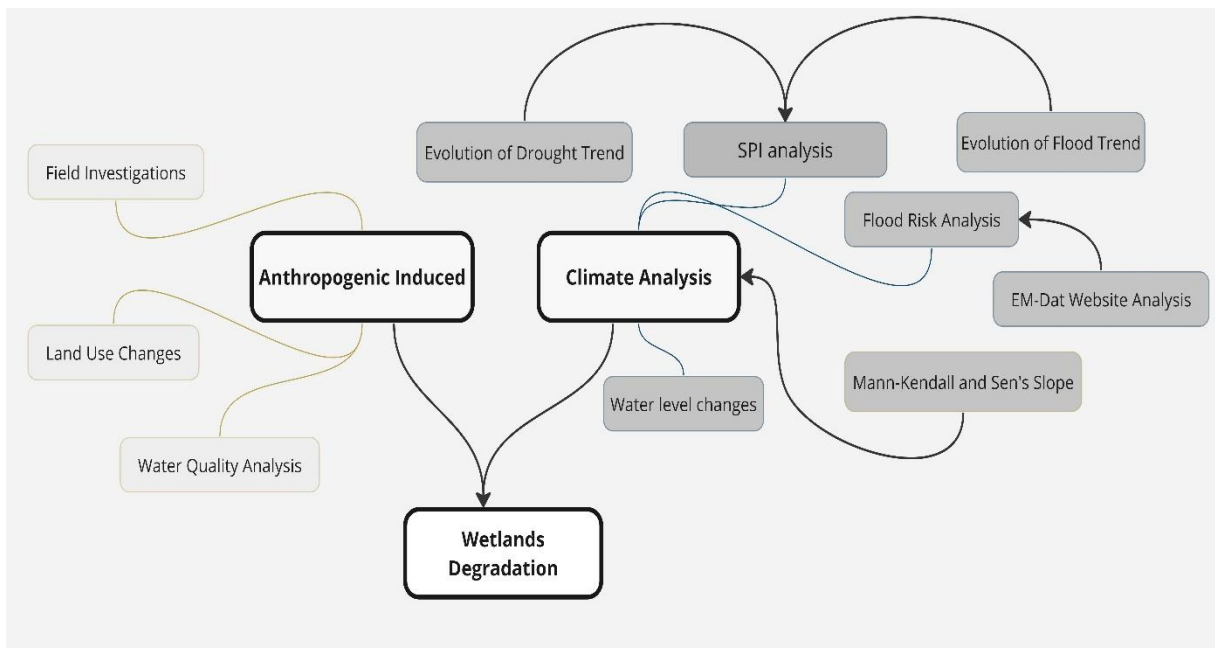
**Figure 3: Current situation in Technopole (A: Est, B: West, C: Middle, D: South, E: North)**





**Figure 4: Pollution diagram in Technopole**

**Source: Development and management plan of Technopole(2022-2026)**



**Figure 5: Flowchart of the Methodology**

## **CHAPTER II: METHODOLOGY**

### **II.2 Data Collection**

#### **II.2.1 Climate Data**

The data were collected at the National Agency for Civil Aviation and Meteorology (NACAM) of Senegal. These monthly data, including temperature, rainfall, and evaporation, were collected from 1978 to 2022.

#### **II.2.2 Water Level Data**

Location and Landsat data (3, 5, 7, and 8) downloaded from the USGS were used to analyze fluctuating water levels in the Technopole urban reserve. The USGS Landsat 8 surface reflectance Tier 1 dataset is the geometrically, radiometrically, and atmospherically corrected surface reflectance from Landsat 8 OLI/TIRS sensors. These images contain 4 visible, 1 near-infrared, two shortwave infrared bands, and 2 thermal infrared bands with a 30 m spatial resolution (<https://developers.google.com/earth-engine/datasets/>). The dataset can be accessed instantly for further analysis on the Google Earth Engine platform (GEE). The GEE is the world's most advanced cloud-based geospatial analysis platform, enabling users to visualize and analyze satellite imagery and vector data of our earth (<https://www.google.com/earth/education/tools/google-earth-engine/>). It has the advantages of cloud computing, batch processing, speed, and efficiency. Moreover, researchers do not need to carry out cumbersome data preprocessing, such as scale conversion, radiation, and atmospheric correction. Compared with traditional remote sensing image acquisition and processing, GEE is no longer limited by the large amount of remote sensing images because users can directly access preprocessed images or upload costly data to perform geographic analysis in a highly efficient way without downloading any image (Kumar & Mutanga, 2018).

#### **II.2.2 Flood risk data**

An increasing number of scientific efforts have contributed to understanding flood risk trends (da Silva et al., 2020). Several studies (Barredo et al., 2012) have directly analyzed past trends in flood losses.

The flood risk map analysis used five (5) parameters: land use/land cover map, rainfall map, road map, slope map, and digital elevation model map.

The LULC map for the year 2022 is an analysis of a supervised classification of Landsat 8 data taken from the United States Geological Survey (USGS) website, accessible at <https://earthexplorer.usgs.gov/>.

Rainfall map data are taken from <https://chrsdata.eng.uci.edu/>. Through this platform, PDIR Now data have been selected. The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Dynamic Infrared Rain Rate near real-time (PDIR-Now) is a real-time global high-resolution ( $0.04^\circ \times 0.04^\circ$  or = 4 km x 4 km;) satellite precipitation product developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI). PDIR-Now has been implemented on the UCI CHRS global real-time satellite precipitation monitoring system iRain (<https://irain.eng.uci.edu>).

Road map data were collected from the OpenStreet Map and transferred to ArcGIS to generate and visualize a map of the Technopole study area.

The slope map data are derived from a high-resolution digital elevation model.

### ***II.2.3 Land use land cover data***

According to Smith et al., (2022), data collection for the present study will use integrated remote sensing to assess the spatiotemporal dynamics of land use comprehensively. The natural reserves of the pikine boundaries selected from the Google Earth dataset serve as geographical boundaries for the study area. The diachronic analysis of land use changes spanned four distinct periods 1988, 2003, 2013, and 2023 using satellite imagery as the primary data source. Satellite images for these years will be downloaded from the United States Geological Survey (USGS) website, which is accessible at <https://earthexplorer.usgs.gov/>. Images will be obtained in GEOTIF format using the WGS 84 Zone 28 N reference coordinate system. Specifically, Landsat 5 TM imagery for 1992, Landsat 7 ETM for 2002, and Landsat 8 OLI for 2012 and 2022 were used. GPS data will be collected in the Field for various land-use units to complement the remote sensing data. These points served as ground-truth data for image processing validation.

Satellite image data were processed using ArcGIS 10.8.1 software. Processing involves three stages: preprocessing, supervised classification, and subsequent validation or postprocessing.

Based on the results obtained from the land-use maps and the surface areas,

calculated for each band, a statistical analysis will be carried out to visualize the rates of change. As a function of land-use evolution, how wetland degradation is analyzed.

Land use activities adjacent to wetlands can affect wetland habitat by altering the inputs of sunlight, sediment, organic debris, nutrients, dissolved carbon, and sometimes contaminants such as pesticides, heavy metals, and organic chemicals. Vegetation and soil alterations in wetland watersheds predominantly affect the wetland through altered hydrology and sediment contributions. Some activities may directly alter outlet hydraulics and thus change a wetland's

hydropattern. Depending on the details of the activity, the abiotic effects of human actions may make a wetland wetter, drier, flashier, sunnier, or more nutrient-rich, and these abiotic changes may alter the biology of the system (Wenger et al., 2009).

#### **II.2.4 Primary Data Collected on the Field**

Primary data were collected from two different sources. Some were obtained through documentation from the natural Reserve's administrative office, and others from visits to stakeholders carrying out activities in the Reserve.

Water, sediment and experimental fish samples were collected from 8 lakes in the Reserve to assess the various changes in quality in the laboratory.

A sampling campaign was carried out in December. Water, sediment and fish samples were taken and sent to the laboratory during the various campaigns. Analyses of nutrients and heavy metals were carried out on water and sediment samples from the various lakes. In addition, fish samples from Ethiopia, Kahira, and Grand Lac were taken for heavy metal analysis, and microbiological analyses were carried out on water samples from the two dependent lakes (Marist Lakes).

- The parameters selected were analyzed using the following methods:
- The XRF fluorescence method for the analysis of heavy metals
- The Rodier 9th edition for the determination of dissolved oxygen and nitrates and nitrites
- NF EN ISO 6878: 2005-04 for phosphate determination
- Standard NF T 90-015-2:2000 for BOD5 measurement
- Standard NF EN ISO 9308-1 for total coliforms and fecal streptococci

### **III Data Processing and Analysis**

#### **III.1 Climate Data Analysis**

Climate data analysis was carried out on R-INSTAT and R-STUDIO. The process began with data collection, clearing, management, and visualization. R-INSTAT software was used to check the temperature and precipitation data quality, while R-STUDIO software was used for Mann–Kendall and Sen's slope tests and drought analysis using the Standardized Precipitation Index (SPI).

### **III.1 Water Level Analysis in the Google Earth Engine**

The analysis of the code is written in Google Earth Engine (GEE) and aims to generate time series charts for the Indice, Normalized Difference Water Index (NDWI) of Technopole spanning the years 1978 to 2022.

First, we define our region of interest, Technopole, chosen the Great lake of the area and load the Landsat image collection relevant to our analysis: Landsat 3 (1978-1981), Landsat 5 (1980-1989), Landsat 5 (1990-1998), Landsat 5 (1999-2002), Landsat 7 (2003-2012), and Landsat 8 (2013-2022).

The function added, which is responsible for calculating the NDWI for each image in the Landsat collection, was used. This function utilizes the normalized difference method to compute the indices and assigns appropriate names to the resulting bands.

Next, we filter the Landsat image collection based on the specified region of interest and the date range. The collection is sorted by cloud cover percentage to prioritize images with lower cloud cover.

Subsequently, monthly NDWI time series were generated. We iterate over each year within the range and calculate the median NDWI for that year. For each annual image, metadata such as the year and the start time are set. The resulting monthly NDWI image collection is then printed. Using the `ui.Chart.image.seriesByRegion` function, we create a time series chart for the annual NDWI. This chart illustrates the changes in NDWI values over the years, allowing for the visualization and analysis of vegetation dynamics.

### **III.2 SPI Processing**

The standardized precipitation index (SPI) was proposed by McKee et al., (1993) Only a relatively long period of precipitation (generally more than 30 years) is needed to calculate the drought index at different time scales. It is applicable to drought monitoring and assessment on a monthly scale. The SPI analyses was conducted by Rstudio with the SPEI package.

SPI has multiple time scales (1, 3, 6, 12, 24, 48 months). For example, the SPI of the December time scale represents the standard deviation of December precipitation. The SPI at the 3-month time scale in December represents the standard deviation of precipitation from October to December. The December 12-month time scale SPI represents the standard deviation of January-December precipitation. This thesis mainly analyzes the SPI's 12-month, 6-month, and 3-month time scales. Because the 12-month time scale SPI can more clearly reflect the changes in drought and flood stages and the 3-month time scale SPI can reflect seasonal drought, it is closely related to agricultural drought. The drought classification was graded according to

drought-level criteria such as those of Mckee et al., (1993), and the degree of drought was added according to the drought-level criteria (Table 5).

