Assessment of animal drinking water quality in livestock farms in Galapagos Islands

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Abstract — **The purpose of this research was to determine the quality of water for bovine consumption on livestock farms in the El Progreso parish - Galapagos by applying a quality index following the Brown methodology proposed by the National Sanitation Foundation of the United States. Information was collected from the livestock farms through a socio-environmental diagnosis of the area, where five localities were considered: San Joaquín, Las Goteras, Cerro Verde, Puerto Chino and El Progreso from which fifteen livestock farms were selected for the respective sampling of the sources. of water. Therefore, nine parameters were considered for the analysis of the respective water sources: pH, TDS, Fecal Coliforms, electrical conductivity, hardness, nitrites, phosphates, temperature and turbidity. Of the total livestock farms monitored, three of them presented a rating of Good quality in a range of 70 to 90, while the remaining farms recorded values with a Medium classification, which are those that recorded AQI values between 51 to 70 according to the criteria established by the NSF. This research highlights the importance of frequently carrying out analyzes of the water sources from which cattle drink to determine the quality of the resource, and also provide technical advice to ranchers in the area on the management and cleaning of the reservoirs.**

Keywords: **reservoirs, canals, quality index, livestock farms, NSF, physicochemical parameters.**

Resumen — **El propósito de esta investigación fue determinar la calidad del agua para consumo bovino en fincas ganaderas de la parroquia El Progreso-Galápagos mediante la aplicación de un índice de calidad siguiendo la metodología de Brown propuesta por la Fundación Nacional de Saneamiento de Estados Unidos. Se recolectó información de las fincas ganaderas mediante un diagnóstico socioambiental de la zona, donde se consideraron cinco localidades: San Joaquín, Las Goteras, Cerro Verde, Puerto Chino y El Progreso, de las cuales se seleccionaron quince fincas ganaderas para el respectivo muestreo de las fuentes de agua. Por lo tanto, se consideraron nueve parámetros para el análisis de las respectivas fuentes de agua: pH, TDS, Coliformes Fecales, conductividad eléctrica, dureza, nitritos, fosfatos, temperatura y turbidez. Del total de fincas ganaderas monitoreadas, tres de ellas presentaron una calificación de Buena calidad en un rango de 70 a 90, mientras que las fincas restantes registraron valores con una clasificación Media, que son aquellas que registraron valores de ICA entre 51 a 70 según los criterios establecidos por la NSF. Esta investigación resalta la importancia de realizar análisis frecuentes de las fuentes de agua de las que bebe el ganado para determinar la calidad del recurso, así también de brindar asesoría técnica a los ganaderos de la zona sobre el manejo y limpieza de los reservorios.**

Palabras Clave: **reservorios, encañadas, índice de Calidad, granjas ganaderas, NSF, parámetros fisicoquímicos.**

I. INTRODUCTION

SINCE water resources have a significant impact on the ecosystem, environmental health, and sustainable development [1], it is crucial to study water quality, particularly that of resources meant for animal consumption, in order to ensure both their continued good condition and the safety of all those who use them [2].

A great deal of water management efforts in Ecuador have concentrated on increasing the quantity of available water, with little regard for the resource's quality [3]. In addition, the conservation of primary water sources is beset by difficulties related to accessibility and limited economic resources, particularly in the island region because of its hydrogeological features [4].

Vulnerable populations are mostly responsible for the problem of water resource contamination in less developed nations as a result of inadequate basic sanitation [5]. The few studies on the water quality of San Cristóbal Island's El Progreso parish, however, leave a lot of problems unanswered, particularly about the suitability of the water for animal use.

The geological richness of the Galapagos Islands, comprising volcanic, sedimentary, and metamorphic rocks, and their volcanic origin are what define them [6]. This becomes important for study since the area's geological makeup, which is primarily composed of sedimentary, metamorphic, or volcanic rocks, affects the physical-chemical properties of the surface water, including its odor [7].

The ravines that form on the island's slopes are the primary source of water for the productive farms in the El Progreso- San Cristóbal parish. These ravines are used directly for agricultural production and cattle hydration [8]. In order to prevent circumstances that could negatively impact the behavior and health of the animals, it is imperative that a water quality index (ICA-NSF) be used in this study to ascertain the incidence in water for animal consumption [9]. The study's goal is to assess the water quality for animal usage on profitable farms in the El Progreso parish (Galápagos). Additionally, it is established as

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a hypothesis that, based on the National Health Foundation of the United States' (NHF) classification of the index, the quality of water for animal consumption on productive farms is medium quality (between 51 and 70 points).

