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HYDROCHEMICAL STUDY OF KHOYANE WATERS (NIAYES AREA, SENEGAL) FOR THEIR USE IN MARKET GARDENING

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ABSTRACT

The village of khoyane is an important agricultural area in the Niayes zone where crop irrigation is facing soil salinisation. This study aims to characterize the geochemical facies of groundwater, and to examine their suitability for irrigation and their spatio-temporal evolution. To do this, water samples were taken according to Rodier's techniques and their physico-chemical characteristics determined. The results showed that the SAR reveals generally low levels of sodium. Salinity levels are relatively variable, ranging from high to excessive salinity. A longitudinal geochemical sequence with a dominant salinity type ranges from the hyper sulphated-calcic facies upstream (near Tanma Lake), to the bicarbonate-calcic facies downstream. In spite of the salinity, the soils are fertile, with acceptable irrigation water, but this requires prior control.
Keywords: Khoyane; Salinisation; Hydrochemical study; Water; Physico-chemical; Soil

1. Introduction

Groundwater, once of good quality, is now threatened by various point and non-point sources of contamination, including salinisation ([1]; [2]).

In Senegal, the Niayes area, which provides the bulk of vegetable production, is subject to high salinisation of irrigation water, which comes mainly from the shallow water table.

This is the case of the village of Khoyane in the commune of Diender where this salinisation of irrigation water threatens economic development. Indeed, farmers are faced with increased problems of reduced yields and abandonment of arable land [3].

The aim of this study is to characterise the geochemical facies of these groundwaters, and to examine their suitability for irrigation and their spatio-temporal evolution. This will make it possible to formulate recommendations.

2. Study materials and methods

2.1. Geographical location of the study area

Khoyane is a village in the rural community of Diender which is located in the Niayes area. It is located in the district of Keur Moussa in the department of Thiès, west of the Tanma lake. It is bordered to the east by the villages of Mbidiumm Wolof and Tieudém **(Figure 1)**.

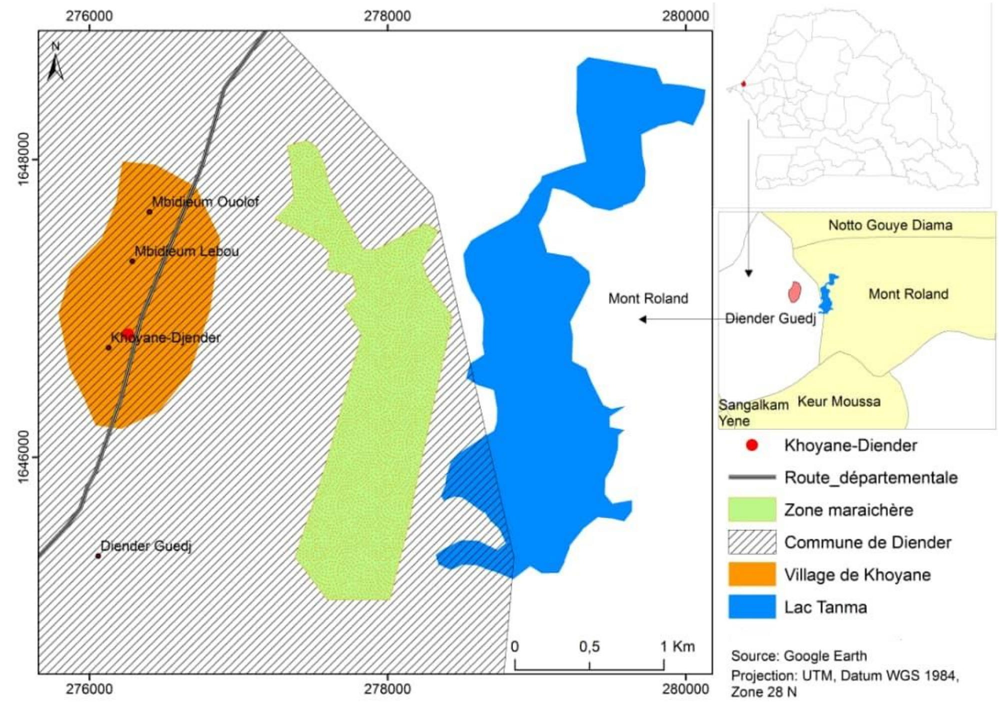

Figure 1: The location map of the study area

The main types of soil encountered are hydromorphic and halomorphic soils. Hydromorphic soils are often located on poorly drained alluvial deposits. Halomorphic soils are chemically rich but their excessive salinity and working difficulties are the weak points.

