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CHLORINATION EFFICIENCY AND CHLORINE DECAY IN WATER DISTRIBUTION SYSTEMS IN PALESTINE: THE CASE OF KUFOR MALEK

MSc. Thesis

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Dedicated to my

Dear Parents

Brothers & Sisters

Wife & Daughters (Leen & Zain)

And to those who care about my success

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First, I should offer my thanks, obedience and gratitude to ALLAH the great from whom I receive my guidance and help.

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List of Contents

List of Tables

List of Figures

Nomenclature

Abbreviation	**Name**
A	Arrhenous constant
CDF	Chlorine-demand free water
C_o	Initial chlorine concentration (ppm)
C	Chlorine concentration at time t (ppm)
DPD	N,N-diethyl-p-phenylenediamine
Ea	Activation energy (J/mol)
ECD	Electron capture detector
GC	Gas Chromatography
k	Specific reaction rate constant (units dependent on the reaction order)
kb	Bulk first order chlorine decay constant (h^{-1})
kw	Wall first order chlorine decay constant (h^{-1})
N0	Number of organisms at time zero
Nt	Number of organisms at time t
R	Ideal gas constant (8.314 J/mol.k)
T	Temperature (Kelvin)
t	Time (h)
THMs	Trihalomethanes
TTHMs	Total trihalomethanes
TOC	Total organic carbon concentration (ppm)
UV	Absorbance at ultraviolet light at a wavelength of 253.7 nm.

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Abstract

Chlorine is added to the extracted groundwater from Ein Samia wells to maintain the minimum chlorine residuals in the distribution system in order to ensure safe water and protection of consumers. Chlorine disappears in the distribution systems due to reaction with organic and inorganic substances that usually exist in water (bulk decay) and due to reaction with pipe walls (wall decay). The loss of chlorine in distribution systems can affect disinfection efficiency by causing re-growth of microorganisms. On the other hand if soluble organics are present in water, the reaction of chlorine with these organics will occur, which leads to formation of trihalomethanes as a result of this reaction. The impact of various levels of chlorine addition might affect the level of trihalomethane formation.

Water quality at source was assessed by analyzing several relevant parameters including: pH, Turbidity, Temperature, SS, Ammonium, TOC, Faecal coliform, EC, Ca, Mg, Fe and Mn. The results showed that all of those parameters have values within the limits of WHO standards, meaning that water has a good quality at source. However, the probability of network exposure to contaminants needs to be monitored in order to ensure consumers' access to good drinking water, especially in terms of residual chlorine and related parameters.

The study also focused primarily on the measurement of residual chlorine in the drinking water network in Kufor Malek town as a part of the water distribution system of Ramallah district. The residual free chlorine values were monitored through the water network during 12 hours and analyzing 84 samples distributed on seven nodes. Many of the measurements have shown residual chlorine concentration lower than the required limits of WHO standards for drinking water except for some points where the concentration of free chlorine residual was within the allowable limits.

The effect of pipe diameter and pipe age on the residual chlorine was studied where the results showed that most of lower values appeared on the pipes with oldest age and smallest pipe diameters.

EPANET software was used for the computation of wall decay coefficients where the pipe wall reaction contribution is more significant than that of bulk fluid reactions which represented by bulk decay coefficient that was measured for chlorinated water samples at the source.

To increase the chlorination efficiency it is recommended to:

1) Replace the old (15-20 years) and small (1″ and 2″) pipes.
2) Step chlorination process is needed through the distribution system at the parts with low residual chlorine value, especially at the start of old pipes with 2" diameters.

الخلاصة

في الابار الجوفية في منطقة عين سامية تضاف اقل كمية من الكلورين الى مياه الشرب المستخرجة و التي يتم ضخها الى شبة التوزيع لمنطقة كفر مالك و المناطق المجاورة وذلك لضمان حماية المياه من البكتيريا حتى تصل الى المستهلك.لكن يعاني تركيز الكلورين في شبكات التوزيع من التلاشي, وذلك بسبب تفاعله مع المواد العضوية والغير عضوية الموجودة في المياه (Bulk Decay) وبسبب تفاعله مع جدران أنابيب المياه (Wall Decay) الأمر الذي من شأنه يؤثر سلبا على كفاءة عملية التعقيم. من جهة أخرى يؤدي تفاعل الكلورين مع المواد العضوية في المياه الى إنتاج مواد غير مرغوب فيها مثل الميثانات ثلاثية الهاليدات و التي تعتبر مسرطنة.

لقد تم تقييم مياه الشرب المستخرجة من آبار عين سامية قبل عملية الكلورة وذلك من خلال معرفة قيم بعض الخصائص الفيزيائية و الكيميائية التي تمثلها بعض العناصر و المركبات الهامة مثل الرقم الهيدروجيني ودرجة العكورة ودرجة الحرارة و التوصيل الكهربائي و المركبات العضوية للكربون الكلي و الامونيوم و المغنيسيوم و الكالسيوم وغيرها. حيث اظهرت النتائج انها تتفق مع المعاير و المقاييس لمنظمة الصحة العالمية الخاصة بمياه الشرب في فلسطين. ولكن هناك احتمال لتلوث بيولوجي للمياه بسبب تدني تركيز الكلوين المتبقي في شبكة المياه. لذلك تم إجراء تحاليل لتحديد نسبة الكلور المتبقي في المكان وذلك عن طريق مراقبة قيم الكلورين الحر لمدة 12 ساعة في بعض النقاط التي تم اختيارها على شبكة التوزيع. كما وتم دراسة اثر احجام أنابيب المياه وأعمارها على قيم الكلرين المتبقي في مياه الشرب.

لقد أظهرت معظم قياسات الكلور المتبقي تراكيز اقل من القيم المسموحة وقريبة جدا من الحد الأدنى (0.2 ملغ/ل) وفق المعايير القياسية لمواصفة منظمة الصحة العالمية (WHO) لمياه الشرب في فلسطين باستثناء بعض النقاط التي كان فيها تركيز الكلور الحر المتبقي ضمن الحدود المسموح بها. كما وأظهرت النتائج ان لعمر وقطر أنبوب المياه اثر كبير للتأثير على تركيز الكلورين في مياه الشرب حيث من الضروري جدا وضع خطة لاستبدال الأنابيب ذات الأحجام الصغيرة وخاصة القديم منها.

لقد تمت مناقشة النتائج التي تم التوصل إليها ووضعت الإيضاحات والمقترحات الهادفة إلى الحفاظ على سلامة ونوعية مياه الشرب ورفع كفاءة عمليات الكلورة في فلسطين.

Chapter One

Introduction

1.1 Background

Most of the natural sources of water around the world are not always suitable for drinking without treatment. In the past, people depended on sun, wind, filtration through soil and time for obtaining pure water. Due to the intensive use of available water resources, the need for water treatment became unavoidable, because of the physical, chemical, and/or biological contaminants, which come from human activities, animals, and nature. The final process in drinking water treatment is disinfection. This process can be done by means of physical and/or chemical methods.

Physical methods: Heating and UV-radiation are the main physical methods. Heating water to the boiling point will destroy the major disease-producing nonspore-forming bacteria. It is commonly used in the beverage and dairy industry but it is not a suitable mean for disinfecting large quantities of drinking water because of the high cost. Ultraviolet radiation is effective in destroying microorganisms. The most effective band for disinfection is in the range of 2000 to 3000 ^{0}A. The UV-radiation penetrates the cell wall of the microorganism and absorbed by cellular materials causing death of the cell. Generally, physical methods give an instantaneous disinfection for drinking water without producing toxic products. However, no residuals left in water to ensure the persistence of disinfection (Roques, 1996).

Chemical methods: Chemical methods represented by using oxidizing chemical agents such as Ozone (O_3), Chlorine dioxide (ClO_2), Chlorine (Cl_2) … etc. In which their powerful action depend on their oxidizing power. Ozone and chlorine dioxide are effective disinfectants especially at low concentrations. In addition, no toxic disinfection by-products produced when applying them to water. Their disadvantages include relatively high cost, short lifetime and do not produce long-lasting residuals in water after disinfection (Roques, 1996). Among physical and chemical methods, chlorination is the most widely used method for disinfection. Peavy et al (1985) defined a good disinfectant, as “it must be toxic to microorganisms at concentrations well below toxic thresholds to humans and higher animals also; it should have a fast rate of kill and should be persistent enough to prevent re-growth of organisms in the distribution systems”. This definition matches chlorine, which has many advantages such as relatively low cost, ease of application, process reliability, residual durability and a broad range of effectiveness.

Minimum chlorine residuals should be maintained in distribution systems to ensure the persistence of protection throughout the distribution up to the consumer’s tap. However, during distribution chlorine concentration decays due to its reaction with chlorine consuming substances that may exist in the aqueous phase, that is referred to as bulk chlorine decay, and due to its reaction with pipes walls, which is referred to as wall decay. Bulk and wall decay represent over all chlorine decay.

Turbidity and dissolved matter in water affect the disinfection process. Colloids cause the turbidity that reduces the contact between microorganisms and chlorine (Shreoder, 1997). On the other hand, dissolved matter in water reacts with chlorine and consumes it before it becomes available for killing the microorganisms.

1.2 Research Problem

When microorganisms are not removed from drinking water, drinking water usage will cause people to fall ill. Water disinfection means the removal, deactivation, or killing of pathogenic microorganisms, resulting in termination of growth and reproduction. Disinfection commonly takes place because of microorganisms' cell wall corrosion, or change in cell permeability, protoplasm or enzyme activity (because of a structural change in enzymes). These disturbances in cell activity cause microorganisms no longer are able to multiply. This will cause the microorganisms to die off.

Chlorine is the disinfectant of choice for most countries in the world today, including Palestine. The injection of chlorine in public water systems as a disinfectant has been one of the great public health advances in modern times. While chlorine is not the only disinfectant available for water purification, it is certainly the most widespread, as it is highly effective and generally the least expensive. Chlorine is normally applied as part of the treatment process prior to water pumping into the distribution system.

Chlorine residual measurement must be carried out throughout the distribution system in order to maintain the integrity of the water while being delivered to the end consumer. The assumed objectives of the residual chlorine are:

- to inactivate microorganisms in the distribution system;
- to indicate variance in distribution system water quality; and
- to control biofilm growth.

There are constant professional debates about how and whether these objectives will be achieved, but regulations are clear that the residual to be maintained. It must, however, be mentioned that not all kinds of microorganisms that may be present in treated water are susceptible to the bactericidal action of chlorine. Certain enteroviruses, cysts of Giardia intestinal and oocysts of Cryptosporidium are resistant to chlorine and its residual compounds.

Water system operators know that in reality the level of chlorine residual is variable throughout the distribution system. This variability and/or loss of disinfectant residual can weaken the barrier against microbial contamination that can occur within the distribution system. Many people assume that because the distribution system remains under positive pressure that intrusion into the system is not likely to occur. However, this may not be necessarily true.

Contamination can enter the system by cross-connections or pipeline breaks. Pipe breaks or construction intrusion are usually followed quickly by line disinfection, but often times there is a lag between the initiation of the event and final disinfection of the system. These events can result in exhaustion of chlorine residual that serves as a mitigating measure against subsequent microbial contamination in distribution lines.

Chlorine residual will also decay “naturally” within the system because of reaction of chlorine with materials in or on the pipe wall. This can be either, the pipe material itself or biofilms especially at low velocity of flow, or sediment at the pipe surface. The ability to predict this chlorine loss is difficult due to the variable physical characteristics of pipes within the distribution system (e.g., age, construction material, diameters, encrustation, sediment accumulation, etc.).

If soluble organics are present in water, trihalomethane would form as a result of chlorine reaction with soluble organics, a carcinogen compound. The impact of various levels of chlorine addition might affect the level of trihalomethane formation.

1.3 Research Statement

Residual chlorine decay “naturally” within the water distribution system because of chlorine reaction in water and/or with constituent material of the pipe or deposited material on the pipe wall in or on the pipe wall. It is very crucial to predict this chlorine loss and (the top up quantity required to ensure that the quality of water in the distribution network is maintained (as safe for use).

The main research question is: is there a way of keeping chlorine concentration within water distribution networks at their standard range of residual concentration?

1.4 Aim and Objectives

The main aim of this research is to improve the disinfection process in the drinking water distribution systems under prevailing practice conditions in Palestine. The specific objectives are:

a) to verify the efficiency of chlorination process,
b) to assess and measure chlorine decay coefficient due to bulk condition,
c) to measure the overall chlorine decay coefficient under real distribution systems, and
d) to predict the wall decay coefficient using EPANET software and recommend positions where step-chlorination is needed.

1.5 Approach and Methodology

Prior to field trials, the drinking water system (source of water - the main tanks - pumping system - distribution tanks - the distribution network) was studied in Kufor Malek town in addition to the methods for chlorine disinfection.

Several relevant parameters including, pH, Turbidity, Temperature, SS, Ammonium, TOC, Faecal coliform, EC, Ca, Mg, Fe and Mn were analyzed to assess the water quality at source. The bulk chlorine coefficient (K_b) was calculated by monitoring the free chlorine values for a sample of water taken directly after the chlorination process where these values were recorded through 12 hours using HANNA Instruments Free and total chlorine ion specific meter with accuracy 0.01 ppm (Figure 1.1).

Figure 1.1 Instruments used to find the free & total chlorine values

Free chlorine values were monitored through the water network by selecting sample locations (nodes) depending on the flow direction, pipe diameter and the pipe age, where 84 samples were analyzed representing seven nodes on different tracks of flow.

A hydraulic model was established using EPANET software to conduct a quality simulation for the distribution system and to predict the effect of wall of pipes on the residual chlorine in the network which is represented by the wall chlorine coefficient (K_f).

1.7 Thesis Outline

Chapter 1 is an introduction that describes the importance of drinking water and the effect of the disinfection processes on the water quality. On the other hand, it shows the research structure according to the problem and the aims of this research. Chapter 2 is a literature review that describes the past and related studies of the factors effecting to chlorination process and how to improve it through many ways. Chapter 3 describes the approach and methodology for achieving the objectives of this research. Chapter 4 is a description of the study area that includes the population and their water consumption in addition to the water system topographic description. Chapter 5 presents the results and discussion according to the required standards for the drinking water. Chapter 6 provides the conclusions and recommendations.

