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# The Effect of Senegal River Irrigation Water Quality on Soil Salinization: A Study of the Main Canal of the M'Pourie Plain in Mauritania

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## ABSTRACT

In this study, the Senegal River, being the main source of water, plays a crucial role in the area's agricultural development. Irrigation on the M'Pourie plain using water from the Senegal River is carried out without any prior sanitation control. An evaluation of the quality of irrigation water and its impact on soil salinization in different agricultural plots soil salinity is crucial for the effective utilization of traditional irrigation water over extended periods. Comprehensive physico-chemical analyses were conducted across nine locations on the M'Pourie plain in Rosso during the dynamic seasons of 2021-2023. Nevertheless, a relatively small number of studies have employed soil salinity indexing methods to examine the consequences of river irrigation on soil salinity. The analysis and interpretation of the results obtained were based both on classic methods (average and correlations) and more advanced techniques such as principal component analysis (PCA) and the Piper diagram which allow characterization and a spatial typology of water. Analysis of the Piper diagram highlights the distinction between two groups of water, weakly and moderately mineralized, ranging from 52.22 µS.cm-1 in the dry season to 72.22 µS.cm-1 in the rainy season, presenting a sodium-potassium bicarbonate facies The variability of irrigation water supplies, proves to be important in the functioning of an agro-systems. Two modes of operation have become individualized: the dry phase mode, characterized by very strong mineralization of the water linked to a significant load of dissolved elements, and the wet phase mode, whose water quality is poorly mineralized but shows the impact that its irrigation water can represent in the loading of organic and mineral pollution and the need for strict control of these waters upstream before their agricultural use. The results of this study show the absence of risks of soil salinization in relation to the chemical nature of irrigation water and the impact of agriculture on the M'Pourie plain.

## INTRODUCTION

The global population is rapidly increasing, and water resources are depleting at an alarming rate, especially in countries where light-textured soils predominate in agricultural areas (Abrisham et al. 2018, Albalasmeh et al. 2022). Water shortages are affecting approximately 700 million people in 43 countries, including regions such as India, the US state of California, the North China Plain, and similar arid and semi-arid areas. Over the last two decades, the annual available freshwater quantity per person has declined by more than 20% (FAO 2020, Khaled et al. 2022).

Vast areas of the world are currently facing challenges related to water availability for agricultural purposes. This predicament is a result of various factors, including climate change, and is expected to worsen in the coming years. In arid zones, soil and irrigation water salinity pose significant environmental constraints on agricultural soils (Alvarez & Sanchez-Blanco 2015, Lakhdhar et al. 2008).

Irrigated agricultural production covers only 4% of Sub-Saharan Africa, in stark contrast to 29% in East Asia and 39% in South Asia (World Bank 2010). Irrigation, the artificial supply of water to cultivated plants to enhance production and foster normal development, is crucial in regions facing a water deficit due to factors such as insufficient rainfall, excessive drainage, or a decline in the water table. This technique is particularly essential in arid and semi-arid regions (El Asslouj et al. 2007).

Several reasons underscore the paramount importance of water quality in irrigation: it directly impacts crop yields, soil productivity, and environmental protection. Agronomists and economists responsible for land development in arid and semi-arid zones are actively concerned about the effects of irrigation water quality on crops. Freshwater, with irrigation being the primary consumer, is a vital resource. Agriculture allocates approximately 70% of freshwater resources, with industry utilizing around 20% and domestic use accounting for about 10%. It's crucial to note that these proportions vary significantly from one country to another, resulting in notable disparities (Escudier et al. 2019, Ocde 2010).

Successful and sustainable agriculture hinges on effective irrigation water management (Al-Zu'bi, 2007). Excessive salinity adversely affects the rhizosphere, limiting the natural distribution of plants in their habitat. Semi-arid and arid regions, characterized by intense sunlight and scarce rainfall, exacerbate the salinization of irrigated areas, rendering them unsuitable for cultivation (Denden et al. 2005). The high concentration of salt in arid zone soils poses a significant environmental challenge to agriculture (Baatour et al. 2004).

Mauritania, an arid zone with low rainfall, abundant sunlight, and limited water resources, faces the challenge of managing its scarce water supply. The river's waters are anticipated to be extensively used for both drinking water and irrigation. Despite agriculture contributing only 22.82% to Mauritania's national GDP, the useful agricultural area (UAA) represents less than 0.5% of the national territory, estimated at 502,000 ha (World Bank 2014).

