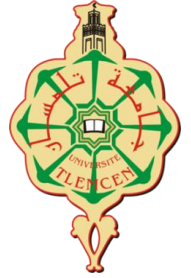




**Institute for Water
and Energy Sciences
(incl. Climate Change)**



**PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)**

Master Dissertation

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ADJI BILLO NIANG

TITLE:

**Assessment the Impacts of Reuse Wastewater for Irrigation on
Soil: Case study: Dakar Niayes Zone**

Defended on 22/04/2024

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DECLARATION

I, Adjil Billo Niang, do declare that this thesis represents my personal work, realized to the best of my knowledge. It has been submitted only to the Pan-African University, Institution of Water and Energy Sciences (Including Climate Change). I also declare that all informations, methods and materials, results from others works presented here, have been cited and referenced in accordance with the academic rules.

Adjil Billo Niang




CERTIFICATION

This is to certify that the work presented has been submitted with my approval as the supervisor.

Professor Nadia Badr
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Signed: 27/03/2024

A light blue rectangular box containing a handwritten signature in cursive script that reads "Nadia Badr".

DEDICATION

This thesis is specially dedicated to my dear beloved Elhadj Tidiane Niang Rahimallahou Hanehou, my lovely Grand Mother Sokhna Maguette Niang Rahimallahou Halayhi the one who has been my source of motivation, the only one who loved me and took care of me during her life.

To my dear aunty: Sokhna Seynabou Seck Rahimallahou Halayhi

To my dear grandfather: Abdoulaye Seck

To my dear father: Elhadj Salif Niang

My dear mothers: Fatou Wade and Fatou Seck

My dear aunties Sophie Seck, Atta Seck and Ndeye Rama Seck

My uncles Babacar Seck and Ndao Seck

To my manager, my best friend, my confident, my love and my all Elhadj Gora Sarr

My dear daddy: Bocar Diop

To my brothers, my sisters and all my family and friends

To the PAUWES administration and students specially my lovely countrymate and my Muslim sisters

This work is for you my dears I love you too much.

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LISTS OF ABBREVIATIONS

BOD₅: Biological Oxygen Demand 5

Ca²⁺: Calcium

CEC: Cation exchange capacity

Cl: Chlorides

COD: Chemical Oxygen Demand

EC: Electrical Conductivity

FAO: Food and Agriculture Organization

HCO₃⁻: Bicarbonates salts

NIP: National Institute of Pedology

IWQI: Irrigation Water Quality Index

K⁺: Potassium

MH: magnesium Hazards

m³/h: cubic meter per hour

m³: cubic meter

meq/l: milli equivalent per liter

Mg²⁺: Magnesium

Na⁺: sodium

%Na: Sodium percentage

ONAS: National Sanitation Office of Senegal

pH: Hydrogen potential

OM: Organic Matter

PI: Permeability Index

PO_4^{3-} : Phosphates

PS: Potential Salinity

RSC: Residual Sodium Carbonate

SAR: Sodium Adsorption Ratio

SO_4^{2-} : sulphates

TSS: Total suspended solids

WWTP: Wastewater Treatment Plant

TABLE OF CONTENT

1	CHAPTER 1: INTRODUCTION	12
1.1	BACKGROUND	12
1.2	PROBLEM STATEMENT	13
1.3	GENERAL OBJECTIVE:.....	14
1.4	SPECIFIC OBJECTIVES:	14
1.5	RESEARCH QUESTION	15
1.6	HYPOTHESIS.....	15
2	CHAPTER 2: LITERATURE REVIEW	16
2.1	THE SOURCES OF WASTEWATER.....	16
2.2	WASTEWATER COMPOSITIONS.....	17
2.3	ADVANTAGES AND DISADVANTAGES OF USING WASTEWATER FOR AGRICULTURAL	17
2.3.1	ADVANTAGES	17
2.3.2	DISADVANTAGES.....	18
2.4	POTENTIAL IMPACTS OF WASTEWATER USE IN AGRICULTURE	20
2.4.1	PUBLIC HEALTH	21
2.4.2	CROPS.....	21
2.4.3	SOIL RESOURCES	22
2.4.4	GROUNDWATER RESOURCES.....	24
2.4.5	PROPERTY VALUES	25
2.4.6	ECOLOGICAL IMPACTS	26
2.4.7	SOCIAL IMPACTS.....	27
3	CHAPTER 3: MATERIALS AND METHODS.....	28
3.1	STUDY AREA.....	28
3.1.1	HISTORIC OF URBAN AGRICULTURE IN DAKAR.....	28
3.1.2	THE GEOGRAPHICAL CONTEXT OF THE DAKAR NIAYES ZONE	29
3.1.3	PRESENTATION OF PIKINE.....	29
3.1.4	PRESENTATION OF NIAYES OF PATTE D'OIE	30
3.1.5	THE CLIMATE FACTORS OF THE STUDY AREA	31
3.1.6	THE GEOMORPHOLOGY FACTORS	32
3.1.7	THE SOIL CHARACTERIZATION	32
3.1.8	HYDROLOGY AND HYDROGEOLOGICAL RESOURCES	34
3.1.9	THE TYPES OF WATER USE FOR IRRIGATION.....	35

3.1.10	THE REUSE OF TREATED WASTEWATER FOR IRRIGATION IN PIKINE	36
3.2	DESCRIPTION OF THE METHODOLOGICAL FRAMEWORK	36
3.2.1	SURVEY WITH FARMERS.....	37
3.2.2	SURVEY OF INSTITUTIONAL ACTOR.....	37
3.2.3	SAMPLING METHOD.....	37
3.2.4	ANALYSIS METHODS.....	39
3.3	DETERMINATION OF IRRIGATION WATER QUALITY INDICES	45
3.3.1	DETERMINATION OF IRRIGATION WATER QUALITY INDEX	46
4	RESULTS AND DISCUSSION.....	51
4.1	REFERENCE FRAMEWORK FOR ANALYZING RESULTS OF WATER.....	51
4.1.1	POTENTIAL HYDROGEN (PH)	53
4.1.2	ELECTRICAL CONDUCTIVITY(EC).....	54
4.1.3	INTERPRETATION OF ANIONS AND CATIONS BY USING PIPER DIAGRAM	57
4.1.4	INTERPRETATION OF INDICES	58
4.2	INTERPRETATION OF SOIL ANALYSIS	70
4.2.1	TEXTURAL TRIANGLE OF THE SOIL	70
4.2.2	THE PH.....	71
4.2.3	THE ELECTRICAL CONDUCTIVITY	73
4.2.4	THE ORGANIC MATTER (OM)	74
4.2.5	CARBONE PERCENTAGE	75
4.2.6	PLANT NUTRIENT ANALYSIS (N, P, K)	76
4.2.7	THE CATION EXCHANGE CAPACITY CEC	78
	CONCLUSION	80
	RECOMMENDATIONS.....	82
	REFERENCES.....	83
	APPENDIX.....	87

TABLE LISTS

Table 1: Pollutants in wastewater and their potential impacts through agricultural use	18
Table 2: The indices for Irrigation purposes, their formula, classification and references	45
Table 3. The Weight for the IWQI parameters	47
Table 4: Limiting value of Qi calculations.	48
Table 5: Classifications and characteristics of general IWQI.....	48
Table 6: Descriptive statistics and comparison of the parameters with FAO values.....	52
Table 7: the result of the statistical values of the indices	58
Table 8: Results of IWQI calculation	66
Table 9: Assessment of the acidity or alkalinity of the soil according to (Ousmane NDIAYE et al., 2012).	72
Table 10: results of the water parameters analysis for the lake	87
Table 11: Results of the water parameters analysis for the groundwater.....	88
Table 12: Results of the water parameters analysis for the treated wastewater.....	89
Table 13: Results of the water parameters analysis for the mixed water.....	90
Table 14 :Statistical analysis of IWQI	91
Table 15: results of the soil parameters analysis for the lake	91
Table 16: results of the soil parameters analysis for the groundwater.....	93
Table 17: results of the soil parameter	94
Table 18: Results of the mixed water	99

FIGURES LISTS

Figure 1: location of the study area.....	31
Figure 2: soil map of the study area.....	34
Figure 3: location of the sampling point.....	39
Figure 4: pH and EC meter.	40
Figure 5: water bath and samples after their remove from the water bath	41
Figure 6: flame photometer for determination Na and K	43
Figure 7 : summary statistical analysis of water parameters	52
Figure 8 : pH of the different water	54
Figure 9 : Average EC values for the different types of water	55
Figure 10: Classification of irrigation water suitability using Wilcox diagram based on SAR and EC of mixed water and groundwater.	57
Figure 11: The Piper diagram of the different water type.	58
Figure 12: Average SAR of the different water type.....	60
Figure 13: Average Na% of the different types of water.....	61
Figure 14: average PI of the different irrigated water.....	62
Figure 15: Average PI of the different irrigated waters.....	63
Figure 16: Average MH of different types of water.	64
Figure 17: PS average of the different water	66
Figure 18: IWQI of the different types of water.....	68
Figure 19: Interpolation of irrigation Water Quality Index using Arcgis.....	69
Figure 20: textural triangle of the soils.....	71
Figure 21: pH values of soil irrigated with the different types of water.....	73
Figure 22: EC of soil irrigated with different water	74
Figure 23: Average % OM of the soil samples.....	75
Figure 24: Average of the % Carbone of the soils irrigated with different types water	76
Figure 25: average % N of soils irrigated with different types of water.....	77
Figure 26: K average of the soils irrigated with different water.....	77
Figure 27: P average of the soils irrigated with the different water.....	78
Figure 28: CEC average of the soils irrigated with different types of water	79

ABSTRACT

Urban agriculture in Dakar occurs within the Niayes region, which possesses highly conducive climatic and hydrological conditions for this practice. As a result of the gradual increase in salinity in the groundwater, agricultural practitioners started employing untreated wastewater from aging drainage pipelines for the purpose of irrigating their fields.

This research aims to assess the impacts of irrigation with treated water on physical and chemical properties of groundwater and soil in Niayes zone, Senegal, using Irrigation Water Quality Index (IWQI) and indices for water irrigation quality. For sampling method 30 water and 74 soil samples were collected into 4 different areas for irrigation: Technopole of Pikine, Patte d'oie, Maristes and Sangalkam our control zone. The physical and chemical water parameters were analyzed and IWQI and indices like SAR, PS, MH, RSC, PI and % Na were calculated for assessing the quality of water for irrigation. Groundwater samples show higher salinity levels than wastewater due to overexploitation for irrigation, leading to salinization and contamination of water tables, posing risks to coastal regions. While wastewater irrigation helps mitigate yield reductions from saline groundwater, concerns arise regarding magnesium hazard and sodium carbonate levels, potentially leading to soil alkalization and decreased agricultural productivity. The Irrigation Water Quality Index suggests caution in using these waters for irrigation without proper soil permeability conditions. Groundwater quality is compromised by excessive salts and elements, contributing to overall declines in water quality indices. Continuous reuse of low-quality wastewater adversely impacts soil fertility and groundwater quality, emphasizing the need for improved wastewater management strategies for sustainable agriculture and water security.

Keywords: Treated wastewater, Niaye zone, Irrigation Water Quality Index, Soil, Dakar, impact

1 CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Water is the most important resource in the world as water resources directly impact the socio-economic development of societies. Therefore, the quality and quantity of a water supply system is important. Water is not only used for domestic purposes but also for industrial and agricultural purposes. It is also used for leisure activities, such as swimming, rafting, water polo, etc., all around the world. Anthropogenic activities across every continent endanger the quality of both surface water and groundwater. Over five billion people worldwide rely on groundwater and surface water systems for a variety of purposes, including potable water, housing, crop production, and manufacturing applications. Recently, the quality of surface water and groundwater are at a threat due to anthropogenic activities all over the world.

Water resources degradation is a well-studied phenomenon that can be caused by natural processes (climate change, water–rock interactions, and geological factors), as well as human activities (Industrial purposes, agriculture practices and urban wastes). Apart from anthropogenic activities, natural rock/soil heterogeneities interact with water, influencing natural water cycles and affecting the water quality across all domains (Siriwardhana et al., 2023). Moreover, climate changes significantly impact the global landscape, affecting, food security, and human health and particularly water resources. In 2017, the Global Panel on Climate Change reported an average global warming of 1°C above pre-industrial levels due to human activities, with projections indicating a potential increase of 3.5°C by 2100. These changes are anticipated to cause regional temperature variations between 1.4 and 5.8°C, contributing to a 20% rise in global water scarcity, as indicated by the Food and Agriculture Organization of the United Nations (FAO) (Food and Agriculture Organization of the United Nations (FAO) 2020).

The Earth possesses a vast water volume of approximately 1,351 million km³, yet only 3% is suitable for consumption and irrigation. In an equitable distribution scenario, each person would have access to 5,000 to 6,000 m³ of freshwater per year. However, the reality, the water availability influenced by factors such as population growth, urbanization, per capita consumption, water pollution, and climate change (Aboye, 2022), deviates from this ideal, leading to a scarcity crisis considered a major impediment to sustainable development.

To safeguard the environment, rational use this "blue gold" in urban settings, combat climate change, attain food self-sufficiency, and fulfill Sustainable Development Goals (SDG 6 and 2), it is imperative to refocus efforts on recycling water through the urban wastewater reuse for irrigation (Hussain I et al, 2002). Pursuing of Sustainable Development Goal (SDG) 6, to ensure clean water and sanitation for all, holds not only intrinsic importance but also serves as a prerequisite for achieving various other SDGs, including overarching goal of poverty eradication. While target 6.3 concentrates on reducing pollution and enhancing wastewater disposal, management, and treatment, these efforts align with several other SDGs. Nutrient recovery and water reuse emerge as pivotal elements in realizing SDG 2 (zero hunger), addressing food security, improved nutrition, and sustainable agriculture (Directorate & Papers, 2000).

1.2 PROBLEM STATEMENT

Occupying the Sahelian area of the tropical zone in a wide coastal strip (500 km along the Atlantic Ocean), Senegal covers some 196,192 km². The climate is subtropical, with two seasons: the dry season which is 9 months, from September to July, and the wet season from July to September (Mbaye & Moustier, 2000). In Senegal, similar to arid and semi-arid regions across Africa, the challenges of a rapidly growing population and a scarcity of water resources are evident. This circumstance has led to the migration of people from rural areas to urban centers, causing food insecurity in these urban areas. To address this issue, there has been substantial growth in urban and peri-urban agriculture in the capital city of Dakar (Ndiaye, 2014). The Dakar region expands 550 km² between 1710 and 1732 West longitude and 1453 and 1435 North latitude. Dakar is bordered on the north, west and south by the Atlantic Ocean while the east is bordered by the Thies region. (Rahman et al., 2016). The selection of Dakar as the capital of Senegal can be attributed to its advantageous position for maritime trade and its proximity to the agriculturally rich Niayes region, named for its extensive fertile lands nestled amidst parallel sand dunes (Mbaye & Moustier, 2000). 70% of the Dakar region's vegetable supply comes from urban agriculture. Urban agriculture in Dakar occurs within the Niayes region, which possesses highly conducive climatic and hydrological conditions for this practice. It comprises a network of dunes and inter-dunes. Notably, the groundwater table in this area is relatively shallow, ranging from 0.5 to 10 meters in depth. The soil composition consists of 96% sand, 2% silt, and 2% clay (Cheikh & Sidy, 2018).

Understanding the impacts of such reuse is crucial for the sustainability of this practice because reusing wastewater can have potential environmental impacts, especially on groundwater quality and soil. These impacts may include changes in nutrient levels, contamination from pollutants, and alterations in the physical and chemical properties of the soil. Assessing the effects of reusing wastewater is important for public health and safety. Understanding whether it introduces contaminants or poses any health risks is essential for maintaining agricultural productivity, ensuring food security and achieving sustainable development goals 6 and 2. Using advanced indices for irrigation like SAR, MH, PS, RSC, PI and % Na and irrigation water quality index (IWQI) can contribute to scientific advancements and innovative solutions for irrigation with reuse wastewater in Senegal.

1.3 GENERAL OBJECTIVE:

This research aims at assessing the impacts of treated wastewater for irrigation on physico chemical properties of soil in Dakar Niayes Zone using Irrigation Water Quality Index (IWQI) and SAR, MH, PS, RSC, PI, % Na indices.

1.4 SPECIFIC OBJECTIVES:

1. To analyze the quality of the wastewater treated for irrigation in the technopole zone of Senegal
2. To assess the impact of treated wastewater for irrigation on soil using IWQI, SAR, MH, PS, RSC, PI, and % Na indices.
- 3) To Investigate the impact of wastewater irrigation on soil characteristics such as texture, organic matter content, nutrient levels, and salinity.
- 4) To identify potential risks and impacts of wastewater irrigation on soil quality in the Dakar Niayes Zone.
- 5) To provide recommendations for sustainable wastewater reuse practices in the Dakar Niayes Zone, considering both agricultural productivity and environmental protection.

1.5 RESEARCH QUESTION

What are the physicochemical characteristics of the treated wastewater used for irrigation in the Dakar Niayes Zone?

How can treated wastewater for irrigation affect the soil properties such as nutrient content, pH levels, and organic matter composition?

What management strategies and interventions can be implemented to mitigate the negative impacts of wastewater reuse on groundwater and soil in the Dakar Niayes Zone?

1.6 HYPOTHESIS

1. Irrigation with treated wastewater improves soil fertility through the addition of essential nutrients.
2. Irrigation with treated wastewater causes soil acidification.

2 CHAPTER 2: LITERATURE REVIEW

2.1 THE SOURCES OF WASTEWATER

Typically, sewage is gathered from diverse origins through the sewer system and subsequently conveyed to a treatment facility (Ali et al., 2021). In general, municipal sewage comprises domestic, industrial, and storm water discharges, as well as infiltration by groundwater into the municipal sewage network (Issues, n.d.). As indicated by (Ali et al., 2021), sewage can be classified into six primary sources:

1. **Domestic sewage:** Originating from residential areas, commercial zones, and institutional and recreational establishments, this encompasses the solid and liquid effluents from humans and animals, posing a significant threat to human health. Common household waste, including paper, cleaning products, detergents, refuse, and other substances, is typically discharged into the sewer system. The primary health risk lies in the millions of bacteria, viruses, and other microorganisms, some of which may be pathogenic, present in the waste stream.

2. **Industrial sewage:** Comprising materials specific to industrial processes, this wastewater can be released into the collection system, containing chemicals, dyes, acids, alkalis, grit, detergents, and highly toxic substances.

3. **Storm water runoff:** Numerous collection systems are designed to handle both community waste and storm water runoff, which often contains substantial amounts of sand, gravel, grit, and excessive water.

4. **Infiltration/inflow (I/I):** This results from the seepage of sewer pipes, introducing groundwater into wastewater flow.

5. **Agricultural sewage:** Originating from agricultural areas due to the use of irrigation water, pesticides, fertilizers, and toxic chemicals, this type of wastewater contains hazardous and toxic substances.

6. **Hospital and pharmaceutical sewage:** Primarily generated by hospitals and pharmaceutical manufacturing industries, this category of wastewater includes refractory micro-pollutants and toxic chemicals that may pose challenges during treatment if present in domestic sewer lines (Ali et al., 2021).

2.2 WASTEWATER COMPOSITIONS

According to (Aboye, 2022), wastewater typically comprises 99% water and 1% suspended, colloidal, and dissolved solids. The investigation conducted by (Issues, 2002) reveals that the specific makeup of wastewater can vary among different communities. Nevertheless, all municipal wastewater generally encompasses the same fundamental categories of constituents.:

- Organic matter
- Nutrients (Nitrogen, Phosphorus, Potassium)
- Inorganic matter (dissolved minerals)
- Toxic chemicals
- Pathogens

About the nutrients, the study of European Investment Bank 2022 titled: Wastewater as a resource, highlights the important of nutrients recovery from the wastewater. Sludge is, however, also rich in nutrients such as nitrogen and phosphorus originating from human waste, food and certain soaps and detergents. These nutrients are useful when soils are depleted or subject to erosion, making them valuable in agriculture as components of fertilizers. Another reason why nutrient recovery is so important is that non-renewable resources, including phosphorus, are diminishing. Phosphorus is a finite resource that is being used at alarming rates for fertilizer production to maintain agricultural productivity and the food supply.

Nitrogen is also very important in irrigation. Ever since the invention of the Haber-Bosch process in 1909, which managed to convert atmospheric nitrogen to ammonia, nitrogen-based fertilizers have supported the largest increase of food production capacity in history. The increased food production achieved by the use of nitrogen-based fertilizers has resulted in nitrogen being excreted (mainly as urea and ammonium) by human beings into wastewater.

2.3 ADVANTAGES AND DISADVANTAGES OF USING WASTEWATER FOR AGRICULTURAL

2.3.1 ADVANTAGES

The advantages of using wastewater for agricultural irrigation are:

- It permits higher crop yields, year-round production, and enlarges the range of crops that can

be irrigated, particularly in arid and semi-arid areas.

- Recycles organic matter and other nutrients to soils.
- It therefore reduces the cost of fertilizers.
- Reduces the use of synthetic fertilizer.
- Acts as a low-cost wastewater disposal method that can also be hygienic conditions.
- Avoids discharging pollutants to surface water bodies (which have a considerably lower treatment capability than soils).
- Increases the economic efficiency of investments in wastewater disposal and irrigation.
- Conserve's freshwater sources and reduces negative impacts on surface water bodies.
- Can recharge aquifers through infiltration.
- Improves soil properties (soil fertility and texture).
- The cost of pumping wastewater from nearby channels is lower than the cost of pumping groundwater.

2.3.2 DISADVANTAGES

The disadvantages of using wastewater for agricultural irrigation are:

- Water salinity and metal content in soils is increased in the long term.
- Storage capacity is needed to adapt/reconcile continuous wastewater production with crops' water demand and water supplied by precipitation.
- Under non-controlled conditions (1) pathogens contained in wastewater can cause health problems for humans and cattle; (2) some substances that may be present in wastewater can be toxic to plants, cattle, or humans consuming crops; (3) some substances that may be present in wastewater can reduce soil productivity; and (4) infiltration of wastewater to aquifers may cause aquifer pollution with pathogens and organic matter.

The table below show the impacts of some parameters on the environment and the health.

Table 1: Pollutants in wastewater and their potential impacts through agricultural use

Pollutant/	Parameter	Impacts
------------	-----------	---------

Constituent		
Plant food nutrients	N, P, K, etc.	<ul style="list-style-type: none"> a. Excess N: potential to cause nitrogen injury, excessive vegetative growth, delayed growing season and maturity, and potential to cause economic loss to farmer b. Excessive amounts of N, and P can cause excessive growth of undesirable aquatic species. (eutrophication) c. Nitrogen leaching causes groundwater pollution with adverse health and environmental impacts
Suspended solids	Volatile compounds, settleable, suspended and colloidal impurities	<ul style="list-style-type: none"> a. Development of sludge deposits causing anaerobic conditions b. Plugging of irrigation equipment and systems such as sprinklers
Pathogens	Viruses, bacteria, helminth eggs, fecal coliforms etc.	<ul style="list-style-type: none"> a. can cause communicable diseases
Biodegradable organics	BOD, COD	<ul style="list-style-type: none"> a. Depletion of dissolved oxygen in surface water b. Development of septic conditions c. Unsuitable habitat and environment d. Can inhibit pond-breeding amphibians e. Fish mortality f. Humus build-up
Stable organics	Phenols, pesticides, chlorinated hydrocarbons	<ul style="list-style-type: none"> a. Persist in the environment for long periods b. Toxic to environment c. Make wastewater unsuitable for irrigation

Dissolved inorganic substances	TDS, EC, Na, Ca, Mg, Cl, and B	<ul style="list-style-type: none"> a. Cause salinity and associated adverse impacts b. Phytotoxicity c. Affect permeability and soil structure.
Heavy metals	Cd, Pb, Ni, Zn, As, Hg, etc	<ul style="list-style-type: none"> a. Bio accumulates in aquatic organisms (fish and planktons) b. Accumulate in irrigated soils and the environment. c. Toxic to plants and animals d. Systemic uptake by plants e. Subsequent ingestion by humans or animals f. Possible health impacts g. Make wastewater unsuitable for irrigation
Hydrogen ion concentrations	pH	<ul style="list-style-type: none"> a. Especially of concern in industrial wastewater b. Possible adverse impact on plant growth due to acidity or alkalinity c. Impact sometimes beneficial on soil flora and fauna
Residual chlorine in tertiary treated wastewater	Both free and combined chlorine	<ul style="list-style-type: none"> a. leaf-tip burn b. groundwater, surface water contamination c. (Carcinogenic effects from organochlorides formed when chlorine combines with residual organic compounds) d. greenhouse effect

Source: Hussain et al., (2002)

2.4 POTENTIAL IMPACTS OF WASTEWATER USE IN AGRICULTURE

The wastewater use in Agriculture has provided the different impacts on agriculture including public health, Crops, Soil resources, Groundwater resources, Property values, Ecological impacts and social impacts.