Chapter Two

Literature Review

2.1 Chemistry of Chlorination

Chlorine may be applied to water in gaseous form (Cl_2) or as an ionized product of solids as $Ca(OCl)_2$, or as liquid solution of NaOCl. When chlorine is added to water two reactions take place: hydrolysis and ionization (Peavy et al., 1985).

- Hydrolysis can be represented as :

$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$ ka $\approx 4.5 \times 10^{-4}$ (at 25 °C).
$Ca(OCl)_2 + 2H_2O \leftrightarrow 2HOCl + Ca(OH)_2$
$NaOCl + H_2O \leftrightarrow HOCl + NaOH$

- Ionization is represented by the following equation:

$HOCl \leftrightarrow H^+ + OCl^-$ ka $= 2.9 \times 10^{-8}$ (at 25 °C).

The total concentration of hypochlorous acid (HOCl) and hypochlorite ion (OCl-) is known as free chlorine. The disinfection efficiency of HOCl is much higher than that of OCl^- ion (White, 1999). When chlorine is applied to water, that contains ammonia, a reaction takes place between chlorine and ammonia leading to formation of chloramines, which is referred to as, combined chlorine as follows (Peavy et al., 1985):
$HOCl + NH_3 \leftrightarrow NH_2Cl + H_2O$ (monochloramine)
$HOCl + NH_2Cl \leftrightarrow NHCl_2 + H_2O$ (dichloramine)
$HOCl + NHCl_2 \leftrightarrow NCl_3 + H_2O$ (trichloramine)

These reactions depend on pH, contact time, and initial chlorine to ammonia-nitrogen ratio. However, the development of chloramines (due to the reaction of free chlorine with ammonia) yield, a curve known as “break point” curve, which was developed by Griffins in 1939 as shown in Figure 2.1.

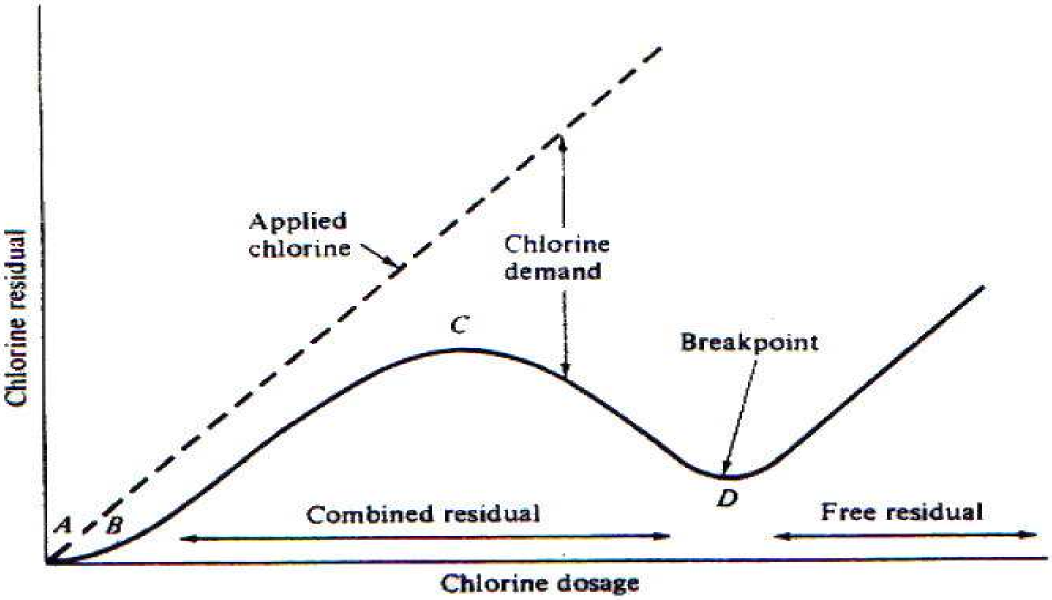


Figure 2.1 Chlorine-residual curve for breakpoint chlorination (Vissman and Hammer, 1985).

At points A and B in the curve chlorine, satisfy the demand for reducing agents (nitrites, ferrous ions and hydrogen sulfide) that may present in water. By adding more chlorine above point B, chloramines starts to form, when all the ammonia has consumes free chlorine begins to appear as in point C. While free chlorine increased, the previously formed chloramines oxidized to form oxidized nitrogen, which, cause reduction of free chlorine as seen on the curve between points C and D. When all chloramines are oxidized and additional chlorine applied to the water, free chlorine develops as indicated by rising curve at point D, which referred to as break point (Vissman and Hammer, 1985).

The disinfection efficiency of chloramines is less than that of free chlorine (Ward et al., 1984; Vissman and Hammer, 1985; and White, 1999).

2.2 Fate of Chlorine in Distribution Systems

Free chlorine consumption in distribution systems is due to chemical reactions occurring in the bulk phase (Bulk decay) and at the pipe walls (Wall decay). This has led some researchers to study wall and bulk decay separately. The simplest method is to define the overall decay constant as the sum of bulk and wall decay constants (k = kb + kw).

2.2.1 Bulk Chlorine Decay

Bulk chlorine decay (which represented by decay rate constant k_b) is estimated by measuring chlorine concentration at different times from glass bottles that have been previously filled with the chlorinated sample. The exact procedure varies but, it is often referred to as bottle or jar test.

In order to describe the behavior of bulk chlorine decay, many models developed. The simplest one as reported by Powell et al. (2000), Hun et al. (1999), Kiene et al. (1998), Vasconcelos et al. (1997), Rossman et al. (1994) and Zhang et al. (1992), is the first-order reaction kinetics with respect to chlorine concentration as defined by the following equation:

$$\frac{dC}{dt} = -k_b C ....(2-1)$$

By integrating equation (2-1):

$$C = C_{0.} e^{(-kbt)} ....(2-2)$$

where

C = chlorine concentration (ppm) at time t,

C_o = initial chlorine concentration (ppm) at time zero, and

k_b = first order bulk chlorine decay constant (time^{-1}).

It was found experimentally that first order decay assumption gives good fit of free chlorine bulk decay. Results obtained from literature showed that kb values has been observed to vary between 0.02 and 0.74 h^{-1} as listed in Table 2.1, which implies that there are factors affecting free chlorine decay rate k_b (h^{-1})

Table 2.1 First order decay constants of bulk chlorine.

***kb* (h^{-1})**	**Number of experiments**	**References**
0.07-0.11	3	Zhang et al. (1992)
0.02	1	Clark et al. (1993)
0.03-0.21	2	Chambers et al. (1995)
0.01-0.74	10	AWWARF (1996)

Powell et al (2000b).

Temperature, total organic carbon concentration and initial chlorine concentration, are the main factors that influence the bulk chlorine decay rate. It has been observed by many researchers that the bulk chlorine decay rate increases with increasing temperature (Jadas-Hecart et al., 1992; and Zhang et al., 1992). None of those researchers has defined a relationship between the bulk chlorine decay rate and temperature. The rate of virtually all chemical reactions increases with increasing temperature. The temperature dependency of reaction rates expressed by Arrhenious equation:

$$k = A.e^{(-Ea/RT)}.......................(2-3)$$

Where: k = rate constant, time^{-1},

Ea = activation energy, J/mol,

R = gas constant, 8.3145 J/k.mol

T = temperature, (K) and

A = Arrhenious constant.

Kiene et al. (1998) and Powell et al. (2000) reported a study carried out by American Water Works Association, Research Foundation AWWARF (1996) about the effect of both TOC and temperature on the bulk chlorine decay rate. Experimental results showed that decay rate increases with increasing TOC concentration and temperature. As a result, the following empirical relationship was developed:

$$k_b = a[TOC].e^{(-b/T)}.......................(2-4)$$

Where

a and b equal Ea/R are functions of characteristics of organic matter. Their estimated values are 1.8 x 10^{6} l/mg ***h*** for ***a*** and 6050 ^{0}C for b (the Celsius scale is used to maintain consistency of units) (Powell et al., 2000).

Initial chlorine concentration has significant effect on decay rate. Hua et al. (1999) studied the effect of initial chlorine concentration on bulk chlorine decay rate. Results showed that the decay constant is proportional to the reciprocal of the initial chlorine concentration.

Powell et al. (2000) studied the effect of temperature, TOC, and initial chlorine concentration on bulk chlorine decay rate separately in order to derive an equation that relates bulk chlorine decay rate to these factors. They used Arrhenius equation to investigate the effect of temperature; the optimum value of Ea/R was 7300^{o}C (Powell et al., 2000). Results showed a proportionality relationship between decay rate constant and TOC but this relation was not directly linear. Also, they observed an inverse relationship between decay rate constant and initial chlorine concentration as in the following equation:

$$k_b = \frac{m}{C_0} \text{......................} (2-5)$$

Where, m is a constant.

According to these results, the following equation derived:

$$k_b = P(\frac{1}{C_0})(TOC - f)e^{(-Ea/RT)} \text{......................} (2-6)$$

where

k_b = decay constant, (time^{-1})

C_o = initial chlorine concentration, (ppm)

p and f are constants.

2.2.2 Wall Chlorine Decay

Several proposed models to stimulate wall decay in pipes and distribution networks. Hunt al., (1988), Biswas et al., (1993), Rossman et al., (1994), and others, proposed a first order reaction kinetics for the decay of chlorinated water flowing through a pipe. The main factors affecting chlorine pipe decay are, pipe diameter, hydrodynamic conditions and the pipe material (Kiene et al., 1998).

2.3 Disinfection of Drinking Water by Chlorine

"Disinfection refers to the selective destruction of disease causing organisms, by use of chemical agents or physical methods. All the organisms are not destroyed during the process; this differentiates disinfection from sterilization which is the destruction of all organisms" (Bergman et al., 1976).

Water born disease-causing organisms that potentially transmitted in drinking water such as cholera vibro; dysentery bacteria (shigella); typhoid and paratyphoid bacteria (salamonella), etc, can efficiently destroyed by chlorine.

The bactericidal action of chlorine results from its strong oxidizing power on the bacteria cell chemical structure, destroying the enzymatic processes required for life (Tortora et al., 1992). The biological quality of drinking water was determined by tests for coliform group bacteria, (related to diseases such as typhoid, dysentery and cholera) which found in the intestinal tract of warm-blooded animals and soil. They are defined as aerobic or facultative anaerobic gram-negative, non-endospor-forming, rod-shaped bacteria that ferment lactose to form gas within 24 hours of being placed in lactose broth at 37 ^{o}C. Also, there is a subgroup of coliforms called fecal coliforms that can grow at 44 ^{o}C, E-coli belongs to this group.

The presence of coliform group in drinking water indicates biological contamination. WHO and Palestinian standard number 41/1997 requires that Fecal coliform bacteria in drinking water should be less than 1 colony per 100 milliliters of sample (<1/100 ml) using most probable number method and should not exist using membrane filtration method (Singleton et al., 1987).

2.4 Factors Affecting Disinfection Efficiency

Several important factors determine disinfection efficiency of drinking water. These are water quality, chlorine concentration, contact time, pH, and temperature. The following is a brief description of the effect of these factors on disinfection efficiency.

2.4.1 Water Quality

The water to be chlorinated should be clear and bright, or render so by filtration or other means. The presence of suspended matter impairs chlorination because it absorbs chlorine and prevents contact between bacteria and chlorine. In addition, water should be free of dissolved organic matter, sulphides, nitrites and iron, which react with chlorine and consumes it (Taylor, 1949; Gary, 1994; and (Rouqes, 1996).

2.4.2 Chlorine Concentration and Contact Time

Chlorine concentration is obviously of great importance. It must be sufficient to satisfy immediate chlorine demand and to destroy bacteria, yet not so high as to render the water odorous and unpalatable, unless dechlorination is employed. The required dosage is that amount of chlorine, which, after satisfying the immediate demand as a result of presence of impurities in the water, leaves sufficient residue to destroy bacteria. Since, this destruction is not instantaneous, adequate contact time is required (Taylor, 1949; Haas et al., 1996; and Shang et al., 2001).

It had been observed that for a given concentration of disinfectant, the longer the contact time, the greater the kill.

Chick in 1908, formalized this observation as first order reaction as follows:

$$\frac{dN}{dt} = -kNt.......................(2-7)$$

where: Nt = number of organisms at time t and k = constant, time^{-1}
Integrating equation 2-7 gives:

$$\ln\frac{Nt}{N_0} = -kt.......................(2-8)$$

Where N_0 is the number of organisms at time zero (Georg et al., 1991).
Sanks (1978) expressed the relationship of chlorine concentration and contact time by:

$$Cn.t_p = k.......................(2-9)$$

where: C = concentration of chlorine, (ppm),
t_p = time required for given percent kill, minutes and
k,n = experimentally derived constants for a given system.

An example of this relationship was reported by Bergman (1976) and as shown in Figure (2.2).

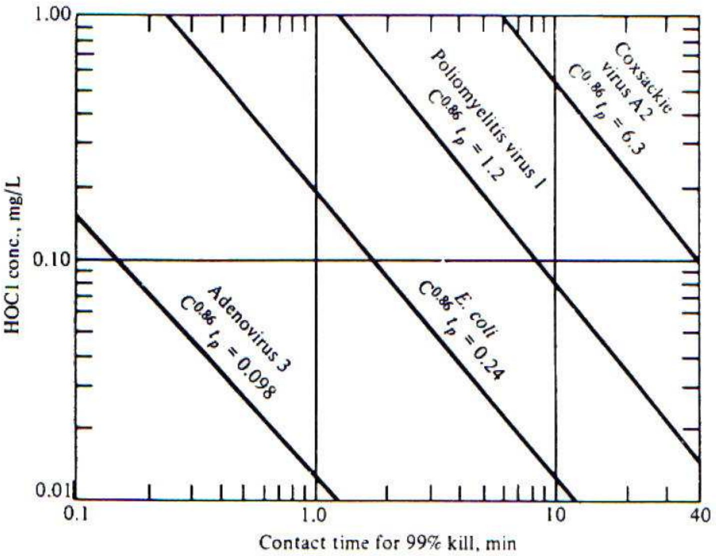


Figure 2.2 Concentration of free chlorine and contact time necessary for 99 percent kill at 6 ^{0}C.

