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Evaluation of groundwater quality for agricultural use in Balzar, province the Guayas, Ecuador

Evaluación de la calidad del agua subterránea para uso agrícola en Balzar, provincia del Guayas, Ecuador

Avaliação da qualidade das águas subterrâneas para uso agrícola em Balzar Guayas, Equador

Leontes Leônidas Zambrano Barcos[1]*
Dioselina Clemencia Navarrete Chevez[1]
Ángel Alberto Arce Ramírez[1]
Marcos Paul Chila Zambrano[1]
Kleber Efraín Medina Rodríguez[1]
Athina Paola Centanaro Paredes[2]

[1]Universidad Agraria del Ecuador. Guayaquil, Ecuador. Dirección postal institucional 090104.
[2]Universidad Estatal de Milagro. Milagro, Ecuador. Dirección postal institucional 0901050.

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Abstract

Water is a natural and vital resource for living beings and ecosystems. Groundwater is of great importance for human consumption and agricultural activities, but over the years, it has become an increasingly scarce resource. The objective of this research was to evaluate the quality of groundwater extracted from wells used for crop irrigation in Balzar, province the Guayas, Ecuador. Four treatments and three repetitions were used; groundwater extracted from three wells plus a distilled water core. Physical, chemical, microbiological analyzes and a toxicity test with dark incubation were carried out on seeds of radish (*Raphanus sativus* L.), cocoa (*Theobroma cacao* L.) and corn (*Zea mays* L.). Turbidity exceeded permitted levels under TULSMA regulations and bicarbonate and chlorine levels exceeded the permitted limit. The microbiological analysis reflected fecal coliform values above 1000 UFC.100 mL^{-1} of water, indicating the presence of contaminants in the water sources. Phytotoxicity tests carried out with radish seeds showed a stimulation of radicle growth in well one and mild toxicity in wells two and three. For cocoa and corn seeds, moderate and mild toxicity was evident, respectively in the three wells. Although the maximum permissible limits were exceeded in some variables, the water from the three wells can be used for irrigation; however, there is a need to take measures to improve the quality of the water in these wells.

*Corresponding author:lzambrano@uagraria.edu.ec

Resumen

El agua es un recurso natural y vital para los seres vivos y los ecosistemas. Las aguas subterráneas son de gran importancia para el consumo humano y actividades agrícolas, pero con los años, se ha convertido en un recurso cada vez más escaso. El objetivo de esta investigación fue evaluar la calidad del agua subterránea extraída de pozos utilizados para el riego de cultivos en Balzar, provincia de Guayas, Ecuador. Se utilizaron cuatro tratamientos y tres repeticiones; agua subterránea extraída de tres pozos, más un testigo de agua destilada. Se realizaron análisis físicos, químicos, microbiológicos y un ensayo de fitotoxicidad con incubación en oscuridad a semillas de rábano (*Raphanus sativus* L.), cacao (*Theobroma cacao* L.) y maíz (*Zea mays* L.). La turbidez superó los niveles permitidos según las regulaciones TULSMA y los niveles de bicarbonatos y cloro excedieron el límite permitido. El análisis microbiológico reflejó valores de coliformes fecales por encima de 1000 UFC.100 mL^{-1} de agua, indicando la presencia de contaminantes en las fuentes de agua. Las pruebas de toxicidad realizadas con semillas de rábano mostraron un estímulo en el crecimiento de la radícula en el pozo uno y toxicidad leve en los pozos dos y tres. Para las semillas de cacao y maíz se evidenció toxicidad moderada y leve, respectivamente en los tres pozos. Pese a que se superaron los límites máximos permisibles en algunas variables, el agua de los tres pozos puede ser utilizada para riego, sin embargo, existe la necesidad de tomar medidas para mejorar la calidad del agua en estos pozos.

Palabras clave: agua de riego, calidad fisicoquímica, calidad microbiológica, pruebas de fitotoxicidad.

