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Physicochemical Properties of Water Used for Irrigation of Rice (*Oryza sativa*) in the Gharb Plain, Morocco

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ABSTRACT

The Sebou River is the main source of irrigation water in the Gharb Plain region. Moroccan rice cultivation depends on this river, which is exposed to several sources of pollution. The objective of this work is to evaluate the physical and chemical properties of irrigation water in rice fields in the Gharb plain of Morocco. The physicochemical properties of the water during a rice planting campaign in the Gharb plain in 2018 was evaluated following standard procedures. The results showed that the physicochemical characterization of the water in the rice field varies according to the stations, and the weather. However, the values of physicochemical parameters recorded did not exceed the Moroccan normative values for irrigation water except for chlorides. Similarly, the statistical analysis (Principal component analysis [PCA]) of the data collected showed the presence of two gradients in opposite directions: an organic matter concentration gradient and the other a mineralization gradient. These gradients resulted in clear segregation between the surveys carried out at the beginning of the submersion of the rice plots, which were characterized by a significant supply of nutrients and a high load of organic matter, and those carried out at the end of the rice submersion.

Keywords: Irrigation water, *Oryza sativa*, PCA, Physico-chemical parameters, Rice.

Introduction

Rice cultivation in Morocco began in the north of the country in 1925, where it was grown on a very small scale by Loukous' company.[1,2] Then, rice fields were identified in the Méknes-Fez region. Before 1934, when the first experiments were conducted at Ouled Ameur in the Gharb and Sidi Slimane regions, rice cultivation only drew the attention of public authorities to the possibility that rice had an impact on malaria. However, it was not until 1949 that the first serious trials were carried out, followed by young rice cultivation, at a time when Moroccan rice cultivation was known to develop as irrigated areas expanded. This cultivation has allowed the hydromorphic lands of the Gharb region to be valued. Historically, this area was exploited at a rate of 9,000 hectares per year in the 1990s.[3]

In 2014, the cultivated area covers only 4,450 hectares. Rice cultivation is practiced exclusively in the lowest part of the Gharb plain in Morocco because of the favorable climatic and soil conditions offered by this area, as well as the richness of its water network.[1] Rice cultivation is a potential source of environmental harm due to phytosanitary treatments, water management, and so on. Rice fields also constitute a component of the mosaic of local habitats as wetlands. They are generally of great interest, allowing many animal species to complete part or all of their life cycle and providing others with abundant food. As a result, there are interactions between the hydro-agro-system of rice fields and their environment.[1]

The sources of pollution such as urban and industrial wastewater, agricultural residues, as well as pesticides in Oued Sebou are constantly increasing and becoming more diversified. These waters are still used for irrigation, but water pollution is on the rise.[2–5] The use of these waters for irrigation can pose a serious health threat. Thus, evaluation of the physical, chemical, or biological properties of these waters will be beneficial to farmers and decision-makers.

This research was aimed at evaluating the physical and chemical properties of irrigation water in rice fields in Morocco's Gharb plain.

Materials and Methods

Study area

The study area was the Gharb plain in Morocco and is located between latitudes 34 and 34°45 'N in the Atlantic littoral zone. It has a hydro-geographic area of 7500 km^2. The Gharb plain has a diverse range of soils, from the Sebou River to Merjas. It has a Mediterranean climate and is abundant in water resources (Figure 1).[1]

Collection of water samples

Forty water samples were collected from five rice field stations (Station 1 [S1], Station 2 [S2], Station 3 [S3], Station 4 [S4], and Station 5 [S5]) as shown on the map in Figure 1. These stations were chosen to study the characteristics of the water samples and track their evolution. The collection of the water samples was done for eight months during the 2018 rice-growing season, beginning with watering in June and ending when the rice fields were dry in October. The water samples were placed in polyethylene vials that had been washed with distilled water before being rinsed three times with water from the rice fields to be analyzed.

Determination of physicochemical parameters

Twelve parameters used to assess the physicochemical properties of water samples collected from the five rice fields included; temperature (T), the concentration of hydrogen ions (pH), electrical conductivity (EC), total hardness (TH), concentrations of calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), bicarbonate ions (HCO_3^-), chloride ions (Cl^-),

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phosphate ions (PO_4^{2-}), nitrate ions (NO_3^-), dissolved oxygen (DO), and chemical oxygen demand (COD). Temperature, pH, and EC were measured on-site, while the other parameters were determined in the laboratory using standard methods.[6]

Statistical analysis

For descriptive statistics (range, mean, and standard deviation) of the physicochemical parameters of the water samples collected from the five rice fields, Minitab software (version 17) was used. Furthermore, the PCA was created by dividing a set of variables by their maximum values using Minitab software (version 17) to understand the relationships and variance among the physicochemical determinants.

