Mundo Fesc, 11 (S4), 2021, pp. 21-29, ISSN 2216-0353, 2216-0388

Statistical analysis of water quality in the drinking water treatment plant of the municipality of Tarqui (Huila, Colombia)

Análisis estadístico de la calidad del agua en la planta de tratamiento de agua potable del municipio de Tarqui (Huila, Colombia)

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Recibido: Junio 1 de 2021 **Aceptado:** Octubre 8 de 2021

Forma de citar: N.J. Cely-Calixto, L.F. Solórzano-Galindo, R.J. Gallardo-Amaya, "Statistical analysis of water quality in the drinking water treatment plant of the municipality of Tarqui (Huila, Colombia)", *Mundo Fesc,* vol. 11, S4, pp. 21-29, 2021

Abstract

The objective of this research was to statistically evaluate the quality of the water in the drinking water treatment plant of the municipality of Tarqui (Huila, Colombia). Monthly data was collected for six years, corresponding to 2010, 2011, 2012, 2013, 2014, and 2016. The study considers four phases: descriptive application, exceedance in the quality of treated water compared to international and national regulations, risk index estimation for the quality of drinking water WQRI, water quality index WQI, and the evaluation of contaminant removal for treated and untreated water. For the treated water parameters, turbidity ($r = 0.58$), pH ($r =0.69$), and free residual chlorine ($r = 0.55$) were the best control parameters. The average turbidity values (2.35 UNT) were significantly higher in 2010 and 2011 and presented a minimum value (0.93 UNT) in the remaining years. Maximum and minimum values for pH were 7.74 and 6.81 in April 2013 and February 2014, respectively. The best correlation occurs between BOD5 and COD parameters ($r = 0.99$), with mean values of 7.23 mg/L and 18.40 mg/L, respectively. 33% of the years analyzed presented a WQRI parameter consistent with low-risk conditions in the study period. The remaining 67% of the years presented a WQRI value associated with no risk for human consumption. The ICA parameter shows that the raw water of El Hígado creek is suitable for human contact. It is concluded that the water treated in the purification plant of the municipality of Tarqui is suitable for human consumption and does not represent threats to the health of its consumers.

Keywords: Statistics, drinking water, raw water, variance, water quality, water sampling.

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Resumen

El abastecimiento del agua potable es esencial para el desarrollo de las actividades humanas. La presente investigación tuvo como objetivo evaluar estadísticamente la calidad del agua en la planta de potabilización del municipio de Tarqui (Huila, Colombia). Los datos se recopilaron mensualmente durante 6 años, correspondientes a 2010, 2011, 2012, 2013, 2014, y 2016. Se desarrollaron cuatro fases: aplicación descriptiva, excedencia en la calidad del agua tratada comparado con la legislación establecida a nivel mundial y nacional, estimación del índice de riesgo para la calidad del agua potable, índice de calidad del agua y por último la evaluación de remoción de contaminantes para el agua tratada y el agua sin tratar. Para el agua tratada se obtuvo que los parámetros turbiedad (r = 0.58), pH (r =0.69), y cloro residual libre (r = 0.55), fueron los mejores parámetros de control. Los resultados promedios de turbiedad fueron significativamente mayores (2.35 UNT) en los años 2010 y 2011, y menores (0.93 UNT) en los años restantes, el pH indicó valores máximo y mínimo de 7.74 y 6.81 para los meses de abril del año 2013 y febrero del año 2014, la correlación entre DBO5 y DQO fue la mejor (r = 0,99), y los valores medios fueron 7,23 mg / L y 18,40 mg / L, el 33% de los años analizados presento un IRCA de riesgo bajo y el 67% restante presento un IRCA sin riesgo para consumo humano, el ICA evidencia que el agua cruda de la quebrada El Hígado permite el contacto humano. Se concluye que el agua tratada en la planta de potabilización del municipio de Tarqui es apta para consumo humano y no representa amenazas para la salubridad de sus consumidores.

Palabras Clave: Estadística, agua potable, agua cruda, varianza, calidad del agua, muestreo de agua.

Introduction

The health status of a population is related to the treatment and supply of drinking water [1]. Poor water quality has been associated with different intestinal, infectious, and parasitic diseases [2]. Therefore, water treatment plants are relevant to counteract diseases caused by inadequate water quality. One of the methods to establish the condition of the water is the analysis of its effectiveness in removing a specific substance [3].

