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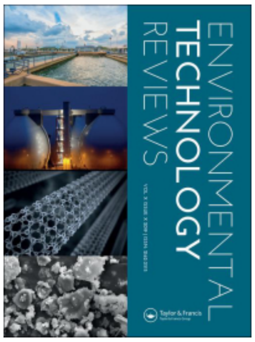

Environmental Technology Reviews

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tetr20

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To cite this article: Fernando García-Ávila, César Zhindón-Arévalo, Lorgio Valdiviezo-Gonzales, Manuel Cadme-Galabay, Horacio Gutiérrez-Ortega & Lisveth Flores del Pino (2022) A comparative study of water quality using two quality indices and a risk index in a drinking water distribution network, Environmental Technology Reviews, 11:1, 49-61, DOI: 10.1080/21622515.2021.2013955

To link to this article: https://doi.org/10.1080/21622515.2021.2013955

Published online: 27 Feb 2022.

ENVIRONMENTAL TECHNOLOGY REVIEWS
2022, VOL. 11, NO. 1, 49–61
https://doi.org/10.1080/21622515.2021.2013955

REVIEW

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A comparative study of water quality using two quality indices and a risk index in a drinking water distribution network

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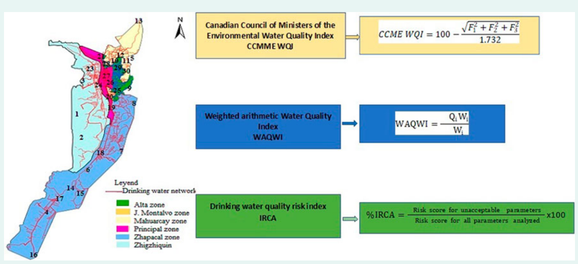
ABSTRACT

This study compares the Canadian Council Water Quality Index (CCME WQI) and the Arithmetic Water Quality Index (WAWQI) methodologies for determining the quality of water in the city of Azogues (Ecuador). Additionally, a drinking water quality risk index (IRCA) was determined to evaluate the degree of risk of disease occurrence related to water consumption. The data generated came from the analyses of twelve physicochemical parameters (pH, turbidity, colour, total dissolved solids, electrical conductivity, total hardness, alkalinity, nitrates, phosphates, sulfates, chlorides, residual chlorine) from 172 samples of water over six months. The calculated average value of CCME WQI (97.59 ± 1.08) indicates that 100% of the drinking system was of 'excellent' quality. The WAWQI average value was calculated to be 26.36 ± 1.13 indicating that 16.67% of the distribution system was of 'excellent' quality and 83.33% of the distribution water was of 'good' quality. The IRCA calculated in all the distribution zones is between 0 and 5% and therefore, the distributed water is considered suitable for human consumption and is rated at the no-risk level. Furthermore, WAWQI is influenced by parameters with low maximum allowed concentration (for example, turbidity value 1 NTU in the Ecuadorian standard was used instead of 5 NTU recommended by the WHO); conversely, CCME-WQI is influenced by parameters with a high maximum allowed concentration (no parameter exceeded the norm in this study). The IRCA is a support instrument to guarantee that the water supplied by the provider companies complies with the characteristics established for drinking water.



ARTICLE HISTORY
Received 18 August 2021
Accepted 22 November 2021

KEYWORDS
Canadian Council's Water Quality Index; chemical-physical parameters; drinking water network; quality risk index; *Weight Arithmetic Water Quality Index*

1. Introduction

High-quality drinking water is becoming limited, it is necessary to evaluate it with the appropriate techniques [1,2]. At the exit of the treatment plant, drinking water is of good quality; however, the quality can be deteriorated in the supply line [3,4]. Therefore, it is necessary to monitor water quality, as it provides an idea of the current state and determines the most appropriate use for any human activity [5,6]. An effective tool for expressing water quality is a Water Quality Index (WQI), which can be used to assess better evaluation and management of water resources, which shows the evolution of water quality during a period [7,8].

To simplify the interpretation of the monitoring data WQIs reduce a large amount of information on physicochemical and biological aspects to a simple expression that is easily interpreted by technicians,

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Supplemental data for this article can be accessed at https://doi.org/10.1080/21622515.2021.2013955.

environmental specialists, and the general public [9]. The WQI provides a unique value that expresses water quality by relating different water quality variables [10].

The main difference between the different existing WQIs lies in the way of assessing the pollution processes and the number of variables considered in the formulation of the respective index [11,12].