Soil salinization poses a widespread issue in the Senegal River delta, as highlighted by Abidine et al. (2018a) and Ngom et al. (2016). This problem significantly impacts both agricultural production and the quality of irrigation water, as indicated by Abidine et al. (2018b), Asfaw et al. (2018), Elgettafi et al. (2011), Elhag (2016), and Yao & Yang (2010). The indicator widely utilized to assess soil salinity is electrical conductivity. The consequences of salinization include a reduction in arable land and a decline in soil quality, as noted by Gorji et al. (2017), Seyedmohammadi et al. (2016), and Tripathi et al. (2015).

Our study focuses on the M'Pourie plain, located in the upper Senegal River delta at Rosso. Covering an area of 1500 Ha, this pilot farm, established in the 80s for agricultural purposes, includes the main canal. The supply of irrigation water in the main canal of the M'Pourie plain emerges as a decisive factor in agricultural production, influencing both crop intensification and the expansion of irrigated areas.

This study aims to evaluate the impact of irrigation water quality from the Senegal River on soil salinization in the M'Pourie plain by monitoring several chemical tracers at the level of irrigation water and sediments from

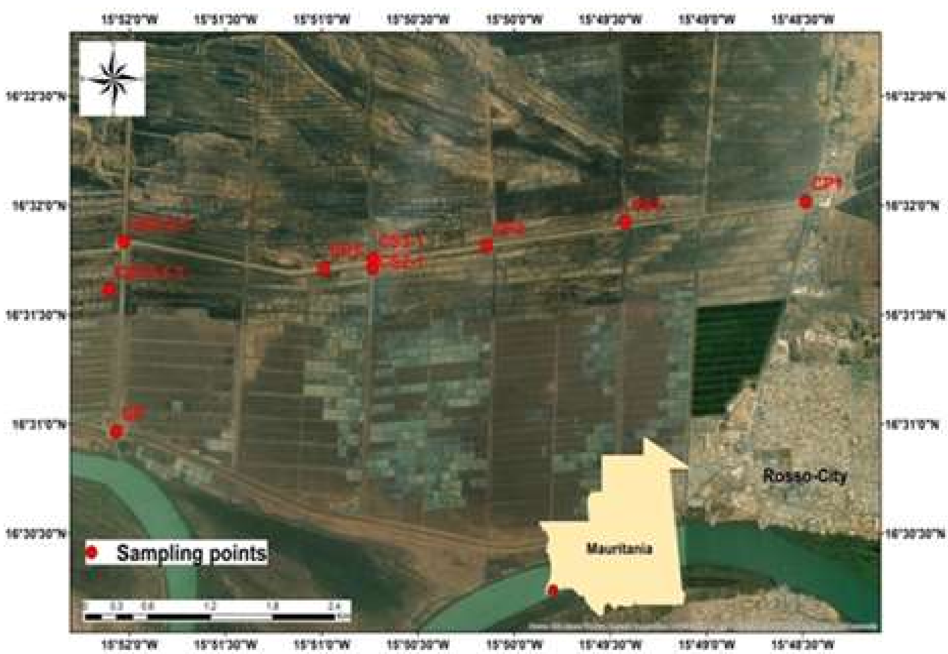


Fig. 1: Map of water sampling sites.

several sampling points. A multivariate analysis (principal component analysis) and the Piper diagram were used to confirm the results obtained.

The scientific and socio-economic interest of this study is to verify whether the use of inputs and, more specifically, appropriate irrigation are the main factors that condition the good agricultural use of soil and its impact on agricultural yield.

## MATERIALS AND METHODS

### Study Area

This study was carried out on the M'Pourie plain in Rosso (Trarza) in southern Mauritania, a pilot farm created in the 1980s and including a machinery department and a pumping station from the Senegal River valley. It covers an area of 1,500 hectares divided into three brigades belonging to the M'Pourie plain and 850 hectares belonging to the cooperatives. The Trarza region lies between latitudes 16°30 and 18°30 and longitudes 14° and 16°, with a surface area of 33,000 $km^2$. The M'Pourie Plain is an area of intense agricultural activity. In this study, 9 sampling sites on the main canal along the M'Pourie were selected for irrigation water assessments, and 03 sites for soil assessments (Fig. 1 & 2).

### Sampling

Samples were collected on the M'Pourie plain at nine sampling sites on both banks of the main M'Pourie canal, with four sites in the middle of the canal (SP, CP3, CP2, CP1), four on the left bank (CST3-1-1, CS3-2-1, CS3-1, CS1) and one on the right bank (CS2-1). Sampling sites were located 100 m apart. Soil samples were taken on the M'Pourie plain at flow (S1), in the middle (S2), and at the end (S3). Samples were extracted from the initial 20 cm layer, and the coordinates of each sampling point were captured using a handheld GPS device (Garmin 78). Samples were taken during the last two years, 2021-2023, as follows:

