hydrology

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Proposal for a Water Quality Index for Supplying Rural Communities in the Brazilian Federal District

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Abstract

The environmental characterization of a given region is fundamental for decision-making by public administrators and, consequently, for sustainable development. Regarding water quality, establishing the use of this resource is a priority, as specific parameters must be defined for each type of usage, to determine water quality in that region. The objective of this study was to propose a water quality index for supplying rural communities, given that the most commonly used indices relate to urban water after treatment. To construct the index, water samples were collected over 12 months from 29 sampling points across seven rural centers without the governmental service of treated water. Principal component analysis was used to identify the most representative parameters, and final weights were assigned considering Brazilian regulatory standards. The results obtained revealed a very simplified index with five variables and five usage classes, with scores ranging from simplified to advanced treatment. It is hoped that the proposed index will better guide rural communities and generate improved policies for water resource management in the Brazilian Federal District and support public policy development in rural areas with limited water treatment infrastructure.

Keywords: water resources; public policy; land use; regional characteristics; water use

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Academic Editor: Evangelos Rozos

Received: 28 July 2025
Revised: 2 September 2025
Accepted: 3 September 2025
Published: 6 September 2025

Citation: Oliveira-Filho, E.C.; Muniz, D.H.F.; Gonçalves, E.C.M.; Malaquias, J.V. Proposal for a Water Quality Index for Supplying Rural Communities in the Brazilian Federal District. *Hydrology* **2025**, *12*, 233. https://doi.org/10.3390/hydrology12090233

1. Introduction

Understanding the environmental characteristics of a given region is a fundamental tool for its sustainable development. This includes studies on the characterization of natural resources, with water being one of the most important. Amid ongoing conflicts over water use in Brazil, there is a pressing need for tools capable of quickly and reliably answering questions related to this natural resource.

One of the most complex issues is the evaluation of water quality, which must be directly related to its intended use. Therefore, a clear definition is needed of the objectives to be achieved with this quality index, as water uses include irrigation, recreation, industry, public supply, and the maintenance of aquatic life, among others [1].

In general, the factors that influence aquatic chemistry are well known, but it is difficult to predict and generalize how these factors interact and to foresee the outcome of this interaction at the regional level, since the results differ between locations [2,3]. Knowledge of these interactions is fundamental for regional planning, sustainable management of natural water resources, and environmental protection [2].

In this regard, the adoption of chemical, physical, and biological methods has been the primary strategy for defining these standards. In any case, the data obtained must be synthesized, processed, and organized to represent the best quality value for their intended use. Water quality indices aim to provide a single value for the quality of a water body, and as a result, the formulation and use of indices has been strongly advocated by agencies responsible for water supply and pollution control. Since water quality data are collected through sampling and analysis, there is a need to translate these data into an easily understandable form [4].

In Brazil, the main Water Quality Index (WQI) used and implemented by the Environmental Company of the State of São Paulo (CETESB) was adapted from that of the National Sanitation Foundation of the United States in 1975 to assess the quality of water for supply after conventional treatment [5]. Several Brazilian states have adopted the CETESB WQI, which is now standardized by the Brazilian National Water Agency (ANA). However, Brazil is a country of continental dimensions and differentiated regional conditions with wide climatic and geomorphological variation, with 7 biomes, 3 ecotones, and 79 ecoregions [6]. Therefore, there is a pressing need for knowledge of the specific characteristics of the environments and their water bodies, since what is considered a pollutant in some cases may be the natural condition in others [7]. In other words, the impacts of any activity on water bodies can only be measured with prior knowledge of their natural characteristics. Furthermore, the CETESB/ANA WQI has nine parameters, some with redundant characteristics and others that are very unsuitable for the region, especially for a rural environment, which is the subject of this proposal.

A broad literature review on water quality indices suggests that there is a need to propose regionalized indicators of drinking water quality in order to consider local aspects in the evaluation process [8].

The Brazilian Federal District (DF) is the site of Brasilia, the nation's capital and the third most populous city in the country. Between the years 2017 and 2022, the DF's total population reached 2,817,381 inhabitants [9], with approximately 3% of this total living in rural areas, equivalent to 85,521 inhabitants, with a current density of 18.84 inhabitants/km^2 [10]. The DF is one of the federative units with the lowest annual per capita surface water availability in the country [10,11]. Despite its high urban water-supply coverage rate—99% in 2023 [12], only 15% of the rural population is served by rural supply systems operated by the Environmental Sanitation Company of the Federal District (CAESB). The percentage not served uses individual alternative sources such as wells or direct sampling of surface water, with little or no water quality control [13,14].

In the Brazilian Federal District, previous data available in several publications show that rivers in rural areas have better water quality than rivers in urban areas, emphasizing the need for the development of differentiated and regionalized quality indices [15–18].

