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# WATER QUALITY MANAGEMENT IN A TREATMENT PLANT USING THE BOX-JENKINS METHOD

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Drinking water systems are critical to society. They protect residents from waterborne illnesses and encourage economic success of businesses by providing consistent water supplies to industries and supporting a healthy work force. This paper shows a study on water quality management in a treatment plant (TP) using the Box-Jenkins method. A comparative analysis was carried out between concentrations of water quality parameters, and Colombian legislation and guidelines established by the World Health Organization. We also studied the rainfall influence in relation to variations in water quality supplied by the TP. A correlation analysis between water quality parameters was carried out to identify management parameters during the TP operation. Results showed the usefulness of the Box-Jenkins method for analyzing the TP operation from a weekly timescale (medium-term), and not from a daily timescale (short-term). This was probably due to significant daily variations in the management parameters of water quality in the TP. The application of a weekly moving average transformation to the daily time series of water quality parameter concentrations significantly decreased the mean absolute percentage error in the forecasts of Box-Jenkins models developed. Box-Jenkins analysis suggested an influence of the water quality parameter concentrations observed in the TP during previous weeks (between 2-3 weeks). This study was probably constituted as a medium-term planning tool in relation to atypical events or contingencies observed during the TP operation. Finally, the findings in this study will be useful for companies or designers of drinking water treatment systems to take operational decisions within the public health framework.

*Keywords:* Box-Jenkins model, Treatment plant, Time series, Water quality

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## 1. INTRODUCTION

Water is a source of life, and in cases of scarcity and pollution, it can be a reason for conflict and a source of disease or even death [1]. The presence of different impurities in water requires that it be treated to be suitable for specific uses and to improve its quality and ensure health, hygiene and security prior to utilization [2]. Thus, drinking water systems are critical to society. They protect residents from waterborne diseases and encourage economic success of businesses by providing consistent water supplies to industries and supporting a healthy work force. Drinking water systems include treatment infrastructure to remove contaminants from water supplies and water distribution system infrastructure to transport treated water to households and businesses [3].

Bogota city (Colombia) is mainly supplied with drinking water through the network of the Bogota Aqueduct Company, which for 2010 reached a coverage of 99.9%. However, the remaining percentage of population did not have optimal service and was susceptible to water quality-related illnesses. It was evidenced between 2008-2010 the cases occurrence of A-type acute hepatitis, enteritis, and acute amebic dysentery; counting a total of 13058 cases in the city and specifically 9011 cases in the localities of Usaquen and Chapinero [4].

In the Colombian context, Resolution 2115 [5] established a Water Quality Risk Index for human consumption as a monitoring and control instrument in relation to water quality supplied by aqueduct service providers. Given the simplicity degree of the index and its basis in compliance or not in relation to maximum limits established by the law, it does not allow analyzing medium- and long-term trends in the drinking water quality supplied. González et al. [6] also reported that on many occasions the water quality parameters met the legislative limits, but these oscillated very close to the admissibility limit, which reflected deterioration in the drinking water quality provided.

In order to analyze the temporal variations of water quality parameters, statistical methods have been developed, which are constituted in an alternative for this purpose. Thus, we can highlight the Box-Jenkins method. This method has been satisfactorily used in studies to assess the water quality in different contexts. For example, Sun and Koch [7] used Box-Jenkins method to assess the salinity in a bay of Florida (USA). Singh and Bhardwaj [8] also obtained satisfactory results when analysing parameters such as pH, BOD, and COD in surface water bodies, demonstrating the usefulness of Box-Jenkins method to analyze the temporal behavior of these parameters and the realization of forecasts.

The main objective of this paper is shows a study on water quality management in a treatment plant (TP) using the Box-Jenkins method. A comparative analysis was carried out between concentrations of water quality parameters, and Colombian legislation and guidelines established by the World Health Organization (WHO). We also studied the rainfall influence in relation to changes in water quality supplied by the TP. A correlation analysis of water quality parameters was carried out to identify management parameters during the TP operation. Box-Jenkins method was developed to study in the short and medium term the TP operation. This study is probably a medium-term planning tool in relation to outlier events or contingencies observed during the TP operation.