Various indices have been developed and used in different investigations to classify the suitability of water for different uses, each with its own characteristics, and generally good results are achieved in the areas where they were obtained [13]. In Canada, the Canadian Council of Environment Ministers developed a WQI with the purpose of assessing the water's ecological quality considering parameters at a reference point generally obtained from a standard or guide of water quality [14,15]. Due to the flexibility of the parameters considered and the use of guidelines for the protection of aquatic life, this index is used to assess the quality of water intended for human consumption.

The WAWQI index methodology uses the most commonly measured water quality variables and classifies the water quality according to its degree of purity [16]. The WAWQI methodology allows data of multiple chemical and biological physical parameters to be incorporated into a mathematical equation that qualifies water quality with a number. It requires few parameters compared to other water quality indices [17] and is useful for communicating general information on water quality to interested policymakers and the public [18].

WQI models have been used globally and have been applied to the main bodies of water; 82% of the applications have been to evaluate the water quality of rivers [18]. Meanwhile, 18% have been used to characterize other types of water such as groundwater, water for irrigation and drinking water [19,20]. The CCME WQI and the National Sanitation Foundation index (NSF-WQI) methodologies have been used in 50% of the studies carried out worldwide [19].

Several studies worldwide have used two or more indexes to assess water quality. Sim and Tai [21] used four indexes to assess the water quality of the Sarawak River, Malaysia. Zooalnoon and Musa [22] used three indexes in their study that aimed to assess the water quality produced in oil fields in the Heglig area, Sudan. Jahan and Strezov [23] used four WQIs to assess seawater quality in six ports in Australia. Finotti et al. [24] calculated two WQIs to monitor and evaluate the water quality of water resources in the urban area of Caxias do Sul, Brazil. Alexakis [25] used two indexes, the CCME and NSF-WQI for groundwater monitoring in agricultural areas of Greece. All the studies reviewed do not include comparisons between the CCMEQWI and WAWQI methodologies and neither consider spatial and temporal fluctuation in determining drinking water quality. Consequently, this issue should be carefully analysed in detail.

The water quality risk index for human consumption (IRCA, for its acronym in Spanish) is a quantitative tool to determine, through a percentage, the degree of risk of disease occurrence related to water consumption. The IRCA measurement is a basic instrument to guarantee that the water supplied by the provider companies complies with the characteristics established for water for human consumption. The IRCA was established through Resolution 2115 of 2007 in the country of Colombia and has been welcomed by other Latin American countries [26].

The objective of this study was to carry out a comparative study between the CCME QWI and WAWQI methodologies and estimate the degree of the level of health risk from drinking water using an IRCA in a drinking water distribution network (DWDN) in Azogues, Ecuador. The results allowed to evaluate the quality of drinking water by applying, the WQI and IRCA as possible monitoring tools for drinking water quality.

2. Materials and methods

2.1. Study area

The data used to calculate CCME WQI and WAWQI came from a program to monitor the quality of drinking water in the DWDN of the city of Azogues, Republic of Ecuador [27]. The drinking water treatment plant (DWTP) that supplies the distribution network under study is a conventional plant with gravity operation, consisting of Coagulation, Flocculation, Sedimentation, Rapid Filtration and Disinfection with chlorine. Raw water comes from a surface source (Tabacay river). The treatment flow rate in this plant is 100 L/s.

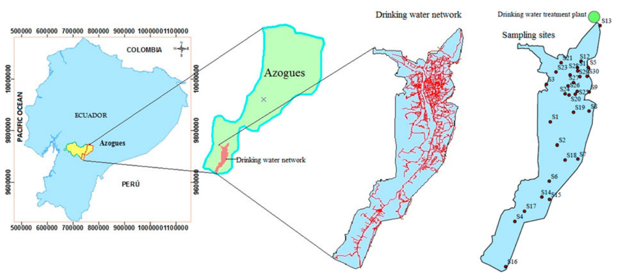

Figure 1. Location of sampling points in the drinking water distribution network in Azogues.

2.2. Plan for monitoring the quality of drinking water

Thirty points for monitoring were selected for the analysis. These monitoring points were selected to create a representative sample of the network, such as: storage tanks, schools, commercial premises (mechanical workshops, restaurants, washing machines, etc.) and homes. The distribution of the 30-drinking water quality monitoring points is shown in Figure 1. Monthly samples were taken in each area for six months. During the six months of monitoring, 24 samples were taken in the Alta zone, 18 samples in the Mahuarcay zone, 18 samples in the J. Montalvo zone, 36 samples in the Principal zone, 24 samples in the Zhigzhiquin zone and 60 samples in the Zhapacal zone. These numbers of samples were considered as a function of the population density and the length of the distribution network.