To collect the samples, we used one-liter plastic bottles, which we immersed in the canals to collect a sufficient quantity. The bottles were then hermetically sealed and stored

| | |
|---|---|
| Main channel 1 | CP 1 |
| Main channel 2 | CP 2 |
| Main channel 3 | CP 3 |
| Secondary channel 1 | CS 1 |
| Secondary channel 2 | CS 2 |
| Secondary channel 2-1 | CS2 1 |
| Secondary channel 3-1 | CS3 1 |
| Secondary channel 3 2-1 | CS3 2-1 |
| Tertiary, secondary canal 3 1-1 | CST3 1-1 |
| Pumping station | SP |
| Soil1 | S1 |
| Soil2 | S2 |
| Soil3 | S3 |

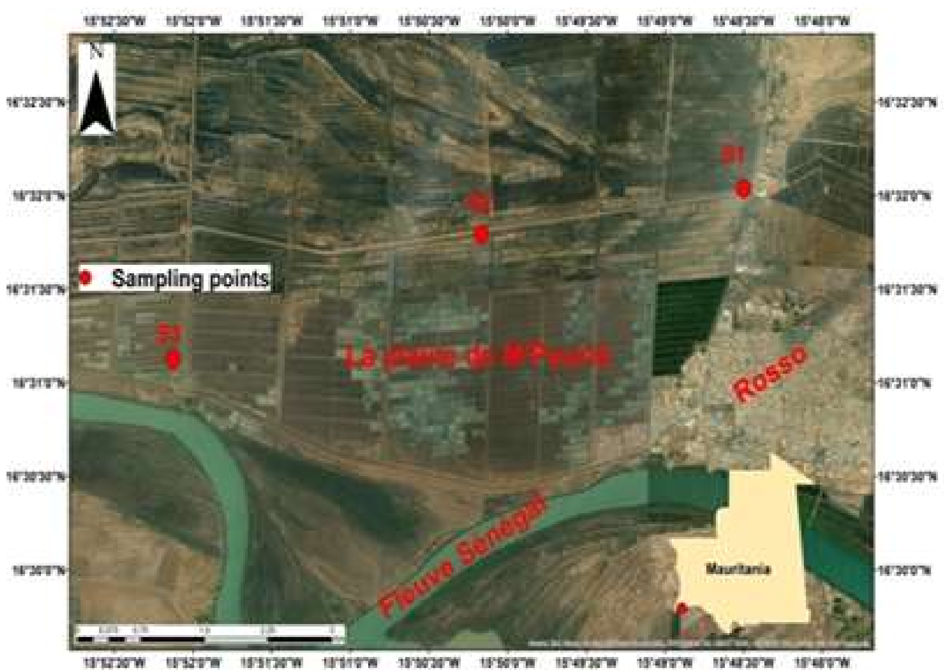


Fig. 2: Map of soil sampling sites.

Table 1: Average physicochemical quality at the study site in the wet and dry seasons.

| | Dry season | | | Rainy season | | | NORMES | |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Moy | Min | Max | Moy | Morocco | FAO |
| pH | 6.9 | 8.41 | 7.51 | 6.61 | 7.39 | 7.08 | 6.5 -8.4 | 6.5 -8.4 |
| T [°C] | 29.1 | 29.5 | 29.16 | 29.8 | 29.9 | 29.84 | 35°C | |
| Ce [ $\mu s.cm^{-1}$] | 50 | 60 | 52.22 | 70 | 80 | 72.22 | 8700 | < 750 |
| TDS [$mg.L^{-1}$] | 23.80 | 28.57 | 24.86 | 33.33 | 38.09 | 34.38 | -- | -- |
| $Ca^{2+}$ [$mg.L^{-1}$] | 3.2 | 8.81 | 6.49 | 24.04 | 98.30 | 54.02 | -- | -- |
| $Mg^{2+}$ [$mg.L^{-1}$] | 1.91 | 4.86 | 3.28 | 1.94 | 44.37 | 10.37 | -- | -- |
| $Cl^-$ [$mg.L^{-1}$] | 24.85 | 31.95 | 28.00 | 25 | 32 | 25.27 | 350 | < 142 |
| $NH_4^+$ [$mg.L^{-1}$] | 0.17 | 0.93 | 0.41 | 0.10 | 0.34 | 0.20 | -- | -- |
| $SO_4^{2-}$ [mg.L] $^{-1}$ | 4 | 90 | 33 | 12 | 80 | 34.22 | 250 | -- |
| N [$mg.L^{-1}$] | 0.35 | 4.15 | 1.56 | 0.20 | 32 | 13.36 | -- | -- |
| $HCO_3^-$ [$mg.L^{-1}$] | 42.7 | 79.3 | 61 | 45 | 80 | 61.55 | 518 | < 91.5 |
| $Na^+$ [$mg.L^{-1}$] | 18 | 21 | 19.44 | 24 | 28 | 25.88 | 69 | -- |
| $K^+$ [$mg.L^{-1}$] | 2 | 6 | 4.22 | 4 | 8 | 6.22 | -- | -- |
| $NO_3^-$ [$mg/L^{-1}$] | 1.54 | 18.26 | 6.89 | 0.04 | 7.27 | 3.03 | 50 | 5.0-30 |
| $NO_2^-$ [$mg.L^{-1}$] | 1.15 | 13.69 | 5.16 | 0.06 | 9.45 | 3.15 | -- | -- |