## **2. MATERIALS AND METHODS**

### **2.1 DRINKING WATER TREATMENT DESCRIPTION**

This study was carried out in the TP 'El Dorado' (Bogota, Colombia). This TP is part of the supply and distribution system of drinking water of the Bogota Aqueduct Company (EAB), which supplies to more than 300000 inhabitants to the south of the city. TP makes drinking the water from three sequential supply reservoirs: 'Tunjos' (2.4 million m<sup>3</sup>), 'Chisaca' (7.4 million m<sup>3</sup>) and 'Regadera' (3.3 million m<sup>3</sup>). Thus, TP makes drinking directly the water collected from the 'Regadera' reservoir. Average flow extracted from the 'Regadera' reservoir for treatment is 0.4 m<sup>3</sup>/s, but the maximum treatment capacity is 1.6 m<sup>3</sup>/s. The treatment system is of conventional type: aeration, coagulation, flocculation, sedimentation, filtration and disinfection using saline electrolysis (MIOX).

### **2.2 SAMPLING SYSTEM**

Daily information was collected for the following water quality parameters: turbidity, color, electrical conductivity, pH, total alkalinity, chlorides, total hardness, total iron, residual aluminum, free residual chlorine, combined residual chlorine, total residual chlorine, and sulphates. The collection period was between 01/12/2006 and 28/02/2015 (3012 days). The analyses were carried out by the water quality laboratory of EAB.

## 2.3 INFORMATION ANALYSIS

*Phase 1. Information processing and analysis:* Initially we evaluated the information representativeness verifying that it counted with more than 75% of data for each one of the time series of water quality parameters considered. A descriptive statistical analysis was also carried out in order to detect trends or anomalies in the time series. A linear correlation analysis was used to evaluate the relationship between water quality parameters in order to establish management parameters or operating indicators of the TP. Information processing was carried out using the statistical software IBM-SPSS V.18.0.

*Phase 2. Rainfall influence:* We analyzed the concentration variation of each one of the water quality parameters measured in the TP in relation to the rainfall variation in the study area. Daily rainfall information of the ‘Santa Maria de Usme’ climatological station (4°28’52.7” N, -74°7’34.6” W) was provided by the Hydrology, Meteorology and Environmental Studies Institute of Colombia (IDEAM). From the information collected, the decrease and increase periods of rainfall (dry and rainy periods) were established using the quintiles and classification ranges method proposed by [9] (Table 1).

Table 1. Classification of dry and rainy periods in relation to monthly rainfall [9]

Climatic period	Quintile
Very dry month	$R_a < Q_1$
Dry month	$Q_1 \leq R < Q_2$
Normal month	$Q_2 \leq R < Q_3$
Rainy month	$Q_3 \leq R < Q_4$
Very rainy month	$R > Q_4$

Note. <sup>a</sup> R = Rainfall

*Phase 3. Box-Jenkins method:* Based on the methodology proposed by [10], the models were built for daily and weekly moving average timescales. This last timescale was used as an alternative to identify medium-term trends during the TP operation due to temporal variability in the water quality information. Box-Jenkins analysis considered the three stages reported by [11]: identification, estimation, and verification. In the identification stage of Box-Jenkins models, the orders of autoregressive and moving average polynomials were determined, as well as the differentiation degree to cancel the non-seasonality of the time series. In other words, the orders for the terms p, d, and q of Box-Jenkins models were determined. The second stage was aimed at determining values for the parameters  $\phi_1, \dots, \phi_p$  and  $\theta_1, \dots, \theta_p$  for each Box-Jenkins model identified using the

maximum likelihood method. Finally, in the third stage, 8 verification assumptions proposed by [10] were evaluated in order to select the best model to be adjusted to the time series in study.

