entrosur
e-ISSN:2706-6800

Research Open Access

daniel.chuquin@espoch.edu.ec

Correspondence:

Quality analysis of atmospheric reservoirs in networks with intermittent service

Análisis de calidad de depósitos atmosféricos en redes con servicio intermitente

Daniel Antonio Chuquín Vasco
Chemical Engineer. Escuela Superior Politécnica de
Chimborazo (ESPOCH).
daniel.chuquin@espoch.edu.ec
https://orcid.org/0000-0001-9637-3140

Nelson Santiago Chuquín Vasco
Mechanical Engineer, Escuela Superior Politécnica de
Chimborazo (ESPOCH).
nelson.chuquin@espoch.edu.ec
https://orcid.org/0000-0001-8998-1156

Juan Pablo Chuquín Vasco
Mechanical Engineer, Escuela Superior Politécnica de
Chimborazo (ESPOCH).
juan.chuquin@espoch.edu.ec
https://orcid.org/0000-0001-6680-507X

Gloria Elizabeth Miño Cascante
PhD in Economics. Escuela Superior Politécnica de
Chimborazo (ESPOCH).
gmino@espoch.edu.ec
https://orcid.org/0000-0003-2896-3987

Abstract

In Latin America, the installation of atmospheric reservoirs is frequent due to various policies related to water availability and management. This type of infrastructure, in addition to modifying the hydraulic behavior of the network, significantly alters the quality of the water, conditioning its microbiological characteristics and exposing the user to health problems. The hydraulic characterization of the reservoirs has been widely approached from the point of view of the way in which their filling/emptying cycles are reproduced, however, they have not taken into account several factors that modify the concentrations of disinfectant in the reservoirs, either promoting a post improvement or an impoverishment of this, in terms of quality. In the present work, the Epanet Toolkit model is applied to analyze the loss of water quality in the tanks as a function of the chlorine concentration conditions available in the main network and based on different intradomiciliary hydraulic peculiarities such as the change in the demand pattern, the variation of the regulation volume, the operation of the valve that controls the level in the cisterns, among others.

http://centrosuragraria.com/index.php/revista, Published by: Edwards Deming Institute, Quito - Ecuador, July - September vol. 1. Num. 14. 2022,

Received January 14, 2022
Approved: June 12, 2022

Key words: atmospheric reservoirs, water quality, intermittent networks.

Resumen

En América Latina es frecuente por diversas políticas referentes a la disponibilidad y gestión del agua, la instalación de depósitos atmosféricos. Este tipo de infraestructuras, además de modificar el comportamiento hidráulico de la red, alteran significativamente la calidad del agua condicionado sus características microbiológicas y exponiendo al usuario a problemas de salubridad. La caracterización hidráulica de los depósitos ha sido ampliamente abordada desde el punto de vista de la forma en la cual se reproducen sus ciclos de llenado/vaciado, sin embargo, no han tenido en cuenta diversos factores que modifican las concentraciones de desinfectante en los depósitos, ya sea que promuevan un post mejoramiento o un empobrecimiento de esta, en términos de calidad. En el presente trabajo, se desarrolla aplica el modelo del Toolkit de Epanet para analizar la pérdida de calidad del agua en los depósitos en función de las condiciones de concentración de cloro disponible en la red principal y en base a distintas peculiaridades hidráulicas intradomiciliarias como son el cambio en el patrón de demandas, la variación del volumen de regulación, la forma de operación de la válvula que controla el nivel en las cisternas, entre otras.

Palabras clave: depósitos atmosféricos, calidad del agua, redes intermitentes

Introduction

Atmospheric reservoirs are one of the main infrastructures present in networks with intermittent service, their use becomes frequent in developing countries, as is the case in Latin America, where in several areas, due to their topography, availability of the fluid or lack of economic resources, having water 24 hours a day is practically unsustainable. Based on available statistics from the Pan American Health Organization (PAHO) and the World Health Organization (WHO), in 2010 and 2011 Mexico and Brazil respectively reported that 40% of the population at some time of the year suffered temporary and/or occasional cuts in supply (Nelson et al., 2017).

In conditions where discontinuity of service is common, the use of private reservoirs is intended to store water during periods of availability of the resource to compensate for shortages when it is not available (Cobacho et al., 2008; Criminisi et al., 2009). For this reason, users store large volumes of water in reservoirs (regulated by proportional float valves) that are usually oversized, resulting in the system becoming dependent on the water head and not on the demand at each node (De Marchis et al., 2010).

Drinking water must meet a minimum quality requirement (Kruger E, 2001), however, in the final stage of distribution the maintenance of the residual disinfectant concentration is complex, since it depends, among other factors, on: a) parameters that act as a source or sink of disinfectant, b) water temperature, c) material and state of conservation of the pipes, d) residence time in the network. In this sense, the problem becomes uncontrollable for the management company when the water enters the tanks and/or reservoirs. Since storage for prolonged periods increases the residence time of the water in the network, the degradation of the disinfectant therefore decreases the residual concentration available in the medium for the inactivation of pathogenic microorganisms. In the case of chlorine disinfection, WHO (2004) recommends that the concentration of chlorine to achieve good disinfection performance should be at least 0.5 mg Cl/L after a contact time of 30 minutes and at pH less than 8.

