Cultivos Tropicales, Vol. 44, No. 3, July-September 2023, e-ISSN: 1819-4087, p-ISSN: 0258-5936, https://ediciones.inca.edu.cu

Cu-ID: https://cu-id.com/2050/v44n3e10

Original article

Analysis and classification of drilling water from Lavalle department, Corrientes-Argentina, for use in agriculture

Análisis y clasificación de aguas de perforaciones para el uso en la agricultura, departamento Lavalle, Corrientes-Argentina

Darío Emanuel Ramírez, María de las Mercedes Yfran Elvira*, Silvia Carlota Rodríguez

Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste (UNNE), Calle Sargento Cabral no. 2131, Corrientes, Argentina. CP 3400

ABSTRACT: Ensuring the availability of clean water represents a fundamental objective worldwide, since water is an essential resource for sustainable development. Volumes of fresh water available for agricultural and urban-industrial use worldwide have decreased considerably due to the excessive use of surface and groundwater destined for agricultural irrigation for the production of food for a constantly growing population. The objective of this study was to evaluate the physicochemical quality of groundwater and determine its aptitude for agricultural use through the criteria of salinity, sodicity and toxicity in the Department of Lavalle in Corrientes province, Argentina. The evaluation and characterization of the physicochemical quality of the waters analyzed for irrigation and applications of phytosanitary products by means of the determination of cations and anions present indicate that they do not show inconveniences to be used in agriculture. According to the Riverside laboratory classification, 73 % of the water samples presented low salinity, all with low sodium content, suitable for irrigation in most cases; and 26 % of the samples with moderate salinity, suitable for irrigation, with low sodium content. In addition, it should be noted that the determination of hardness, nitrate, phosphates and potassium are important data when making a fertilization plan. In the case of toxic ions such as chlorine and sodium, the samples presented low values, so they do not represent a problem for their use.

Key words: water quality, underground water, cations, anions, agricultural holdings, irrigation.

RESUMEN: Garantizar la disponibilidad de agua limpia representa un objetivo fundamental a nivel mundial, ya que el agua es un recurso imprescindible para el desarrollo sostenible. Los volúmenes disponibles de agua dulce para uso agrícola y urbano-industrial, a nivel mundial, han disminuido considerablemente debido al uso excesivo de aguas superficiales y subterráneas destinadas al riego agrícola, para la producción de alimentos de una población en constante crecimiento. El objetivo del presente estudio fue evaluar la calidad fisicoquímica del agua subterránea y determinar su aptitud para uso agrícola, mediante los criterios de salinidad, sodicidad y toxicidad en el Departamento de Lavalle, provincia Corrientes, Argentina. La evaluación y caracterización de la calidad fisicoquímica de las aguas analizadas para riego y aplicaciones de productos fitosanitarios, mediante la determinación de cationes y aniones presentes, indican que no muestran inconvenientes para ser usadas en la agricultura. Según la clasificación del laboratorio de Riverside, el 73 % de las muestras de aguas presentaron baja salinidad, todas con bajo contenido en sodio, aptas para el riego, en la mayoría de los casos, y el 26 % de las muestras con salinidad moderada, aptas para el riego, con bajo contenido en sodio. Además, cabe destacar que la determinación de la dureza, nitrato, fosfatos y potasio son datos importantes a la hora de realizar un plan de fertilización. En el caso de los iones tóxicos como el cloro y el sodio, las muestras presentaron valores bajos, por lo que no representan un problema para su uso.

Palabras clave: calidad del agua, aguas subterráneas, cationes, aniones, explotaciones agropecuarias, riego.

*Author for correspondence: mariyfran077@hotmail.com

Received: 29/11/2021

Accepted: 12/02/2022

Conflict of interest: The authors declare that they have no conflict of interest.

Authors' contribution: Conceptualization- Silvia Carlota Rodríguez. **Research-** Ramírez Darío Emanuel; María Yfran Elvira; I Silvia Carlota Rodríguez. **Methodology-** María Yfran Elvira; I Silvia Carlota Rodríguez. **Supervision-** María Yfran Elvira; I Silvia Carlota Rodríguez. **Initial draft writing, Final writing and editing, and Data curation-** Ramírez Darío Emanuel.

INTRODUCTION

Ensuring the availability of clean water is a fundamental global objective, as water is an essential resource for sustainable development (1-3). The available volumes of freshwater for agricultural and urban-industrial use worldwide have decreased considerably, due to the excessive use of surface and groundwater for agricultural irrigation (4,5) to produce food for an ever-growing population. The amount of water for irrigation depends on the water requirements of the crops and the water that is naturally available for the crops (6,7). However, the natural water used for irrigation may contain contaminants of an inorganic nature, especially fertilizers and agrochemicals, which are important because of their toxicity to living organisms (8), causing an increase in the amount of total solids, nitrates, sulfates, chlorides and sodium (9).