To estimate water quality, it is necessary to use clear criteria, such as the maximum tolerable concentrations of a given harmful substance [4]. For this reason, the water quality index (WQI) and the water quality risk index for human consumption (WQRI) are determined, which guarantee a comprehensive evaluation and a considerable reduction of the sanitary risk through the use of purification water processes [5].

To analyze water quality, descriptive statistics is used as the main tool to evaluate drinking water treatment processes [6]. In this regard, some numerical and statistical patterns were developed to distinguish the variation of water quality indicators over time. Among these, the autoregressive integrated moving average (ARIMA) models stand out, because they seek to obtain the representation of a time series of its elements [7]. Laboratory analytical techniques are also essential to determine the chemical, biological and physical characteristics of water to determine its actual and potential use, as well as the appropriate treatment [8]. This research aims to statistically evaluate the quality of water in the drinking water treatment plant in the municipality of Tarqui (Huila, Colombia). For this purpose, phases of excess in treated water quality were determined compared to the world and national legislation. In addition, the WQRI and WQI were estimated for treated and untreated water during the study period.

Materials and methods.

The research was developed using the following methodological details.

Description of the research site

The water treatment plant in the municipality of Tarqui (Huila) is supplied by El Hígado stream, which originates in the strategic ecosystem of Serranía de Las Minas. The water treatment plant is located at an elevation of 1338 masl at coordinates 2°09'38.98" N, 75°51'58.92" W (WGS84 reference system). The public utility company of the municipality of Tarqui (Huila, Colombia) monitors water quality at six points; one located at the intake (raw water) and five points located after the purification process (treated water), as shown in Figure 1.

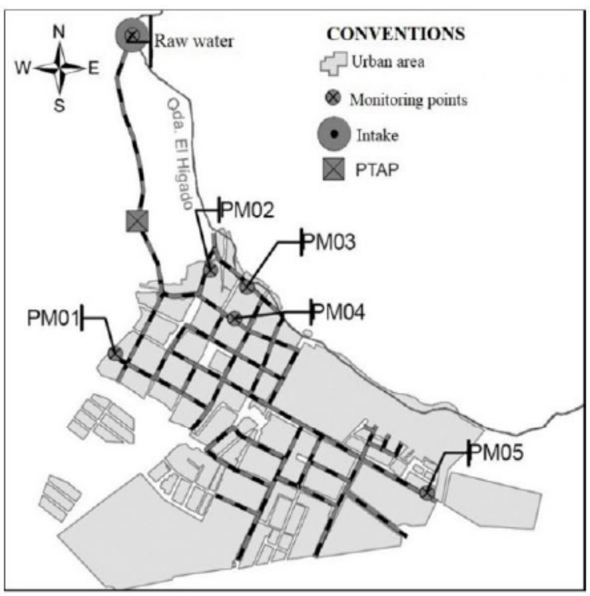

Figure 1. Water quality monitoring points.

The water treatment plant is a conventional type with a capacity of 25 L/s, where coagulation processes are carried out with aluminum sulfate type B, vertical flow hydraulic flocculation, and laminar flow sedimentation. It also includes a filtration process consisting of four independent units and, finally, disinfection with granulated chlorine and chlorine gas.

Data collection system

The investigation of time series in the description of dynamic phenomena makes it possible to assimilate time variability, to identify regular and non-regular oscillations and to understand the processes that originate these oscillations [9]. Whereby, data were collected monthly for 6 monitoring years, corresponding to 2010, 2011, 2012, 2013, 2014, and 2016. Taking into account that only 12 months of treated water results were available for 2010. For the remaining years, it was possible to obtain 12 months of raw water data and treated water data each year. It should be clarified that since the municipal water service provider did not report the necessary information, it is not possible to obtain values for 2015. The data obtained correspond to the result of a simple sample water sampling of the physicochemical and microbiological parameters of the raw water at the entrance of the urban aqueduct in El Hígado river. Information on the same parameters was also obtained for treated water at five monitoring points (Figure 1).