2.3. Sampling and analysis of water

One litre polyethylene containers were used to collect the water samples. The samples were kept at 4°C and analysed in the laboratory of the municipal company in Azogues responsible for the distribution of drinking water. The analysis was performed according to the standard methods for the examination of water and wastewater [28,29]. On-site measurements of Hydrogen ion concentration (pH), total dissolved solids (TDS), electrical conductivity (EC) and temperature were performed with the Hach Multiparameter HQ 40d. Meanwhile, in the laboratory, chloride (Cl^-), nitrate (NO_3^-), phosphate(PO_4^{3-})and sulphate (SO_4^{2-}) were determined with the HACH DR 2500 spectrophotometer; the total hardness (TH) and alkalinity (Alk) were measured by the titration method; the colour (Col) and residual chlorine (Cl_2) were analysed with a HACH 890 colorimeter, and the turbidity was measured with the HACH 2100P turbidimeter [27]. The determination of faecal coliforms was carried out according to the Most Probable Summit (MPN) method established in the Standard Methods [28].

2.4. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

This index is based on the determination of three factors: scope, frequency, and amplitude. Scope (F1) defines the percentage of variables that have values outside the range of desirable levels for the use being evaluated with respect to the total variables considered. Frequency (F2) is found by the relationship between the number of values outside the desirable levels with respect to the total data of the variables studied.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \tag{1}$$

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

Amplitude (F3) represents the average deviation of failed test values from their respective guidelines. The relative deviation of a failed test from the objective is termed an excursion and is calculated as follows: When the test value must not exceed the objective:

$$\text{Excursion}_i = \frac{\text{Failed test value}_i}{\text{Objective}_j} - 1 \tag{3a}$$

When the test value must not fall below the objective:

$$\text{Excursion}_i = \frac{\text{Objective}_j}{\text{Failed test value}_i} - 1 \tag{3b}$$

The collective amount by which individual tests are out of compliance is calculated as follows:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Number of tests}} \tag{4}$$

Table 1. CCME WQI index categorization scheme.

Rank	WQI value	Description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Very Good	80–94	Water quality is protected with a slight presence of threat or impairment conditions close to natural or pristine levels
Good	80–88	Water quality is protected with only a minor degree of threat or impairment, conditions rarely depart from natural or desirable levels
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

where nse is the normalized sum of the excursions from the objectives.

The F3 factor is then calculated by a formula that scales the nse to yield a range between 0 and 100.

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01} \tag{5}$$

Water quality index (CCME WQI) was determined by the following equation:

$$\text{CCME WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{6}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the 'worst' water quality and 100 represents the 'best' water quality [14]. Table 1 shows the five categories of WQI that qualify water for a given course established by the Council of Environment Ministers of Canada [14,30,31].

2.5. Weighted arithmetic Water Quality Index (WAQWI) method

The method for calculating the Weight Arithmetic Water Quality Index (WAWQI) incorporates multiple water quality parameters into a mathematical equation that qualifies the health of the body of water through a number called the water quality index, as well as describes the suitability of surface and underground water sources for human consumption [16]. The drinking water in this study comes from surface sources.

This method is widely used by scientists [16–18] and the calculation of this WQI was performed using the following equation:

$$\text{WAQWI} = \frac{\sum_i^Q W_i}{\sum_i^W} \tag{7}$$

where Q_i = quality rating, W_i = Relative weight.

The water quality rating scale (Q_i) for each parameter was calculated using the following formula recommended by Kumar and Sharm [7]:

$$Q_i = \frac{C_i}{S_i} \times 100 \tag{8}$$

$$Q_i = \frac{C_i - V_i}{S_i - V_i} \times 100 \tag{9}$$

where Q_i = quality rating; C_i = concentration of each physical or chemical parameter in each water sample in mg/L; S_i = value of the water quality parameter obtained from the recommended standard WHO or Ecuadorian standard for drinking water (INEN 1108).

Equation (8) was used for all parameters except pH and residual chlorine.

In Equation (9), V_i = ideal value of the parameter in pure water (V_i = 0) and is considered as 7.0 for pH and 0.3 mg/L for residual chlorine.

Equation (8) ensures that Q_i = 0 when there is no presence of the contaminant in the water sample. Meanwhile, Q_i = 100 when the parameter has a value equal to its allowable value. The more contaminated the water, the higher the value of Q_i.

Relative weight (W_i) for each water quality parameter which is inversely proportional to the values of the recommended standards was calculated by García-Ávila et al. [12]:

$$W_i = \frac{K}{S_i} \tag{10}$$

where K = constant proportionality, which was calculated using the following equation:

$$K = \frac{1}{\sum_{i=1}^n \frac{1}{S_i}} \tag{11}$$

The calculated WAWQI values were classified according to Table 2 as excellent, good; poor; very poor and inadequate or not suitable for human consumption [16].

