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Disinfection of Intermitted Water Supply System and Its Health Impact: Um Al Nasser Village as a Case Study

Hanafi Sadallah[1], Husam Al-Najar [2,*]

[1]M.Sc Infrastructure Engineering, The Islamic University of Gaza. P.O.Box 108
[2]The Islamic University of Gaza, P.O.Box 108
*Corresponding author: halnajar@iugaza.edu.ps

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Abstract The main objective of the research is to study the effect of chlorine depletion in intermitted municipal water supply networks on the proliferation of water-borne diseases in marginalized communities. WaterCad model was built to investigate the behavior of the water systems under the action of intermittent supply and the distance from nine testing points from the chlorination source based on the flow direction. The measurements of residual chlorine in the drinking water network in the period between January 2010 until December 2013, of nine sampling points were conducted. At the same time, the prevalence of waterborne diseases amongst the local residents was registered. Results show that 68% of the sampling points in the water supply network have residual chlorine concentrations lower than the recommended values given by The World Health Organization. One variable exponential regression model is used to estimate the effect of distance on the residual chlorine decaying in intermitted water distribution system. A significant correlation between the distance and the decrease of chlorine concentration is shown, R^2 for 2010 is 0.75, while for 2011, 2012 and 2013 the R^2 is 0.81, 0.72 and 0.58, respectively. Among four water borne diseases, a significant correlation was found only for increasing the number of incidences of Diarrhea in Winter and Summer with a decrease of average residual chlorine in drinking water networks R^2 = 0.65 and 0.61 (ANOVA test 0.003 and 0.003), respectively. The investigation and four years monitoring are important to the water and public health relevant institutions to improve the public water supply sector.

Keywords: *chlorination, amoebiasis, ascariasis, giardiasis, diarrhoea, Pin Worms, Um Alnasser village*

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1. Introduction

Some water sources contain disease-causing organisms which need to be removed or killed before the water can be used in drinking. Bio-films in drinking water systems can be a source for microbial contamination, leading to a potential health risk for consumers [1,2]. Water hygiene and sanitation systems continue to be a burden for developing countries despite the painstaking effort to solve these problems [3].

Disinfection through inactivation is usually achieved by the use of chlorine, ozone, chlorine dioxide, or a combination of chlorine and ammonia (chloramines) which prevents the water from containing pathogenic microorganisms [4]. Chlorination as a disinfectant can remain even after the disinfecting process to provide protection of drinking water from water source to the consumer [5,6]. When chlorine is added to water, some of the chlorine initially reacts with organic materials and metals in the water and is therefore not available for disinfection; this is called the 'chlorine demand' of water. The remaining chlorine is defined as 'Total Chlorine'. Total chlorine is further divided into: 1) the amount of chlorine that reacts with nitrates and is thus unavailable for disinfection (which is called "Combined Chlorine') and, 2) the 'Free Chlorine', which is the chlorine available to inactivate disease-causing organisms. Free chlorine in drinking-water is not particularly toxic to human when its concentration is below the health-based guideline value (GV). The major source of human exposure to chlorine is drinking-water where, GV of residual chlorine (the sum of hypochlorous acid and hypochlorite ions) was established at 5 mg/l [7]. Based on the taste and odor threshold of free chlorine, it is doubtful however that consumers would tolerate such a high level of chlorine. Most individuals are able to taste chlorine at concentrations below 5 mg/l, and some at levels as low as 0.3 mg/l. Therefore, the health-based GV for chlorine should not be interpreted as a desirable level of chlorination. Groundwater is the main source of water supply in Gaza Strip where the main pollution is the salinity due to the seawater intrusion [8,9]. Accordingly, the Ministry of health adopted the WHO limitations for chlorination to protect the water from further pollution during the distribution process.

In order for the chlorine to function as a disinfectant it must be allowed time to react with the water and the

targeted disease-causing organisms. Chlorine dosages must be adequate to exceed the chlorine demand, and leave behind chlorine residual. The longer the contact time the more effective the disinfection will be. A pre-determined chlorine concentration is applied to the water for a specified length of contact time. The chlorine concentration is the lowest continual chlorine residual in the treatment process, while the time is the exposure time for that residual [10].