Thus, the objective of this study was to propose a Water Quality Index for Rural Supply (WQIRS) for use in the Federal District of Brazil that will reflect regional and local water quality conditions, facilitating water sampling and providing greater reliability for farmers and users of this natural resource.

2. Materials and Methods

2.1. Study Area

To identify the characteristics of the water used in rural areas of the Federal District and qualify the determining parameters for the index, 29 sampling points were selected in seven Rural Centers of the Brazilian Federal District that do not receive treated water from the Environmental Sanitation Company of the Federal District (CAESB). The rural population that is not served by CAESB uses individual water wells that do not have water quality control and are subject to various contaminations [9], as they collect water from springs, streams, rivers, lakes or wells that are exposed to various contaminating factors [19].

The sampling points were chosen because they serve as a main source of water supply for rural residences in 29 different properties located in seven rural centers (Figure 1), which are as follows: three properties in the Taquara Rural Center (TAQ); four in the Santos Dumont Rural Center (SD); five in the Sítios Agrovale Rural Center (AGRO); four in the Rajadinha Rural Center (RAJ); five in the Tabatinga Rural Center (TAB); four in the Incra-8 Rural Center, one in the Incra-7 Rural Center (INCRA) and three in the Chapadinha Rural Center (CHAP). All water samples collected came from alternative supply sources such as springs or rivers, dug wells, and artesian wells.

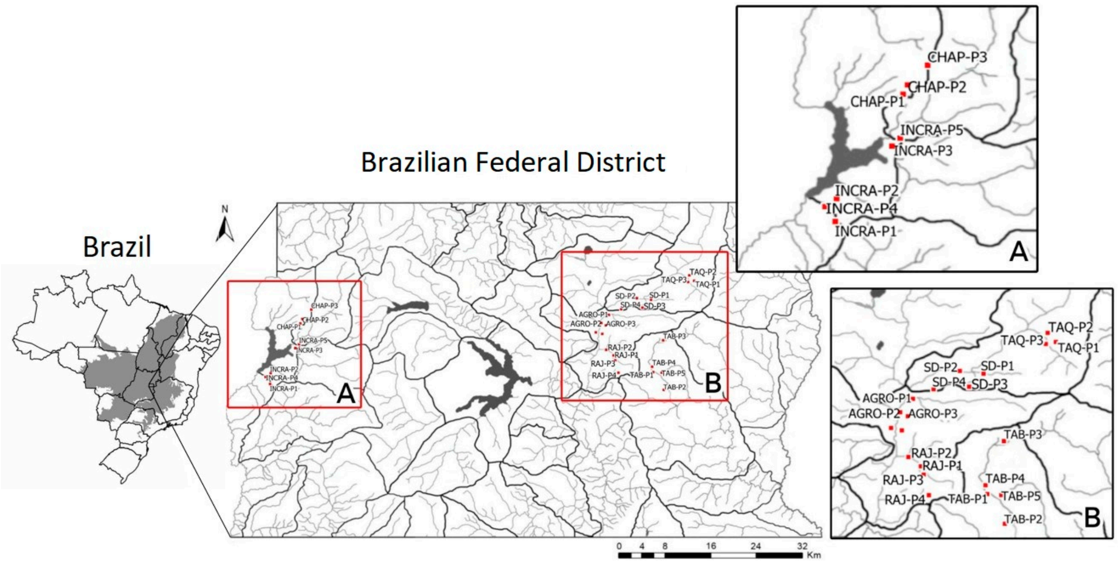

Figure 1. Sampling points in the Brazilian Federal District.

2.2. Sample Collection and Laboratory Analysis

Water sampling occurred monthly from May 2023 to April 2024, totaling 12 campaigns. Each water sample was analyzed for 20 physical, chemical, and microbiological variables, such as potential hydrogen (pH), apparent color (COLOR), turbidity (TURB), total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), anions: bromide (Br^-), chloride (Cl^-), fluoride (F^-), phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), and sulfate (SO_4^{2-}), and cations: sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), ammonium (NH_4^+), total coliforms (TC), and *Escherichia coli* (ECOLI). Water samples for physical–chemical analysis were collected in properly prepared 350 mL polyethylene bottles, and samples for total coliform and *E. coli* analysis were collected in sterile containers. All bottles were identified and stored in a thermal box, under adequate refrigeration and away from light, until arrival at the Water Analytical Chemistry Laboratory of Embrapa Cerrados (Planaltina-DF).

The electrical conductivity and total dissolved solids variables were determined in the laboratory using a portable multiparameter meter, model HQ40d (Hach, Loveland, CO, USA). pH was measured using a Thermo Scientific (Walthan, MA, USA) Orion Star A211 benchtop pH meter. Turbidity was measured using a portable turbidimeter, model 2100P (Hach, Loveland, CO, USA), and apparent color was obtained using a CheckerHC color meter (Hanna, Woonsocket, RI, USA). Total hardness was determined by titration using the EDTA-Na titrimetric method. To determine ions, samples were filtered through 0.45 µm PTFE microfiber membranes (Millipore Burlington, MA, USA) and analyzed by ion chromatography using a Metrohm 761 Compact IC Ion Chromatograph, Herisau, Switzerland. Analyses for total coliforms (TC) and *E. coli* (ECOLI) were performed in the laboratory on the day of sampling using the Colilert® enzyme substrate method (Idexx, Westbrook, ME, USA).