### 3. RESULTS AND DISCUSION

#### 3.1 WATER QUALITY MANAGEMENT WITH REFERENCE LIMITS

On average, the daily turbidity of treated water during the study period was 0.27 NTU, with variations between 0.03-1.84 NTU (Table 2). This parameter remained within the admissibility limits established by the Colombian law (2.0 NTU) and WHO guidelines (5.0 NTU). We observed that 0.73% of the data were higher than 1.0 NTU, indicating probably a reduction in efficiency of the purification process during these time intervals. Though, the results obtained were comparatively lower than those reported by similar studies. For example, Akoto et al. [12] and Farooq and Hashmi [13] reported in TP average turbidity values of 1.10 and 1.0 NTU, respectively. In relation to pH, an average daily value of 6.95 was observed during the study period. This parameter varied between 5.19-9.93 (Table 2). Non-compliances were also observed for 12 days, which exceeded the limits established by the Colombian legislation and WHO guidelines. The results showed that the limits established by the Colombian legislation for pH were more permissive in relation to the WHO guidelines. Non-compliance with pH did not evince a risk to human health but could probably be related to a decrease in efficiency of the TP operation. Akoto et al. [12] suggested that the failure to comply with this parameter could be mainly related to unitary processes of coagulation and flocculation, or to the lime application in purification process.

On average, the daily concentrations of free residual chlorine were 1.48 mg/l, with daily variations between 0.28-2.59 mg/l. The WHO [14] mentioned that it is common to supply water with concentrations greater than 1.0 mg/L as prevention during the water distribution process, and that adverse effects have not been reported when consuming water with high chlorine concentrations. Thus, concentrations greater than the maximum permissible limit established by the Colombian legislation did not mean a public health risk and could probably be related to the presence of reducing agents in raw water. Ibarguen and Bernal [15] reported similar results in purification systems.

In relation to the other water quality parameters, the greater variations in order of importance were for the following parameters: total iron, residual aluminum, color, and chlorides. In these water quality parameters, the maximum concentrations observed were 34, 13, 10, and 5 times higher than

the average daily concentrations observed (Table 2). The results suggested that the water characteristics supplied by the study TP were not constant over time, possibly by the characteristics of raw water treated or by the dosage of reagents used in purification processes. All previous results showed that the water supplied by the TP was suitable for human consumption during the study period.

### 3.2 RAINFALL INFLUENCE

In the study area, rainfall showed a bimodal regime, where the dry period was observed between January and March, and August and September. Rainy period was observed between April and July, and October and December. The previous trend could be affected by influence of the climatic phenomena of 'El Niño' and 'La Niña' (ENSO climate phenomenon), which occurred between the years 2010-2011 and 2013-2015, respectively. On average, the daily concentrations of water quality parameters in the TP varied in relation to the identified climate periods. For example, during rainy periods the following parameters tended to increase in relation to the dry periods: turbidity, electrical conductivity, total and calcium hardness, total iron, residual aluminum, free residual, combined and total chlorine, and sulfates. On the contrary, the following water quality parameters tended to decrease during rainy periods: color, pH, chlorides, and total alkalinity. Ibrahim and Abu-Shanab [16] reported a similar trend in relation to the rainfall influence. Fig. 1 shows the variation in water turbidity in relation to these two climate periods during 2011. On average, during rainy periods the turbidity increased by 15% in relation to dry periods. In these rainy periods, turbidity reached maximum values of up to 0.97 NTU while during the dry periods it did not exceed 0.5 NTU.

Therefore, the results suggested that the purification process efficiency was conditioned by the rainfall variation observed in the study area, probably influencing the physical and chemical characteristics of water collected for the purification process. Romero [17] reported a similar trend in relation to the increase of turbidity in rainy periods, suggesting the need to increase the coagulant concentration (aluminum sulfate) in the raw water collected for its decrease. This also generated an increase in the concentration of its residuals in the treated water: residual aluminum and sulfates.