Resumo

A água é um recurso natural e vital para os seres vivos e ecossistemas. As águas subterrâneas são de grande importância para o consumo humano e para as atividades agrícolas, mas ao longo dos anos tornaram-se um recurso cada vez mais escasso. O objetivo desta pesquisa foi avaliar a qualidade da água subterrânea extraída de poços utilizados para irrigação de culturas em Balzar, Guayas, Equador. Foram utilizados quatro tratamentos e três repetições; água subterrânea extraída de três poços mais um núcleo de água destilada. Foram realizadas análises físicas, químicas, microbiológicas e teste de toxicidade com incubação no escuro em sementes de rabanete (*Raphanus sativus* L.), cacau (*Theobroma cacao* L.) e milho (*Zea mays* L.). A turbidez excedeu os níveis permitidos pelas regulamentações da TULSMA e os níveis de bicarbonato e cloro excederam o limite permitido. A análise microbiológica refletiu valores de coliformes fecais acima de 1000 UFC.100 mL^{-1} de água, indicando presença de contaminantes nos mananciais. Testes de fitotoxicidade realizados com sementes de rabanete mostraram estímulo ao crescimento de radículas no poço um e leve toxicidade nos poços dois e três. Para sementes de cacau e milho, foi evidente toxicidade moderada e leve, respectivamente, nos três poços. Embora os limites máximos permitidos tenham sido ultrapassados em algumas variáveis, a água dos três poços pode ser utilizada para irrigação, no entanto, há necessidade de tomar medidas para melhorar a qualidade da água nestes poços.

Palavras-chave: água de irrigação, qualidade físico-química, qualidade microbiológica, testes de fitotoxicidad.

Introduction

Water is a basic human right; however, its quality continues to be a problem in different areas. The evaluation of water quality allows control, treatment and mitigation actions to be taken, seeking to guarantee the supply of safe water (Valenzuela and Yucra, 2021). Water is a natural resource destined to fulfill different functions that contribute to the sustainability and survival of living beings (Castillo *et al*., 2022). It is a vital resource for living beings and their ecosystems, which is why comprehensive management should be made with emphasis on a sustainable world (Fuerte, 2019).

For Gutiérrez *et al*. (2022), groundwater is an important source of water for human consumption, crop irrigation, industrial use, among others, but it is becoming an increasingly scarce resource. The assessment of groundwater quality becomes relevant for activities that require its use, especially agriculture, which, according to the Statistics Division of the Food and Agriculture Organization of the United Nations [FAOSTAT] (2018), accounts for 70 % of the freshwater withdrawn in the world.

Water quality includes an assessment of its physicochemical and biological properties, as well as the effects that may influence the health of aquatic systems and humans. Population growth, pollution, surface leaching, runoff, and extensive use of fertilizers in agricultural areas are considered the main causes of groundwater quality deterioration (Kumar *et al*., 2021).

Groundwater is a resource that provides development opportunities to Balzar, with great importance for irrigation in different crops found in the area; being of great help in economic and social aspects, among others. For Llerena *et al*. (2017) the importance of irrigation water lies in the fact that agriculture is one of the activities that consumes large amounts of water, due to the fact that irrigation of crops needs water daily for them to develop. According to Grammont (2010), crop yields that can be obtained with irrigation can be more than double those that can be obtained in rainfed conditions.

For Kaloterakis *et al*. (2021) irrigation water quality influences soil salt content. The salinity content of irrigation water has an impact on plant growth. The slope of the land affects the increase of salinity content in the water of rivers and reservoirs, due to soil erosion, which transports minerals to rivers and subway aquifers.

The quality of water in rivers, groundwater and reservoirs depends on several factors, such as general geology, ion exchange, degree of mineral weathering, evaporation, groundwater flow and different human activities. Groundwater in different areas may have different qualities and properties for agricultural use (Pant *et al*., 2021).

In another context, and as mentioned above, in the province of Guayas, specifically in La Carlota area of Balzar canton, there are different crops that are irrigated with groundwater extracted from wells, including radish (*Raphanus sativus* L.), a plant belonging to the Brassicaceae family, corn (*Zea mays* L.) of the Poaceae family, and cocoa (*Theobroma cacao* L.), a perennial plant of the Malvaceae family.