Although sampling was conducted in rural areas, pesticides were not included in the study because they are more difficult to analyze, both from a training and capacity perspective and due to the cost of analysis, which precludes their inclusion in an index proposed for use in continuous monitoring. Furthermore, recent studies in one of the study regions showed the presence of pesticides in surface and groundwater at levels below the limits permitted by Brazilian legislation [20,21].

2.3. Index Analysis

Based on these laboratory analyses, the selection of variables for the Index was based on the identification of the variables that contributed to the highest factor charges in the Principal Component Analysis (PCA) applied to the data matrix of water analyses from the four different sources (dug well, artesian well, river, spring), according to a methodology adapted from Meireles et al. [22] and Muniz et al. [18]. Furthermore, after selecting the variables based on the PCA, the weights were distributed according to the variable's level of importance for human drinking water standards, as established in Ministry of Health Directive GM Nº 888/2021 [23] and Conama Resolution Nº 357/2005 [24].

3. Results and Discussion

3.1. Water Quality Used for Supply

During the monitoring year, 696 samples were collected monthly from 4 sampling points (13.9%) in springs or rivers, 8 points (27.5%) in artesian wells, and 17 points (58.6%) in dug wells.

In the year 2004, it was reported that the increase in groundwater demand is primarily due to irregular urban densification in areas beyond the reach of integrated water supply systems [25]. Since then, one of the main uses of groundwater in the Federal District has been for rural domestic water supply (through shallow dug wells) [26,27].

During the monitoring period, two variables attracted the most attention in terms of their presence levels and their relationship to human health: the bacterium *Escherichia coli* (ECOLI) and the chemical compound nitrate.

The bacterium *Escherichia coli* was present at all sampling points except for point INCRA-P2 (dug well), which was absent in 100 mL of samples throughout the entire study period, in accordance with Directive GM/MS No. 888/2021 (Brazil, 2021) (Figure 2).

In water, depending on its intended use, bacteriological analyses must show low or no microorganisms to ensure that the water does not transmit diseases. If the water is for consumption and supply, according to Ministry of Health Directive Nº 888, the concentration of *E. coli* in 100 mL must be absent [23].

According to the World Health Organization (WHO), exposure to microbiological pathogens occurs primarily due to the ingestion of contaminated water, and this exposure is calculated based on the concentration of pathogens present in the water multiplied by the volume of water consumed [28].

Regarding the results obtained for the monitored rural areas, a possible explanation for the high concentration of *E. coli* recorded in the samples could be due to inadequately treated sewage in the region, which allows for proximity to septic tanks and some alternative water sources, explaining the contamination of the collected water. Muniz et al. [15] state that the main cause of water contamination in the Federal District is inadequate domestic sewage treatment, and Siqueira et al. [29] report that improper sewage disposal contaminates groundwater, which consequently contaminates the wells used by the community for water.

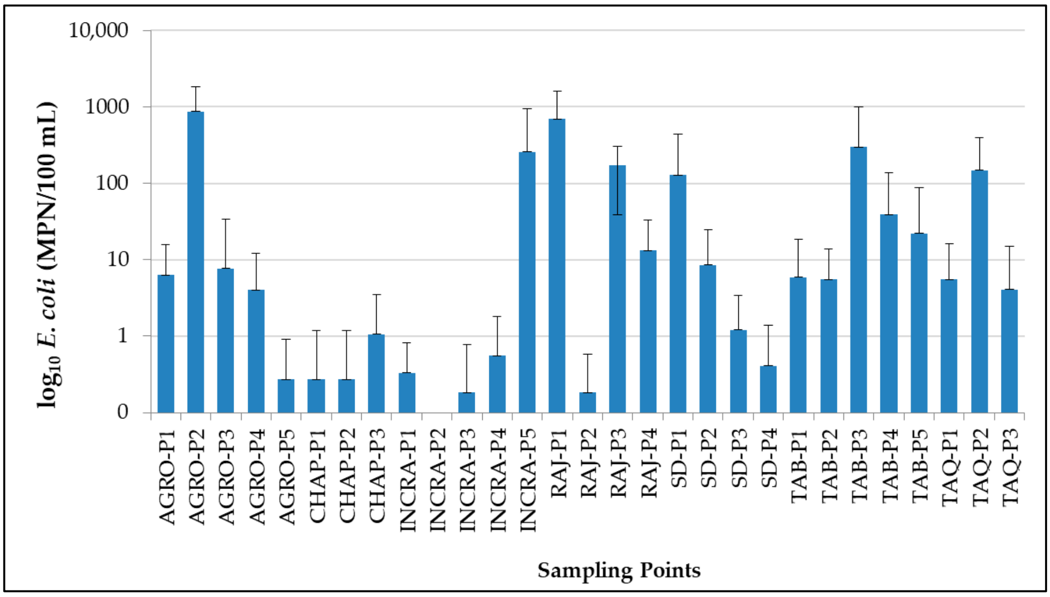

Figure 2. Average values (n = 12) for *E. coli* (MPN/100 mL) in the sampling points.