2.4.3 pH and Temperature

pH effect on disinfection efficiency is due to the fact that the pH of water determines the relative amounts of HOCl and OCl^- according to the following reaction:

$HOCl(aq) \leftrightarrow H+(aq) + OCl^-(aq)$

This dissociation reaction is governed by pH see Figure (2.3). At low pH the formation of HOCl is favored over OCl^- while the opposite is favored at high pH (Vissman et al., 1985). The effect of temperature can be represented by Van`t Hoff- Arrhenius relationship as follows:

$$\ln\frac{t_1}{t_2}=\frac{Ea(T_2-T_1)}{RT_1T_2}......................(2-10)$$

where:

t_1, t_2 = time required for given kills,
T_1, T_2 = temperature corresponding to t_1, t_2 in Kelvin,
R = gas constant, 8.314 J/mol.k and
Ea = activation energy related to pH (J/mol).

It was reported by Roques (1996) and Hass et al., (1996) that increasing the temperature results in a more rapid kill of bacteria. Junli et al., (1997) studied the effect of temperature rise (5 – 32 ^{0}C) on disinfection efficiency of chlorine dioxide and free chlorine. The results showed that at low temperature, if a temperature increase by 10 ^{0}C in a certain range, it will double bacteria death rate for both chlorine dioxide and free chlorine at pH ranges 5 to 10 .

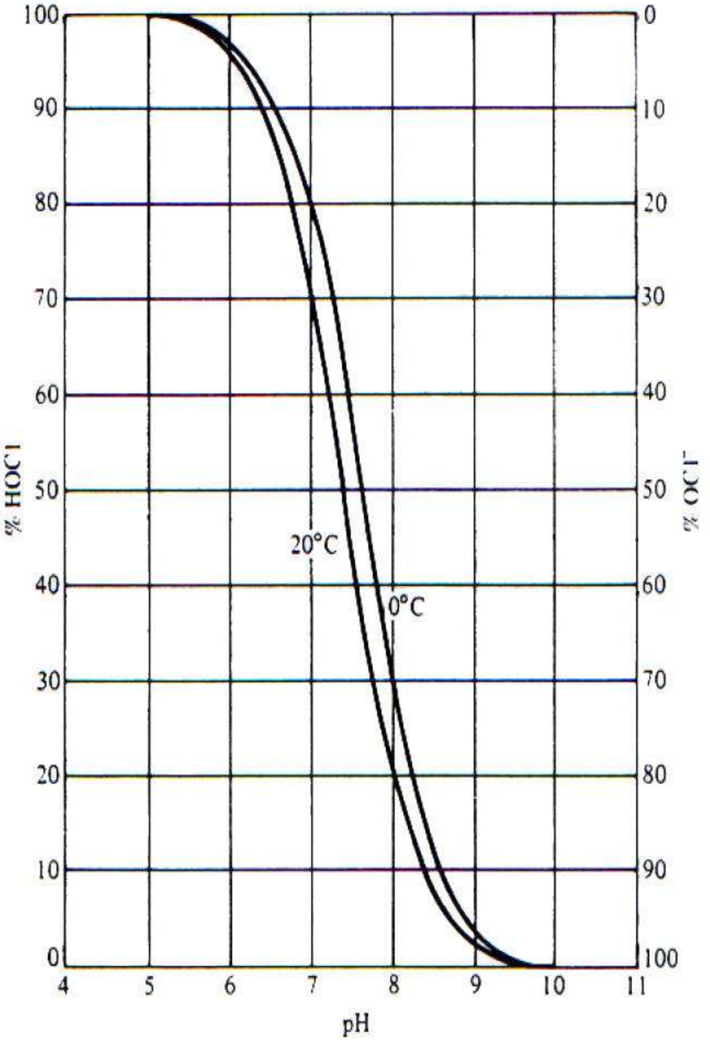


Figure 2.3 Distribution of HOCl and OCl⁻ as a function of pH. (Vissman and Hammer, 1985)

2.5 Chlorine Residual Determination

When chlorine compounds were introduced as means of water disinfection, many methods for testing residual chlorine were established, the most known of these are:

2.5.1 Iodometric Method

It was the first established method for measuring total residual chlorine (free chlorine and chloramines), but it cannot distinguish between free chlorine and combined chlorine. The principle of this method is based upon the phenomenon of the release of elemental iodine, which is quantitatively proportional to the chlorine residual present. The liberated iodine (from KI solution) is titrated with a standard solution of sodium thiosulfate (NaS_2O_3) using starch as indicator at pH 4 to 3.

$Cl_2 + 2I^- \longrightarrow I_2 + 2Cl^-$

I_2 + starch → blue color (qualitative test)

$I_2 + 2Na_2S_2O_3 \longrightarrow S_4O_6^{--} + 2NaI$

The minimum detectable concentration by this method is approximately 40 μg Cl as Cl_2 if 0.01 M $Na_2S_2O_3$ is used with 1000 ml sample. Concentrations below 1 ppm cannot be determined accurately by this method.

Since this method depends on the oxidizing power of free and combined chlorine residuals, the presence of oxidizable forms of manganese, nitrites and organic sulfides may make interferences (White, 1999; Roques, 1996; and Eaton et al., 1995).

2.5.2 Amperometric Titration Method

This method also used for the determination of total residual Chlorine, and it can differentiate between free and combined chlorine residuals. Phenylarsine oxide (C_6H_5AsO, reducing agent) used as the titrating agent; it reacts with free chlorine residuals at pH of 6.5 to 7.5, a range in which combined chlorine reacts slowly. This pH range is used since at higher pH values the reaction becomes sluggish. The combined chlorine, in turn titrates in the presence of a proper amount of KI in the pH range of 3.5 to 4.5.

A special amperometric cell is used to detect the end point of the residual chlorine phenylarsine oxide titration. The cell consists of a nonpolarizable reference electrode that is immersed in a salt solution and a readily polarizable noblemetal electrode that is in contact with both salt solution and the sample being titrated. This method can measure chlorine residuals over 2 ppm by analyzing small samples (Morrow, 1966; White, 1999; and Eaton et al., 1995).

2.5.3 N,N-diethyl-p-phenylenediamine (DPD) Methods

This method is capable of distinguishing between free and combined chlorine residuals. Its principle is similar to that of the amperometric method. When N,N-diethyl-p phenylenediamine (DPD) indicator is added to the sample containing free chlorine residual, an instantaneous reaction occurs producing red color. If a small amount of iodine is then added, monochloramine reacts to produce iodide that in turn oxidize more DPD to form additional red color. Excess addition of iodide dichloramines reacts to form more red color.

By measuring the intensity of the red color produced in the pH range of 6.2 to 6.5 after each of the three steps outlined above, free chlorine, monochloramines and dichloramines residuals can be determined. The intensity of the red color produced can be determined by two ways:

- **A)** Titration with ferrous ammonium sulfate until the red color disappears; the minimum detectable concentration is approximately 18 ppb Cl as Cl_2
- **B)** Measuring absorbance at wavelength of 515 nm, the minimum detectable concentration is approximately 10 ppb Cl as Cl_2.

The most significant interfere is manganese (White, 1999; Cooper, 1982; and Eaton *et al.,* 1995).

2.6 Bacteriological Analysis

It is impractical and not possible always to test water for all pathogens. However, the microbial quality of drinking water is based on testing for an indicator organism, which is defined as a microorganism whose presence indicates that the water has been polluted with human or warm-blooded animal feces.

Coliform bacteria considered the famous group whose presence in drinking water indicates pathogenic contamination. There are two kinds of coliform bacteria, total coliform that comes from feces, soil or other origin and fecal coliform, which comes only from human or warm-blooded animal feces.

Besides testing for the indicator bacteria, total Heterotrophic Plate Count can tested, which indicates the extent of bacterial presence in drinking water in general, without identifying its type. This test used commonly to assess disinfection efficiency and changes during water treatment and distribution.

The two general methods for bacteriological analysis in drinking water are described in the forthcoming sections.

2.6.1 Membrane Filtration Method

This method commonly used when large numbers of water samples are routinely analyzed and when the quantity of bacteria is very small as in drinking water. It consists of; drawing the measured volume of water through the filter membrane (pore size of 0.45μm) then placing the filter paper on a growth medium in a culture dish (Figure 2.4). This technique assumes that each bacterium retained by the filter paper grows and form a small colony. Counting the number of typical colonies and expressing this value in terms of number per 100 ml of water determine the number of bacteria present in a filtered sample (Dutka, 1981; Viessman et al., 1993; and Eaton et al., 1995).

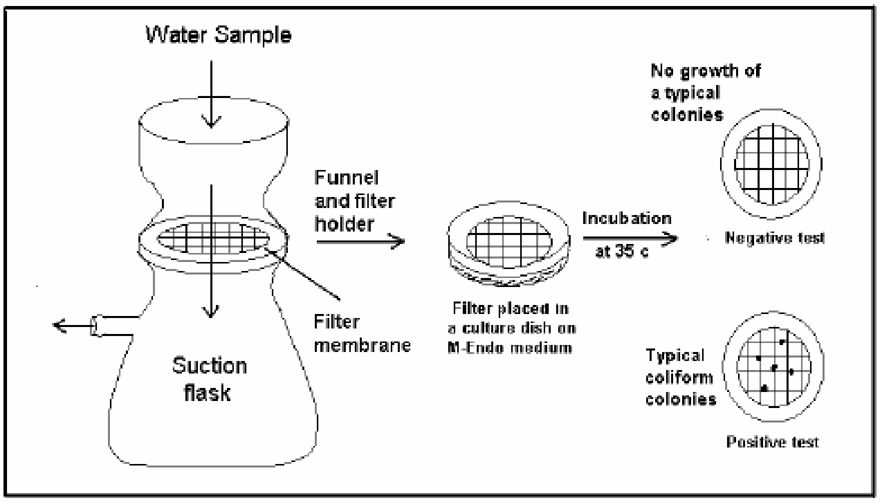
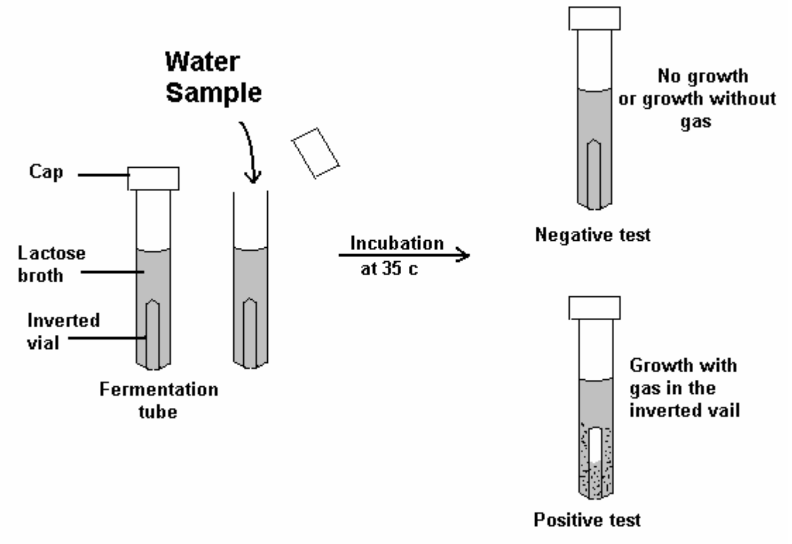
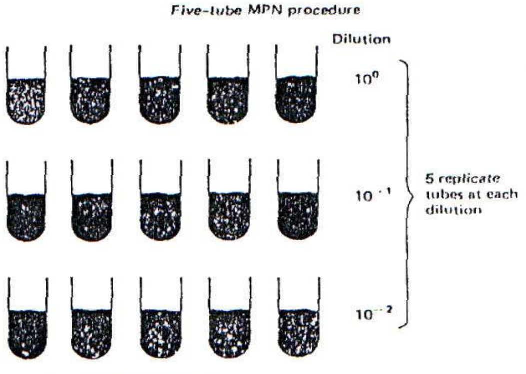


Figure 2.4 Diagram of Membrane Filtration Method.

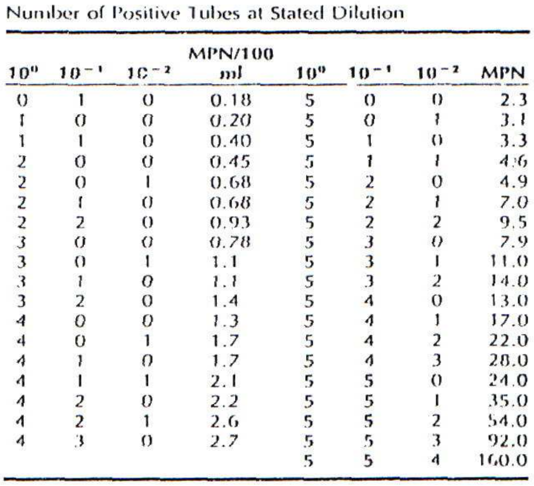
2.6.2 Multiple-tube Fermentation Method

This method considered the most used one for testing coliform and fecal coliform bacteria, especially in wastewater samples. It is based on gas and acid production during fermentation of lactose or laury tryptose broth at 37 °C. For each sample, five replicate tubes for each dilution are examined. Results are reported in terms of the most probable number (MPN) of organisms present. This number, which based on certain probability formula, is an estimate of the mean density of coliforms in the sample. See Figure 2.5 (Viessman et al., 1993; Tortara et al., 1992; and; Eaton et al., 1995).





1 – Inoculate replicate tubes
2 – Incubate
3 – Record number of positive tubes at each dilution
4 – Consult MPN table
5 – Record MPN of bacteria



Number of Positive Tubes at Stated Dilution

10^0	10^{-1}	10^{-2}	MPN/100 ml	10^0	10^{-1}	10^{-2}	MPN
0	1	0	0.18	5	0	0	2.3
1	0	0	0.20	5	0	1	3.1
1	1	0	0.40	5	1	0	3.3
2	0	0	0.45	5	1	1	4.6
2	0	1	0.68	5	2	0	4.9
2	1	0	0.68	5	2	1	7.0
2	2	0	0.93	5	2	2	9.5
3	0	0	0.78	5	3	0	7.9
3	0	1	1.1	5	3	1	11.0
3	1	0	1.1	5	3	2	14.0
3	2	0	1.4	5	4	0	13.0
4	0	0	1.3	5	4	1	17.0
4	0	1	1.7	5	4	2	22.0
4	1	0	1.7	5	4	3	28.0
4	1	1	2.1	5	5	0	24.0
4	2	0	2.2	5	5	1	35.0
4	2	1	2.6	5	5	2	54.0
4	3	0	2.7	5	5	3	92.0
				5	5	4	160.0

Figure 2.5Multiple-Tube Fermentation Method.