Accordingly, it is necessary to review the quality of groundwater used for irrigation purposes in order to apply corrective measures where necessary. The objective of this research was to evaluate the quality of groundwater from wells used for crop irrigation in La Carlota area of the Balzar canton, Guayas province, Ecuador.

Materials and Methods

Description of the study area

The study was conducted in three groundwater catchment points located in La Carlota precinct of Balzar canton, Guayas province, Ecuador. Average annual temperature of 25 °C and precipitation of 1,500 mm per year [Instituto Nacional de Metereología e Hidrología (INAMHI), 2018].

The coordinates, elevation with respect to sea level (masl) and distance, are presented in table 1.

Table 1. Location of the collection points, La Carlota of the Balzar canton, province of Guayas, Ecuador.

Wells	Latitude	Longitude	Elevation (masl)	Distance (m)
1	1°9'38.90"S	79°45'54.55"O	63	P1-P2 (641)
2	1°9'41.41"S	79°46'15.19"O	58	P2-P3 (631)
3	1°9'18.44"S	79°45'55.63"O	52	P3-P1 (929)

Research type and design

The research was of an applied type (Galindo, 2020). The design was non-experimental, transectional, since specific samples were taken to analyze microbiological and physicochemical parameters and determine their quality. Phenomena are observed as they occur in their natural context, and then analyzed or compared with a standard. Transectional designs collect data at a single point in time. Their purpose is to describe variables and analyze their incidence and interrelationship at a given time. Four treatments and three replicates were evaluated. The treatments corresponded to water from each of the wells, plus a distilled water control.

Groundwater sampling

Irrigation water was extracted by pumping (Altamira pump, model Flux 12, Mexico), letting out the initial flow at 20 $L.s^{-1}$ for 5 min. Subsequently, it was poured into a container to achieve homogeneity. For the physicochemical analyses, 3 samples of 1 L were collected for each well. The samples were collected in sterile, hermetically sealed plastic bottles to avoid oxidation of the compounds in contact with air. For microbiological analyses, 3 samples of 0.75 L were collected for each well. In this case, sterile glass containers (Ilmabor, model TGI 1000 mL, Germany) were used.

Physical, chemical and microbiological analyses

The analyses were performed at the microbiology laboratory of the Universidad Agraria del Ecuador. The water quality of the wells used for irrigation was determined through sampling and subsequent physical, chemical and microbiological analyses and a phytotoxicity test. Water quality characterization was performed based on the reference values proposed in the exto Unificado de Legislación de Medio Ambiente, TULSMA (Ministerio del Ambiente del Ecuador, 2016).

The physical variables evaluated were temperature (°C), electrical conductivity (EC) ($dS.m^{-1}$), total dissolved solids (TDS) ($mg.L^{-1}$), turbidity (UNT) and hardness ($mg.L^{-1}$). With the exception of turbidity and hardness, all of the above parameters were measured *in situ*. Temperature was measured with a thermometer (model E5565AS1, Femometer, United States of America), pH with a portable digital pH meter (HACH, model HQ11D, United States of America). A portable conductivity meter (HACH, model Q14D, United States of America) was used to measure electrical conductivity and dissolved solids.

The chemical variables evaluated were the concentration of Ca^{2+}, Na^{+}, Mn^{2+}, CO_3^{2-}, HCO_3^{3-}, Cl^{-}, SO_4^{2-}, $NO_3^{-,}$ Fe^{2+}, B^{3+}, pH and sodium adsorption ratio (SAR). These analyses were performed at the Laboratorio de Análisis de Suelos, Tejidos Vegetales y Aguas de la Estación Experimental Tropical Pichilingue "INIAP" (Atomic Absorption method and EPA 6020 method, respectively). The microbiological variables evaluated were total coliforms and fecal coliforms, which are a sub-group of total coliforms, represented by heat-resistant microorganisms that are specific to the intestinal tract of warm-blooded animals, including humans. Among these bacteria are *Escherichia coli* and species of the genera *Klebsiella*, *Enterobacter* and *Citrobacter*. The samples were taken to the laboratory "AGROLAB", the determination of coliform bacteria was performed by the multi-tube fermentation method of APHA *et al*. (2017), with results expressed in $MPN.100\ mL^{-1}$.