at 4°C for analysis (Rodier J., 2009). Analyses were carried out in the laboratory of the Water-Pollution-Environment unit of the FST of the University of Nouakchott.

### Analytical Methods

Various physicochemical parameters were measured, including temperature (T), hydrogen potential (pH), electrical conductivity (EC), total dissolved solids (TDS), magnesium, sodium, sulfate, potassium, calcium, bicarbonate, chloride, nitrogen, ammonium, nitrate, and nitrite.

The Hanna HI 9024 pH meter was used to measure temperature and hydrogen potential, while the Hanna HI 8733 conductivity meter was employed for electrical conductivity (E.C.) measurements.

To determine chloride ($Cl^-$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), and bicarbonates ($HCO_3$), Mohr's volumetric method was used, as described by P. Jagals et al. (1997).

Nitrates ($NO_3^-$), nitrites ($NO_2^-$), ammonium ($NH_4^+$), and sulfates ($SO_4^{2-}$) were measured using a UV-visible spectrophotometer (WEG 7100). Sodium ($Na^+$) and potassium ($K^+$) were determined using a Corning-type flame photometer.

## RESULTS AND DISCUSSION

### Assessment of River Water Quality in the M'Pourie Plain

The results obtained from measuring various quality parameters of irrigation water at M'Pourie are represented in Table 1.

In Mauritania, no established regulations exist outlining water quality standards for irrigation. Consequently, we benchmarked the obtained results against the standards set by Morocco and the Food and Agriculture Organization (FAO). State of average physicochemical quality at the study site in wet and dry seasons as illustrated in Table 1.

During the dry season, the surface waters of the M'Pourie plain exhibit pH values ranging between 6.9 and 8.41. Similarly, in the rainy season, pH varies from 6.61 to 7.39. It is noteworthy that, in all instances, the pH values closely approach neutrality. The seasonal variation in pH does not surpass the standards set by Moroccan or FAO. These findings align with those reported by Bouaroudj et al. (2019). Furthermore, the pH values obtained are lower than those reported by Al-Zu'bi (2007).

The recorded results indicate that the temperature fluctuates between 29.1°C and 29.5°C during the dry season and between 29.8°C and 29.9°C during the rainy season in the studied waters. Notably, there is no significant variation in temperature between these two sampling periods. It is essential to highlight that these results comply with both Moroccan regulations and FAO standards. However, they surpass the temperatures documented in the study conducted by Bouaroudj et al. (2019).

In the M'Pourie plain, surface water displays limited mineralization with electrical conductivity levels ranging from 50 $\mu s.cm^{-1}$ to 60 $\mu s.cm^{-1}$ in the dry season and 70 $\mu s.cm^{-1}$

to 80 µs.$cm^{-1}$ in the rainy season. These conductivity values are lower than those reported by Bouaroudj et al. (2019). Additionally, it is worth noting that conductivity is higher during the rainy season compared to the dry season. An analysis of the temporal distribution of electrical conductivity reveals a specific increase during the rainy period.

Total Dissolved Solids (TDS) values in the dry season fluctuate between 23.80 mg.$L^{-1}$ and 28.57 mg.$L^{-1}$, while in the rainy season, they range from 33.33 mg.$L^{-1}$ to 38.09 mg.$L^{-1}$. These readings fall within the established limits of Moroccan and FAO standards and are lower than those documented by Kahimba et al. (2016). This observation suggests that the Senegal River water used for irrigation exhibits relatively low mineralization, indicating a comparatively low mineral content.

Sulfate concentrations in the examined waters vary significantly between the dry and rainy seasons. During the dry season, the waters exhibit sulfate levels ranging from 4 mg.$L^{-1}$ to 90 mg.$L^{-1}$, while in the rainy season, they fluctuate between 12 mg.$L^{-1}$ and 80 mg.$L^{-1}$. Researchers (Bouaroudj et al. 2019) documented higher concentrations than those observed in this study. Agricultural activities are likely responsible for the elevated sulfate values observed in the study area, with the primary source of sulfate in the surface waters of the M'Pourie plain being the presence of secondary formations, particularly gypsum. It is noteworthy that these concentrations fall within the acceptable limits established by Moroccan standards.