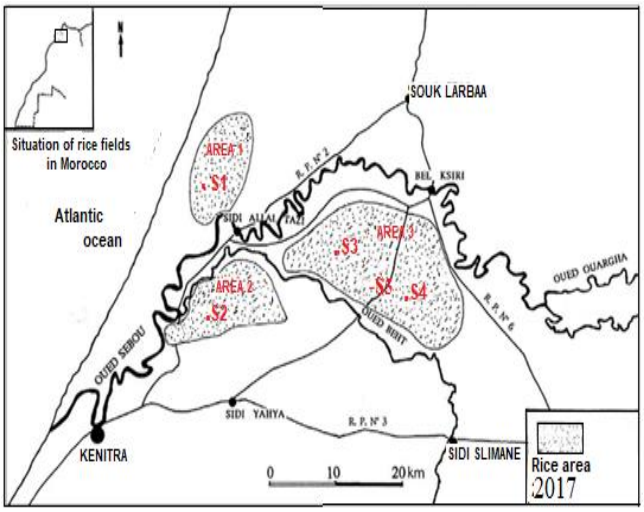

Figure 1: Location of the study area in the Gharb plain in Morocco.

Results and Discussion

The temporal evolution of rice grown in 2018 was studied at the level of five stations to monitor the development of river water in seasons and to understand the basics of the mechanisms that govern it. The results from the parameters for determining the physicochemical properties of the water samples are presented in Tables 1 and 2, as well as Figures 2 to 13.

Temperature

Water temperatures measured at the five stations ranged from 16.30 to 31.40°C, with an average of 24.92±4.71 (Table 1 and Figure 2). Changes in atmospheric temperature had an impact on these thermal values. The highest temperature was recorded at station S4, at 31.40°C. However, from mid-August, a decrease in the water temperature was observed in all the stations. These fell to their lowest value (16.30°C) near the end of the rice-growing season. This drop in water temperature could be explained by the placement of the plant cover (primarily *Oryza sativa*), which forms a screen for the penetration of radiant energy during this period. The temperature of the water during the study cycles varies significantly between the various sections surveyed. Temperature is a factor that is directly related to rice development. Overall, the change in surface and pore water temperatures varies with atmospheric temperature during the first months of cultivation, due to the nature of the rice fields, which were fully open during this period.[7] From July, there was a gradual drop in the temperature of the surface and pore water, which no longer followed that of the air. This observation was due to the placement of the plant cover, which formed a screen, preventing the rise in water levels. It was observed that all the recorded temperature values did not exceed the microcaine standard for the quality of irrigation water (35°C).

pH

The pH encapsulates the stability of the equilibrium established between the various forms of carbonic acid dissociation. This parameter is primarily determined by the source of the water, the petrographic nature of the environment traversed, and the wastewater discharge.[8] The pH values measured at the five stations (Table 1 and Figure 3) ranged from 7 to 8.5, with an average of 8.2±0.51. Thus, these values initially vary around 8.5 at the start of the rice-growing cycle and gradually decreased towards the end of the cycle, with most stations recording pH values around 7. As a result, the pH of the rice fields remains slightly alkaline. This slight alkalinity is due, on one hand, to the geological nature of the rice-growing soils of the Gharb plain, which have an alkaline pH. Furthermore, the slight alkalinity could be attributed to a strong phytoplankton development, which causes significant carbonic acid absorption and, consequently, an increase in the pH values of the water.[9,10] The influence of irrigation water from the Sebou River during high tide (saltwater loaded with free alkalis) may also be a contributing factor.[11] All the measured pH values did not exceed the microcaine standard for the quality of irrigation water (pH 6.5-8).

Table 1: Statistics of the physicochemical parameters of water samples collected from five rice fields in the Gharb plain in Morocco and Moroccan limit standard value.