2.4.1 PUBLIC HEALTH

Wastewater contains pathogenic microorganisms such as bacteria, viruses, and parasites, which have the potential to cause disease. Human parasites such as protozoa and helminth eggs are of special significance in this regard as they prove to be most difficult to remove by treatment processes and have been implicated in a number of infectious gastrointestinal diseases in both developed and developing countries. However, in evaluating health impacts it must be remembered that it is the actual risk that make people fall ill that must be quantified and not the presence of pathogens in water. The use of untreated wastewater for irrigation, no doubt, pose a high risk to human health in all age groups. However, the degree of risk may vary among the various age groups. Untreated wastewater irrigation leads to relatively higher prevalence of hookworm (Feenstra et al. 2000; and Issues, n.d.), and Ascariasis infections among children (Cifuentes et al. 2000; Habbari et al., 2000; and Issues, n.d.). Heavy metals in wastewater pose a health risk if they are ingested in sufficient concentrations and can be dangerous. In principle, uptake of heavy metals by crops and the risk posed to consumers may not be an issue as plants cannot resist high concentrations of these pollutants and die off before they become a threat to humans. Shuval et al., (1986) and Hussain Intizar (2002), made an extensive study of health effects of pathogens but there is no comprehensive study which assess the impact of heavy metals and the real risks posed to human health. These findings have important implications for the valuation of public health risks associated with wastewater irrigation. First, they indicate that valuation of public health risk is an important decision variable in wastewater irrigation and both adult population as well as children should be considered as potential exposure group. Second, the entire population, living within and outside the wastewater irrigation zone, should be considered as the potential exposure groups for economic valuation purposes.

2.4.2 CROPS

Wastewater (treated and untreated) is extensively used in agriculture because it is a rich source of nutrients and provides all the moisture necessary for crop growth. Most crops give higher than potential yields with wastewater irrigation, reduce the need for chemical fertilizers, resulting in net cost savings to farmers. If the total nitrogen delivered to the crop via wastewater irrigation exceeds the recommended nitrogen dose for optimal yields, it may stimulate vegetative growth, but delay ripening and maturity, and in extreme circumstances, cause yield losses. Crop scientists have

attempted to quantify the effects of treated and untreated wastewater on a number of quality and yield parameters under various agronomic scenarios. The use of untreated municipal wastewater, as is the practice in many countries, pose a whole set of different problems. Nevertheless, the high concentration of plant food nutrients becomes an incentive for the farmers to use untreated wastewater as it reduces fertilizer costs, even when the higher nutrient concentrations may not necessarily improve crop yields. Most crops, including those grown in peri-urban agriculture, need specific amounts of NPK for maximum yield. Once the recommended level of NPK is exceeded, crop growth and yield may negatively be affected. For example, urea plant effluents are a rich source of liquid fertilizer but in concentrated forms they have adverse effects on rice and corn yields (Singh and Mishra 1987; and Hussain Intizar 2002). The composition of municipal wastewater also has to be taken into account. Predominance of industrial waste brings in chemical pollutants, which may be toxic to plants at higher concentrations. Some elements may enter the food chain, but most studies indicate that such pollutants are found in concentrations permitted for human consumption. On the other hand, predominance of domestic wastewater may result in high salinity levels that may affect the yield of salt sensitive crops. The above discussion shows that the economic impacts of wastewater on crops may differ widely depending upon the degree of treatment and nature of the crops. From an economic viewpoint, wastewater irrigation of crops under proper agronomic and water management practices may provide the following benefits: (1) higher yields, (2) additional water for irrigation, and (3) value of fertilizer saved. Alternatively, if plant food nutrients delivered through wastewater irrigation result in nutrient over supply, yields may negatively be affected.

2.4.3 SOIL RESOURCES

Soil serves as the basis for plant growth, human agricultural production, and the source of various agricultural products. It occupies a critical interface between the atmosphere, lithosphere, hydrosphere, and biosphere, playing a role in multiple processes involving physics, chemistry, and biochemistry (Li et al., 2017). In India, the study by Friedel et al. (2000) in the irrigated area of Bhilwara in Rajasthan, demonstrated that wastewater irrigation had an impact on the physical and chemical properties of the soil. When compared to groundwater irrigation, wastewater irrigation led to increased bulk density (BD), particle density (PD), water-holding capacity (WHC), as well

as higher concentrations of pH, electrical conductivity, organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) in the soil.

Regarding golf courses in Denver and Fort Collins, Colorado, USA, a study conducted by (Qian & Mecham, 2005) explored the impact of using recycled wastewater for irrigation on the chemical properties of the fairway soil. The authors found that when comparing two sites, one irrigated with wastewater and the other with surface water, several significant differences emerged. The site irrigated with wastewater exhibited notably higher levels of extractable Sodium Adsorption Ratio (SAR), sodium (Na), electrical conductivity (EC), phosphate at the surface depth of 11.5 cm, extractable and calcium (Ca). Specifically, SAR increased by 481%, Na by 200%, EC by 187%, phosphate by 30%, and Ca by 24%. Additionally, the magnesium (Mg) content was twice as high as the surface-water-irrigated site, and a pH increase of 0.3 units was observed. Furthermore, the authors noticed a salinity stress in sites subjected to long-term recycled wastewater irrigation, especially in areas with fine-textured soil and inadequate drainage. They stated that prolonged use of recycled wastewater could lead to reduced soil infiltration and permeability in clayey soils, particularly in areas with high levels of traffic and compaction pressure.

Impact from wastewater on agricultural soil, is mainly due to the presence of high nutrient contents (Nitrogen and Phosphorus), high total dissolved solids and other constituents such as heavy metals, which are added to the soil over time. Wastewater can also contain salts that may accumulate in the root zone with possible harmful impacts on soil health and crop yields. The leaching of these salts below the root zone may cause soil and groundwater pollution (Bond 1999 and Hussain Intizar 2002). Prolonged use of saline and sodium rich wastewater is a potential hazard for soil as it may erode the soil structure and effect productivity. This may result in the land use becoming no sustainable in the long run. However, soil reclamation measures are costly, adding to economic constraints resulting in losses to crop productivity. Moreover, it may not be possible to restore the soil to the original productivity level, by using these soil amendments. Hence, wastewater irrigation may have long-term economic impacts on the soil, which in turn may affect market prices and land values of saline and waterlogged soils. Wastewater induced salinity may reduce crop productivity due to general growth suppression, at pre-early seedling stage, due to nutritional imbalance, and growth suppression due to toxic ions (Kijne et al. 1998 and Hussain Intizar 2002). The net effect on growth may be a reduction in crop yields and potential loss of income to farmers. Wastewater irrigation may lead to transport of heavy metals to soils and may cause crop

contamination affecting soil flora and fauna. Some of these heavy metals may bio-accumulate in the soil while others, e.g., Cd and Cu, may be redistributed by soil fauna such as earthworms (Kruse and Barrett 1985; and Hussain Intizar 2002). Studies conducted in Mexico (Assadin et al. 1998; and Hussain Intizar 2002), where wastewater mixed with river water has been used for crop irrigation for decades, indicated that polluted water irrigation may account for up to 31% of soil surface metal accumulation and lead to heavy metal uptake by alfalfa. However, heavy metal concentrations in alfalfa pose no risk to animal or human health. In a critical assessment of USEPA heavy metal guidelines, McBride (1995); and Hussain Intizar (2002), argued that heavy metals applied through sewage use can harm sensitive plants with possible loss of soil productivity in the long run, if available in sufficient quantities. In general, heavy metal accumulation and translocation is more a concern in sewage sludge application than wastewater irrigation, because sludge formed during the treatment process consists of high concentrations of most heavy metals. The impact of wastewater irrigation on soil may depend on a number of factors such as soil properties, plant characteristics and sources of wastewater. The impact of wastewater from industrial, commercial, domestic, and dairy farm sources are likely to differ widely.

2.4.4 GROUNDWATER RESOURCES

Wastewater application has the potential to affect the quality of groundwater resources in the long run through excess nutrients and salts found in wastewater leaching below the plant root zone. However, the actual impact depends on a host of factors including depth of water table, quality of groundwater, soil drainage, and scale of wastewater irrigation. For instance, the quality of groundwater would determine the magnitude of the impact from leaching of nitrates. If the groundwater is brackish, the leaching of nitrates would be of little concern as the water has no valuable use attached to it. The proximity of wastewater irrigation to sources of potable water supplies such as wells or tube wells will influence how we evaluate the severity of groundwater pollution effects. Groundwater constitutes a major source of potable water for many developing country communities. Hence the potential of groundwater contamination needs to be evaluated before embarking on a major wastewater irrigation program. In addition to the accretion of salts and nitrates, under certain conditions, wastewater irrigation has the potential to translocate pathogenic bacteria and viruses to groundwater (NRC report 1996). Farid et al., (1993), reported that in Gabal El Asfar farm in the Greater Cairo region, where untreated or primary treated

wastewater has been used for irrigation since 1915, the long-term use of wastewater for crop irrigation has interestingly led to an improvement in the salinity of the groundwater. This was offset by evidence of coliform contamination of groundwater which was also observed in Mexico (Downs et al. 1999, Gallegos et al. 1999; and Hussain Intizar 2002).

A companion study carried out by Rashed et al. (1995), revealed that in the wastewater irrigated Gabal el Asfar region, concentrations of chloride, sulfate, TDS, and dissolved oxygen in groundwater is much higher than average concentrations in sewage effluents. The leaching and drainage of wastewater, applied for crop irrigation, to groundwater aquifer may serve as a source of groundwater recharge. In some regions, 50-70 percent of irrigation water may percolate to groundwater aquifer (Rashed et al. 1995; and Hussain Intizar 2002). The influence of percolated wastewater on groundwater quality and its recharge is thus likely to be substantial. Despite poor quality, groundwater recharge through wastewater application can be a vital environmental and economic service in regions where freshwater supplies are limited and groundwater removal rates exceed replenishment rates. In this context it may be viewed as a benefit under some circumstances. Thus, there is an obvious tradeoff between groundwater recharge benefits and groundwater pollution costs.

In the zone of Faisalabad City of Pakistan, a study conducted by (Yehia, 2000) explored the environmental impact of sewage water on groundwater quality. Within this examination, the authors collected three distinct samples: one comprised entirely of wastewater, another solely consisting of canal water (representing groundwater), and a third containing a mixture of 50% wastewater and 50% canal water. The research findings revealed that variations in groundwater salinity were most pronounced in the region irrigated with 100% wastewater, suggesting higher salinity levels in the groundwater compared to the other treatments. The study suggests that the increased salinity in groundwater may be attributed to the extensive use of wastewater for irrigation. Evidently, the elevated salinity levels observed in groundwater immediately beneath wastewater-irrigated fields indicate that wastewater irrigation has led to further contamination of groundwater when compared to fields irrigated with canal water.

2.4.5 PROPERTY VALUES

In discussing the effects of environmental pollution on property values, we must distinguish between two types. The first is the discomfort from a pollution source associated with, nuisance,

noise, odor, hazards, and unsightliness, have been studied extensively. The costs may include health, cleanup costs and legal liability (Page and Rabinowitz 1993). Properties located along a polluted stream had significantly lower market prices than properties located along clean streams (Epp and Al-Ani 1979 and Hussain Intizar 2002). Pollution-related beach closures have been known to reduce property values in New Jersey by about 23 % (Polhemus et al. 1985; and Hussain Intizar 2002). The second type is the eventual use one might make of a polluted resource associated with property. Residential, commercial or industrial areas that use groundwater as a source of water may reduce in property value as opposed to areas with clean groundwater because the resource cannot be used for the designated purpose. Wastewater induced salinity and solidity may also have negative effects on soil productivity, which in turn may affect land prices and lease revenues. On the other hand, given the resource value of wastewater, lands irrigated with wastewater may also appreciate in value. Thus, we can assume that wastewater irrigation has the potential to influence property values depending on the circumstances and will affect property values positively or negatively. It should, therefore, be accounted as a cost and benefit item in analyzing the impacts of wastewater irrigation.

2.4.6 ECOLOGICAL IMPACTS

When drainage water from wastewater irrigation schemes drains particularly into small confined lakes and surface water, and if phosphates in the orthophosphate form are present, the remains of nutrients may cause eutrophication. This causes imbalances in plant microbiological communities of water bodies (Smith et al. 1999; and Hussain Intizar 2002). This may in turn affect other higher forms of aquatic life and influence the presence of water birds and reduce biodiversity. Insofar as these water bodies serve local communities for their needs, the ecological impacts can be translated into economic impacts, which can be quantified. For example, overloading of organic material resulting in decreases in dissolved oxygen that may lead to changes in the composition of aquatic life, such as fish deaths and reduced fishery. The eutrophication potential of wastewater irrigation can be assessed using biological indices or biomarkers, which in turn can be quantified in monetary units using appropriate economic valuation techniques. The likelihood of heavy metals from wastewater affecting the food chain is addressed under soil resources. Soil usually acts as a filter and retains heavy metals in the soil matrix.

2.4.7 SOCIAL IMPACTS

Social impacts are the concerns/doubts expressed by the public about wastewater irrigation. These concerns can be classified as follows:

- a. General concerns such as nuisance, poor environmental quality, poor hygiene, odor, noise, higher probability of accidents, etc. Social concerns such as food safety, health and welfare, impaired quality of life, loss of property values, and sustainability of land use. Natural resource concerns such as pollution of vital water resources, loss of fish, wildlife, exotic species, etc.
- b. Public concerns about the perceived or real risks of wastewater irrigation may create business risks, which have to be addressed adequately to avoid exploitation by lobby groups. Business risks and potential liability can be covered by obtaining appropriate levels of insurance. The premium for general risk assurance against wastewater irrigation is likely to be high at the beginning because, most developing countries, including Pakistan, do not have experience in agriculture sector insurance. Moreover, premium and indemnity structures are likely to vary significantly among crops and regions. (Hussain Intizar 2002).

3 CHAPTER 3: MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 HISTORIC OF URBAN AGRICULTURE IN DAKAR

Food security in urban areas is even more worrying in the cities of developing countries where the poverty rate is high. It is in this context that urban and peri-urban agriculture is developing by occupying an essential place in urban food supply (Luca, 2019). Agriculture is one of the booming sectors of activity in Senegal. The growing demand for agricultural products, due to strong population growth, has pushed public authorities to place particular emphasis on the development of the agricultural (Diallo et al., 2019). In Dakar, agriculture, particularly market gardening, is a very old practice and well anchored in the ecosystem urban and peri-urban. First developed during the colonization (Sposito, 2010; Ba & Cantoreggi, 2018), it was quickly adopted by local populations, particularly those from the rural exodus and formerly farmers in their villages. For as much, urban market gardening in the Senegalese capital presents important particularities. It is carried out there and perceived as a self-consumption activity guaranteeing the poorest urban households a food security through direct access to food costs. However, market gardening in Dakar comes out of this stereotype. Even if it occupies a preponderant place in terms of food supply of products costs and job creation for the city (Temple and Moustier, 2004, Guèye et al, 2009, IAGU, 2011; Ba & Cantoreggi, 2018), it constitutes an essentially commercial activity. The study of (Diallo et al., 2019) showed that according to USAID (1990), SAED (1994) and the Directorate of Agriculture (1994): arable land in Senegal represents only 19% of the country's surface area (3.8 million hectares). The areas cultivated annually oscillate around 2.5 million hectares (65% of arable land), of which 98% rainfed and 2% irrigated. The highest rates of exploitation of arable land are observed in the peanut basin (81%) in the center of Senegal, Niayes (65%) compared to only 40% in Casamance and Eastern Senegal (Khouma, 1998). The Niayes area constitutes an important agro-ecological zone because it alone provides 80% of the country's market gardening crops, 1% of the cattle herd, 3% of small ruminants and a very significant part of industrial poultry farming in Senegal (Diallo et al., 2019).

The portion of Niayes which concerns the Dakar region is part of a broad strip oriented parallel to the Atlantic coast. The Niayes represent approximately 200,000 ha between the mouth of the

Senegal River and the Cape Verde peninsula. They are composed of a succession of elongated depressions nested in a dune system to which more or less functional alluvial axes were connected perpendicularly. This environment was remarkable for the complexity of the composition of its flora favored by the presence of a shallow water table, which during the rainy seasons gave rise to more or less perennial bodies of water. Over the years, this area has become the leading economic region of Senegal, producing 80% of horticultural production, 1% of cattle breeding and 3% of small ruminants. At the same time, it is experiencing an intensification of industrial poultry farming and the establishment of dairy farms often associated with horticulture.(Felix, 2005)

3.1.2 THE GEOGRAPHICAL CONTEXT OF THE DAKAR NIAYES ZONE

Urban agriculture in Dakar is practiced in an area with favorable climatic and hydrographic conditions: the Niayes zone (Gaye et al., 2010). The big Niayes of Dakar constitutes a vital segment of the Niayes eco-geographic zone situated within the Dakar region, where Senegal's capital resides. Bounded to the north and south by the Atlantic Ocean, and to the west by the Hann Forest and zoological park alongside the Khar Yalla district, its eastern limits are defined by Thiaroye Gare, the districts of Diacksao, and Tivaouane (Aimée et al., 2018).

3.1.3 PRESENTATION OF PIKINE

The big Niaye of Pikine constitutes the first horticultural production basin in the Dakar metropolitan area. It is essentially made up of farms of less than 1 hectare. Market gardening is practiced there all year round in the depressions and on the dunes. The main crops are lettuce or salad (*Lactuca sativa*), which is the crop of choice, followed by pepper (*Capsicum*), cabbage (*Brassica oleracea*), bitter eggplant (*Solanum aethiopicum*), onion (*Allium cepa*), eggplant (*Solanum melongena* L.), field mint (*Mentha arvensis*), etc. Horticulture is an opportunity for “the urban population experiencing chronic unemployment and rural residents experiencing seasonal migration” (Bâ Diao, 2004, p. 4). In addition, this activity employs a significant number of housewives who are involved in the marketing of vegetables in the local markets of Dakar (Khalifa, Cheikh 2019).

3.1.4 PRESENTATION OF NIAYES OF PATTE D'OIE

It is the only agricultural area located in the Dakar department, which explains its high urbanization compared to other areas located in the same strip of Niayes. Nestled in the south-east of the district commune of Patte d'Oie, the agricultural zone of Patte d'Oie covers an area of approximately 100 hectares, or a third of the total area of the commune. Due to its proximity to the city center, it is the object of all desire, particularly from real estate developers (Ba et al., 2024). The location of Patte d'oie, which is in the lower levels of the Dakar city was considered the natural outlet for the city's wastewater or more specifically the preferred area for the construction of wastewater treatment plants. In the Niayes de la Patte d'Oie there are two obsolete wastewater treatment plants. The pipes which were used to supply these stations in addition to the evacuation networks which appeared with the new constructions of the Patte d'Oie had become the preferred sources of supply of irrigation water to farmers who do not have access has acceptable salinity water. The use of wastewater as irrigation water in the Patte d'Oie area remained very limited. However, with the increase in salinity in the waters of "ceanes" linked to the low rainfall made this practice more widespread in the area (Felix, 2005).

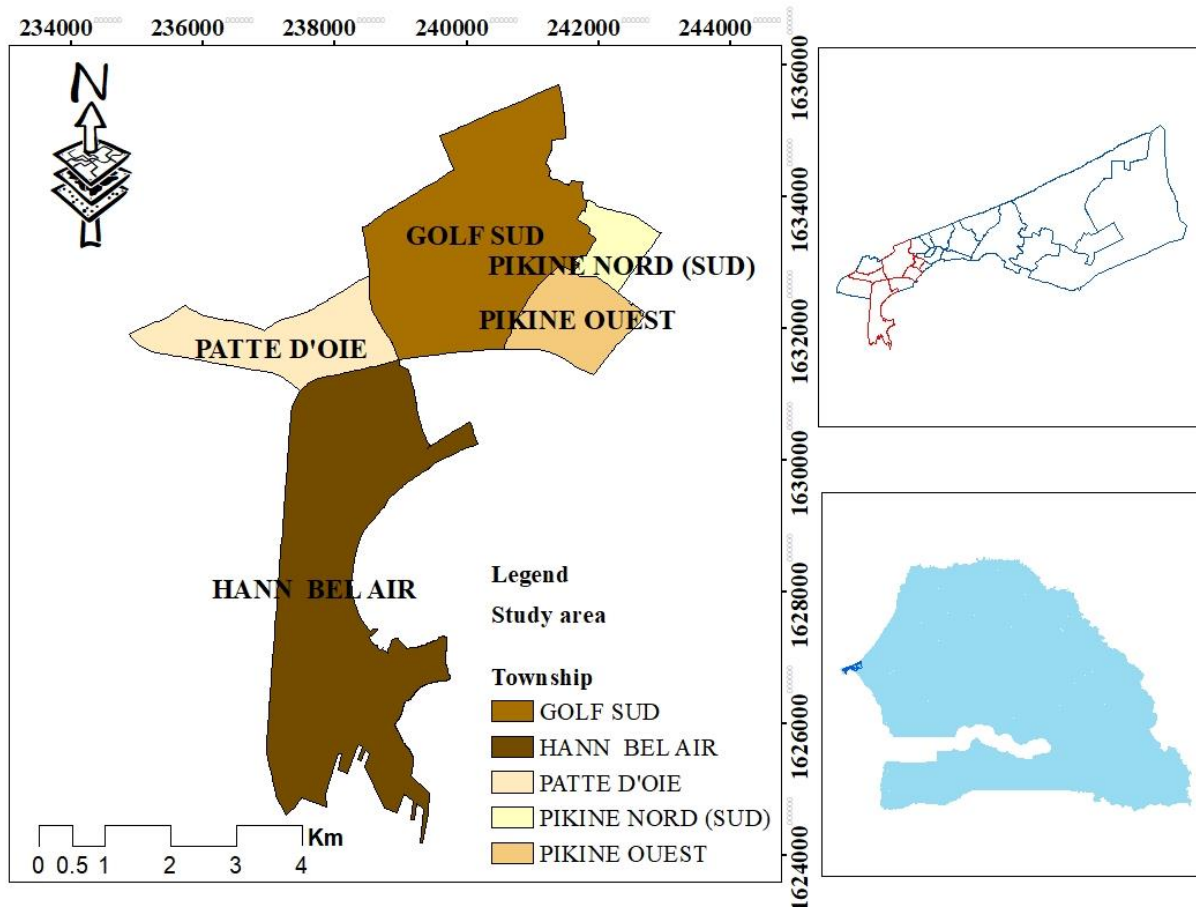


Figure 1: location of the study area

3.1.5 THE CLIMATE FACTORS OF THE STUDY AREA

By the presence of a maritime facade surrounding almost the entire region, the Niayes zone is characterized, for a good period of the year, by a microclimate marked by the influence of the maritime trade wind, hence the existence of almost permanent and relatively high freshness and humidity. The Temperature varies between 17° and 25° C from December to April and from 27° to 30° C from May to November (Gueye et al., 2022). the rainfall is characterized by a relatively short duration of wintering of three months from July to September with a mean of 124 mm. (ANDS,2022).

3.1.6 THE GEOMORPHOLOGY FACTORS

The Niayes region is characterized by Quaternary sedimentary formations which rest on older formations. The ante quaternary formations are, essentially, those of the secondary and tertiary Maastrichtian, Lower Paleocene, Lower Eocene, Lower Lutetian and superior. The Quaternary formations are made up of sandy material which covers most of the Senegalese territory. On the northern coast, these formations are characterized by a succession of dunes of different ages, textures and colors from the coast to the interior.