Table 2. Water quality rating as per WAWQI method.

WQI Value	Grading	Rating of water quality
0–25	A	Excellent
26–50	B	Good
51–75	C	Poor
76–100	D	Very poor
Above 100	E	Unsuitable for drinking purpose

The drinking water quality standards according to WHO and Ecuadorian standards for each parameter have been given in Table 3.

2.6. IRCA determination

According to Resolution 2115 of 2007 (Colombian standard for the quality of water for human consumption), the calculation of the IRCA per sample analysed is defined by Equation (12) [32]:

$$\%\text{IRCA} = \frac{\sum \text{Risk score for unacceptable parameters}}{\sum \text{Risk score for all parameters analysed}} \times 100 \quad (12)$$

Table 4 presents the risk score assigned to each of the physical, chemical and microbiological characteristics that do not comply with the maximum limits.

The IRCA has the following categorization: 80.1–100% (sanitary infeasible), 35.1–80% (high-risk level), 14.1–35% (medium-risk level), 5.1–14 (low-risk level), and 0–5 (no risk) [33].

It is not necessary to have all 22 parameters of Table 4 to calculate the IRCA. Thus, in this study, 11 parameters were used (Table 9). To calculate the IRCA, first, the numerator of the Equation (12) (risk score for unacceptable parameters) must be calculated, for which it must be compared if any of the 11 parameters does not comply with the regulations; then, the score level of risk of those parameters that do not comply with the regulations must be added; for this study, all the parameters complied with the regulations; therefore the numerator had a value of zero. Meanwhile, to calculate the denominator (risk score for all parameters) the score level of risk of each of these 11 parameters was added. Thus, there would be a risk score for all parameters equal to 86.5 (Table 9). By applying Equation (12), an IRCA of 0% was calculated. Therefore, it is possible to use any of the 22 parameters established in Table 4. If you use all 22 parameters, the sum of scores assigned in the denominator will be 100. If you use fewer parameters, the denominator will be less than 100.

Table 3. Drinking water quality standards used in the calculation of WAWQI and CCME WQI.

Chemical physical parameter	WHO standard	Ecuadorian standard
pH	8.5	8.5
Turbidity (NTU)	5	1
Colour (UC_Pt Co)	15	15
Total Dissolved Solid (mg/L)	1000	1000
Total Hardness (mg $CaCO_3$/L)	200	300
Alkalinity (mg $CaCO_3$/L)	200	200
Nitrate (mg/L)	50	10
Phosphates (mg/L)	-	0.1
Sulphates (mg/L)	250	200
Chlorides (mg/L)	250	250
Residual chlorine (mg/L)	5	1.5

Table 4. IRCA's risk scores.

Characteristic	Risk score
Apparent colour	6
Turbidity	15
pH	1.5
Free residual chlorine	15
Total alkalinity	1
Calcium	1
Phosphate	1
Manganese	1
Molybdenum	1
Magnesium	1
Zinc	1
Total hardness	1
Sulphate	1
Total iron	1.5
Chloride	1
Nitrate	1
Nitrite	3
Aluminium	3
Fluoride	1
Total Organic Content	3
Total coliforms	15
Escherichia coli	25
Total assigned score	100

2.7. Statistical analysis

Pearson's correlation test was performed to evaluate the statistically significant variables of the system with a level of significance of 95%. The correlation analysis was performed to detect the variations of the physical–chemical parameters over time and in each zone. Likewise, the measures of central tendencies and measures of dispersion in a box plot were determined.

3. Results and discussion

3.1. Physico-chemical characteristics of water

The average laboratory data of the 12 physicochemical parameters analysed in the six zones of the DWDN are shown in Table 5. Turbidity varied

Table 5. Average values and standard deviation of the water quality parameters in the six zones of the distribution network.

