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The effect of travelling time on chlorine decay in the distribution system

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Abstract

Chlorine is rated as one of the disinfectants used by utilities and water services providers to kill, inactivate microorganisms so that they cannot infect humans. This disinfectant is readily available, cheap and easy to transport; occur in a gaseous, liquid and solid form. However, when chlorine is injected in water and transported through the water pipes of the distribution networks, it undergoes reactions with the bulk water and with the inner pipe wall naturally along the distance of travel .These reactions result in the dissipation and loss of residual chlorine which pose a major threat in weakening the barriers against water safety and create a chance of recontamination. According to world health organization a limit for residual chlorine concentration at public water stand pipes was set to be 0.2-0.3 mg/L at 30 minutes contact time. Therefore a methodology for predicting the free chlorine residual at points in the distribution system distant from the points of chlorination would be helpful to water utilities in maintaining chlorine residual throughout the system. The aim of this study is to assess the effect of travelling distance on the chlorine decay in the distribution system. Free chlorine residual measurements were analyzed in the field at the reservoir inlet, outlet and direct feed using a pocket colorimeter and DPD (N, N. diethylenediamine) tablets that cause the color to change pink in the presence of chlorine. The concentration of residual chlorine in mg/L and travel time in hours was recorded. The study areas selected were reservoirs and their distributions located in the north of Johannesburg. Free residual chlorine measurements for the reservoirs were examined over a period of one year. In conclusion, it was observed that, residual chlorine concentration decreases as distance increases. Hence according to the comparison of the work done by [5] it was concluded that the distance travelled had been the major causes of decrease in residual chlorine concentration and increased bacterial growth.

Key words: disinfectants, disinfectant, travelling time

1. Introduction

According to world health organization standard, a limit or residual chlorine concentration at public water stand taps was set up to be 0.2 – 0.3mg/L at 30 minute contact time, less than this, the water is not fit for direct consumption [3]. Everywhere in the world, the drinking water utilities face the challenge of providing water of good quality to their consumers as significant water quality changes can occur within drinking water distribution systems due to contamination. Disinfectant like chlorine can control growth of pathogens but it reacts with organic and inorganic matter in water, the chlorine concentration decreases in time called the chlorine decay [4]. So, as water moves through a water system, chlorine is expended as it interacts with microbes and pipe material which reduces the residual chlorine levels as it reaches the end of the distribution line [6]. Therefore, knowledge of effective chloramines and residual chlorine concentration at reservoirs and distribution points in drinking water distribution system is essential to avoid chlorine decay during travelling time and maintain the quality of water supplied to the consumers.

Chlorine is such a strong oxidizer, it reacts with a wide range of chemicals and naturally occurring organic and inorganic matter in the treated or distributed, therefore, it is very essential for any water supply authority to manage the chlorine disinfection within lower and upper limit of residual chlorine to safeguard the consumers from water-borne diseases and harmful DBPs simultaneously [4]. To cope up with the decay in chlorine, higher mass rate of chlorine is applied at the source to maintain the minimum residual chlorine up to the farthest end, which results in harmful DBP formation at the nearest locations to the source and less concentration of residual chlorine at farthest location. Thus, the objectives of microbial-free water with proper quantity and pressure is difficult to achieve through conventional water supply networks without targeting continuous water supply and constantly pressurized system [4]. Secondary disinfection by Chloramination is an excellent disinfectant as chlorine does not remain active for much longer than 6 to 8 hours. Disinfection needs to be repeated but this time with a less powerful agent that will remain active for long periods so that the water may be protected right up to the end consumer. This is achieved by dosing chlorine and ammonia at the booster pumping station in the correct mass ratio of not less than 4:1 and forming the monochloramines in situ.The monochloramines, although less active than chlorine, then protects the water against bacterial regret for periods of up to 8 days [9].

2. Methodology

Chlorine sample preparation

Chlorine samples were taken following aseptic techniques guided by sampling SOP and monitored according to ISO 17025 standard 5.7 with the laboratory having a sampling plan and procedures. In the field, taps were allowed to run at full speed for 3 minutes before analysis.