II. MATERIALS AND METHODS

A. Study area

This research was carried out in September 2023, during the rainy season, in fifteen livestock farms in the El Progreso parish of the San Cristóbal canton, Galapagos province, Republic of Ecuador. The parish is located at the eastern end of the archipelago, between 0° 40' 40" and 0° 57'00" south latitude and 89° 14' 10" and 89° 37' 30" west longitude, as shown in figure 1. The altitude of the farms ranges between 320 and 600 meters above sea level.

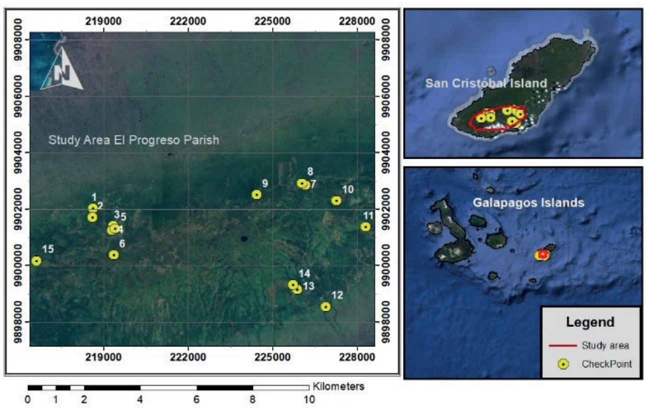

Fig. 1. Geographic location of the study area - "El Progreso Parish". Images taken from [10] and [11].

The study was descriptive in nature, non-experimental, and involved analyzing and interpreting the current nature and composition of pertinent aspects of each detected water sample in order to calculate the water quality index [12]. There are roughly 535 people living in the El Progreso parish. Based on the findings, of the total of 76 cattle ranchers registered in the database of the Ministry of Agriculture and animal of San Cristóbal's Technical Office an intentional sample of 20% was selected, resulting in 15 animal farms to carry out this study [8]. Due to the number of producers, farms were chosen that have participated in the Livestock Field School programs carried out by the technical office and that have water reservoirs to give livestock drinking, which facilitated the study of monitoring water for animal consumption [11].

B. Socio-environmental diagnosis of the livestock farms of the El Progreso parish (Galápagos)

In order to identify the research area of the El Progreso parish (Galápagos), the base information was processed using ArcGIS version 10.5. A GARMIN eTrex 10 GPS model was used to calculate the farms' geographic coordinates and height [14]. Then, a survey was made up by fourteen questions adapted from [15], [16], and [17]; this instrument was used to find out the current state of water management and storage on livestock farms. It was divided into three sections: sociodemographic, productive, and cattle water consumption [8]. Using Microsoft Excel software, the survey data were tallied, and pie charts were used to illustrate the average response [18].

C. Determination of the water quality index in the livestock farms of the El Progreso Galapagos parish

Using the US EPA Standards-600/4-79-0120 "Methods for the Collection and Analysis of Water and Waste," the samples were taken straight from the surface of the livestock drinking fountains. Each point was measured for pH, total dissolved solids (TDS), and temperature in a sterile bottle (500 mL) [16].

A HANNA brand pH meter, given by the Environmental Chemistry laboratory of the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, was used to measure pH, TDS, and temperature. Total coliform analysis was done at the ESPAM MFL facilities; nitrite and phosphate analysis were done at the Technical University of Manabí, which is situated in Portoviejo. The turbidity analysis was done in the Terrestrial Ecology Laboratory, which is part of the Universidad San Francisco de Quito, San Cristóbal Campus, Galapagos Science Center. Table I displays the techniques.

Brown's methodology, which is a modified version of the UWQI (Universal Water Quality Index), was used to obtain a simplified index to establish the quality of water used for animal consumption [19] through the weighted arithmetic average of nine variables, this research being a pioneer in the evaluation of the quality of animal drinking water in the livestock sector of the island of San Cristóbal-Galapagos, evidenced a need to develop applied research in livestock areas that are aligned with the precepts of environmental sustainability.