Variable	Units	Minimum	Maximum	Mean	SD	Limit standard value (Moroccan)
T	°C	16.30	31.40	24.92	4.71	35°C
pH	-	7.10	8.90	8.21	0.51	6.5-8.4
EC	µs/cm	420.00	2850.00	1604.50	517.90	<3000 µS/cm
HCO_3^-	mg/L	89.70	335.40	198.12	59.75	518 mg/L
Cl^-	mg/L	95.50	556.90	287.90	113.50	350 mg/L
DO	mg/L	0.95	13.85	4.13	3.31	-
DCO	mg/L	8.20	70.50	31.70	12.59	-
Ca^{2+}	mg/L	32.50	87.00	53.82	11.88	-
Mg^{2+}	mg/L	2.40	116.80	48.02	26.20	-
TH	mg/L	70.00	182.50	101.83	25.08	-
NO_3	mg/L	0.15	7.75	1.93	1.62	30 mg/l
PO_4^{3-}	mg/L	0.02	2.25	0.46	0.54	-

Temperature (T), Hydrogen potential (pH), Electrical conductivity (EC), Chloride ions (Cl^-), Dissolved oxygen (DO), Chemical oxygen demand (COD), Calcium ions (Ca^{2+}), Magnesium ions (Mg^{2+}), Total hardness (TH), Nitrate ions (NO_3^-), and Phosphate ions (PO_4^{3-})

Electrical conductivity

The electrical conductivity values range between 400 and 2850 µs/cm, with an average of 1604.50±517.90 µs/cm. In September 2018, the peak was recorded at station S2 (2850 µs/cm). Meanwhile, the lowest value (up to 400 µs/cm) was recorded in the same year at station S1 (Figure 4). The electrical conductivity, which is proportional to the number of ionizable salts, indicates the degree of mineralization of the water.[12] Generally, the electrical conductivity of water in rice fields is quite high. On the one hand, this could be explained by the excessive mineralization of organic matter.[13] Also, atmospheric evaporation increases the ionic concentration in the various rice plots, which are only partially made up of irrigation water. Water with an electrical conductivity greater than 1500 µS/cm is unfit for crop irrigation.[14] The electrical conductivity of pure water was much higher than that of surface water. It increased from a value of 600 µS/cm in surface water to 1440 µS/cm in pore water. The solubilization of part of the salts precipitated at the level of the surface horizon of the soil.[15] However, the values did not exceed the Moroccan quality standard for irrigation water (3000 µS/cm).

Alkalinity (HCO_3^-)

Alkalinity levels range from 89.7 to 335.4 mg/L, with a mean value of 198.12±59.75 mg/L. The analysis of alkalinity values during the two rice growing seasons reveals high but irregular levels of bicarbonate ions at each station. The highest concentrations were found in July of the second rice season, with values of 335.4, 299.8, 326.8, and 301.8 mg/L at stations S1, S3, S4, and S5, respectively, as shown in Figure 5. This obvious increase in alkalinity is related to the increase in mineralization caused by the influx of water-rich cations (Ca^{2+}) and anions (Cl^-, SO_4^{2-}, and HCO_3^-) from the Oued Sebou. These findings are consistent with previous research on the physicochemical analysis of inundation from the same environment.[9,11] The spatial irregularity of this parameter recorded during harvest season, on the other hand, is related to the growth of the submerged plant cover and, therefore, to photosynthetic activity.[9,11] At the end of the rice-growing cycle, the activity of the submerged flora is less important due to a decrease in light energy under the plant cover, and the alkalinity values are relatively stable, oscillating between 100 and 150 mg/L. All the observed values were therefore lower than that of the Moroccan quality standard for irrigation water (30 mg/l).

Concentration of chloride ions (Cl^-)

The values of chloride ions range from 95.50 to 556.90 mg/L, with an average of 287.90±113.50 mg/L (Figure 6). The chloride content of submerged water remained sufficiently pronounced. This is due to evapotranspiration in rice field water, excessive mineralization of organic matter, and the contribution of salts for crop fertilization, in addition to the land's soil nature.[16-19] It was observed that the chloride concentration in some stations exceeded the value of the Moroccan standard for irrigation water quality (350 mg/L).