2.2. Geological setting

The study area is an integral part of the Niayes region [4], which is located in the Senegalese-Mauritanian sedimentary basin of secondary and tertiary age. It is partly covered by the Maestrichtian and Quaternary sand sheets.

- **The Maestrichtian** covers the whole of the Ndiass massif [5] and outcrops towards the south, along the cliff coasts, and over part of the area covering the region from Sébikhotane to Sangalkam. These Maestrichtian formations are disappearing due to faulting [6]. In the East, an accident brought it into contact with the Paleocene. Towards the North, from the commune of Pout, the roof of the Maestrichtian falls parallel to the topographic surface. Under Lake Tanma, it drowns under the discordant Lower Eocene. The Maestrichtian is marked by variable depths [6]. East of Thiès, there is a 200-300 m long azoic series with a calcareous facies with intercalations of black shale clay levels; west of the Ndiass horst, a 70 m long sandstone and limestone series.

- the **Quaternary sand tablecloths** cross the Niayes. These recent and very mobile sands have filled all the depressions and their thickness is very variable. The aquifers are captured either by village wells (10 to 20 m deep in the valleys and 25 to 45 m deep on the plateaux) or by shallow drillings, about 40 m deep [4]. They are mainly fed by rainwater.

In the Quaternary, the geological and geomorphological history of the basin is marked by a succession of transgressions and regressions which led to an alternation of dry and wet phases, intensifications and slowing of the winds. This has led to the construction of three series of dune belts [7] interspersed with lacustrine depressions. The latter gave rise to the lakes of Mbaouane, Retba and Tanma. Around Lake Tanma, it is this quaternary water table which must satisfy the irrigation water needs of several farmers **(Figure 2)**.