TABLE I
PARAMETERS TO BE ANALYSED (NSF)
IN THE STUDY. ADAPTED FROM [20], [21]

Parameter	Method	Weight NSF
Total coliforms	AOAC 991.14	---
pH	Multiparameter meter	0.12
Water hardness	Test Strips	---
Electrical conductivity		---
Temperature	Pocket meter	0.1
Total Dissolved Solids (TDS)		0.08
Turbidity	Turbidimetric	0.08
Nitrates	Ultraviolet spectrophotometry	0.17
Phosphates	Checker Hanna HI706	0.17

The determination of the water quality index was carried out using Microsoft Excel software, automatically calculating the parameters that directly influence water quality. With the quality factor, the weighting factor and the equation defined for the calculation, the ICA-NSF index was determined for each farm [23]. [24] mention that the weighting factor is obtained from the value of the laboratory analysis of the parameter in the quality curves, which reflect the professional criteria of responses on a scale (Q) of 0-100, which decreases with the increase in water pollution. To calculate the Brown Index, the additive method was used, which consists of the weighted linear sum of the by-products of each quality parameter and the weights assigned to each one.

The water quality index was determined through the equation 1 [22]:

$$WQI = \sum_{i=1}^{i=n} (Q_i * W_i) \quad (1)$$

Where:

W_i: represents the importance or weighting factor of the variable (i) with respect to the remaining variables that make up the index.

Q_i: corresponds to the scale factor of the variable, depends on the magnitude of the variable and is independent of the rest.

i: represents the variable or parameter considered.

For the determination of the water quality index, a summary matrix was developed with the parameters analyzed according to their methods and corresponding weights described in table 1 according to [20], as well as with the result of the analysis by parameter obtained from the laboratory and the Q value obtained from the relevant graphs, as indicated in table 2, this table is a projection of how the AQI was calculated during the data analysis.

TABLE II
MATRIX MODEL DESIGNED FOR THE CALCULATION OF THE ICA-NSF WATER QUALITY INDEX. ADAPTED FROM [23]

Parameter	Result	Unit	Q. Value	Weighting factor	Subtotal
Dissolved oxygen [DO]		mg/L		0.17	
Faecal coliforms		UFC/100 mL		0.15	
pH		-		0.12	
DBO_5		mg/L		0.10	
Nitrates		mg/L		0.10	
Phosphates		mg/L		0.10	
Temperature		ºC		0.10	
Turbidity		NTU		0.08	
Total dissolved solids		mg/L		0.08	

The NSF quality indicators were established using the methods suggested by [21], [25] then used the derived ICA values to classify the results as excellent, good, half-bad, bad, and very bad, as shown in table III.

TABLE III
WATER QUALITY CLASSIFICATION ADAPTED FROM [26]

Range	Class	Color
0-25	Very bad	
26-50	Bad	
51-70	Medium	
71-90	Good	
91-100	Excellent	

III. RESULTS AND DISCUSSION

Of the total number of farmers surveyed, 87 % consider their water source to be crystal clear, while 13 % indicate the presence of turbidity as reflected in figure 2a. While for the odor variable, 100 % of respondents consider that the water sources of their farms for cattle consumption do not have an odor, as evidenced in figure 2b.

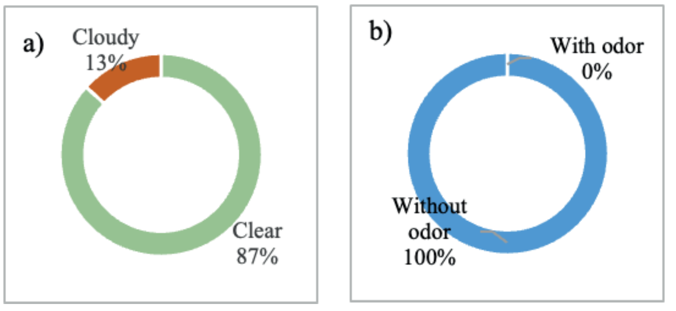

Fig. 2. Perception of surveyed farmers regarding a) color and b) odor of water sources for bovine consumption.

For [27], physicochemical factors such as iron, manganese and tannins, organic matter, which is produced when the remains of plants and animals decompose, cause water to color, generating an impact on organoleptic characteristics such as color, smell and taste. According to [28], the number of total coliforms influences the water's odor. Similarly, the presence of other dissolved contaminants, including heavy metals, impacts the water's quality and suitability for human uses, including agriculture and raising cattle.