Chapter Three

Approach and Methodology

To fulfill the objectives of this study and answer the research questions, two experimental activities were conducted; field work and laboratory tests.

3.1 Filed Work

3.1.1 Study Area

Water network of Ramallah city considered one of the oldest and largest water systems in the West Bank, where more than 33,000 people covered by this system in the city itself and Al Bireh in addition to all the neighboring towns and villages where they were to extend the original distribution network in the early fifties of the twentieth century. The water system provided from two sources, Ein Samia wells and purchased water from the Israeli water company ‘Mekorot’, since this study aims to monitor the level of efficiency Palestinian chlorination of drinking water, the water network of Kufor Malek town was selected as a study area because it is the closest to Ein Samia wells.

Kufor Malek town is the nearest village to the wells Ein Samia with a population of 4,000 people (PCBS, 2009), it has a distribution system with different pipe diameters and ages which is suitable for this study.

3.1.2 Field Visits

Prior to field trials, the drinking water system (source of water - the main tanks - pumping and traction lines - distribution tanks - the distribution network) was studied in Kufor Malek town and the methods for disinfection the drinking water by chlorine. Several relevant parameters including, pH, Turbidity, Temperature, SS, Ammonium, TOC, Faecal coliform, EC, Ca, Mg, Fe and Mn were analyzed to assess the water quality at source. The bulk chlorine coefficient (Kb) was calculated by monitoring the free chlorine values for a sample of water taken directly after the chlorination process where these values were recorded through 12 hours using HANNA Instruments Free and total chlorine Ion specific meter Figure 1.1.

3.1.3 Selecting Sampling Points

Unchlorinated samples were taken at the source to analyze some parameters which show the quality of water in comparison with the WHO standards.

Chlorinated sample was taken directly after chlorination process at the source where the bulk chlorine coefficient (Kb) was calculated by monitoring the free chlorine values through 12 hours using HANNA Instruments Free and total chlorine Ion specific meter.

Free chlorine values were monitored through the water network by selecting sample locations (nodes) depending on the flow direction, pipe diameter and the pipe age, where 84 samples were analyzed representing 7 nodes on different flow tracks.

3.1.4 Using Software

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes with different diameters and lengths were fed into the EPANET software according to the plan of the distribution system obtained from the JWU (2011). The pipe roughness was derived from the information of the pipe materials and ages. According to the data of nodes (pipe junctions) were taken from JWU/2011 as the elevations of these nodes and the distribution of water demand on each one. The information of the pumps curves was also taken according to the JWU. Data obtained from the various experiments will feed into the EPANET software also to predict wall decay coefficients.

3.1.5 Step Chlorination

Based on the results obtained, recommended locations for step chlorination will be suggested to get the suitable amount of chlorine in the water network.

3.2 Laboratory Approach

3.2.1 Instrumentation

UV-VIS spectrophotometer (Spectronic 1201 Milton Roy Company), UV-VIS spectrophotometer (Varian Carry 100E), Varian CP-3800 Gas Chromatography (with a

63Ni electron capture detector (ECD), and capillary DB-624, 60m _ 0.25mm, 1.4 µm film thickness column), O-I Analytical 1010 (Total Organic Carbon Analyzer, Autosampler), pH meter (Hanna Field Multimode Meter). (Inolab level 1 WTW), Water bath (Techne TE-8A). Thermostat circulator (Julabo F25 Germany), Autoclave, Incubator, Sand filter (Park International USA), Mettler AE 163 electronic balance with accuracy of ± 0.0001.

3.2.2 Methods of Analysis

2.2.2.1 EC

Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. EC was measured at source using Hanna Field Multimode Meter.

3.2.2.2 pH

pH is a measure of the acidity or alkalinity of water, expressed in terms of its concentration of hydrogen ions. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH of less that 7 are acidic; substances with pH greater than 7 are basic. pH was measured at source using Hanna Field Multimode Meter.

3.2.2.3 Temperature

Temperature is an important physical parameter for groundwater monitoring. It has an effect on the dissolution of minerals, microbial activities and the dispersion rates of pollutants in groundwater. It is measured in °C. The measured temperatures of all samples were made by using Hanna Field Multimode Meter.

3.2.2.4 Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity. Turbidity is considered as a good measure of the quality of water.

Turbidity is measured in NTU: Nephelometric Turbidity Units. The instrument used for measuring it is called nephelometer or turbidimeter, which measures the intensity of light scattered at 90 degrees as a beam of light passes through a water sample. The WHO (World Health Organization), establishes that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU.

3.2.2.5 Fecal Coliform

Fecal coliform bacteria are a group of bacteria that are passed through the fecal excrement of humans, livestock and wildlife. They aid in the digestion of food. A specific subgroup of this collection is the fecal coliform bacteria, the most common member being Eschericia coli. These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated only with the fecal material of warm-blooded animals. Bacteria reproduce rapidly if conditions are right for growth. Most bacteria grow best in dark, warm, moist environments with food. Some bacteria form colonies as they multiply which may grow large enough to be seen. By growing and counting colonies of fecal coliform bacteria from a sample of stream water, we can determine approximately how many bacteria were originally present. Fecal coliform bacteria indicate the presence of sewage contamination of a waterway and the possible presence of other pathogenic organisms.

Membrane filtration is the method of choice for the analysis of fecal coliforms in water. Samples to be tested are passed through a membrane filter of particular pore size (generally 0.45 micron). The microorganisms present in the water remain on the filter surface. When the filter is placed in a sterile petri dish and saturated with an appropriate medium, growth of the desired organisms is encouraged, while that of other organisms is suppressed. Each cell develops into a separate colony, which can be counted directly, and the results calculated as microbial density. Sample volumes of 1 ml and 10 ml will be used for the water testing, with the goal of achieving a final desirable colony density range of 20-60 colonies/filter. Contaminated sources may require dilution to achieve a "countable" membrane.

A 100 ml volume of a water sample is drawn through a membrane filter (45 μm pore size) through the use of a vacuum pump. The filter is placed on a Petri dish containing M-FC agar and incubated for 24 hours at 44.50 ^{o}C. This elevated temperature heat shocks non-fecal bacteria and suppresses their growth. As the fecal coliform colonies grow they produce an acid (through fermenting lactose) that reacts with the aniline dye in the agar thus giving the colonies their blue color.

According to the WHO (2006) standards, the Fecal coliform bacteria in drinking water should be zero.

3.2.2.6 TOC

Total organic carbon (TOC) is the amount of carbon bound in an organic compound and often used as a non-specific indicator of water quality or cleanliness of pharmaceutical manufacturing equipment.

Typical analysis for TOC measures both the total carbon present as well as the so called "inorganic carbon" (IC), the latter representing the content of dissolved carbon dioxide and carbonic acid salts. Subtracting the inorganic carbon from the total carbon yields TOC. Another common variant of TOC analysis involves removing the IC portion first and then measuring the leftover carbon. This method involves purging an acidified sample with carbon-free air or nitrogen prior to measurement, and so is more accurately called non-purgeable organic carbon (NPOC).

Persulfate-Heating Oxidation Method for TOC Determination: 50 ml of the water sample were filtered through 0.45 μm glass filter paper and, few drops of concentrated phosphoric acid were added to 5 ml of the sample, then the sample was purged with N_2 gas for 10 minutes (to get rid of inorganic carbon compounds). However, the purged sample is injected in TOC analyzer in which the organic compounds are oxidized to CO_2 by per sulfate in the presence of heat, then detected by infrared analyzer.

3.2.2.7 Mg ,Ca, Mn, Fe

- **Calcium and Magnesium (Ca^{+2}, Mg^{+2}):** Calcium is the major cation found in almost all groundwater, the presence of calcium is mainly due to the dissolution processes of minerals in the top soil and bedrocks during the percolation of rainfall water. High levels of calcium and magnesium cause water to be hard, which is objectionable for domestic and industrial uses. The acceptable concentrations of calcium and magnesium (Table 5.1) are 100 and 25 mg/L respectively (Todd, 1980, Price, 1996), above these concentrations; water becomes hard for some industrial and domestic uses. High concentrations of magnesium are laxative and cause abdomen problems.

- **Mn and Fe:** In drinking water plants, Iron and Manganese should be measured to insure highest quality of drinking water. WHO stated limits for Iron of 0.3 mg/l and Manganese of 0.1mg/l. Iron and manganese (Fe/Mn) are common in groundwater supplies used by many Forest Service water systems. Iron is the more frequent of these two contaminants, but they often occur together. High levels of these contaminants can result in discolored water, stained plumbing fixtures, and an unpleasant metallic taste to the water. This can lead to employee and visitor complaints about the water. Iron deposits can buildup in pressure tanks, storage tanks, water heaters, and pipelines. Iron-deposit buildup can decrease capacity, reduce pressure, and increase maintenance. These deposits can also cause self-closing valves to stick (Land, 1999).

3.3 Monitoring the Residual Chlorine

3.3.1 Bulk Chlorine Decay Determination

There is no standard procedure for measuring bulk chlorine decay. Hence, the following procedure which was adopted by Powell et al., (2000) as followed: All glassware was treated so that they were chlorine demand free in which, freshly cleaned glassware was filled with distilled water that had been dosed to 10 ppm free chlorine using concentrated sodium hypochlorite solution, and left to stand for 24 hours. Then the glassware was emptied, rinsed thoroughly with distilled water, and left to dry. A 2.5 liter Winchester bottle was filled with the sample and left for 15 minutes to ensure homogeneity. The sample then decanted into 125 ml brown glass bottles and sealed with glass stoppers. However, all bottles were placed in a water bath set at the required temperature, and Chlorine concentration from one of the 125 ml bottles was measured via DPD spectrophotometric method and the time noted as the start time. After that, Chlorine concentration measured at intervals from the remaining bottles in the same manner. Finally, results prepared into a spreadsheet, and decay constants then calculated according to first-order reaction kinetics.

3.3.2 Residual Free Chlorine Determination in the Network

Free chlorine values were monitored through the water network by selecting sample locations (7 nodes) depending on the flow direction, pipe diameter and the pipe age. The chlorine values monitored on each node through 12 hours (6:00 AM to 6:00 PM) where 84 samples were analyzed. These samples represent seven nodes on different tracks of flow. The chlorine values were measured using HANNA Instruments, free and total chlorine ion specific meter.

Chapter Four

Study Area

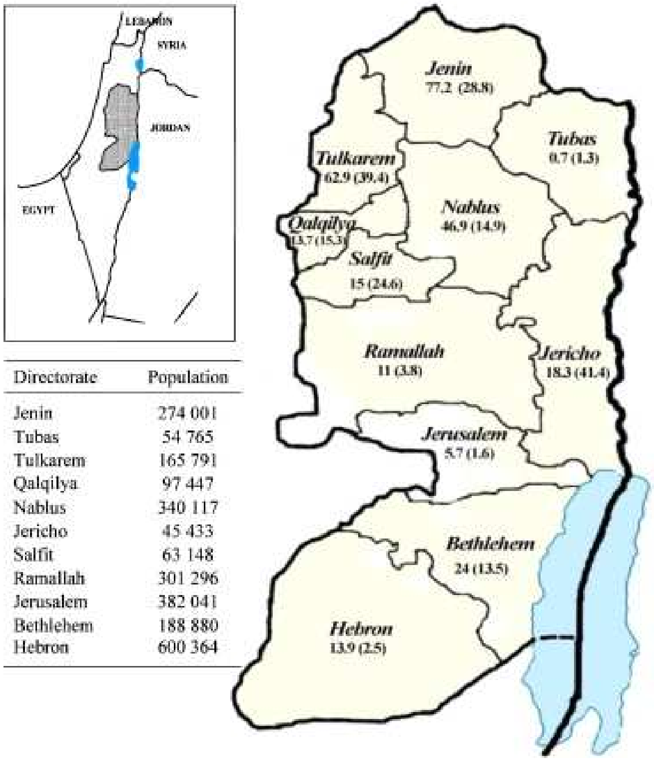
4.1 Study Area

4.1.1 Ramallah

In the central area of the West Bank, lies the governorate of Ramallah and Al-Bireh. It is bordered by the Jerusalem governorate in the south, the Nablus and Salfit governorates in the north, Jericho governorate in the east, and the 1948 borderline between Israel and West Bank from the west, as shown in Figure 4.1. The twin cities of Ramallah and Al-Bireh are located within this governorate. The two cities are about 860 meters above sea level, and have a moderate and pleasant climate, allowing them to be a center for commercial and tourist attraction.

The Ramallah and Al-Bireh governorate covers an area of about 855 km^2 and holds a population of approximately 279,730 persons, as of December 1, 2007. This includes 140,827 males and 138,903 females. The population density is about 327 capita/km^2. The population of Ramallah and Al-Bireh governorate can be classified by type of locality, where 136,406 or 51.9% of the total governorate population live in urban areas, 111,259 or 42.3% of the total governorate population live in rural areas, 15,276 or 5.8% of the total governorate population live in camps. The total number of households in the governorate is 49,676, where 27,182 are located in the urban areas, 19,750 are in the rural areas, and 2,744 are in camps. The average size of the governorate households is 5.3 and the population natural increase rate is 3% (PCBS, 2009).

In calculating the water demand for Ramallah and Al-Bireh governorate, the World Health Organization standard for required water for drinking and other domestic uses per capita of 150 l/c/d is adopted (WHO, 2006), but the demand calculation in Kufor Malik town was depending on the real consumption taken from JWU. Considering the most recent population consensus for 2007 was 279,730 inhabitants, the needed amount of water is about 15.3 Mcm/yr. The Palestinian Central Bureau of Statistics calculated the per capita daily allocation of water for Ramallah- Al Bireh governorate from the quantity of water supplied, which is about 13.70 Mcm, with a population of about 279,730, leading to a daily allocation per capita of 134.2 l/c/d. The Palestinians can supply only about 3.4 Mcm/yr from their own resources (PCBS, 2008); the rest are purchased from the Israeli water company 'Mekorot'.



Directorate	Population
Jenin	274 001
Tubas	54 765
Tulkarem	165 791
Qalqilya	97 447
Nablus	340 117
Jericho	45 433
Salfit	63 148
Ramallah	301 296
Jerusalem	382 041
Bethlehem	188 880
Hebron	600 364

Figure 4.1: Location map for Ramallah and Al-Bireh governorate.