### III.3 Flood risk Data Analysis

The flood risk map data were analyzed using ArcGIS. The different strips of each map were reclassified according to five (5) risk rank types (very high 5, high 4, moderate 3, low 2, and very low 1). This classification is based on the probability of flooding a strip. The LULC map is classified according to water bodies (5), barren land (4), settlements (3), natural vegetation (1), and agricultural land (2).

The rainfall and slope maps are classified according to quantity and slope rate. This means that low rainfall and low slopes indicate low flood probability. The reclassification for the DEMs is based on a low elevation, indicating a high flood probability. Being very close to the road means a very high flood probability for the distance from the road.

After reclassification, these maps were superimposed according to flood-inducing probability percentages. According to this classification, LULC is assigned 20%, road distance 5%, rainfall 35%, slope 20%, and digital elevation model 20%.

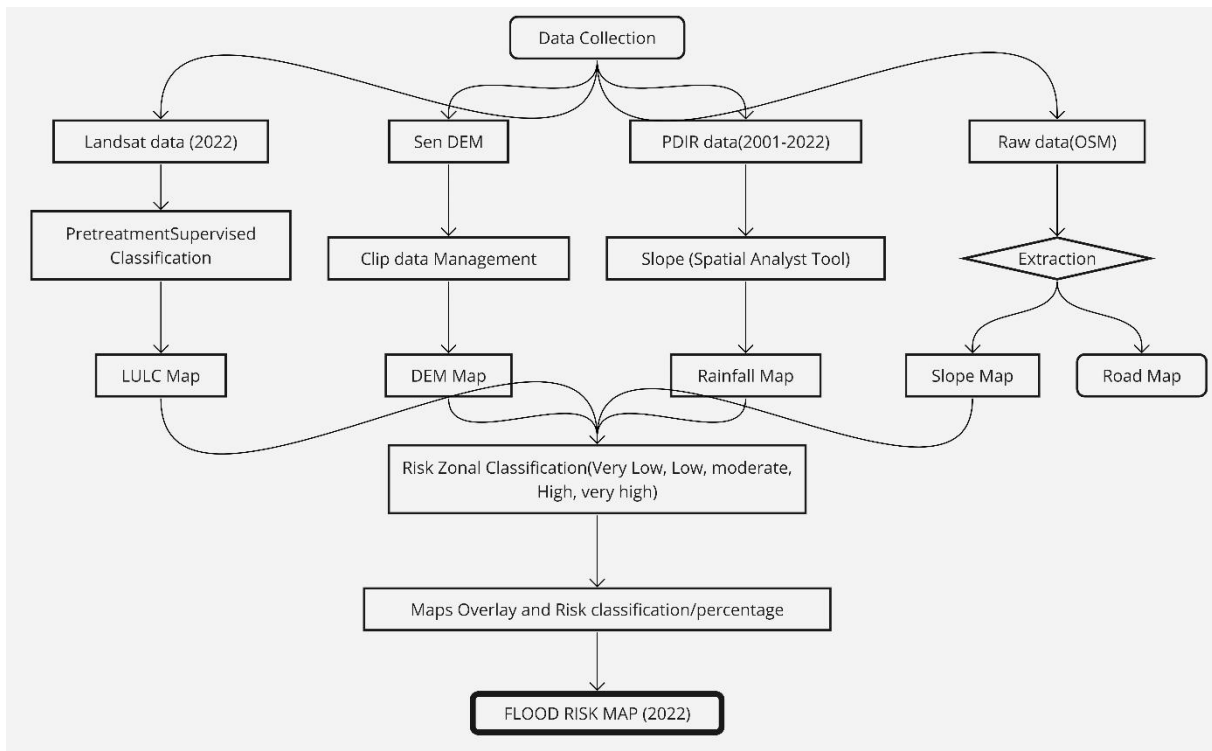


Figure 6: Conceptual Framework of the Flood Risk Map

### III.4 Satellite data analysis

The satellite image data were processed using ArcGIS 10.8.1 software. The processing comprised three distinct stages: preprocessing, supervised classification, and subsequent

validation or postprocessing (Figure 2). In the initial preprocessing of Landsat data, several steps were executed to enhance radiometric quality and rectify geographical misalignments. These steps included the following procedures: unzipping and importing the image bands, merging the individual image bands, implementing radiometric corrections, and applying color composites to the spectral bands of the images, as detailed in prior studies (Oxoli et al. 2020).

The chosen approach was supervised classification for the generation of land use maps corresponding to each date, informed by a comprehensive understanding of the study area. This methodology facilitated the establishment of a land use nomenclature consisting of five distinct classes: agricultural land (AL), settlements (S), water bodies (WB), barren land (BL), and Typha (vegetation) (T). It is important to note that the Typha class included small trees. The classification process employed the maximum likelihood algorithm, with the creation of training plots guided by previous research findings (Minglu et al., 2010).

Following the supervised classification, subsequent post-classification procedures involving the validation of classifications through remote observations using Google Earth imagery and on-site field visits were conducted. After validation, refinements were applied to the land use maps, and rigorous accuracy assessments were performed. Calculations of overall accuracy and the kappa coefficient were executed to quantify accuracy, drawing upon established methodologies documented in earlier works (Atef et al., 2023), as outlined.

To determine the area of each land use class, the "Calculate Geometry" tool was used. Additionally, the overall rate of change (Oc) and the annual rate of change (Ac) for various periods, including 1988-2003, 1988-2013, 1988-2023, 2003-2013, 2003-2023, and 2013-2023, were computed. Equations 1 and 2 were employed for these calculations, and these equations have been widely utilized by researchers in diverse regions across the globe to assess land use dynamics (Desneux et al., 2022). Transition matrices across various temporal scales have been applied to understand the dynamic changes in land use comprehensively.

$$Oc = \frac{(S_2 - S_1) \times 100}{S_1} \quad (1)$$

$$Ac = \frac{(\ln S_2 - \ln S_1) \times 100}{(t_2 - t_1) \times \ln e} \quad (2)$$

With: Overall rate of change (Oc), annual rate of change (Ac), land cover class area at the starting year of the scale period ( $S_1$ ), land cover class area at the end year of the scale period ( $S_2$ ), natural logarithm (ln), base of natural logarithms (e), starting time of a given scale period ( $t_1$ ) and ending time of a given scale period ( $t_2$ ).

### III.5 Primary data analysis (field investigation)

The data collected during the field investigation were used to analyze and identify the practices and various threats to the resources of the Pikine Nature Reserve. A notebook, a drone, camera and bottles of water, sediment and fish samples were analyzed to illustrate the results found on the site.

*Table 1: Data Collected and Used*

<b>Collected Data</b>	<b>Sources</b>	<b>Purposes</b>
Rainfall	ANACIM agency	Climate Analysis
Temperature	ANACIM agency	Climate Analysis
Evaporation	ANACIM agency	Climate Analysis
PDIR data	<a href="https://chrsdata.eng.uci.edu/">https://chrsdata.eng.uci.edu/</a>	Rainfall Map
Landsat(5,7 and 8)	<a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a>	Land use Changes
Landsat(3,5,7 and 8)	<a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a>	Water Level Changes
High resolution DEM	WASCAL	Slope, Delineation Map
Photos	On the Field	Illustration
Water samples	On the Field	Water quality analysis
Technopole Road Data	Open Street Map	Flood Risk Map

## **CHAPTER III: RESULTS AND DISCUSSION**

### **III.1 Analysis of the impact of climate change on wetland degradation in Technopole**

The water resources situation, already critical, is likely to become a problem hampering any further development. Climate change will have direct and indirect adverse consequences on water resource potential, both in terms of quantity and quality, on water requirements and on the efficiency of water use for different purposes. Ecosystems will have to cope with temperatures and precipitation patterns that differ from current conditions. Future changes in national climatic conditions, combined with future sea-level rise, will alter water availability and strongly influence the nature and function of certain wetlands, including the types of plant and animal species found there. These changes are likely to affect waterbirds, for which wetlands, designated as sites of global importance by the Ramsar Convention, provide a habitat (Alibou, 2002).

#### **III.1.1 Climate data quality control**

Reliable weather observations are the basis to assess climate change and variability. Compared to other regions of the world, long time series of weather observations are sparse in many countries of Sub-Saharan Africa. Various activities at national or international level are ongoing to improve the availability and quality of climate databases. In that context also quality control is performed and data are made publicly available. Recent climate observations can be complemented by digitization of historical hand-written weather observations which are available in distributed archives. International data centers, such as the Global Precipitation Climatology Centre (GPCC), collect international data. They perform quality-control of these observations and provide derived products in support of global and regional climate assessments. These activities can also contribute to the improvement of national climate databases, as e.g., demonstrated in a cooperation among selected countries with the SASSCAL initiative (Southern African Science Service Centre for Climate Change and Adaptive Land Management). Satellite-based observations are an additional source that can provide climatological information for selected parameters. In particular, the METEOSAT satellite series provides valuable data for the African continent (Kaspar et al., 2022).

##### **III.1.1.a Rainfall quality control in R-INSTAT**

The Qc rainfall control showed 65 different rainfall events exceeding 100 mm in Dakar and 65 events when 2 consecutive days did not receive the same quantity.

Consecutive rainfall analysis revealed that since 1978, only 8 consecutive rainy days have occurred (1978, 1979, 1992, 1993, 1995, 2001, 2005, and 2013), with an average of 11.15 mm. These 5 consecutive days are repeated one year later between 1978 and 1979 and remain 8 years later before repeating themselves from 2005 to 2013. Analysis of the dry months shows that from 1978 to 2022, only October experienced dry pockets during the winter period, unlike July, August, and September, which are winter months and have no dry pockets. The number of wet months averaged 4, with an average rainfall of 88 mm. Unusual rainfall was noted in nine different years, with low rainfall of approximately 2 mm in January and February.

#### **III.1.1.b Temperature quality control in R-INSTAT**

The Qc Tp of the control was 74 days, with an average maximum Tp of 35°, and was only one day in 2019, with a maximum Tp of 38°. Similarly, for min Tp, which was only 75 days in 2019, the minimum temperature reached 24°. and none of the temperatures (max and min) repeated consecutively over 127 days for a maximum Tp of 40° and minimum Tp of 25°.

#### **III.1.3 Mann–Kendall and Sen’s Slope Analysis**

Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic (Mavromatis & Stathis, 2011) and in hydrologic time series (Yue & Wang, 2004). There are two advantages of using this test. First, it is a non parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al., 2011). Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set (Karmeshu, 2012). According to this test, the null hypothesis H0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H1, which assumes that there is a trend (Önöz & Bayazit, 2003).

##### **Hypothesis**

Null Hypothesis (H=0): The dataset shows no trend 2.

Alternate hypothesis: » There is a trend in the dataset

**Table 2: Mann–Kendall trend variables of rainfall**

Variables	Values
Z	2.2988
n	45
P value	0.02151
S	2.36E+02
Var S	1.05E+04
tau	2.38E-01

Alternative hypothesis: true S is not equal to 0      **Sen's slope = 0.3968636**

**Table 3: Meaning of the values of test statistic 'S'(Maiti et al., 2023)**

Si.no	Condition	Meaning
1	$S > 0$	Upcoming observations in the time series are greater than those that appeared prior in the time series
2	$S < 0$	Upcoming observations in the time series are smaller than those that appeared prior in the time series

The value of tau is highly imperative for understanding the presence and direction of trends in a dataset. The interpretations of the different tau values are given in Table 4. Positive values of Kendall's tau show an increasing trend, while negative values show a decreasing trend, but the meaning of significance remains the same (Akoglu, 2018).