Concentration of dissolved oxygen (DO)

The values of dissolved oxygen as highlighted in Figure 7 range from 0.95 to 13.85 mg/L, with a mean value of 4.13±3.31 mg/L. Dissolved oxygen concentrations were high at the beginning of the rice cycle in all the stations (up to 13.85 mg/L). Dissolved oxygen concentrations were high at the beginning of the rice cycle in all the stations (up to 13.85 mg/L). This was because the light intensity reaching the body of water, which was greatest at the beginning of the rice-growing season, promoted the development of phytoplankton, the proliferation of the floral procession (algae and moss), and thus an increase in photosynthetic activity to which the highest dissolved oxygen concentrations correspond.[15] As the two cycles progressed, the concentrations of dissolved oxygen became weaker and weaker (between 2 and 4 mg/L). These low concentrations could be linked, on the one hand, to a lack of light energy and wind mixing with the water blade, as a result of the rapid development of macrophytes, particularly rice, and the non-renewal of irrigation water. This resulted in an excessive accumulation of organic matter.[16]

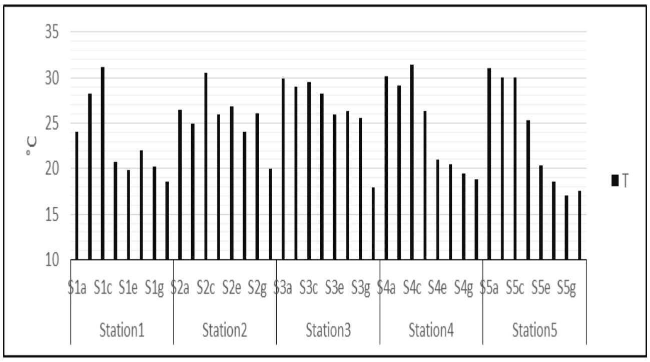

Figure 2: Evolution of the water temperature during the rice-growing season in 2018.

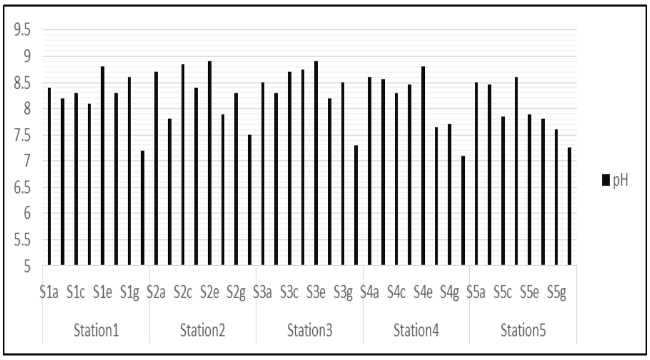

Figure 3: Evolution of the water pH during the rice-growing season in 2018.

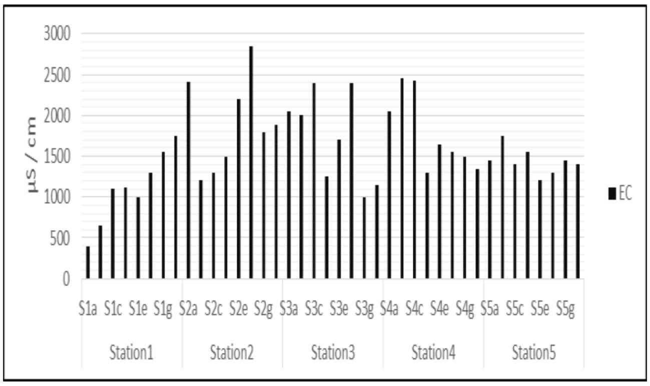

Figure 4: Evolution of the water electrical conductivity during the rice-growing season in 2018.

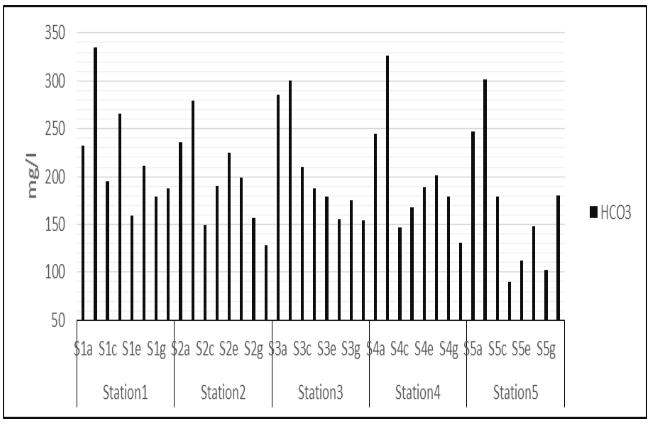

Figure 5: Evolution of the water bicarbonate ions during the rice-growing season in 2018.