Parameter	Unit	Alta Zone		Mahuarcay Zone		J. Montalvo Zone		Zhigzhiquin Zone		Principal Zone		Zhapacal Zone	
		Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Turbidity	NTU	0.51	0.13	0.44	0.03	0.49	0.12	0.54	0.12	0.48	0.09	0.57	0.12
Colour	UC	0.04	0.09	0	0.00	0.11	0.25	0.29	0.09	0.06	0.06	0.5	0.09
pH		7.23	0.14	7.21	0.12	7.2	0.15	7.32	0.15	7.22	0.13	7.24	0.14
Temperature	°C	16.96	1.22	16.41	1.86	17.59	1.34	17.59	0.54	17.57	0.83	18.17	0.70
TDS	ppm	67.71	11.94	57.17	7.16	68.83	13.36	73.38	11.87	65.75	11.07	72.85	11.75
Conductivity	µS/cm	107.5	19.95	91.75	11.78	109.83	22.77	117.71	20.75	104.75	18.55	116.02	20.27
T. Hardness	mg $CaCO_3$/L	67.92	8.96	57.42	4.83	71.83	8.55	69.38	12.62	65.47	9.11	72.58	10.85
Res. Chlorine	mg/L	0.85	0.13	0.52	0.24	0.71	0.19	0.67	0.07	0.76	0.10	0.68	0.10
Sulphates	mg/L	16.79	4.83	11.17	4.42	18.83	4.28	20.67	4.80	15.97	4.90	20.04	4.39
Alkalinity	mg $CaCO_3$/L	50.13	10.71	40.33	4.89	48.51	11.22	47.92	10.77	46.97	8.11	49.85	11.62
Chlorides	mg/L	5.53	1.61	6.85	2.79	5.58	1.20	5.29	0.97	5.96	1.61	5.4	1.11
Nitrates	mg/L	0.51	0.02	0.57	0.03	0.53	0.03	0.49	0.02	0.46	0.01	0.45	0.02
Phosphates	mg/L	0.08	0.002	0.07	0.002	0.08	0.002	0.07	0.003	0.08	0.002	0.09	0.002

between 0.44 and 0.57 NTU. The lowest turbidity (0.44 NTU) occurred in Mahuarcay, which is in the zone closest to the treatment plant. Meanwhile, the greatest turbidity (0.57 NTU) occurred in the Zhapacal zone, which is, the zone farthest from the treatment plant. In all zones, turbidity was within the Ecuadorian and WHO regulations.

The colour varied between 0.00 and 0.50 UC_Pt Co; the lowest colour (0 UC_Pt Co) was found in Mahuarcay, which is, the zone closest to the treatment plant. Meanwhile, the highest colour (0.50 UC_Pt Co) was found in Zhapacal, wich is, the zone farthest from the treatment plant. In all zones, colour was within the Ecuadorian and WHO regulations. The pH of drinking water, which is one of the most important indicators of water quality varied between 7.21 and 7.32. The pH in all zones were within the drinking water quality standards during the study period.

Water temperature varied between 16.41°C and 18.17 °C during the monitoring. The lower temperatures were due to the higher altitude (2823 metres above sea level) where the DWDN begins, and the highest water temperatures were at the lowest altitude (2390 metres above sea level), where the distribution network ends. The conventional potabilization process did not affect the dissolved solids content of treated water. Therefore, the TDS and the EC were not significantly affected during the transport of the water in the supply network. The increase in the value of Total Hardness decreased the corrosivity of water [30], the Ca^{2+} allowing the formation of a passivation film on the surface of the pipe, reducing corrosion. According to the data in Table 5, the TH varied between 57.42 and 72.58 mg/L. These Total Hardness values are slightly low (≤72.58), which influenced the presence of some corrosion in the distribution network [34].

The residual chlorine value (0.52 mg/L) was lower in Mahuarcay, which is the zone closest to the treatment plant. However, in the Alta zone a chlorination redosing point, the residual chlorine increased to 0.85 mg/L [35] and [36]. It decayed in Zhapacal, which is the furthest zone, with a value of 0.68 mg/L. Alkalinity is necessary for the reaction of alum with water during the coagulation process in the Treatment Plant [37]. Water corrosivity also increases as alkalinity decreases [34]. The average alkalinity values for the different zones varied between 40.33–50.13 mg/L as $CaCO_3$. The low alkalinity values that were found allowed the water to be slightly corrosive.

Table 6. Correlation coefficient matrix of physico–chemical parameters measured in the DWDN.

	Turbidity	Colour	pH	TDS	EC	TH	Cl_2	SO_4	Alk	Cl^-	NO_3	PO_4
Turbidity	1											
Colour	0.92	1										
pH	0.52	0.49	1									
TDS	0.93	0.76	0.60	1								
EC	0.93	0.77	0.62	0.99	1							
TH	0.86	0.66	0.26	0.93	0.91	1						
Cl_2	0.31	−0.06	−0.01	0.47	0.43	0.54	1					
SO_4	0.90	0.74	0.56	0.99	0.99	0.94	0.42	1				
Alk	0.78	0.49	0.24	0.86	0.84	0.91	0.81	0.84	1			
Cl^-	−0.86	−0.62	−0.52	−0.97	−0.97	−0.94	−0.63	−0.96	−0.94	1		
NO_3	−0.77	−0.65	−0.35	−0.71	−0.69	−0.61	−0.48	−0.65	−0.67	0.64	1	
PO_4	0.31	0.09	−0.48	0.30	0.26	0.54	0.71	0.28	0.66	−0.39	−0.48	1

The values of chloride and sulfate ions in all zones were within Ecuadorian and WHO regulations. Nutrients (nitrate and phosphate) are important, as living microorganisms need them for physiological processes. However, they are considered contaminants when their concentrations exceed the allowed limit. In this study, nitrate and phosphate values were well below the permissible limit of the Ecuadorian and WHO standards.