There are three dune systems predominate as following:

- Coastal dunes, also called white dunes or bright dunes because of their mobility, are characterized by beaches of shell sand constantly blown up by the wind. Their origin dates to the subcurrent to the present (2,000 to 1,800 years before the Present [BP]).
- The yellow dunes or semi-fixed dunes are interrupted by lakes, especially in the Dakar region (Retba, Mbeubeuss, Youi, Malika, etc.) and numerous temporary ponds in the Thies region.
- The continental red dunes, or interior dunes, form a large erg from the southwest of Mauritania to the west of Senegal. They are made up of red soils, commonly called diors soils in local terminology. Their origin dates from the Ogolian (15,000 to 20,000 years BP), which gives them the name Ogolian dunes. The plant cover is quite significant, even forming wooded savannahs in places.

3.1.7 THE SOIL CHARACTERIZATION

The soil map of the study area reveals a variety of soil types, each possessing unique characteristics and ecological importance. This finding is corroborated by Aimée et al. (2018) in their comprehensive study, which categorizes and elucidates the soil types present within the study area. The map in ArcGIS shows us two soils type:

ferruginous soils (known as Diors soils) are located on the dunes of the coast. These soils are formed in the presence of manganese, iron or (and) alumina oxides and are yellow and red in

color. They are well drained in their surface horizon and poor in organic matter and humus. They represent an area of approximately 6.52 km² (or 50.28%) of the surface area of the study area.

Hydromorphic soils (Pseudo gley or gley on sand) are located mainly in interdune depressions. They are formed in asphyxiating and reducing conditions due to excess humidity. These are the characteristic soils of Niayes proper which are permanently or temporarily flooded. Their permeability is therefore very low. They are black in color and are rich in organic matter. They cover an area of approximately 5.3 km² (or 40.84%) of the surface area of the study area.

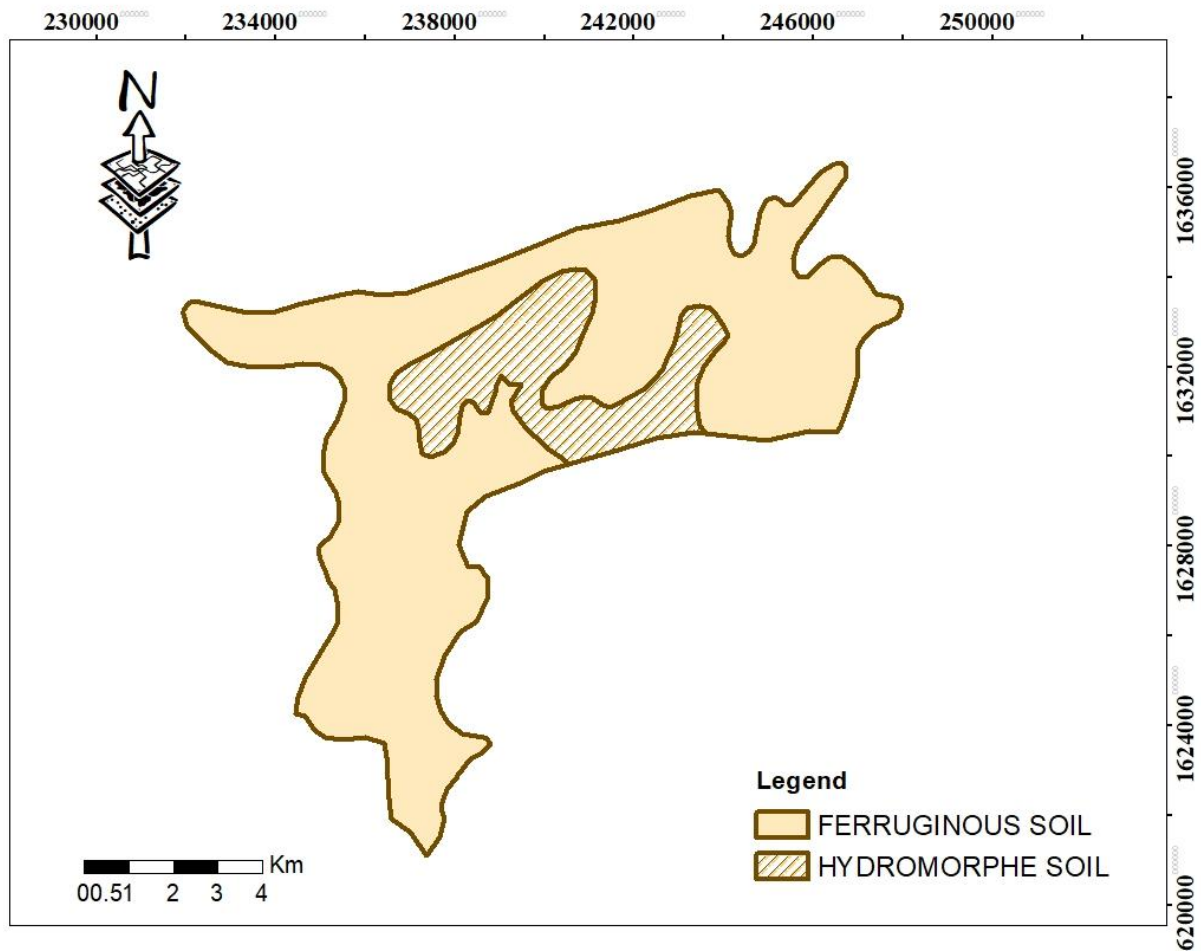


Figure 2: soil map of the study area.

3.1.8 HYDROLOGY AND HYDROGEOLOGICAL RESOURCES

Water resources in the Niayes come essentially from the water table of the Quaternary sands which characterize this environment. The Quaternary sand table is of capital importance due to its multiple uses. Indeed, it is used for the water supply of the local population, particularly for the city of Dakar (Martin, 1970), the feeding of animals and, finally, for the agricultural needs which give the region all its importance. The Quaternary sand layer is contained in the coastal sands present in the Northwestern part to the West of the Dakar-Saint Louis road over an area of 5000 km². This aquifer, commonly called the Quaternary sand aquifer of the northern coast, is a free aquifer which presents interesting performances with drillings capable of providing up to more than 100 m³/h with less than 10 m of drawdown (Dieng, 1987). At the pass of the Cape Verde peninsula, we can also distinguish the free aquifer of the Quaternary sands of Thiaroye. It constitutes the natural extension of the sub basaltic sand aquifer with which it is in continuity.

The thickness of this layer follows the variations in the morphology of the marly bedrock of Eocene age; it is very variable and can reach 50 m. The storage coefficients are of the order of 1.0×10^{-2} and the permeability values are between 8.9×10^{-4} and 2.8×10^{-5} m/s (BRGM, 1992; WHO, 1974). These different values highlight a heterogeneity of the parameters which is certainly linked to the proportion of clay elements contained in the sandy aquifer which can vary from one place to another.

The limits of the Quaternary sand table are:

- To the West: the limit is made up of the coastline where the aquifer system is in contact with the oceanic environment.
- To the East: the limit corresponds to an eastern extension limit of the Eocene limestones which approximately follows a Sagata-Diourbel line. This limit is characterized by the thinning of limestone and the development of marly facies.
- To the South: the limit approximately follows a Méouane-Baba Garage line.
- To the North: the limit is poorly defined and is probably located north of a Rao-Sakal line.

Recharging, from the infiltration of part of the precipitation, appears to be the only one from which the aquifer system can benefit, with the very occasional exception of the infiltration of part of the National Company's spreading water of Taïba Phosphates. The sea trips, the emergence of the water table at the Niayes, as well as the samples are the only known pumping. This effective recharge, associated with a generally very low topography (marked only by fossil dune cords), generally results in a very shallow depth of the static level and, consequently, a great vulnerability of the aquifer to pollution of agricultural and anthropogenic origin.

This potential is threatened by overexploitation which manifests itself in a progressive drawdown in depth of the aquifer. However, the shallow depth of the water table, associated with increasingly high temperatures and greater wind intensity, maintains a high evapotranspiration demand. Therefore, significant capillary rise in depressions in the dry season which concentrates in situ and becomes sodic and alkaline (Peer-reviewed et al., 2022). The Niayes of Dakar are characterized by a shallow groundwater table (0.5 to 10 m deep) which rests on a salt water table. (Gueye et al., 2022).

3.1.9 THE TYPES OF WATER USE FOR IRRIGATION

According to farmers which we met in these areas, 4 types of water allow the irrigation: the groundwater (ceane, well); treated wastewater; or mixed water (treated wastewater + ceane or treated wastewater + lake) and the lake of Marist. Céane is used by farmers in all sites. These are traditional wells with a shallow depth of 1 to 3 m and a width of 4 to 5 m. The treated wastewater come from the wastewater treatment plant of Pikine called Niayes WWTP. It was created since 2008 with a daily capacity of 3000 m³/day. The type of the treatment is biological process, and the source is domestic in Pikine and Guediawaye department. The farmers used this water because the lake and the groundwater are very saline, and the treated wastewater is very rich in fertilizer. Some farmers can use that water only, and others mix it with the ceane because the water in this area is salty and cannot be used alone and the BOD and COD concentration is very high. Moreover, the treated wastewater is usually containing sludge and forms a paw on the superficial part of the ground. The leg formed by the sludge prevents water from infiltrating and reaching the roots of plants. Therefore, they do the mixture to reduce the damage could happen from two types of water. The farmer near the lake like Hann or Pikine Technopole use it for their irrigation purpose.

3.1.10 THE REUSE OF TREATED WASTEWATER FOR IRRIGATION IN PIKINE

Senegal is a sub-Saharan African country facing great difficulties in managing its environment, particularly wastewater. In 2015, Senegal did not reach the 77% target set by the Millennium Development Goals (MDGs) to improve sanitation coverage, which was 37% at the national level (ANSD, 2014; Gueye et al., 2022). The Senegalese capital Dakar, in due to the rural exodus and the growth of its demographics, it releases large quantities of wastewater, the management of which poses problems. The majority of discharged wastewater does not undergo treatment and is dumped into the sea, the streets or sometimes even in areas that should be specially protected such as wetlands. The Senegalese capital discharged more than 200,000 m³ of wastewater per day in 2006 (Akpo, 2006; Gueye et al., 2022). Wet ecosystems play important socio-economic functions for the development of the Dakar region and its inhabitants. Thus, the treatment of wastewater and its reuse are among the major activities developed in the Technopole wetland in the Pikine department in Dakar. To combat pollution in this area by wastewater discharges, a wastewater treatment plant was installed in the Technopole area of Dakar in June 2008 to receive and treat wastewater from neighboring neighborhoods. The Technopole area is an area very suitable for agriculture (Badiane et al., 2017; Gueye et al., 2022), therefore the water treated by the wastewater treatment plant is reused by market gardeners to grow all kinds of agricultural products. In the wet zone of the Technopole, wastewater treated despite their abundance and the insufficiency of the treatment are not even sufficient for market gardening (Gueye et al., 2022).

3.2 DESCRIPTION OF THE METHODOLOGICAL FRAMEWORK

To properly carry out our studies, field surveys were firstly carried out with farmers in our study area, namely Pikine, Patte d'oie and Hann, to find out the type of water used for their irrigation; and with the director of the Niayes WWTP. Then a sampling session of the irrigated water with its soil (treated wastewater, groundwater, and lake water) was carried out. Finally, the analysis session of its samples to evaluate the impact of the reuse of wastewater on the soil and on groundwater.

3.2.1 SURVEY WITH FARMERS

To better understand farmers' perception of water quality and their attitude regarding the irrigation practices (i.e., the use of treated wastewater, lake, groundwater or mixed water), an interview with farmers from our study area was carried out. Farmers were selected randomly within their water use. The questionnaire included open, semi-open, and closed questions covering several aspects of the reuse of treated wastewater. The questions are: 1) the general information of the farm (name of the farmer, the location of the farm, area of the land, agricultural practice); 2) type of water use ; 3) if they use the treated wastewater and since when; 4) wastewater perception, 5) the impacts of reuse wastewater on soil and groundwater; 6) the impacts of reuse wastewater on their crops.

3.2.2 SURVEY OF INSTITUTIONAL ACTOR

ONAS (National Sanitation Office of Senegal) has 4 Wastewater treatment plants in Dakar including the Wastewater treatment plant of the Pikine which treat the wastewaters from Pikine and Guediawaye. This wastewater after treatment is distributing for the farmers of the Niayes Pikine which use it for their irrigation proposes. To better understand the quality and the quantity of that water, an interview with the lab director of the WWTP was done. He was chosen because he is the manager of the WWTP. Several questions were asked: the creation date of the WWTP, the source of the wastewater, the treatment process, the quantity of wastewater treated and reuse for irrigation.

3.2.3 SAMPLING METHOD

3.2.3.1 WATER SAMPLING METHOD

30 water samples were collected from 3 different irrigation areas: Technopole of Pikine, Patte d'oie and Maristes.

The reason of the selection of this different irrigated water is:

1) In Technopole of Pikine, there is one WWTP and some farmers are irrigated with treated wastewater, other with mixed (ceane+ treated wastewater), and groundwater (Ceane, well).

2) For Patte d'oeie, in 2009 to 2012, farmers were irrigated with treated wastewater from the WWTP of Camberene. Now they are irrigated with wells, borehole or the lake because the use of the treated wastewater for irrigation is prohibited.

3) About Maristes, the farmers are irrigated with the lake of Mariste.

A GPS Garmin 64S was used for the delimitation and the location of the sampling area. Samples were carried out during selected dates: 17/01/2024, 22/01/2024, 23/01/2024 and 30/01/2024 where 7 treated wastewater samples and 6 mixed waters (treated water +ceane) were collected from Pikine. For the groundwater, 11 samples were collected: from Pikine (2 boreholes, 1 ceane), from Patte d'oeie (5 wells and 3 ceanes water), and from Maristes 7 lake water. All samples were collected in polyethylene containers, transferred to the NIP laboratory in cooling boxes, and preserved at 4°C until analysis that may took place immediately or within 24h.

3.2.3.2 SOIL SAMPLING METHOD

Soil samples was taken from the same irrigated land of water samples where the depth was 0-20cm and from 20cm-40 cm using a soil auger. Samples were labelled and stored in plastic bags and carried out to the INP laboratory for further analysis. Soil samples were air dried for 3 to 4 days, then crush it, and sieve it through a 2 mm sieve.

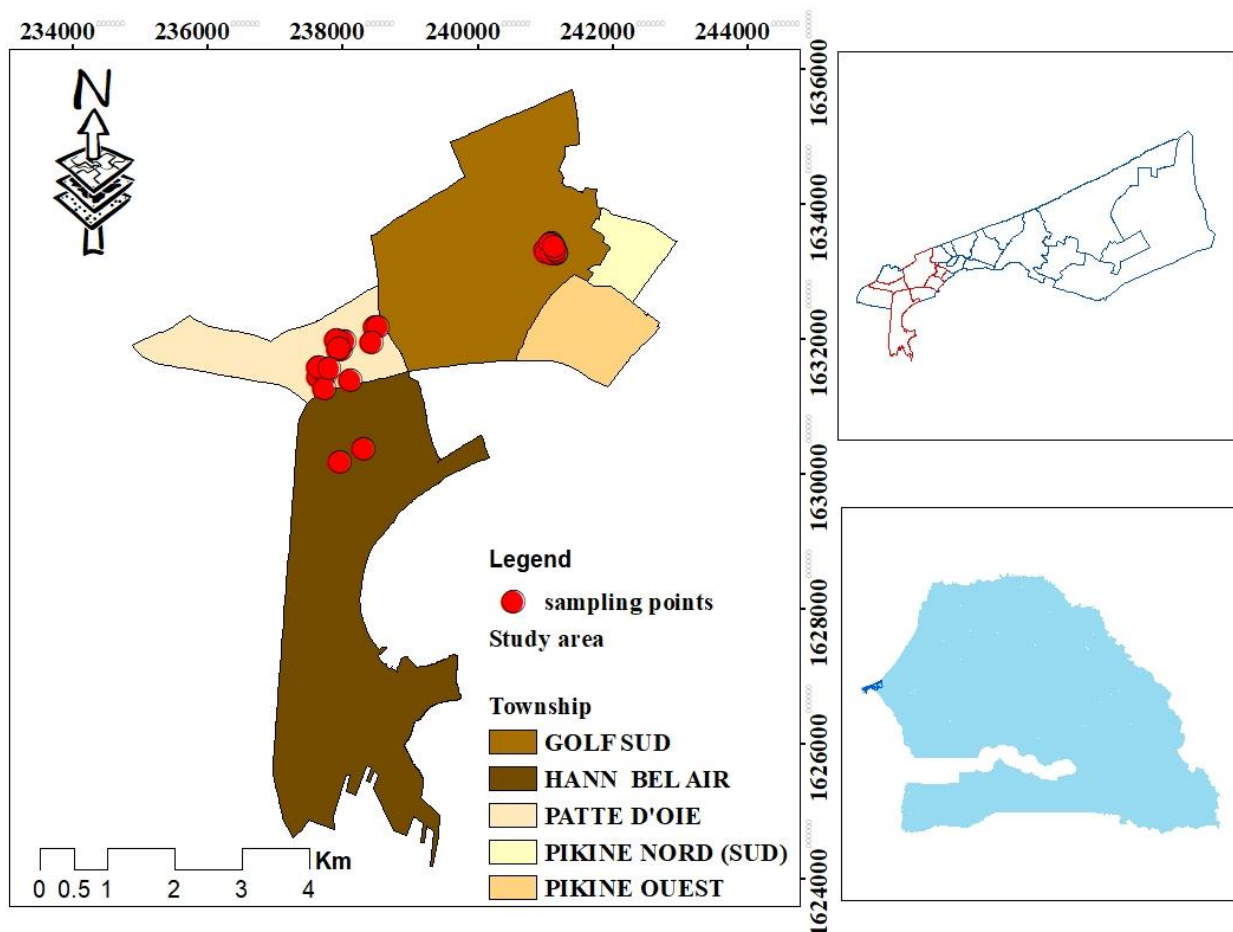


Figure 3: location of the sampling point

3.2.4 ANALYSIS METHODS

The physical and chemical parameters like pH, electrical conductivity (EC), Phosphorus P; cations such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), and anions like Bicarbonate (HCO_3^-), Carbonate (CO_3^{2-}), Chloride (Cl^-) and Sulfate (SO_4^{2-}) were analyzed at INP (National Institute of Soil). All ion concentrations are defined in meq l^{-1} .

3.2.4.1 SOIL ANALYSIS

The main soil analyzes carried out according to National Pedology Institute

The main soil analyzes carried out are:

- **pH analysis:** the water method was chosen.

PROCEDURE: take 20g of soil from the sample and put in a container labeled with the identification of the sample:

- 1.add 50ml of distilled water to the plastic jar.
2. shake vigorously for 30 minutes using the magnetic stirrer.
- 3.start reading, but in most lands, stabilization is achieved within the first minute, so in some cases it is sometimes necessary to wait up to 4 minutes.



Figure 4: pH and EC meter.

➤ **EC analysis:** the water method was chosen.

Procedure: Weigh 20g of the sample into a plastic beaker.

1. add 200 ml of distilled water in a plastic jar.
- 2.put in the shaker to shake it for 30 minutes.
3. read the value

➤ **Phosphate analysis:** Bray method was chosen. For the procedure:

1. Measure 5g of the sample in a plastic jar.
2. Pour 35 ml of the Bray extraction solution into the plastic jar the sample.

3. Place the jar in a shaker and agitate for 30 minutes.
4. After agitation, filter the solution using filter paper to remove any solid particles.
5. extract 20 ml of the filtered solution into a 50 ml Erlenmeyer flask.
6. Add 20 ml of ascorbic acid and 2 ml of sulfoMolybdate to the Erlenmeyer flask.
7. Place the flask containing the solution in a Marie bath set at 300°C for 10 minutes.
8. After heating, remove the flask from the water bath.
9. Adjust the volume of the solution to 50 ml by adding distilled water.
10. Preparation of the blank solution with 20 ml of Bray's extraction solution under the same conditions.
11. Calibrate the spectrophotometer with a blank solution.
12. Take readings in the spectrophotometer, starting with the blank solution, and record the absorbance values.



Figure 5: water bath and samples after their remove from the water bath

➤ **Analysis of Ca^{2+} , Mg^{2+} , Na^{+} and K^{+}**

For the analysis of this cation, the method of Ammonium Acetate was chosen.

For the procedure:

1. Measure 20g of soil sample in a Erlenmeyer flask
2. add 50 ml of Ammonium Acetate solution for one night.
3. Filter the solution in the next day.
4. add a second time 50 ml of Ammonium Acetate solution.
5. wait for 30 min before filtering the solution
6. add a third time 50 ml of Ammonium Acetate solution, filter and start their analysis

➤ **Calcium Ca^{2+} and Mg^{2+} analysis:**

To do this, we first determine the $\text{Ca}^{2+} + \text{Mg}^{2+}$

1. We add 20ml of the exchangeable base solution in a Erlenmeyer flask
2. carefully add the buffer solution with a pH of 10.1 to the solution.
3. add 3 drops of Eriochrome T black indicator.
4. titrate the solution, carefully observing until it transitions to a blue color.
5. Record the value at this point.

➤ **Ca^{2+} analysis :**

1. measure 20 ml of the exchangeable base solution in a Erlenmeyer flask
2. add 2 ml of the NAOH solution.
3. Add 3 to 4 drops of Ca^{2+} indicator
4. titrate until it turns purple and read the value

➤ **Sodium(Na^+) analysis:**

1. We calibrate with the Na^+ solution (20 meq/L)
2. set the flame photometer to 100 and
3. Start reading the sample with the exchangeable cation solution.

➤ **Potassium(K^+) analysis:**

1. We calibrate the K^+ solution (10 meq/L)
2. set the flame photometer to 50
3. start reading the samples with the exchangeable cation



Figure 6: flame photometer for determination Na and K

3.2.4.2 WATER ANALYSIS METHOD

For the **pH analysis:**

Add the water sample in the Erlenmeyer flask, introduce the pH meter and read the value.

EC: Add the water sample in the Erlenmeyer flask, introduce the pH meter and read the value.

For the Ca^{2+} , Mg^{2+} , Na and K, we have used the same method of the soil method (Ammonium Acetate method) :

1. measure 20 ml of water sample in a Erlenmeyer flask
2. add 150 ml of Ammonium Acetate solution in three different time:

measure 20 ml of water sample in a plastic jar and add 50 ml of Ammonium Acetate solution for one night. Then we add a second time 50 ml of Ammonium Acetate solution and wait for 30 min, then add a third time 50 ml of Ammonium Acetate solution.

➤ **Calcium Ca^{2+} and Mg^{2+} analysis:**

To do this, we first determine the $\text{Ca}^{2+} + \text{Mg}^{2+}$

1. Take 20ml of the exchangeable base solution
2. add 5ml of pH 10.1 buffer solution add 3 drops of Eriochrome T black indicator
3. titrate until it turns blue then note the value.

➤ **Ca²⁺ analysis :**

1. measure 20 ml of the exchangeable base solution
2. add 5 ml of the NAOH solution.
3. Add 3 to 4 drops of Ca²⁺ indicator
4. titrate until it turns purple and read the value.

➤ **Sodium (Na⁺) analysis:**

1. We calibrate with the Na⁺ solution (20 meq/L)
2. set the flame photometer to 100
3. start to read the Na⁺ with the solutions of the exchangeable bases.

➤ **Potassium(K⁺) analysis:**

1. We calibrate the K⁺ solution (10 meq/L)
2. set the flame photometer to 50
3. start reading the samples with the exchangeable bases.

➤ **Carbonate**

1. Take 20 ml of the water sample.
2. add 10 drops of Phenolphthalein

If we obtain a pink color, we titrate it with sulfuric acid until we have the initial color.

➤ **Bicarbonate(HCO₃⁻) analysis:**

1. add 20ml of the water sample in the Erlenmeyer flask
2. add a few drops of Methyl orange
3. titrate with sulfuric acid until it has a pink color.

➤ **Chloride (Cl⁻) analysis:**

1. Take 10 ml of the sample in a 100 ml flask and add distilled water up to the mark.
2. Take 10 ml of this solution and add a few drops of potassium dichromate
3. finally titrate it with the AgNO₃ solution until we have a brick red color.

➤ **Sulfate(SO₄²⁻) analysis:**

1. Add 10 ml of the water sample into a 100 ml flask.
2. add distilled water up to the mark and extract 25 ml of the solution.

3. Add 10 ml of NaCl solution, 2 ml of acacia gum and 1g of Barium chloride.
4. add distilled water up to the gauge mark, put the solution in the spectrophotometer and record the value.