Chemical oxygen demand (COD)

Chemical oxygen demand (oxidability) values range from 8.20 to 70.50 mg/L, with an average of 31.70±12.59 mg/L (Figure 8). The temporal evolution shows that the levels of oxidability increased after the rice fields were submerged. During the two culture cycles, the highest values (up to 70 mg/L) were observed in July. The high level may be attributed to the abundance of humic substances found in fertilizers and manure used by rice farmers at the start of the crop. This concentration decreased in all stations in August, and a second enrichment of the submerged water in organic matter beginning in mid-September was observed. This was due to the decomposition of certain animal and plant organisms, as well as the non-renewal of submersion water.[17,18]

Concentration of calcium ions (Ca^{2+})

Calcium ion concentrations in rice field water range between 32.5 and 87 mg/L, with a mean of 53.82±11.88 mg/L (Figure 9), indicating that the rice field water was calcium-rich. This hardness exceeds 20 mg/L in all of the stations studied. These high contents are associated with the predominance of limestone and marl soils in the Gharb plain.[19,20]

Concentration of magnesium ions (Mg^{2+})

The changes in magnesium concentration in the water of different rice paddies during the growing season were obvious, with magnesium concentrations ranging from 2.40 to 116.80 mg/L, with an average of 48.02 ± 26.20 mg/L as presented in Figure 10. Magnesium concentrations reached their highest in Station S4, and the importance of magnesium in mainland water was compared to the importance of calcium. This is involved in the formation of the chlorophyll molecule, which is found in plant composition.[21] At high tide, seawater mixed with Sebou River water was used to irrigate rice fields.

Total hardness

Throughout the study period, the temporal evolution of total hardness shows high levels in all stations. The values of total hardness range between 70 and 182.5 mg/L, but they occasionally exceeded 150 mg/L (Figure 11). These high levels could be related to the nature of the substrate (limestone and dolomite), as well as the mobilization of soluble salts in the soil and irrigation water.[22] This submersion water can thus be qualified as hard water because the levels often exceed 25 mg / l.[23]

Concentration of nitrate ions (NO_3^-)

Figure 12 depicts the concentration of nitrate ions during the rice-growing season, which ranges between 0.25 and 7.75 mg/L. The spatiotemporal evolution of nitrate levels reveals high levels in the first samples after the rice fields were filled with water during the study period. These high levels are most likely the result of nitrate solubilization in the sediment caused by fertilizer nitrates. These observations are similar to those made in the rice fields of Camargue, France.[20] Following that, a decrease in nitrate levels was observed in all stations beginning in August. Nitrates are present in the form of traces near the end of the season. However, this decrease could be explained by its exhaustion by algal phylogenesis rather than by macrophytes, and, on the other hand, denitrification, which occurs 2 to 5 days after pre-cultural fertilization.[24]

Concentration of orthophosphate (PO_4^{3-})

Phosphate concentrations during rice cultivation ranged from 0.02 to 2.25 mg/L, with a mean of 0.46±0.54 mg/L (Figure 13). Meanwhile, the concentrations of orthophosphates fluctuated in the same way that nitrates did. The high levels observed at the beginning of the two rice growing cycles were due to large amounts of PO_4^{3-} buried in the soil during pre-cultural fertilization, as well as inputs from irrigation water. As a result, beginning in July, there was a significant drop in this mineral element. This drop could be attributed to plant consumption of this element.[24,25]

Multidimensional analysis

Principal component analysis (PCA) was used to understand the structures of variations of all the physicochemical parameters involved in determining water quality.

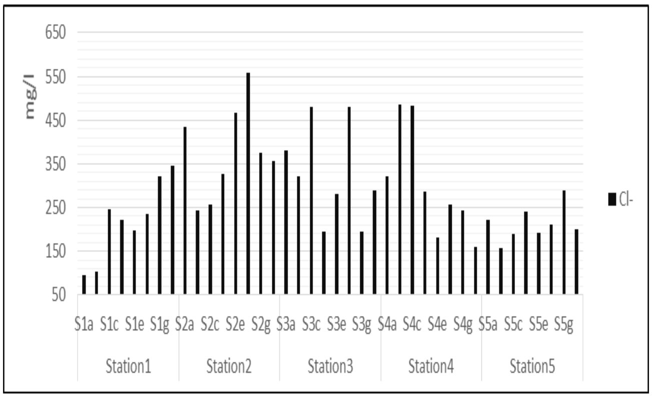

Figure 6: Evolution of the water chloride ions during the rice-growing season in 2018.