Studies indicate that accidental or unintentional ingestion of contaminated water can cause respiratory or gastrointestinal infections, weakening people's immune systems [30,31]. The presence of *E. coli* in water can be harmful to human health because this bacterium is capable of adhering to intestinal cells and producing enterotoxins, leading to dysentery, among other problems [32–34].

In addition to the use of contaminated water from alternative water sources, rainwater stored in reservoirs is also used, potentially causing *E. coli* contamination in rural populations in semiarid regions of Brazil [35–38].

Regarding nitrate potability standards, the RAJ-P2 (well), INCRA-P2 (dug well), INCRA-P4 (dug well), and CHAP-P3 (dug well) sites showed average values above those legally mandated (10 mg/L) [23,24] (Figure 3).

In natural aquatic environments, the most common forms of nitrogen are found in the oxidized form: ammonia (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-), and their toxicological significance in living organisms is being researched [39]. For example, nitrate and nitrite can be carcinogenic to stomach tissue in the human gastrointestinal system [40,41].

In contrast to the data obtained in the present study, Pires et al. [42] found low nitrate levels in groundwater and surface water near agricultural areas in the Brazilian Federal District. On the other hand, Stradioto et al. [43] linked considerable nitrate contamination in groundwater in the state of São Paulo to possible sewage leaks originating from urban areas. In any case, in the present study, there was no direct relationship between *E. coli* and nitrate contamination in the water, thus hindering a possible correlation with the presence of domestic sewage.

Figure 4 presents the Pearson Correlation Matrix showing all variables monitored in the study, except Br^- and NO_2^-, as they had values below the detection limit (<DL) (Table S1—Supplementary Material). The figure shows the low correlation between the ECOLI and Nitrate variables (−0.10), further justifying the presence of both in the proposed index.

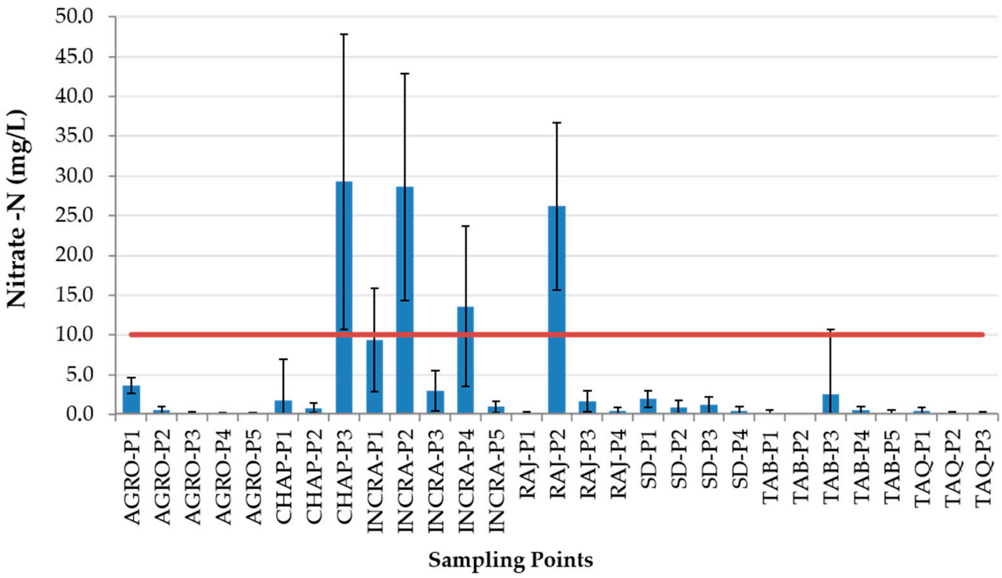

Figure 3. Average values (n = 12) for nitrate in the sampling points. Red line represents the Maximum Allowed Value by Brazilian normative rules.