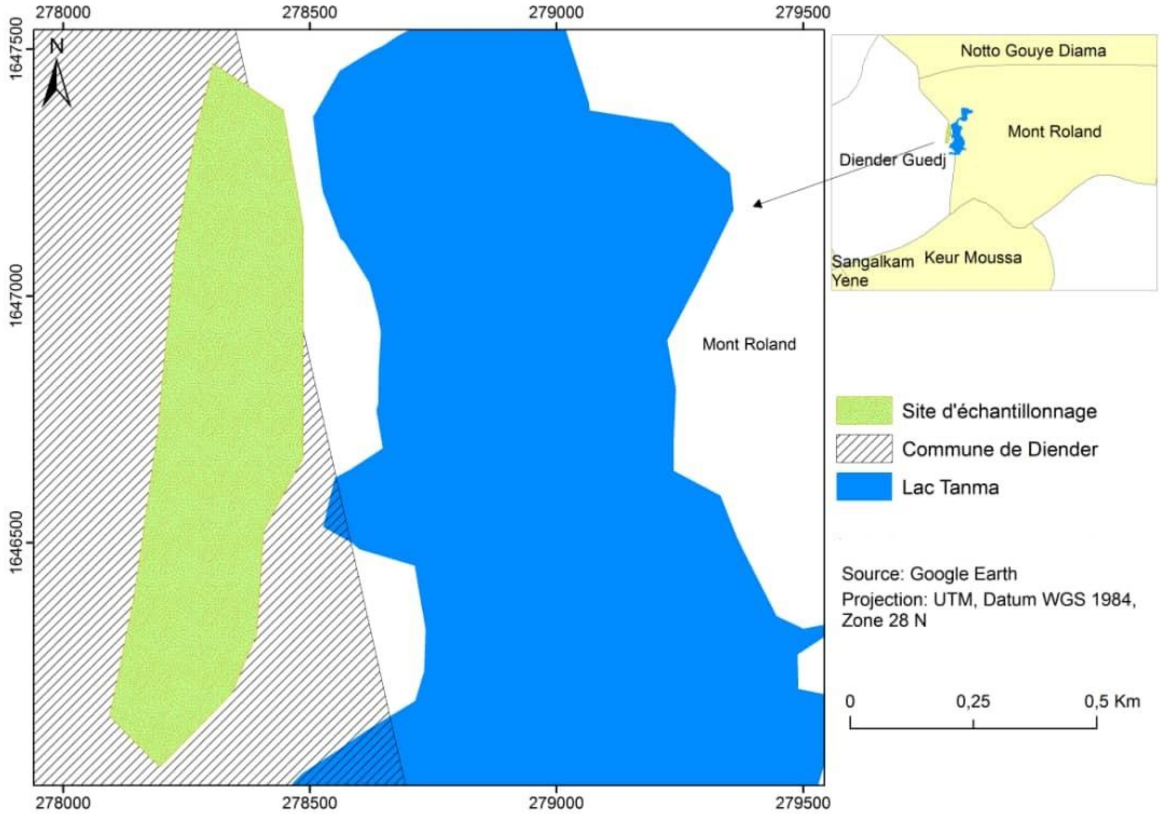

Figure 2: The Khoyane site near Lake Tanma

2.3. Hydrogeological framework

The reserve of the Maestrichtian aquifers is important, but recharge is limited due to its impermeability and the steep nature of the slopes, which only run down towards Lake Tanma [8]. As a result, recharge is lower than dewatering in some environments. The reservoir of these aquifers is made up of sandstone, sandy and clayey-sandy levels linked to the Senonian and locally to the base of the Paleocene; the continental and epicontinental facies in the East become marine in the West. This captive nappe, found between 50 and 500 m below the surface of the ground, is surmounted by a heterogeneous carbonate and detrital assemblage, containing discontinuous superficial or semi deep nappes [9].

The Niayes dune massif, which encompasses the study area, is underlain by impermeable bedrock from the Lower Eocene and marl-limestone from the Lower Tertiary [8]. The thickness of the sands reaches 80 m at the level of the coast. One can distinguish [3] :

- A fossil lagoon tablecloth, salty or over salty and deep. Its emergences feed lakes and coastal lagoons.
- A homogeneous "internal" water table that flows in a north-east-south-west direction with the lagoons where the water is discharged evaporates. This tablecloth is by far the most important.

2.4. Methods of study

224.1. Sampling: Six (6) water samples were taken according to the techniques of Rodier [10]. The wells were selected according to the difference in colour of the soil. The water samples taken were placed in plastic bottles and then sent to the pedology laboratory of the Institut National de Pédologie (I.N.P) for various types of analysis.

2.4.2. Chemical analysis

The chemical parameters determined are pH, measured with a pH meter, and electrical conductivity (EC), measured with a conductivity meter. The chemical parameters were carried out by volumetric dosage, for chlorides, bicarbonates, carbonates, calcium and magnesium; and by flame spectrophotometry for sodium, potassium and sulphates. The sodium absorption rate (SAR) was determined by calculating the concentrations of $Na^{+,}$ Ca^{2+} and Mg^{2+} expressed in meq/l.

2.4.3. Method of analysis

2.4.3.1. Geochemical characterisation of water

The Piper diagram was used to characterise the geochemical facies. This diagram is one of the most classical representations to compare the chemical compositions of natural waters. It allows a representation of cations and anions on two specific triangles whose sides show the relative contents of each of the major ions in relation to the total ions [11-15].

The Piper diagram illustrates the chemical evolution of water in an aquifer and the mixtures of waters of different mineralisation, to have a relationship between the chemistry of the water and the lithological nature of the aquifer, but also to follow the physico-chemical properties in the course of their spatiotemporal evolution.