In general, the supply of drinking water in the West Bank can be classified into two main sources: i) wells and springs managed by municipalities, village councils, or water distribution organizations; and ii) purchased water from the Israeli water company 'Mekorot', which is distributed by the West Bank Water Department (PWA, 2007). In the Ramallah and Al-Bireh governorate, the sources of domestic water supply are Palestinian owned wells, purchased water resources, and springs. About 25% of water in the Ramallah-Al Bireh governorate is obtained from Palestinian owned wells, mainly the Ein Samia groundwater wells, which are operated by the Jerusalem Water Undertaking (JWU) and about 75% of water is purchased from Mekorot (PWA, 2007). The water produced from the Ein Samia wells is mixed with the water purchased from Mekorot to supply about 50 communities in the Ramallah and Al-Bireh governorate, and some communities within the jurisdiction of the Jerusalem governorate.

4.1.2 Palestinian owned wells

Ein Samia Well Field: This well field is made up of 5 Palestinian wells owned by the Jerusalem Water Undertaking (JWU) for the Ramallah and Al-Bireh governorate. The JWU is responsible for the management, operation, and monitoring of these wells. The Ein Samia wells are located in the eastern aquifer of the West Bank at a depth of 60 to 600 meters below ground level. The annual extraction from the Ein Samia wells in 2007 was about 3.356 Mcm (PCBS, 2008). The maximum annual extraction capacity of the wells in Ein Samiya is 3.5 Mcm which is possible only with adequate rainfall during the winter season. This field provides most of the water required by the villages and towns located in the east and north side of Ramallah city including Kufor Malek town.

Due to the status quo regarding the utilization of basin and to some hydrogeological factors, Ein Samia well field (Eastern Sub basin) is JWU only own source of water. Ein Samia well field is located about 20 km NE of Ramallah. It lies 500 m lower than the city at an altitude of 400 m above sea level, halfway down towards the Jordan valley. The history and use of Ein Samia well field, the spring of Princess Samia, dates back to the Roman time and even before. Ruins of a mill, an aqueduct and mosaics of Roman to Ottoman age are found there. Its modern history as a well field started after 1948 during the Jordanian rule. The following Map shows the assumed boundaries, recharge and distribution estimates of the West Bank basins, and the location of Ein Samia well field.

In years of dry winters such as 1998, 1999 and 2000, the total production capacity was negatively affected. Currently, 5 wells operate in Ein Samia. The wells are distributed over a small area and tap different aquifers at different depths. A brief description for each existing well is detailed hereafter.

Well No. 1, hand shafted in 1964, replaced the former spring Ein Samia. With an average production capacity of 100 m^3/h in normal winters, this well consumes water from the most shallow, probably perched, aquifer. Its water table fluctuates between wet and dry seasons, thus the discharge usually drops to half in summer seasons.

Well No. 2 was first drilled in 1965/66 with a production capacity of 45 m^3/h. By the year 1991, the discharge of the well fell about 34 m^3/h. The Deviation in the vertical alignment of the borehole and its small diameter were amongst the technical problems that prevented its possible rehabilitation. Therefore, JWU approached the German Government to finance the drilling of a new substitute well. In the context of the German funded project: Water Supply Development Project of GTZ, the drilling of the substitute well No. 2a began in 1996 at an adjacent location. The completed new well No.2a is 250 m deep and produces 165 m^3/h from the Upper Aquifer of Cenomanian age. Its water table lies at 170 m below ground level.

Well No. 3 was drilled in 1980 and taps the Lower Aquifer down to a depth of 526 m. The well was rehabilitated in 1996 through the a.m. GTZ project. Since its rehabilitation, it has the second largest yield amongst all JWU wells at 180 m^3/h.

Well No. 4, was drilled in 1990. Although, it is the deepest well (616 m deep), its production capacity does not exceed an average quantity of 1000 m^3/d from the lower aquifer (62 m^3/h during 16 hours daily). The reason for this low productivity seems to be due to a complicated hydro-geological situation. A deep throwing fault system lies between well No. 4 and the other wells. Most probably, this fault acts as a semi-barrier indicated by a small drop of >100 m. It decreases the wells recharge considerably. Israeli wells in the area are also affected by this phenomenon.

Well No.5: is closed

Well No.6: with German funding through GTZ, drilling of Well No.6 commenced in March 1999, completed in July of the same year, the borehole was drilled to 640 m, refilled to 590 m and 26 inch casing was installed to 411 m below ground level. A pump test was conducted at 330 m3/h discharge rate. The drawdown of water table amounted to 80 m and almost there was no measurable impact on the other existing wells. The Well had been equipped and put into operation since August 2000 with an average production capacity of

200 m^3/h and is significantly contributing to alleviate the suffering from the shortage of water in JWU service area.

Figure 4.2: Well No. 6-Final Test at 330 m^3/h Discharge Rate (19-21 July, 1999)

4.1.3 Purchased Water Resources

These include water purchased for the West Bank Water Department and from the Israeli water company ‘Mekorot’.

- West Bank Water Department (WBWD) Wells: These wells are originally Palestinian wells which were drilled during the Jordanian Mandate period, but were confiscated by the Israeli occupation authorities and were handed over to Mekorot. The WBWD holds the responsibility for distribution of waters to the Palestinian cities, villages and the Israeli settlements inside the West Bank. Four wells are located in the Shibtin area, west of Ramallah city, but only one of them is currently in operation, producing about 0.552 Mcm/yr, (PWA, 2007).
- Israeli Water Company (Mekorot): The sources of water for Mekorot are either from wells inside the green line or inside the West Bank, and recently also from desalination plants constructed inside Israel. The total amount of the purchased water from Mekorot in 2007 was about 10.875 Mcm (PCBS, 2008) to supply the major parts of Ramallah and Al-Bireh governorate. This includes the pumped water from the wells which are located in the Palestinian Territory and controlled by Mekorot.

The supplied water is chlorinated at source (groundwater wells) before its pumped uphill to the storage tank at Al-Taweel. The part of the water supply system was chosen for the study is Kufor Malek town.

4.1.4 Kufor Malek Town

With a population of 4,000, Kufor Malek town is the first area that received the drinking water from Ein Samia wells; water at source from all wells mixes at the balancing tank before pumping to the distribution systems. This town located at North east of Ramallah city. Kufor Malek town features a dry and semi dry climate with relatively constant temperatures throughout the course of the year. The town of Kufor Malek covers an area of approximately 2,290 donum with altitudes ranging from 680 to 950 msl. The city has water coverage of 100%. Kufor Malik town supplied with water from the Ein Samia wells managed by the JWU. Most of the pipes are old aged pipes which made from coated steel were laid in the 1995 (JWU, 2011).

4.2 Chlorination Processes

Groundwater is pumped from five wells (Appendix 5) to storage tank with a capacity of 500 m^3 where then it is pumped into the distribution network through 16 " and 10" pipelines. 0.5 mg of liquid chlorine (NaOCl) per liter injected to the pumped water at the point of discharge before pumped to the distribution network (Figure 4.3).

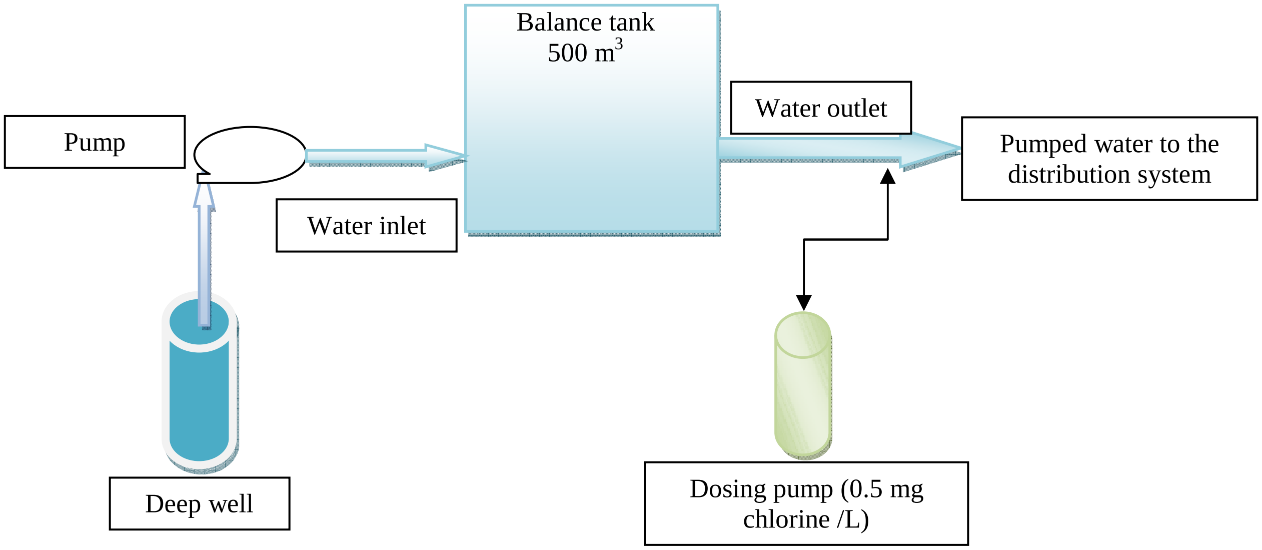


Figure 4.3: *Chart of chlorination process.*

Chapter Five

Results and Discussion

5.1 Source Assessment

5.1.1 Quality of Raw Water

To assess the water quality at source, several relevant parameters including, pH, Turbidity, and Temperature, Ammonium, TOC, Faecal coliform, EC, Ca, Mg, Fe and Mn were analyzed as shown in Table 5.1. The following parameters were measured for the raw water before chlorination process:

Table 5.1: Quality of the groundwater

Parameter	Unit	Amount	Standard (WHO)
pH		7.9	6.5-8
Turbidity	NTU	5.2	<5
Temperature	^{o}C	19.4	-
Ammonium	Mg/l	0.00	-
TOC	MG/L	0.15	3
Faecal coliform	MPN/100ML	0.00	0.0
EC	µS/cm	350	-
Ca	Mg/l	50	100
Mg	Mg/l	20	25
Mn	Mg/l	0	0.4
Fe	Mg/l	0.01	0.3
TDS	MG/L	175	1000

The quality of the water in Ein Samia wells meets the WHO standard, which means that this water is suitable for human use and for drinking.

It seems that this water does not need any kind of treatment or disinfection process. But the potential of future water pollution within the network due to leakage of some of the contaminants associated with wastewater or other natural pollutants requires the most attention and take the necessary precautions to any threat that could lead to contamination of water and thus impact on people's health. Hence, the need for disinfection of water by chlorine or other disinfectant, and the need to maintain a certain amount in the network to eliminate any entry of contaminated objects.

5.1.2 Bulk Chlorine Decay Rate

Estimation of bulk chlorine decay rate constant (kb)

After taking a sample of water being distributed by the referred water supply system, we implemented the procedure described in the following diagram:

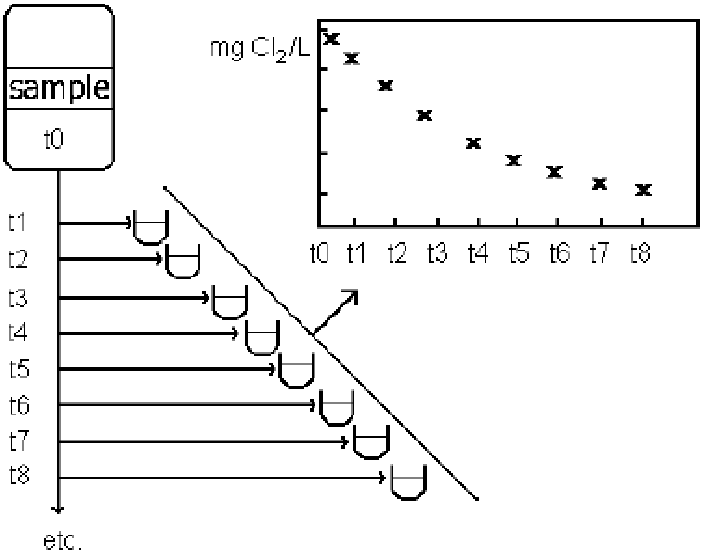


Figure 5.1 Diagram of laboratory method used in calibrating Kb.

Chlorine decay rate constant k_b values were calculated according to first order reaction kinetics as in equation 5-1 by measuring chlorine concentration at several time intervals.

$$\ln C = \ln C_0 - kbt ....(5-1)$$

where:

C = Chlorine concentration at time t (ppm),

C_0 = Initial chlorine concentration (ppm),

k_b = Chlorine decay constant (h^{-1}) and

t = Time (hours)

Plotting lnC vs. t gives a straight line in which its slope equal kb value. Results shown in Table 5.2 and Figure 5.2

Table 5.2 Data required for measuring kb

time	Acc.Time (hours)	CL_2 conc. ppm Total	CL_2 conc. ppm Free	Ln Free CL_2 conc.
12:30 pm	0	0.46	0.41	-0.89
1:30	1	0.3	0.23	-1.47
2:30	2	0.19	0.15	-1.90
4:00	3.5	0.17	0.12	-2.12
5:30	5	0.15	0.12	-2.12
7:00	6.5	0.15	0.09	-2.40
9:30	9	0.15	0.09	-2.40
11:00	11.5	0.15	0.07	-2.66
12:00	12.5	0.14	0.06	-2.81

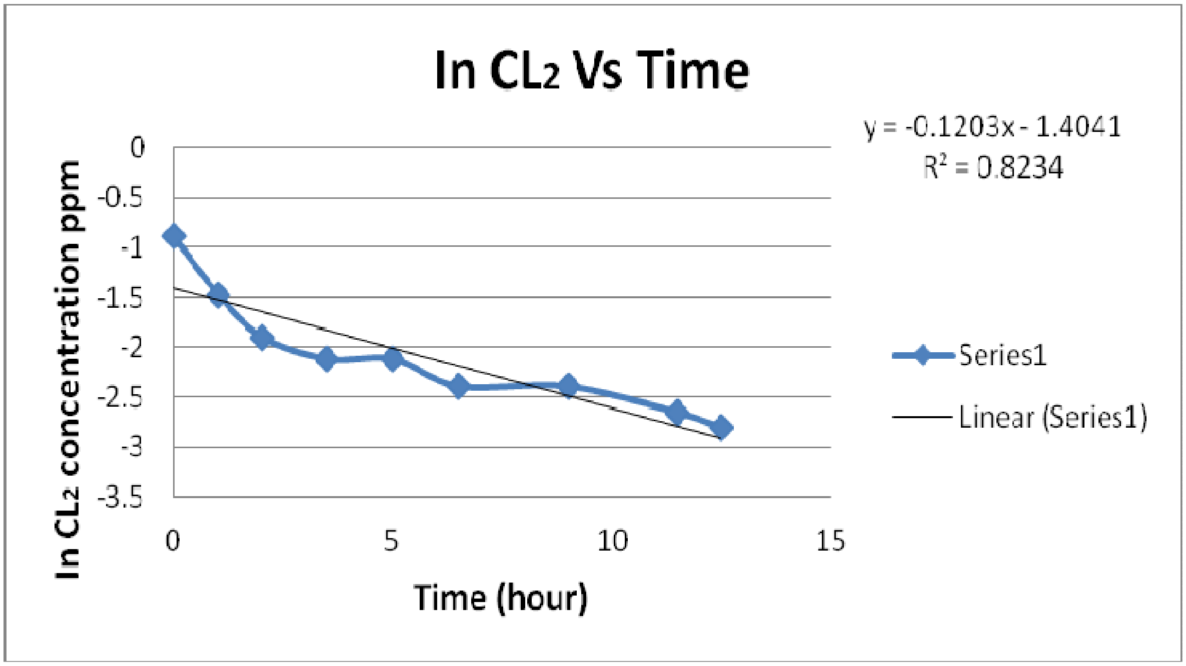


Figure 5.2 Chlorine decay at bulk fluid and respective first order adjustment.