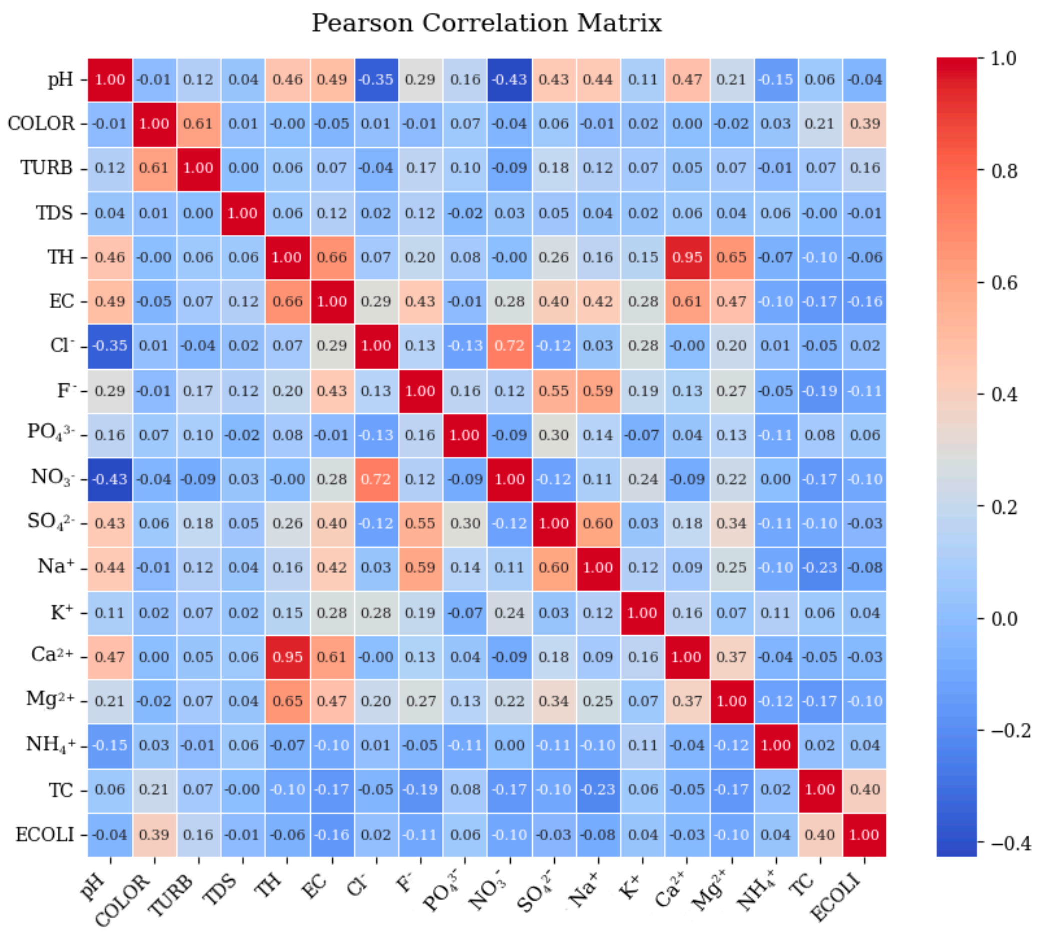

Figure 4. Pearson correlation matrix for the variables monitored in the study.

3.2. Water Quality Index for Rural Supply

The selection of variables for the composition of the index was carried out based on the largest factor loadings of the principal component analysis (PCA) (Table 1), applied to the data matrix of the water quality analyses, in the four different supply sources (dug well, artesian well, river, and spring), as adapted from the methodology of Meireles et al. [22] and Muniz et al. [18].

Table 1. Loadings, eigenvalues, and percentage of variance explained for the first three PCs of the data matrix.

		Loads	
	PC1	**PC2**	**PC3**
Eigenvalue	2.81	2.04	1.3
Explained variance (%)	25.53	18.58	11.84
Escherichia coli	**0.685** *	0.259	−0.140
Total dissolved solids	**0.887** *	−0.009	0.283
Turbidity	0.070	**0.913** *	0.187
Total hardness	**0.850** *	0.097	0.000
Nitrate	**−0.631** *	**0.526** *	0.061
Sulfate	**0.534** *	0.107	0.085

* Values in bold consider loads > 0.500.

The weight values (wi) were obtained by summing the contributions of all selected principal components, each calculated as the eigenvalue (Fj) multiplied by the loading (Aij) of variable i on component j, as determined by PCA. Mathematically, we organized the loadings into a matrix $A \in R^{n\ x\ k}$ (where rows correspond to variables and columns to components) and the explained variances (eigenvalues) into a vector $F \in R^{k\ x\ 1}$. The matrix product computed the raw scores for each variable.

The resulting weights were then normalized so that the sum of all w_i values equals 1, according to Equation (1):

$$w_i = \frac{\sum_{j=1}^{k} A_{ij} \cdot F_j}{\sum_{i=1}^{n} \sum_{j=1}^{k} A_{ij} \cdot F_j} \tag{1}$$

where w_i = weight of variable i in the WQIRS; F_j = eigenvalue (explained variance) of principal component j; A_{ij} = loading (explainability) of variable i on component j; n = number of variables selected by the model; k = number of principal components; i = number of variables varying from 1 to n, and j = number of principal components selected in the model, varying from 1 to k. Table 2 presents the weights calculated for each variable.