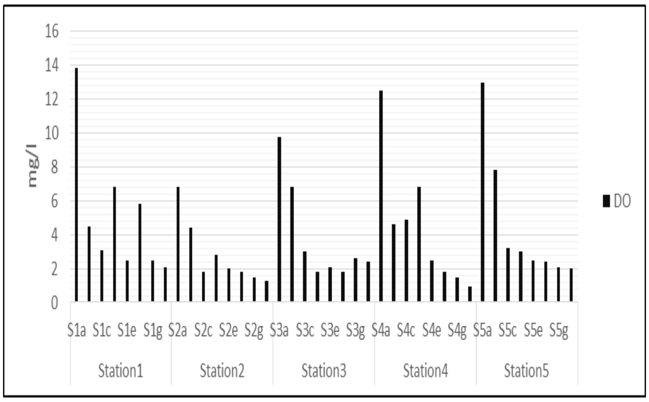

Figure 7: Evolution of the water dissolved oxygen during the rice-growing season in 2018.

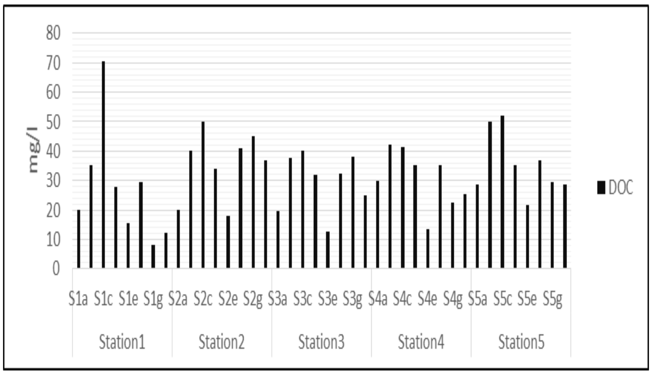

Figure 8: Evolution of the water chemical O_2 demand during the rice-growing season in 2018.

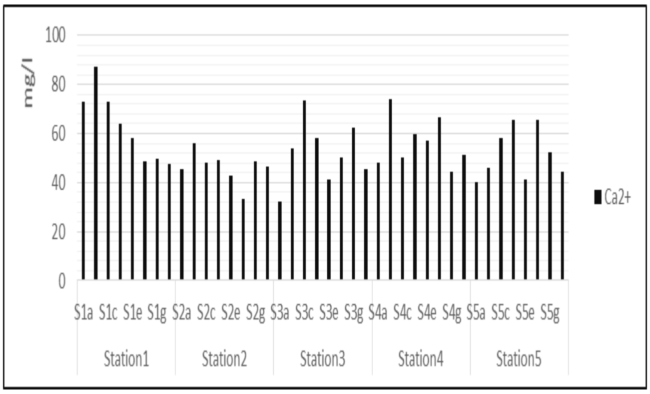

Figure 9: Evolution of the water calcium ions during the rice-growing season in 2018.

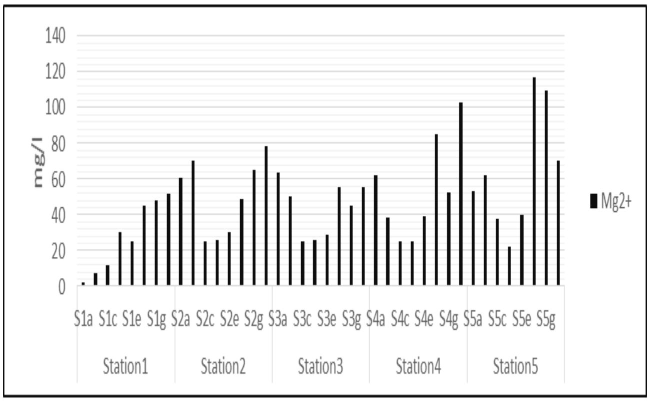

Figure 10: Evolution of the water magnesium ions during the rice-growing season in 2018.