The World Health Organization has estimated that 94% of diarrhea cases can be prevented through environmental interventions, amongst them increasing the availability of safe drinking water [11]. Giardiasis, Entamabiasis, Ascariasis, Diarrheal diseases Hepatites A, Salmonilasis and Shegellosis are some of the waterborne diseases registered in Gaza Strip. Also, these diseases can be transmitted to human by food. In Gaza Strip as a whole, a strong positive correlation was found for Giardiasis and diarrhea diseases with Fecal Coliform contamination in water networks. Diarrhea was strongly associated with source of drinking water in Gaza Strip [12]. 1996 saw the launch of the Water and Wastewater Services Improvement Project (SIP) for Gaza strip, financed by the World Bank. This project contributes to the proper operation and maintenance of water systems to ensure the provision of microbiologically safe drinking water in order to minimize the disease burden of the human population potentially emanating from water systems. Within this project, The World Bank representative proposed to monitor the microbiological contamination in drinking water. Accordingly, the operator of the SIP started the process of monitoring for 150 testing points all over Gaza Strip. At present, Sodium hypochlorite solution is used to disinfect the water supply from groundwater wells [13]. The drinking water supplied in the Gaza Strip is insufficient and is plagued with supply interruption sometimes lasting for several days. With inadequate disinfection, such practices will lead to suitable conditions for biofilm bacteria growth [14]. The Water-related diseases are most prevalent in the village of Um Al-Nasser, including the disease meningitis, inflammation of the liver Epidemiological, pneumonia, Alascrias, bedwetting, Gardia and widespread diarrhea among children under the age of three years [15].

Therefore, the aim of the current research is to investigate the ongoing chlorination process and the effect of chlorine depletion in the intermitted water supply on the incidence of various water-related diseases amongst the customers of Um Al-Nasser village as a case study.

2. Study Area and Methodology

The village of Um Al-Nasser is located in the northern part of Gaza Strip. The coordinates of Um Al Nasser village are 31°34'50" north, 33 ° 31'31"east and its rise about 38 m above sea level. The total population is 5000 inhabitants living in a space of approximately 800,000 m^2 [16].

2.1. Water Distribution System Modeling

A computer program (Watercad v8i) was used to determine 1) the direction of flow and 2) the travel distance to each individual sampling point in the network from the source. The water distribution network feeds with water from one ground water well, the safe yield of the well is approximately 115 m^3/hr. The chlorine is added directly to the main line from the well using a chemical injection pump that continuously pumps the chlorine solution into the water through an in-line venture device to mix the pre-treated water. The distribution network consists of about 16.29 km of water pipe ranging in diameter from 2 to 6 inches as shown on Figure 1. The existing system consists of a variety of pipe types including: UPV, Steel and High Density Polyethylene (HDPE) pipe; the dates for pipe installation vary also. Sampling points are distributed along network representing the whole area as shown in Figure 1.