Table 2. Weights (w_i) calculated for each variable, based on principal component analysis.

Variable	w_i
Total dissolved solids	0.24
Total hardness	0.21
Escherichia coli	0.19
Turbidity	0.16
Sulfate	0.15
Nitrate	0.05
	$\sum = 1.00$

PCA is an exclusively statistical technique, which can assign greater weight to variables with high dispersion, even if they do not represent normative relevance. Therefore, although the sulfate variable obtained a qualified charge for inclusion in the index, and consequently a weight was defined for it, it was considered more important to value the *E. coli* and nitrate variables, due to their relevance to human health issues, their significant presence in Brazilian water quality legislation [23,24], and because they were variables found in considerable quantities in the analyzed samples (Figures 3 and 4), from a regional perspective.

The sulfate values observed during the monitoring period varied gradually between 0 and 2.1 mg/L (Table S1—Supplementary Material). This dispersion was likely the relevant factor in its selection by the PCA. However, because the Brazilian drinking water Directive set a maximum permitted sulfate value of 250 mg/L, it was decided that this variable was not significant enough to be included in the index. It is worth noting that the Brazilian Directive includes sulfate in an important group for qualifying the organoleptic drinking standard, and the total hardness and TDS variables, which are also part of this group, had greater representation in the studied region and were selected to be present in the proposed index [23].

Based on this point, it was decided to exclude the sulfate variable from the proposed index, distributing its weight equally among the other remaining index variables.

Seeking to increase the importance of the *E. coli* and nitrate variables, a second weighting level (w_i level 2) was introduced. This new component aims to adjust the index to the regional reality and current normative criteria. According to Brazilian legislation, the *E. coli* variable cannot be present in untreated drinking water, and the nitrate variable must be a maximum of 10 mg/L N-NO_3 in untreated drinking water. It is worth noting that, because this is a Rural Supply Index (WQIRS), the presence of *E. coli* and nitrate was detected in varying quantities in the analyzed samples (Figures 2 and 3), which further highlights the proposed methodological actions.

Although traditional WQIs often assign a priori weights, which can lead to misclassifications, dynamic weighting systems have been developed to account for site-specific characteristics [44]. For this reason, adopting a second weighting stage, based on weights derived from PCA combined with normative multipliers, allows for the simultaneous integration of the statistical relevance of variables and compliance with legal and environmental standards. This approach, aligned with best practices for building composite indicators, such as convex combination and robustness analysis, reduces biases and enhances the index's ability to reflect local conditions, strengthening the reliability of classifications and recommendations for water quality management [45,46].

Therefore, for the proposed index, multipliers (m_i) were defined for each remaining variable, with values ranging from 0.3 to 5.1, depending on their importance for the health of the water user population, as well as their greater presence in the analyses performed (Figures 2 and 3, Table S1). The multipliers were applied directly to the statistical weights (w_i), according to Equation (2):

$$w_{ilevel\ 2} = w_i \, . \, m_i \tag{2}$$

Thus, Table 3 presents the weights defined after including the assigned weighting levels.

Table 3. Final $w_{ilevel\ 2}$ weights, calculated for each variable, based on the inclusion of the second weighting level, seeking to meet the values provided for in national water quality requirements.

Variable	$w_{ilevel2}$
Nitrate	0.41
Escherichia coli	0.35
Total dissolved solids	0.09
Total hardness	0.08
Turbidity	0.07
	$\sum = 1.00$

In this context, the quality values (q_i) were calculated using Equation (3), based on the tolerable limits for each class of each variable (Table 4) and the analytical results obtained in the laboratory for each point:

$$q_i = q_{imax} - \left[\frac{\left(x_{ij} - x_{inf} \right) \cdot q_{iamp}}{x_{amp}} \right] \quad (3)$$

where q_{imax} is the maximum q_i value for the class; x_{ij} is the observed value for the variable; x_{inf} is the value corresponding to the lower limit of the class to which the variable belongs; q_{imax} is the class range; x_{amp} is the class range to which the variable belongs. To evaluate x_{amp} for the last class of each variable, the highest value determined in the water analyses was considered as the upper limit.

Table 4. Limit values of each class for the calculation of the quality values (q_i) for the selected variables.

Class	q_i	TDS mg/L	Total Hardness mg/L $CaCO_3$	*Escherichia coli* NMP/100 mL	Turbidity uT	Nitrate-N mg/L
I	75–100	0–300	0–60	0–100	0–5	0–5
II	50–74	300–600	60–120	100–500	5–10	5–10
III	25–49	600–1000	120–180	500–1000	10–50	10–50
IV	0–24	>1000	>180	>1000	>50	>50

Limit values of each class based on Guidelines for drinking water quality [28] and Directive n° 888/2021 [23].