### 3.3 ASSOCIATION BETWEEN WATER QUALITY PARAMETERS

Correlation analysis was done under three-time scales: daily, weekly, and monthly. The results showed that the best correlations were observed under the monthly timescale (Table 3). The best correlations in order of importance were observed for the following parameters: chlorides, free residual chlorine, turbidity, electrical conductivity, and total iron. In relation to chlorides, the higher correlations were observed with the following water quality parameters: electrical conductivity ( $r = 0.68$ ), calcium hardness ( $r = -0.63$ ), total hardness ( $r = -0.58$ ), and free residual chlorine ( $r = -0.52$ ). The previous trend was probably because the water conductivity depended on the dissolved ionized substances concentration, including the chloride ion ( $\text{Cl}^-$ ). Romero [17] reported similar results in purification systems.

We also observed significant correlations between free residual chlorine and the following water quality parameters: Total iron ( $r = 0.59$ ), chlorides ( $r = -0.52$ ), and electrical conductivity ( $r = -0.46$ ). These results differed in relation to the reports of [19]. However, Romero [17] mentioned that this correlation might be associated with the disinfection process. In this process the chlorine to be an oxidizing agent was combined quickly with Fe present in the water and in turn the free residual chlorine ( $\text{HOCl}$ ) reacted with it to form  $\text{Fe}^{+++}$ .

Similarly, for turbidity, a direct correlation was observed with total iron ( $r = 0.54$ ) and color ( $r = 0.53$ ), and indirect with total alkalinity ( $r = -0.49$ ) and pH ( $r = -0.41$ ). This trend probably showed the pH and alkalinity influence on the purification process efficiency in relation to the turbidity elimination. From the relationships exposed, the results suggested in order of importance to the following water quality parameters as the most representative to evaluate the TP operation (management indicators): (i) chlorides, (ii) free residual chlorine, (iii) turbidity, (iv) electrical conductivity, and (v) total iron.

Table 2. Statistics for quality parameters of treated water in the TP

Parameter	Unit	Minimum	Maximum	Average			Standard deviation	Colombian legislation [5] <sup>a</sup>	WHO <sup>b</sup>
				Dry-Rainy period	Dry period	Rainy period			
Turbidity	NTU	0.03	1.84	0.27	0.26	0.28	0.14	2.00	5.00
Color	PCU	0.00	18.0	1.76	1.93	1.54	1.29	15.0	15.0
Electrical conductivity	$\mu\text{s}/\text{cm}$	4.69	119	57.3	56.9	57.7	10.3	1000	1000





ALK	-0.49	-0.10	0.24	0.46	1.00									
CHL	-0.27	0.09	0.68	0.48	0.25	1.00								
HAR	0.20	-0.03	-0.05	-0.22	0.09	-0.58	1.00							
HCA	0.27	0.00	-0.19	-0.25	0.05	-0.63	0.96	1.00						
TI	0.54	0.43	-0.35	-0.33	-0.11	-0.30	0.32	0.37	1.00					
RA	0.15	0.18	-0.13	-0.31	-0.38	-0.16	0.09	0.04	0.26	1.00				
FRC	0.40	0.34	-0.46	-0.29	-0.23	-0.52	0.40	0.44	0.59	0.11	1.00			
CRC	-0.11	-0.29	0.17	0.12	0.03	-0.21	0.19	0.16	-0.12	-0.16	0.05	1.00		
TRC	0.34	0.24	-0.38	-0.23	-0.21	-0.54	0.43	0.46	0.52	0.07	0.95	0.36	1.00	
SUL	0.15	-0.18	0.50	-0.03	-0.29	0.00	0.45	0.40	0.02	0.23	0.01	0.18	0.07	1.00

Note. TUR: Turbidity, COL: Color, EC: Electrical conductivity, ALK: Total alkalinity, CHL: Chlorides, HAR: Total hardness, HCA: Calcium hardness, TI: Total iron, RA: Residual aluminum, FRC: Free residual chlorine, CRC: Combined residual chlorine, TRC: Total residual chlorine, and SUL: Sulfates. Values in bold correspond to linear correlations higher or lower to 0.40 and -0.40, respectively.