**Table 4: Interpretation of different values of Mann-Kendall's Tau(Maiti et al., 2023)**

Sr. no	Value of tan	Significance
1	$> 9$	Highly Significant
2	0.7 - 0.9	Significant
3	0.4 - 0.7	Moderately Significant
4	0.2 - 0.4	Weakly Significant
5	$< 0.2$	Not significant

-Since  $S > 0$ , the trend is positive

-The Tau value was 0.2, and the trend was weakly significant.

-The test is statistically significant since the p-value is less than 0.05. Therefore, we accept the alternate hypothesis that a trend exists in the rainfall dataset.

The value of Sen's slope is 0.39, which suggests that the change is 0.39 per unit of time.

-As our periodic interval is annual and the rainfall is measured in mm, Sen's slope suggests that as per the trend, rainfall may increase by 0.39 mm per year.

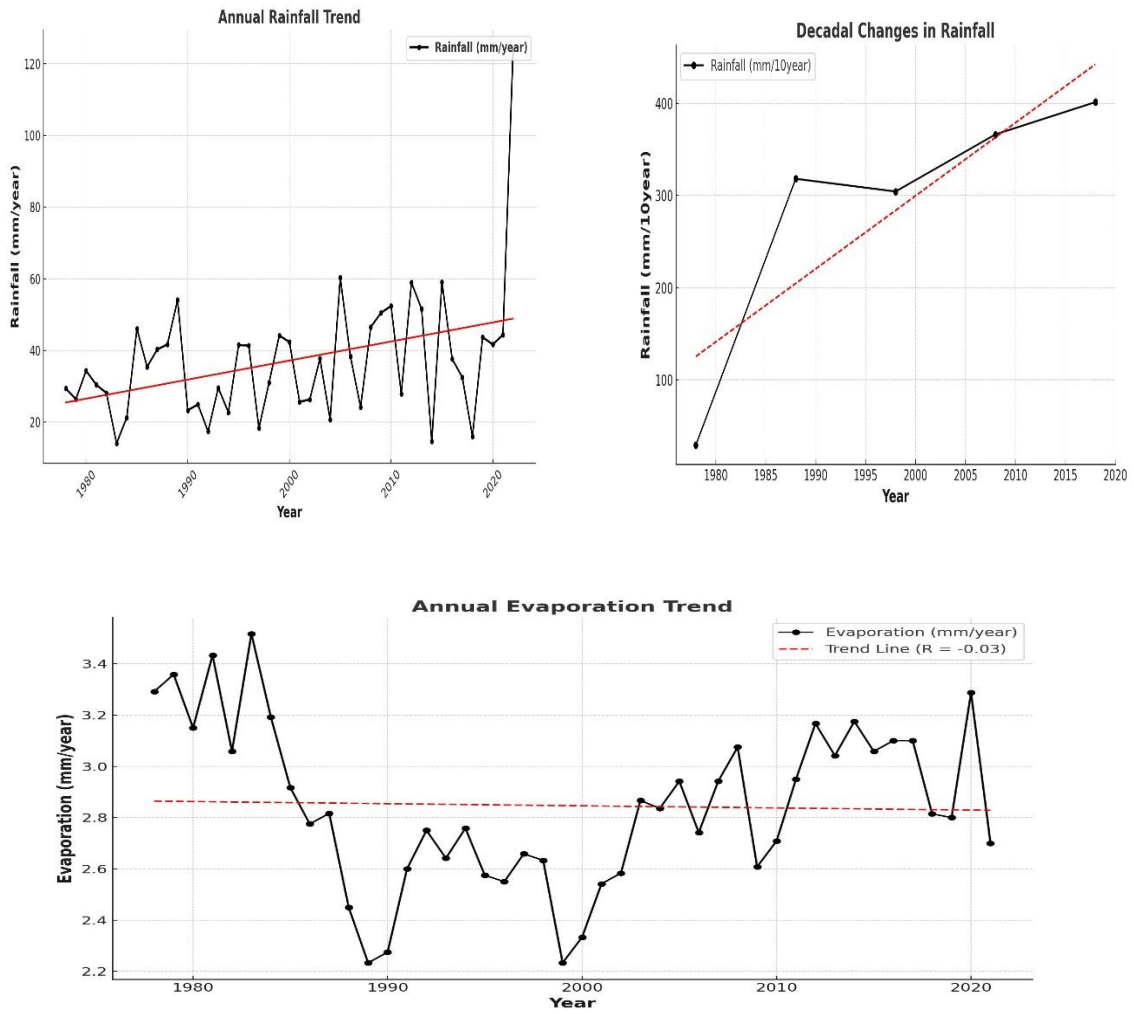


Figure 7: Rainfall and evaporation trends in the Dakar region

## Mann–Kendall trend test of maximum temperature

*Table 5: Mann–Kendall trend variables of maximum temperature*

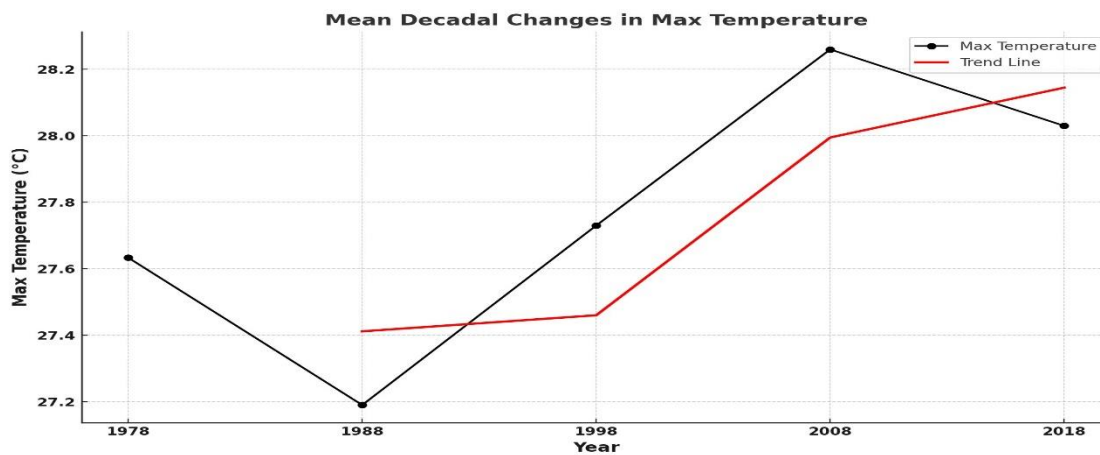
Variables	Values
Z	4.6583
n	46
P value	3.188e-06
S	4.93e+02
Var S	1.16e+04
tau	4.76e-01

Alternative hypothesis: true S is not equal to 0    **Sen's slope** = 0.03938889

-Since  $S > 0$ , the trend is positive

-The Tau value was 0.4, and the trend was moderately significant

At the Yoff station, temperatures show very wide seasonal variations. In winter, minimum temperatures can reach 25°C, while maximum temperatures are around 29°C (1978-2022). From the figure 8 onwards, the warm season runs from March to November, while the wet season extends from November to March. Temperatures show an upward trend (period 1978-2022). This is perfectly consistent with the upward trend in temperature observed on a global scale. Precipitation varies from year to year, with an annual average of 35 mm. For the series of years analysed (1978 to 2022), there are years with rainfall well above average, such as 1989, 2005, 2010, 2012 and 2013, and others with deficits, with the latter predominating.



*Figure 8: Decadal Changes in Maximum Temperature*

The test is statistically significant since the p-value is less than 0.05. Hence, we reject the null hypothesis and accept the alternate hypothesis that a trend exists in the given dataset.

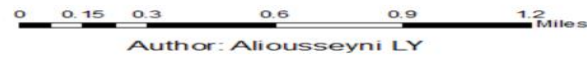
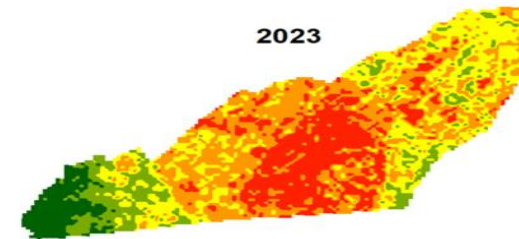
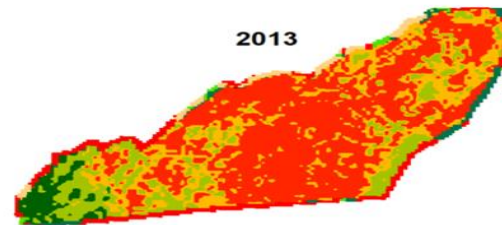
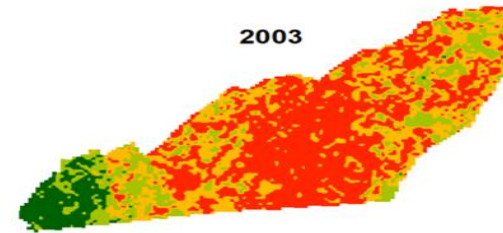
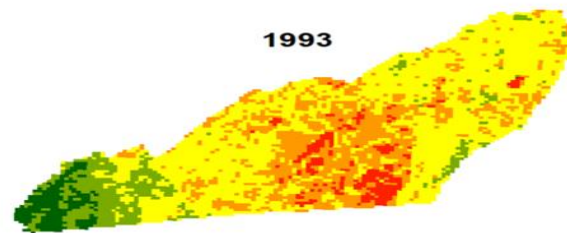
The value of Sen's slope is 0.39, which suggests that the change is 0.39 per unit of time. As the periodic interval is annual and temperature is measured at 0°C, Sen's slope suggests that as per the trend, the temperature may increase by 0.039°C per year.

Finally, we reject the null hypothesis is rejected and accept the alternate hypothesis is accepted which means that a trend exists in the given dataset.

Analyses and fluctuations in rainfall and temperature parameters illustrate the many changes in Dakar's climate. Rainfall trends gradually broke with long droughts in the Sahel, which altered the region's hydrological balance. The return of rainfall after these drought scenarios brought flooding to Dakar, filling the technopole receptacles and causing flooding in approximately 2005, as shown in the diagram of rainfall trends.

#### **III.1.4 Analysis of flood risk in Pikine**

The flood risk map represents overlaid parameters and is composed of a LULC map, rainfall map, slope map, distance from the road map, and digital elevation model map. These maps show 5 levels of flood risk probability in the Technopole area. Very low risk and low risk are identified in the southern part of Technopole, where agricultural activities are frequent, and moderate levels are almost everywhere in Technopole, especially in the North, where natural vegetation is large. High and very high risks are found more in the center, coinciding with the largest lake in the Reserve, with the high risk surrounding the very high-risk zone. The analysis also revealed that flood risk was more frequent in 2003 and 2013, which coincided with the elongation of the surfaces of the water bodies in these areas.