3.3 DETERMINATION OF IRRIGATION WATER QUALITY INDICES

Irrigation Water Quality (IWQ) indices provide crucial assistance for identifying problems that may arise in soil and crops due to the quality of irrigation waters used. The selection of irrigation indices is based on some agronomic issues related to water/soil salinity, soil permeability, crops toxicity (Badr & Tawfik, 2023). These indices are: The Sodium Ratio Adsorption (SAR) which indicates the concentration of sodium in irrigation wastewater and soil , the Sodium Percentage (%Na) which evaluates the appropriateness of irrigation water and its impact on soil and groundwater, The Residual sodium carbonate (RSC) to assess the risk of excessive carbonate/bicarbonate on suitability for irrigation, The Permeability Index (PI) to evaluate the classification of the irrigation water, Magnesium Hazard (MH) to estimate the magnesium concentration of the water and its impact on the suitability of water for irrigation purposes , Potential Salinity(PS) to measure the total dissolved salts in irrigation water (Doneen (1964). Table 2 shows the different indices, their formula, classification and their type according to the references.

Table 2: The indices for Irrigation purposes, their formula, classification and references

Parameter	Formula	Classification	Type	References
Sodium Ratio Adsorption (SAR)	$SAR = \frac{Na}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$	SAR > 26	Unsuitable	(Al-hadithi et al., 2019)
		18 < SAR < 26	Doubtful	
		10 < SAR < 18	Good	
		SAR < 10	Excellent	

Sodium Percentage(% Na)	$\%Na = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$	80<%Na<100 60<%Na<80 40<%Na<60 20<%Na<40 %Na<20	Unsuitable Doubtful Permissible Good Excellent	(Moussaoui et al., 2023)
The Residual sodium carbonate (RSC)	$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	RSC>2.5 RSC < 1.25 1.25<RSC< 2.5	Unsuitable Safe Good	(Iwqi et al., 2023)
The Permeability Index (PI)	$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$	class I: PI> 75%, class II: 25<PI<75 class III: PI< 25%,	Suitable Good Unsuitable	(Rawat et al., 2018)
Magnesium Hazard (MH)	$MH = \frac{Ca^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	MH>50 MH<50	Unsuitable Suitable	(Moussaoui et al., 2023).
Potential Salinity (PS)	$PS = Cl^- + \frac{SO_4^{2-}}{2}$	PS> 10 5<PS<10 PS<5	Unsatisfactorily Good to injurious Excellent	(Moussaoui et al., 2023)

3.3.1 DETERMINATION OF IRRIGATION WATER QUALITY INDEX

The overall IWQI can be utilized to evaluate the suitability of water for irrigation through the conversion of large analytical data into a single numeric score to be used by decision makers for the improved explanation of water quality. The EC, Na⁺, Cl⁻, HCO₃⁻ and SAR parameters suggested by Meireles et al., (2010) will be used to calculate the IWQI (Al-hadithi et al., 2019). The concentration units were transformed from [mg/L] to [meq /L].

In the first step, values of the accumulation weights (W_i) suggested by (Meireles et al., 2010) are based on their relative significance to the irrigation water quality standard. Its normalized values and their total are equal one as shown in Table 3. Based on different parameters recommended by (Ayers and Westcot, 1994), (Q_i) value will be estimated in the second step as shown in Table 4. It represents non-dimensional number with the higher value indicating a better water quality and vice versa. Restriction to water use classes were characterized based on Meireles et al (2010) as shown in Table 5.

Table 3. The Weight for the IWQI parameters

Parameters	W_i
[EC]	0.211
[Na]	0.204
[HCO ₃ ⁻]	0.202
[CL]	0.194
[SAR]	0.189
Total	1

The determination of Q_i is calculated according the following equation (Al-hadithi et al., 2019)

$$Q_i = q_{\max} - \frac{[(x_{ij} - x_{inf}) * q_{iamp}]}{x_{amp}} \dots \dots \dots (1)$$

Where:

q_{\max} : is the maximum value of Q_i for each class,

x_{ij} : is the observed value of each parameter,

x_{inf} : is the value corresponding to the lower limit of the class to which the parameter belongs,

q_{iamp} : is the class amplitude

x_{amp} : is upper limit of the last class of each parameter

Table 4: Limiting value of Qi calculations.

HCO_3^-	Cl^-	Na^+	SAR	EC	Qi
$1 \leq \text{HCO}_3 < 1.5$	$1 \leq \text{Cl} < 4$	$2 \leq \text{Na} < 3$	$2 \leq \text{SAR} < 3$	$200 \leq \text{EC} < 750$	85-100
$1.5 \leq \text{HCO}_3 < 4.5$	$4 \leq \text{Cl} < 7$	$3 \leq \text{Na} < 6$	$3 \leq \text{SAR} < 6$	$750 \leq \text{EC} < 1500$	60-85
$4.5 \leq \text{HCO}_3 < 8.5$	$7 \leq \text{Cl} < 10$	$6 \leq \text{Na} < 9$	$6 \leq \text{SAR} < 12$	$1500 \leq \text{EC} < 3000$	35-60
$\text{HCO}_3 < 1$ or $\text{HCO}_3 \geq 8.5$	$1 < \text{Cl} \geq 10$	$\text{Na} < 2$ or $\text{Na} \geq 9$	$2 \leq \text{SAR} \geq 12$	$\text{EC} < 200$ or $\text{EC} \geq 3000$	0-35

Table 5: Classifications and characteristics of general IWQI

IWQI	Exploitation restrictions	soil	plant
[85-100]	No restriction (NR)	Water can be used for almost all types of soil. Soil is exposed to lower risks of salinity/sodicity problems	No toxicity risk for most plants
[70-85]	Low restriction (LR)	Irrigated soils with a light texture or moderate permeability can be adapted to this range. To avoid soil	Elevated risks for salt sensitive plants

		sodicity in heavy textures, soil leaching is recommended.	
[55-70]	Moderate restriction (MR)	The water in this range would be better used for soils with moderate to high permeability values. Moderate leaching of salts is highly recommended to avoid soil degradation	Plants with moderate tolerance to salts may be grow
[40-55]	High restriction (HR)	This range of water can be used in soils with high permeability without compact layers. High frequency irrigation schedule	Suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO ₃ ⁻ values
[0-40]	Severe restriction (SR)	Using this range of water for irrigation under normal conditions should be avoided	Only plants with high salt tolerance, except for waters with extremely low values of Na ⁺ , Cl ⁻ and HCO ₃ ⁻ .

The IWQI will be calculated according to the following equation:

$$IWQI = \sum_{i=1}^n Qi * Wi \dots \dots \dots (2)$$

where IWQI : is the non-dimensional irrigation water quality index ranging from 0 to 100;

Qi : is the quality measurement of the parameter,

(i th): a number from (0 to 100) is a function of its concentration; and

W_i : is the normalized weight of the i th parameter.

4 RESULTS AND DISCUSSION

4.1 REFERENCE FRAMEWORK FOR ANALYZING RESULTS OF WATER

After sampling, the physical and chemical parameters of water for irrigation was analyzed at the National Institute Pedology of Senegal, then their min, max, mean and standard deviation were calculated. The results were interpreted with referencing to the FAO standard (Table 6). The interpretation of the results for certain parameters (pH, EC) and the indices (% Na, PI, SAR, RSC, MH and PS) was carried out using a bar chart for the average of these parameters and indices to have a better comparison of the reused wastewater and mixed wastewater with groundwater and lake water in order to assess their impacts on soil and groundwater. The software Piper diagram was made in such a way that the milliequivalents percentages of the major cations and anions are plotted in separate triangle (Kumar, 2014). These plotted points in the triangular fields are projected further into the central diamond field, which provides the overall character of the water. In contrast, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis, and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle, depending upon the size of the scales chosen for X and Y coordinates. The milliequivalent percentage differences between alkaline earths and alkali metals, and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub-fields. The major advantage of this diagram is that it can be drawn in any spreadsheet software packages.

```

> summary(data)
      lake                pH                EC                SAR
Length:30             Min.   :6.400         Min.   : 755         Min.   :0.800
Class :character      1st Qu.:7.200         1st Qu.:1865        1st Qu.:1.100
Mode  :character      Median :7.250         Median :2315        Median :1.250
                                Mean  :7.377         Mean  :2755        Mean  :1.867
                                3rd Qu.:7.475        3rd Qu.:3390        3rd Qu.:1.575
                                Max.  :8.800         Max.  :7150        Max.  :5.800

      Na                RSC                PI                MH
Min.   :15.50         Min.   :-14.800        Min.   :23.30        Min.   :45.70
1st Qu.:26.10         1st Qu.: -2.475        1st Qu.:47.10        1st Qu.:55.48
Median :29.30         Median : 4.150         Median :65.50        Median :64.55
Mean   :32.93         Mean   : 1.963         Mean   :62.71        Mean   :63.13
3rd Qu.:35.10         3rd Qu.: 6.875        3rd Qu.:73.60        3rd Qu.:71.35
Max.   :55.30         Max.   : 15.000        Max.   :94.90        Max.   :85.90

      PS                IWQI
Min.   :11.60         Min.   : 0.00
1st Qu.:18.50         1st Qu.:26.93
Median :28.00         Median :37.55
Mean   :29.49         Mean   :32.40
3rd Qu.:32.00         3rd Qu.:40.30
Max.   :68.00         Max.   :49.60

```

Figure 7 : summary statistical analysis of water parameters

Table 6: Descriptive statistics and comparison of the parameters with FAO values.

Water quality parameters	min	max	mean	median	Standard deviation	FAO standard Limit
pH	6.8	8.8		7.25	0.4	6,5-8.5
EC(_S/cm)	750	7150	2754.9	2315	1415.1	3000
Ca ²⁺ (meq/L)	2.2	12.4	5.1	4.5	2.7	20
Mg ²⁺ (meq/L)	1	10	3.2	2.2	2.4	5
Na ⁺ (meq/L)	1.1	16.5	4	2.4	4	40

K ⁺ (mg/L)	4.2	24.1	12.9	12.3	5.5	2
Cl ⁻	11	70	29.5	27.8	15.6	30
SO ₄ ²⁻	0	3.3	0.5	0.4	0.7	20
HCO ₃ ⁻	3.5	20	9.6	10	4	10
CO ₃ ²⁻	1.25	2.5	0.7	2	1	1
SAR	0.8	5.8	1.9	1.3	1.3	15

4.1.1 POTENTIAL HYDROGEN (PH)

The pH balance of a water supply describes how acidic or alkaline it is. The acidity (or alkalinity) of a water supply can affect plant growth, irrigation equipment, pesticide efficiency and drinking water. For instance, the amalgamation of CO₂ with water gives rise to carbonic acid, a key factor influencing water pH (Di et al., 2023). Water with a pH below 7 is acid and water with a pH above 7 is alkaline. Most natural waters are between pH 5 and 8. Alkaline water may contain high concentrations of bicarbonate (generally in water of pH 8 and above) and carbonates (generally pH 9 and above). This can cause calcium and magnesium to precipitate from the soil which can affect plant growth. Some trace elements, like copper and zinc, will also be less available to the plant in this situation. A pH greater than 7.5 is likely to reduce the effectiveness of chlorine disinfection. Acidic water can also have a detrimental effect on plant growth, particularly causing nutritional problems, while strongly acidic water (below pH 4) can contribute to soil acidification. A pH less than 6 indicates corrosiveness, which can lead to damage to metal pipes, tanks and fittings (Brunton, 2011). That's why FAO defines a permissible limit for pH ranged from 6.5 to 8.5. In our study, variations in pH were observed across samples, ranging from 6.4 to 8.8. Notably, 28 samples fell within the permissible pH range outlined by the Food and Agriculture Organization (FAO) for water irrigation, across from 7 to 8.4. However, two samples, namely P3 located in Patte d'oie with a pH of 6.4, and P11 from the lake with a pH of 8.8, slightly deviated from the FAO's standard limit for irrigation. Despite this, all treated and mixed water samples fell within the acceptable pH range set by the FAO that's mean they will not have negative effect on groundwater and the soil. The figure 8 shows the different water and their pH compared to the FAO Limit.

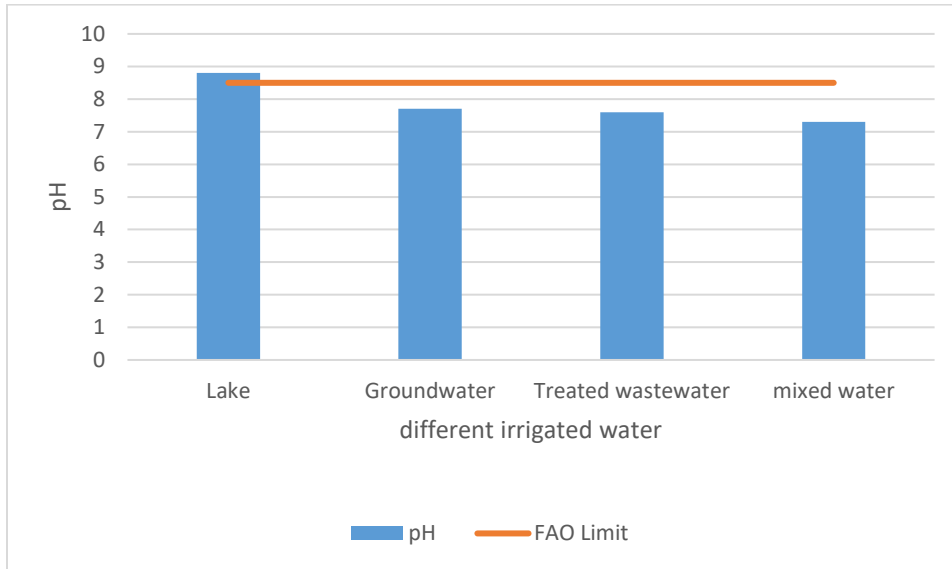


Figure 8 : maximum pH value of the different water

4.1.2 ELECTRICAL CONDUCTIVITY(EC)

Conductivity, as measured in water, serves as an indicator of the concentration of dissolved salts, as explained by Moussaoui et al. (2023). This electrical property, often denoted as electrical conductivity (EC), offers insights into the overall salt content by quantifying the ionic concentrations in the water (Di et al., 2023). Notably, EC values are influenced by factors such as temperature, ion concentration, and the types of ions present.

In our study, we observed exceptionally high EC values ranging from 755 $\mu\text{S}/\text{cm}$ to 7155 $\mu\text{S}/\text{cm}$. Remarkably, approximately 20 samples adhered to the FAO Standard limit, while the remaining 10 surpassed this threshold, indicating their high salinity. Such elevated salinity levels render these

waters unsuitable for various applications, including irrigation, unless robust management and treatment strategies are enacted.

Specifically, sites P4 (5490 $\mu\text{S}/\text{cm}$, located in Patte d'oise) and P16 (7150 $\mu\text{S}/\text{cm}$, comprising the groundwater in Patte d'oise) exhibited the highest EC values. The heightened salinity associated with these sites poses risks of soil salinization and crop damage.

Notably, only one treated wastewater sample (P23: 3210 $\mu\text{S}/\text{cm}$) fell outside the FAO standard limit, underscoring the efficacy of treatment processes. On the contrary, six groundwater samples were considered unsuitable for irrigation, while three mixed water samples met the FAO standards because of their high salinity. This high salinity is found in other Niayes zone Like The Niayes of the Northern Coast of Senegal which present a significant EC values around 10920 $\mu\text{S}/\text{cm}$ for groundwater according to the study of (Marième Fall, Souleymane et al., 2022). The high salinity of the groundwater is indicative of seawater intrusion into the environment and salinization of the Quaternary water table.

The accompanying Figure 9 illustrates the average EC values across different water types sampled in our study, providing a visual representation of the salinity variations among the samples.

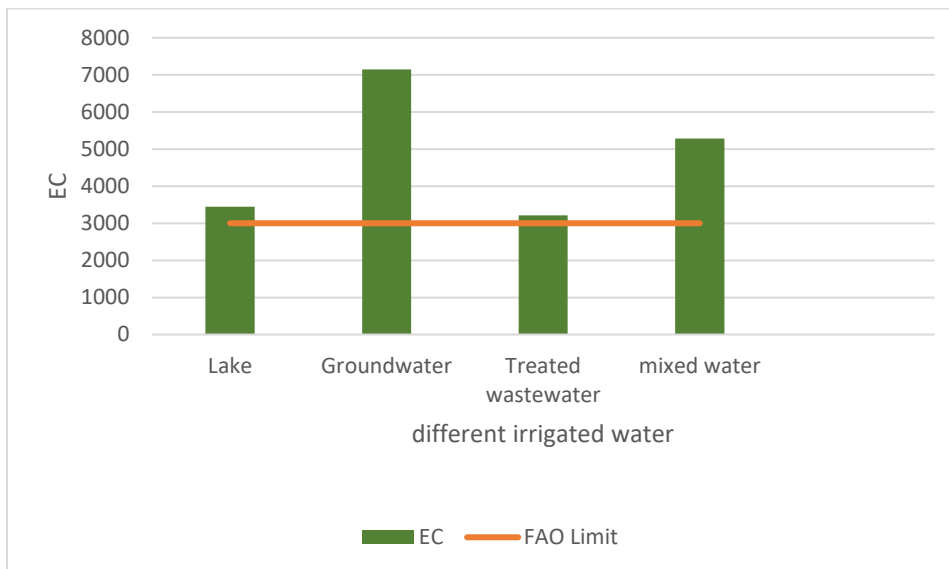


Figure 9: maximum EC values for the different types of water

This is confirmed by the Richards plot on the US salinity diagram (Moussaoui et al., 2023) in the figure 10 for employing EC to assess salinity hazard and SAR to evaluate alkalinity hazard, the diagram shows that the samples fell into C3S1 to C4S1 except the P4(well) and two the mixed water samples (P16 and P26) which are outside the classes explained that they have a very high salinity and very low alkalinity hazard.

According to (Ş & Yildiz, 2019) :

C3: Water with high salinity ($750 < EC < 2250 \mu S /cm^{-1}$) cannot be used on soils with limited drainage, some plants can tolerate.

- C4: Water with very high salinity ($EC > 2250 \mu S /cm^{-1}$): the soil should be permeable with insufficient drainage.

S1: Water with low sodium content. This can be used on all kinds of soil.

(Moussaoui et al., 2023) categorized water quality based on conductivity and corresponding salt content into four categories. “Excellent”: water with a conductivity of less than $250 \mu S/cm$ and a corresponding salt content of less than 160 mg/L . This water is considered as excellent quality and suitable for various uses, including irrigation. “Low salinity”: with a conductivity of $750 \mu S/cm$ and a corresponding salt content between 160 and 500 mg/L .

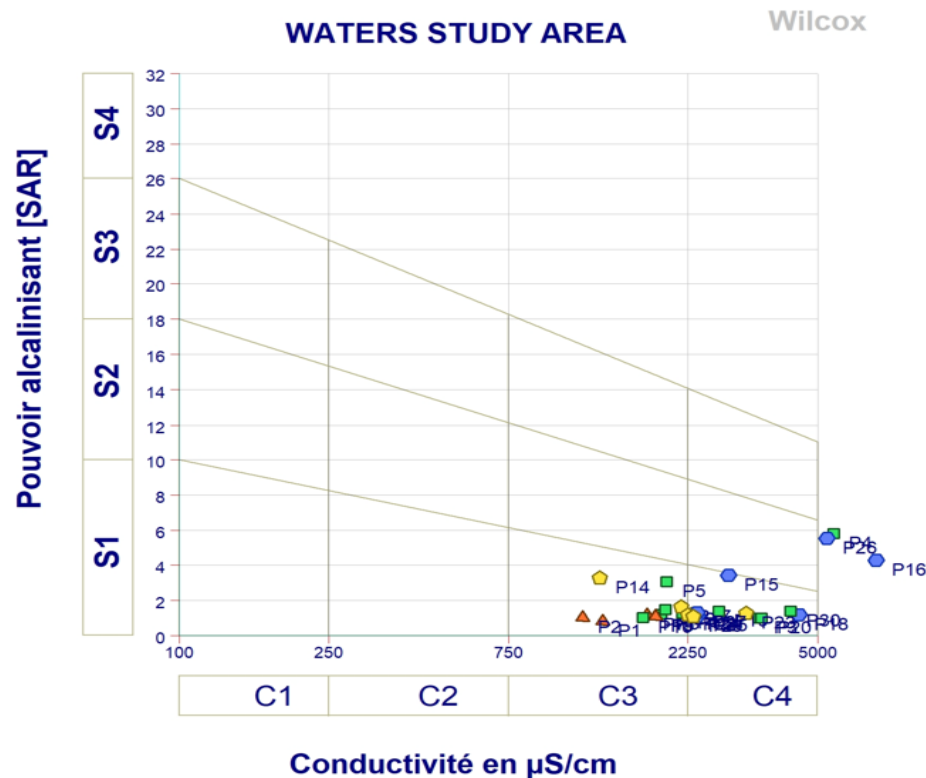


Figure 10: Classification of irrigation water suitability using Wilcox diagram based on SAR and EC of different water.

4.1.3 INTERPRETATION OF ANIONS AND CATIONS BY USING PIPER DIAGRAM

The determination of cations and anions was conducted using the Piper diagram method, a widely employed tool in hydrogeochemical analysis (Piper, 1944). Analysis of groundwater samples revealed a predominant classification as calcium chloride and mixed types, consistent with findings in similar hydrogeological studies (Appelo and Postma, 2005). Specifically, the anions predominantly belonged to the chloride type, in line with observed trends in groundwater chemistry (Güler et al., 2002). Regarding cations, classification varied: samples from locations P4 exhibited dominance of sodium and potassium, while those from P6 and P30 were predominantly calcium rich. Other samples lacked a clear dominant type, aligning with the heterogeneous nature of groundwater chemistry (Gupta and Deshpande, 2004).

Lake water samples predominantly demonstrated chloride, sodium, and potassium types, indicative of common lake water chemistry patterns (Drever, 1997).

For the treated wastewater samples, anions were primarily categorized as bicarbonate, consistent with the composition of untreated wastewater (Metcalf & Eddy, 2014). Cation classification revealed a lack of dominance, although two samples exhibited characteristics of sodium and potassium type, along with calcium type, which could reflect varying sources and treatment processes (EPA, 2004).

Regarding the mixed water: they belong to the chloride class for anion and no dominant type for cations except P15 and P26 which are potassium and sodium type

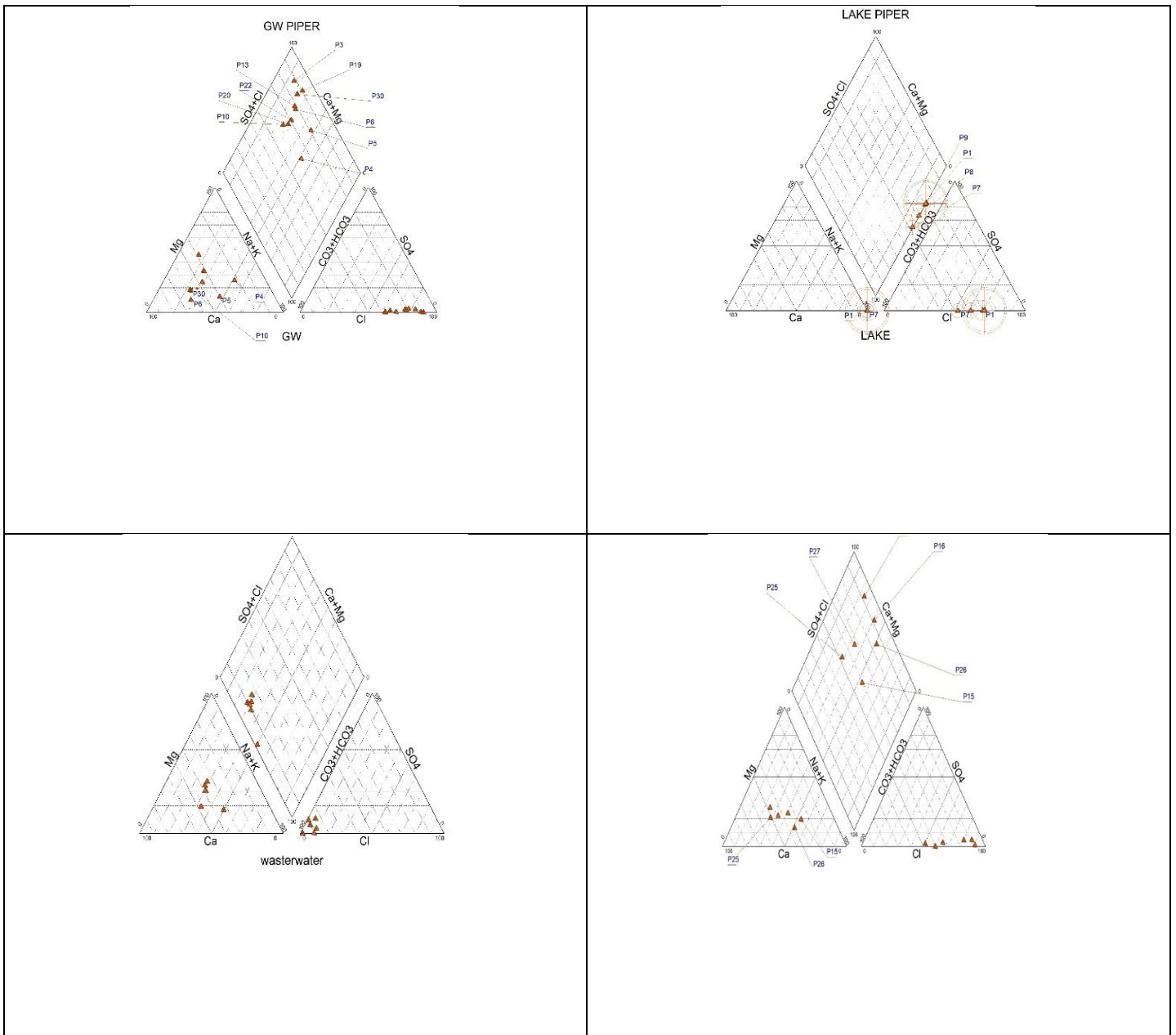


Figure 11: The Piper diagram of the different water type.