### 3.4 MANAGING USING BOX-JENKINS MODELS

We determined the Box-Jenkins models (p,d,q) for the daily and weekly moving average timescales from the parameters identified as management indicators in the study TP: chlorides, free residual chlorine, turbidity, electrical conductivity, and total iron. The models obtained to represent the temporal behavior of these parameters are showed in Table 4.

In relation to the autoregressive term (p) of Box-Jenkins models developed, the results showed under a daily timescale that parameters such as total iron and free residual chlorine were not influenced by concentrations of days immediately preceding (p = 0). This trend was probably associated with that these water quality parameters depended on controlled operation conditions to ensure optimum water treatment in the TP; specifically, in relation to the pH stabilization and coagulating agent dosage (aluminum sulfate).

Table 4. Box-Jenkins models for management indicator variables in the TP

Parameter	Model <sup>a</sup>		R <sup>2</sup>	MAPE <sup>d</sup> (%)	Model <sup>b</sup>		R <sup>2</sup>	MAPE (%)
	(p,d,q)	Transf. <sup>c</sup>			(p,d,q)	Transf.		
Turbidity	(2,0,5)	NI	0.578	24.90	(2,1,7)	NI	0.956	4.709
	(3,0,3)	NI	0.577	24.89	(3,1,7)	NI	0.956	4.704
Electrical conductivity	(1,1,12)	NI	0.856	4.888	(2,1,12)	NI	0.992	0.949
	(1,0,12)	NI	0.857	4.854	(2,1,11)	NI	0.992	0.949

Chlorides	(1,1,3)	SR	0.806	20.96	(1,0,16)	NI	0.984	3.783
	(1,0,3)	SR	0.786	21.77	(0,1,16)	NI	0.984	3.768
Total iron	(0,1,12)	SR	0.524	70.41	(1,1,12)	SR	0.916	21.04
	(0,1,15)	SR	0.525	70.83	(1,1,14)	SR	0.916	21.00
Free residual chlorine	(0,1,4)	SR	0.400	10.52	(1,1,8)	N	0.969	1.621
	(0,1,6)	SR	0.394	10.53	(2,1,7)	NI	0.968	1.647

Note. <sup>a</sup> Daily timescale; <sup>b</sup> Weekly moving average timescale; <sup>c</sup> Transformation: NI = Natural logarithm, SR = Square root, and N = None; <sup>d</sup> MAPE = Mean absolute percentage error.

On the other hand, parameters such as turbidity, electrical conductivity, and chlorides showed a short memory under a daily timescale. In other words, concentrations at a specific time depended on concentrations observed between one and two days immediately preceding ( $p = 1$  and  $2$ ). This was probably related to corrective operation actions during previous days to comply with the permissible water quality limits in the TP. For example, these corrective operation actions were probably associated with changes in turbidity according to the rainfall frequency.

In relation to the moving average term of Box-Jenkins models, the results showed that concentrations at a specific time were influenced by random events from previous days; specifically, for the parameters of electrical conductivity and total iron. In these water quality parameters, the influence of up to 12 days immediately preceding was observed ( $q = 12$  and  $15$ ). The foregoing probably could be attributed to the fact that the time-series fluctuations of these water quality parameters were not visible in the short term due to the high variability of concentrations over time. Instead, parameters such as turbidity and chlorides showing a low variability in relation to its average value, showed a lower order for this term in the Box-Jenkins models developed ( $q < 5$ ).

The results showed in relation to the Box-Jenkins models' adjustment that the determination coefficient was elevated ( $R^2 > 0.75$ ) for parameters like electrical conductivity (1,0,12) and chlorides (1,1,3), whereas for turbidity, total iron, and free residual chlorine the determination coefficient was low. Also, in these last water quality parameters was observed a mean absolute percentage error (MAPE) of up to 70% (Table 4). This indicated that the Box-Jenkins models were not adequately adjusted to the time series in study, possibly by variability in the daily information observed.