We have determined that the value of Kb is -0.1203 hour^{-1}.

5.2 Residual Free Chlorine through the Water Network

The values of residual chlorine were monitored on the water network for 12 hours through the day, which started from 6 am to 6 pm on different days of the week.

Seven sample locations were chosen on the network (Figure 5.3) based on: the direction of flow presented by the black arrows, pipe diameter and the pipe age. The elevation for each node is represented in Appendix 4.1

The locations of the selected nodes that form three water tracks described in the Table 5.3.

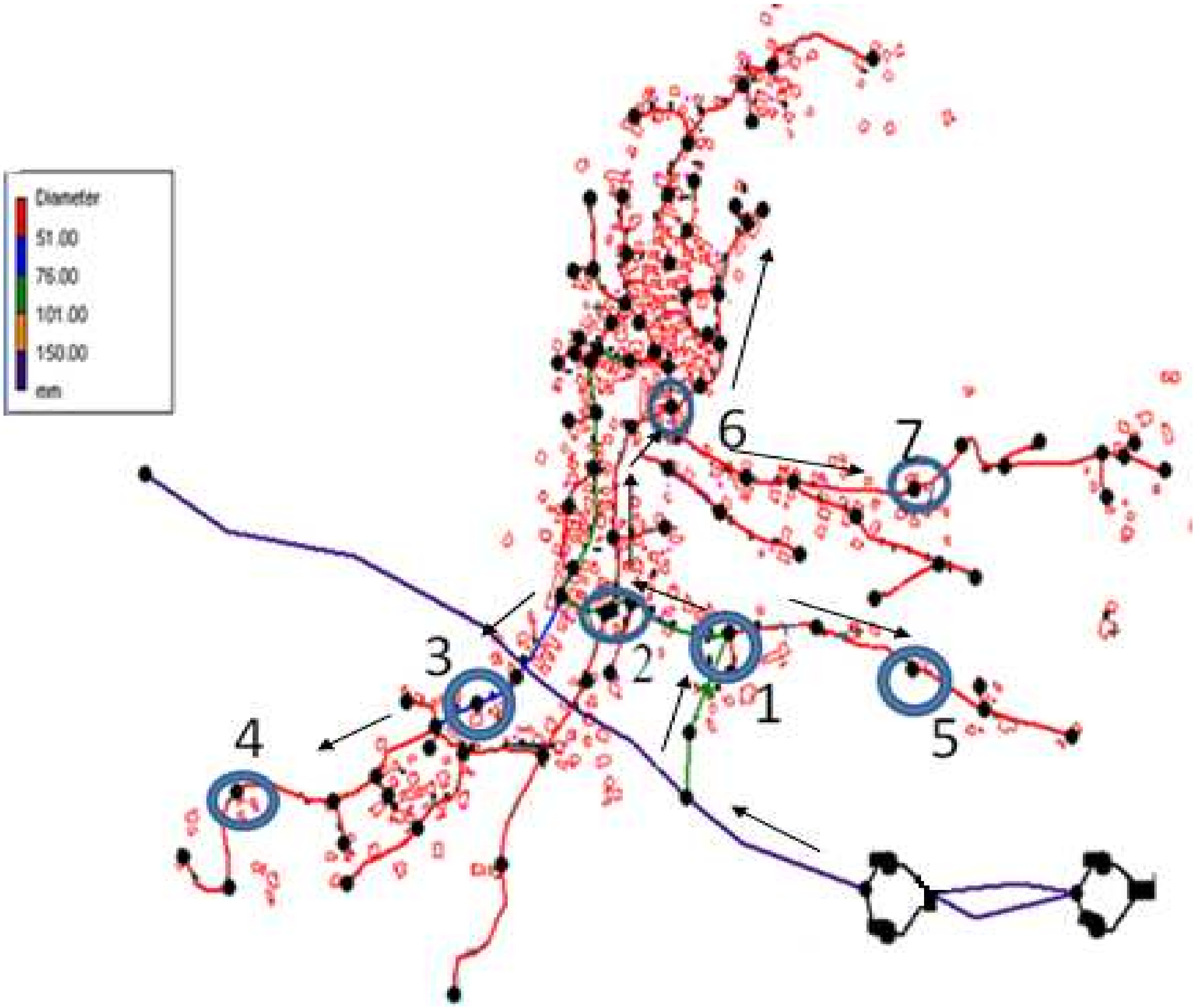


Figure 5.3: Sample locations on Kufor Malek network

Table 5.3 Selected water tracks on Kufer Malek distribution system.

Track no.	Represented nods	Total length(m)	flow direction		(pipes diameters) (inches)	Ages of pipes
			From	To		
1	1,2,3 & 4	1160	1	4	4 ,3 &2	Old (15-20 years)
2	1 & 5	195	1	5	4 &2	Old (15-20)
3	2,6 & 7	620	2	7	2	New(5years & old (15 years)

The following values of free chlorine as well as Temperature and pH recorded for each water sample on each location where the feacal coliform analyzed:

1- *Node 1*

This node is beginning of TRACK 1 and located on old pipe (15-20 years) with 4" diameter. Samples were taken on (12/3/2011) Table 5.4.

Values of residual free chlorine at node 1 ,(Table 5.4) is relatively high or close to the initial concentration of chlorine because of this node is the first node received the chlorinated water directly from the source which subjected to continues injection of chlorine.

Table 5.4, CL_2, ph and T values at different time intervals on node 1 through the tracks1& 2. (feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	ph	T
6:00AM	0.00	0.32	8.10	14.0
7:00	1	0.35	8.20	14.5
8:30	2.5	0.44	7.93	15.6
10:00	4	0.42	7.94	16.8
11:00	5	0.40	7.80	18.3
12:00	6	0.30	7.77	18.1
1:00pm	7	0.38	7.83	21.1
2:00	8	0.40	7.80	19.3
3:00	9	0.32	7.80	21.0
4:00	10	0.41	7.82	20.1
5:00	11	0.39	7.89	19.5
6:00	12	0.40	7.87	19.0

2- *Node 2*

The second node of TRACK 1 and the beginning of track 2 which is located on old pipe (15-20 years) with 4" diameter. Samples were taken on (12/3/2011) Table 5.5.

Table 5.5 CL_2, pH and T values at different time intervals on node 2 through the tracks 1 &3. (feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	ph	T
6:00AM	0.00	0.29	8.30	14.3
7:00	1	0.30	7.90	14.7
8:30	2.5	0.36	7.90	15.6
10:00	4	0.38	7.94	16.8
11:00	5	0.35	7.80	18.13
12:00	6	0.25	7.77	18.1
1:00pm	7	0.32	7.83	21.1
2:00	8	0.38	7.81	19.3
3:00	9	0.28	7.82	21.0
4:00	10	0.37	7.85	20.1
5:00	11	0.33	7.89	19.5
6:00	12	0.38	7.87	19.0

3- *Node 3*

The third node of TRACK 1 which is located on Old pipe (15-20 years) with 3" diameter. Samples were taken on (12/3/2011) Table 5.6

Table 5.6 CL_2, ph and T values at different time intervals on node 3 through the track 1.
(feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	pH	T
6:00AM	0.00	0.12	8.4	13.5
7:00	1	0.15	8.0	13.7
8:30	2.5	0.34	7.85	15.8
10:00	4	0.28	7.91	16.1
11:00	5	0.28	7.88	19
12:00	6	0.18	7.92	19.2
1:00pm	7	0.27	7.87	20.8
2:00	8	0.26	7.81	21.1
3:00	9	0.17	7.9	19.8
4:00	10	0.28	7.86	20.1
5:00	11	0.22	7.97	20.2
6:00	12	0.28	7.88	19.6

4- *Node 4*

The fourth node of TRACK 1 which is located on Old pipe (15-20 years) with 2" diameter. Samples were taken on (12/3/2011) Table 5.7.

Table 5.7 CL_2,ph and T values at different time intervals on node 4 through the track 1.
(feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	pH	T
6:00AM	0.00	0.08	8.4	12.00
7:00	1	0.11	8.0	13.5
8:30	2.5	0.15	7.85	16.12
10:00	4	0.12	7.70	18.6
11:00	5	0.08	7.9	18.8
12:00	6	0.05	8.00	19.1
1:00pm	7	0.25	7.88	19.9
2:00	8	0.20	7.92	20.2
3:00	9	0.10	8.1	20.4
4:00	10	0.22	7.81	20.4
5:00	11	0.18	8.20	19.8
6:00	12	0.27	7.78	18.5

5- *Node 5*

The second node of TRACK 2 which is located on Old pipe (15-20 years) with 2" diameter. Samples were taken on (13/3/2011) Table 5.8.

Table 5.8 CL_2,ph and T values at different time intervals on node 5 through the track 1.
(feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	pH	T
6:00AM	0.00	0.05	8.3	14.1
7:00	1	0.08	8.1	14.7
8:30	2.5	0.15	7.9	15.5
10:00	4	0.13	8.1	16.1
11:00	5	0.09	7.9	15.5
12:00	6	0.13	7.79	17
1:00pm	7	0.08	7.78	15.5
2:00	8	0.07	7.87	14.5
3:00	9	0.09	7.92	14.0
4:00	10	0.14	7.85	14.1
5:00	11	0.10	8.01	14.2
6:00	12	0.14	7.80	14.1

6- *Node 6*

The second node of TRACK 3 which is located on new pipe (5-7years), with 2" diameter. Samples were taken on (15/3/2011) Table 5.9

Table 5.9 CL_2,ph and T values at different time intervals on node 6 through the track 1.
(feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	pH	T
6:00AM	0.00	0.24	8.3	14.5
7:00	1	0.30	8.0	16.1
8:30	2.5	0.33	8.03	17
10:00	4	0.38	7.77	18.1
11:00	5	0.31	7.55	22.7
12:00	6	0.21	7.46	22.1
1:00pm	7	0.27	7.95	22.0
2:00	8	0.32	7.87	21.6
3:00	9	0.29	7.85	20.1
4:00	10	0.33	7.65	19.7
5:00	11	0.28	7.79	18.8
6:00	12	0.35	7.83	18.1

7- *Node 7*

The third node of TRACK 3 which is located on old pipe (15-20 years) with 2" diameter. Samples were taken on (15/3/2011) Table 5.10.

Table 5.10 CL_2, ph and T values at different time intervals on node 7 through the track 1. (feacal coliform =0)

time	Time (accumulated)	CL_2 (free) ppm	pH	T
6:00AM	0.00	0.10	8.1	13.0
7:00	1	0.16	8.07	14.1
8:30	2.5	0.03	8.06	14.4
10:00	4	0.09	7.9	14.4
11:00	5	0.21	7.65	17.77
12:00	6	0.15	7.79	16.5
1:00pm	7	0.20	8.01	19.1
2:00	8	0.11	8.12	17.2
3:00	9	0.09	8.01	18.1
4:00	10	0.15	7.86	18.1
5:00	11	0.10	7.96	17.5
6:00	12	0.14	7.88	16.5

5.3 Analysis and Discussion

5.3.1 Efficiency of Chlorination Process

5.3.1.1 Chlorine values through the day on node 1

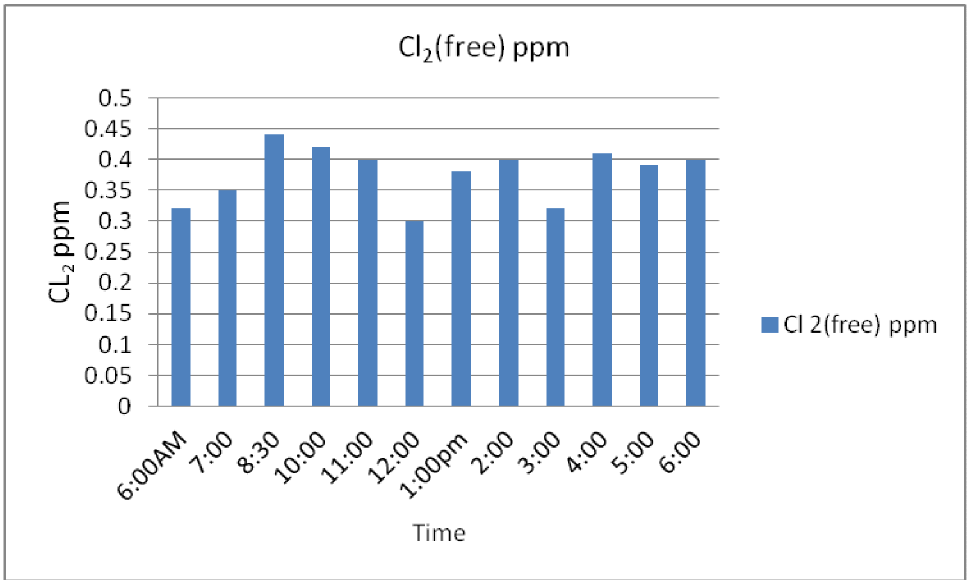


Figure 5.4: Variation of free chlorine values through the day on node 1.