4.1.4 INTERPRETATION OF INDICES

The table 7 below shows the results of the Indices and their statistical values.

Table 7: the result of the statistical values of the indices

water type	SAR	%Na	RSC	PI	MH	PS
groundwater						

Min	1.0	15.5	-14.8	23.3	45.7	22.8
max	5.8	52.4	9.0	92.1	85.9	68.0
mean	2.1	31.3	-1.0	53.7	66.5	34.9
median	1.4	28.4	1.2	53.2	70.5	29.4
Standard deviation	2.8	10.7	8.3	18.6	13.5	14.7
lake						
Min	0.8	23.7	-3.0	39.9	46.2	16.0
max	2.9	49.2	9.0	80.0	71.2	40.0
mean	1.3	29.6	4.4	66.7	59.0	25.0
median	1.3	29.6	4.4	66.7	59.0	25.0
Standard deviation	1.0	8.8	4.0	13.7	10.8	9.2
wastewater						
Min	1.3	29.3	-2.1	45.6	48.1	11.6
max	3.3	51.2	8.3	82.9	71.4	65.0
mean	1.6	34.7	4.5	70.3	58.4	24.3
median	1.2	31.7	5.1	71.8	56.1	15.4
Standard deviation	1.4	8.3	3.5	13.0	8.9	20.5
wastewater+groundwater						
Min	1.3	25.5	-9.3	38.8	58.0	12.2
max	5.5	55.3	15.0	94.9	72.4	52.3
mean	2.7	39.5	2.8	69.8	66.3	29.1
median	1.5	35.3	6.1	73.7	66.7	28.8
Standard deviation	3.7	13.5	9.8	21.9	5.9	14.7

4.1.4.1 THE SODIUM ABSORPTION RATIO (SAR)

Sodium Absorption Ratio (SAR) is an important indicator to measure the concentration of Na⁺ in irrigation water and soil. It refers to the ability of sodium ions to replace the Calcium and Magnesium ions from soil (Iwqi et al., 2023). This phenomenon leads to the dispersion of soil particles and the breakdown of soil structure. A higher SAR value indicates a greater adsorption effect on Na⁺, which can alter the structure of soil agglomerates and reduce the pore size and makes less infiltration to water to reach the roots of plants that in turn lead it to dry, compact, and hard ultimately decrease the drainage performance. (Meena & Bisht, 2020).

For the area under investigation, all the 4 types of water are found to be excellent for irrigation because they have low sodium hazard ranged from 0.8 to 5.8 which indicate that we have less sodium concentration and the wastewater that can lead to make the soil permeable.

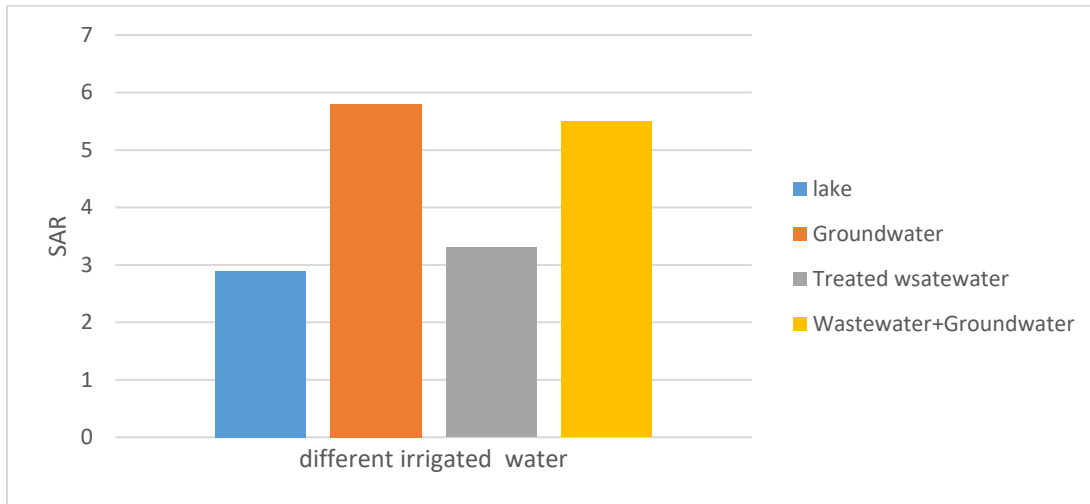


Figure 12: Average SAR of the different water type.

4.1.4.2 THE SODIUM PERCENTAGE %NA

It is a crucial factor in evaluating the appropriateness of irrigation water and its impact on soil and groundwater. The percentage of sodium content in all natural waters is a commonly used parameter for evaluation of suitability for agricultural irrigation (Wilcox, 1955). As an important ion for evaluation of irrigation water, Na^+ may pose toxicity issues for some crops (Bauder *et al.*, 2010). High Na^+ concentrations in irrigation water may result in absorption by clay particles, thus inducing the displacement of Mg^{2+} and Ca^{2+} , reduction in soil permeability and weak interior drainage. Also if water contains high levels of sodium, it can react with carbonates and causes soil alkalinity to rise (Ş & Yildiz, 2019). Additionally, excessive amounts of sodium chloride can lead to soil salinization, which decreases soil permeability and hinders water flow through the soil, ultimately affecting crop growth (Iwqi *et al.*, 2023). In our study area, the %Na values ranged from 15.5% to 55.3% that's mean all samples haven't high concentration of sodium that's why they are classified as permissible, good to excellent for irrigation. The mixed water and groundwater has the lowest value of % Na with an average value of 23.4 and 23.5 respectively. For mixed water, 4

are good for irrigation and 2 are permissible. For the lake water, among the 7 samples, 6 are considered as good for irrigation and the p11 as permissible for irrigation.

About the treated wastewater among the 6 samples, the 5 fell within good for irrigation and 1 is considered as permissible which is P14.

For the groundwater, 2 are considered as excellent for irrigation, 7 are good for irrigation and 2 as permissible.

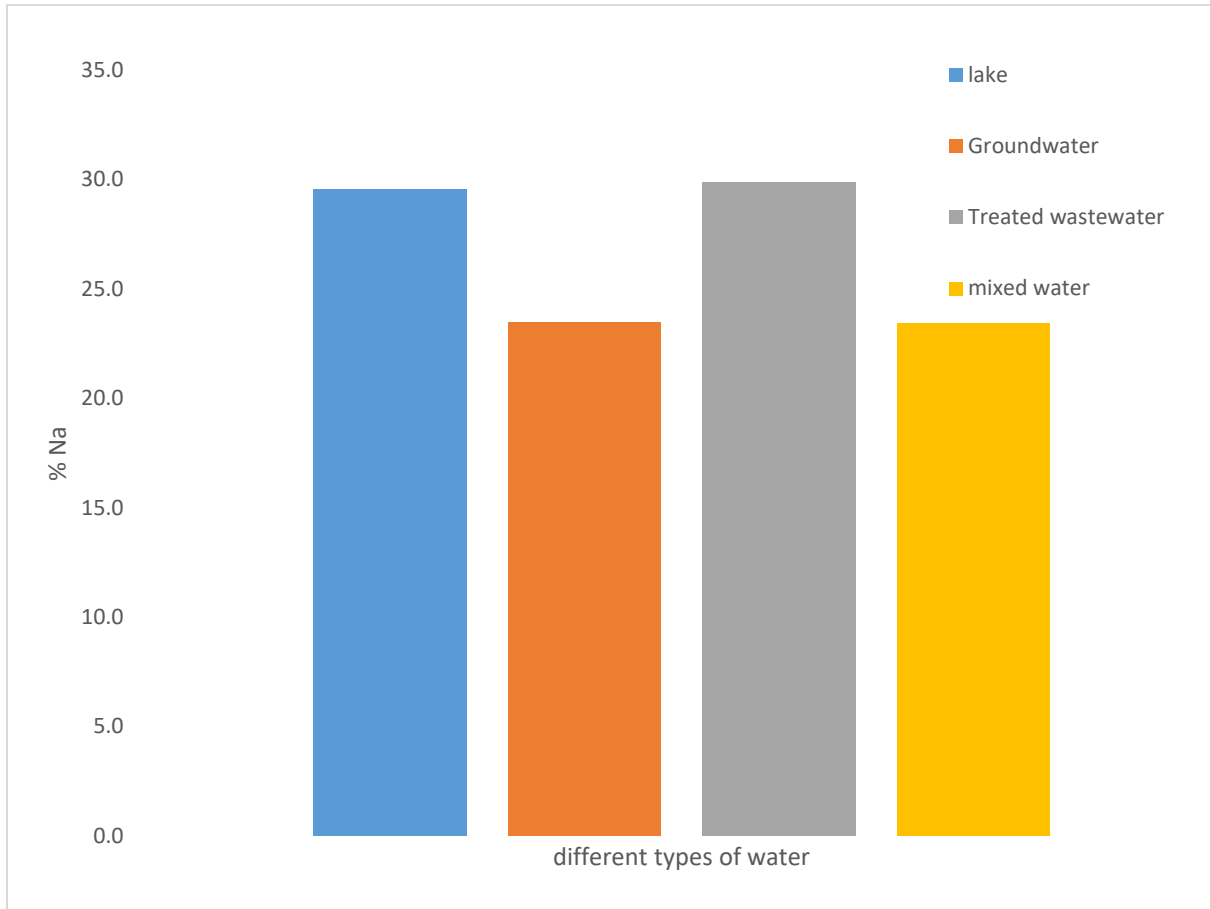


Figure 13: Average Na% of the different types of water

4.1.4.3 PERMEABILITY INDEX (PI)

The soil structure is significantly influenced by the Potential Irrigation (PI) parameter, which serves as a key indicator for assessing water suitability for irrigation purposes (Richards, 1954). The PI is derived from the correlation between cations and bases present in water (Jury and Horton, 2004). Excessive concentrations of specific ions such as calcium, magnesium, sodium, and

bicarbonate can detrimentally impact soil structure, leading to reduced permeability (Hillel, 1980). This reduction in permeability hampers nutrient absorption and can impede crop growth (Brady and Weil, 2008).

Our samples exhibit PI values ranging from 23.3% to 94.9%, placing them within classes 1 and 2, indicating suitability and goodness for irrigation, respectively (USSL, 1954). These values suggest that the water sources studied are unlikely to adversely affect soil permeability.

Analysis reveals that the lake water demonstrates the highest suitability for irrigation, with an average PI of 66.7 (Figure 14), with most samples falling into the "good" category (USSL, 1954). Conversely, only a few samples from other sources meet the criteria for "good" irrigation suitability, with the majority being classified as "suitable" (USSL, 1954). For instance, out of the Treated wastewater samples, one (p17) exhibits a PI of 45.6%, qualifying as "good" for irrigation, while the majority are deemed "suitable" (USSL, 1954). Similarly, mixed water sources predominantly fall into the "good" category, with a smaller proportion classified as "suitable" (USSL, 1954). Groundwater sources generally exhibit high suitability for irrigation, with the majority falling into the "good" category (USSL, 1954).

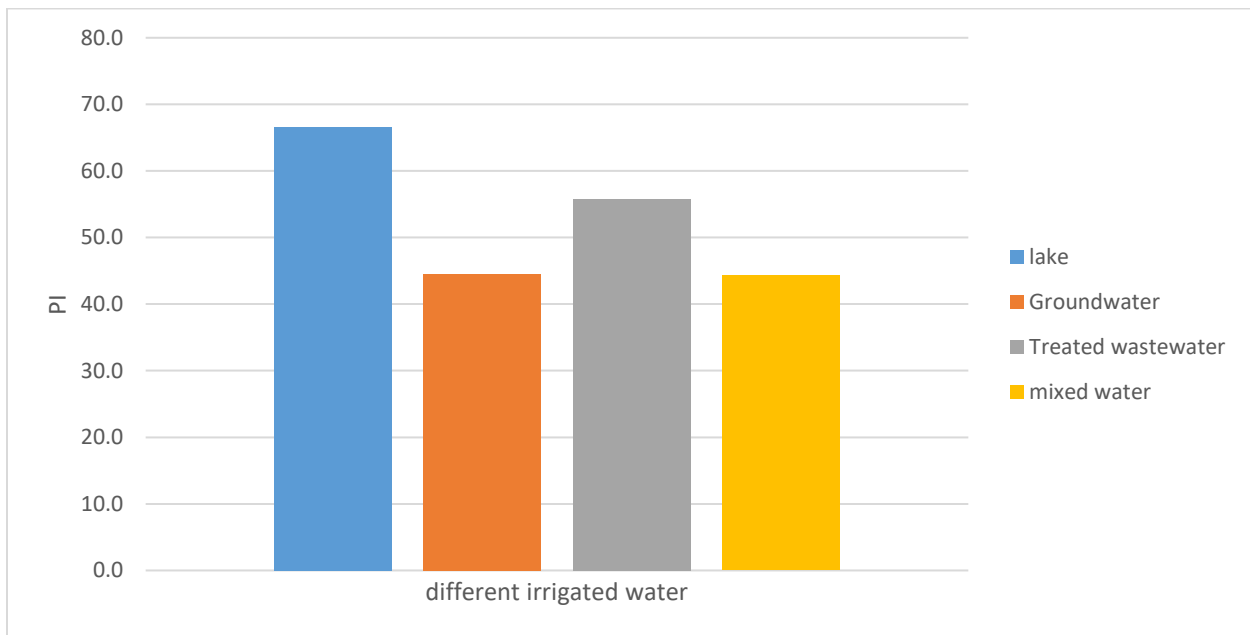


Figure 14: average PI of the different irrigated water

4.1.4.4 RESIDUAL SODIUM CARBONATE (RSC)

The Residual Sodium Carbonate (RSC) content, characterized by the excess presence of sodium, bicarbonate, and carbonate in water, is widely recognized for its adverse effects on soil physical properties due to its tendency to induce organic matter dissolution (Di et al., 2023). In our investigation, RSC values spanned from -14.8 to 15, with approximately 60% of our sampled water sources falling into the category of unsuitability for irrigation. Specifically, the treated wastewater in Pikine exhibited an average RSC of 5.2 (see Figure 15), with a maximum recorded value of 9 rendering it unsuitable for irrigation in most cases. Among these samples, 5 fell within the unsuitable range for irrigation, while one was deemed safe.

Regarding mixed water sources, 3 were classified as unsuitable for irrigation, while the remaining 3 were considered safe. Similarly, in the case of groundwater, 6 samples were deemed suitable for irrigation, whereas 5 were unsuitable.

In the context of lake water, only 1 sample was classified as suitable for irrigation, with an additional sample considered safe, while 5 samples were deemed unsuitable for agricultural use.

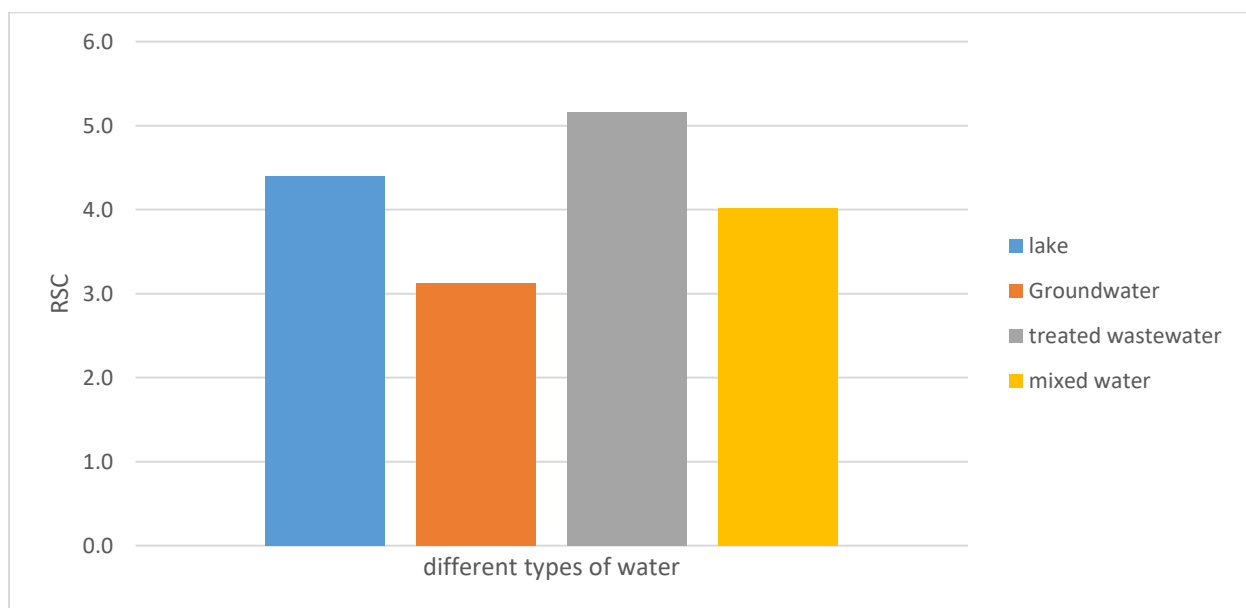


Figure 15: Average PI of the different irrigated waters

4.1.4.5 MAGNESIUM HAZARD (MH)

Szaboles and Darab (1964) introduced the concept of Magnesium Hazard (MH) as a parameter for assessing water suitability for irrigation. Elevated levels of Mg^{2+} in soil are known to induce alkalization, adversely affecting soil structure and crop yield (Ş & Yildiz, 2019). A threshold of $MH > 50\%$ indicates unsuitability for irrigation (Moussaoui et al., 2023), while $MH < 50\%$ suggests suitability.

Our calculations revealed MH values ranging from 85.9% to 45.7%, with 83% of samples estimated unsuitable for irrigation due to high magnesium content. Notably, the lake exhibited the highest average MH at 59%.

Assessing Treated wastewater MH, five out of six samples were unsuitable for irrigation with $MH > 50\%$, while only one was suitable. For groundwater, nine samples were unsuitable, while two were suitable for irrigation.

Mixed water sources were universally unsuitable for irrigation. Figure 16 illustrates that only the lake water met the criteria for irrigation suitability.

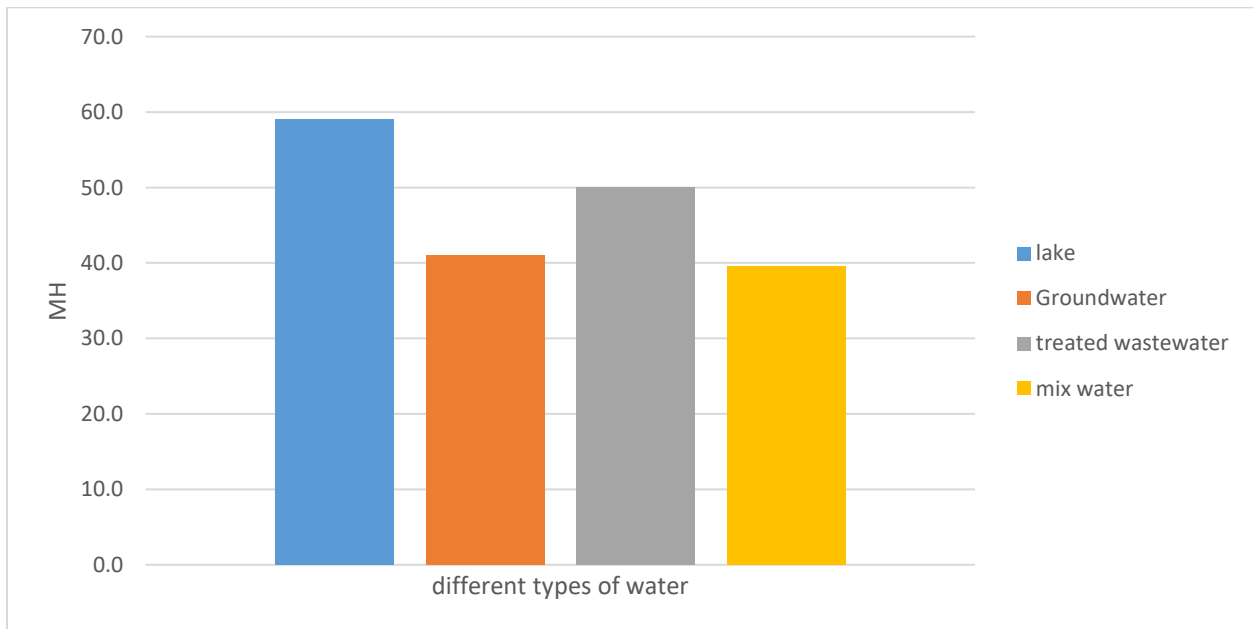


Figure 16: Average MH of different types of water.

4.1.4.6 POTENTIAL SALINITY (PS)

The water's suitability is indicated based on the concentration of insoluble salts (Meena & Bisht, 2020). In our study, all samples except for the mixed water are deemed unsatisfactory, suggesting high salinity levels and insoluble salt concentrations across various water sources. Groundwater exhibits the highest PS value at 68 meq/l, averaging at 34.7 meq/l (Figure 17), with the borehole P22 in Patte d'oe showing the highest PS value. This could be attributed to prolonged wastewater use in the area, leading to leaching into groundwater and subsequent salinity increase.

Salinization of groundwater is a severe consequence of wastewater irrigation (WWI) practices. These practices result in significant salt accumulation in soils due to the high salt content in wastewater, which then leaches into aquifers, altering groundwater chemistry. Furthermore, WWI practices can elevate groundwater sodicity through processes like NaCl leaching and reverse cation exchange, where dissolved Ca is exchanged by Na on aquifer surfaces. Integrated irrigation systems using groundwater and wastewater may exacerbate salinity and sodicity due to the evaporative effects of return flows (Torres-Martínez et al., 2021).

Overall, increasing salinity and sodicity may transition groundwater from a Ca-Mg-HCO₃ type to NaCl dominance, particularly in areas where groundwater is used for integrated irrigation.