The agricultural sector consumes about 70 % of fresh water for crop irrigation (10,11). In water for agricultural use, quality is defined by the concentration of specific ions of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) as cations; carbonates ($CO_3^{\ 2-}$), chlorides (Cl^{-}) and sulfates ($SO_4^{\ 2-}$) as anions, and others of lesser proportion, such as nitrate ($NO_3^{\ -}$) (8,9). Electrical conductivity (EC) is also useful for determining the total concentration of soluble salts. EC and Na^{+} are two fundamental parameters that define the suitability of water for irrigation. The high content of salts in irrigation water generates an increase in osmotic pressure in the soil solution, decreasing water adsorption by plants, besides directly affecting plant growth, affecting soil constitution, permeability and structure (9,12). The sodium adsorption ratio (SAR) is a parameter that reflects the possible influence of the sodium ion on soil properties, since it has dispersant effects on soil colloids and affects permeability. This equation (SAR) gives an idea of the potential danger due to an excess of sodium over calcium and magnesium (9); the soil becomes more waterlogged, with worse aeration and, therefore, with worse characteristics for crop establishment. This is really worrisome in soils with a clayey profile (13). Similarly, sulfate, chloride and phosphate ions should be evaluated, since they can accumulate in crops in concentrations high enough to reduce crop yields and facilitate the obstruction of some irrigation systems. The possible causes of contamination are of human origin, depending on industrial activities, population growth, and wastewater management (4,8). Therefore, it is important to evaluate the chemical quality of water, since this is integrated by the concentration of salts and the proportion of different ions in solution that could affect soil and crop resources in their long-term use.

The objective of the present study was to evaluate the physicochemical quality of groundwater and determine its suitability for agricultural use using salinity, sodicity and toxicity criteria in the Department of Lavalle in Corrientes province, Argentina.

MATERIALS AND METHODS

Study area

The work was carried out in the Department of Lavalle, Corrientes province, Argentina (29°01′40″S; 59°10′55″O), in farms of small producers of that locality.

Nineteen samples were taken from water sources from boreholes of depths ranging from 25 to 40 meters, which producers use for agricultural production.

Sample collection

The extracted samples (1L) were stored in polyethylene containers.

Sampling was carried out as follows: before taking the sample, the pump was run for about 10 minutes, the container was rinsed with water from the borehole three times, and then completely filled, avoiding the presence of air inside.

They were determined *in situ*:

- Temperature: which was recorded with a Mercury thermometer with bulb, formed by a glass capillary of uniform diameter, with Celsius scale.
- pH: measured with an "Adwa" AD101 Standard Pocket Tester pH Portable pH meter, microprocessor based, with automatic calibration and automatic temperature compensation.
- Electrical conductivity: with an "Adwa" AD203 Standard Pocket Teste portable conductivity meter, with automatic temperature compensation.

Sample conditioning and transport

The refrigerated samples were immediately transported to the Analytical and Agricultural Chemistry Laboratory, Faculty of Agricultural Sciences, National University of the Northeast (UNNE). It is important to refrigerate the samples because some chemical species (such as nitrates and sulfates) are transformed by microbial action.

The following determinations were carried out in the laboratory:

Calcium and Magnesium: by complex formation volumetry (14).

Sulfate: by Turbidimetry (ASTM D 516-90 method) (15).

Alkalinity: by neutralization volumetry (14).

Sodium and Potassium: by atomic absorption spectrometry (14).

Chloride: by precipitation volumetry, Mohr's method (14).

Phosphate: by molecular absorption spectrophotometry: molybdenum blue method (14).

Nitrate: by molecular absorption spectrophotometry: sodium salicylate method (16).

RESULTS AND DISCUSSION

pH and Alkalinity

These parameters are conceptually different from each other, but are highly correlated. The pH is not a fundamental factor in determining water quality, but it serves to evaluate the relative concentrations of dissolved carbonate species. In addition, its values have important implications on the availability and management of nutrients, since the normal range of water for agricultural use is between 5.6 and 7.3, which is suitable for most crops due to the maximum availability of nutrients (13).

The convenient pH for applying herbicides is 4 to 6. High pH of the solution has negative effects on herbicides (17) in terms of stability and penetration into the plant.

pH 3.5-6.0: considered satisfactory for most applications, except for acid-sensitive products.

pH 6.1-7.0: can be used as long as the product is not kept in the tank for more than 1 hour.

pH 7.0 or higher: it is advisable to add a buffer or acidifier.