The temporal variation of the parameters by month and by zone has been included in Appendix.

3.1.1. Correlation analysis of the physicochemical parameters

The linear association between the physicochemical parameters was measured by Pearson's correlation (Table 6). This analysis indicates the correlation between the chosen variables. When the correlation coefficient is closer to +1 or −1, the linear relationship is perfect [10]. In this case it was observed that turbidity has a high interrelation with colour, TDS, Total Hardness, and sulfates ($r = 0.92$, $r = 0.93$, $r = 0.86$, $r = 0.90$, respectively). Turbidity showed a significantly negative correlation with chlorides ($r = -0.86$) (Table 6). TDS also had a high interrelation with EC, TH, sulfates, and alkalinity ($r = 0.99$, $r = 0.93$, $r = 0.99$, $r = 0.86$ respectively). TDS showed a high negative correlation with chlorides ($r = -0.97$). Conductivity showed a high relationship with sulfates ($r = 0.99$) and a high negative correlation with chlorides ($r = -0.97$). Total hardness showed a high relationship with sulfates ($r = 0.94$) and a high negative correlation with chlorides ($r = -0.94$). The residual chlorine showed a positive correlation with alkalinity ($r = 0.81$). Nitrates showed a significantly positive correlation with chlorides ($r = 0.64$) and a significantly negative correlation with turbidity ($r = -0.77$). Phosphates had a significant positive relationship with residual chlorine and chlorides ($r = 0.71$, $r = 0.66$ respectively).

3.2. Water Quality Index (WQI) for drinking water assessment

From the data of the physical and chemical parameters obtained for each zone, the value of WAQWI and CCME WQI was estimated. These two calculated indices are presented in Figure 2. WAWQI was calculated using the average values of the chemical physical parameters for each zone presented in Table 5. The CCME WQI was calculated using all the data obtained during the six monitoring campaigns in each zone. For the calculation of CCME WQI, the Ecuadorian standard was used since it has a more restrictive turbidity (1 NTU) compared to the WHO (5 NTU). The other parameters have similar values in WHO and Ecuadorian standards (Table 3). The CCME WQI values indicate that all the drinking water samples in the six zones were excellent. A summary of the CCME QWI calculation is presented in Table 7. The Mahuarcay, J. Montalvo and Principal

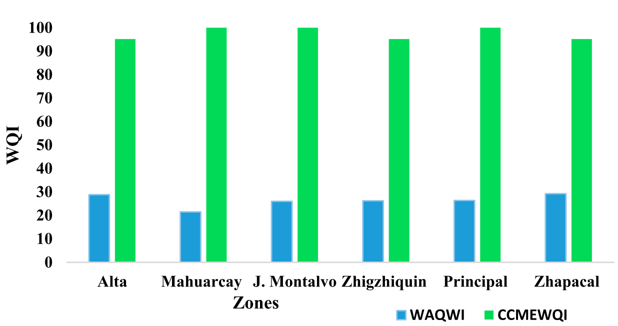

Figure 2. Comparison of WQI according to weighted and Canadian arithmetic methods for each zone of the distribution network.

Table 7. Factors obtained in the calculation of CCME WQI: F1 (Scope), F2 (Frequency), F3 (Amplitude).

Variables/objectives/ factors	Alta zone	Mahuarcay zone	J. Montalvo zone	Zhigzhiquin zone	Principal zone	Zhapacal zone
N failed variables	1	0	0	1	0	1
Total number of variables	12	12	12	12	12	12
F1 (Scope)	8.33	0	0	8.33	0	8.33
N failed test	1	0	0	1	0	3
Total number of test	288	144	216	288	432	744
F2 (Frequency)	0.35	0	0	0.35	0	0.40
Σexcursion	0.12	0	0	0.06	0	0.14
nse	0.00042	0	0	0.00021	0	0.00019
F3 (Amplitude)	0.04165	0	0	0.02083	0	0.01881
CCMEWQI	95.18	100	100	95.18	100	95.18

Table 8. Comparison of Canadian Council's Water Quality Index and the Weight Arithmetic Water Quality Index.