On a daily basis, the results suggested that fluctuations in the short-term did not allow demonstrating through Box-Jenkins models the temporary structure of the time series of water quality parameters. Therefore, in this study was applied to the daily information a transformation of

7-days moving average (weekly), which allowed to develop Box-Jenkins models of medium-term for management indicator parameters in the TP. The models developed did not show orders greater than 3 in relation to the autoregressive term ( $p = 3$ ), probably showing the operation influence in the TP between one and two weeks immediately preceding.

In relation to the moving average term in Box-Jenkins models, the results showed that the variations observed during previous weeks might not be assimilated instantaneously. In other words, these variations influenced the time series after several weeks; as was reported by [11]. The results showed better determination coefficients ( $R^2 > 0.90$ ) and lower MAPE (5%) in relation to the Box-Jenkins models developed at weekly level. Except for Box-Jenkins models developed for total iron (1,1,12 and 1,1,14), in which the mean absolute percentage error was greater than 21%. The results suggested that the operative efficiency of TP was affected by events that occurred during previous weeks, either by variations in physicochemical characteristics of the water collected (e.g., climate factors), or by the deficiencies detection during its operation (i.e., water quality supplied).

## 4. CONCLUSIONS

The findings of this study make it possible to raise the following conclusions:

- The results show the usefulness of Box-Jenkins method to analyze the TP operation under a weekly timescale (medium term). In other words, under a daily timescale there are significant variations in the water quality parameters that make it difficult to analyze the TP operation in the short term.
- The application of a 7-day moving average transformation to the daily time series of water quality parameters decreases the mean absolute percentage errors (MAPE) of forecasts generated with Box-Jenkins models.
- The results suggest the influence of water quality parameter concentrations observed during weeks immediately preceding (between 2-3 weeks) on the TP operation. In this way, the use of Box-Jenkins method in TP is probably constituted in a medium-term planning tool against atypical events or contingencies during its operation.