Chloride values range between 24.85 mg.$L^{-1}$ and 31.95 mg.$L^{-1}$ during the dry season and between 25 mg.$L^{-1}$ and 32 mg.$L^{-1}$ during the rainy season. Both Moroccan regulations and the FAO standard comply with these values. The observed bicarbonate values vary between 42.70 mg.$L^{-1}$ and 79.30 mg.$L^{-1}$ during the dry season and between 45 mg.$L^{-1}$ and 80 mg.$L^{-1}$ during the rainy season. It should be noted that these values are within the limits set by Moroccan regulations.

This study reports calcium levels of 3.20 mg.$L^{-1}$ and 8.81 mg.$L^{-1}$ during the dry season and 24.04 mg. L and 98.3 mg.$L^{-1}$ during the rainy season. Good quality irrigation water typically contains calcium concentrations ranging from 20 to 400 mg. $L^{-1}$ (Rodier J.2009). Magnesium values are 1.91 mg.$L^{-1}$ and 4.86 mg.$L^{-1}$ in the dry season, 1.94 mg.$L^{-1,}$ and 44.37 mg.$L^{-1}$ in the rainy season.

In the dry season, sodium and potassium levels respectively measure 18 mg.$L^{-1}$ and 21 mg.$L^{-1}$, while in the rainy season, they measure 24 mg.$L^{-1}$ and 28 mg.$L^{-1}$. Additionally, in the dry season, sodium and potassium levels are 2 mg.$L^{-1}$ and 6 mg.$L^{-1}$, whereas in the rainy season, they are 4 mg.$L^{-1}$ and 8 mg.$L^{-1}$.

The examination of nitrogen compounds reveals notable concentrations, with some exceeding Moroccan standards. Nitrate levels vary between 1.54 mg.$L^{-1}$ and 18.26 mg.$L^{-1}$ in the dry season and 0.04 mg.$L^{-1}$ to 7.27 mg.$L^{-1}$ in the rainy season, aligning with Moroccan regulations. During the dry season, nitrite levels range from 1.15 mg.$L^{-1}$ to 13.69 mg.$L^{-1}$, and in the wet season, from 0.06 mg.$L^{-1}$ to 9.45 mg.$L^{-1}$, with the highest values observed in the dry season. Mounjid et al. (2014) documented similar nitrite concentrations.

Ammonium concentrations display seasonal fluctuations, measuring 0.17 mg.$L^{-1}$ to 0.93 mg.$L^{-1}$ in the dry season and 0.10 mg.$L^{-1}$ to 0.34 mg.$L^{-1}$ in the rainy season. The elevated concentrations may be attributed to excessive fertilizer use in agricultural regions.

**Typology of the Upper Senegal River Delta by ACP**

To exploit all the physicochemical results obtained at the study site (Table 2), a multivariate analysis (Principal Component Analysis) was used. The matrix used includes analyses carried out in the wet phase (h) and the dry phase (s).

This method enables the statistical exploration of complex quantitative data by reducing its dimensionality. It transforms the data from a multi-dimensional (more complex) space into a much smaller one, typically two dimensions. The goal is to retain as much information as possible about the dispersion of the data while simplifying its representation (Jollifie 2002, Besse 1992).

Table 3 and Fig. 3 show the factorial axes deduced from the application of the PCA method. Only the first three factors will be considered. They express 81.3% of the total variance, of which 44.6 % is represented by F1, 25% by F2, and 11.65% by F3.

Fig. 4 shows the projection circle of the variables measured in the F1 and F2 factor space of the PCA. It illustrates the organization of the variables into two main groups. The first group is located in the positive part of F1 and strongly correlated with T, TDS, EC, TU, $TH^-$, $Ca^{2+}$, $Mg^{2+}$, and $Cl^-$. It defines a mineralization gradient increasing from left to right during the hot season with a significant contribution of chlorides, calcium, and a strong presence of dissolved substances.

The second group is situated in the positive part of F2 correlated with CuT, $NH_4^+$, $SO_4^+$, and $NO_3^-NO_2^-$. This axis defines a gradient of enrichment in nutrient substances, particularly nitrogenous elements and total copper. It represents an enrichment linked to agricultural activities and the use of fertilizers and a powerful fungicide, copper sulfate.