The findings of the biological and physicochemical analyses of the 15 farms in the parish of "El Progreso" are shown in Table IV.

TABLE IV
RESULTS OF THE PHYSICOCHEMICAL AND BIOLOGICAL PARAMETERS EVALUATED

POINT	PLACE	pH	T(°C)	PO_4 (mg/l)	NO_3 (mg/l)	TDS (mg/l)	TURBIDITY (NTU)	HARDNESS (ppm)	EC	TOTAL COLIFORMS (UFC / 100 mL)
1	San Joaquín	7.32	20	2.45	5.33	44	3.70	445	93	<1.0
2	San Joaquín	6.67	20	2.25	2.10	14	1.46	267	29	<1.0
3	San Joaquín	10.07	20	1.22	2.23	36	2.03	267	76	<1.0
4	San Joaquín	8.4	20	1.53	0.33	10	1.61	356	21	9.0×10^1
5	San Joaquín	8.12	20	1.84	3.84	13	4.27	356	27	<1.0
6	San Joaquín	7.4	20	3.67	0.33	14	2.36	267	42	<1.0
7	Las Goteras	7.79	20	1.53	0.68	10	1.83	267	21	<1.0
8	Las Goteras	7.5	20	0.61	1.84	12	1.26	89	25	1.0×10^1
9	Las Goteras	6.5	20	3.37	1.55	17	0.82	89	36	<1.0
10	Cerro Verde	6.55	20	1.22	0.5	12	1.50	445	25	<1.0
11	Cerro Verde	7.10	20	1.53	0.35	51	0.36	445	108	<1.0
12	Puerto Chino	7.36	20	1.22	1.23	44	0.99	445	93	<1.0
13	Puerto Chino	7.45	20	3.98	1.16	36	0.54	178	76	1.0×10^1
14	Puerto Chino	7.08	20	1.22	1.72	35	4.45	445	74	2.0×10^1
15	El Progreso	8.16	20	5.2	5.58	55	8.26	356	117	<1.0

It was found that, in comparison to the other farms that maintain a neutral pH, farms 3, 4, 5, and 15 in the town of San Joaquín had high pH values. The water sources in the various locations maintained a temperature of 20˚C. El Progreso recorded the greatest total dissolved solids content, with a maximum of 55 mg/L, while Cerro Verde recorded 51 mg/L. Farm 15 had a turbidity rating of 8.26 NTU, a value below the maximum acceptable level in drinking water for animals [29]. With hard water in mind, the hardness measured values at Puerto Chino, San Joaquín, and Cerro Verde were 445 PPM. At last, farm 4 was found to have a higher concentration of total coliforms, measuring 9.0 × 101 nmp / 100 mL.

The following conditions must be met by water used for livestock: a pH between 6 and 9, a maximum of 3000 mg/L of total dissolved solids (TDS), a maximum of 1000 NMP of fecal coliforms, and a maximum of 50 mg/L of nitrates (NO_3), as stated in Ministerial Agreement 097-A [30].

Farm 3's pH exceeds the maximum allowable limit (10.07), which can be explained by high photosynthetic activity caused by the community of bacteria and algae found in surface water sources. This would supersaturate the aquatic system with oxygen, depleting carbon dioxide and raising the pH of the water. This is one explanation offered [31] for the alkaline pH values observed. Nonetheless, [7] clarify that the values of the various parameters in the water are changed by the geological makeup of the region where surface or subsurface runoff passes, which is primarily composed of volcanic, sedimentary, or metamorphic rocks.

For instance, the discharge of minerals like iron from volcanic rocks can lower the pH of the water by acidifying it [32], [33]. However, carbonates found in sedimentary rocks can function as pH buffers, maintaining a neutral or slightly alkaline pH [34], [35] Similarly, minerals released by metamorphic rocks might affect the water's alkalinity [36]. Table V presents the classification according to the NSF ICA index.

TABLE V
RESULTS OF THE NSF WATER QUALITY INDEX.