For the analysis of raw water, the following physicochemical parameters were taken into account: Conductivity, Total Hardness, Chlorides, Fluorides, Iron, Total Phosphates, Nitrates, True Color, Nitrites, Total Solids, Hydrogen Potential (PH), Sodium, Turbidity, Sulfates, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD5), the latter two being criteria indicative of contamination and the index of organic compound content in the water [10]. For the treated water, the physicochemical parameters taken were: Hydrogen Potential (PH), Apparent Color, Turbidity and Free Residual Chlorine. Microbiological data were also compiled for raw, and treated water, corresponding to Total Coliforms (TC) and Escherichia Coli (EC). The information collected was obtained from Empresa

Aguas del Huila S.A. - E.S.P., in charge of providing water and sewage services in the municipality of Tarqui (Huila, Colombia).

Analysis of the information

Based on the data obtained from the microbiological and physicochemical parameters of the raw and treated water, the temporal evaluation was carried out using a statistical analysis of time series with a descriptive approach. Water quality after treatment exceeds the standard period according to World Health Organization (WHO) legislation [11] and Resolution 2115 of 2007. [12].

To estimate the quality of raw water concerning the quality criteria for the destination of the resource for human and domestic consumption, Decree 1594 of 1984 [13] was used as a reference. The percentage of efficiency in the removal of physicochemical and microbiological contaminants was calculated using (1) [3].

$$Efficiency\,(\%) = \left(\frac{[Input]-[Output]}{[Input]}\right)100. \quad (1)$$

Where, [Input] is the concentration of the parameter in the raw water, and [Output] is the concentration of the parameter in the treated water.

Additionally, the WQRI index was determined according to Resolution 2115 of 2007, whereby, after the analysis of the physicochemical and biological factors of treated water, a risk assessment was conferred [14]. Meanwhile, for raw water, the WQI index proposed by the National Sanitation Foundation (NFS) of the United States in 1970 was determined [15]. In the estimation of the WQI index, the values of seven parameters in particular, such as BOD5, total solids, Escherichia coli, total phosphates, pH, turbidity, and nitrates, were required, these are brought to a similar scale using graphs and, subsequently, included numerically by assigning weights [16].

Results and Discussion

The results obtained are presented below.

Temporary evaluation at monthly level

The summary of statistical measures for the parameters evaluated for raw and treated water is presented in Table I.

Table I. Summary Descriptive Statistical Analysis.

Parameters	M	Me	Mo	S	S 2	Min	Max
Treated Water							
Free Residual Chlorine	0.78	0.76	0.68	0.14	0.02	0.43	1.15
Color Apparent*	5.13	4.86	5.50	1.17	1.84	1.67	9.67
PH***	7.21	7.19	7.12	0.21	0.05	6.80	7.75
Turbidity****	1.37	1.39	2.43	0.48	0.33	0.37	3.90
Raw Water							
Chlorides	13.6	13.9	12.5	6.89	59.2	0.30	35.5
True Color*.	10.5	9.70	9.40	5.07	29.4	1.00	35.0
Conductivity **	157	149	142	56.5	3437	6.00	410
BOD_5	7.23	5.48	3.34	6.17	72.6	0.90	64.3
COD	18.4	13.8	11.6	15.1	361	1.50	110
Total Hardness	74.9	74.2	76.8	26.4	797	6.00	182
Fluorides	0.22	0.19	0.11	0.16	0.03	0.01	0.95
Total Phosphates	0.37	0.20	0.07	0.45	0.71	0.00	6.40
Iron	0.10	0.10	0.03	0.07	0.01	0.01	0.38
Nitrates	0.75	0.70	0.56	0.39	0.18	0.00	2.90
Nitrites	0.02	0.02	0.02	0.01	0.00	0.00	0.08
PH***	7.43	7.39	7.17	0.38	0.16	6.54	8.32
Sodium	2.87	2.53	1.51	1.65	4.64	0.03	17.2
Total Solids	176	105	37	225	9867	10.0	2144
Sulfates	9.28	8.70	8.20	4.66	23.5	1.00	26.00
Turbidity	44.7	12.4	4.89	71.7	2072	0.54	987.3

Conventions: Mean (M); Median (Me); Deviation (S); Mode (Mo); Variance (S2); Minimum (Min); Maximum (Max).
*Note: All parameters are given in mg/L except: *UPC. **µS/cm. ***Units****NTU (Nephelometric Turbidity Unit)*

From the evaluation, for the treated water it was obtained that the parameters turbidity (r = 0.58), pH (r = 0.69), and free residual chlorine (r = 0.55), were the best control parameters. For turbidity, the average turbidity results were significantly higher (2.35 NTU) in the years 2010 and 2011, and lower (0.93 NTU) in the remaining years, in relation to those reported by Akoto [17], as these offered a weighted assessment of 1.10 NTU, determined during the period of decreased rainfall. Similarly, the pH parameter indicated maximum and minimum values of 7.74 and 6.81, reported for April 2013 and February 2014, respectively. It can be considered that the PH values fluctuated homogeneously. In addition, they were within the range established by Colombian legislation and the WHO.