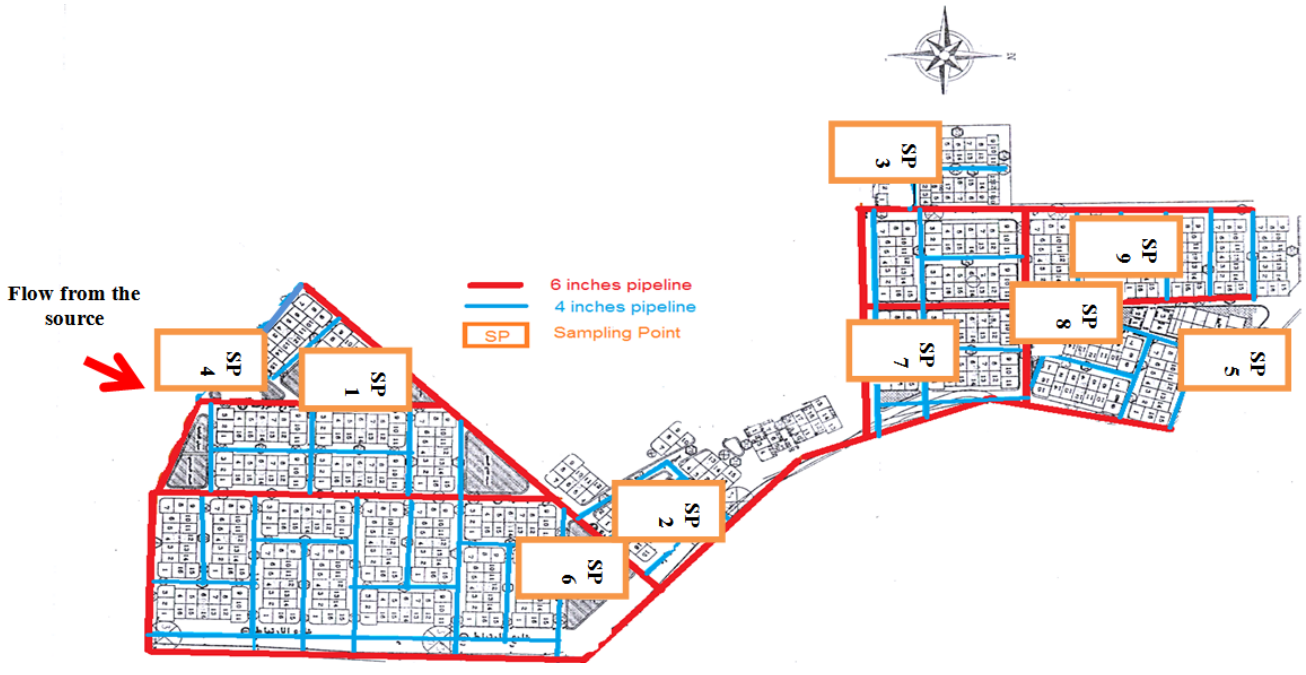


Figure 1. Um Al Nasser Water Distribution system and the location of sampling points (Source: 18)

2.2. Sampling System and Analysis

As a general guide, the World Health Organization [17] recommends that one sample location per 1000 persons be examined each month for a water supply system that serves up to 100,000 persons. According to this recommendation, the number of residual chlorine testing points for Um Al Nasser district should be 5 considering the total population served by the distribution network is 5000 inhabitants. Yet the actual sampling points taken for this study are nine locations distributed throughout the network. Samples were collected for a four year period (2010- 2013) on a monthly basis from the nine sampling points and analyzed for residual chlorine. The following digital colorimeters where used:

A DPD-1 (free chlorine) or DPD-3 (total chlorine, used in tablet or powder form) is added to a vial of sample water which turns the water pink. The vial is then inserted into a digital meter which emits a wavelength of light to determine the degree of color change. The degree of color change is essentially the amount of free or total chlorine in the sample which is expressed digitally in mg/l

In order to link the occurrence of water borne diseases and the concentration of free chlorine in the drinking water distribution system, information on the number of the residents who were infected, including diagnoses, were gathered from the village medical centre during the same time of network sampling. The data was computer analyzed using Microsoft Excel Program and SPSS.