Chlorine analysis

Water quality parameters monitored in this study included free chlorine and monochloramines. These parameters were chosen due to the effective disinfectant characteristic of monochloramines and residual chlorine concentration at reservoirs and distribution points in drinking water distribution system. These parameters were monitored bi-monthly. Below (Table 1.) shows the parameters measured, the frequency of measurement of each parameter, and the regulatory limit as per SANS241-1 (2015) for each parameter.

Table 1: Monitoring Frequency and Regulatory Limits for Monitored Parameters [1]

Parameter (Unit)	**Monitoring Frequency**	**Regulation by SANS 241 (2011)**	**Regulatory Limit(s)**
Free chlorine (mg/l)	Bi-monthly	Yes	0.2*- ≤5
Monochloramines (mg/l)	Bi-monthly	Yes	≤3

Free chlorine and monochloramines analysis

Chlorine levels were analysed on site with both Total and Free chlorine being done using the ULR-DPD method. It is USEPA-accepted method for total chlorine and free determinations in drinking water and wastewaters. The DPD (N, N. diethylenediamine) titration method is based on the same chemistry as the DPD colorimetric method – in that DPD (N, N. diethylenediamine) is oxidized by chlorine to the magenta-colour species. Analysis was done on site using HACH: Pocket Colorimeter using the ULR-DPD method for free chlorine analysis. It is USEPA-accepted method for total chlorine and free determinations in drinking water and wastewaters. The DPD (N, N. diethylenediamine) titration method is based on the same chemistry as the DPD (N, N. diethylenediamine) colorimetric method – in that DPD (N, N. diethylenediamine) is oxidized by chlorine to the magenta-colour species. [2,7]

The colorimeter was switched on and set on chlorine reading mode where a vial is inserted containing the sample and press the blank button. When the instrument read 0.00, proceeded to rinse the vial and lid with the sample and added 10 ml of sample. DPD (N, N. diethylenediamine) no. 1 tablet was added, lid covered and mixed by gently inverting the vial several times until the DPD (N, N. diethylenediamine) no. 1 tablet was dissolved. Covered vial was inserted into the instrument and reading taken immediately. Result was recorded after reading on the sampling sheet, retained the solution and proceeded with total chlorine test where DPD (N, N. diethylenediamine) no. 3 tablet was added to the retained solution and mixed to dissolve. Covered vial was inserted into the instrument and let stand for 2 minutes. Reading was recorded on the sampling sheet and the vial with lid rinsed thoroughly after use[8].