Author: Aliousseyni LY

### Legend

- Very Low Risk
- Low Risk
- Moderate
- High Risk
- Very High Risk

Figure 9: Flood Risk Maps of Technopole

### III.1.5 Analysis of Drought using the Standardized Precipitation Index (SPI) in Dakar

R STUDIO was used to conduct the SPI analyses using the SPEI package. Precipitation data were input into R-studio to complete the SPI analysis. The SPI can be calculated for multiple timescales, allowing process different drought types due to its temporal flexibility in evaluating precipitation conditions relative to water supply. The SPI was designed to quantify the precipitation deficit through moving averaging windows at multiple timescales. These timescales reflect the impacts of drought on different water resources.

In agricultural drought, meteorological and soil moisture conditions respond to precipitation anomalies on relatively short timescales (1–6 months), whereas streamflow, reservoirs, and groundwater respond to longer-term precipitation anomalies (6–24 months and longer). The SPI for this research was calculated at 3, 6, and 12 months. The SPI values can be used to categorize drought severity based on Table 6 SPI classifications.

*Table 6: SPI drought and flood level classification*

Apportionment Entropy	Classification
Extremely wet	2.0+
Very Wet	1.5-1.99
Moderately Wet	1.0-1.49
Near Normal	0.99 to 0.99
Moderately Dry	-1.0 to -1.49
Severely Dry	-1.5 to -1.99
Extremely Dry	-2 and less

The multi-time scale characteristics of the SPI can be used to monitor different types of droughts and floods. The synthetic application of the SPI at each time scale can be used to comprehensively monitor and evaluate droughts and floods. Figure 1 shows the evolution of SPI3 (3 months), SPI6 (6 months), and SPI12 (12 months) in the Dakar region from 1978 to 2022. As shown in the figure, since the SPI3 value is strongly affected by the monthly precipitation, it is weak in duration and frequently changes between months, reflecting the characteristics of the monthly changes in drought and flood conditions. SPI3 represents short-term water deficits, influenced mainly by short-term (3 months) precipitation. The SPI3 values fluctuated throughout the study period, reflecting the long-term change characteristics of drought and flooding in Dakar. As the time scale increases, the SPI6 response shows a small difference. SPI6 shows the same fluctuations as SPI3, with the exception of 2013, when SPI6 experienced heavy flooding. This shows that rainfall conditions over a 3-month period are consistent with those over a 6-month period. In the SPI12, the drought and flood changes are

more stable, the cycle is more obvious, and it better reflects the underlying soil moisture, vegetation development, river runoff, groundwater level and reservoir water storage capacity. The characteristics of long-term changes in drought and floods can be clearly reflected.

The SPI indicates a significant change in the ratios of dry, normal, or wet periods at Dakar station. However, SPIs 3 and 6 show 6 severe droughts during 1980, 1983, 1993, 1999, 2015 and 2019, unlike the 9 extreme wet years of 1979, 1987, 1989, 1992, 1995, 2000 to 2003, 2006 and 2013.

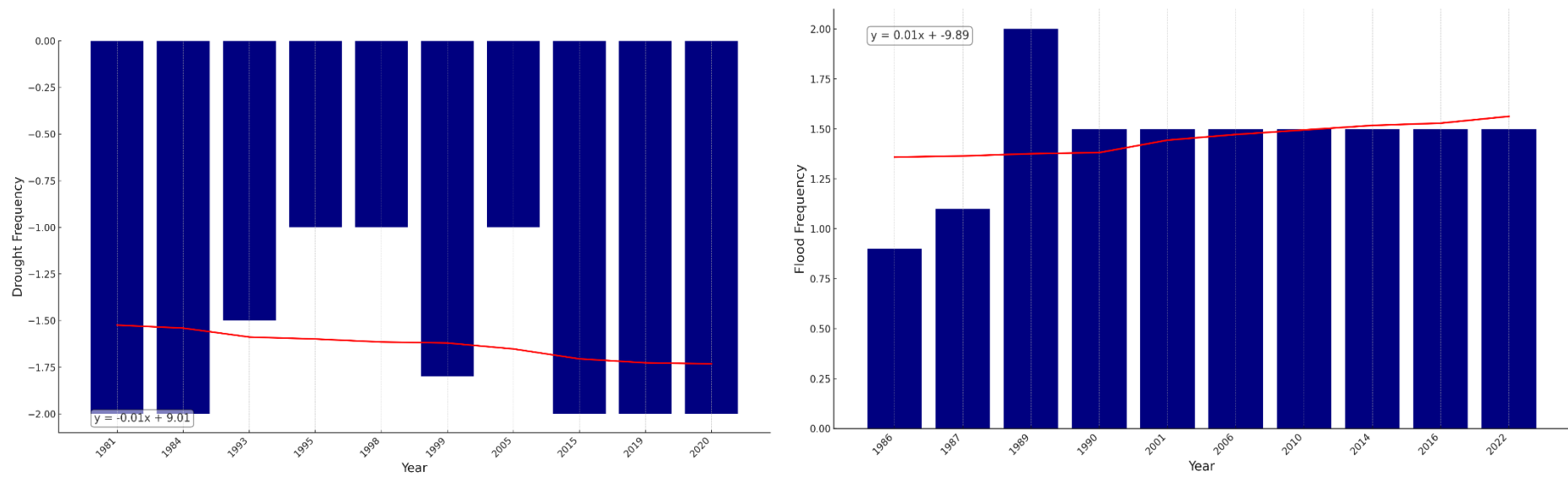
SPI 12 showed extreme flooding in 1989, followed by very wet scenarios in 1991, 2006, 2013 and 2016. The same SPI had 6 extreme droughts in 1981, from 1983 to 1985, 1999, 2015, 2019 and 2020, accompanied by severe and moderate droughts in 1993 and 2005, respectively.

With the change in the SPI time scale, the levels of droughts and floods will also change, and the onset time and end time of droughts and floods will be delayed correspondingly with the increase in the SPI time scale, which fully reflects the cumulative effects of previous precipitation changes (Liu et al., 2018).



**Figure 10: The evolution of SPI3, SPI6 and SPI12 in the Dakar region from 1978 to 2022**

The flood and drought graphs are the results of the 12 SPI analyses in the Dakar region. The SPI trend analyses revealed homogeneous trends and direct evolutions without any oscillations for the years they occurred. The decreasing SPI emphasized on increased drought as per the scale mentioned in the table 5 and and the figure 5 in 1980. The trend until 2020, showing that drought scenarios increased during the years they were observed. The flood scenarios also increased from 1988 to 2022, which is in line with the gradual increase in rainfall in the Dakar region.



**Figure 11: Evolution of drought and flood trend based on annual average of SPI-12 in the Dakar region**

Despite these challenges, establishing a statistical relationship between the occurrence of disasters and climate anomalies is an important step (Tschumi & Zscheischler, 2020).

Some previous studies have compared these global databases from various points of view on the number of human and economic losses (Bakkensen et al., 2018).

The EM-DAT analysis aims to distinguish climatic hazard impacts and enhance climate risk indicators (Woollings et al., 2018).

EM-DAT is an actively and constantly maintained global database of disaster losses. The threshold for recording data is clear, and the data are stored in a uniform format, which enables users to compare trends in disaster losses internationally (Moriyama et al., 2018).

A previous report showed that the quality and reliability of the EM-DAT are complementary to those of other disaster data reporting organizations (e.g., NatCat and Sigma) since the EM-DAT data are derived mainly from humanitarian agencies and development organizations (Guha-Sapir & Below, 2000).

*Table 7: Deaths related to floods on the EM-DAT website*

Location	Date	Disaster	Origin	Total Affected	No. Injured	Total Deaths
Dakar	1988	Flood	Heavy rains	10000	0	0
Pikine, Guediawaye and Rufisque	2005	Riverine flood	Heavy rains	4545	0	0
Dakar	2009	Riverine flood	Heavy rains	24000	0	6
Dakar provinces	2013	Riverine flood	Heavy rains	40826	25	4
Rufisque, Guédiawaye	2019	Flood	Heavy rains	4484	24	3
Dakar	2020	Flood	Heavy rains	1545	0	1
Dakar	2022	Flash flood	Heavy rains	6670	57	0

### III.1.6 Analysis of water level fluctuations

Figure 12 shows fluctuations in lake levels at Technopole, highlighting seasonal variations between 1978 and 2022, with July to October corresponding to the rainy season and November to June to the dry season.

The results show that in August 1978, during the rainy season, the NDWI was zero, indicating horizontal layers of water at Technopole. In December 1979, the levels increased slightly (NDWI = 0.01), then decreased to -0.5 in February and to 0.3 in September 1980, coinciding

with the rainy season, before decreasing to -0.1 in December 1980. This decrease continued until -0.15 between March and October 1986, before increasing to 0.07 in November 1990.

From 1990 onward, lake levels fell to -0.01 in 1991, then remained constant until 1994, before rising in May (NDWI = 0.05) and falling in November 1999 to -0.2.

For the whole of 2000, fluctuations in lake levels were positive, reaching a maximum value of 0.28 before decreasing in December 2000 to reach -0.1. From March 2001 to May 2002, the fluctuations were positive, with a maximum value of 0.25. Lake levels then fell to -0.1 in September 2002 before rising to 0.15 in November.

The values are negative from December 2002 to June 2012, indicating very low levels. However, from 2013 to 2022, levels continue to rise in all seasons (winter and dry), with a maximum value of 0.3.

These fluctuations result from the variability of precipitation and buildings at Technopole. Indeed, as shown in Figure 4, precipitation decreased drastically after 1970 (approximately -25 mm) until 1983, reducing water levels at the technopole. This was followed by slight fluctuations in precipitation, with a maximum value of 55 mm from 1984 to 2011, and the elongation of the built-up area, resulting in mixed lake levels and oscillating water dynamics. Decreases in precipitation have also led to decreases in water levels, unlike the period from 2013 to 2022, when lake levels have risen sharply as a result of the dynamics and development of urbanization (over 140 hectares of built-up area since 1993) in the Reserve and increasing precipitation (125 mm).

The various fluctuations in water levels due to variations in rainfall, evaporation (over 3.5 mm/d in 1980) and building development within the nature reserve have meant that the technopole's wetlands have experienced a loss of biodiversity in fauna and flora (such as prosopis and fish) and the drying up of water bodies between 1978 and 2005, in contrast to the high risk of flooding observed at the lakes between 2013 and 2023.