On the contrary, acidification of solutions can lead to an increase in the degree of degradation of sulfonylurea herbicides (17).

Figures 1 and 2 show the pH and electrical conductivity values of the water samples analyzed.

The pH results obtained are in the range of 5 to 6 (Figure 1), which is a very acceptable value with respect to the values considered standard, both for irrigation and for agricultural applications, except for those products sensitive to acidity, for example, herbicides of the chemical group of sulfonylurea herbicides.

With respect to the alkalinity results, only sample 9 showed levels higher than 150 mg L^{-1}, categorized as high alkalinity values, according to Kevern's reference values (18). Samples with low values were 4, 7, 16, 17 and 19, while the rest of the samples presented average alkalinity values (Figure 2, Table 1).

Table 1. Alkalinity reference values

Range	Alkalinity (mg L^{-1})
Low	< 75
Medium	75-150
High	> 150

Sodium bicarbonate, a natural water pollutant in some areas, reduces the herbicide activity of the cyclohexanedione family (such as clethodim, setoxydim), MCPA, 2,4-D, glyphosate, dicamba, but the antagonism on the mentioned herbicides begins at 300 mg L^{-1} (17).

Figure 2 shows that no sample reaches 300 mg L^{-1} of bicarbonates, therefore, the activity of the agrochemicals would not be affected. Similar results were found in samples from the area of Bella Vista, Corrientes (19).

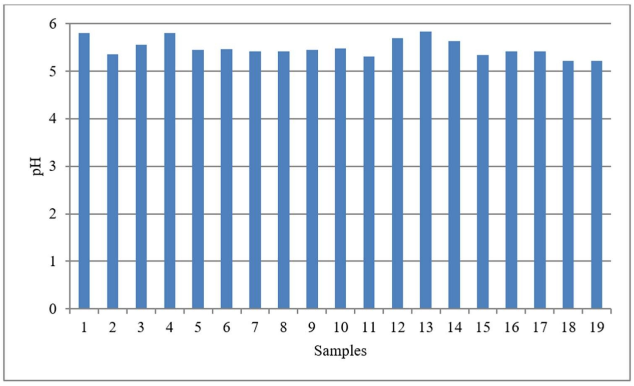

Figure 1. pH values of the samples analyzed

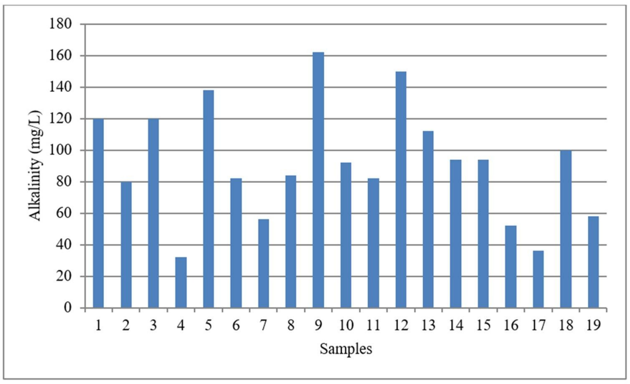

Figure 2. Alkalinity values of the water samples analyzed

Electrical conductivity (EC)

When water is classified to determine its suitability for irrigation, the EC value and the sodium adsorption ratio (SAR) are taken into account, since it is classified according to these values for the possible saline and sodium hazard that irrigation water may have. From the point of view of human consumption, the EC and sodium values are relevant.

The EC defines the ease with which an electric current passes through water. Conductivity gives an idea of the total salt content of the water. The higher the salt content, the higher the electrical conductivity. The Riverside standards establish a relationship between the electrical conductivity (µS cm^{-1}) and the RAS index (Tables 2 and 3) and according to these two parameters, categories or classes of water are established according to the letters C and S affected by a numerical subscript (20).

Figures 3 and 4 show the results of electrical conductivity and sodium content in the waters analyzed. Samples 9, 12, 13, 15, 18 showed EC between 250-750 µS cm^{-1}, corresponding to category C2 moderate salinity hazard, suitable for irrigation, recommending the use of salinity-tolerant crops.

The rest of the samples analyzed showed EC below 250 µS cm^{-1}, therefore of low salinity (C1), suitable for irrigation. Similar results were found in samples from San Roque, province of Corrientes (21).