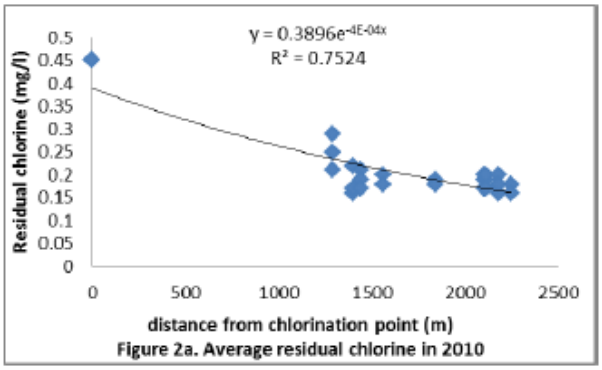


Figure 2a. Average residual chlorine in 2010

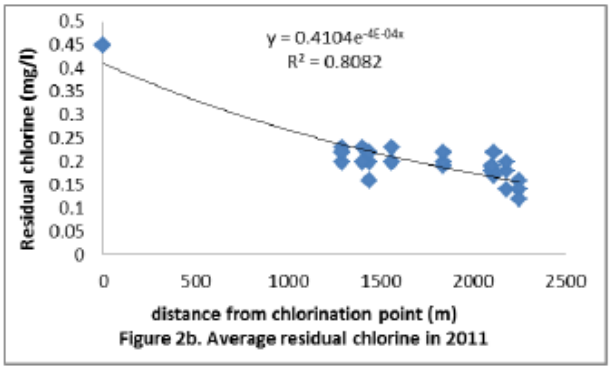


Figure 2b. Average residual chlorine in 2011

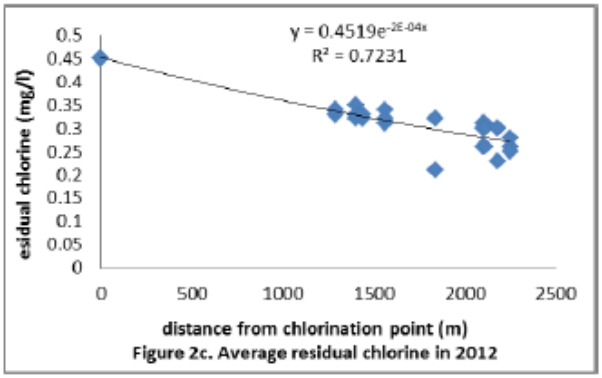


Figure 2c. Average residual chlorine in 2012

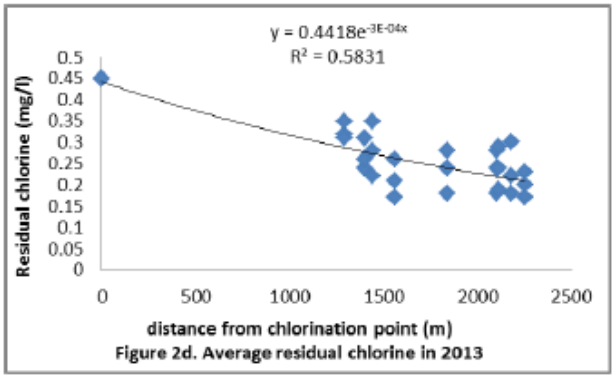


Figure 2d. Average residual chlorine in 2013

Figure 2. Free chlorine concentration at the nine sampling points 2010, 2011, 2012 and 2013

Table 1. Statistical analysis and correlation of chlorine concentration in the distribution network and the distance from chlorination source

Year	ANOVA				Coefficients					
		DF	F	Sig.		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
						B	Std. Error	Beta		
2010	Regression	1	85.107	.000	distance	.000	.000	-.867	-9.225	.000
	Residual	28			(Constant)	.390	.029		13.523	.000
	Total	29								
2012	Regression	1	117.973	.000	distance	.000	.000	-.899	-10.862	.000
	Residual	28			(Constant)	.410	.028		14.654	.000
	Total	29								
2013	Regression	1	73.132	.000	distance	.000	.000	-.850	-8.552	.000
	Residual	28			(Constant)	.452	.021		21.621	.000
	Total	29								
2014	Regression	1	39.155	.000	distance	.000	.000	-.764	-6.257	.000
	Residual	28			(Constant)	.442	.041		10.818	.000
	Total	29								

3. Results

3.1. Residual Chlorine at Various Distances

The first sampling point is the location of the well where the water is pumped from. As shown in Figure 1, the next sampling point is CT4 at 1290 m from the source followed by another 8 sampling points; CT1, CT6, CT2, CT7, CT3, CT8, CT9 and CT5 at distances 1400, 1400, 1560, 1840, 2100, 2110, 2180 and the farthest sampling point CT5 at 2250 m from the chlorination unit, respectively. The distances of the sampling points were measured using the flow direction of the water distribution network and the WaterCad model. The chlorine concentrations were calculated using monthly results recorded at each sampling point and taking the monthly average (2010-2013). The relationship between the residual chlorine and the distance between the disinfection source and the nine sampling points for Um Al Nasser's water network during the four continuous years are shown in Figure 2,a,b,c,d and Table 1. The chlorine given at the source has a concentration of 0.45 mg/l. The variation in the correlation factor R^2 is high in various years from 2010 to 2013 in all sampling locations based on the distance from chlorination source.

A significant correlation between the distance and the decrease of chlorine concentration is shown, R^2 for 2010 is 0.75, while for 2011, 2012 and 2013 the R^2 is 0.81, 0.72 and 0.58, respectively. Moreover, ANOVA test indicates clear correlation between the chlorine depletion and the distance from chlorination source (Table 1). As in Figure 2a, b,c,d. there are no samples in the network above or equal to the maximum recommended by the WHO (>1.2 mg/l) because of the chlorine injected at the source is 0.45 mg/l. Also 220 out of the 324 samples over the 4 years period are below the minimum value (<0.2 mg/l).