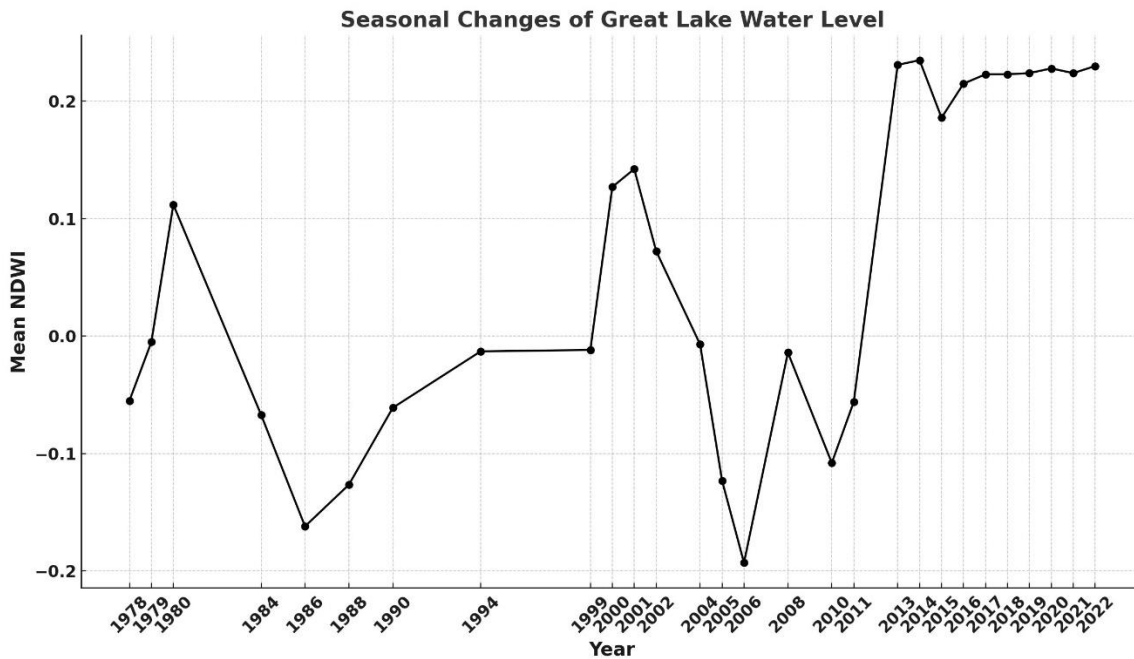


Figure 12: Monthly fluctuations in technopole lakes between 1978 and 2022

## III.2 Impact of anthropogenic factors on wetland degradation in Technopole

### III.2.1 Temporal changes in land cover classes (1988-2023) in Technopole

The 1988 occupancy map shows five different classes. These are made up of barren land, agricultural land, water bodies, settlements and natural vegetation (Typha and Prosopis) and show changes that are either expanding or shrinking depending on the classes (Figure 15). Of the four classes in 1993, natural vegetation occupied 527.63 Ha, which was 86.24% of the total area, followed by settlements, barren land, and water bodies, which covered 35.01 Ha (7.58%), 45.05 Ha (7.36%) and 4.07 Ha (0.67%), respectively.

Significant changes occurred in 2003. The percentage of natural vegetation decreased by 22% (from 519.13 to 115.02) in 2003 before increasing by 18% in 2013 and by a slight 1% in 2023. Settlements have changed over the years. Their surface area gradually increased from 26.88% in 2003 to 28.58% in 2013 before declining by 6.88% in 2023.

Barren land, agricultural land, and water bodies show irregular trends. The surface area increased by 9.59%, 25% and 4.64% in 2003, decreased by 6.65% and 21.6%, and increased by 10.78% for water bodies in 2013 before decreasing for the barren land and the water bodies and increasing for agricultural land, with values of 5.52%, 2.69% and 14.54, respectively, in 2023.

### ***III.2.2 Land use conversion dynamics (1988-2023) in Technopole***

The transition matrices (Table 12) highlight the different forms of conversion that land use classes have undergone between 1993 and 2023. From 1993 to 2003, agricultural land expanded by approximately 16.97%. These extensions result from converting 146.54 ha of natural vegetation, i.e., 27.9% of its surface area, and increases of 20.64%, 18.71%, and 4.05% in the BL, S, and WB plots, respectively. This means increases of 68 Ha, 187.61 Ha and 29.12 Ha, respectively.

Between 1993 and 2013, agricultural and barren land declined by 13% and 17%, respectively. These losses are attributable mainly to natural vegetation and slightly to settlements. During 1993-2013 and 1993-2023, the dynamics of land change were moderate and favored natural vegetation and settlements, respectively, and settlement.

Between 2003 and 2013, the agricultural and barren land areas underwent regressions equal to 22 and 11 Ha, respectively. These conversions were allocated to settlements (12 Ha of which came from AL and 4.73 from BL), natural vegetation (5 Ha of which came from AL and 2 Ha from BL), and water bodies (17% of which came from agricultural land and 8.06% from barren land). The water body surface area increased by 4 ha in this decade as a result of changes in settlements and natural vegetation. During this decade, AL and BL losses were converted into NV, S and WB losses.

Between 2013 and 2023, the surfaces of the barren land, settlements and water bodies all experienced slight decreases.

The decreases of 1.5 Ha, 110.25 Ha and 64.86 Ha in the BL, S, and WB treatments were converted to the NV and AL treatments for 115.5 and 14.12 Ha, respectively.

In this decade, the areas lost to water bodies are converted to S and NV for 6% and 1.5%, respectively.

Over the 30-year study period (from 1992 to 2023), a considerable reduction was noted for natural vegetation and barren land, with values of approximately 304.59 Ha and 15.8 Ha, respectively. These areas lost were converted into settlements, agricultural land and water bodies. The gains in surface area were 133 Ha, 109.87 Ha, and 77.88 Ha for S, AL and WB, respectively.

*Table 8: Landsat quality metrics across different years*

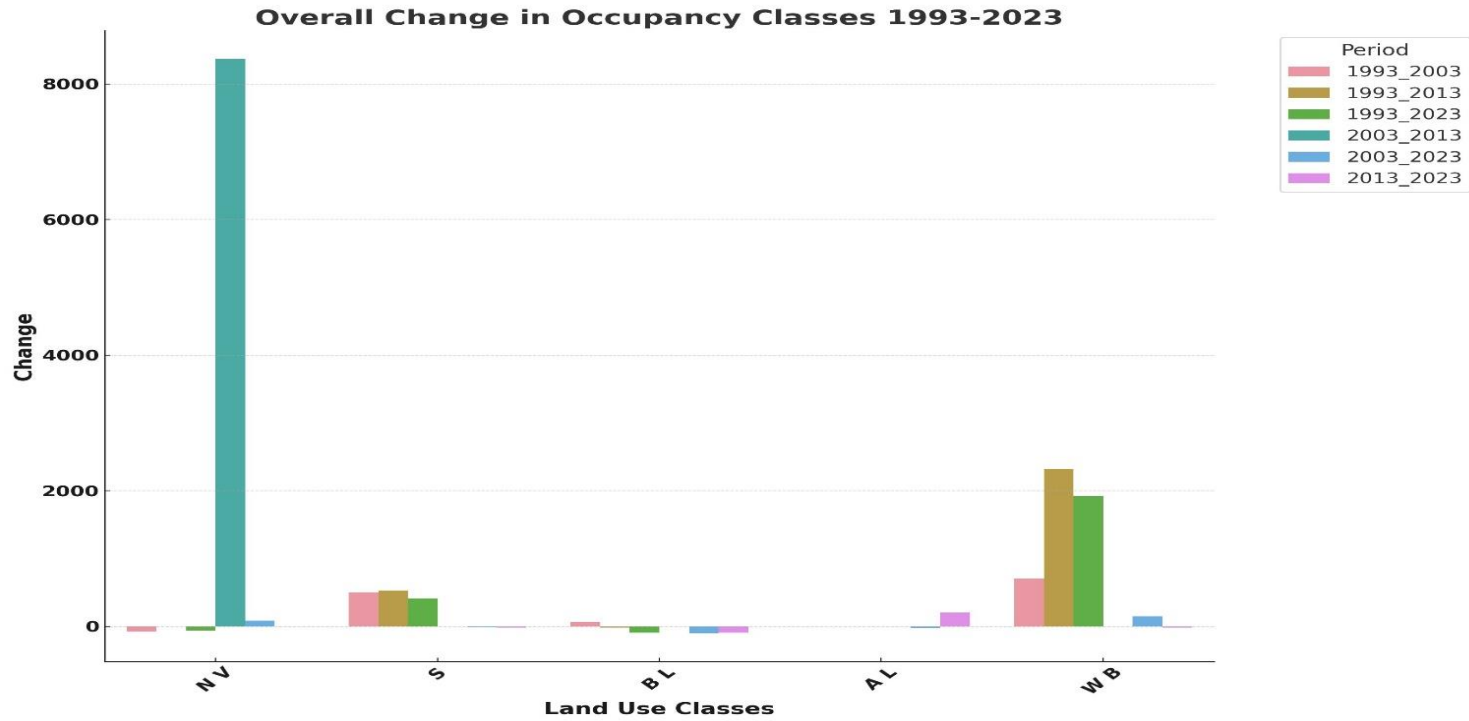
The number of (NSB), mapper (TM), thematic (ETM), and land imager	Raster data	NSB	Year	Resolution	Overall accuracy	Kappa coefficient	spectral bands thematic enhanced mapper operational (OLI)
	Landsat 5/TM	6	1993	30*30(m)	84%	80%	
Landsat 7/ETM	9	2003	30*30(m)	97.6%	99.3%		
Landsat 8/OLI	11	2013	30*30(m)	98.5%	97.4%		
Landsat 8/OLI	11	2023	30*30(m)	97.2%	98.5%		

*Table 9: Land use class surface area dynamics in Pikine from 1988 to 2023*

Land Use Classes	1993		2003		2013		2023	
	Ha	%	Ha	%	Ha	%	Ha	%
N V	527.63	86.24	115.02	18.77	211.27	34.54	214.54	35.08
S	35.01	5.72	211.23	34.47	221.23	36.17	179.17	29.29
B L	45.05	7.36	77.13	12.59	36.32	5.94	2.57	0.42
A L	00	00	176.58	28.81	44.12	7.21	133.05	21.75
W B	4.07	0.67	32.85	5.36	98.74	16.14	82.28	13.45
<b>Total</b>	<b>611.76</b>	<b>100.00</b>	<b>611.46</b>	<b>100.00</b>	<b>611.68</b>	<b>100.00</b>	<b>611.61</b>	<b>100.00</b>