4.4.3.2. Suitability of water for irrigation

To assess the suitability of the water for irrigation, the Riverside and Wilcox diagrams were used:

- The Riverside diagram [16] has been used to assess the risk of soil salinisation and sodisation [17-19]. This method takes into account the two major dangers that can be posed by water used for irrigation: salinisation and sodisation (or alkalisation) of soils. In this diagram, classes are defined on the basis of Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC). If the water is very rich in sodium, the sodium can bind to the soil complex and then act as a deflocculant. To assess the alkaline risk, the concentration of Na^+ and that of Ca^{++} and Mg^{++} are compared using the formula :

  SAR= (1); Na^+, Ca^{2+} and Mg^{2+} concentrations are expressed in meq/L.

- The Wilcox diagram is based on the_values of the sodium absorption ratio (SAR) and the electrical conductivity of the ions contained in the water. The objective is to represent the samples on the diagram in order to facilitate the characterisation of the irrigation suitability of the water [20-21]. This method also makes it possible to determine the risk of salinity of the water because the increase in Na^+ load negatively influences plant development.

The classification defines five classes of water**:** excellent, good, acceptable, poor and bad [22]. This classification is defined by the formula :

% Na^+ = (2); the concentrations of Ca^2+, Mg^{2+}, Na^+ and K^+ are expressed in meq/L.

3. Results & Discussion

3.1. Analysis of physical parameters

The results of the chemical analyses recorded in **Table 1** show that the pH is very acidic for samples E1 (3.7) and E2 (3.4), moderately acidic for samples E5 (5.9) and E6 (5.2) and neutral for samples E2 (7.6) and E4 (7.3).

The electrical conductivity of water is variable. It is higher for samples E2 (6410 µS/Cm) and E4 (6040 µS/Cm), then for samples E1 (3040 µS/Cm) and E3 (2970 µS/Cm) and lower for samples E5 (1782 µS/Cm) and E6 (1053 µS/Cm). This reflects a salinity scale ranging from high (750 < EC µs/cm < 2250), very high (2250 < EC µs/cm < 5000) and excessive salinity (> 5000 EC µs/cm) (Table 2).

3.2. Analysis of hydrochemical parameters

The results in **Table 3** show that the concentrations of major ions vary between 0.02 meq/L (SO_4^{2-}) and 30 meq/L (Ca^{2+}).

The waters are characterised by a predominance of carbonate ions followed by magnesium and sodium ions. Sulphates and potassium are in small proportion in these waters. These results reflect a great heterogeneity of the major ions.

3.2.1. Geochemical analysis of water

The chemical facies of the waters is given by the Piper diagram **(Figure 3)**. The diagram shows that the hyper sulphate-calcareous facies dominates in the groundwater sampled. The content of potassium ions varies between 3.5 and 0.3 meq/l, between 0.28 and 0.02 meq/l for sulphate ions and between 33 and 6.2 meq/l for calcium ions. The magnesium content varies between 19 and 2.4 meq/l, and between 17.7 and 3.7 meq/l for sodium.

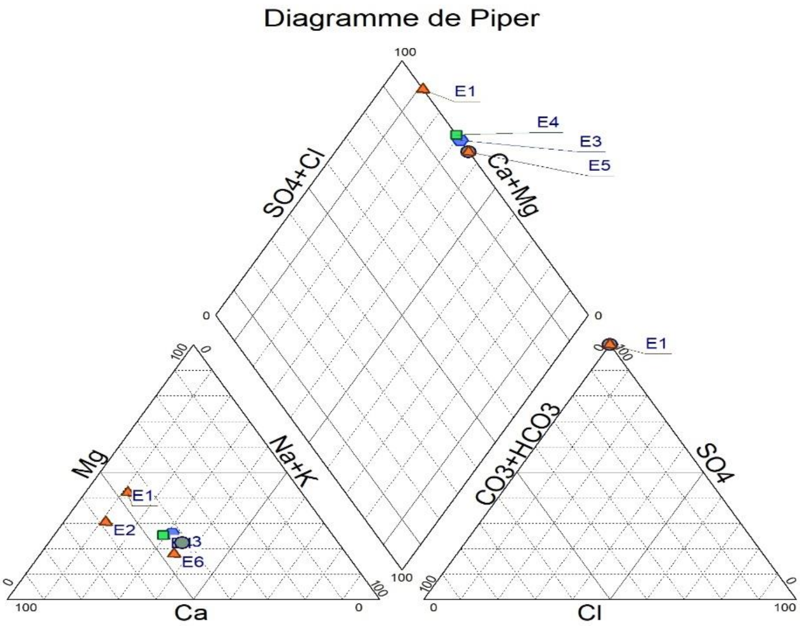

Figure 3: Piper water diagram

3.2.2. Suitability of water for irrigation

The Riverside Diagram **(Figure 4)** and **Table 4** show three classes of different degrees:

- . class 3 includes samples E5 and E6, it represents slightly saline to saline waters with low alkalinity ;
- . class 4 includes samples E1 and E3 whose EC represents very saline waters with an average SAR ;
- . class 5 includes samples E2 and E4, it represents excessively salty water with an average SAR.

According to electrical conductivity and SAR value, the Wilcox diagram **(Figure 5)** and **Table 4** show three (3) classes**:**

- . class C3S1, corresponding to samples E5 and E6, designates water admissible for the irrigation of salt-tolerant crops, on well-drained soils or soils of good permeability whose salinity evolution must be controlled ;
- . class C4S1 corresponding to samples E1 and E3, it indicates mediocre waters with a high mineral content, likely to be suitable for the irrigation of certain salt-tolerant species and on well-drained and filtering soils ;

- . an out-of-class that corresponds to wells E4 and E2, where the water is unsuitable for irrigation but may be suitable for certain salt-tolerant species and on well-drained and filtering soils.

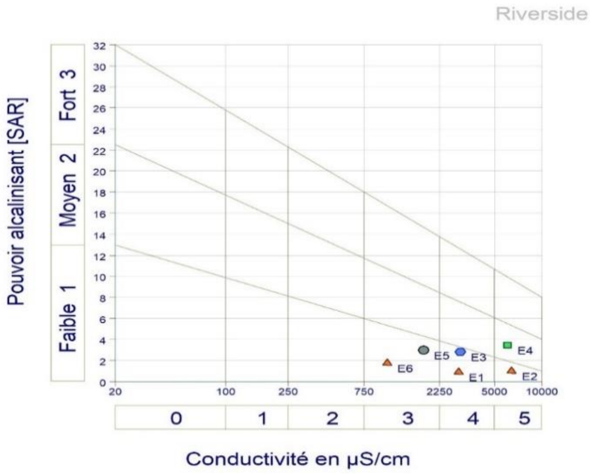

Figure 4: Riverside Water Diagram

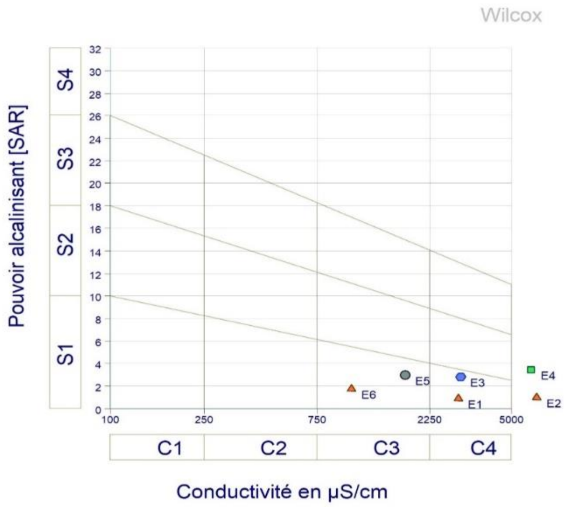

Figure 5: Wilcox water diagram

Table 1: Results of physicochemical water analyses

Samples	pH	EC (µs/cm)
E1	3,7	2970
E2	7,6	6410
E3	3,4	3040
E4	7,3	6040
E5	5,9	1782
E6	5,2	1053

Table 2: Classification of waters according to their total salinity [32]

WATER					
CE at 25° in micromhos	250	250-750	750-2250	2250-5000	< 5000
Salinity	Low	Average	Forte	Very strong	Excessive