The free chlorine values were monitored at the referenced point which represented by node 1 on the hydraulic layout shown in Figure 5.3 where divers values through the day as shown in Figure 5.4

The graphs show that free chlorine values range as 0.3-0.44 ppm which meets the standards of WHO. Figure 5.4 shows the variation in residual chlorine values in the network, where the values seem high at some times and low at other times due to the pattern of water consumption in the town. More water consumption by the people leads to the renewal of water in water network and thus obtaining the chlorinated water from the source. For example the value of residual chlorine appears high between 7:00-10:00 AM due to more human activity and more use of water.

On the other hand, the amount of residual chlorine decreases in the afternoon due to the lack of water consumption which leads to stagnation of water in the pipes for a longer time and resulting an increase in the reactions of chlorine with the elements of water in the bulk phase, as well as the wall of the pipe.

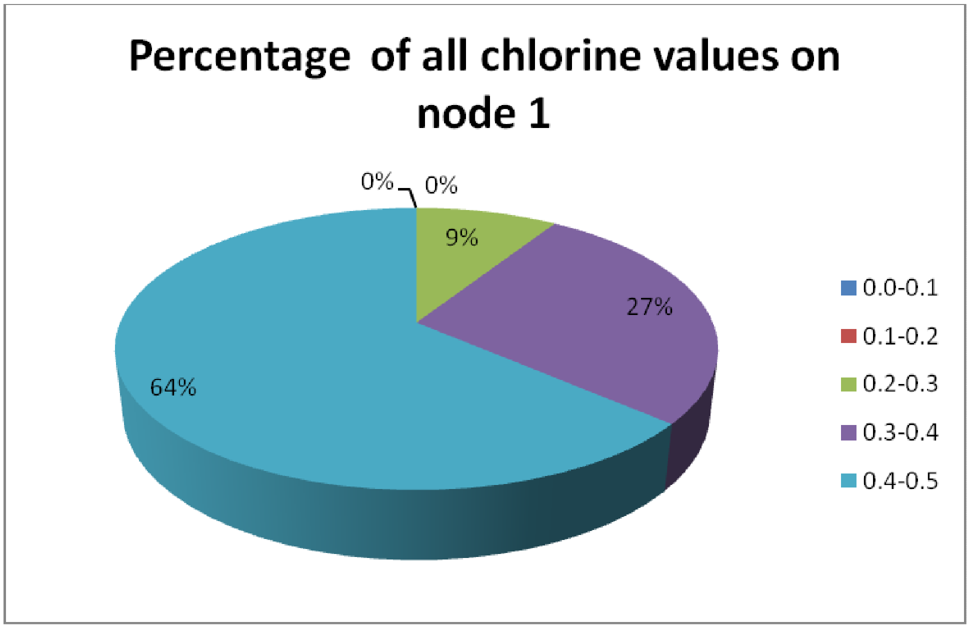


Figure 5.5: percentages of free Cl_2 values on node 1

100% chlorine values meet the WHO standards as shown in Figure 5.5 where 27% of the values range between 0.5-0.4 ppm, 64% range between 0.4-0.3 ppm and the rest range between 0.2-0.3 ppm that means that all of the readings are more than 0.2 ppm and less than 0.8 ppm.

5.3.1.2 Chlorine values through the day on node 2

The free chlorine values were monitored at node 2 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.6. The graphs show that free chlorine values range as 0.25-0.40 ppm that meets the standards of WHO.

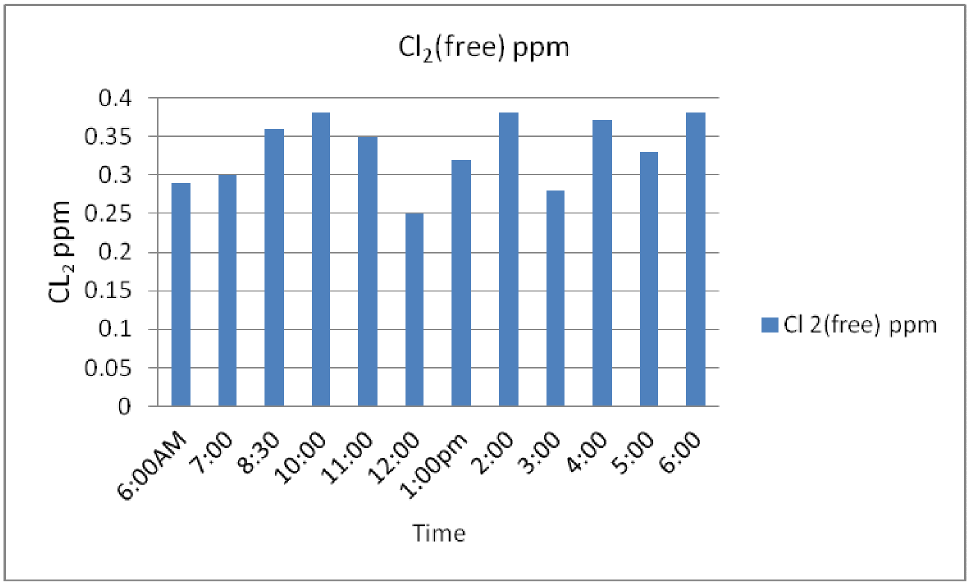


Figure 5.6: Values of free Cl_2 through the day on node 2

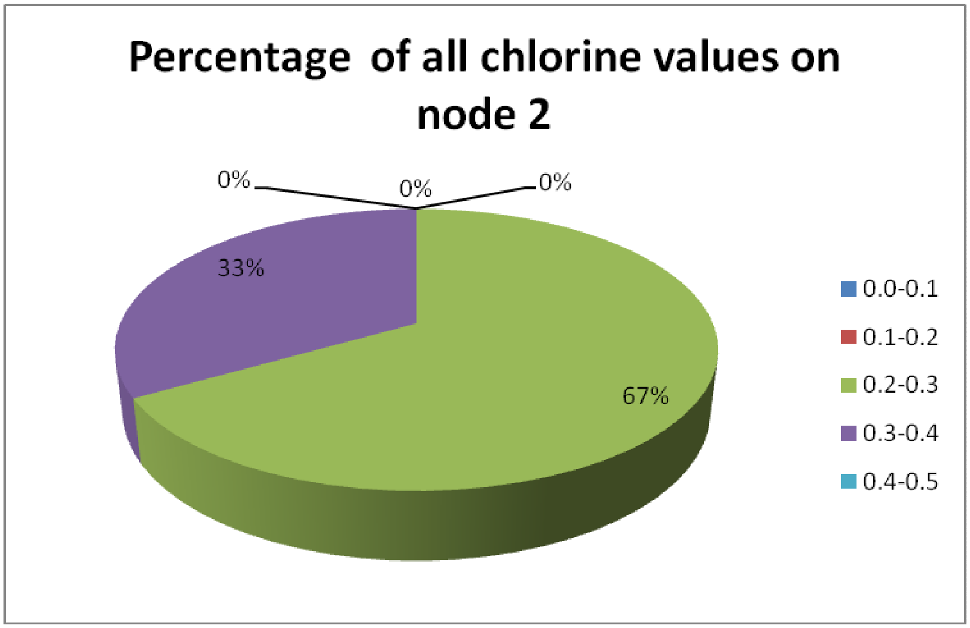


Figure 5.7: Percentages of free Cl_2 values on node 2

Results show that 100% of chlorine values meets the WHO standards as shown in Figure 5.7, where 67% of the values ranges between 0.4-0.3 ppm and 33% ranges between 0.3-0.2 ppm, which means that all of the readings are more than 0.2 ppm and less than 0.8 ppm.

5.3.1.3 Chlorine values through the day on node 3

The free chlorine values were monitored at node 3 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.8. The graphs show that free chlorine values range as 0.35-0.1 ppm which do not meet the WHO standards.

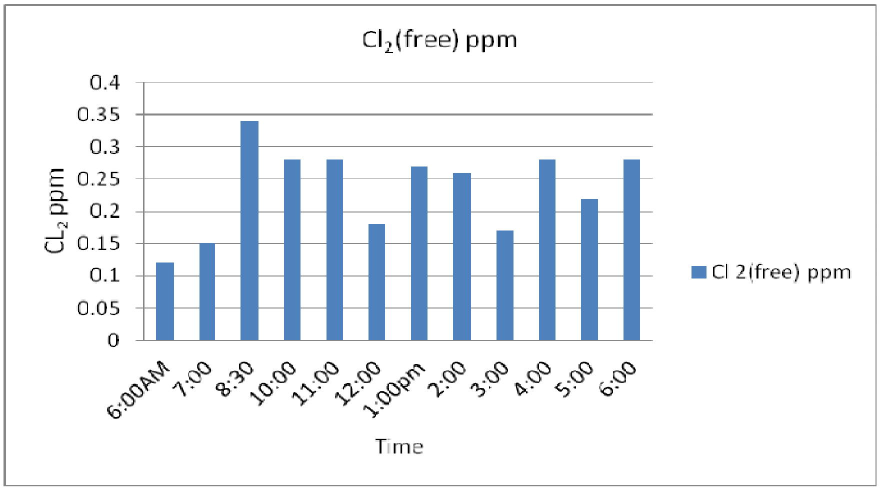


Figure 5.8: Variation of free chlorine values through the day on node 3

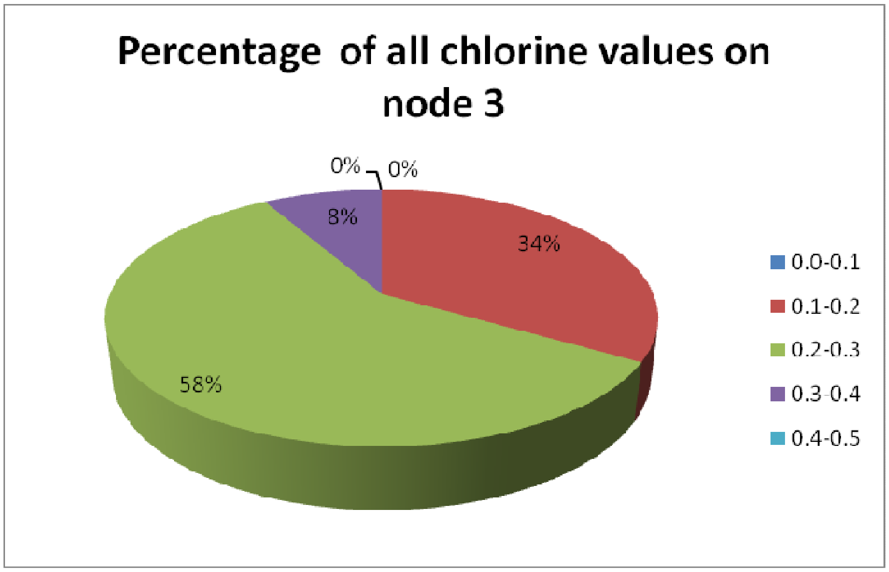


Figure 5.9 Percentages of free Cl_2 values on node 3

According to node 3, which is the third node on the track 1 and located on 3” pipe diameter, where the residual chlorine needs more attention, 34% of the residual chlorine values do not meet WHO standards (Figure 5.9) which is an indication that any leakage of pollutants in this region may lead to the presence of microorganisms and thus negatively impact the human health.

On the other hand, 58% of readings correspond to the required specifications, but very close to the lower limits, which increase the potential of water pollution if the leak with large quantities of contaminants into water network.

5.3.1.4 Chlorine values through the day on node 4

The free chlorine values were monitored at node 4 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.10. The graphs show that free chlorine values range as (0.05-0.0.28) ppm which don’t meet the standards of WHO.

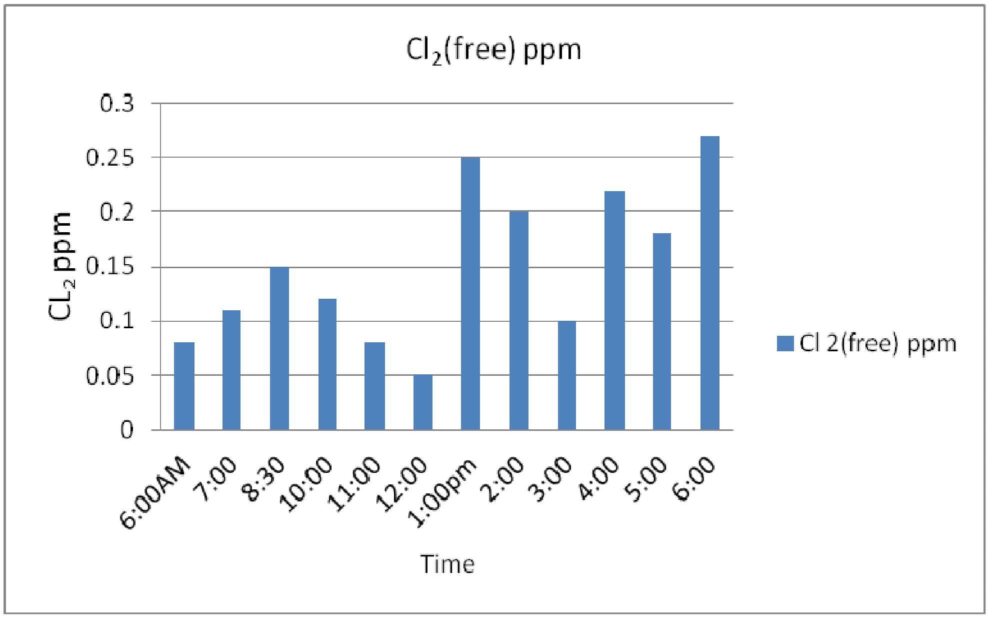


Figure 5.10 Variation of free chlorine values through the day on node 4

According to node 4, which is the last node on the track 1 and located on 2” pipe diameter, where the residual chlorine need more attention too, more than 70% of the residual chlorine values do not meet the WHO standards (Figure 5.11) and the rest values close to the lower limit of the standard, which is an indication that any leakage of pollutants in this region may lead to the presence of microorganisms and thus high negatively impact on human health.