*Table 10: Overall change in occupancy classes 1993-2023*

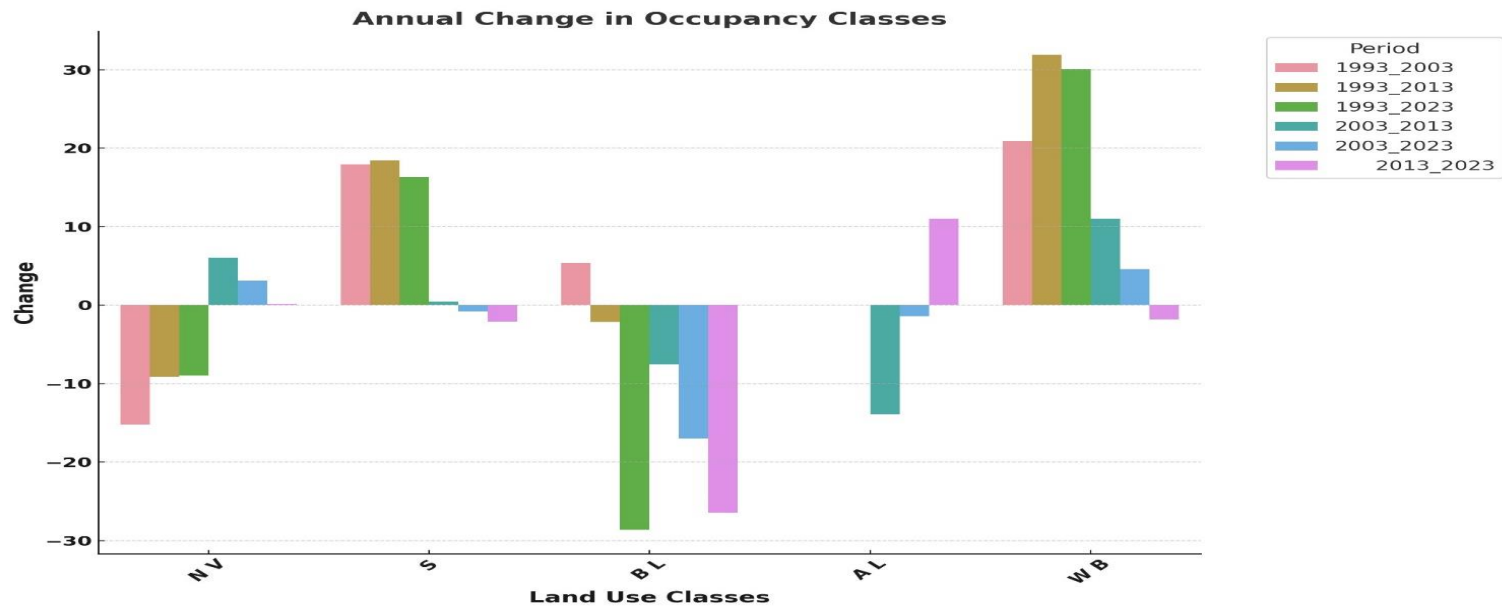
Land Use Classes	1993_2003	1993_2013	1993_2023	2003_2013	2003_2023	2013_2023
N V	-78.20	-0.59	-59.33	83,68	86.52	1.54
S	503.34	531.90	411.76	4.73	-9.26	-19.01
B L	71.21	-19.37	-94.29	-52.91	-96.67	-92.92
A L	00	00	00	-75.01	-24.65	201.56
W B	707.13	2326.04	1921.62	200.57	150.47	-16.67



*Figure 13: Overall Changes in Land Use*

*Table 11: Annual change in occupancy classes*

Land Use Classes	1993_2003	1993_2013	1993_2023	2003_2013	2003_2023	2013_2023
N V	-15.23	-9.15	-8.99	6.08	3.12	0.15
S	17.97	18.43	16.32	0.46	-0.82	-2.1
B L	5.38	-2.15	-28.63	-7.53	-17	-26.48
A L	00	00	00	-13.87	-1.42	11.04
W B	20.88	31.89	30.06	11	4.59	-1.82



*Figure 14: Annual Changes in Land Use*

*Table 12: Land use change matrices in Technopole from 1993 to 2023*

1993 to 2003						
	BL	NV	S	WB		
AL	16.97	146.54	11.33	0.0	174.84	
BL	<b>20.64</b>	51.98	4.43	0.0	77.05	
NV	0.31	<b>113.88</b>	0.45	0.0	114.64	
S	6.88	183.80	<b>18.71</b>	0.01	209.40	
WB	0.00	28.80	0.00	<b>4.05</b>	32.85	
total	44.80	525.00	34.92	4.07	608.78	

1993 to 2013						
	AL	BL	NV	S	WB	
BL	5.93	<b>6.34</b>	10.21	20.62	1.51	44.62
NV	35.57	27.07	<b>197.71</b>	180.47	84.95	525.78
S	2.38	2.35	2.91	<b>18.76</b>	8.24	34.64
WB	0.00	0.00	0.00	0.03	<b>4.04</b>	4.07
total	43.89	35.76	210.84	219.85	94.70	605.04

1993 to 2023						
	AL	BL	NV	S	WB	
AL	<b>00</b>	12.33	115.97	3.83	0.75	132.89
BL	00	<b>1.89</b>	0.68	0.00	0.00	2.57
NV	00	12.26	<b>196.76</b>	4.71	0.35	214.07
S	00	16.73	142.13	<b>18.01</b>	0.14	177.00
WB	00	1.42	70.07	7.96	<b>2.83</b>	82.28
total	00	44.62	525.61	34.51	4.07	608.81

2003 to 2013						
	AL	BL	NV	S	WB	
AL	<b>22.03</b>	17.35	50.92	68.06	17.07	175.43
BL	3.88	<b>11.88</b>	14.66	38.58	7.96	76.96
NV	5.3	2.09	<b>73.62</b>	20.31	13.29	114.61
S	12.84	4.73	71.08	<b>89.23</b>	31.44	209.32

WB	0	0	0.53	3.33	<b>28.98</b>	32.85
Total	44.05	36.05	210.82	219.51	98.74	609.17
<b>2003 to 2023</b>						
	AL	BL	NV	S	WB	
AL	<b>14.12</b>	7.43	62.97	30.29	17.95	132.75
BL	0.09	<b>1.53</b>	0.59	0.36	0	2.57
NV	13.51	6.83	<b>115.59</b>	64.66	13.61	214.2
S	16.18	20.16	28.52	<b>110.79</b>	2.33	177.98
WB	0	0	3.28	14.15	<b>64.86</b>	82.28
Total	43.9	35.95	210.94	220.24	98.74	609.78
<b>2013 to 2023</b>						
	AL	BL	NV	S	WB	Total
AL	<b>14.12</b>	7.43	62.97	30.29	17.95	132.75
BL	0.09	<b>1.53</b>	0.59	0.36	0	2.57
NV	13.51	6.83	<b>115.59</b>	64.66	13.61	214.2
S	16.18	20.16	28.52	<b>110.79</b>	2.33	177.98
WB	0	0	3.28	14.15	<b>64.86</b>	82.28
Total	43.9	35.95	210.94	220.25	98.74	609.78

\***AL:** Agricultural Land

\***BL:** barren land

\***NV:** Natural Vegetation

\***S:** Settlements

\***WB:** Water Bodies

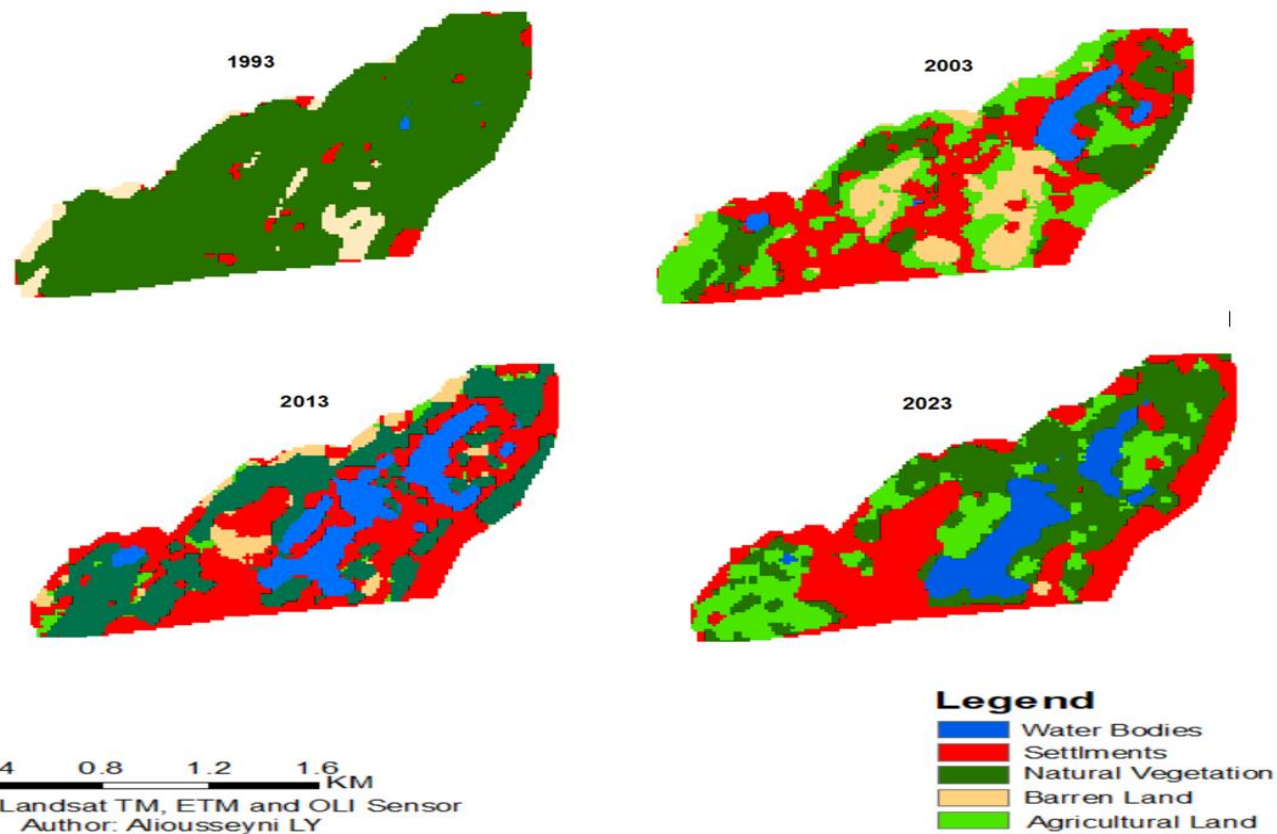


Figure 15: Land use/land change maps

The wetlands of Dakar's Niayes region are, for the most part, highly suitable sites for developing certain economic activities. Given the biogeographical conditions of these sites, market gardening remains the most suitable activity. Nonetheless, there are other very important activities whose value is underestimated (DAMCP, 2022). Despite their socioeconomic support for the populations concerned, these activities do not spare the integrity of the Reserve's marine ecosystems. Nature reserves are characterized by water pollution, land pressure and unsustainable use of natural resources.

### ***III.2.3 The National Sanitation Office of Senegal***

This state-owned company, whose job is to purify domestic wastewater, poses a major threat to the various lakes in nature reserves. Every day, this wastewater treatment plant discharges more than a million m<sup>3</sup> into the lakes of the Reserve through several connections to different lakes, in addition to clandestine lakes. These thousands of m<sup>3</sup> laden with cholera vibrios and fecal coliforms affect the fauna of these marine ecosystems, such as fish, which are victims of water pollution and struggle to find all the amenities for proper development. Hence, the very small size of these fish was noted during experimental fishing and sampling (average of 15 cm in adulthood). These waters, which are laden with ONAS pollutants, are also responsible for the death of vegetation directly in contact with the outlets.



***Figure 16: Connection and discharge of wastewater in the Technopole Nature Reserve***

### **III.2.4 Agricultural Activities**

Market gardening is one of the major activities practiced in Grande Niaye de Pikine. The latter first appeared in the area in 2003 and occupied 9.54% of the activity sectors (DAMCP, 2014).

This activity brings together more than 700 market gardeners spread across the Reserve.

Agricultural plots are directly connected to different locations for irrigation purposes. Agricultural land pressure, annual and continuous irrigation, and phytosanitary products such as fungicides, insecticides and nematicides for fertilization and soil disinfection pollute parts of directly connected water bodies. These chemicals are used annually for production to meet the growing demand in the capital at risk of polluting the Niayes groundwater table, which is 2 m high.



*Figure 17: Agricultural plots at Technopole*

### **III.2.5 Fishing**

Fishing is a fairly recent activity in Dakar's wetlands. Traditionally, this practice has grown rapidly, particularly in the Technopole area, and the number of permanent fishermen is estimated to be approximately 50 (DAMCP, 2016).