3.2. Residual Chlorine and Diseases

The concern of the current study is given to some of the most common waterborne diseases such as Pin Worms, Giardiasis, Amoebiasis, and Diarrhea of Um Al Nasser village for the period between January, 2010 to December, 2013. The variation in disease type from January 2010 to December 2013 is very small; the numbers of infected residents during the study period are 557, 578, 557and 1145 with Pin Worms, Amoebiasis, Giardiasis and Diarrhea, respectively.

This study attempts to measure the impact of residual chlorine depletion on relevant waterborne diseases in the Um Al Nasser network. SPSS and Excel programs were used to analyze the data collected about residual chlorine concentration in different locations of the water distribution network and the incidence of Pin Worms, Giardiasis, Amoebiasis and Diarrhea in the targeted locations. The results and analysis of winter data are shown in Figure 3 a, b, c and d and Table 2. The incidence of Pin worms decreases when the residual chlorine increase, the correlation is not significant $R^2 = 0.13$ (Figure 3a), while the ANOVA test is accounted for 0.267. Giardiasis incidence is not correlated with residual chlorine concentration as indicated by $R^2 = 0.24$ (Figure 3b) and ANOVA test 0.125 same as Amoebiasis where R^2 and ANOVA test accented for 0.22 and 0.141 (Figure 3c), respectively. Diarrhea incident cases are decrease when residual chlorine concentration increase significantly, the correlations are $R^2 = 0.65$ (Figure 3d) and ANOVA test 0.003 less than 0.05 indicating significant correlation between the decrease of the residual chlorine and the increase of incidence number. In general for correlated relations the ANOVA test should be less than 0.05.