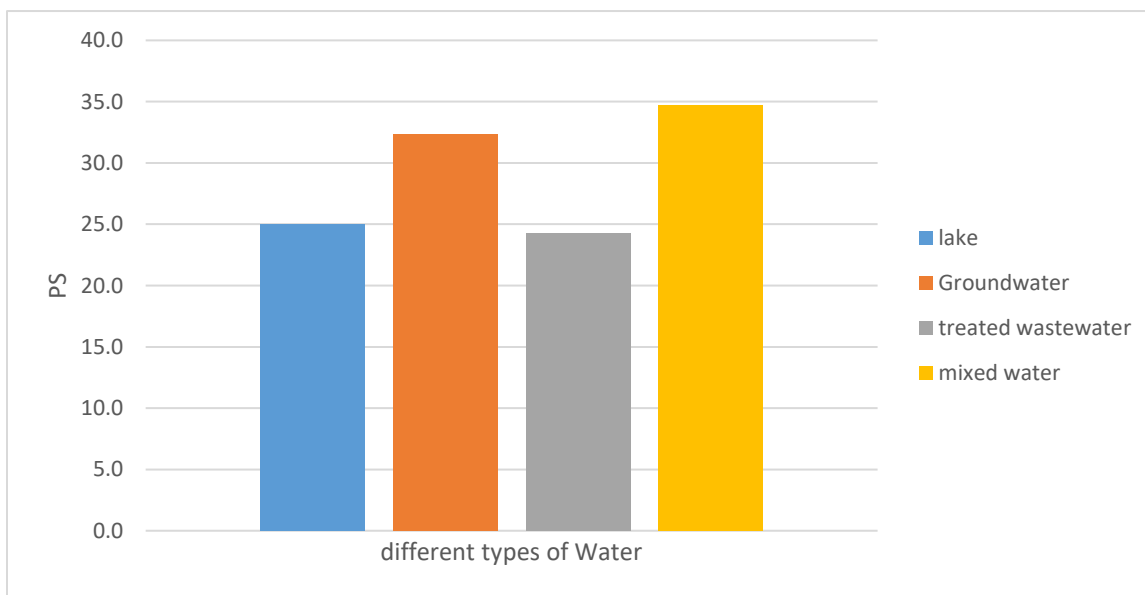


Figure 17: PS average of the different water

4.1.4.7 INTERPRETATION OF IWQI

IWQIM which is a specified method was developed primarily by Meireles et al. and initially used for water quality assessment for agricultural purposes. There are gentle differences between these methods and WQI based method was employed by WHO. However, In the IWQI model, firstly, the dominant parameters which play an important role in the water quality or agricultural purposes must be identified which are including EC, Na⁺, Cl⁻, HCO⁻³ and SAR. In the second step, the weight of water quality parameters including: the water quality measurement parameter value (Qi), and the accumulation witness (Wi) should be determined depending on each individual parameter value and finally taking account in to the criteria which were proposed by Ayers and Westcot. (Abbasnia et al., 2018).

There are four main factors that will have a major impact on crop yields and crop productivity. These influencing factors are: 1- affect soil salinity, 2- affect soil infiltration character, 3- toxic ions, 4- affect plants in different ways (Table 4). Parameter weighting (table 2) in IWQI and Qi (equation 2) was used as a basis for determining the classification of quality values of irrigation water originating from wastewater 4 types of water.

Table 8: Results of IWQI calculation

IDS	Colonne1	qi EC	qi SAR	qi HCO3-	qi Na	qi Cl-	IWQI
P1	Lake	33,5	55,8	41,3	50,6	8,8	38,0
P2	Lake	40,2	51,6	44,4	41,6	8,8	37,4
P3	Groundwater	29,5	52,7	64,2	85,1	-35,0	39,7
P4	Groundwater	6,0	61,5	0,0	6,0	-54,3	3,6
P5	Groundwater	52,1	84,4	38,1	63,5	-43,8	39,1
P6	Groundwater	53,1	48,3	38,1	95,0	-26,3	42,3
P7	Lake	55,7	48,9	27,1	100,0	14,0	49,6
P8	Lake	54,2	50,3	30,6	99,5	-5,3	46,4
P9	Lake	54,3	50,6	30,6	35,6	-43,8	26,0
P10	Groundwater	56,6	51,2	22,8	36,1	-21,0	29,5

P11	Lake	84,8	86,0	35,0	70,6	-35,0	48,8
P12	Lake	29,8	45,9	27,1	80,2	-70,0	23,2
P13	Groundwater	48,7	47,4	49,1	89,4	-8,8	45,7
P14	Treated Wastewater	66,1	82,7	26,3	62,8	-17,5	44,3
P15	Wastewater+Groundwater	36,8	81,3	0,0	64,6	-33,3	29,9
P16	Wastewater+Groundwater	-13,4	74,2	68,3	16,1	-143,5	0,4
P17	Treated wastewater	49,0	41,4	37,6	77,7	17,5	45,0
P18	Treated Wastewater+ Groundwater	18,1	49,4	60,0	91,6	-112,0	22,2
P19	Groundwater	39,7	45,5	56,9	82,4	-168,0	12,7
P20	Groundwater	28,8	52,6	25,4	45,4	-17,5	27,0
P21	Groundwater	33,0	49,2	29,8	96,6	-28,0	36,5
P22	Groundwater	52,2	44,0	35,0	83,6	-29,8	37,7
P23	Treated Wastewater	32,6	47,6	35,0	37,6	-157,5	0,0
P24	Treated Wastewater	46,7	48,3	39,4	35,7	24,5	39,0
P25	Treated Wastewater+Groundwater	45,2	50,2	30,6	38,0	28,0	38,4
P26	Wastewater+Groundwater	8,4	63,9	55,3	12,1	-28,0	22,1
P27	Wastewater+Groundwater	45,3	47,0	35,0	36,6	-7,0	31,6
P28	wastewater	47,5	49,5	38,5	38,3	17,5	38,4
P29	wastewater	46,2	50,9	35,0	39,1	31,5	40,5
P30	Groundwater	20,5	45,6	55,3	78,2	-35,0	33,3

Legend

$0 < q_i < 35$ $35 < q_i < 60$ $60 < q_i < 85$ $85 < q_i < 100$ $40 < IWQI < 55$
 $0 < IWQI < 39$



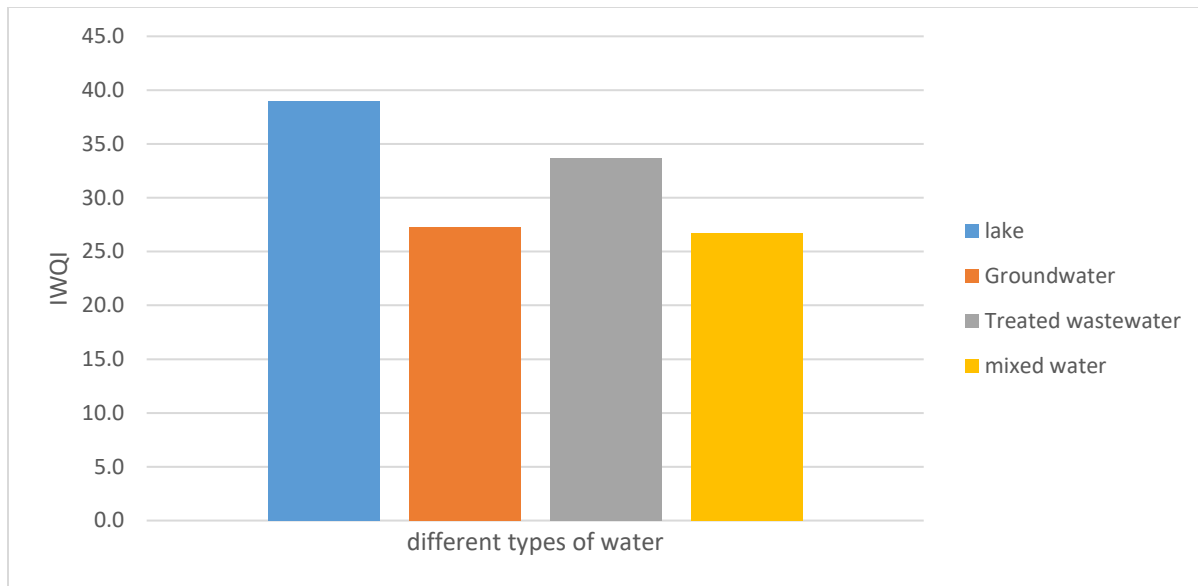


Figure 18: IWQI of the different types of water

According to Table 8, our samples fall within class IV and V categories of water quality, denoting high restriction and severe restriction respectively. With a maximum value of 49.6 and a minimum of 0, our dataset reflects a broad range of water quality parameters. Notably, approximately 73% of our samples exhibit severe restriction conditions, indicating significant water quality challenges. When considering specific water sources, we observe that 57% of wastewater samples, all mixed water samples, and 81% of groundwater samples also fall within the severe restriction category. To provide a comprehensive assessment, interpolation of the Interpolated Water Quality Index (IWQI) was conducted, and the results are visually presented in the figure below.

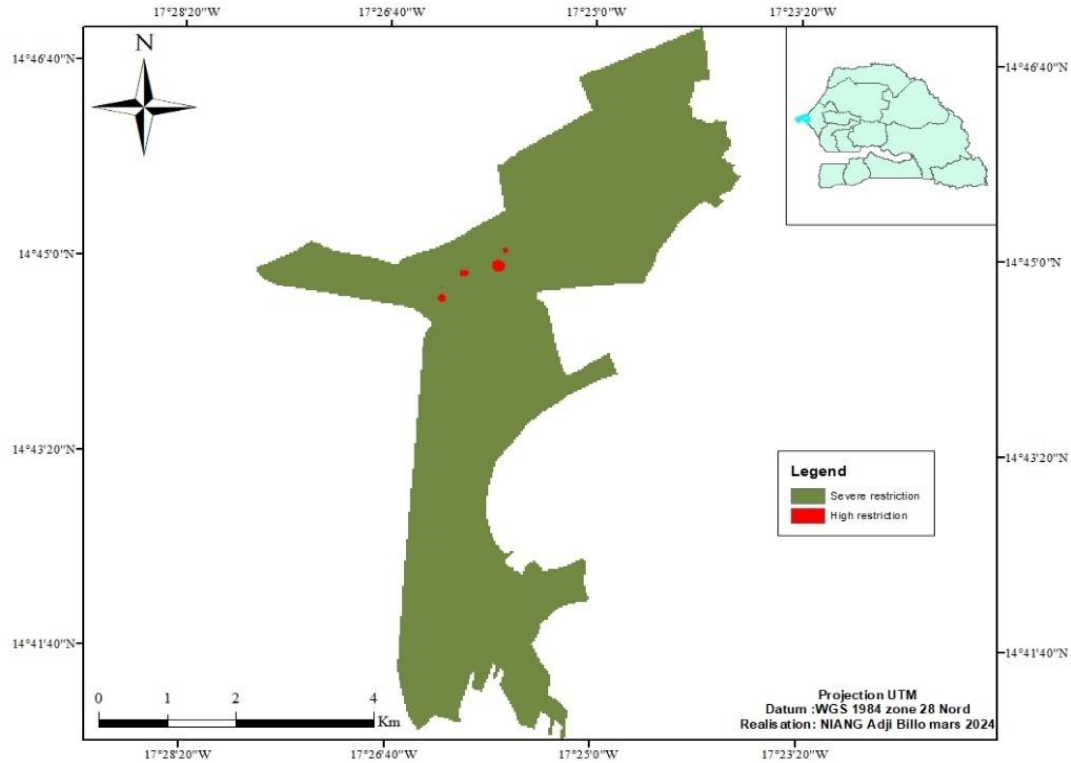


Figure 19: Interpolation of irrigation Water Quality Index using Arcgis

For soil recommendation regarding irrigation water with high restrictions, it is advisable to utilize them in soils characterized by high permeability without compact layers. High-frequency irrigation schedules are recommended for water with an Electrical Conductivity (EC) above 2.000 dS m⁻¹. For instance, P13 is suitable for groundwater, while P17 and P29 are recommended for wastewater irrigation (Rengasamy, 2006; Ayers & Westcot, 1985).

Regarding plant recommendation, such water sources should be employed for plants exhibiting moderate to high tolerance to salts, alongside implementing specific salinity control practices. However, waters with low sodium (Na), chloride (Cl), and bicarbonate (HCO₃) levels (e.g., P6, P7, P8, P13, P14, P17, and P29) require attention due to their low Na and HCO₃ but high Cl content (Rhoades & Loveday, 1990).

For soil recommendation concerning water with severe restrictions, it is generally advisable to avoid its use for irrigation under normal conditions. However, in special cases, occasional

utilization may be considered. Water with low salt levels and high Sodium Adsorption Ratio (SAR) necessitates gypsum application (Ayers & Westcot, 1985). In soils exposed to high saline content water, maintaining high permeability is crucial, and excess water should be applied to prevent salt accumulation (Qadir et al., 2014).

For plant recommendation under such conditions, only plants exhibiting high salt tolerance should be considered, except for waters characterized by extremely low Na, Cl, and HCO₃ values (Grieve & Grattan, 1983).

4.2 INTERPRETATION OF SOIL ANALYSIS

The interpretation of soil analysis was carried out to evaluate the impact of the application of different water use on the soils physical and chemical properties. The general results are shown in appendix.

4.2.1 TEXTURAL TRIANGLE OF THE SOIL

The textural analysis was done in NIP and they are shown that in this study area the soil texture is with more than 90% of sand that's why the soil is very infiltrate.

ZONE DES NIAYES

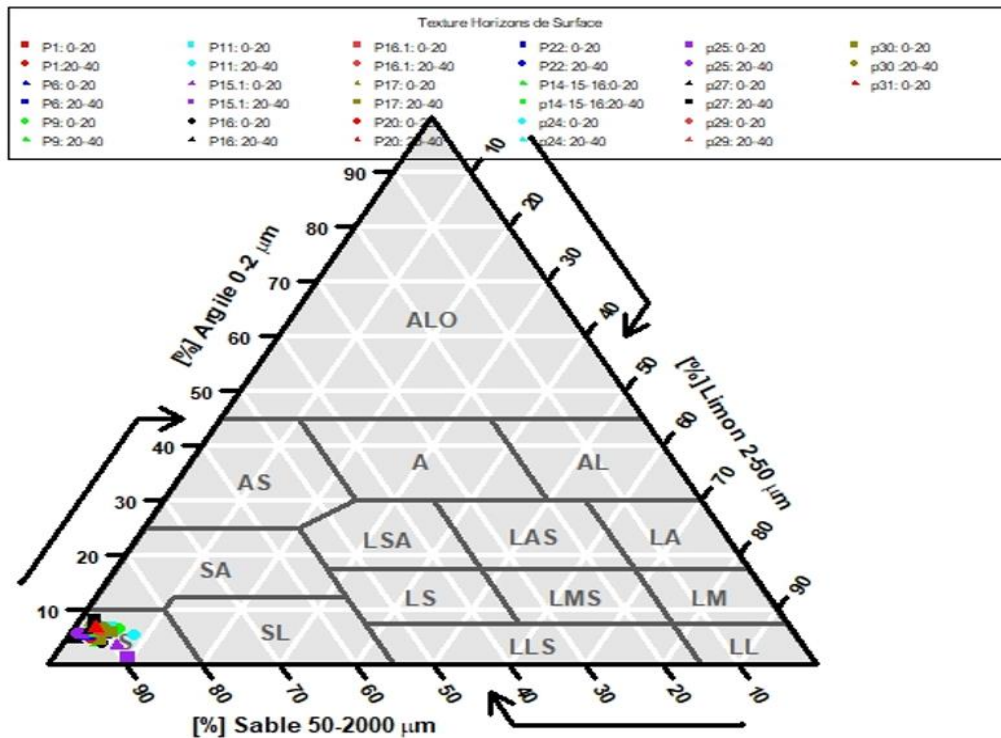


Figure 20: textural triangle of the soils

4.2.2 THE PH

Soils are referred to as being acid, neutral, or alkaline, depending on their pH, with 7 being neutral, below 7 acidic and above 7 alkaline. (FAO, 2021) The pH range normally found in soils varies from 3 to 9. As pH is measured in terms of hydrogen ion activity, pH is thus a measure of only the intensity of H⁺ activity and not the amount of acidity present. The desirable soil pH range for optimum plant growth varies among crops. Generally, a soil pH between 6.0-7.5 is acceptable for most plants, as most nutrients are available in this pH range. However, some plants have soil pH requirements above or below this range. An acidic pH may cause higher mobility of toxic elements potentially leaching into ground water or taken up and accumulated in plants. Additionally, inhibited plant growth may be observed in low pH soils due to aluminum toxicity. In higher pH soils, phosphorus and most micronutrients may become less available. As the pH value of many soils correlates with base saturation, it may also be used in the field for preliminary classification purposes.

Our study reveals a significant decrease in soil pH resulting from irrigation with Treated wastewater and mixed water. Notably, in our study area, mixed water exhibits the lowest pH value recorded at 2.70 (P25: 20-40), indicating an extremely acidic environment. Soil samples irrigated with wastewater and mixed water consistently demonstrate highly acidic pH levels, ranging from 4.5 to 4.6 on average. Conversely, soils irrigated with lake water and groundwater tend to be alkaline. Groundwater exhibits the highest recorded pH value at 9 (P5:20-40; well).

Previous research supports our findings, attributing the decline in soil pH in long-term treated wastewater-irrigated soils to increased mineralization of organic matter (Laurenson et al., 2012), while Xu et al. (2010) suggest that the acidity of applied wastewater contributes to this effect. Overall, the impact of wastewater irrigation on soil pH appears to be influenced by both the initial pH of the wastewater source and the soil's buffering capacity against pH changes (Xu et al., 2010; Laurenson et al., 2012).

Table 9: Assessment of the acidity or alkalinity of the soil according to (Ousmane NDIAYE et al., 2012).

pH	Nature of the soil
<4.5	Extremely acid
4.6-5.2	very acid
5.3-5.5	Acid
5.6-6.0	Moderately acid
6.1-6.6	slightly acid
6.7-7.2	Neutral
7.3-7.9	Slightly alkaline
8.0-8.5	Alkaline
8.5	Very alkaline

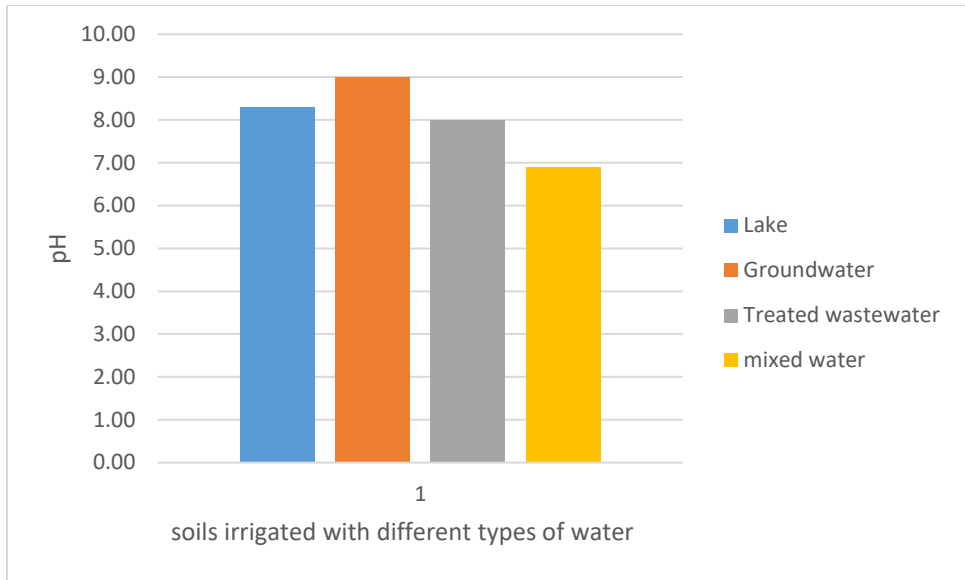


Figure 21: pH values of soil irrigated with the different types of water

4.2.3 THE ELECTRICAL CONDUCTIVITY

study findings indicate that none of the samples exhibit significant salinity, as evidenced by their electrical conductivity (EC) values below 250 $\mu\text{S}/\text{cm}$. Both Treated wastewater and mixed water used for irrigation in the Patte d’oie and Pikine areas of the study zone did not contribute to soil salinity, as they demonstrated the lowest mean EC values compared to those of the lake and groundwater.

However, certain soil samples irrigated with lake water, such as P2: 0-20, P7: 0-20, and P9: 0-20 and 20-40, displayed slight salinity according to Table 13, while others, notably P11: 0-20 and 20-40, exhibited higher levels of salinity, with respective EC values of 264 $\mu\text{S}/\text{cm}$, 451 $\mu\text{S}/\text{cm}$, 470 $\mu\text{S}/\text{cm}$, 413 $\mu\text{S}/\text{cm}$, 603 $\mu\text{S}/\text{cm}$, and 523 $\mu\text{S}/\text{cm}$. This salinity variation can be attributed to the soil texture prevalent in the area.

Soils irrigated with groundwater, particularly P31: 0-20 (from the ceane) and P4 (from a well), also showed slight salinity, with P4: 20-40 displaying saline characteristics. This observation may be attributed to the intrusion of saline water from the marine ocean, affecting both the groundwater and the soil. Notably, P31 displayed EC values of 269 $\mu\text{S}/\text{cm}$, 347 $\mu\text{S}/\text{cm}$, and 526 $\mu\text{S}/\text{cm}$, further highlighting the influence of saline intrusion on soil salinity levels.

On the other hand, the salinization of soils in this zone could be mainly attributed to a rainfall deficit which is the cause of the lowering of the water table and the intrusion of sea water inside the lands.

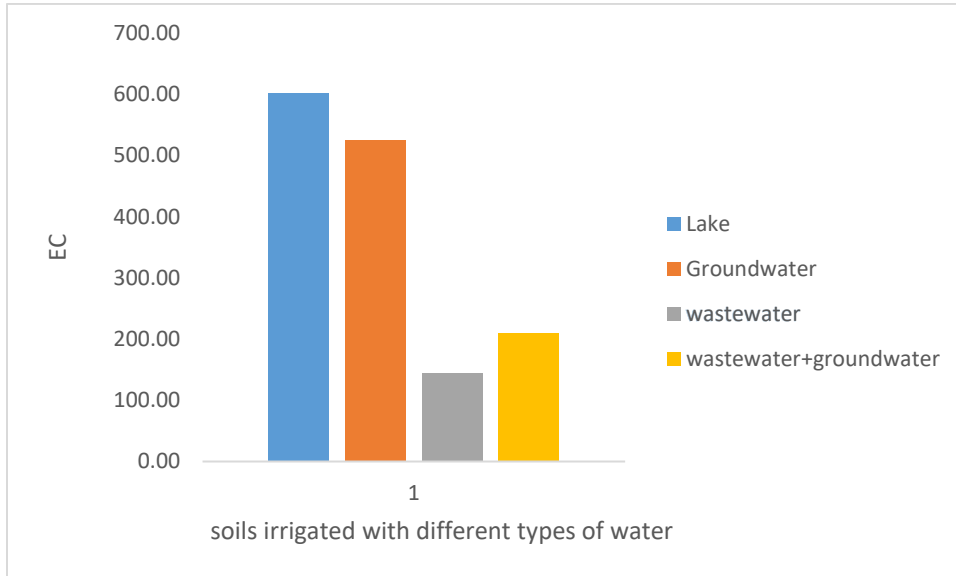


Figure 22: EC of soil irrigated with different water

4.2.4 THE ORGANIC MATTER (OM)

This figure 23 shows that the groundwater and the lake have the highest OM than the wastewater and the mixed, the mixed water and the wastewater have the lowest.

OM content is one of the most important factors that control the accumulation, mobility, and bioavailability of heavy metal(loid)s in wastewater-irrigated soils. Increase in SOM content can lead to increased soil adsorption capacity by which accumulation of heavy metal(loid)s will be enhanced. Qishlaqi and Moore (2007) carried out statistical analysis of the sources and accumulation of heavy metal(loid)s in agricultural soils and noticed that SOM was the most important factor controlling the distribution of heavy metal(loid)s. It was revealed that soil samples with high SOM content accumulated significantly higher concentrations of heavy metal. (Laurenson et al., 2012)

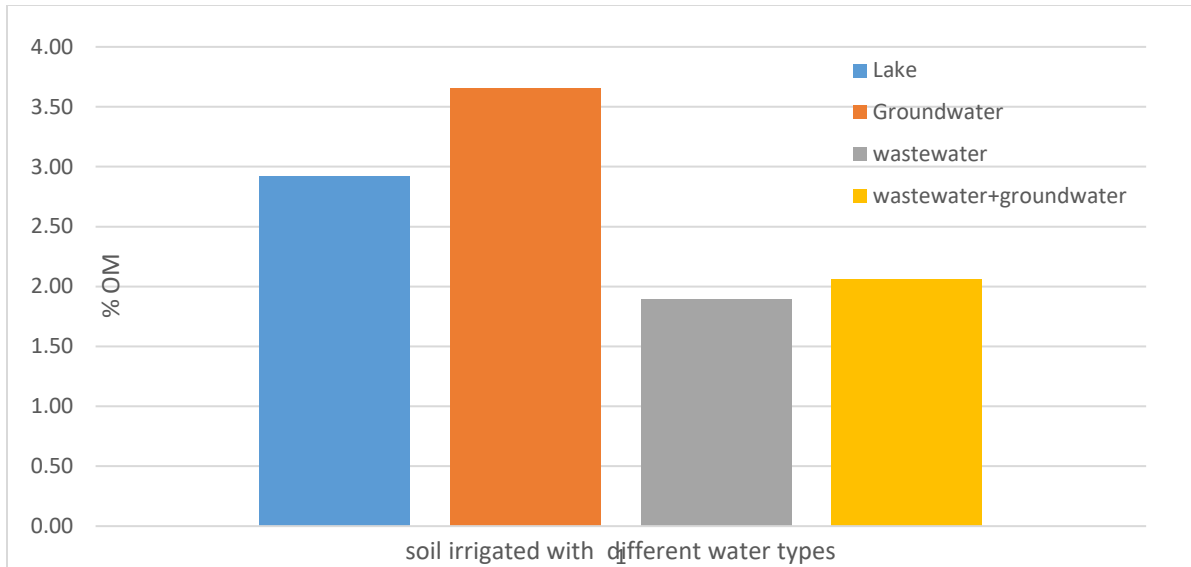


Figure 23: Average % OM of the soil samples.