Fishing occurs in two parts of the day, from 5 a.m. to 10 a.m., a very propitious time, and from 10 a.m. to 3 p.m., depending on the period.

These practices alter the balance of ecosystems due to the biological absence and use of nonselective mesh, which captures all types and sizes of fish. These practices are thus the result of a considerable decline in the quantities of fish caught, which, in addition to the absence of biological rest, constitutes an obstacle to the renewal of species. In addition to the continuous aspect of fishing activity, passive nets can capture nontarget species, degrade benthic habitats such as coral reefs, seagrass beds, and seabeds, and lead to the overexploitation of fish populations.

### **III.2.6 Craft Activities**

Craftsmanship is a highly developed sector on the site. Craftsmen are grouped in associations. They include mechanics, carpenters, butchers, extension workers, welders, charcoal sellers, restorers, and founders. This activity is a hindrance to conservation in the Reserve.

Garages are located on the dune edges of the technopole in the commune of South Golf and the extension zone of the soprimes. They are made up of mechanics, sheet metal workers and electricians.

Mechanical activities are the source of continuous noise pollution, which disrupts the peace and quietness of bird populations in lakes; oil is discharged into the surrounding areas, eliminating the nearest vegetation; and there is a continuous loss of space, reducing the area occupied by vegetation and secondary bodies of water.

The artisanal processing of animal skins is a major source of pollution. This activity takes place in the vicinity of the Grand Lac. The waste from this activity is dumped directly into the lake, leading to local eutrophication of this area.



*Figure 18: Craft activities at Technopole*

### **III.2.7 Infrastructures and Companies and Land Pressure**

Commercial activities are mainly concentrated in the reserve industrial zone. This zone, an integral part of the Reserve, is home to approximately one hundred warehouses and almost 1,000 jobs. The industrial zone is dominated by the commercial sector, which accounts for almost 58% of the total, followed by transport (17%) and construction (7%). However, companies are also operating in other sectors, such as materials handling and mechanics. The occupation of these industries has drastically reduced the surface area. They occupy more than 35 hectares of the Reserve, i.e., 5% of the total surface area.

These industries have led to a drastic transposition of vegetation into construction. This commercial activity constantly pushes back the limits and increases the pressure on the Reserve's vegetation and water bodies.

In addition to the expansion of the industrial zone, land pressure and the dumping of waste have led to the filling of water bodies on the outskirts of the Reserve to build housing. These practices, such as the 4-hectare extension of the Pikine cemeteries, negatively impact the wetlands' sustainability. The passage of a freeway between the two Maristes Lakes is also the cause of the high rate of eutrophication due to the absence of water circulation. These practices are accelerating the disappearance and extinction of the biotic and abiotic biodiversity of these areas.



*Figure 19: Urbanization at Technopole*

### ***III.2.8 Analysis of lake water quality in Technopole***

The Toxicology and Hydrology Laboratory of the Faculty of Medicine, Pharmacy, and Odontostomatology studied water quality at Cheikh Anta Diop University in Dakar. The results thus obtained constitute a reference condition for the various lakes.

The pH value was within the range set by standard NS05-033 (6-9.2) for all the lakes sampled, although it was closer to the threshold value. For conductivity, the values found are well above the limit value (2.7 mS/cm) set by standard NS05-033. This may be linked to a certain salinization of the water, which is not conducive to the development of freshwater species. Considering turbidity, the turbidity values are greater in the large lakes, Lake Orange and Lake << Kahira". However, none of the lakes reached the threshold value (5 NTU) set by standard NS-05-033. With regard to heavy metals, only cadmium slightly exceeded the threshold value set by standard NS05-033 at Lake << Tigo >>.

In conclusion, the results of the samples submitted for analysis are below the standards, which seems favorable to aquatic life. However, the conductivity values explain a certain salinization of the water and, therefore, do not favor the development of freshwater species.

For lakes in the dependency zone, analyses were carried out to determine the values of pollution parameters such as BOD5 and COD and microbiological parameters such as fecal coliforms, salmonella and cholera vibrios.

This study indicated an advanced deterioration in water quality, which may be linked to the wastewater discharge noted in the area. The upsurge in these discharges has led to an overabundance of organic matter in the environment and, thus, to an increase in the quantity of oxygen required for biodegradation. This is reflected in the BOD5, COD, cholera vibrio, and fecal coliform values well above the threshold values for these pollution parameters.

All this characterization confirms the presence of pathogenic elements in these waters, linked in part to ONAS discharges and the use of chemical fertilizers by market gardeners and flower growers.

*Table 13: Water sample analysis results*

			Results of water samples analysis						
Requied Parameters	Analyze Method	Unit	DEP1 C30127EC1	DEP2 C30127 EC2	GREAT LAKE C3012TEC3	LAKE ORANGEC30127ECA	ETHIOPIA C30127EC5	LAKE TIGO C30127EC6	LAKE KAHIRA C30127EC7
Phosphate	NF EN ISO 6878:2005-04	mg/l	8.5	9.19	5.82	3.26	0.46	3.64	0.31
Ammonium	NF T 90-015- 2:2000	mg/l	0.14	0.11	0.19	0.11	0.17	2.67	<0.1LOQ
Sulphate	HACH 680	mg/l	40	16	116	108	166	72	132
DBO5	NH EN 1899-1	mg/l	1 1,7	12.1	8.96	8.94	2.96	51.68	2.26
Dissolved oxygen	Rodier 9e Edition	mg/l	6.92	5.91	6.96	6.66	5.4	2.97	5.72
Nitrates	Rodier 9e Edition	mgN03/l	3.9	3.2	2.5	3.7	4	6.4	3.6
Nitrates	Rodier 9e Edition	mgN03/l	<0,02LOQ	<0,02	<0,02	<0,02	<0,02	0.07	<0,02
Faecal Streptococci	ISO 7899	100mI	detected	detected					
Total coliforms	NF EN ISO 9308-1	100 ml	detected	detected					

## IV DISCUSSION

This research aimed to analyze the effects of climate variabilities and human activities on wetland degradation at Technopole.

Analysis of the Mann-Kendall and Sen slope tests revealed increasing trends in the Dakar maximum temperature and rainfall parameters. These annual increases of 0.39 mm and 0.39°C explain the low variations in these parameters, in addition to the low flows recorded since 1978, which means that the water requirements of the wetlands and floral biodiversity of the Technopole are not being renewed. This increases the salinity of the lakes (21g/l), as shown in the water quality analysis, and decreases the water levels in the lakes, as shown in Fig 12, between 1985 and 1994 (NDWI= -0.23) due to the low rainfall (on average 33 mm/10 years) and the low rate of urbanisation (less than 10 ha of occupation). In general, increasing salinity concentrations are accompanied by a decrease in biodiversity (micro-organisms, algae, plants and animals) (Klieger et al., 2014). Our results corroborate those of Niasse et al., (2004), who reported that a decrease in water flow significantly reduced the main wetland and vegetation. These results explain the presence of flood risks in the plains and the presence of severe drought scenarios from 1978 to 2020 in the Dakar region. Furthermore, the natural state of the Niayes was initially affected by natural disturbances before human actions fragmented the urban model and substituted human needs for ecological functions (Mbow et al., 2008).

The flood risk results show different classes depending on the level of exposure of the site studied. The very high risk and the high risk are located exactly where the reserve's water bodies are. The low risk is located in sites where agricultural activities predominate, thus eliminating any risk of water branching and flooding, for which climatic variability is the main cause. However, our results are perfectly consistent with those of Saliu et al., (2014), who argue that the Technopole is home to buildings of high socio-economic value to the Dakar region, such as the Société nationale de communication (SONATEL), the Agence informatique de l'État (ADIE), the Golf Club, and the housing estate known as Fayçal City. As a result, they are exposed to the risk of flooding. This danger is justified by the construction of a national wrestling arena in the Technopole and the gradual settlement of households in the nature reserve. Flooding in the Dakar region is not as natural as it might seem. The return to normal rainfall only reveals the poorly controlled occupation of the land (Sene, 2002).

According to the classification, the SPI calculated for the Dakar station shows severe droughts for all the different month scales from 1978 to 2020, with the exception of SPI 12, where rainfall has increased considerably. These droughts are a continuation of those of the 1970s, which severely affected sub-Saharan countries including Senegal. This peri-urbanisation coincided with a major drought that led to rural poverty and mass migration of rural populations to Dakar (Mbow et al., 2008). As a result, these long and severe droughts reduced the flow of rivers and led to the disappearance of marine and plant species in the Technopole reserve, as well as the extension of built-up areas (an increase of almost 88% in 10 years) and the reduction of areas of natural vegetation (by up to 18% in 2003), as shown on the 2003 land-use map, which corresponds to the period just before the return of the rains to Dakar in 2006.

Drought, flooding and evaporation scenarios have increased between 1978 and 2022. This clearly shows the large-scale changes in climatic parameters in the Dakar region, causing rivers to dry up in the 1980s and 1984 and flooding episodes in the years 2006 to 2020, as confirmed by Figure 8, and the loss of human life, as confirmed by the analyses on the EM-Dat site. These results are confirmed by Diongue (2016), who confirmed the loss of property and equipment during flood scenarios in North Yeumbeul.

The diversity of human activities in the Technopole reserve and its location in the Dakar region mean that it is threatened by the loss of ecological resources. The thousands of m<sup>3</sup> of water discharged daily into the lakes of the Technopole reserve and its outbuildings by official and clandestine ONAS connections, laden with faecal coliforms, salmonella and cholera vibrio (Table 13), are altering the integrity of these lakes to the point of making them unusable and destroying marine biodiversity. Phosphates and nitrates encourage the sometimes exaggerated growth of aquatic flora, leading to eutrophication of rivers and lakes (Gueye et al., 2023). The very high concentration of nitrogen in treated water from the Pikine Technopole wastewater treatment plant is due to incomplete treatment of wastewater by the plant (Dame et al, 2020). Wastewater from septic tanks is treated to less than 70%, which prevents complete denitrification of the treated water (Gueye et al., 2023). Our results corroborate those of Gueye et al., (2023), who reported high nitrogen concentrations in treated wastewater. The analysis also revealed the presence of suspended solids such as faecal streptococci (Table 13), which threaten biodiversity. The high concentrations of suspended solids (85.9 mg/L), chemical oxygen demand (1789 mg/L) and total nitrogen (67.6 mg/L) contribute to a reduction in dissolved oxygen and thus degrade the biodiversity of aquatic ecosystems.

In addition, the use of phytosanitary products for agricultural purposes, which find their way into the lakes through rinsing and the dumping of leftover containers into the environment, and the use of the lakes for agricultural irrigation mean that the water is harmful to the health of consumers, biodiversity and the reserve's soils. The physico-chemical and microbiological parameters of wastewater treated by WWTPs and used for irrigation far exceed the standards for reuse in agriculture (Gueye et al., 2023).

Extreme climatic conditions have greatly accelerated the urbanisation of Dakar, supported by strong migration. Between 1968 and 1985, the rapid urbanisation of Dakar was driven by large-scale migration. According to Richard (1990) this period of drought, marked by pronounced rainfall deficits in 1970-1973, 1976-1977 and 1983-1984, was particularly difficult for the inhabitants after years of abundant rainfall. Dakar, as an urban centre, attracted a net migration of 20,000 people, contributing to its expansion. The absence of a return to normal rainfall maintained this migration, redistributing the population in favour of the urban areas of Dakar and Pikine.