Table 2: Physico-chemical data matrix for PCA analysis.

| code | stations | pH | T | Cs | TDS | Tur | TH | Ca2+ | Mg | Cl- | CuT | Mn | NH4+ | SO4+ | NT | $HCO_3^-$ | Na+ | K+ | $NO_{3-}^-$ | $NO_{2-}^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | °C | µs.cm$^{-1}$ | mg.L$^{-1}$ | NTU | °F | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | Mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ | mg.L$^{-1}$ |
| E1s | CP1 | 7.11 | 30 | 70 | 33 | 489 | 14 | 64 | 4.4 | 32 | 2.3 | 0.001 | 0.13 | 39 | 10.15 | 67 | 25 | 5 | 2.3 | 3.0 |
| E2s | CS1 | 7.39 | 30 | 80 | 38 | 54 | 20 | 39 | 4.8 | 29 | 0.75 | 0.02 | 0.1 | 19 | 32 | 62 | 27 | 7 | 7.3 | 1.7 |
| E3s | CP2 | 7.25 | 30 | 70 | 33 | 681 | 4 | 32 | 9.7 | 25 | 2.2 | 0.11 | 0.2 | 37 | 3 | 63 | 26 | 7 | 0.7 | 0.9 |
| E4s | CS2 | 7.03 | 30 | 70 | 33 | 649 | 24 | 88 | 4.9 | 26 | 0.47 | 0.03 | 0.21 | 15 | 5.55 | 65 | 28 | 8 | 1.3 | 1.7 |
| E5s | CP3 | 7.17 | 30 | 70 | 33 | 797 | 10 | 34 | 2.9 | 29 | 3.95 | 0.03 | 0.34 | 80 | 31.2 | 80 | 25 | 5 | 7.1 | 9.5 |
| E6s | CS3 1 | 6.99 | 30 | 70 | 33 | 837 | 10 | 46 | 2.9 | 28.5 | 0.62 | 0.013 | 0.32 | 25 | 11.1 | 55 | 24 | 4 | 2.5 | 3.4 |
| E7s | CS3 2-1 | 7.14 | 30 | 70 | 33 | 870 | 7 | 24 | 1.9 | 29 | 0.49 | 0 | 0.31 | 16 | 17.55 | 55 | 25 | 5 | 4.0 | 5.3 |
| E8s | CST3 1-1 | 7.03 | 30 | 80 | 38 | 383 | 22 | 59 | 17.5 | 29 | 4.05 | 0.021 | 0.11 | 65 | 9.55 | 62 | 26 | 7 | 2.2 | 2.9 |
| E9s | SP | 6.61 | 30 | 70 | 33 | 77 | 149 | 98 | 44.4 | 29 | 0.26 | 0.02 | 0.14 | 12 | 0.2 | 45 | 27 | 8 | 0.0 | 0.1 |
| E1h | CP1 | 8.41 | 29 | 50 | 24 | 107 | 1.1 | 1.1 | 0 | 0.9 | 1.25 | 1.12 | 0.26 | 0.26 | 0.2 | 67.1 | 18 | 2 | 3.5 | 2.6 |
| E2h | CS1 | 7.71 | 29 | 60 | 29 | 35 | 1.8 | 1.1 | 0 | 0.8 | 0.4 | 0.26 | 0 | 17 | 0 | 61 | 19 | 4 | 5.5 | 4.1 |
| E3h | CP2 | 7.66 | 29 | 50 | 24 | 104 | 1.4 | 0.4 | 0 | 0.7 | 1.3 | 1.28 | 0.49 | 37 | 0.37 | 61 | 18 | 5 | 8.6 | 6.4 |
| E4h | CS2 | 7.42 | 29 | 50 | 24 | 30 | 1.4 | 0.6 | 0 | 0.7 | 0.28 | 0.28 | 0.17 | 8 | 0.13 | 67.1 | 21 | 6 | 1.5 | 1.2 |
| E5h | CP3 | 7.37 | 29 | 50 | 24 | 403 | 1.4 | 0.8 | 0 | 0.8 | 2.9 | 1.32 | 0.93 | 90 | 0.73 | 79.3 | 20 | 5 | 18.3 | 13.7 |
| E6h | CS3 1 | 7.45 | 29 | 50 | 24 | 36 | 1.6 | 0.6 | 0 | 0.8 | 0.42 | 0.52 | 0.18 | 20 | 0.13 | 54.9 | 21 | 2 | 1.8 | 1.3 |
| E7h | CS3 2-1 | 7.27 | 29 | 50 | 24 | 26 | 1.3 | 0.9 | 0 | 0.8 | 0.3 | 0.42 | 0.24 | 14 | 0.18 | 54.9 | 18 | 4 | 3.1 | 2.3 |
| E8h | CST3 1-1 | 6.9 | 29 | 60 | 29 | 289 | 1.5 | 0.9 | 0 | 0.8 | 2.95 | 3.65 | 0.78 | 69 | 0.6 | 61 | 21 | 5 | 15.0 | 11.2 |
| E9h | SP | 7.41 | 29 | 50 | 24 | 35 | 1.4 | 0.9 | 0 | 0.8 | 0.18 | 0.16 | 0.32 | 4 | 0.24 | 42.7 | 19 | 5 | 4.8 | 3.6 |

Table 3: Eigenvalues.

| | F1 | F2 | F3 |
|---|---|---|---|
| Valeur propre | 8.5 | 4.75 | 2.21 |
| Variabilité (%) | 44.6 | 25.00 | 11.65 |
| % cumulé | 44.6 | 69.63 | 81.29 |

In the projection of observations from 9 sites and 2 climatic periods onto the F1XF2 factorial plane, two water groups can be distinguished (Fig. 5).