Table 2. Riverside Standards: Classification for assessing irrigation water quality based on EC and SAN

Types	Quality and standards of use
C 1	Low salinity water, suitable for irrigation in all cases. Problems may exist in soils with very low permeability.
C 2	Medium salinity water, suitable for irrigation. Use salinity tolerant crops.
C 3	High salinity water that can be used for irrigation in well-drained soils
C 4	Very high salinity water that in many cases is not suitable for irrigation. It should only be used in very permeable and well-drained soils.
C 5	Water of excessive salinity, which should only be used in very few cases, taking all the precautions mentioned above.
C 6	Water with excessive salinity, not advisable for irrigation.
S 1	Water with low sodium content, suitable for irrigation in most cases. However, problems may occur with crops that are very sensitive to sodium.
S 2	Water with medium sodium content, and therefore with some danger of sodium accumulation in the soil, especially in fine-textured soils with low permeability.
S 3	Water with high sodium content and great danger of sodium accumulation in the soil.
S 4	Water with very high sodium content. Not advisable for irrigation in general

Table 3. Salt hazard classification according to the EC

Category	Salt hazard	EC (µS cm^{-1} to 25 ºC)
C1	Low	up to 250
C2	Moderate	250-750
C3	Medium	750-2.250
C4	High	2,250-4,000
C5	Very high	4,000-6,000
C6	Excessive	over 6,000

Sodium adsorption ratio (SAR)

SAR index (Table 4) gives an idea of the potential danger due to an excess of sodium over calcium and magnesium (13). It is expressed by the following equation:

$$SAR = \frac{Na(meq/l)}{\sqrt{\frac{Ca\,(meq/l) + Mg(meq/l)}{2}}}$$

With respect to this parameter (Figure 5), all the water samples analyzed correspond to class S1, Low Sodium Hazard.

The following graph shows the SAR results obtained.

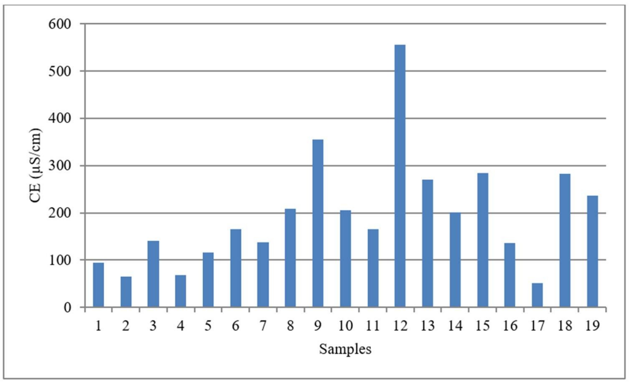

Figure 3. Electrical conductivity values of the water samples analyzed

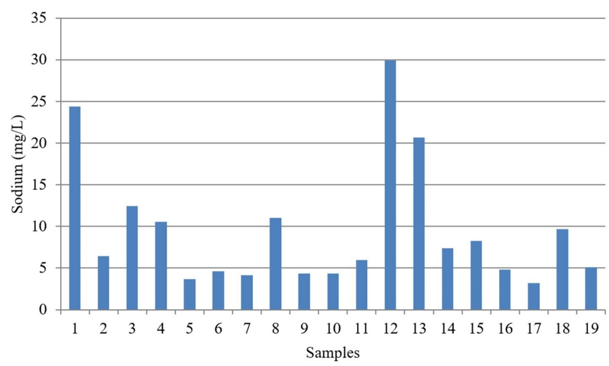

Figure 4. Sodium contents in the water samples analyzed

Total hardness

In most cases, water hardness is mainly due to the presence of calcium and magnesium ions; sometimes other bivalent cations also contribute to hardness, such as strontium, iron and manganese, but to a lesser degree since they are generally found in small quantities (17). It is important to know the degree of hardness of the water for the risk of obstructions in the irrigation branches, drip and nozzles and to know if we can use them in a certain soil for irrigation. For example, to correct a soil with excess sodium, it is advisable to use water rich in calcium (22).

According to Table 5, Cánovas Cuenca's classification (22), none of the water samples analyzed presented any problem to be used for irrigation and applications of phytosanitary products (Figure 6), since 21 % of the samples were categorized as very soft and 79 % as moderately soft water.

Table 4. SAR values proposed by Riverside

Class	Classification	SAR
S1	LOW sodium hazard	0-10
S2	MEDIUM sodium hazard	10-18
S3	HIGH sodium hazard	18-26
S4	VERY HIGH sodium hazard	Over 26

Anion and K+ cation analysis:

The chloride anions, sulfates, phosphates and the potassium cation in the water samples analyzed (Table 6) were not found at values that exceed the maximum limits for use in irrigation (based on Table 7 (23).