Concerning to the parameters analyzed for raw water, chlorides showed stable levels in drinking water with an average of 13.6 mg/L. Similarly, there was a strong correlation with the parameters turbidity (r = 0.72) and iron (r = 0.63). Turbidity of raw water correlates positively with total hardness (r = 0.75), total phosphate (r = 0.51) and sulfate (r = 0.60). Nitrite and nitrate show stable concentrations in 75% of the analysis data.

The correlation between BOD5 and COD is the best (r = 0.99), and the mean values are 7.23 mg/L and 18.40 mg / L, respectively. According to the established classification range (30 <BOD5 ≤ 120; 40 < COD ≤ 200), the maximum value of the two parameters corresponds to polluted surface water [9]. These values show a contribution of organic matter to the El Hígado stream on the day of the monitoring where the maximum values occurred, possibly coming from domestic sewage. However, 95% of the observations met the acceptable classification for surface water (6 <BOD5 ≤ 30; 20 <COD ≤ 40), showing that the raw water of El Hígado stream has a strong self-purification capacity.

Legislative assessment for raw water and treated water.

The raw water from the supply source was evaluated on a monthly, annual and multi-annual basis. The inferences from the multi-year assessment are shown in Table II.

Table II. Acceptable Values for raw water - Human Consumption.

Parameter	Unit	Multi-Year Result	Allowable Value
Chlorides	mg/L	13.5	≤ 250
Royal Color	UPC	10.55	≤ 75
Nitrates	mg/L	0.75	≤ 10
Nitrites	mg/L	0.02	≤ 1.0
PH	Units	7.43	5.0 - 9.0
Sulfates	mg/L	9.28	≤ 400
Total Coliforms	MPN/100 mL	913.78	≤ 20000
Escherichia Coli	MPN/100 mL	235.42	≤ 2000

Maximum permissible limit Article 38, decree 1594 of 1984

The monthly, annual, and multi-annual evaluations of the quality of the raw water in the municipality of Tarqui have shown that it complies with the permitted values specified in Decree 1584 of 1984. Thus, it is affirmed that this water source presented a water apt to be treated through the conventional process of potabilization, such as the one carried out in the water treatment plant of the municipality of Tarqui.

Table III shows the multi-annual weighted data for the concentrations of the parameters evaluated for treated water for human consumption.

Table III. Acceptable Values of treated water

Parameter	Unit	Multi-Year Result	Allowable Value	Allowable Value**
Chlorine residual	mg/L	0.78	0.3 - 2.0	0.5 - 5.0
Apparent color	UPC	5.11	≤ 15	≤ 15
Turbidity	NTU	1.41	≤ 2	≤ 5
PH	Units	7.21	6.5 - 9.0	6.5 - 8.5
Total Coliforms	MPN/100 ml	0	0	0
Escherichia Coli	MPN/100 ml	0	0	0

Maximum permissible limit Article 38, decree 1594 of 1984
Maximum permissible limit by WHO

According to Table III, for the evaluated parameters corresponding to free residual chlorine, apparent color, PH, turbidity, total coliforms, and Escherichia coli, compliance of treated water was evidenced for the 6 parameters studied at the annual and multiannual levels. Unlike the monthly level evaluation, the percentage of excess turbidity parameters (≤ 2 NTU) related to Resolution 2115 of 2007 was found, as shown in Figure 2.

Pollutant Removal Efficiency

In the temporal evaluation of the water quality of the water treatment plant of Tarqui (Huila, Colombia), the efficiency of pollutant removal was taken into account as an important active plant for its control and operation [18]. Therefore, during the study period, the parameters of color, Escherichia Coli, turbidity and total coliforms, of the monthly results of the raw water and treated water obtained from the water treatment plant were taken into account; subsequently, the monthly removals obtained for each of the study years were averaged to reach the removal rate, as shown in Figure 2.