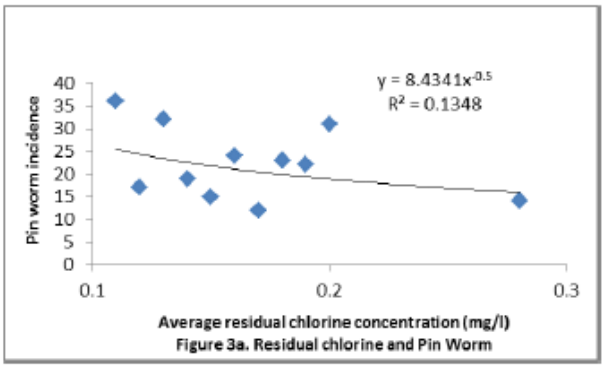


Figure 3a. Residual chlorine and Pin Worm

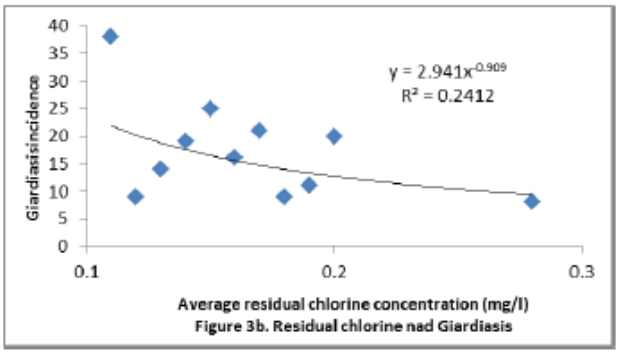


Figure 3b. Residual chlorine nad Giardiasis

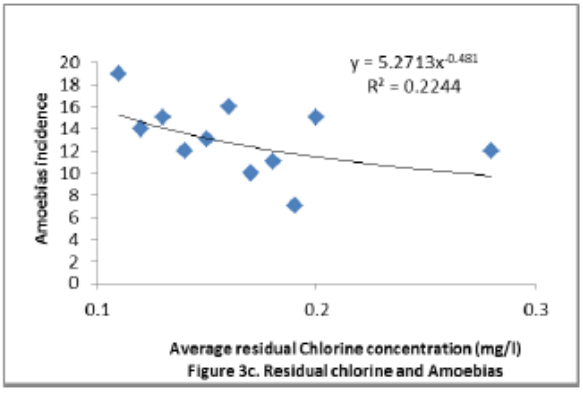


Figure 3c. Residual chlorine and Amoebias

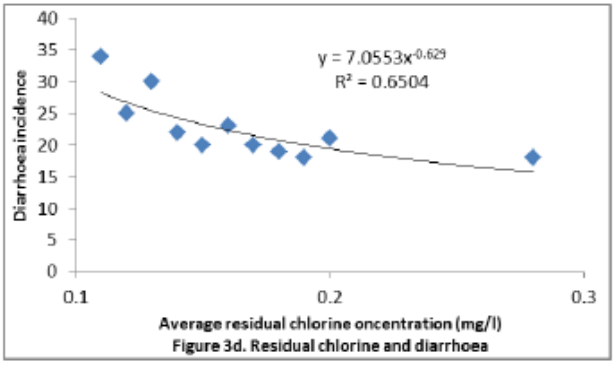
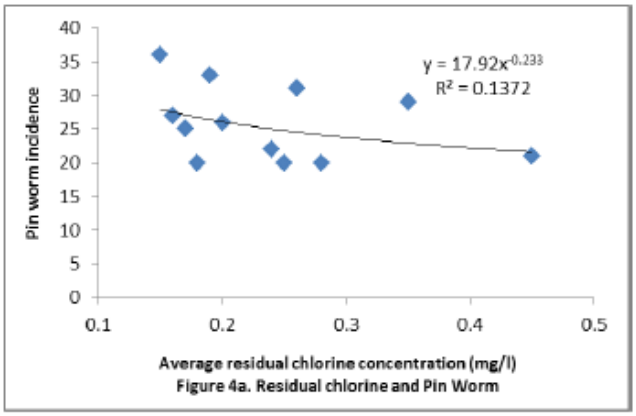


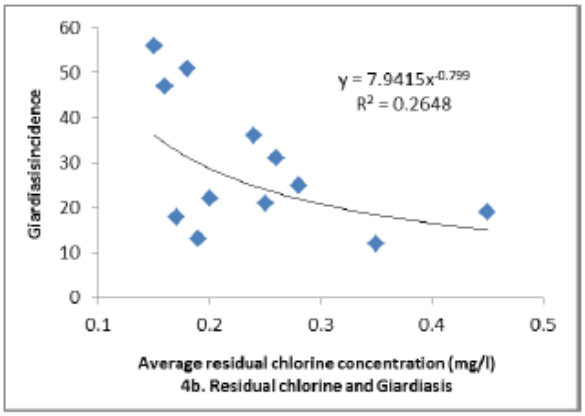
Figure 3d. Residual chlorine and diarrhoea

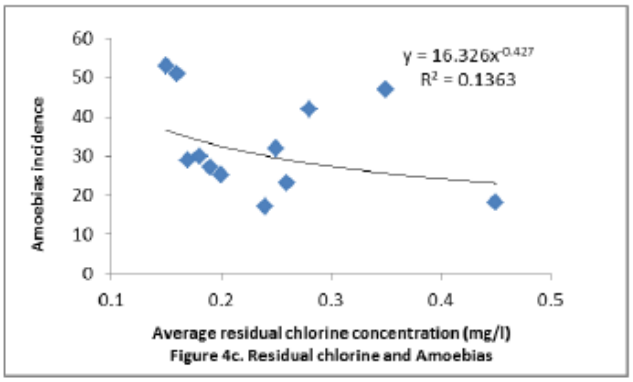
Figure 3. Correlation factor between average residual chlorine and general water borne diseases in Winter

Table 2. Statistical analysis and correlation of chlorine concentration in the distribution network and water borne diseases in Winter

Disease	ANOVA				Coefficients					
		DF	F	Sig.		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
						B	Std. Error	Beta		
Pin Warm	Regression	1	1.402	.267	Chlorine Concentration	-.500	.422	-.367	-1.184	.267
	Residual	9			(Constant)	8.434	6.564		1.285	.231
	Total	10								
Giardiasis	Regression	1	2.861	.125	Chlorine Concentration	-.909	.537	-.491	-1.692	.125
	Residual	9			(Constant)	2.941	2.913		1.010	.339
	Total	10								
Amoebias	Regression	1	2.604	.141	Chlorine Concentration	-.481	.298	-.474	-1.614	.141
	Residual	9			(Constant)	5.271	2.899		1.819	.102
	Total	10								
Diarrhea	Regression	1	16.747	.003	Chlorine Concentration	-.629	.154	-.807	-4.092	.003
	Residual	9			(Constant)	7.055	2.000		3.527	.006
	Total	10								