Zone	WAQWI	Clasificación	CCMEWQI	Clasificación
Alta	28.81	Good	95.18	Excellent
Mahuarcay	21.48	Excellent	100	Excellent
J. Montalvo	25.99	Good	100	Excellent
Zhigzhiquin	26.22	Good	95.18	Excellent
Principal	26.39	Good	100	Excellent
Zhapacal	29.25	Good	95.18	Excellent

zones presented excellent quality water with a rating of 100. The Alta, Principal and Zhapacal zones also presented excellent water quality but with a rating of 95.18 (Table 7). The only failed variable was turbidity.

From the average data for each of the physical and chemical parameters obtained, it was estimated that the WAWQI value was 28.81, 21.48, 25.99, 26.22, 26.39, 29.25 for the zones: Alta, Mahuarcay, J. Montalvo, Zhigzhiquin, Zhapacal respectively (Table 8). According to the values obtained from WAQWI, the water supply network can be classified as Good to Excellent. Therefore, Azogues water is safe for human consumption. It should be noted that the standard turbidity value used to calculate WAWQI was 1 NTU. However, if the value of 5 NTU (indicated by WHO) had been used, the WAWQI values in all zones would also have been of excellent quality, the same as the result obtained with the CCME WQI method. This indicates that the determination of WAWQI depends mainly on the standard value of the physicochemical parameters that are considered for its calculation.

Figure 2 shows that the CCME WQI values do not vary much in each of the six zones. Similarly, WAWQI did not vary significantly between zones. The Mahuarcay zone is the one with the best water quality (excellent) according to the WAQWI (it has the lowest value = 21.48), which coincides with the CCME WQI methodology that also qualifies the Mahuarcay zone as 'excellent' quality (presents higher value = 100). It should be noted that the Treatment Plant is in the Mahuarcay zone. On the other hand, the Zhapacal zone presents 'good' water quality according to the WAQWI (it has a value = 29.25), while, with the methodology of the WQI CCME, qualifies the Zhapacal zone as 'excellent' quality (value = 95.18). The Zhapacal zone is the zone furthest from the Treatment Plant. This allows us to conclude that as the water is transported through the distribution network, the water quality decreases slightly.

Among the few studies that used two or more indices to evaluate the quality of drinking water, the following can be mentioned: Agarwal et al. [15] in their study applied in the northern part of India found that the quality indices of groundwater samples indicated that 82% (WAWQI) and 77% (CCME WQI) of samples have poor to unsuitable type of water. Observing that the results obtained by the two methodologies do not differ from each other, as found in this study. Al-Ridah et al. [31] in their study applied to the Babylon Governorate, found that the applying weighted arithmetic method shows that the water quality is varied from 'excellent' to 'unfit', while the CCME WQI classification of the water is good for the same purpose. Indicating that CCME WQI method gives a greater water quality value as compared to the other method, in other words, CCME WQI is considered more flexible.

3.3. IRCA Assessment

According to the results presented in Table 9, no parameter analysed exceeded the maximum limit allowed by the regulations. Therefore, the sum of the risk scores for unacceptable parameters was zero, and consequently, the %IRCA was also zero. In

Table 9. Level of health risk according to IRCA for each zone of the drinking water distribution network.

N°	Parameter	Standard value	Score level of risk	Alta zone	Mahuarcay zone	Montalvo zone	Zhigzhiquin zone	Principal zone	Zhapacal zone
1	Turbidity (NTU)	1	15	0.49	0.44	0.49	0.52	0.48	0.55
2	Colour	15	6	0.04	0	0.11	0.29	0.06	0.5
3	pH	6.5–8.5	1.5	7.23	7.21	7.2	7.32	7.22	7.24
4	Total Hardness (mg $CaCO_3$/L)	300	1	67.92	57.42	71.83	69.38	65.47	72.58
5	Residual chlorine (mg/L)	0.3–1.5	15	0.85	0.52	0.71	0.67	0.76	0.68
6	Sulphates (mg/L)	200	1	16.79	11.17	18.83	20.67	15.97	20.04
7	Alkalinity (mg $CaCO_3$/L)	200	1	50.13	40.33	48.51	47.92	46.97	49.85
8	Chlorides (mg/L)	250	1	5.53	6.85	5.58	5.29	5.96	5.4
9	Nitrate (mg/L)	10	1	0.51	0.57	0.53	0.49	0.46	0.45
10	Phosphates (mg/L)	0.1	1	0.08	0.07	0.08	0.07	0.08	0.09
11	Escherichia coli (MPN/100 mL)	0	25	Absence	Absence	Absence	Absence	Absence	Absence
			Σ=68.5						
	IRCA %			**0**	**0**	**0**	**0**	**0**	**0**
	IRCA's Classification			No-risk	No-risk	No-risk	No-risk	No-risk	No-risk

this case, the resulting IRCA in all the distribution areas is between 0 and 5%. Thus, the distributed water is considered suitable for human consumption and is classified at the No-Risk level.