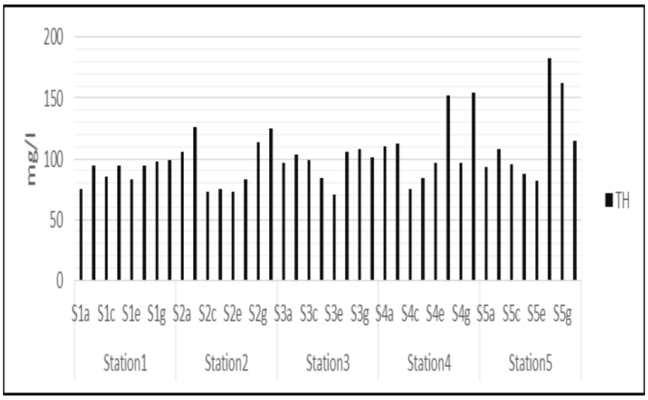

Figure 11: Evolution of the water total hardness during the rice-growing season in 2018.

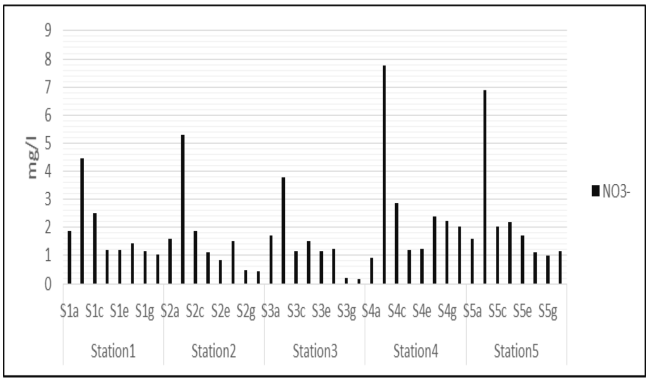

Figure 12: Evolution of the water nitrate ions during the rice-growing season in 2018.

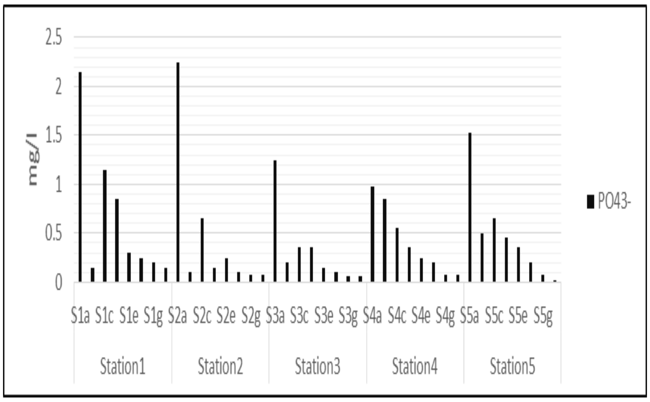

Figure 13: Evolution of the water phosphate ions during the rice-growing season in 2018.

Table 2: Distribution of inertia among the three axes (F1x F2 x F3) during the rice-growing seasons in 2018

Eigenvalue	3.6895	2.2612	1.9187	7.8695
% variance	0.307	0.188	0.16	0.656

Table 3: Loadings of the principal components 1 and 2 of 13 experimental variables

Variable	Factor 1	Factor 2	Factor 3
pH	0.197	-0.082	-0.155
T	0.23	-0.085	0.108
EC	0.027	-0.399	0.179
HCO_3^-	0.174	0.061	0.22
Cl^-	0.026	-0.397	0.111
DO	0.171	0.08	0.019
DOC	0.068	0.049	0.289
Ca^{2+}	0.067	0.281	0.109
Mg^{2+}	-0.193	-0.039	0.264
TH	-0.169	0.092	0.327
NO3	0.117	0.096	0.346
PO_4^{3-}	0.173	0.04	-0.027

Also, PCA was employed to evaluate the similarities between the different values obtained at the station level and to highlight the correlations between the variations of these parameters. PCA is a factorial method based on the analysis of the correlations between the variables that reduce the number of characters by constructing new synthetic characters or principal components resulting from the linear combination of the initial characters.[26,27] The physicochemical analysis of the "rice paddy" hydro-system was based on 12 abiotic descriptors. The analysis of the table of variables is made possible by the transformation of each parameter into a modality, which was accomplished by using a graphical method that allowed the grouping of the states that were the most similar. Five stations were chosen from each of the three rice-growing regions. During the four months of the rice cycle (July to October), and the 2018 study year, these sampling points were prospected and collected 40 surveys (8 surveys per rice season x 5 stations). As a result, a matrix of 12 variables x 140 readings were obtained and submitted to the PCA. The inertia percentages of the first three main axes total nearly 65.5%, or half of the total information on variable and reading distribution; 30.7% for F1, 18.8% for F2, and 16% for F3 (Table 2 and Figure 14).