4.2.5 CARBONE PERCENTAGE

The comparison of Carbone percentage of the soils irrigated with different types of water is represented in the Fig 24. It indicated that the soils irrigated with groundwater have more Carbone percent than the soils irrigated with Treated wastewater and mixed water. It may be the long use of the wastewater which infiltrates on the groundwater.

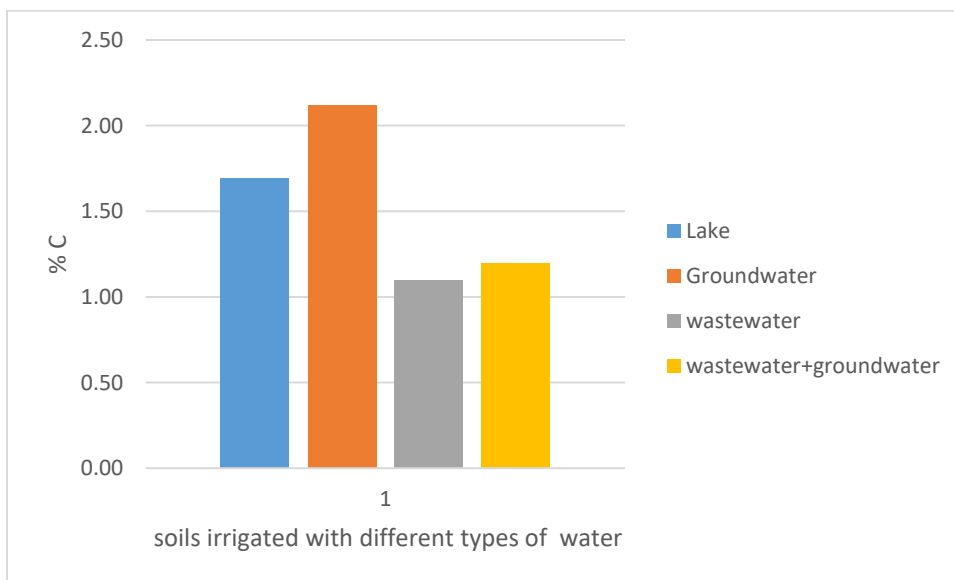


Figure 24: Average of the % Carbone of the soils irrigated with different types water

4.2.6 PLANT NUTRIENT ANALYSIS (N, P, K)

the figures below show the average of N, P and K. it indicates that the soil irrigated with groundwater has more N and P than the soils irrigated with Treated wastewater and mixed. NPK compounds can leach through the soil profile and contaminate groundwater, posing risks to human health and the environment (Keraita et al., 2008). High levels of nitrogen, in particular, can contribute to groundwater nitrate contamination, which has been linked to various health issues, including methemoglobinemia in infants (Diaz et al., 2015). According to (Torres-martínez et al., 2021), Groundwater nitrogen contamination in wastewater irrigated areas is one of the most relevant issues of concern because high nitrate concentrations in groundwater may cause serious human health threats (such as methemoglobinemia in bottle-fed infants) and disrupt multiple water-related environmental services . During WWI, nitrogen enters the system in form of organic matter contained in the sewage. Thus, the organic matter is degraded/oxidized by bacteria in the upper soil horizons and ammonium (NH_4^+) is released from organic nitrogen. Subsequently, part of NH_4^+ is volatilized as ammonia (NH_3) and the rest percolates to lower soil horizons, where heterotrophic nitrification occurs under the influence of nitrifying bacteria. Unreacted NH_4^+ together with nitrite (NO_2^-) and nitrate (NO_3^-) infiltrates into shallow aquifers and their permanence will depend on factors such as pH, dissolved oxygen and dissolved organic carbon (DOC) concentrations, $\text{NO}_3^-/\text{NO}_2^-$ ratios, the redox potential of the system and the presence of selected N transforming bacterial communities such as nitrifying, denitrifying and ammonifying bacteria, among others. Nitrates are also very soluble and can easily be transported through soils and may contaminate aquifers therefore affecting the quality of groundwater(Keraita et al., 2016).

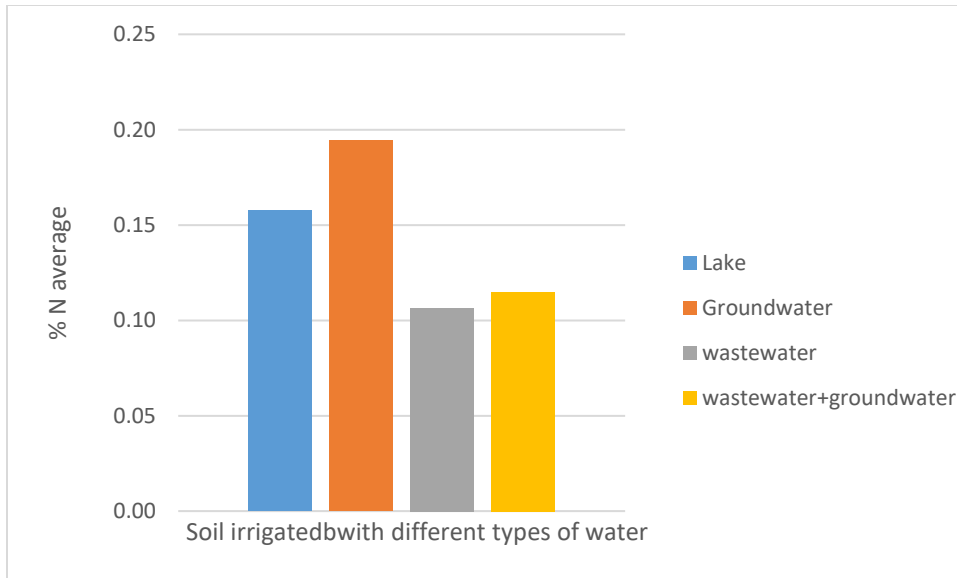


Figure 25: average % N of soils irrigated with different types of water

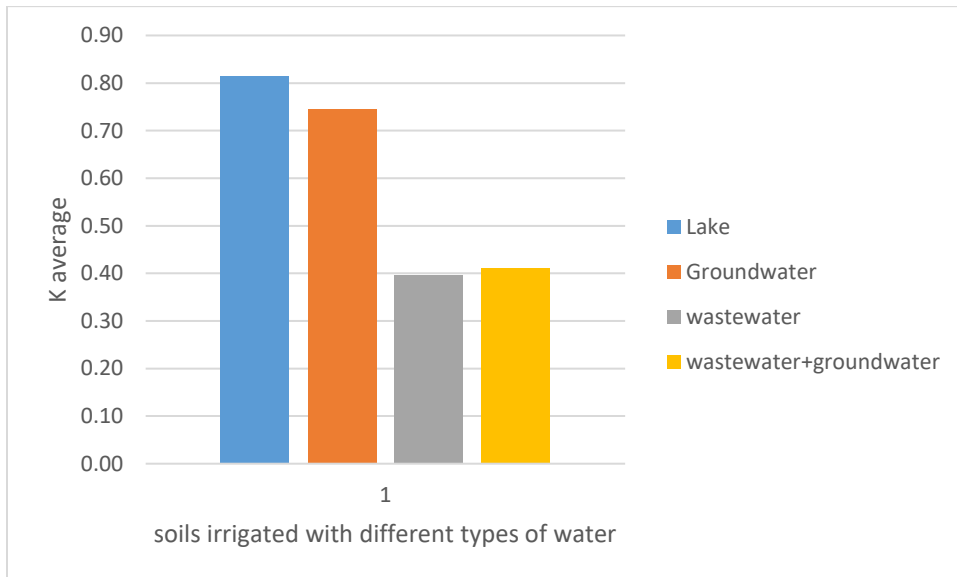


Figure 26: K average of the soils irrigated with different water

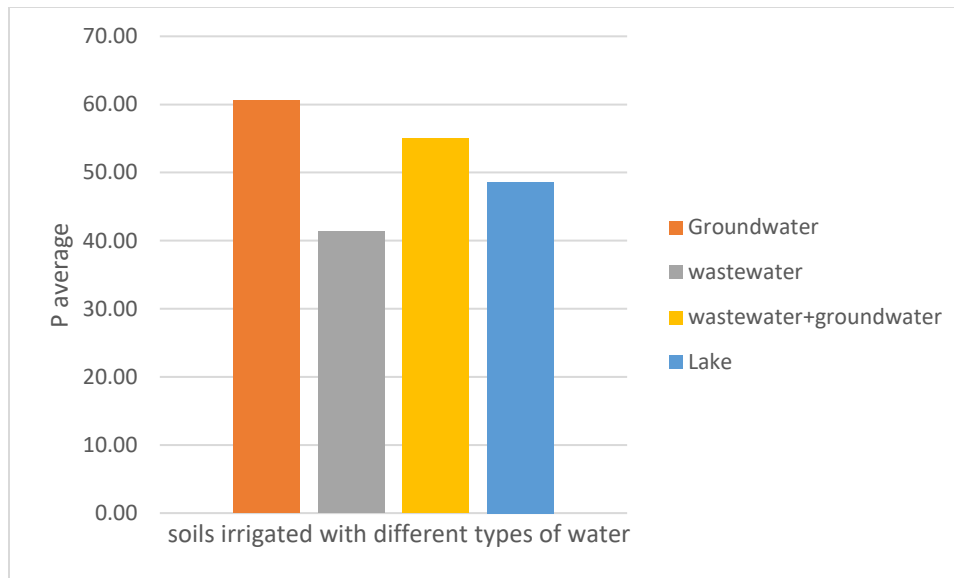


Figure 27: P average of the soils irrigated with the different water

4.2.7 THE CATION EXCHANGE CAPACITY CEC

The figure 28 below shows the EC average of the soils irrigated with different water. It indicates that the Treated wastewater and the mixed wastewater have the highest values in this study area. The study of (Laurenson et al., 2012) shows that A long-term increase in SOM content resulting from wastewater irrigation, which is sometimes accompanied by an increased soil pH, can result in an increase of the CEC (Angin et al., 2005; Falkiner and Smith, 1997). This has been observed, for example, in a 5-year study conducted in Portugal comparing the impact of potable water, primary effluent, and secondary effluent on various chemical parameters including CEC (Marecos do Monte, 1998). Qishlaqi et al. (2008) reported that the CEC of a sandy topsoil that has been irrigated with raw wastewater for about 20years increased by about 880%. Others, however, did not observe a significant increase in CEC in spite of significantly increased SOM contents through wastewater irrigation (Gharaibeh et al., 2007). Madyiwa et al. (2002) studied the effects of combined sewage sludge and effluent application on soil properties of a sandy soil under pasture. The relatively high metal(loid) (Cu, Ni, Pb, and Zn) concentrations within the top 10cm compared to the lower horizons in the irrigated area confirmed the immobility of most heavy metal(loid)s. They argued that considering the lower clay content in top 20cm, the high CEC resulting from high OM content of these layers attributed to metal(loid) immobilization.

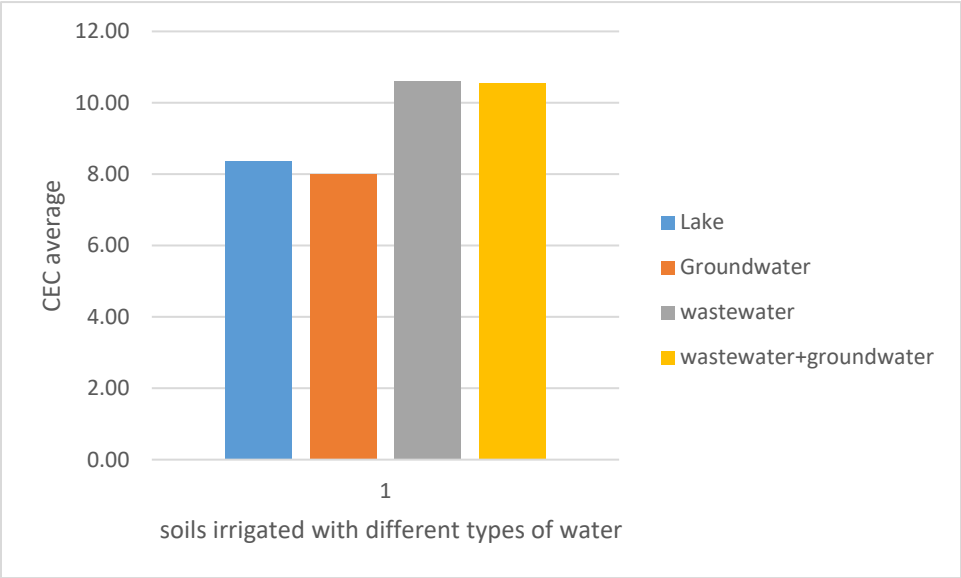


Figure 28: CEC average of the soils irrigated with different types of water

CONCLUSION

Our study reveals a significant impact of irrigation with wastewater on both soil and groundwater quality in the Niayes zone. Groundwater samples exhibited higher salinity levels compared to the wastewater itself, primarily attributed to overexploitation for crop irrigation, leading to salinization and contamination of water tables, particularly those near coastal areas. This phenomenon poses a substantial risk to coastal regions reliant on groundwater for water supply, potentially resulting in marine invasion.

Contrastingly, while Treated wastewater irrigation contributes to an increased salinity due to the shallow water table, local farmers report beneficial effects due to the mitigation of yield reductions from saline groundwater. Soil and groundwater analysis, through indices like SAR, % Na, and PI, suggests suitability for irrigation indicating no significant negative impact on soil structure and groundwater quality due to manageable sodium levels and salinity ratios.

However, concerns arise with Magnesium Hazard and Residual Sodium Carbonate levels, where most samples, including treated wastewater, are deemed inappropriate for irrigation. This could lead to soil alkalization and impact agricultural productivity. Our Irrigation Water Quality Index classifies the waters from high to severe restriction, suggesting caution in their use for irrigation without proper soil permeability conditions.

Supporting evidence from Elizabeth et al. indicates that groundwater quality, as manifested in low WQI scores, is largely compromised by excessive salts and elements often originating from industrial-domestic wastewater seepage and agricultural runoffs. This degraded water quality has not only elevated the soil organic matter, carbon content and nutrients in long-term wastewater-irrigated lands but has also contributed to the overall decline in the water quality index.

Regarding the pH, our study aligns with previous research, which indicates that long-term wastewater irrigation leads to a decline in soil pH. A decrease in soil pH is a consequence of irrigation with treated wastewater and mixed water. Particularly marked is the extreme acidity

observed in our study area, with mixed water recording the lowest pH value at 2.70, indicative of highly acidic conditions. Consistently, soil samples irrigated with treated wastewater and mixed water exhibit pH levels ranging from 4.5 to 4.6 on average respectively, underscoring the acidic impact of these irrigation sources. Conversely, soils irrigated with lake water and groundwater tend to display alkaline pH levels, with groundwater registering the highest recorded pH value at 9. The cumulative effects denote that continual reuse of low-quality treated wastewater for irrigation adversely impacts soil fertility, causing spikes in nitrogen and phosphorus levels and increasing organic matter. This practice leads to deterioration in groundwater quality, reflecting urgent needs for improved wastewater management strategies to ensure sustainable agriculture and water security. Overall, while wastewater irrigation offers potential benefits such as SOM enrichment and enhanced soil fertility, its long-term impacts on soil properties and metal(loid) mobility warrant careful consideration.

Future research should focus on elucidating the mechanisms underlying these observed effects and developing sustainable management practices to mitigate potential risks associated with wastewater irrigation.

RECOMMENDATIONS

This study is very important to develop the irrigation of Dakar and achieve the food security. We should improve quality of the wastewater reuse for irrigation to help the farmers to achieve their goal and reduce the exploitation of the groundwater which increases the salinity.

implement comprehensive wastewater management strategies to minimize the adverse effects of irrigation with wastewater on soil and groundwater quality. This includes proper treatment of the domestic wastewater to reduce the levels of salts, elements, nitrogen, and phosphorus before it is reused for irrigation purposes.

To mitigate these impacts, careful monitoring, and management of wastewater reuse practices including the implementation of effective treatment methods are essential. Furthermore, proper regulation and management of wastewater reuse practices are necessary to protect the groundwater and soil quality in the Dakar Niayes Zone.

Establish a comprehensive monitoring system to regularly test soil and groundwater quality in the Niayes Zone, allowing for timely detection of pollution and degradation.

Consider implementing remediation measures for soils that have already been affected by wastewater use, which may include phytoremediation or the application of amendments that bind contaminants.

Proper management practices, including irrigation scheduling, soil testing, and crop selection, are essential for mitigating potential risks associated with wastewater reuse and optimizing its benefits for soil health and productivity.

Encourage the adoption of sustainable irrigation practices that prioritize the use of treated wastewater with acceptable levels of contaminants. Promote efficient irrigation techniques such as drip irrigation to minimize water wastage and reduce the risk of soil salinization.

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APPENDIX

Table 10: results of the water parameters analysis for the lake

Lake	pH	EC µs/Cm	CO ₃ ²⁻		HCO ₃ ⁻		Cl ⁻¹	
			meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P1	7.3	1334	TRACES	TRACES	7.50	465.00	17.50	621.25
P2	7.4	1185	TRACES	TRACES	7.00	434.00	17.50	621.25
P7	7.2	1761	2.25	108.17	12.25	759.50	16.00	568.00
P8	7.7	1848	2.25	108.17	11.25	697.50	21.50	763.25
P9	7.7	1844	2.00	96.15	11.25	697.50	32.50	1153.75
P11	8.8	755	TRACES	TRACES	10.00	620.00	30.00	1065.00
P12	8.4	3450	TRACES	TRACES	10.50	651.00	40.00	1420.00
Min	7.2	755	2	96.1538462	7	434	16	568
max	8.8	3450.0	2.3	108.2	12.3	759.5	40.0	1420.0
mean	7.8	1739.6	0.9	44.6	10.0	617.8	25.0	887.5
median	7.8	1739.6	0.9	44.6	10.0	617.8	25.0	887.5
Standard deviation	0.6	855.4	1.2	55.8	2.0	123.2	9.2	327.9

Lake	Ca		Mg		Na		K		SO ₄ ²⁻	
	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P1	2.20	44.09	1.50	18.23	1.11	25.46	0.11	4.17	0.06	2.70
P2	3.30	66.13	1.50	18.23	1.62	37.37	0.13	5.27	0.06	2.70
P7	3.80	76.15	1.70	20.66	2.00	45.96	0.20	7.91	0.02	0.90
P8	3.00	60.12	3.50	42.53	2.03	46.79	0.19	7.47	0.04	1.80
P9	3.00	60.12	3.30	40.10	1.97	45.23	0.19	7.36	0.06	2.70
P11	3.70	74.15	1.50	18.23	4.73	108.68	0.16	6.15	TRACES	TRACES
P12	6.90	138.28	6.60	80.19	3.57	82.19	0.46	18.23	TRACES	TRACES
Min	2.2	44.08818	1.5	18.225	1.107	25.46297	0.1064	4.174154	0.018692	0.898634
max	6.9	138.3	6.6	80.2	4.7	108.7	0.5	18.2	0.1	2.7
mean	3.7	74.1	2.8	34.0	2.4	56.0	0.2	8.1	0.0	1.5
median	3.7	74.1	2.8	34.0	2.4	56.0	0.2	8.1	0.0	1.5
Standard deviation	1.5	30.2	1.9	23.0	1.3	29.0	0.1	4.7	0.0	1.2

Table 11: Results of the water parameters analysis for the groundwater

Groundwater	pH	EC µs/Cm	CO ₃ ²⁻		HCO ₃ ⁻		Cl ⁻¹	
			meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P16	7.2	7150	2.5	120.19	3.5	217	61	5325
P3	6.4	3470	TRACES	TRACES	4	248	30	1065
P4	7.7	5490	1.5	72.12	20	1240	35.5	1260.25
P5	7.4	1973	TRACES	TRACES	8	496	32.5	1153.75
P6	7.2	1915	TRACES	TRACES	8	496	27.5	976.25
P10	7.3	1707	2	96.15	13.5	837	26	923
P13	7.5	2180	TRACES	TRACES	6.25	387.5	22.5	798.75
P19	7.2	2720	2.25	108.17	5	310	68	3727.5
P20	7.3	3530	TRACES	TRACES	12.75	790.5	25	887.5
P21	7.2	3170	TRACES	TRACES	11.5	713	28	994
P22	7.2	1970	2	96.15	10	620	28.5	1011.75
P30	7.3	4240	TRACES	TRACES	5.25	325.5	30	1065
Min	6.4	1707	1.5	72.1	3.5	217	22.5	798.8
max	7.7	7150	2.5	120.2	20	1240	68	5325
mean	7.2	3292.9	0.9	41.1	9	556.7	34.5	1599
median	7.25	2945	2	96.2	8	496	29.3	1038.4
Standard deviation	0.3	1656.3	1.1	51.9	4.8	299.9	14.5	1414.2

Groundwater	Ca		Mg		Na		K		SO ₄ ²⁻	
	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P16	12.40	248.50	8.40	102.06	13.86	318.80	0.50	19.66	3.33	159.96
P3	8.40	168.34	10.00	121.50	2.99	68.83	0.32	12.41	0.21	9.88
P4	7.50	150.30	8.50	103.28	16.47	378.84	0.55	21.42	0.39	18.87
P5	5.00	100.20	1.60	19.44	5.58	128.35	0.35	13.62	1.31	62.90
P6	6.10	122.24	1.00	12.15	2.33	53.62	0.37	14.39	0.93	44.93
P10	5.00	100.20	1.50	18.23	1.94	44.51	0.19	7.58	0.09	4.49
P13	4.90	98.20	3.90	47.39	2.70	62.21	0.35	13.62	0.62	29.65
P19	6.20	124.25	5.00	60.75	3.32	76.29	0.46	18.23	0.09	4.49
P20	3.00	60.12	1.00	12.15	1.40	32.29	0.17	6.81	0.56	26.96
P21	5.50	110.22	1.50	18.23	2.23	51.24	0.38	14.94	TRACES	TRACES
P22	6.00	120.24	3.10	37.67	3.17	72.97	0.48	18.67	0.22	10.78
P30	11.50	230.46	3.50	42.53	3.82	87.88	0.61	24.06	0.93	44.93
Min	3.00	60.12	1.00	12.15	1.40	32.29	0.17	6.81	0.09	4.49
max	12.40	248.50	10.00	121.50	16.47	378.84	0.61	24.06	3.33	159.96
mean	6.8	136.1	4.1	49.6	5.0	114.7	0.4	15.5	0.7	34.8
median	6.05	121.24	3.30	40.10	3.08	70.90	0.37	14.66	0.56	26.96

Standard deviation	2.8	55.4	3.2	39.1	4.9	112.8	0.1	5.2	0.9	43.9
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Table 12: Results of the water parameters analysis for the treated wastewater

Treated wastewater	pH	EC $\mu\text{s}/\text{Cm}$	CO_3^{2-}		HCO_3^-		Cl^-	
			meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P14	7.6	1316	TRACES	TRACES	12.50	775.00	25.00	
P17	7.2	2160	TRACES	TRACES	9.25	573.50	15.00	532.50
P23	7	3210	2.50	120.19	10.00	620.00	65.00	2307.50
P24	7.6	2300	TRACES	TRACES	8.75	542.50	13.00	461.50
P28	7.2	2250	1.25	60.10	9.00	558.00	15.00	532.50
P29	7.2	2330	TRACES	TRACES	10.00	620.00	11.00	390.50
Min	7	1316	1.25	60.1	8.8	542.5	11.0	390.5
max	7.6	3210	2.5	120.2	12.5	775.0	65.0	2307.5
mean	7.3	2261	0.625	30.0	9.9	614.8	24.0	844.9
median	7.2	2275	1.875	90.1	9.6	596.8	15.0	532.5
Standard deviation	0.2	601.7	1.0	50.3	1.4	84.7	20.7	819.7