The hydraulic behavior of reservoirs has been addressed in several investigations (De Marchis et al., 2010, 2011, 2013; Fontanazza et al., 2007; Puleo & Milici, 2015). The works were based on the study of the inequitable distribution of water in the network from different scenarios of water scarcity, and on the determination of the errors of the metering curves of the meters from the evaluation of the apparent losses due to the damping effect introduced by the reservoirs in the pattern of demands and in the underestimation of the flow rates entering through the meter.

Now, although there is a conceptualized approach to the parameters involved in the filling process of the reservoirs. The complexity, the change in the modulation curve of the demand and the increase in the residence time of the water make it difficult to control the quality of the fluid consumed by the users. Regardless of the geometry and type of operation of the reservoirs, they are not able to preserve water quality (Basile et al., 2009).

At present, few studies have characterized the hydraulic and water quality conditions in intermittent supply systems, despite the impact and the risk of contamination that they introduce in the environment (Erickson et al., 2017). In this aspect, few are the studies that have investigated the loss of quality in residential atmospheric tanks through models, where the research conducted by Mohamed & Gad, (2011) prevails, in which through a simulation in an extended period of 48 hours for a 12-story building, applying the EPANET quality model developed by (Clark et al., 1995), analyzed the influence of the size of the tanks and the change in the renewal volume, in the degradation of chlorine and the age of the water. Similarly, Lemke & DeBoer (2012) developed a model using CompTank software to study chlorine degradation as a function of filling/emptying cycles, influent concentration and degradation coefficients.

In contrast, other existing studies focus on monitoring campaigns and laboratory analyses to study: the influence of temperature and storage time on the increase of microbial activity (Evison & Sunna, 2001); the influence of reservoirs on the variation of quality parameters before and after storage (Jensen et al., 2002); the influence of reservoir construction materials and respective maintenance on the loss of physical, chemical and microbiological water quality (Schafer & Mihelcic, 2012); the effects of intermittent service on water storage reservoirs in Tamale(Ghana) (Alexandra & Renwick, 2013); the type of mixing and demand patterns in laboratory-scale elevated reservoirs by comparing results using computational techniques (Hernandez-Lopez et al., 2016); the quality of tap water, private tanks and filtered water dispensers by analyzing residual free chlorine, color, turbidity, pH, conductivity, pathogens(E.Choli), total solids(Kordach et al., 2018).

This work aims to analyze the influence of the water quality of the main network and to estimate a concentration above which water storage does not alter its final quality (to such an extent that it is unfit for consumption). Subsequently, to determine the influence of the float valve (proportional, all/nothing) that controls the inflow to the subway tank (cistern) in the conservation of the water quality and finally to analyze the influence of the tank volume on the water quality and finally by means of an analysis the factor that most alters the characteristics of the water quality will be determined.

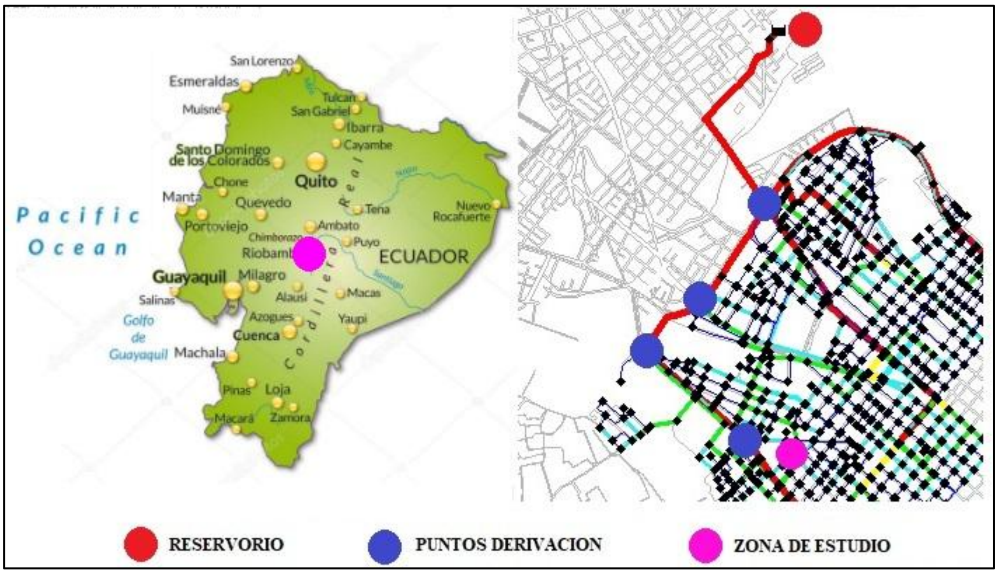
Materials and methods

A. Case study

The sector of the exemplified network used was adapted from the drinking water supply network of Riobamba-Ecuador (Figure 1), where 55% of the population has a continuous 18-24 hour service, 38% rationalized in 3 schedules, 5% for 12 hours and 2% by tankers.

The modeling scenario was adapted from a "Bonilla Abarca" sector of the Savoy network. A total of 10 households were analyzed (Figure 2.3) to examine the negative effects of water storage in the reservoirs.