Table 3: Results of chemical analyses of water

Samples	Ca^{2+} meq/L	Mg^{2+} meq/L	Na^+ meq/L	K^+ meq/L	SO_4^{2-} meq/L
E1	21	19	4,1	1,1	0,02
E2	30	15,6	4,9	0,9	0,09
E3	16,3	9,9	10,2	1,8	0,28
E4	33	18,5	17,7	3,5	0,17
E5	9,8	5,2	8,1	0,3	0,04
E6	6,2	2,4	3,7	1,1	0,22

Table 4: Wilcox sodium percentage classification

Degree	Quality	Class	State of use
1	Excellent	C1 -S2	Water that can be safely used for irrigation of most crops, on most soil.
2	Good	C2-S1 C2-S2	In general, water that can be used without special control for the irrigation of moderately salt-tolerant plants on soils with good permeability.
3	Eligible	C3-S1 C3-S2 C2-S3	In general, water is suitable for the irrigation of salt-tolerant crops on well-drained soils, but the evolution of salinity must be controlled.
4	Mediocre	C4-S1 C4-S2 C3-S3	In general, highly mineralised water is suitable for irrigation of certain salt-tolerant species and on well-drained and leached soils.
5	Wrong	C3-S4 C4-S3 C4-S4	Water not generally suitable for irrigation but can be used under certain conditions. Very permeable soil, good leaching, plants are very salt-tolerant.

5.3. Discussion

The SAR reveals generally low levels of sodium levels, between 1 and 4 but with an increasing dependency on salinity. This tends to reduce the "destructuring" effect of water on the absorbent complex [23].

Salinity levels are relatively variable (from high to excessive salinity). This typology is justified by the measurement of the electrical conductivity of the water sampled. The salinity gradient increases from upstream to downstream of the basin; salinity is therefore all the stronger the closer one gets to Lake Tanma. A longitudinal geochemical sequence whose dominant salinity type ranges from the hyper sulphated-calcic facies upstream (near Tanma Lake), to the bicarbonate-calcic facies downstream. These are very unfavourable conditions for cultivation.

For example, highly acidic (3.7 and 3.4) and moderately acidic (5.9 and 5.2) pH values have been observed in some irrigation waters. In addition, the salts thus brought to the surface are likely to concentrate in clayey shallows and present a danger to the soil and surface water table [24-25].

Given the hydrogeological context described above and the semi-arid climate of the area, several causes of groundwater salinisation can be considered. These include cultivation practices and the use of chemical fertilizers that strongly influence water quality. Crop pollutants emitted over a small area will only affect a limited sector of the water table, which may spread by diffusion. Sulphates in groundwater are supplied by the dissolution of gypsum [26-27]. In addition, the dissolution of evaporites, the remobilisation of marine water trapped during marine intrusions and the return to the aquifer of irrigation water concentrated on the surface by evaporation are phenomena which contribute largely to the salinisation of the aquifers [28-30].

The origin of the salinity can also be attributed to the intrusion of salt water from the Tanma lake, given its proximity to exploited water tables, the leaching of existing salts in the soil and the intensive application of fertilisers. These multiple causes require the use of different chemical tracers in order to discriminate between the different possible origins of the mineralisation; all the more so as the groundwater is marked by a predominantly chloride-calcic facies, making it difficult to detect the components.

5. Conclusion

Groundwater is the only exploitable water potential for market gardening in the area. It is subject to intensive and uncontrolled extraction. In spite of a salinity of the calcium type, the soils are fertile, with acceptable irrigation water, but this requires prior control (control of the evolution of salinity).

Although the salinisation of groundwater appears to be an irreversible phenomenon, it is always possible to limit its aggravation and geographical extension. Controlling abusive exploitation, using water-saving techniques in irrigation, optimising the use of fertilisers, insecticides and pesticides are the actions to be taken to reduce the risks of degradation of groundwater quality. It may also be possible to improve the characteristics of the water by letting it rest in aerated tanks and by adding gypsum. Experiments carried out in this direction have given positive results on the waters of the Kaolack region by causing a strong decrease in SAR and residual alkalinity [31]. A groundwater exploitation scheme should be established and the possibilities of artificial recharge in the most affected sectors of the area should be examined.

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