Farm	Place	WQI NSF	Classification NSF
1	San Joaquín	63.96	Medium
2	San Joaquín	62.70	Medium
3	San Joaquín	55.45	Medium
4	San Joaquín	68.00	Medium
5	San Joaquín	61.50	Medium
6	San Joaquín	67.70	Medium
7	Las Goteras	69.00	Medium
8	Las Goteras	73.00	Good
9	Las Goteras	63.00	Medium
10	Cerro Verde	66.04	Medium
11	Cerro Verde	71.00	Good
12	El Chino	71.00	Good
13	El Chino	67.10	Medium
14	El Chino	66.40	Medium
15	El Progreso	60.70	Medium

Based on the NSF's established criteria, farms 8, 11, and 12 were classified as having good quality, with AQI values between 51 and 70. The remaining farms were rated as having a medium quality. These results are based on the results of the water quality index. The water sources with the highest values for pH, hardness, total dissolved solids, turbidity, and total coliforms were classified as medium. Figure 3 depicts how water supplies behave on farms raising livestock.

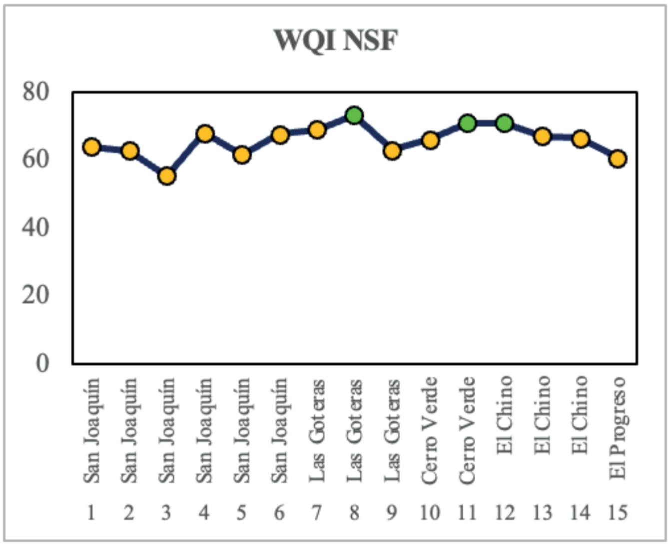

Fig. 3. Behavior of the Water Quality Index of the farms.

Regarding what solutions can be proposed to improve water quality, considering the nature of the special regime that the Galapagos Islands have, there are three possible solutions to be implemented in cattle farms: a treatment with hydrogen peroxide to reduce the microbiological load to 3 % to eliminate the microbiological load of the drinking water [37], a chlorination treatment (1:5 NaClO 15 % m/v is diluted in water (36 g/L)) as it improves growth performance without detrimental side effects on health or nutrient digestibility [38] and a third treatment with oxygen-enriched drinking water that has potential effects on cattle fattening performance [39].

The results of this research become a key piece to reduce knowledge and technology gaps in the livestock sector, allowing the strengthening of local capacities of livestock farmers; this is related to what is described by [40] who mention that livestock activity has one of the largest environmental footprints and therefore should promote practices that reduce these impacts.

The situation of livestock in Galapagos is going through a series of difficulties and limitations for its maintenance and development within the framework of sustainability [41]; since it is a protected natural area with unique characteristics, it is necessary to minimize the impact of anthropic activities without conditioning the satisfaction of the basic needs of the island's inhabitants [42]; that is why getting traditional livestock farming to transition to more sustainable livestock farming with access to information on animal and environmental health will lead to better decision-making in the livestock sector.

With regard to environmental health, the monitoring of water quality through a physicochemical analysis is of utmost importance for its productivity since, in ruminants, especially cattle, water consumption is directly related to dry matter consumption, so an animal that drinks little water due to its availability, palatability or low quality can manifest stress and consequently meat or milk production will be decreased [43].

IV. CONCLUSION AND RECOMMENDATION

The average ICA NSF water quality index was 65.78, placing it in the medium quality category. Of the total number of participating farms, 20 % (3 farms) have good quality water and 80 % (12 farms) have medium quality water. The quality of water on cattle farms is affected by sanitation problems, mainly due to the way water is stored and exposure to the elements.

The results obtained serve as a basis for future studies that analyze the quality of water for bovine consumption in different seasons between dry and rainy seasons, which could be carried out in the coming years, including in the analysis of water the study of minerals or heavy metals depending on how each livestock farm obtains water.

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