Figure 1. Geographic Zone - Schematization of the Savoy Network



Source: Authors,2022

Different situations were analyzed:

1) How the chlorine [Cl] concentration evolves as a function of the quality of the mains.

2) The influence of the float valve (proportional, all/nothing) controlling the inflow to the subway reservoir on the final water quality.

3) The influence of reservoir volume on final water quality.

Based on the preliminary analysis of the area, it was determined that the common characteristic in the hydraulic design of the domiciles is the presence of both subway (cisterns) and elevated atmospheric reservoirs (Figure 3), typical of systems with intermittent supply (Mastaller & Klingel, 2017).

Figure 2. Schematic model in EPANET

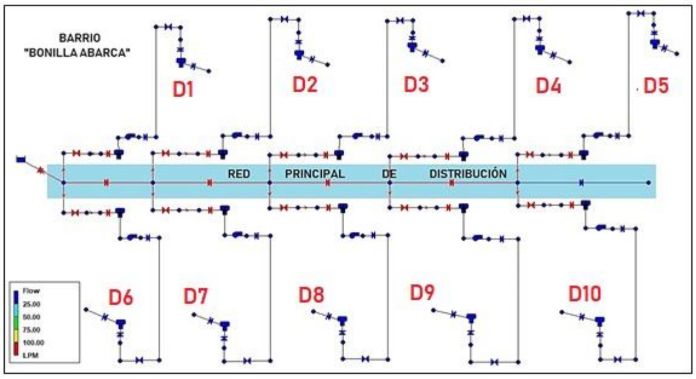
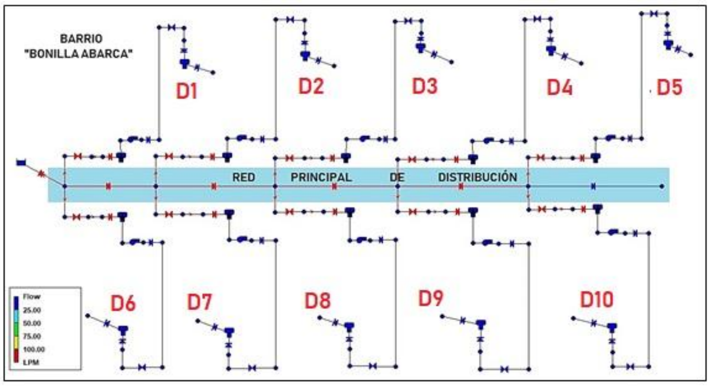


Figure 3. Hydraulic schematization of the installations



B. Quality model

Considering mass conservation balances in tanks (Eq.1), and assuming complete mixing in tanks (Rossman, 2006), chlorine degradation has been quantified from first-order kinetics, considering the effects of temperature as a determining factor in the variation of the chlorine degradation coefficient (Monteiro et al., 2015), from the Arrhenius equation (Eq.2):

C. $\frac{d(VC)}{dt} = \sum Q_{in}C_{in} - \sum Q_d C - k_T C$ (1)

D.

$$k_T = k_{b_{20}} * e^{\left(\frac{\frac{E_A}{R(20-T)}}{(273+20)(273+T)}\right)} \tag{2}$$

where *V* tank volume, *C* chlorine concentration in the medium, C_{in} chlorine concentration of Q_{in} , k_T chlorine degradation constant corrected for temperature, kb_{20} degradation constant at 20°C, E_A chlorine activation energy, R universal gas constant and T the temperature.

C. Water quality standards

The comparative and statistical analyses of the modeling results were performed based on the NTE INEN 1 108:2006 standard (INEN, 2006) and according to WHO guidelines (WHO, 2011). The Ecuadorian technical standard on drinking water requirements establishes that the maximum permissible limit of free residual chlorine in the network should be in the range of 0.3 - 1.5 mg/L, while the WHO recommends that free chlorine should be at least 0.2 mg/L at the extremities of the network and 0.5 - 1 mg/L after at least 30 minutes of contact for chlorination to be effective.

D. Statistical analysis

The analyses of the results were developed with StatGraphics software (STATPOINT TECHNOLOGIES, 2014) with a confidence interval of 95%, in which statistical tests were performed for the study of the concentration and influence of the factors that modify water quality.

E. Application of the method

The following hydraulic and quality characteristics were considered as normal operating conditions (N.C.):

-Tank volume = 2000 L, controlled by proportional valve.

-Elevated tank volume = 1000 L.

-Free residual chlorine from the mains (0.5 mg Cl/L).

-Pumping stations (0.5 - 3 HP) on site, operated with switches depending on the levels of the elevated reservoirs.

-Initial quality of tanks and cisterns = 0.56 mg Cl/L. In situ chlorination is not considered.

-Base demand = 8.46 L/min.

The study of the evolution of chlorine in the tanks was carried out for a simulation period of 336 hours (14 days) on a minute scale.