Backfilling and daily fishing for housing and commerce, respectively, as well as the extension of the Pikine cemeteries and the dumping of rubbish in the reserve, remain common practices. These activities, compounded by the pressure of urbanisation on the reserve, are reducing the surface area of the Technopole's water bodies, endangering the regeneration of fish in the lakes and encouraging the proliferation of natural vegetation. In addition to flooding, urban expansion in the Niayes area has facilitated the spread of invasive species such as *Typha* (Manful, 2021). This species is currently recognised as a major threat to biodiversity in the Niayes (MEDD, 2019). The encroachment of the urban front disproportionately affects peri-urban wetlands. The situation in the Grande Niaye de Pikine (Technopôle) is a poignant example (Diaouma, 2018). Myers (2018) affirms our observations, pointing out that the urbanisation process in Pikine is significantly encroaching on wetlands.

The uncontrolled development of market gardening and artisanal activities also poses a threat to the preservation of the Technopole. In the absence of land allocated to market gardening in the capital, which is frequently subject to eviction, market gardeners are relocating to the Niayes (Manful, 2021). In the Technopôle area, growers are clearing the vegetation and filling it with household waste to take over new plots. This practice contributes to the degradation of vegetation cover and alters water flow paths, further increasing the vulnerability of populations to flooding (Manful, 2021).

## **IV Logical Framework Proposition for the Technopole Development and Management Plan**

The Grande Ndiaye de Pikine et dépendance nature reserve is a highly strategic site located in Senegal's capital between the three departments of Dakar, Pikine and Guediawaye.

The development of the site for its ecological, social and economic enhancement is an absolute necessity. To this end, the development of the site is seen as an outlils for its sustainable enhancement.

### **Sports infrastructure development**

The reserve needs a spatial installation well suited to the site. The practice of sport should be envisaged in such a place, where all the conditions seem to be met apart from the infrastructure. The practice of sport and certain sports-related leisure activities must be accompanied by the creation of suitable infrastructures.

- Creation of a sports trail
- Development of cycle paths

### **Restoration and revegetation of the reserve**

- Dredging, cleaning and mowing of water bodies
- Development of fish ponds
- Internal and external reforestation
- Development of the dune area
- Re-population of low-lying areas with palm and coconut trees
- Protection of sensitive areas

### **Inspections**

- Strengthen community policing
- Eliminate polluting practices (craft activities)
- Promote organic farming on the shores of the lakes
- Require wastewater treatment before discharge into lakes
- Make Technopole the blue lung of the Dakar region.

## IV.1 Action Plan

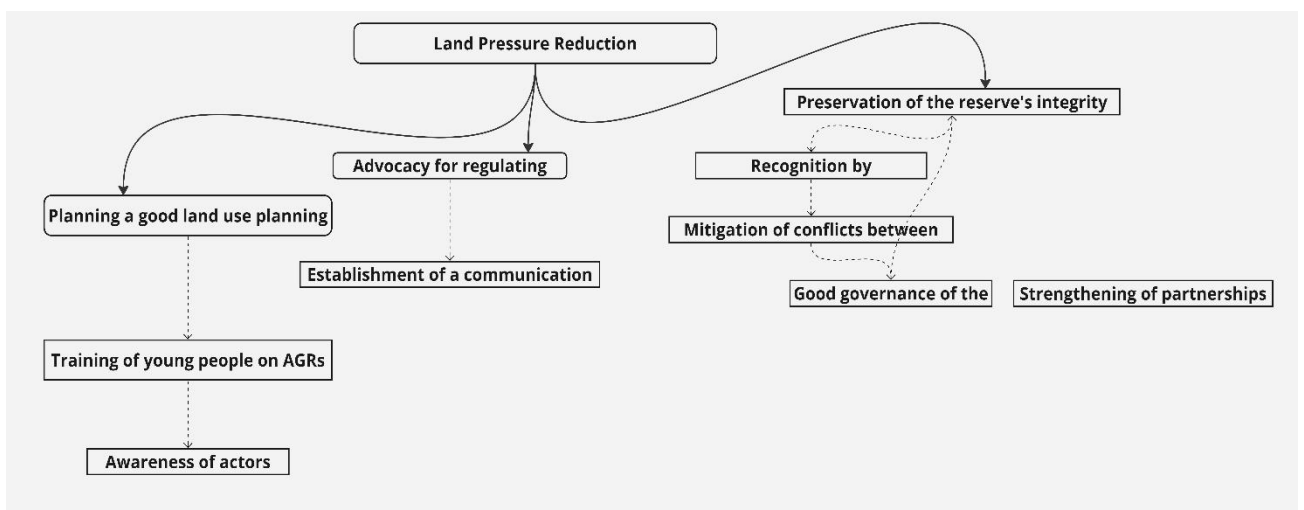
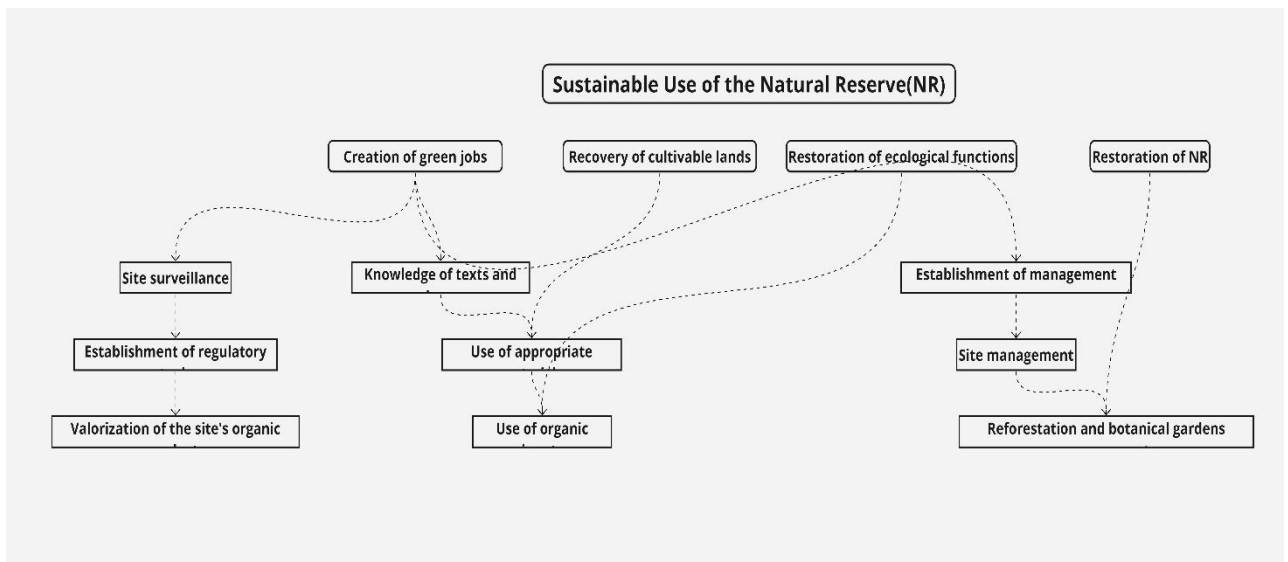
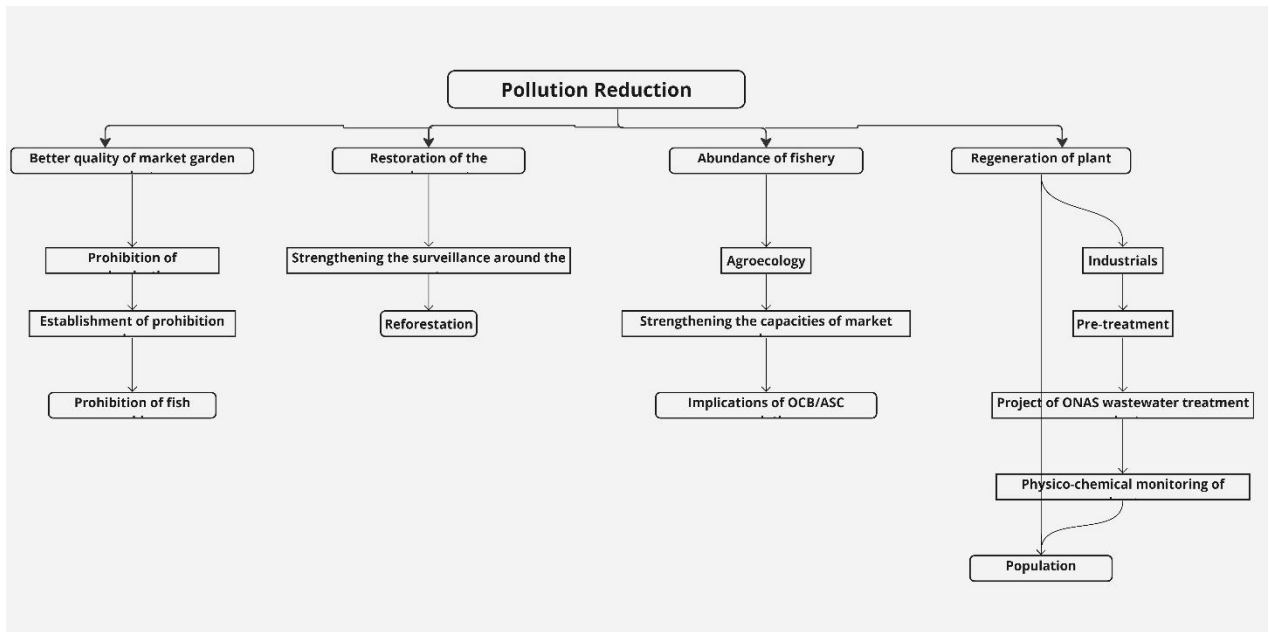


Figure 20: Strategies For the Natural Reserve's Integrity

## IV CONCLUSION

The Technopole nature reserve is one of the last wetlands in the Dakar region where natural bodies of water are rare. Climate change has led to an increase in water level fluctuations, a reduction in recharge and an increase in water salinity, which has had a negative impact on local biodiversity due to the scarcity of rainfall. While the immediate risk of flooding appears minimal due to the presence of existing water bodies, drought scenarios, assessed by the SPI index, reveal periods of severe drought between 1978 and 2020 before rainfall resumes in Dakar. At the same time, human activities such as the massive dumping of untreated domestic wastewater, the filling in of water bodies, non-selective fishing and rapid urbanisation have emerged as major factors in the pollution and degradation of the wetlands of Lakes Technopole and Mariste. Artisanal and mechanical activities add a further layer to these problems by contributing to water pollution through the discharge of animal debris and oils, thereby exacerbating the environmental challenges. It is essential to understand the climatic and human dynamics of wetland degradation. These valuable ecosystems require integrated management and effective conservation measures to ensure their preservation in the face of current and future challenges.

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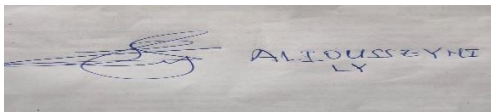
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**Supervisor: Samehahmed KANTOUSH**

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**Student: Aliousseyni LY**

Handwritten signature of Aliousseyni LY, featuring a stylized signature followed by the name 'ALIOUSSEYNI LY' written in capital letters.