With respect to human consumption, the CAA establishes that the maximum nitrate value for this type of use is 45 mg L^{-1}. Table 7 shows that sample 3 has values above those established, so it is important that this water sample not be consumed.

Although there is no risk of these parameters in the water analyzed for irrigation use, it is important to have this information when deciding on crop fertilization.

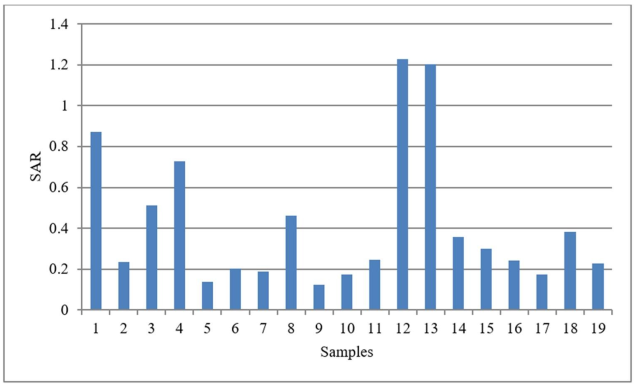

Figure 5. SAR values of the water samples analyzed

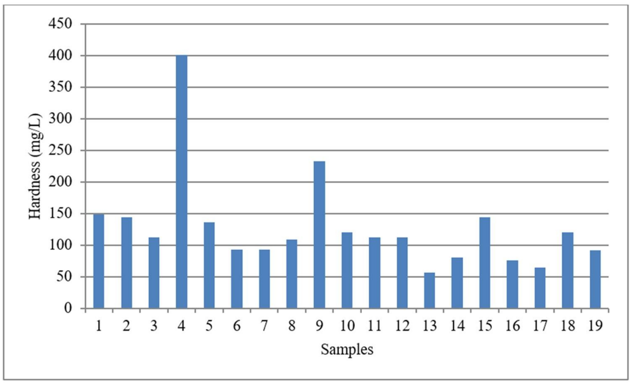

Figura 6. Total hardness values of analyzed waters (mg L^{-1} $CaCO_3$)

CONCLUSIONS

- With regard to the evaluation and characterization of the physicochemical quality of the water analyzed for irrigation and applications of phytosanitary products, by determining the cations and anions present, they indicate that they do not show any inconvenience for use in agriculture.
- In addition, it should be noted that the determination of hardness, nitrate, phosphates and potassium are important data when making a fertilization plan.
- In the case of toxic ions such as chloride and sodium, the samples showed low values, so they do not represent a problem for their use.
- These results show us the relevance of water analysis for its use.
- Water is one of the most precious goods within the production system and it is imperative to have knowledge of its quality, which determines its suitability for irrigation use or if it presents a limitation in crop development.

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Table 5. Classification of waters according to their hardness

Type of water	mg L^{-1} of $CaCO_3$
Very soft	Lower than 70
Soft	70-140
Medium soft	140-220
Medium hard	220-320
Hard	320-540
Very hard	Over 540

Table 6. Nitrate, sulfate, phosphate, chloride and potassium content expressed in mg L^{-1}

Water sample	Nitrato	Sulfate	Chlorides (mg L^{-1})	Phosphate	Potassium
1	2.67	7.07	55	0.2	0.585
2	8.82	3.58	15	0.21	0.195
3	49.44	2.21	10	0.02	0.195
4	6.54	2.58	15	0.07	0.195
5	7.64	1.42	7	0.19	0.39
6	23.73	2.82	9	0.031	0.195
7	20.25	3.7	12	0.32	0.39
8	4.28	4.72	25	0.67	0.39
9	4.04	7.25	18	0.64	0.39
10	1.68	6.62	17	0.4	0.78
11	18.45	5.04	15	0.35	0.39
12	5.22	6.34	68	0.53	0.39
13	4.16	1.76	18	0.21	0.195
14	3.54	0.91	5	0.66	0.195
15	11.37	9.8	22	0.43	0.585
16	8.88	7.87	9	0.34	0.78
17	6.96	3.85	9	0.34	0.78
18	4.9	9.53	15	0.64	0.39
19	14.78	9.04	25	0.32	0.975

Table 7. Optimal ranges of anions and K+ cation in irrigation water

Water quality parameters	Symbol	Optimum range in irrigation water(mg L^{-1})
Chloride	Cl^-	0-1000
Sulfate	SO_4^{2-}	0-950
Phosphates	PO_4^{3-}	0-2
Potassium	K^+	0-2

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