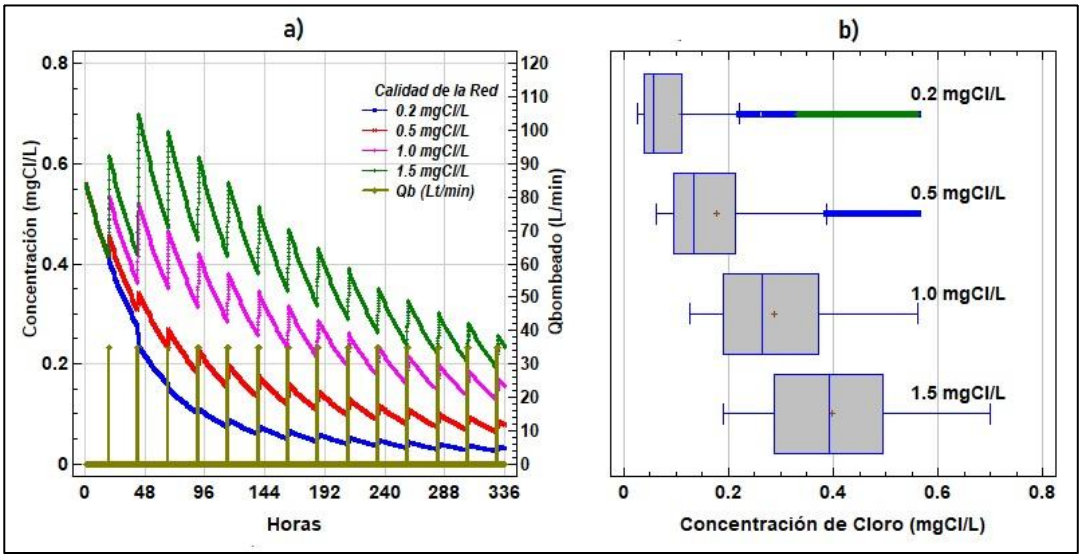
Result

A. Analysis of the influence of the chlorine concentration of the main network.

Figure 4 is the result of 4 scenarios that exemplify the evolution of chlorine in private reservoirs as a function of the existing quality of the network (1.5;1;0.5;0.2 mg/L).

In the best case, as specified by WHO, the minimum residual chlorine level that ensures safe drinking water conditions is 0.2 mg/L, and in the most favorable case a typical free residual chlorine concentration in the areas close to the source of 1.5 mg Cl/L.

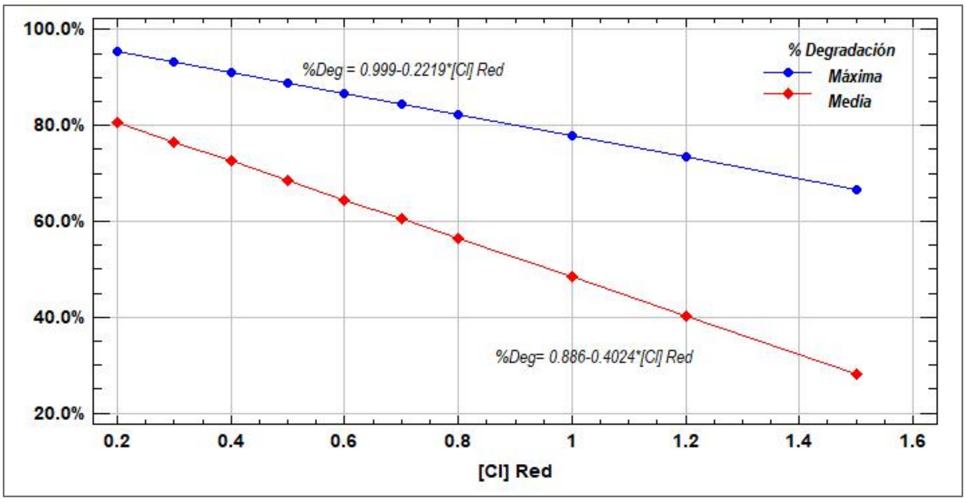
Figure 4. a) Evolution of chlorine in the reservoirs as a function of the quality of the main network; b) Range of variation of [Cl] in the reservoirs.



Source: Authors,2022

As it is evident that the incidence of [Cl] in the network is a transcendental factor in the final water quality, the trend observed is a gradual decrease in the concentration that tends to improve when the pumping stations (intradomiciliary) come into operation, renewing the water in the reservoirs. This is notorious in cases where the [Cl] in the network is higher than 0.5 mg/L (Figure 4a) where the trend is the increase and subsequent decrease of the concentration in the tanks almost proportional, indicating that the concentration available in the network is higher than that in the tanks (Scenario 3 and 4: 1.0 and 1.5 mg Cl/L) favoring its increase and therefore ensuring a minimum concentration within the range of 0.2 - 0.5 mg Cl/L. The opposite, happens in scenarios 1 and 2 (0.2 and 0.5 mg Cl/L) where minimum [Cl] variation ranges of (0.05 - 1) and (0.1 - 0.21 mg Cl/L) respectively are observed (Figure 4b). In these 2(two) scenarios, despite the availability of continuous pumping to the elevated reservoir there is no recovery of considerable concentration levels, indicating that the water available from the network ([Cl] = 0.2 mg/L) does not guarantee a mixing, between the water stored in the reservoir and that available for pumping, which greatly favors the increase of [Cl]. These illustrated scenarios demonstrate, on the one hand, the advantage of having water of adequate quality in areas close to the headwater reservoir, while, on the other hand, demonstrating the vulnerability to developing quality problems in areas where the concentration of chlorine available in the network does not guarantee a [Cl] higher than 0.2 mg/L once stored in the private reservoirs. Unlike strategically located areas, where the quality of the stored water remains in good condition for about 240 hours (Scenario 3 and 4), the problem is evident for users located several kilometers from the main reservoir after the third day of storage (80 hours). Figure 5 shows the average and maximum percentages of concentration reduction in the reservoirs. As can be seen, there is a linear reduction trend in the degradation percentage as the [Cl] of the distribution network increases.