This spatio-temporal typology represents the individualization of two operating models of this agrosystem. During the dry phase, this environment records a very strong mineralization linked to a drop in water supply, causing solubilization of cations such as calcium and magnesium and anions such as chlorides.

In the phase of a significant supply of water from the river, the environment records a great dilution of the water, causing a drop in mineralization. This decline is accompanied by a water supply of organic nitrogen and mineral pollution, particularly copper, which is generally used as a fungicide.

This presence could represent a risk of an accumulation of this element in the sediments and organisms present in this agrosystem (Eijsackers et al. 2005).

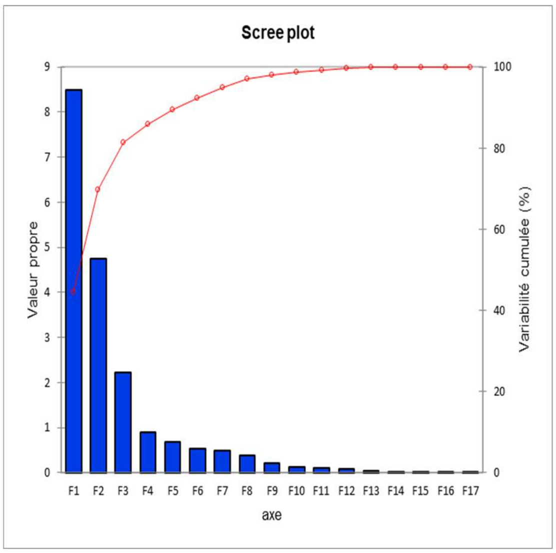


Fig. 3: Distribution of inertia between axes (PCA).

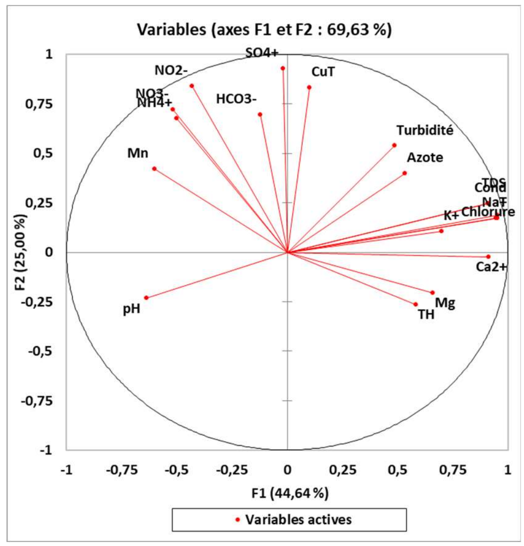


Fig. 4: correlation circle for variables on the F1XF2 factorial axis.

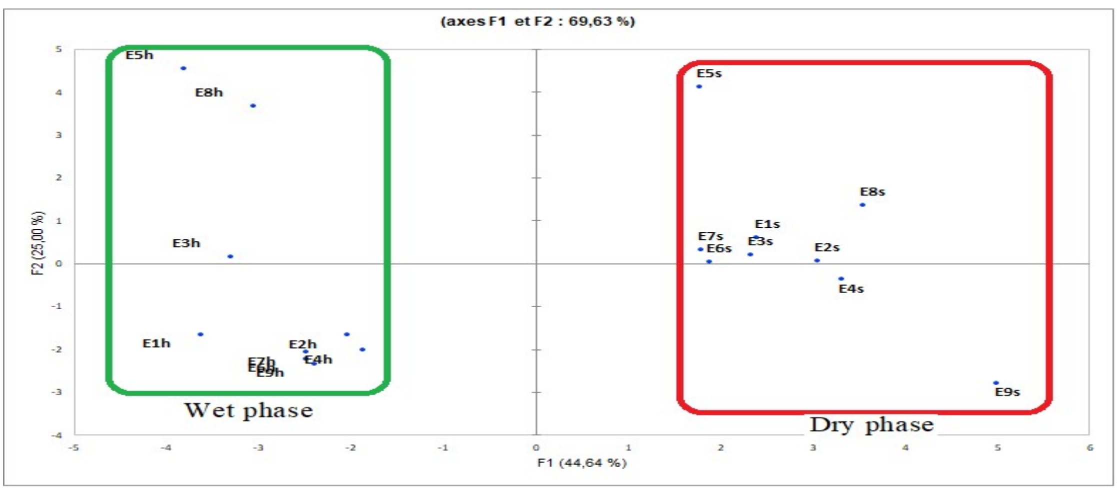


Fig. 5: Projection of individuals on the F1XF2 factorial axis.