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## REFERENCES

1. A. Benalia, K. Derbal, A. Panico, F. Pirozzi, F., “Use of acorn leaves as a natural coagulant in a drinking water treatment plant”, *Water*, 11(57): 1-12, 2019. <https://doi.org/10.3390/w11010057>.
2. M. Race, “Applicability of alkaline precipitation for the recovery of EDDS spent solution”, *Journal of Environmental Management*, 203(Pt 1): 358-363, 2017. <https://doi.org/10.1016/j.jenvman.2017.08.013>.
3. S. E. Schwetschenau, J. M. VanBriesen, J. L. Cohon, “Integrated simulation and optimization models for treatment plant placement in drinking water systems”, *Journal of Water Resources Planning and Management*, 145(11), 04019047, 2019. [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0001106](https://doi.org/10.1061/(ASCE)WR.1943-5452.0001106).
4. SDA - Secretaría Distrital de Salud. (2011). Secretaría Distrital de Ambiente. Recuperado el 29 de Marzo de 2018, de Secretaría Distrital de Ambiente: [http://ambientebogota.gov.co/c/document\\_library/get\\_file?uuid=17817255-1588-4942-ba6a-27dfa217ef29&groupId=55886](http://ambientebogota.gov.co/c/document_library/get_file?uuid=17817255-1588-4942-ba6a-27dfa217ef29&groupId=55886).
5. Ministerio de Ambiente, Vivienda y Desarrollo Territorial - MAVDT. Resolución 2115 (2007). Por medio de la cual se señalan características, instrumentos básicos y frecuencias del sistema de control y vigilancia para la calidad del agua para consumo humano [Characteristics, basic instruments and frequencies of the control and surveillance system for water quality for human consumption]. Colombia.
6. J. González, N. Gómez, A. Quijano, “Comparación entre los índices de agua potable IAP y los índices de riesgo de la calidad de agua para consumo humano IRCA utilizados para la determinación de la calidad del agua para consumo humano [Comparison of water rates iap risk indices and the quality of drinking water irca used for determining the quality of drinking water]”, *Revista Publicaciones e Investigación*, 4(1): 53-69, 2010. <https://doi.org/10.22490/25394088.578>.
7. H. Sun, M. Koch, (1996). *Geohydraulik Kassel*. Recuperado el 30 de marzo de 2018, de [http://www.uni-kassel.de/fb14/geohydraulik/koch/paper/1996/Cancun/Cancun\\_Arima.pdf](http://www.uni-kassel.de/fb14/geohydraulik/koch/paper/1996/Cancun/Cancun_Arima.pdf)
8. K. Singh, R. Bhardwaj, “Statistical, time series, and fractal analysis of full stretch of river Yamuna (India) for water quality management”, *Environmental Science and Pollution Research*, 22(1): 397-414, 2015. <https://doi.org/10.1007/s11356-014-3346-1>.
9. E. Bolognesi, “Análisis de criterios para clasificar totales mensuales de precipitación aplicados a series de República Argentina”, *Meteorológica*, 2(1-3), 171-205, 1971.
10. G. Box, G. Jenkins, “Time Series Analysis, Forecasting and Control”, San Francisco: Holden – Day, 1970.
11. V. Guerrero, “Análisis estadístico de series de tiempo económicas”, México, D.F.: Thomson, 2003.
12. O. Akoto, O. Gyamfi, G. Darko, V. Rex, “Changes in water quality in the Owabi water treatment plant in Ghana”, *Applied Water Science*, 7(1): 175-186, 2014. <https://doi.org/10.1007/s13201-014-0232-4>.
13. S. Farooq, I. Hashmi, I. Qazi, S. Qaiser, S. Rasheed, “Monitoring of coliforms and chlorine residual in water distribution network of Rawalpindi, Pakistan”, *Environmental Monitoring and Assessment*, 140(1-3), 339-347, 2008. <https://doi.org/10.1007/s10661-007-9872-2>.
14. WHO - World Health Organization. *Guidelines for Drinking Water Quality* (4° Ed.). Malta: World Health Organization, 2011.
15. M. Ibarguen, L. Bernal, “Establecer la demanda de cloro en el acueducto Tribunales Córcega de la Ciudad de Pereira [Establishing the demand for chlorine in the Tribunales Córcega aqueduct of Pereira City]”, *Repositorio Universidad Tecnológica de Pereira*, Recuperado el 9 de abril de 2018, de Trabajo de grado para optar por el título de Técnico Químico: <http://repositorio.utp.edu.co/dspace/bitstream/11059/1784/1/628166286132112.pdf>
16. H. Ibrahim, M. Abu - Shanab, “Monitoring of some disinfection by-products in drinking water treatment plants of El-Beheira Governorate, Egypt”, *Applied Water Science*, 3(4), 733-740, 2013. <https://doi.org/10.1007/s13201-013-0121-2>.
17. Romero, J. (2009). *Calidad del Agua [Water Quality]* (Third ed.). Bogotá D.C: Escuela Colombiana de Ingeniería.
18. M. M. Barbooti, G. Bolzoni, I. A. Mirza, M. Pelosi, I. Barilli, R. Kadhum, G. Peterlongo, “Evaluation of quality of drinking water from Baghdad, Iraq”, *Science World Journal*, 5(2), 35-46, 2010. <https://doi.org/10.4314/swj.v5i2.61512>.

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Fig. 1. Turbidity variation in the TP relative to 2011 rainfall. a) Dry period, and b) rainy period

Table 1. Classification of dry and rainy periods in relation to monthly rainfall [10]

Table 2. Statistics for quality parameters of treated water in the TP

Table 3. Pearson's linear correlation coefficients between water quality parameters (monthly timescale)

Table 4. Box-Jenkins models for management indicator variables in the TP

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