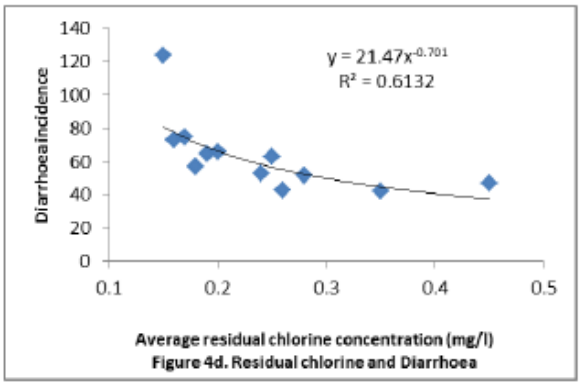


Figure 4. Correlation factor between average residual chlorine and general water borne diseases in Summer

Table 3. Statistical analysis and correlation of chlorine concentration in the distribution network and water borne diseases in Summer

Disease	ANOVA				Coefficients					
		DF	F	Sig.		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
						B	Std. Error	Beta		
Pin Warm	Regression	1	1.590	.236	Chlorine Concentration	-.233	.185	-.370	-1.261	.236
	Residual	10			(Constant)	17.920	5.022		3.569	.005
	Total	11								
Giardiasis	Regression	1	3.602	.087	Chlorine Concentration	-.799	.421	-.515	-1.898	.087
	Residual	10			(Constant)	7.942	5.063		1.568	.148
	Total	11								
Amoebias	Regression	1	1.578	.238	Chlorine Concentration	-.427	.340	-.369	-1.256	.238
	Residual	10			(Constant)	16.326	8.401		1.943	.081
	Total	11								
Diarrhoea	Regression	1	15.855	.003	Chlorine Concentration	-.701	.176	-.783	-3.982	.003
	Residual	10			(Constant)	21.470	5.721		3.753	.004
	Total	11								

As shown in Figure 4 a,b,c and d and Table 3 (results for summer months), the incidence of Pin worms is not correlated with residual chlorine concentration $R^2 = 0.14$ (Figure 4a) and ANOVA test 0.236. The increase of incidence cases of Giardiasis and Amoebiasis are not correlated with the decrease of residual chlorine $R^2 = 0.26$ and 0.14 (Figure 4b and Figure 4c) and ANOVA test 0.087 and 0.238, respectively, i.e. the increase of incident cases coincide with the decrease of residual chlorine, but this is not the case, the results show insignificant increase of residual chlorine and decrease of incident number of Pinworm, Giardiasis and Amoebiasis, indicating that the incident cases may have other cause such as contamination of food. The increase in Diarrhea is highly correlated with the decrease of residual chlorine concentration $R^2 = 0.61$ (Figure 4d) and significant ANOVA test 0.003.

4. Discussion

It has been shown in the literature that biofilms cells are more resistant to antimicrobial agents including disinfectants used in practice for water treatment [19,20].

Total coliform contamination percentages in wells fluctuated from 6% to 13% during the 5 years study conducted by Yassin et al., 2006 for the Gaza Strip. In water networks, the values fluctuated from 12% to 20%. Faecal coliform contamination in wells ranged from 2% to 8%, whereas, in networks, it ranged from 4% to 12%. It is obvious that total and fecal coliform contamination levels exceeded the World Health Organization (WHO) limit (< 5% for total coliform and free for faecal coliform), and these levels were generally higher in water networks than in wells. In the current study fecal coliforms were not tested, but the low residual chlorine in some locations of the network provides further evidence for facal coliform contamination.