3. Results and Data analysis

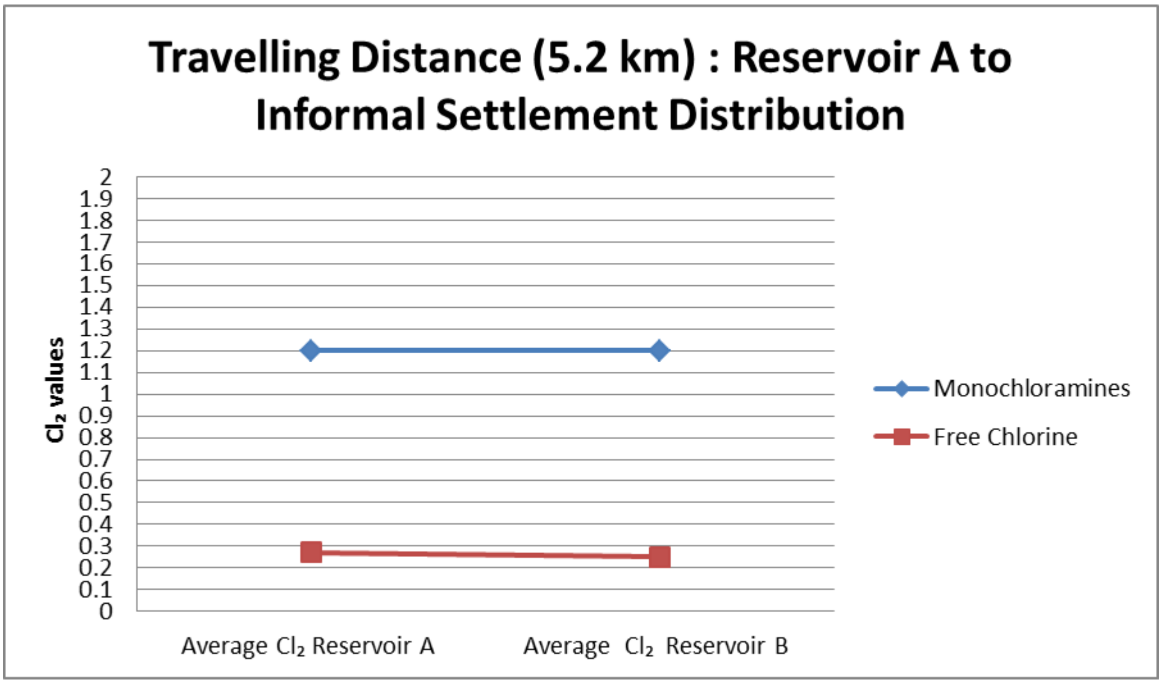

Figure 1. Graph representing a decrease in residual chlorine over 5.2km distance

Percentage loss formula:

$$\text{Percentage \% } Cl_2 \text{ loss} = (\text{Initial } Cl_2 - \text{Final } Cl_2) / \text{Initial } Cl_2 * 100\%$$

Table 2. Calculation for percentage loss using average free chlorine and monochloramines

Areas	Averages	Calcultations		Percentage loss	
		Monochloramines	Free Chlorine	Monochloramines	Free Chlorine
Reservoir A					
Free chlorine (field test)	0.27				
Monochloramine	1.2				
Distribution point 959					
Free chlorine (field test)	0.25				
Monochloramine	1.2	0	7.407407407	0%	7%

These parameters were monitored bi-monthly at selected location across the city. Chlorine and monochloramines' values were averaged over a period from June 2018 to June 2019 from reservoir A and distributed to distribution point. Levels of chlorine and monochloramines at distribution point 959 indicate no loss in chlorine and monochloramines with percentage loss is evident to minimal to no decay within travelling distance as see in Fig. 1.

Using the distance from reservoir A to distribution point, I plotted the average annual chlorine and monochloramines' values against distance the water travelled from source to identify trend in chlorine decay. Chlorine and monochloramines' levels are expected to diminish as distance increases. The percentage of chlorine monochloramines' loss was calculated by subtracting the sample residual chlorine from initial chlorine level at reservoir, then dividing by the initial chlorine value multiplied by 100% as seen in Table 2.

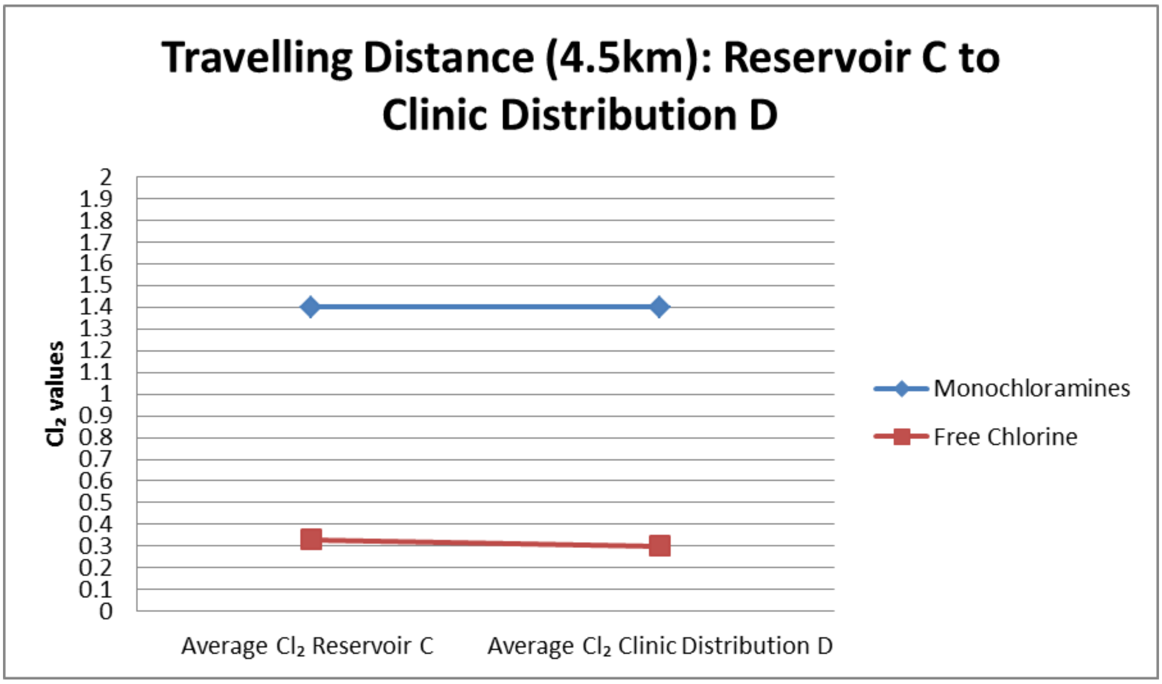

Figure 2. Graph representing a decrease in residual chlorine over 4.5km distance

Percentage loss formula:

$$\text{Percentage } \% \ Cl_2 \text{ loss} = (\text{Initial } Cl_2 - \text{Final } Cl_2) / \text{Initial } Cl_2 * 100\%$$

Table 3. Calculation for percentage loss using average free chlorine and monochloramines

Areas	Averages	Calcultations		Percentage loss	
Resesrvoir C		Monochloramines	Free Chlorine	Monochloramines	Free Chlorine
Free chlorine (field test)	0.34				
Monochloramine	1.44				
Clinic Distribution D					
Free chlorine (field test)	0.3				
Monochloramine	1.42	1.39	11.8	1.40%	12%

These parameters were monitored bi-monthly at selected location across the city. Chlorine and monochloramines' values were averaged over a period from June 2018 to June 2019 from reservoir C and distributed to distribution point D. Levels of chlorine and monochloramines at distribution point D indicate no loss in chlorine and monochloramines with percentage loss is evident to minimal to no decay within travelling distance as see in Fig. 2.

Using the distance from reservoir C to distribution point D, I plotted the average annual chlorine and monochloramines' values against distance the water travelled from source to identify trend in chlorine decay. Chlorine and monochloramines' levels are expected to diminish as distance increases. The percentage of chlorine monochloramines' loss was calculated by subtracting the sample residual chlorine from initial chlorine level at reservoir, then dividing by the initial chlorine value multiplied by 100% as seen in Table 3.

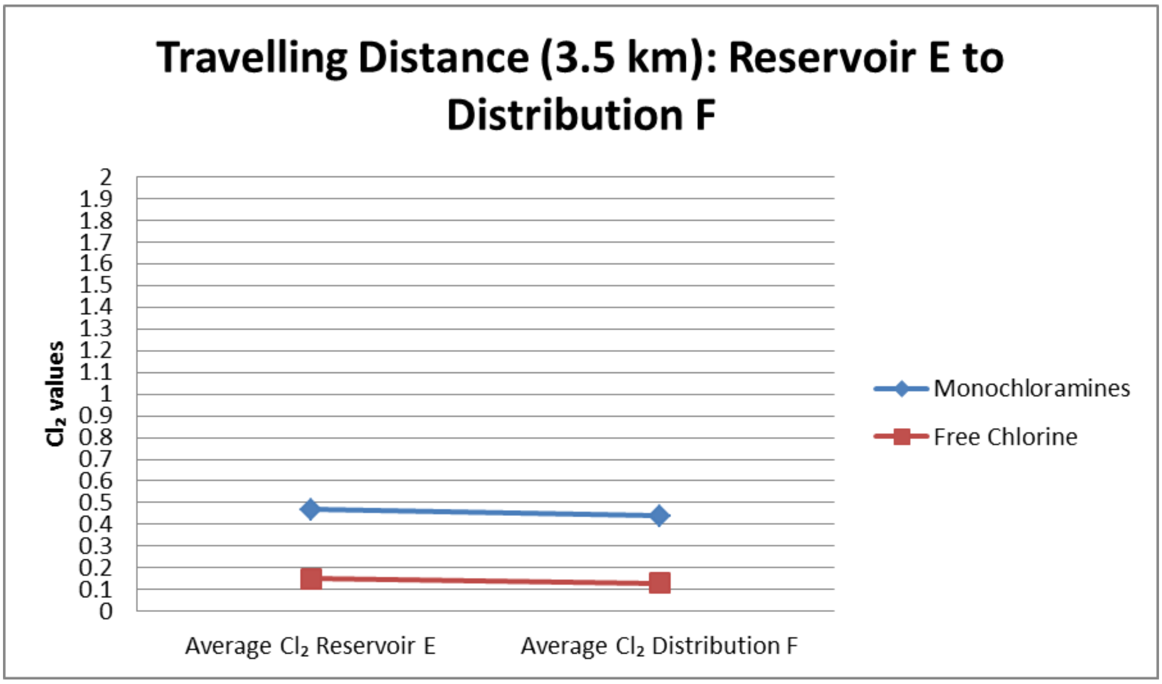

Figure 3. Graph representing a decrease in residual chlorine over 3.5km distance

Percentage loss formula:

$$\text{Percentage \% } Cl_2 \text{ loss} = (\text{Initial } Cl_2 - \text{Final } Cl_2) / \text{Initial } Cl_2 * 100\%$$

Table 4. Calculation for percentage loss using average free chlorine and monochloramines

Areas	**Averages**	**Calcultations**		**Percentage loss**	
Reservoir E		Monochloramines	Free Chlorine	Monochloramines	Free Chlorine
Free chlorine (field test)	0.16				
Monochloramine	0.47				
Distribution F					
Free chlorine (field test)	0.14				
Monochloramine	0.44	6.38	6,6712,5	6%	7%

These parameters were monitored bi-monthly at selected location across the city. Chlorine and monochloramines' values were averaged over a period from June 2018 to June 2019 from reservoir E and distributed to distribution point F. Levels of chlorine and monochloramines at distribution point F indicate no loss in chlorine and monochloramines with percentage loss is evident to minimal to no decay within travelling distance as see in Fig. 2.

Using the distance from reservoir E to distribution point F, I plotted the average annual chlorine and monochloramines' values against distance the water travelled from source to identify trend in chlorine decay. Chlorine and monochloramines' levels are expected to diminish as distance increases. The percentage of chlorine monochloramines' loss was calculated by subtracting the sample residual chlorine from initial chlorine level at reservoir, then dividing by the initial chlorine value multiplied by 100% as seen in Table 3.

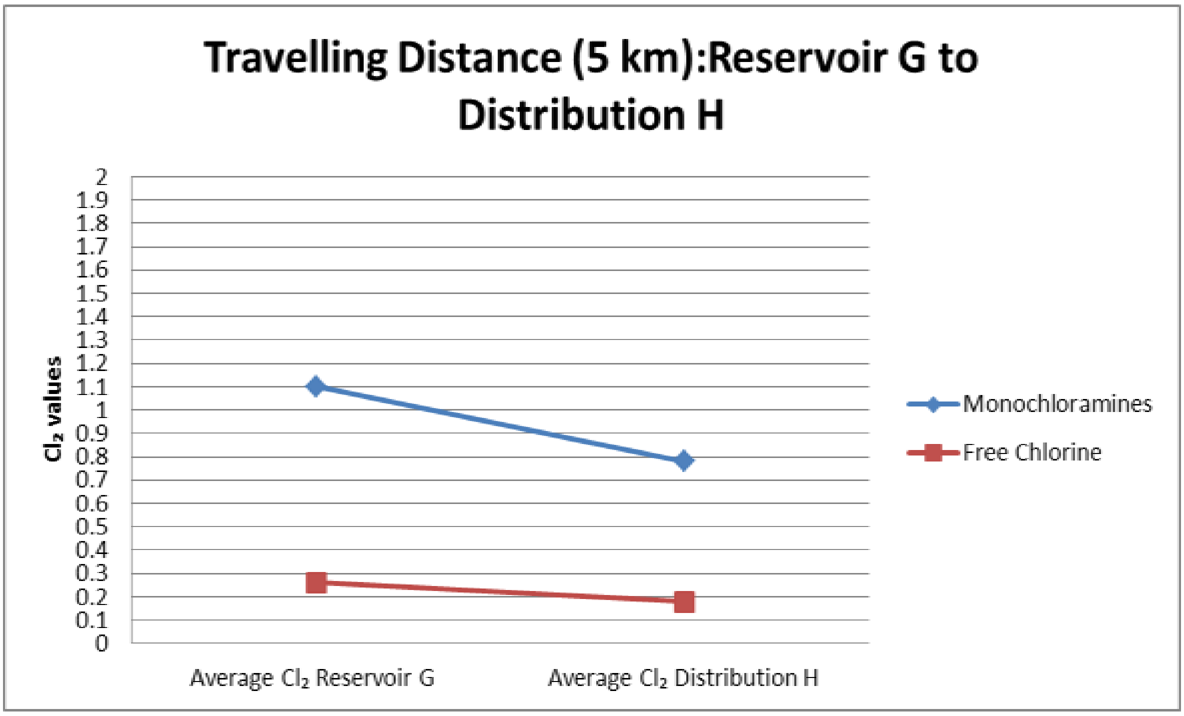

Figure 4. Graph representing a decrease in residual chlorine over 5km distance

Percentage loss formula:

$$\text{Percentage \% } Cl_2 \text{ loss} = (\text{Initial } Cl_2 - \text{Final } Cl_2) / \text{Initial } Cl_2 * 100\%$$

Table 5. Calculation for percentage loss using average free chlorine and monochloramines

Areas	**Averages**	**Calcultations**		**Percentage loss**	
Reservoir G		Monochloramines	Free Chlorine	Monochloramines	Free Chlorine
Free chlorine (field test)	0.27				
Monochloramine	1.08				
Distribution H					
Free chlorine (field test)	0.18				
Monochloramine	0.78	27.8	33.3	28%	33%

These parameters were monitored bi-monthly at selected location across the city. Chlorine and monochloramines' values were averaged over a period from June 2018 to June 2019 from reservoir G and distributed to distribution point H. Levels of chlorine and monochloramines at distribution point H indicate no loss in chlorine and monochloramines with percentage loss is evident to minimal to no decay within travelling distance as see in Fig. 2.

Using the distance from reservoir G to distribution point H, I plotted the average annual chlorine and monochloramines' values against distance the water travelled from source to identify trend in chlorine decay. Chlorine and monochloramines' levels are expected to diminish as distance increases. The percentage of chlorine monochloramines' loss was calculated by subtracting the sample residual chlorine from initial chlorine level at reservoir, then dividing by the initial chlorine value multiplied by 100% as seen in Table 3.

4. Discussion

The use of data accumulated over a period of 13 months (June 2018-June2019) gave an indication that under different operational conditions of distribution system travelling distance where chlorine and monochloramines decay is a factor, regulation, compliance and safety becomes primarily important. Figure 1 plots annual residual chlorine values where the graph shows minimal percentage loss in residual chlorine decay between reservoir A and the distribution point B which indicates that residual activity last longer due to Chloramination which a less powerful agent that will remain active for long periods so that the water may be protected right up to the end consumer. Figure 2 also plots annual residual chlorine values where the graph shows minimal percentage loss in residual chlorine decay between reservoir C and the distribution point D which indicates that residual activity last longer due to Chloramination which a less powerful agent that will remain active for long periods so that the water may be protected right up to the end consumer, local clinic, which the community mostly use. Figure 3 also plots annual residual chlorine values where the graph shows minimal percentage loss in residual chlorine decay between reservoir E and the distribution point F which indicates that residual activity last longer due to Chloramination which a less powerful agent that will remain active for long periods so that the water may be protected right up to the end consumer. Figure 4 plots annual residual chlorine values where the graph shows a percentage loss in residual chlorine decay between reservoir G and the distribution point H that is much higher than other areas which may indicates that there is a decrease in residual activity caused by the increased distance but the end values are acceptable they are of safety standard and complies with SANS 241-1:2015 for drinking water. The residual chlorine compliance entails that a disinfectant residual must remain after disinfection and shall be sustained at a level not less than the value defined throughout the distribution system to reduce increasing risk to health [1]

5. Conclusion

Based on the data analysed for this study, it was evident that residual concentration, although minimal, decreases as the distance increases. Literature review was the guidance and according to [6] lower chlorine are expected in areas farthest from the water source since this means the chlorine has a greater amount of time to interact with organic and inorganic materials and therefore be “used up” in the system [6].The objective of the study was to analyse the effects of distance on residual chlorine decay. This would have allowed the analysis of factors contributing to the residual degradation over distance and to determine further approach to minimize such degradation. A water quality modelling investigation can assist in increasing the scope and areas covered in this study as this will also assist in assessing the impact of the age of distribution pipes on the chlorine decay. There is also a need to use free chlorine and monochloramines sensors as an onsite monitoring tools. Based on the data analysed for this study, it was evident that residual concentration, although minimal, decreases as the distance increases.

6. References

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