When reviewing the methodology for calculating the risk index for water quality for human consumption (IRCA), the 22 parameters evaluated have a causal association between waterborne diseases and the quality of the water itself (Table 4). Forty points are concentrated on parameters of microbiological characteristics due to their high incidence and causal relationship with waterbone diseases. The apparent colour group, turbidity adds up to 21 points (physical parameters). Meanwhile, the rest of the (chemical) parameters add up to 39 remaining points. In accordance with the above, greater weight is given to those parameters highly related to waterborne diseases. A conscientious statistical analysis that more accurately estimates the minimum number of samples that allows this index to be more robust from this point of view is proposed as the subject of future research.

According to the reported results of the surveillance of the quality of water for human consumption in Colombia, during the 2008–2012 period, it was found that the average of the national urban IRCA was 13.4%, classifying it as a low-risk level [32]. Sierra-Porta [38] in their study applied in the department of Santander indicated that most of the stations studied either reported water either with low risk or risk-free (≈57%) or of excellent and good water quality (≈73%) according to the methodology used for the quality index. In their study, Duarte-Jaramillo et al. [26] indicate that the results obtained showed that the water sources of both municipalities (Sincerín and Gambote) are sanitarily infeasible for human consumption, which poses a high risk to human health.

Table 10. Comparison of the results of this study with other studies that applied indices in drinking water.

Authors	Similar results	Different results
Damo and Icka [30]	The CCME WQI of 87.81 indicates that drinking water quality for Pogradec city tap water is ranked 'good.' The turbidity is the main problem in quality	This study did not apply the WAWQI methodology, nor did IRCA
Agarwal et al. [15]	There is no similarity in the results with the present study	The WQI values calculated from WAWQI method ranged from 36 to 2162. About 82% of the samples were classified as a type of water, from bad to inadequate. In 77% of the samples analysed, the CCMEWQI ranged between 29 and 73. The water quality was classified from poor to marginal. This study did not apply IRCA
Finotti et al. [24]	There is no similarity in the results with the present study	Applying the CCME WQI, poor water quality was obtained, with a value between 16 and 33. This study did not apply the WAWQI methodology, nor the IRCA
Al-Ridah et al. [31]	The CCME WQI method classified the treated water as 'good' for drinking, with a value between 80 and 87	The WAQWI rated the treated water ranged from having a value between 16.19 and 140.58, from 'excellent' to 'severely contaminated'. This study did not apply IRCA
Sierra-Porta et al. [38]	According to the IRCA, no or very few samples have been reported as posing a high risk or being sanitary infeasibility. This study does not apply CCME WQI	When applying WAWQI, just over 25% of the monitored stations reported poor quality sanitary water, compared to the present study, where 100% of the samples reported good quality water

Table 10 compares the results of this study with other studies. This table emphasizes the similar and different results obtained by other authors who have applied at least one of these indices to drinking water.

Improving water quality is a vital requirement to safeguard public health, productivity, and economic prosperity. Detailed knowledge of water quality is essential so that drinking water can be properly treated, and contamination of its sources can be prevented. These challenges present the opportunity to use water quality indices, such as those used in this study. The application of these indices could help to achieve the sixth sustainable development goal (Clean water and sanitation).

4. Conclusion

The two WQI methodologies evaluated, as well as the calculated IRCA, showed similar behaviour, and it can be concluded that the drinking water distributed in the city of Azogues is of good to excellent quality. However, it was found that the CCME WQI methodology classifies drinking water quality as 'excellent' (values obtained between 98.15 and 100) and the WQWQI as 'good' to 'excellent' (values obtained between 21.48 and 29.25). The difference is because WAWQI was calculated using an Ecuadorian standard value of 1 NTU rather than the WHO-recommended 5NTU; this resulted in this index being slightly higher than 25 and thus classified as good quality. The analysis indicated that the WAWQI is particularly sensitive to the standard value used for its calculation. The advantage of using these two indices to evaluate water quality is that the number of parameters used is not limited. Compared to WAWQI, the algorithm used to calculate the CCME WQI does not integrate any subscripts. The CCME is used from a regulatory perspective. However, the index is quite generic and requires careful selection of parameters and does not consider weightings between parameters. All the areas of the DWDN had an IRCA between 0 and 5% and therefore, the distributed water is considered suitable for human consumption and is classified at the No-risk level. The results of this study showed that CCME WQI, WAWQI and IRCA can be used as a valuable tool to assess and understand the quality of drinking water in a DWDN.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data supporting the findings of this study are available within the article.

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Appendix 1. Monthly variation of each parameter by zone area