Chlorination of water did not totally prevent reactivation of stressed bacterial cells, it however, helps to reduce the role of reactivation [20]. The correlation between the depletion of residual chlorine and the distance from the chlorination source in Um Al Nasser water distribution network as shown in Figure 2 for four years monitoring emphasizes the fact of microbial contamination along the distribution network, in this case chlorine is consumed in the network as an oxidant to the microorganism which is the mechanism of disinfection [21]. The chlorine is consumed exponentially with the distance from chlorination point at the well. Water distribution system in Um Al Nasser suffers from the infiltration of wastewater to the water distribution system especially during winter where the sewage system is overloaded in Gaza Strip [22,23,24]. Such a pollution is very common in the intermitted supply system due the difference in pressure inside and outside the pipe lead to the seepage of wastewater to the system. The exponential decay of chlorine in the distribution system indicates the existence of microorganisms as a consumptive matter to the chlorine. The chlorine itself causes many health problems such as asthma, cancer, fertility problems, heart diseases, eczema and birth defect [25,26,27] when outside the acceptable range given by WHO at the upper limits of 1.2 mg/l. The percentage of samples that are less than the minimum allowable was 68% and this prevents the hazardous materials to form in the water but did not provide adequate disinfection leading to growth of microorganisms within the water network. A study by [28] showed that some concentrations of residual chlorine in municipal water distribution network infringed recommended values according to WHO standards by 41.4%. Therefore the chlorination process should be monitored and fixed values of chlorine dosage should be added to the system according to WHO limitation and standards to prevent the buildup of biofilms in water distribution system. The problem of upper limits 1.2 mg/l of WHO are never reached in Um Al Nasser village, thus the previously mentioned health problems due to the upper limits are not detected in the village.

Nutrient availability, hydraulic conditions, water temperature, pH, the type and concentration of disinfectant residues will affect biofilm growth in water distribution networks [29,30,31,32].

Diarrheal diseases were the most frequently self-reported disease among residents in Gaza City. Such diseases were more prevalent among people using municipal water than people using desalinated water and water filtered at home for drinking [33,34,35]. Even though, there is traces of residual chlorine in all sampling points in the network, the Giardiasis and Diarrheal diseases still exist. The number of infected residents due to the lack of chlorine in the system and the significant correlation between the increase of Diarrhea incident and the decrease of chlorine concentration as shown in Figure 3d and Figure 4d agrees with the UN Humanitarian Country Team and AIDA, 2009 [36] study who mentioned that without access to safe water, adequate sanitation and proper hygiene, children are particularly vulnerable to sickness caused by water borne diseases. In Gaza, diarrhea, an easily preventable disease, is the cause of 12 cent of young deaths. Furthermore, lack of safe water is the cause of mal-nutrition for millions of children, which can have long term impacts on a child's cognitive and physical development. The Department of Health of the UN Relief and Works Agency (UNRWA) reports that: "Watery diarrhea as well as acute bloody diarrhea and viral hepatitis remain the major causes of morbidity among reportable infectious diseases in the refugee population of the Gaza Strip" [15]. It is relevant to carefully assess whether chlorination of drinking-water in the public domain is a priority when a rural water-supply scheme is planned, especially if chlorination cannot be done reliably [37,38,39]. The continuous treatment with 0.3 mg/l free chlorine (limit value German Drinking Water Ordinance) leads to a reduction of the CFU/cm2 down to the detection limit after 70 days [40]. Chlorination and heath are not a problem in developing countries only, but it is a worry of high income countries, in Switzerland for example rural water supply and sanitation review showed that there is some decline in the incidence of water-related diseases, such as diarrheal diseases, due to improved water supply and sanitation coverage [41]. The results of the study conducted for three villages in a remote and rural area in the Vhembe District, situated in the north-eastern parts of Limpopo Province in South Africa show reductions in diarrheal morbidity of about 57% due to the improvement in water supply system [42].

5. Conclusion

This study shows the imbalance in the performance of the chlorination process in the Um Al Nasser water supply system. This can be clearly shown in the amount of residual chlorine in the intermitted water supply system. The number of samples which have a residual chlorine concentration less than 0.2 mg/l (the lowest value recommended by WHO) is 220 out of 324. A significant correlation between the distance and the decrease of chlorine concentration is shown, R^2 for 2010 is 0.75, while for 2011, 2012 and 2013 is 0.81, 0.72 and 0.58, respectively. Diarrhea incidence cases in winter and summer seasons are significantly correlated with chlorine concentration in the network. A strong correlation was found between the increase of chlorine concentration and the decrease of Diarrheal incidence R^2 = 0.65 and 0.61, winter and summer seasons, respectively. It is highly recommended to conduct further studies to identify the characteristics and types of micro-organisms to redefine of doses used or the use of multiple chlorine disinfection units in the network to substitute the depletion of chlorine dosage due to large water distribution systems. Moreover, to study the causes of other diseases such as Pinworm, Giardiasis, and Amoebias those have insignificant correlation with the current range of chlorine dosage.

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