The values obtained during this analysis were relatively high, indicating that the majority of the variables studied are involved in sample discrimination. However, T, EC, pH, DO, PO_4^{3-}, HCO_3^-, Cl^-, and TH were taken into account based on the first principal component F1, as are seven metrological variables forming group I as represented in Table 3. On the other hand, this typology of abiotic variables was accompanied by a typology of records. Thus, the F1 axis shows an opposition between readings taken at the beginning of the rice-growing cycle (July) and readings taken at the end of the cycle (October), as presented in Figures 15 and 16. The F2 axis, for its part, generated the grouping of variables 1, which includes NO_3^-, COD, Ca^{2+}, and Mg^{2+} (Table 3). Furthermore, the seasonal analysis of the samples shows a clear distinction between summer surveys on the positive side of the axis and those taken at the beginning of the autumn season on the negative side (Figure 15).

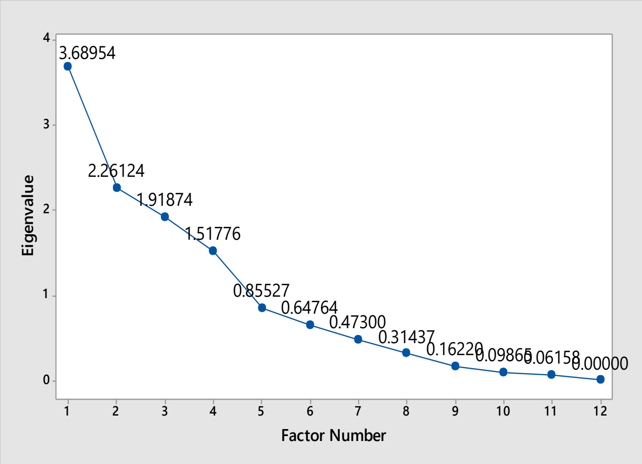

Figure 14: Graphical approach to the principal component analysis (PCA) of the physicochemical parameters of water samples according to the F1x F2 plan.

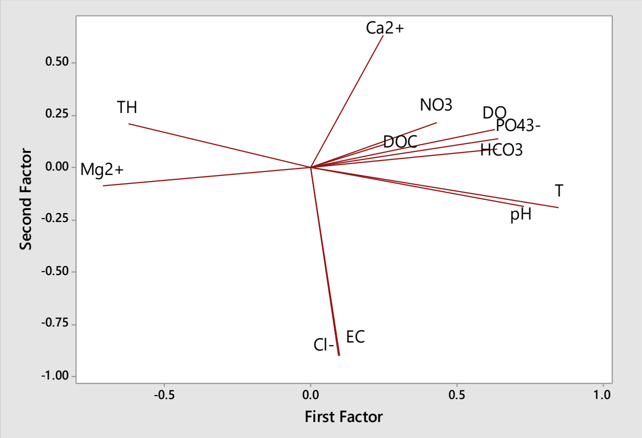

Figure 15: Distribution of inertia between the physicochemical parameters.

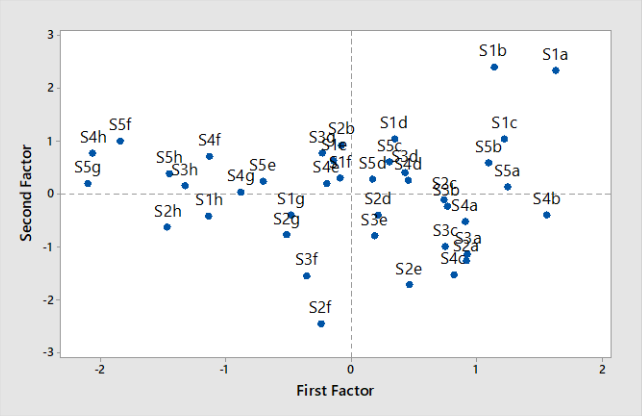

Figure 16: Distribution of principal component analysis (PCA) of the physicochemical parameters of water samples according to the F1x F2 plan.

Conclusion

Although the rice fields in this study were irrigated by the same water source, the physicochemical properties of the water samples vary depending on time and station, according to the findings of this study. However, the values of the physicochemical properties of the water samples from the rice field stations did not exceed the Moroccan standard values for irrigation water, except for chlorides. Furthermore, the principal component analysis (PCA) reveals two types of gradients that develop from the first period of paddy field reservation to the second; an increasing gradient of organic matter and an opposite gradient of mineralization.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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