Toxicity and germination tests

To test the phytotoxic effect of the groundwater extracted from the wells analyzed, the method proposed by Rodríguez *et al*. (2014) was used. Twenty radish, corn and cocoa seeds (because they are established crops in the area where the evaluated wells are located) were placed in a Petri dish with filter paper (Cytiva, model R201, Germany) moistened with 10 mL of the water samples to be evaluated. The plates were incubated in darkness for 4 days in the microbiology laboratory. Relative germination (GRS) (Equation 1), relative radicle growth (RGR) (Equation 2) and germination index (GI) (Equation 3) were determined.

$$RS = \frac{Sprouted\ seed}{Control\ sprouted\ seeds} * 100 \quad (1)$$

$$RGR = \frac{Radicle\ length}{Control\ radicle\ length} * 100 \quad (2)$$

$$I = \frac{GRS}{CRR} * 100 \quad (3)$$

The normalized residual germination index (NGI) (Equation 4) and the root elongation index (REI) (Equation 5) were calculated according to Bagur *et al*. (2011). Both indexes establish toxicity values from -1 to 0, which are categorized as follows: between 0 and -0.25, low toxicity; between -0.25 to -0.5, moderate toxicity; between -0.5 and -0.75, high toxicity; and between -0.75 and -1, very high toxicity. Values above 0 indicate root growth or hormesis (Bagur *et al*., 2011).

$$NGI = \frac{Sprouted\ seeds - Control\ sprouted\ seeds}{Control\ sprouted\ seeds} \quad (4)$$

$$REI = \frac{Radicle\ length - Control\ radicle\ length}{Control\ radicle\ length} \quad (5)$$

Data processing and analysis

The data obtained were transcribed in the Excel program. An analysis of variance (ANOVA) and Tukey's mean comparison test, with a confidence level of 95 %, were performed for the phytotoxicity test. The statistical test was performed individually for each species. The statistical package Statical Analisys System (SAS®) (SAS, 2014) was used for data processing.

Results and discussion

Physical, chemical and microbiological analyses

The physical analyses reflected that turbidity and total solids were presented below the ranges for the three wells. Table 2 presents the results of the analyses of the physical parameters and the appropriate ranges established in the TULSMA (Ministerio del Ambiente del Ecuador, 2016) for irrigation water.

Table 2. Physical analysis of groundwater extracted from wells evaluated in the province of Guayas, Ecuador.

Variables	Well 1	Well 2	Well 3	Required ranges for irrigation water*
Temperature (°C)	27.1	26.7	27.4	20 – 40
Turbidite (UNT)	3.3	13.6	15.6	100
STD (mg.L^{-1})	47.0	62.0	66.0	450 – 2000
EC (dS.m^{-1})	0.13	0.10	0.13	0 – 3
Hardness (mg.L^{-1})	42.0	51.0	55.0	0 – 500

TDS: total dissolved solids.
*TULSMA (Ministerio del Ambiente del Ecuador, 2016).

These results coincided with those reported by Castillo *et al*. (2022) regarding temperature between 25.5 °C and 27.4 °C; indicating, that temperature levels are an indicator of water quality which, in turn, exerts direct influence on the behavior of other quality indicators, such as the absence of oxygen, pH, electrical conductivity, among others.

All the values reflected should be considered from the agricultural point of view, since the use of the resource in unsuitable conditions could represent a source of inoculum of phytopathogens. Brousett *et al*. (2018) indicated that high turbidity values can influence the rate of bacterial proliferation, protecting microorganisms from the effects of disinfection and stimulating their development. High turbidity is related to high sediment content, which can be negative for localized irrigation systems, due to clogging.