From this point on, the calculation of the WQIRS was obtained by the sum of the individual quality (q_i) of each variable weighted by the weight of this variable (w_i) in the evaluation of water quality for rural supply according to Equation (4):

$$\text{WQIRS} = \sum_{i=1}^{n} q_i w_i \quad (4)$$

Table 5 presents the class defined for the WQIRS as well as the respective recommendations for water use in rural supply.

Table 5. Class of WQIRS and recommendations for use of water in the supply.

WQIRS	Class	Recommendations
91–100	Very Good	Low Risk of Contamination – Human consumption only after simplified treatment *
81–90	Good	Risk of Contamination – Human consumption only after simplified treatment *
71–80	Medium	High Risk of Contamination – Consumption only after conventional treatment **
50–70	Bad	Contaminated – Consumption only after advanced treatment ***
1–49	Unsuitable	Contaminated – Avoid consumption

Legend: * As provided by Conama Resolution N° 357/2005 [24], simplified treatment involves processes such as filtration, disinfection, and pH correction when applicable. ** Conventional treatment involves clarification using coagulation and flocculation, followed by disinfection and pH correction, as performed in WTPs. *** Advanced treatment involves techniques for removing and/or inactivating constituents that are resistant to conventional treatment processes and can impart characteristics such as color, odor, taste, and activity that is toxic or pathogenic. This refers to techniques that aim to remove or inactivate substances that are not removed by conventional water treatment methods. Examples include adsorption, reverse osmosis, oxidation, and ion exchange.

From the index developed and applied at the sampling points, Table 6 was obtained, which includes the presentation of the average water quality index for rural supply (WQIRS) for the 12 months at each sampling point.

Table 6. Sampling points and respective average WQIRS for 12 months.

Sampling Point	Rural Center	Coordinates	Supply Source	Average WQIRS
TAQ-P1	Taquara	S15° 37′ 25.9″ W047° 31′ 12.2″	Taquara river spring	
TAQ-P2	Taquara	S15° 37′ 20.5″ W047° 31′ 40.5″	Dug well	
TAQ-P3	Taquara	S15° 37′ 12.1″ W047° 31′ 57.4″	Dug well	
SD-P1	Santos Dumont	S15° 39′ 40.4″ W047° 35′ 26.8″	Dug well	
SD-P2	Santos Dumont	S15° 40′ 11.7″ W047° 38′ 13.0″	Dug well	
SD-P3	Santos Dumont	S15° 40′ 24.6″ W047° 38′ 01.8″	Dug well	
SD-P4	Santos Dumont	S15° 40′ 41.1″ W047° 38′ 19.7″	Dug well	
AGRO-P1	Sítios Agrovale	S15° 41′ 06.5″ W047° 39′ 37.4″	Dug well	
AGRO-P2	Sítios Agrovale	S15° 41′ 56.0″ W047° 40′ 17.6″	Dug well	
AGRO-P3	Sítios Agrovale	S15° 41′ 41.7″ W047° 39′ 49.1″	Artesian well	
AGRO-P4	Sítios Agrovale	S15° 41′ 52.5″ W 047° 39′ 50.9″	Artesian well	
AGRO-P5	Sítios Agrovale	S15° 41′ 52.0″ W 047° 40′ 18.0″	Artesian well	
RAJ-P1	Rajadinha	S15° 45′ 31.0″ W 047° 38′ 50.0″	Lobo river	
RAJ-P2	Rajadinha	S15° 45′ 34.2″ W047° 39′ 02. 9″	Artesian well	
RAJ-P3	Rajadinha	S15° 45′ 25.0″ W047° 38′ 57.0″	Lobo river	
RAJ-P4	Rajadinha	S15° 46′ 46.4″ W047° 38′ 41.9″	Dug well	
TAB-P1	Tabatinga	S15° 46′ 22.8″ W047° 35′ 33.2″	Dug well	
TAB-P2	Tabatinga	S15° 48′ 33.1″ W047° 34′ 14.6″	Artesian well	
TAB-P3	Tabatinga	S15° 43′ 37.0″ W047° 34′ 15.6″	Saco dos Pilões spring	
TAB-P4	Tabatinga	S15° 46′ 11.6″ W047° 35′ 19.9″	Artesian well	
TAB-P5	Tabatinga	S15° 46′ 46.1″ W047° 34′ 24.9″	Artesian well	
INCRA-P1	Incra 8	S15° 46′ 49.6″ W048° 13′ 06.5″	Dug well	
INCRA-P2	Incra 8	S15° 46′ 46.7″ W048° 12′ 39.2″	Dug well	
INCRA-P3	Incra 8	S15° 44′ 18.2″ W048° 10′ 03.9″	Dug well	
INCRA-P4	Incra 8	S15° 46′ 45.0″ W048° 12′ 54.0″	Dug well	
INCRA-P5	Incra 7	S15° 44′ 00.3″ W048° 09′ 46.7″	Artesian well	
CHAP-P1	Chapadinha	S15° 41′ 32.6″ W048° 09′ 27.5″	Dug well	
CHAP-P2	Chapadinha	S15° 41′ 26.0″ W048° 09′ 26.2″	Dug well	
CHAP-P3	Chapadinha	S15° 40′ 37.8″ W048° 08′ 35.1″	Dug well	

From the indices presented in Table 6, it can be observed that the majority (75.9%) of the water used for supply at the sampling points has Very Good quality. Of the total, 13.8% had a quality index classified as Good, where there is a risk of contamination and the water should only be used after simplified treatment. Only 10.3% of the points were considered of Medium quality, not suitable for consumption before conventional treatment.