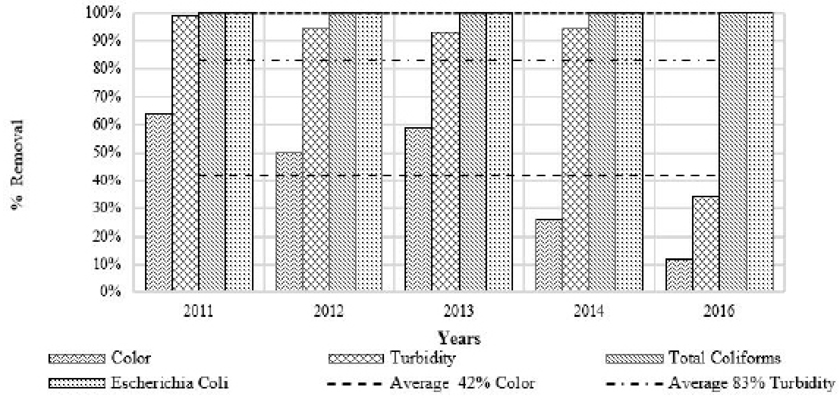

Figure 2. Pollutant Removal Efficiencies.

The annual average results showed high efficiencies and were corroborated with the t-test applied for each parameter in relation to the results of raw water and treated water. A P (T ≤ t) was obtained a tail < 0.05, therefore, the high efficiency in the decrease of pollutants in the water treatment plant. On the other hand, the analysis of variance, technique used in statistics to identify differences in means of more than two variables in the presence of factors that may interfere with the mean data obtained [19], applied to the removals obtained for the evaluated parameters, evidenced the presence of considerable inequalities between the groups, due to the percentages of removal obtained for the color parameter. In this sense, it was observed that the lowest removal presented at monthly, annual, and multiannual level, was that of real color (raw water) to apparent color (treated water), obtaining maximum removal of 64% in 2011 and minimum removal of 12% in 2016.

Water quality indexes.

Table IV shows the values obtained and the classification of the raw water characteristics and the risk level according to the WQRI values obtained for treated water.

Table IV. Results of the WQI and WQRI indexes

Year	Results for raw water		Results for drinking water	
	WQI	Classification of quality	WQRI(%)	Risk Level
2010	-	-	9	Under
2011	76.54	Good	7	Under
2012	78.25	Good	0	No Risk
2013	64.81	Media	1	No Risk
2014	73.09	Good	0	No Risk
2016	76.20	Good	0	No Risk

Table IV shows that 33% of the years analyzed presented a low-risk WQRI and the remaining 67% presented an WQRI without risk for human consumption, which indicates a positive result compared to the evaluation of the drinking water treatment plant. The descriptive statistics performed with an interval of 95 % confidence, obtained an S = 0.041 and a coefficient of variability of 1.49, which shows heterogeneity in the results [20]. In this sense, a weighted value of 2.83 % was found during the period time between 2010 - 2014 and the year 2016, included in the classification of "No Risk" according to resolution 2115 of 2007.

The WQI values show that the raw water of El Hígado stream allows human contact and generates a synergy with the aquatic diversity without problems [21]. Despite this, it is essential to take into account that the water quality for 2013 showed an average quality, unlike other years because in October there was an increase of *Escherichia coli* of 150 NMP/100 mL and a low pH of 3.87 units; thus, presenting an WQI for this month of bad category, altering the WQI valuation from good category in 2012 to average category in 2013.

Conclusions

The temporal evaluation, the evaluation of the concentrations of the parameters, and the determination of the indexes, allow inferring that the water treated in the drinking water treatment plant of the municipality of Tarqui is at levels indicated for human consumption and does not represent threats to consumers. Despite this, the values obtained from the evaluation suggest exercising continuous monitoring of the factors that indicate the optimal state of the water, because no results were obtained for 2015 from the organization linked to the provision of the public drinking water service of the municipality, generating uncertainty in the treatment processes applied in the drinking water treatment plant during this year. It is useful for the entities in charge of monitoring and controlling water quality, as a fundamental aspect in the integral management of public health.

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