Treated wastewater	Ca		Mg		Na		K		SO_4^{2-}	
	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P14	4.00	80.16	2.00	24.30	5.67	130.42	0.31	12.19	0.02	0.90
P17	5.90	118.24	5.40	65.61	3.88	89.22	0.56	22.08	0.64	30.55
P23	3.00	60.12	1.20	14.58	1.85	42.65	0.23	9.12	0.04	1.80
P24	2.80	56.11	2.20	26.73	1.96	45.03	0.24	9.56	0.36	17.07
P28	2.70	54.11	2.10	25.52	1.81	41.71	0.28	11.09	1.12	53.92
P29	2.50	50.10	2.70	32.81	1.76	40.58	0.31	12.19	1.27	61.11
Min	2.5	50.1	1.2	14.6	1.8	40.6	0.2	9.1	0.0	0.9
max	5.9	118.2	5.4	65.6	5.7	130.4	0.6	22.1	1.3	61.1
mean	3.5	69.8	2.6	31.6	2.8	64.9	0.3	12.7	0.6	27.6
median	2.9	58.1	2.2	26.1	1.9	43.8	0.3	11.6	0.5	23.8
Standard deviation	1.3	26.0	1.5	17.7	1.6	37.2	0.1	4.8	0.5	25.7

Table 13: Results of the water parameters analysis for the mixed water

Mixed water		EC µs/Cm	CO ₃ ²⁻		HCO ₃ ⁻		Cl ⁻¹	
	pH	CE	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P15	7.2	2890	TRACES	TRACES	20	1240	29.5	1047.25
P18	7.2	4450	TRACES	TRACES	4.5	279	52	1846
P25	7.2	2390	TRACES	TRACES	11.25	697.5	12	426
P26	7.2	5280	TRACES	TRACES	5.25	325.5	28	994
P27	7.3	2380	1.25	60.1	10	620	22	781
Min	7.2	2380	1.3	60.1	4.5	279	12	426
max	7.3	5280	1.3	60.1	20	1240	52	1846
mean	7.2	3478	0.3	12	10.2	632.4	28.7	1018.9
median	7.2	2890	1.3	60.1	10	620	28	994
Standard deviation	0	1316	0.6	26.9	6.2	384.9	14.7	522.9

Mixed water	Ca		Mg		Na		K		SO ₄ ²⁻	
	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
P15	2.90	58.12	2.10	25.52	5.45	125.24	0.33	13.07	0.02	0.90
P18	6.00	120.24	3.50	42.53	2.56	58.90	0.51	20.10	0.56	26.96
P25	3.70	74.15	1.50	18.23	1.83	42.02	0.24	9.34	0.47	22.47
P26	10.50	210.42	4.00	48.60	14.90	342.61	0.45	17.47	1.59	76.38
P27	2.80	56.11	1.40	17.01	1.91	43.89	0.25	9.67	0.90	43.13
Min	2.8	56.1	1.4	17.0	1.8	42.0	0.2	9.3	0.0	0.9
max	10.5	210.4	4.0	48.6	14.9	342.6	0.5	20.1	1.6	76.4
mean	5.2	103.8	2.5	30.4	5.3	122.5	0.4	13.9	0.7	34.0
median	3.7	74.1	2.1	25.5	2.6	58.9	0.3	13.1	0.6	27.0
Standard deviation	3.2	65.0	1.2	14.4	5.5	127.6	0.1	4.8	0.6	28.1

Table 14 :Statistical analysis of IWQI

Colonne1	IWQI
Min	0,0
max	49,6
mean	32,3
median	37,5
Standard deviation	13,6

Table 15: results of the soil parameters analysis for the lake

Label	IDS2	pH	CE	%C	MO %	N %	C/N	Ca meq/100g
Lake	P1: 0-20	7.9	56.00	0.53	0.92	0.0616	9	1.125
Lake	P1:20-40	7.9	36.00	0.35	0.61	0.042	8	3.375
Lake	P2: 0-20	7.3	131.00	2.22	3.82	0.203	11	10.5
Lake	P2: 20-40	7.0	264.00	3.10	5.35	0.2786	11	12.225
Lake	P7: 0-20	7.7	451.00	5.76	9.93	0.5082	11	6.375
Lake	P7: 20-40	7.7	192.00	3.99	6.88	0.3556	11	4.875
Lake	P8: 0-20	8.0	54.00	0.98	1.68	0.0952	10	4.875
Lake	P8: 20-40	7.9	57.00	0.09	0.15	0.0238	4	1.875
Lake	P9: 0-20	8.0	470.00	3.55	6.11	0.3164	11	8.85
Lake	P9: 20-40	8.3	413.00	0.09	0.15	0.0196	5	4.65
Lake	P11: 0-20	7.9	603.00	0.89	1.53	0.0882	10	4.35
Lake	P11: 20-40	7.3	523.00	0.53	0.92	0.0574	9	4.2
Lake	P12: 0-20	8.0	97.00	0.98	1.68	0.0952	10	6.75
Lake	P12: 20-40	8.1	65.00	0.62	1.07	0.0644	10	4.275
Lake	max	8.3	603.00	5.76	9.93	0.51	11.34	12.23
Lake	min	7.0	36.00	0.09	0.15	0.02	3.72	1.13
Lake	mean	7.8	243.71	1.69	2.91	0.16	9.33	5.59
Lake	standard deviation	0.4	205.39	1.75	3.02	0.15	2.40	3.12
Lake	median	7.9	161.50	0.93	1.60	0.09	10.15	4.76

Label	IDS2	Mg meq/100g	Na meq/100g	K meq/100g	P ppm	S meq/100g	CEC meq/100g	T %	PSE %
Lake	P1: 0-20	0.75	0.1625	0.21	42.25	2.25	6.00	37.46	2.71
Lake	P1:20-40	2.25	0.7875	0.76	39.09	7.17	6.00	119.48	13.13
Lake	P2: 0-20	3.75	0.2875	0.77	100.30	15.31	9.00	170.08	3.19
Lake	P2: 20-40	4.5	0.45	1.32	80.24	18.49	7.00	264.16	6.43
Lake	P7: 0-20	3.375	0.695	1.65	14.38	12.10	7.00	172.81	9.93
Lake	P7: 20-40	2.25	0.36	1.08	25.91	8.56	7.00	122.33	5.14
Lake	P8: 0-20	2.25	0.195	0.46	48.06	7.78	10.00	77.82	1.95
Lake	P8: 20-40	0.75	0.2225	0.39	35.98	3.24	11.00	29.45	2.02
Lake	P9: 0-20	3	0.76	0.66	47.93	13.27	10.00	132.68	7.60
Lake	P9: 20-40	2.25	0.4325	0.57	54.84	7.91	9.00	87.85	4.81
Lake	P11: 0-20	2.325	0.8425	1.18	31.58	8.69	6.00	144.89	14.04
Lake	P11: 20-40	2.325	0.6525	0.97	27.14	8.14	9.00	90.48	7.25
Lake	P12: 0-20	2.25	0.2125	0.78	59.24	10.00	10.00	99.97	2.13
Lake	P12: 20-40	2.175	0.14	0.62	73.41	7.21	10.00	72.06	1.40
lake	max	4.50	0.84	1.65	100.30	18.49	11.00	264.16	14.04
Lake	min	0.75	0.14	0.21	14.38	2.25	6.00	29.45	1.40
Lake	mean	2.44	0.44	0.82	48.60	9.29	8.36	115.82	5.84
Lake	standard deviation	1.01	0.26	0.39	23.48	4.35	1.78	60.78	4.15
lake	median	2.25	0.40	0.76	45.09	8.35	9.00	109.72	4.97

Table 16: results of the soil parameters analysis for the groundwater

Label	IDS2	pH	CE	%C	MO %	N %	C/N	Ca meq/100g
Groundwater	P3: 0-20	7.30	55.00	5.32	9.17	0.4704	11	2.25
Groundwater	P3: 20-40	7.10	51.00	3.10	5.35	0.2786	11	1.35
Groundwater	P4: 0-20	8.60	526.00	3.55	6.11	0.3164	11	3.375
Groundwater	P4: 20-40	8.30	347.00	1.86	3.21	0.1722	11	0.75
Groundwater	P5: 0-20	7.80	89.00	6.12	10.54	0.539	11	7.5
Groundwater	P5: 20-40	9.00	178.00	0.44	0.76	0.049	9	7.875
Groundwater	P6: 0-20	8.10	77.00	4.88	8.40	0.4354	11	8.625
Groundwater	P6: 20-40	8.00	100.00	0.09	0.15	0.0196	5	3.75
Groundwater	P10 : 0-20	7.00	88.00	0.02	0.03	0.0126	1	5.475
Groundwater	P10 : 20-40	6.80	64.00	1.06	1.83	0.1036	10	3.75
Groundwater	P13:0-20	6.90	75.00	5.32	9.17	0.4704	11	5.625
Groundwater	P13:20-40	7.00	54.00	5.76	9.93	0.5082	11	5.775
Groundwater	P19:0-20	6.90	61.00	0.71	1.22	0.0728	10	0.75
Groundwater	P19:20-40	7.40	69.00	0.39	0.67	0.0448	9	6.75
Groundwater	P20: 0-20	7.70	234.00	0.18	0.31	0.0266	7	6.75
Groundwater	P20: 20-40	7.70	179.00	5.32	9.17	0.4704	11	4.5
Groundwater	P21: 0-20	7.60	39.00	0.09	0.15	0.0196	5	7.125
Groundwater	P21: 20-40	7.70	89.00	0.35	0.61	0.042	8	2.25
Groundwater	P22: 0-20	7.60	52.00	0.44	0.76	0.049	9	1.5
Groundwater	P22: 20-40	7.80	41.00	0.62	1.07	0.0644	10	6.75
Groundwater	P31: 0-20	6.80	269.00	0.71	1.22	0.0728	10	3.75
Groundwater	P31: 20-40	2.90	65.00	0.27	0.46	0.035	8	0.75
Groundwater	max	9.00	526.00	6.12	10.54	0.54	11.35	8.63
Groundwater	min	2.90	39.00	0.02	0.03	0.01	1.41	0.75
Groundwater	mean	7.36	127.36	2.12	3.65	0.19	9.10	4.41
Groundwater	standard deviation	1.16	121.00	2.28	3.94	0.20	2.70	2.56
Groundwater	median	7.60	76.00	0.71	1.22	0.07	9.74	4.13

Table 17: results of the soil parameter

Label	IDS2	pH	CE	%C	MO %	N %	C/N	Ca meq/100g
Treated wastewater	P14.1: 0-20	4.90	48.00	0.71	1.22	0.0728	10	1.5
Treated wastewater	P14.1: 20-40	4.10	48.00	0.35	0.61	0.042	8	1.125
Treated wastewater	P14.2: 0-20	3.20	52.00	0.09	0.15	0.0196	5	6.375
Treated wastewater	P14.2: 20-40	3.10	39.00	0.09	0.15	0.0196	5	0.6
Treated wastewater	P14.3: 0-20	3.20	69.00	3.99	6.88	0.3556	11	0.75
Treated wastewater	P14.3: 20-40	4.00	69.00	1.42	2.44	0.1344	11	1.125
Treated wastewater	P17: 0-20	5.80	79.00	0.67	1.16	0.07	10	2.775
Treated wastewater	P17: 20-40	5.60	49.00	1.24	2.14	0.119	10	1.35
Treated wastewater	P23: 0-20	7.00	66.00	1.77	3.06	0.1638	11	2.25
Treated wastewater	P23: 20-40	8.00	145.00	1.77	3.06	0.1638	11	1.875
Treated wastewater	P24: 0-20	3.00	78.00	5.32	9.17	0.4704	11	0.9
Treated wastewater	P24: 20-40	6.30	143.00	1.33	2.29	0.126	11	3.375

Treated wastewater	P28: 0-20	3.20	60.00	0.09	0.15	0.0196	5	0.75
Treated wastewater	P28: 20-40	3.00	72.00	0.09	0.15	0.0196	5	0.75
Treated wastewater	P29: 0-20	4.70	50.00	0.09	0.15	0.0196	5	0.75
Treated wastewater	P29: 20-40	4.90	36.00	0.09	0.15	0.0196	5	1.125
Treated wastewater	P30: 0-20	4.00	61.00	0.02	0.03	0.0154	1	1.875
Treated wastewater	P30 :20-40	4.50	53.00	0.62	1.07	0.0644	10	0.75
Treated wastewater	max	8.00	145.00	5.32	9.17	0.47	11.31	6.38
Treated wastewater	min	3.00	36.00	0.02	0.03	0.02	1.15	0.60
Treated wastewater	mean	4.58	67.61	1.10	1.89	0.11	7.86	1.67
Treated wastewater	standard deviation	1.48	30.43	1.45	2.50	0.12	3.29	1.41
Treated wastewater	median	4.30	60.50	0.65	1.12	0.07	9.63	1.13

Label	IDS2	Mg meq/100g	Na meq/100g	K meq/100g	P ppm	S meq/100g	CEC meq/100g	T %	PSE %
Groundwater	P3: 0-20	1.125	0.16	0.52	70.55	4.05	6.00	67.55	2.67
Groundwater	P3: 20-40	0.6	0.1125	0.36	54.50	2.43	6.00	40.44	1.88
Groundwater	P4: 0-20	1.95	0.8625	0.87	19.38	7.06	11.00	64.14	7.84
Groundwater	P4: 20-40	0.9	0.2875	0.57	56.34	2.51	9.00	27.91	3.19
Groundwater	P5: 0-20	2.25	0.285	0.84	60.82	10.88	7.00	155.36	4.07
Groundwater	P5: 20-40	3	0.43	1.33	6.15	12.64	12.00	105.29	3.58
Groundwater	P6: 0-20	3.075	0.3775	1.05	30.73	13.13	10.00	131.28	3.78
Groundwater	P6: 20-40	2.625	0.24	0.69	54.63	7.30	10.00	73.01	2.40
Groundwater	P10 : 0-20	3.075	0.2025	0.59	131.88	9.34	7.00	133.44	2.89
Groundwater	P10 : 20-	2.25	0.135	0.52	136.58	6.65	7.00	95.04	1.93

	40								
Groundwater	P13:0-20	3	0.1925	0.49	104.57	9.31	4.00	232.69	4.81
Groundwater	P13:20-40	2.925	0.19	0.56	120.44	9.45	4.00	236.25	4.75
Groundwater	P19:0-20	0.75	0.14	0.50	129.75	2.14	11.00	19.49	1.27
Groundwater	P19:20-40	3	0.1875	0.57	31.92	10.51	9.00	116.79	2.08
Groundwater	P20: 0-20	3.15	0.305	1.02	49.59	11.23	7.00	160.39	4.36
Groundwater	P20: 20-40	2.25	0.3725	1.09	51.86	8.21	7.00	117.35	5.32
Groundwater	P21: 0-20	2.25	0.5275	1.58	48.83	11.48	8.00	143.56	6.59
Groundwater	P21: 20-40	0.75	0.1475	0.71	44.60	3.86	7.00	55.16	2.11
Groundwater	P22: 0-20	0.375	0.3375	0.55	61.89	2.76	8.00	34.48	4.22
Groundwater	P22: 20-40	2.4	0.415	0.91	41.40	10.48	7.00	149.64	5.93
Groundwater	P31: 0-20	6.9	0.49	0.77	19.63	11.91	5.00	238.20	9.80
Groundwater	P31: 20-40	0.75	0.1675	0.28	7.26	1.95	14.00	13.91	1.20
Groundwater	max	6.90	0.86	1.58	136.58	13.13	14.00	238.20	9.80
Groundwater	min	0.38	0.11	0.28	6.15	1.95	4.00	13.91	1.20
Groundwater	mean	2.24	0.30	0.74	60.60	7.69	8.00	109.61	3.94
Groundwater	standard deviation	1.42	0.18	0.32	39.76	3.81	2.54	68.68	2.18
Groundwater	median	2.25	0.26	0.64	53.18	8.76	7.00	111.04	3.68

Label	IDS2	Mg meq/100g	Na meq/100g	K meq/100g	P ppm	S meq/100g	CEC meq/100g	T %	PSE %
Treated wastewater	P14.1: 0-20	0.75	0.1525	0.39	91.34	2.79	8.00	34.93	1.91
Treated wastewater	P14.1: 20-40	0.75	0.145	0.28	100.30	2.30	11.00	20.91	1.32
Treated wastewater	P14.2: 0-20	3.375	0.4775	0.88	70.17	11.11	13.00	85.46	3.67
Treated wastewater	P14.2: 20-40	0.525	0.1625	0.41	86.34	1.69	14.00	12.10	1.16
Treated wastewater	P14.3: 0-20	0.75	0.1775	0.31	10.67	1.99	13.00	15.27	1.37
Treated wastewater	P14.3: 20-40	0.75	0.1675	0.24	47.37	2.28	11.00	20.73	1.52
Treated wastewater	P17: 0-20	0.825	0.1425	0.35	51.56	4.09	9.00	45.47	1.58
Treated wastewater	P17: 20-40	0.825	0.0875	0.36	59.33	2.63	10.00	26.27	0.88
Treated wastewater	P23: 0-20	1.125	0.175	0.70	69.14	4.25	10.00	42.50	1.75

Treated wastewater	P23: 20-40	0.75	0.2175	0.63	59.33	3.47	6.00	57.88	3.63
Treated wastewater	P24: 0-20	0.6	0.18	0.17	11.35	1.85	14.00	13.20	1.29
Treated wastewater	P24: 20-40	0.75	0.3275	0.50	15.28	4.96	7.00	70.81	4.68
Treated wastewater	P28: 0-20	1.875	0.225	0.32	17.24	3.17	13.00	24.40	1.73
Treated wastewater	P28: 20-40	1.125	0.255	0.32	12.51	2.45	14.00	17.51	1.82
Treated wastewater	P29: 0-20	0.375	0.245	0.32	18.69	1.69	9.00	18.80	2.72
Treated wastewater	P29: 20-40	0.75	0.25	0.29	5.38	2.42	8.00	30.24	3.13
Treated wastewater	P30: 0-20	0.375	0.2175	0.31	8.11	2.78	11.00	25.23	1.98
Treated wastewater	P30 :20-40	0.75	0.1925	0.35	10.63	2.04	10.00	20.43	1.93
Treated wastewater	max	3.38	0.48	0.88	100.30	11.11	14.00	85.46	4.68
Treated wastewater	min	0.38	0.09	0.17	5.38	1.69	6.00	12.10	0.88
Treated wastewater	mean	0.95	0.21	0.40	41.37	3.22	10.61	32.34	2.11
Treated wastewater	standard deviation	0.69	0.09	0.18	32.70	2.17	2.50	20.68	1.03
Treated wastewater	median	0.75	0.19	0.34	33.03	2.54	10.50	24.82	1.79

Table 18: Results of the mixed water

Label	IDS2	pH	CE	%C	MO %	N %	C/N	Ca meq/100g
Mixed water	P15.1: 0-20	4.10	53.00	1.42	2.44	0.1344	11	1.125
Mixed water	P15.1: 20-40	4.10	44.00	0.80	1.38	0.0798	10	1.5
Mixed water	P15.2: 0-20	4.60	51.00	0.71	1.22	0.0728	10	2.475
Mixed water	P15.2: 20-40	5.70	43.00	0.89	1.53	0.0882	10	2.625
Mixed water	P16: 0-20	4.70	124.00	1.24	2.14	0.119	10	2.775
Mixed water	P16: 20-40	3.60	90.00	0.53	0.92	0.0574	9	1.125
Mixed water	P16.1: 0-20	4.90	76.00	1.51	2.60	0.1414	11	1.125
Mixed water	P16.1: 20-40	5.30	58.00	0.62	1.07	0.0644	10	0.9
Mixed water	P16.2: 0-20	3.90	105.00	1.05	1.80	0.1022	10	3.6

Mixed water	P16.2: 20-40	3.90	99.00	1.28	2.20	0.1218	10	1.275
Mixed water	P18: 0-20	5.30	211.00	4.43	7.64	0.3934	11	3.525
Mixed water	P18: 20-40	5.70	170.00	6.03	10.39	0.5306	11	3.75
Mixed water	P25: 0-20	2.90	54.00	0.53	0.92	0.0574	9	0.9
Mixed water	P25: 20-40	2.70	46.00	0.02	0.03	0.0154	1	0.75
Mixed water	P26: 0-20	6.40	47.00	0.09	0.15	0.0196	5	1.275
Mixed water	P26: 20-40	6.90	55.00	0.09	0.15	0.0196	5	1.65
Mixed water	P27: 0-20	2.80	59.00	0.09	0.15	0.0196	5	1.125
Mixed water	P27: 20-40	3.00	44.00	0.25	0.43	0.0322	8	0.75
Mixed water	Max	6.90	211.00	6.03	10.39	0.53	11.36	3.75
Mixed water	Min	2.70	43.00	0.02	0.03	0.02	1.15	0.75
Mixed water	Mean	4.47	79.39	1.20	2.06	0.11	8.63	1.79
Mixed water	standard deviation		47.46	1.57	2.70	0.13	2.93	1.04
Mixed water	median	4.35	56.50	0.75	1.30	0.08	9.87	1.28

Label	IDS2	Mg meq/1 00g	Na meq/1 00g	K meq/1 00g	P ppm	S meq/1 00g	CEC meq/100g	T %	PSE %
Mixed water	P15.1: 0-20	0.525	0.1375	0.46	118. 65	2.25	11.00	20.45	1.25
Mixed water	P15.1: 20-40	0.75	0.125	0.45	89.6 3	2.82	11.00	25.66	1.14
Mixed water	P15.2: 0-20	0.75	0.1075	0.49	86.3 4	3.82	9.00	42.47	1.19
Mixed water	P15.2: 20-40	0.75	0.1	0.42	10.6 7	3.90	6.00	64.92	1.67
Mixed water	P16: 0-20	0.75	0.1125	0.34	75.9 7	3.97	9.00	44.15	1.25
Mixed water	P16: 20-40	0.825	0.2025	0.34	66.7 9	2.49	12.00	20.74	1.69
wastewater+ groundwater	P16.1: 0-20	0.75	0.18	0.35	66.5 8	2.41	8.00	30.06	2.25
Mixed water	P16.1: 20-40	0.675	0.155	0.29	74.6 9	2.02	7.00	28.91	2.21

Mixed water	P16.2: 0-20	1.5	0.15	0.42	72.9 8	5.67	11.00	51.55	1.36
Mixed water	P16.2: 20-40	0.825	0.2025	0.39	37.9 9	2.69	11.00	24.50	1.84
Mixed water	P18: 0-20	2.25	0.37	0.83	104. 57	6.97	11.00	63.37	3.36
Mixed water	P18: 20-40	2.325	0.385	0.85	110. 54	7.31	16.00	45.71	2.41
Mixed water	P25: 0-20	0.6	0.2275	0.34	14.2 1	2.06	14.00	14.74	1.63
Mixed water	P25: 20-40	0.375	0.1975	0.24	12.8 0	1.56	15.00	10.40	1.32
Mixed water	P26: 0-20	0.975	0.24	0.25	12.5 1	2.74	6.00	45.70	4.00
Mixed water	P26: 20-40	0.6	0.2975	0.31	12.5 5	2.86	4.00	71.39	7.44
Mixed water	P27: 0-20	0	0.155	0.34	6.15	1.62	15.00	10.77	1.03
Mixed water	P27: 20-40	0.375	0.1725	0.31	15.7 9	1.61	14.00	11.47	1.23
Mixed water	Max	2.33	0.39	0.85	118. 65	7.31	16.00	71.39	7.44
Mixed water	min	0.00	0.10	0.24	6.15	1.56	4.00	10.40	1.03
Mixed water	mean	0.87	0.20	0.41	54.9 7	3.27	10.56	34.83	2.13
Mixed water	standard deviation	0.60	0.08	0.17	39.4 3	1.75	3.47	19.55	1.55
Mixed water	median	0.75	0.18	0.34	66.6 9	2.72	11.00	29.49	1.65