It should be noted that as this is water for residential supply, the information about the quality must be issued at a defined frequency and safety measures must be continually applied to avoid health problems, since the dispersion and release of pollutants into the environment are dynamic and continuous.

A study in northeastern Brazil showed that physical, chemical, and biological parameters, represented by coliform bacteria, are fundamental for water quality classification and that their combined use provides a good basis for decision-making and the formulation of water resource management strategies [47].

In any case, as stated by Roldán-Reascos et al. [48], there is a consensus that it is impossible to monitor all water quality parameters continuously due to the financial implications and time involved. Therefore, the most critical parameters should be considered when developing a quality index.

Several studies have employed Water Quality Indexes (WQIs) to evaluate groundwater and surface water sources in rural regions. In India, a modified WQI method was proposed to better reflect the actual water quality of supplied groundwater [49]. Similarly, in Gwalior district, India, groundwater samples were found to have poor WQI due to high concentrations of total dissolved solids, hardness, and alkalinity [50]. In Colombia, drinking water samples from rural settlements showed high risk levels according to the Drinking-water Quality Risk Index (IRCA), with 100% of samples containing *E. coli* and total coliforms [51]. In Ecuador, both WQI and Simplified WQI (SWQI) were used to assess water quality, indicating the need for conventional treatment before human consumption [48]. In all cases, it is possible to observe that the assessment must be carried out on a case-by-case basis and using parameters that are more indicative of risk in each region

After the monitoring was carried out and the survey of the observed regional characteristics was performed, the data obtained in this proposal show a very effective index for the monitored region, considering the most important pollutants and providing sufficient information for decision-making by users and consequently by public managers.

4. Conclusions

Based on the results obtained, it can be concluded that, although the Federal District has a high supply coverage rate (99%), many rural areas and properties continue to depend on alternative means of capturing water, which often do not meet adequate quality conditions for consumption, posing health risks if not properly treated.

The results of this study fill the gap in the assessment of specific water quality data in the rural areas studied and have the potential to assist the government in managing the quality of the region's water resources. Even so, future analyses in these areas are necessary for effective water quality monitoring in rural regions without access to treated water from the Federal District.

The water quality survey in the selected rural communities revealed the presence of *E. coli* bacteria as the main problem in virtually all rural areas studied. However, simplified treatment with chlorination or filtration can minimize this problem. On the other hand, nitrate was also present in significant amounts in some samples collected during the period at certain points. In these cases, the WQIRS classified the water as Medium quality, and conventional treatment is necessary before use. The detection of these variables in the observed quantities presents a potential risk of adverse health effects on the exposed rural population, highlighting the need for minimal treatment according to quality guidelines.

The WQIRS obtained in this study presents a simplified list of variables that significantly represent the main problems potentially observed in the region's waters. The microbiological issue is well represented by the *E. coli* variable, which can be a problem in groundwater use; the chemical issue, represented by the nitrate and total hardness variables, is a problem in agricultural areas and in areas with limestone soil, present in the Federal District region; and physical variables such as suspended total solids and turbidity, responsible for color and odor aspects and related to the presence of organic matter, algae, and sand. Studies continue to seek the most accurate and representative assessment possible, but overall, the WQIRS presents itself as an easy-to-use tool that can be applied by public administrators as a way to improve communication with rural communities.

The results obtained in this study will be forwarded to public administrators and shared with participating families, aiming to disseminate information and ensure better health conditions for this population.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/hydrology12090233/s1, Table S1: Minimum, maximum, mean, and standard deviation of water quality variables at each sampling point.

Author Contributions: Conceptualization, E.C.O.-F. and D.H.F.M.; methodology, D.H.F.M. and E.C.M.G.; formal analysis, E.C.O.-F., D.H.F.M. and J.V.M.; investigation, D.H.F.M. and E.C.M.G.; resources, E.C.O.-F.; data curation, D.H.F.M.; writing—original draft preparation, E.C.O.-F., D.H.F.M. and E.C.M.G.; writing—review and editing, E.C.O.-F. and D.H.F.M.; project administration, E.C.O.-F.; funding acquisition, E.C.O.-F. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by Federal District Research Support Foundation (FAP-DF grant numbers: 193.00002283/2022-91).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

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