Figure 5. Average and maximum percentages of [Cl] degradation in the reservoirs as a function of the quality of the distribution network**.**



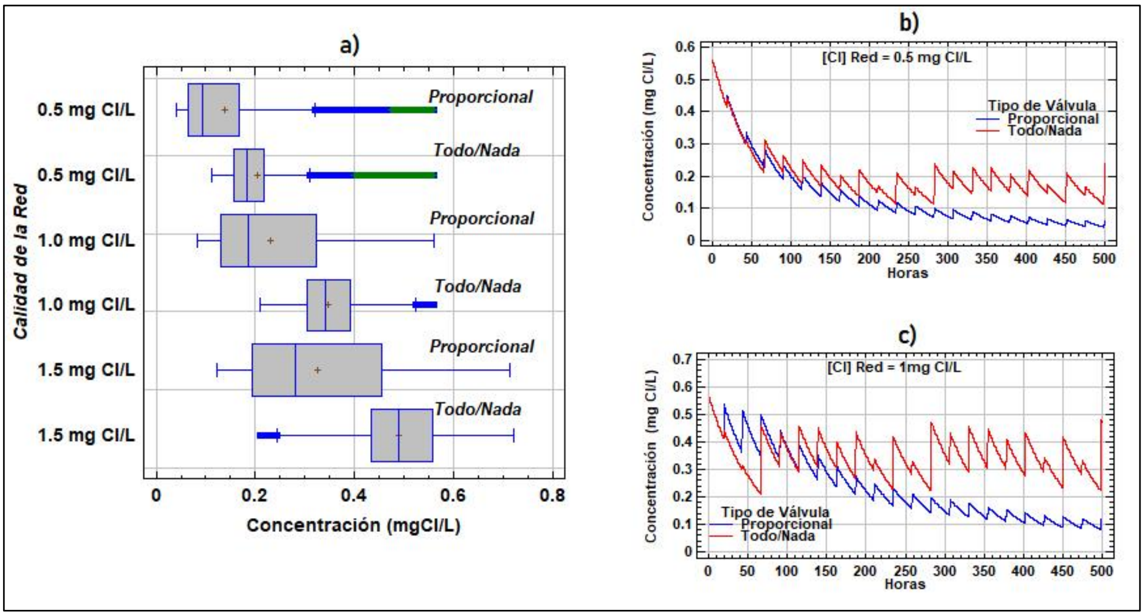
B. Analysis of the type of valve (proportional, T/N) controlling the tank level.

In this analysis based on the simulation it is specified that during the first hours of the simulation the T/N valve results in low chlorine concentrations. In cases where the water level in the tank (controlled by the T/N valve) does not allow the admission of incoming flow, there will be no mixing with the water coming from the network during the hours that the minimum level is not reached for the valve to open and therefore the water suffers a degradation process without the possibility of renewal until the first filling cycle (Figure 6c). However, there is a turning point where the evolution of chlorine in the system follows a clear trend once the model has stabilized from the initial simulation conditions and an increase in the concentration levels in the tanks is observed, which are even better in contrast to what happens when proportional float valves are used for level control.

A priori, proportional valves allow a constant renewal of the water in the tank that is pumped to the upper reservoir, however, in periods where the demand is low the increase in [Cl] is not relevant unlike what happens in the T/N valves. Based on Eq.1 the left term (dc/dt) is proportional to the flow rate admitted by the valve and consequently increases when the term (Q_in C_in) is higher. Therefore, when the T/N valve is completely open, it allows the entry of larger volumes of water that considerably improve the concentration in the tank and subsequently by pumping in the upper tanks. This is evident in Figure 6b, where after 60 hours of storage (stabilization of the model), the water quality in the tanks improves considerably and follows a clear trend of increasing and decreasing depending on the start/stop cycles of the pumping system.

In addition, as shown in Figure 6a, independent of the [Cl] in the main network, the fluctuation ranges of chlorine concentrations in the tanks improve when the water levels in the tank are controlled with T/N float valves, thus minimizing the problem of water quality loss. It is also important to note that although the chlorine concentration increases to high levels (1 mg/L, Figure 6c) with the use of proportional valves, the minimum concentration levels are not recovered because the final concentration (C) of the dc/dt term in Eq.1 increases by $(Q_{in}C_{in})$ but at the same time decreases by (kb*C), the latter term being more decisive with respect to the latter because the inlet flow is relatively small and there is no considerable increase and on the other hand the degradation reaction rate increases (due to the increase in available concentration) promoting the gradual disappearance of chlorine. The opposite happens with T/N valves, where, although the reaction rate is maintained with respect to the previous case, the input flows are high and therefore the term $Q_{in}C_{in}$ has a greater impact than degradation, thus increasing concentration levels.

Figure 6. Range of variation of [Cl] as a function of the type of valve controlling the water level and the quality of the network; b, c) Evolution of [Cl] for each type of valve when the quality of the network is 0.5 mg/L and 1.0 respectively.