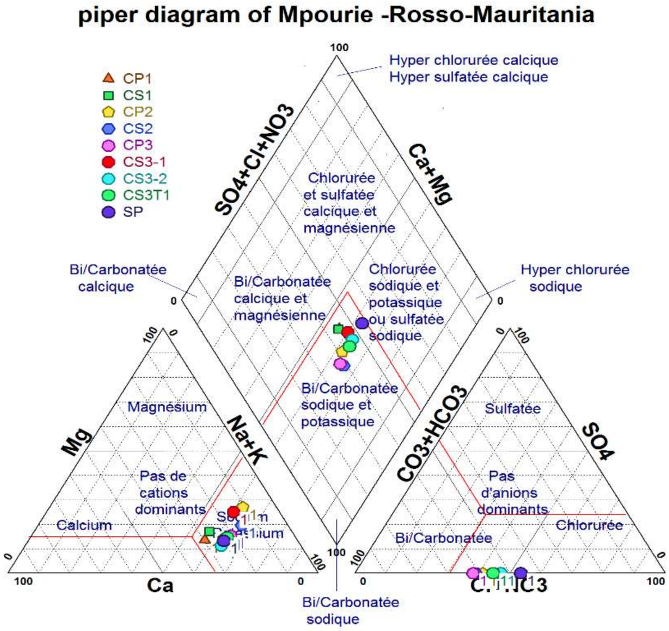


Fig. 6: Piper diagram evaluation in the M'Pourie plain.

## Evaluation of the Hydrological Study Using the Piper Diagram

The Piper diagram is a particularly suitable tool for studying the evolution of water facies as a function of increasing mineralization or for comparing different sample groups and highlighting the dominant cation and anion types. The waters of M'Pourie in the Senegal River have low mineralization. Piper used the presentation of these waters as a simulation method to compare river waters and determine the dominant chemical facies at each site and during each climatic season.

The analyses used in the hydrological study originate from the collection of several samples at nine sites spread along the main M'Pourie canal. The results of the analyses for M'Pourie surface water are shown in Fig. 6.

Most of the analyses exhibit sodium-potassium bicarbonate facies, wherein sodium and potassium are the predominant cations, and chloride is the primary anion.

## Evaluation of Soil Salinity in the Senegal River

Electrical conductivity (EC) is an essential measure for assessing soil salinity. Soil is generally considered salty when its EC exceeds 4 $mmhos.cm^{-1}$. The analysis of this parameter at the soil level of the stations considered (Table 4) shows values lower than the salinity threshold tolerated in agriculture (Abidine et al. 2018a). This result is confirmed by the agronomic scale developed by the U.S. Salinity Laboratory (U.S.S.L, 2017), which is graded according to Table 5. This classification places the soil in our environment in the unsalted category and does not present any reaction toward crops.

Table 4: Conductivity results on the M'Pourie plain

| Website | Conductivity $mmhos.cm^{-1}$ |
|---|---|
| S1 | 0.32 |
| S2 | 0.34 |
| S3 | 0.35 |

## CONCLUSION

At the end of this study, the importance of climate changes, illustrated in this study by the variability of irrigation water supplies, proves to be important in the functioning of agro-systems. In fact, two modes of operation have become

Table 5: Interpretation table for electrical conductivity values (USSL, 2017)

| American scale | Unsalted | Lightly salted | Salted | Very salty | Extremely salty |
|---|---|---|---|---|---|
| CE mmhos/cm 25°C | <2 | 2-4 | 4-8 | 8-16 | >16 |
| Crop reaction | Negligible effects | Harvests of highly sensitive crops are reduced | Harvests of many crops are reduced | Only highly tolerant crops produce results | Only a small number of crops produce harvests |

individualized: the dry phase mode, characterized by a very strong mineralization of the water linked to a significant load of dissolved elements, and the wet phase mode, whose water quality is poorly mineralized but shows the impact that its irrigation water can represent in the loading of organic and mineral pollution and the need for strict control of these waters upstream before their agricultural use.

Irrigation with highly mineralized water can lead to an accumulation of salts in the soil and negatively affect soil structure and nutrient availability to plants. Certain ions, like sodium, can be particularly damaging in the long term.

Furthermore, the results obtained for the soil do not reveal a major impact on the salinization of the latter. However, this problem remains to be verified in the medium and long term by an approach within agricultural fields and with a productivity monitoring of cultivated plants.

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