Another aspect to highlight is the low salinity in the three wells analyzed. The values recorded are lower than those reported by Castellón *et al*. (2015), who evaluated groundwater from wells intended for irrigation, finding that in all samples, the water did not exceed 0.7 dS.m^{-1}, qualifying them as high quality for agricultural use.

The groundwater extracted from the three wells can be used for irrigation; however, there is a need to evaluate the situation presented in some parameters to improve water quality. In this sense, Conde *et al*. (2023) pointed out that irrigation alternatives should be sought that allow greater water productivity, evaluating the amount of water applied to crops through irrigation, with a control of the irrigation regime, the volume of water applied and the yield.

Table 3 shows the results of the chemical analyses and the maximum permissible limits according to the regulations established in the TULSMA. In this aspect, potassium (K^+) stands out in well one, with a concentration of 2.34 mg.L^{-1}, exceeding the maximum permissible limit (mg.L^{-1}). This could be attributed to the edaphic fertilization and leaching that occurred during the planting of short-cycle crops prior to sampling. Kumar *et al*. (2021) reported that leaching and the permanent use of chemical fertilizers influence the detriment of groundwater quality.

Table 3. Chemical variables of groundwater extracted from wells evaluated in the province of Guayas, Ecuador.

Variables (mg.L^{-1})	Well 1	Well 2	Well 3	Permissible limit*
Ca^{2+}	15.70	10.90	14.60	100
Mn^{2+}	0.04	0.03	0.05	0.2
Na^{+}	3.59	2.09	4.44	3.0 - 9.0
K^{+}	1.56	2.34	1.56	2
HCO_3^{3+}	43.90	29.30	46.40	1.5 - 8.5
Cl^{+}	17.50	14.00	17.50	4 – 10
SO_4^{2+}	2.00	3.40	3.50	250
Fe^{2+}	0.33	0.78	0.51	5
B^{3+}	0.05	0.05	0.06	0.75 – 1
pH	7.00	7.00	7.40	6.5 – 8.4
RAS (meq.L^{-1})	0.21	0.14	0.26	3 – 9

*TULSMA (Ministerio del Ambiente del Ecuador, 2016).

A high concentration of bicarbonates was observed in the three wells, significantly exceeding the maximum permissible limit of 8.5 mg.L^{-1} (table 3). Irrigation with this type of water can limit the production of certain fruit trees, due to the increase in pH it causes in the soil. The magnitude of this effect depends on the concentration of bicarbonates, the buffering capacity of the soil and the sensitivity of the referenced plant (Bennardi *et al*., 2018). Cl^- was another element that exceeded the maximum permissible limits. Gutiérrez *et al*. (2022) indicated that irrigating with water with high Cl^- content, can be detrimental to soil micro fauna, in addition to having a deleterious effect on roots, inhibiting nutrient uptake. Alcívar *et al*. (2017) in their research in Ecuador in well water samples, reported values above the maximum limit allowed by TULSMA, such as hardness, total dissolved solids, ammonium, aluminum and nitrates.

Since the levels of Ca^{2+} and Na^+ were very low (table 3), from a chemical point of view, there would be no major problem for the use of these wells for irrigation. These values differ from those reported by Bagur *et al*. (2011), who obtained high levels of salts derived from Ca^{2+} and Na^+, which are highly soluble, thus limiting the increase in the sodium adsorption ratio. Mn^{2+} was found to be within the permissible range of agrua for irrigation.

Table 4 shows the results of the microbiological analysis and the maximum permissible limits according to the regulations established in the TULSMA. The microbiological analysis revealed that there is a high level of fecal coliforms, exceeding the maximum permissible limit in the three wells; in this sense, Ríos *et al*. (2017) pointed out that finding total and fecal coliforms in irrigation water, confirms that these as indicators, evidence that the quality of the water resource is affected, being able to cause various diseases such as diarrheal syndrome, so it is necessary to have strategies that allow an adequate management of it.

Although these values do not necessarily represent a risk for agricultural use, the associated dangers for human health and the environment should be considered. Water contaminated with coliforms should be restricted for agricultural use. The origin of this contamination could be due to wastewater management in the communities settled in the study area, where sanitation is precarious and sewerage is nonexistent, so that households must manage their waste through septic tanks, latrines, among others.