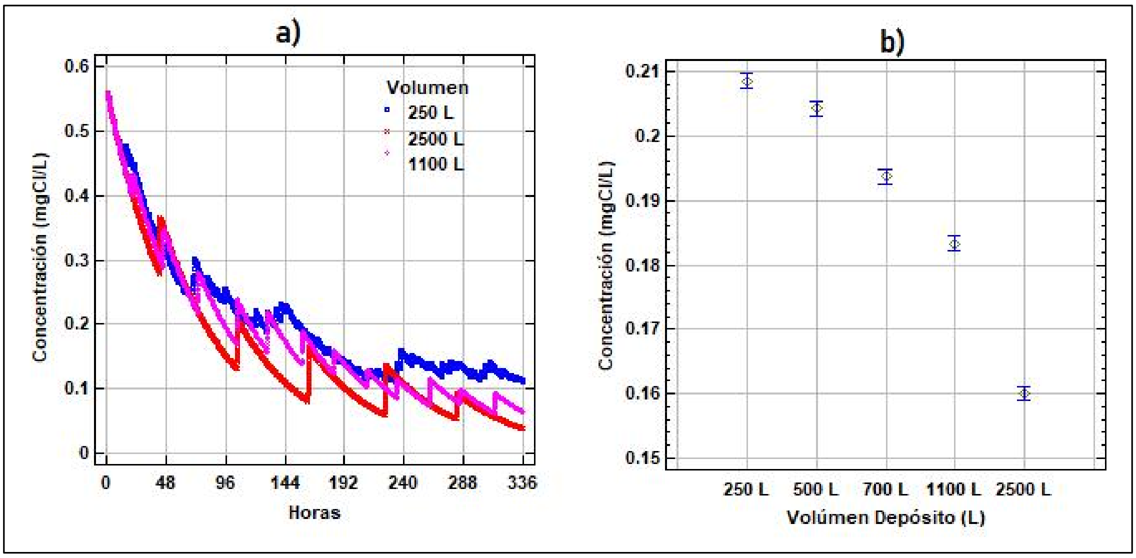


Source: Authors,2022

C. Analysis of the influence of the type of the volume of the reservoir

The increase in the total volume of the tank increases the residence time of the water in the network and indirectly, according to Eq.1, the concentration of chlorine due to the effects of time increases according to the constant kb (dia^{-1}). However, the loss of quality begins to be evident when there are large variations with respect to the regulation volume which, being larger, decreases the operating cycles of the pumps and the inflow of water in better quality conditions to the tank. In other words, quality is conditioned both by the pump start-up cycle that gives rise to the term $(Q_{in}C_{in})$ of Eq.1, as well as by the degradation kinetics (kb*C). Consequently, if tank filling and emptying rates and levels of chlorine concentrations at the tank inlet are low (<0.4 mg/L) there will not be sufficient water turnover to promote recovery of internal concentration levels. Therefore, maintaining the same demand pattern, oversizing a tank can significantly affect water quality. Figure 7 shows the evolution curve for different volumes, the concentration decreases in poorly sized tanks at higher rates to such an extent that, as can be seen, levels below 0.1 mg/L (V=2500 L) are reached.

Figure 7. a, b) Evolution and range of variation of [Cl] as a function of reservoir volume.



Source: Authors,2022

In effect, reservoirs that store water for long periods of time when there are very low consumption patterns minimize the turnover of water in the reservoirs and therefore the concentration of free residual chlorine available, increasing the risk of contamination. The [Cl] and average degradation percentages are detailed in Table 1, and as can be seen in Figure 7b, the average concentration in the tanks decreases linearly as the tank volume increases.

Table 1. *Average concentration of chlorine in tanks of different volume.*

Volume(L)	**[Cl] Deposit**	**Standard Deviation**	**Minimum**	**Maximum**	**Average %Degradation**	**Maximum %Degradation**
250 L	0.209	0.103	0.110	0.56	62.75%	80.37%
500 L	0.204	0.107	0.075	0.56	63.53%	86.52%
700 L	0.194	0.103	0.090	0.56	65.41%	83.94%
1100 L	0.183	0.112	0.061	0.56	67.26%	89.02%
2500 L	0.160	0.117	0.038	0.56	71.41%	93.23%

D. Analysis of the most determining factor

As developed in the previous analysis, there are different factors that modify the characteristics of the quality of the water available to users, the most detrimental being the oversizing of the tanks for a given base demand that remains constant over time. The increase of residence times in the network and the decrease of cycles that renew the volumes of water in the tanks reduce the possibility of generating mixtures that allow the recovery of chlorine concentration levels, making it difficult to reach minimum levels that guarantee the innocuousness of microorganisms, giving rise to water contamination, the result of which is the lack of potabilization and the appearance of problems in the health of the users.

Table 2 summarizes the factors considered in the study by means of a sample comparison analysis. It details the mean concentrations, standard deviations, maximum and minimum limits of concentrations, percentages of quality loss.

As mentioned above and as confirmed in Table 2, the factor that promotes greater chlorine degradation is the increase in the volume capacity of the tank (F3), with respect to normal operating conditions (V=1000 L), the average degradation percentage increases by 4.24%, while the factor that contributes to guaranteeing the final water quality is the increase in concentration in the main network (F1), which decreases the degradation percentage with respect to the N.C. by 9.79%.

The results are corroborated by the percentile analysis (Table 3). When the tank volume (F3) increases 50% of capacity, 75% of the concentrations are below 0.176 mg Cl/L, which does not guarantee the minimum concentration recommended by the WHO.

It is also important to note that the type of valve that controls the level of the tanks is an important factor in the recovery of the concentration levels, when using all/nothing valves (F2) 50% of the data take values below 0.1886 mg/L, as opposed to the N.C. (proportional valves) where 50% of the data take values below 0.1348 mg/L.

Table 2. *Summary statistics of the factors that modify the [Cl].*

FACTOR	QUALITY	Percentage (%)	Average	Standard Deviation	Min	Max	% Reduction medium [Cl] % Reduction medium [Cl] % Reduction medium [Cl
Normal Conditions (NC)	Mala	72.77%	0.1762	0.1123	0.06	0.56	68.52%
	Regular	12.29%					
	Optimum	14.94%					
	Total	100.00%					
> [Cl] in the Network (F1)	Mala	50.15%	0.2328	0.108	0.093	0.56	58.43%
	Regular	24.88%					
	Optimum	24.97%					

	Total	100.00%					
All/Nothing Valve (F2)	Mala	56.55%	0.215	0.091577	0.1065	0.56	61.51%
	Regular	29.08%					
	Optimum	14.38%					
	Total	100.00%					
> Deposit Volume (F3)	Mala	77.22%	0.152	0.1184	0.0466	0.56	72.76%
	Regular	9.38%					
	Optimum	13.40%					
	Total	100.00%					

Note: For comparison F1 (Chlorine concentration was increased with respect to the N.C. by 50%), F2 the proportional valve was changed to T/N valve, F4 (Tank volume was increased with respect to the N.C. by 50%).

Table 3. *Percentile analysis of the factors studied.*

Volume(L)	**[Cl] Deposit**	**Standard Deviation**	**Minimum**	**Maximum**	**Average %Degradation**	**Maximum %Degradation**
250 L	0.209	0.103	0.110	0.56	62.75%	80.37%
500 L	0.204	0.107	0.075	0.56	63.53%	86.52%
700 L	0.194	0.103	0.090	0.56	65.41%	83.94%
1100 L	0.183	0.112	0.061	0.56	67.26%	89.02%
2500 L	0.160	0.117	0.038	0.56	71.41%	93.23%

Source: Authors, 2022

Conclusions

This work analyzes the impacts on water quality conditions in elevated reservoirs typical of distribution networks with intermittent service. The application of the model confirms the relevant negative effects that the tanks introduce in the water quality, being the main result the non-compliance with the water potabilization criteria and giving way to possible sanitary problems in the population. The results of the analysis are shown in the following points:

The users close to the headwater reservoir are the ones that will receive water with the best quality parameters ([Cl] = 1.5 mg Cl/L), which guarantee that the water passing through the reservoirs meets the minimum requirements established by the WHO (0.2 mg Cl/L), however, the [Cl] in the extremities of the network due to its degradation in the system will drop to 0.2

- 0.5 mg Cl/L which represents that approximately 75% of the concentrations in the reservoirs over time will be below 0.21 mg/L. The T/N valves allow the recovery of chlorine concentration levels in the tanks to a greater extent than the proportional valves. Due to the volume of water admitted ($Q_{in}C_{in}$), according to the equations governing the variation of concentration, they allow a greater restitution of the concentration. The average concentration loss percentage for the T/N and proportional valves is 61.51 and 68.52% respectively. The loss of water quality begins to be evident when there are large variations with respect to the regulation volume (tank volume); when the volume is larger, the pump operation cycles decrease and the entry of water in better quality conditions to the tank decreases.

The factor that most affects the loss of quality is the increase in storage volume. If the volume increases 50% of its capacity, the loss of concentration increases 4.24%. Future developments will focus on the incorporation of water quality in private reservoirs in the modeling of networks with intermittent service where optimization is taken into account in terms of the relationship between energy efficiency and the costs involved in meeting water potability criteria.

References

Alexandra, D., & Renwick, V. (2013). The Effects of an Intermittent Piped Water Network and Storage Practices On Household Water Quality in Tamale , Ghana. http://web.mit.edu/watsan/Docs/Student Theses/Ghana/2013/Thesis_D_Vacs_Renwick_FINAL_5-31-13.pdf.

Basile, N., Fuamba, M., & Barbeau, B. (2009). Optimization of Water Tank Design and Location in Water Distribution Systems. Water Distribution Systems Analysis 2008, 1-13. https://doi.org/10.1061/41024(340)32

Clark, R. M., Rossman, L. A., & Wymer, L. J. (1995). Modeling Distribution System Water Quality: Regulatory Implications. Journal of Water Resources Planning and Management, 121(6), 423-428. https://doi.org/10.1061/(ASCE)0733-9496(1995)121:6(423).