Table 4. Microbiological variables of groundwater extracted from wells evaluated in the province of Guayas, Ecuador.

Variables	Well 1	Well 2	Well 3	Maximum allowed*
	(NMP.100 mL^{-1})**			
Total coliforms	20000	7000000	500000	-
Fecal coliforms	6000	500000	3000	1000

*TULSMA (Ministerio del Ambiente del Ecuador, 2016).
**Most probable number per 100 mL of water sample

Phytotoxicity test

For the means corresponding to relative germination, relative radicle growth and germination index, there were no significant differences ($p>0.05$) between treatments for relative germination in *R. sativus* and *Z. mays*, while for *T. cacao* there were ($p<0.05$), with respect to the control, which may indicate a possible hormesis phenomenon (growth stimulation) (Bagur *et al*., 2011) (table 5).

Table 5. Comparison of means of phytotoxicity test variables by species and treatment.

Species	Well	Relative germination (%)	Relative radicle growth (%)
R. sativus	1	100.00[a]	3.81[a]
	2	95.00[a]	4.23[a]
	3	96.67[a]	2.48[b]
	Distilled water	95.00[a]	2.38[b]
Z. mays	1	100.00[a]	2.75[a]
	2	100.00[a]	2.45[a]
	3	96.67[a]	2.77[a]
	Distilled water	90.00[a]	2.22[a]
T. cacao	1	100.00[a]	1.18[a]
	2	100.00[a]	1.07[a]
	3	100.00[a]	1.20[a]
	Distilled water	80.00[b]	0.87[a]

[a, b]Values with the same letter in each group of data are not statistically different according to Tukey's test at 95 % reliability.

Table 6 shows the values of residual germination index and root elongation index for the three species analyzed. The results of the residual germination index indicated root growth in *R. sativus* (0.03), *T. cacao* (0.67) and *Z. mays* (0.02) with the groundwater extracted from the three wells. In well one, high levels of K^+ were found, while in all three wells high levels of Cl^- and bicarbonates were found, which could have favored germination. On the other hand, the *T. cacao* and *Z. mays* crops showed negative root elongation index values in all wells, indicating a moderate level of toxicity for *T. cacao* and mild for *Z. mays*. The *R. sativus* crop presented positive values for this index, with the exception of well 2.

It is important to note that some ions, such as Na^+, Cl^- and B^{3+}, can accumulate in crops in high concentrations to reduce plant development and yield, and may even cause clogging of some irrigation systems. Likewise, the nutrients contained in the water should be considered when making the fertilization program for each crop. According to Illa (2016) the chloride ion is an important producer of phytotoxicity, due to its characteristics (making it highly mobile both in the soil and in the plant), it produces significant reductions in growth, antagonizes nitrate absorption, demonstrating that toxicity is directly proportional to the concentration of chlorides.

Table 6. Residual germination and root elongation index for the species evaluated.

Species	Well	IGN	IER
R. sativus	1	0.03	1.61
	2	0.05	-0.28
	3	0.02	0.01
Z. mays	1	0.11	-0.24
	2	-0.11	-0.10
	3	0.07	-0.18
T. cacao	1	0.67	-0.52
	2	0.67	-0.53
	3	0.67	-0.41

IGN: normalized residual germination index.
IER: root elongation index.

Toxicity tests conducted with radish seeds showed stimulation of radicle growth in well one and mild toxicity in wells two and three (-0.28). Groundwater extracted from the three wells tested caused moderate toxicity to cocoa seeds and mild toxicity to corn. These results indicate the need to take measures to improve water quality in the wells evaluated.

Conclusions

According to the physical, chemical and microbiological analyses, the water from the three wells can be used for irrigation, except for direct consumption crops, due to the amount of coliforms present.

Toxicity tests with radish seeds determined growth stimulation with water from well one and toxicity with wells two and three. Cocoa and corn seeds showed moderate and mild toxicity respectively in all three wells.

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