Cobacho, R., Arregui, F., Cabrera, E., & Jr, E. C. (2008). Private Water Storage Tanks : Evaluating Their Inefficiencies. Technology, 3(1). https://doi.org/10.2166/WPT.2008025

Criminisi, A., Fontanazza, C. M., Freni, G., & La Loggia, G. (2009). Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. Water Science and Technology, 60(9), 2373-2382. https://doi.org/10.2166/wst.2009.423.

De Marchis, M., Fontanazza, C. M., Freni, G., La Loggia, G., Napoli, E., & Notaro, V. (2010). Modeling of distribution network filling process during intermittent supply. Integrating Water Systems - Proceedings of the 10th International on Computing and Control for the Water Industry, CCWI 2009, 189-194.

De Marchis, M., Fontanazza, C. M., Freni, G., La Loggia, G., Napoli, E., & Notaro, V.

(2011). Analysis of the impact of intermittent distribution by modelling the network-filling process. Journal of Hydroinformatics, 13(3), 358. https://doi.org/10.2166/hydro.2010.026.

De Marchis, M., Fontanazza, C. M., Freni, G., La Loggia, G., Notaro, V., & Puleo, V. (2013). A mathematical model to evaluate apparent losses due to meter under-registration in intermittent water distribution networks. Water Science and Technology: Water Supply, 13(4), 914-923. https://doi.org/10.2166/ws.2013.076.

Erickson, J. J., Smith, C. D., Goodridge, A., & Nelson, K. L. (2017). Water quality effects of intermittent water supply in Arraij an, Panama. https://doi.org/10.1016/j.watres.2017.02.009

Evison, L., & Sunna, N. (2001). Microbial Regrowth in Household Water Storage Tanks. Journal (American Water Works Association), September, 85-94.

Fontanazza, C. M., Freni, G., & La Loggia, G. (2007). Analysis of intermittent supply systems in water scarcity conditions and evaluation of the resource distribution equity indices. WIT Transactions on Ecology and the Environment, 103, 635-644. https://doi.org/10.2495/WRM070591

Hernandez-Lopez, R. D., Tzatchkov, V. G., Martin-Dominguez, A., & Alcocer-Yamanaka, V. H. (2016). Study of hydraulics and mixing in roof tanks used in intermittent water supply. Journal of Water, Sanitation and Hygiene for Development, 6(4), 547-554. https://doi.org/10.2166/washdev.2016.147

Jensen, P. K., Ensink, J. H. J., Jayasinghe, G., van der Hoek, W., Cairncross, S., & Dalsgaard, A. (2002). Domestic transmission routes of pathogens: the problem of in-house contamination of drinking water during storage in developing countries. Tropical Medicine & International Health : TM & IH, 7(7), 604-609. http://www.ncbi.nlm.nih.gov/pubmed/12100444

Kordach, A., Chardwattananon, C., Wongin, K., Chayaput, B., & Wongpat, N. (2018). Evaluation on the Quality of Bangkok Tap Water with Other Drinking Purpose Water. E3S Web of Conferences, 30, 01011. https://doi.org/10.1051/e3sconf/20183001011. https://doi.org/10.1051/e3sconf/20183001011

Kruger E. (2001). Water Quality Deterioration in Potable Water Reservoirs Relative To Chlorine Decay (Issue 921). http://www.wrc.org.za/Knowledge Hub Documents/Research Reports/921-1-01.pdf.

Lemke, A., & DeBoer, D. E. (2012). Effect of Storage Tank Mixing on Water Quality. 146.

Mastaller, M., & Klingel, P. (2017). Adapting the IWA water balance to intermittent water supply and flat-rate tariffs without customer metering. Journal of Water Sanitation and Hygiene for Development, 7(3), 396-406. https://doi.org/10.2166/washdev.2017.116

Mohamed, H. I., & Gad, A. A. M. (2011). Effect of Cold-Water Storage Cisterns on Drinking-Water Quality. Journal of Water Resources Planning and Management-Asce, 137(5), 448-455. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000132.

Monteiro, L., Viegas, R. M. C., Covas, D. I. C., & Menaia, J. (2015). Modelling chlorine residual decay as influenced by temperature. Water and Environment Journal, 29(3), 331-337. https://doi.org/10.1111/wej.12122.

Nelson, K. L., Perroni, E. A., & Buss, S. (2017). Intermittent supply in the context of efforts to improve drinking water supply in Latin America and the Caribbean Intermittent supply in the context of efforts to improve drinking water supply in Latin America and the Caribbean. https://publications.iadb.org/bitstream/handle/11319/8027/Suministro-intermitente-en-el-contexto-de-esfuerzos-por-mejorar-el-abastecimiento-de-agua-potable-en-America-Latina-y-el-Caribe-Lecciones-de-un-estudio-de-caso-en-Arraijan-Panama.pdf?sequence=2

Puleo, V., & Milici, B. (2015). Water losses dynamic modelling in water distribution networks. AIP Conference Proceedings, 1702(180004). https://doi.org/10.1063/1.4938953

Rossman, L. A. (2006). The effect of advanced treatment on chlorine decay in metallic pipes. Water Rese, 40. https://doi.org/10.1016/j.watres.2006.04.046

Schafer, C. a, & Mihelcic, J. R. (2012). Effect of storage tank material and maintenance on household water quality. Journal American Water Works Association, 104(9), 49-50. https://doi.org/10.5942/jawwa.2012.104.01253516846