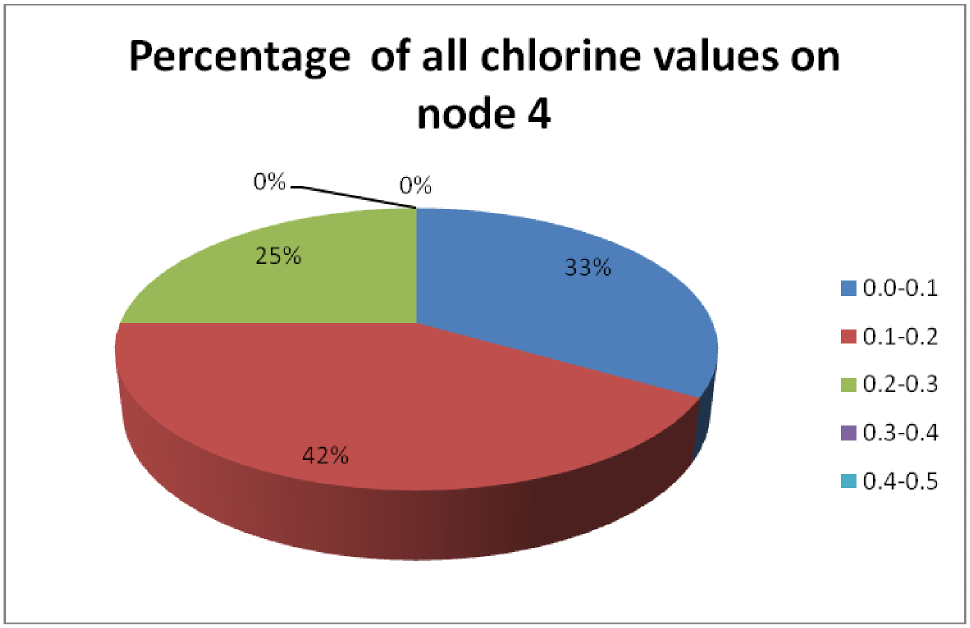


Figure 5.11 Percentages of free Cl_2 values on node 4

5.3.1.5 Chlorine values through the day on node 5

The free chlorine values were monitored at node 5 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.12. The graphs show that free chlorine values range as (0.05-0.15) ppm, which completely does not meet the standards of WHO.

According to node 5, which is the last node on the track 2 and located on old 2” pipe diameter, where the residual chlorine need more attention too, all of the residual chlorine values do not meet the WHO standards (Fig 5.13) which is an indication that any leakage of pollutants in this region may lead to the presence of microorganisms and thus high negatively impact on human health.

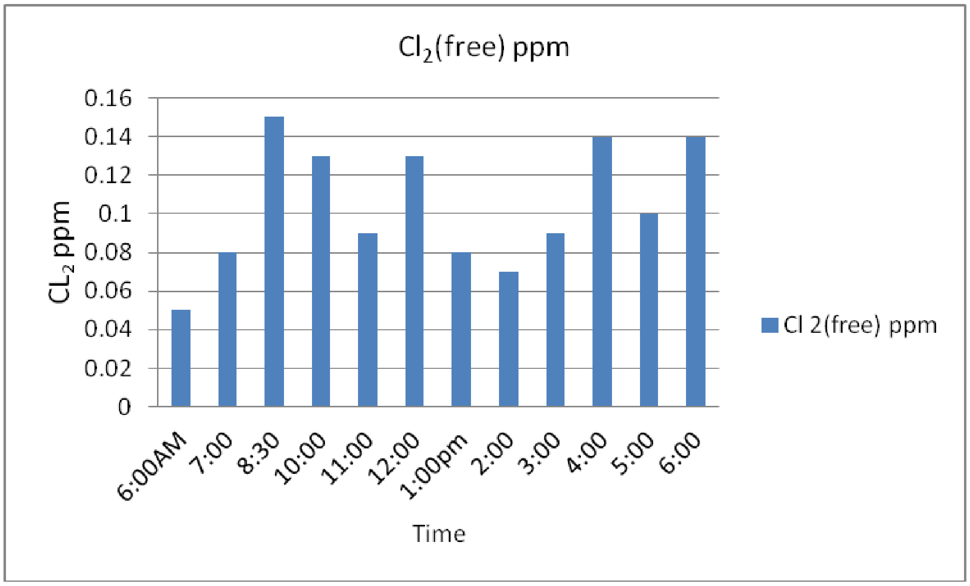


Figure 5.12 Variation of free chlorine values through the day on node 5

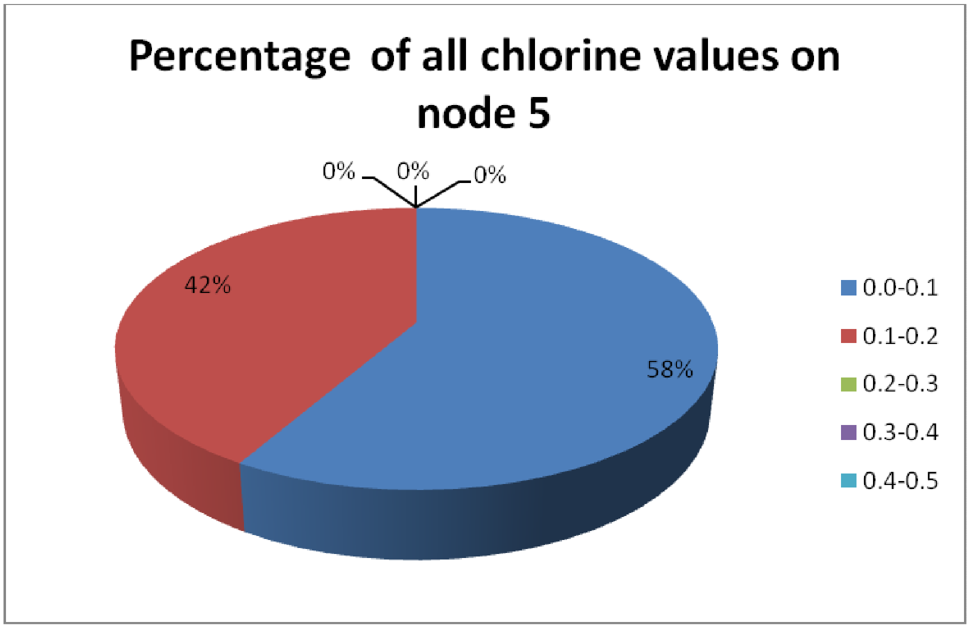


Figure 5.13 Percentages of free Cl_2 values on node 5

5.3.1.6 Chlorine values through the day on node 6

The free chlorine values were monitored at node 6 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.14.

The graphs show that free chlorine values range as (0.22-0.38) ppm, which meet the standards of WHO.

According to node 6, which is the second node on the track 3 and located on new 2” pipe diameter, all of the residual chlorine values meet the WHO standards (Figure 5.15) which is an indication that any leakage of pollutants in this region may faced by an enough amount of free chlorine to prevent living the microorganisms in the drinking water.

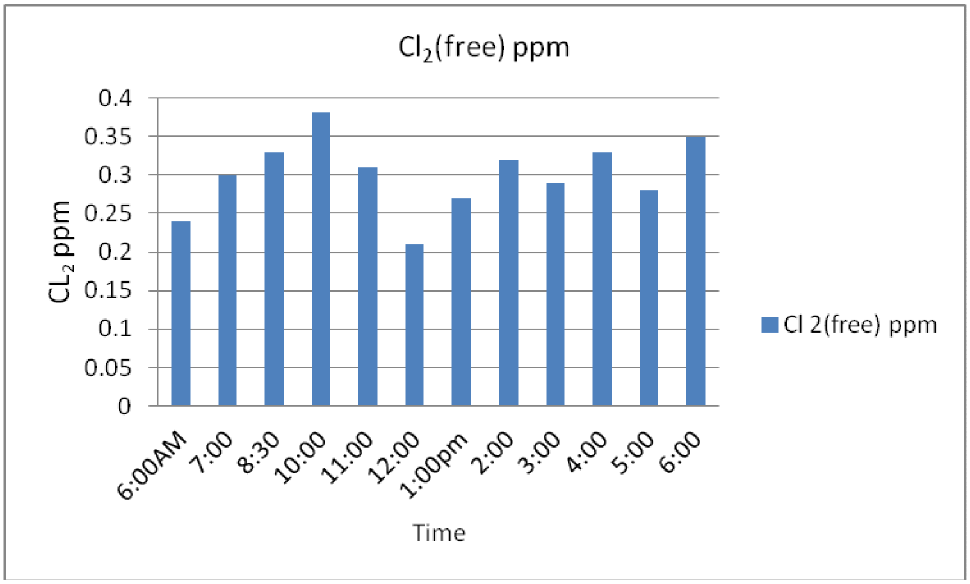


Figure 5.14 Variation of free chlorine values through the day on node 6

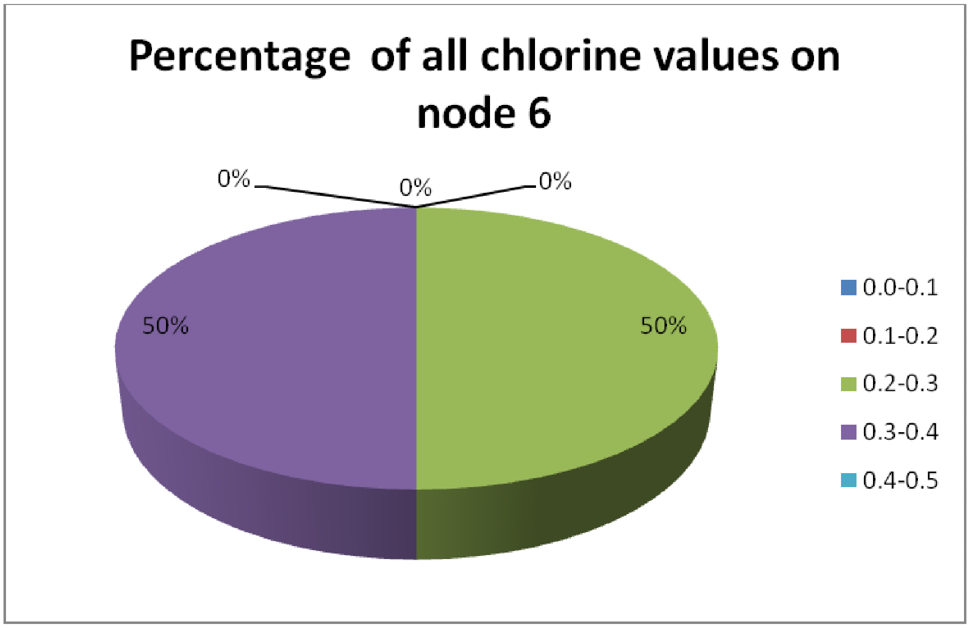


Figure 5.15 Percentages of free Cl_2 values on node 6

5.3.1.7 Chlorine values through the day on node 7

The free chlorine values were monitored at node 7 on the hydraulic layout in Figure 5.3 where divers values through the day as shown in Figure 5.16. The graphs show that free chlorine values range as (0.04-0.0.2) ppm which do not meet the standards of WHO.

According to node 7, which is the last node on the track 3, and located on old 2” pipe diameter, most of the residual chlorine values did not meet WHO standards (Figure 5.17) which is an indication that any leakage of pollutants in this region may lead to the presence of the microorganisms in the drinking water.

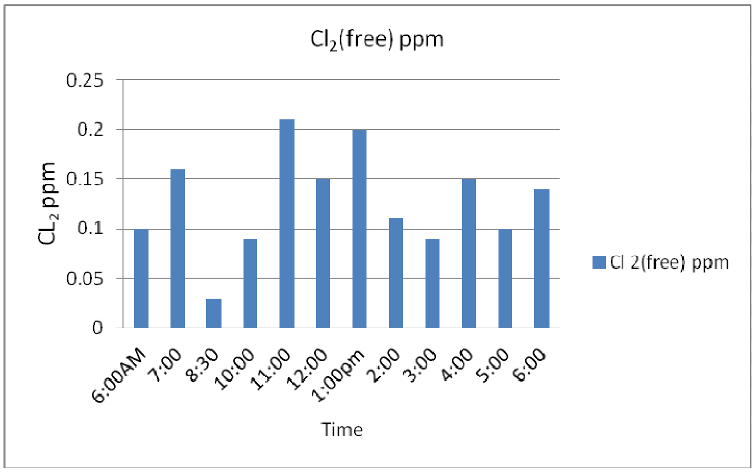


Figure 5.16 Variation of free chlorine values through the day on node 7

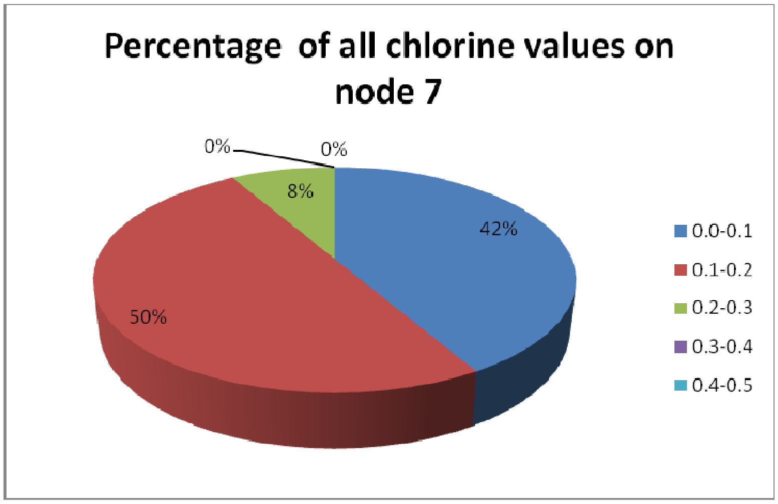


Figure 5.17 Percentages of free Cl_2 values on node 7

All the residual free chlorine values (Appendix1) of the selected locations in the distribution system were divided into five ranges (Table 5-11): the first one represent the values of 0.0-0.1ppm, the second represent the values of 0.1-0.2ppm, the third represent the values of 0.2-0.3ppm, the forth represent the values of 0.3-0.4ppm, and the last one represent the values of 0.4-0.5ppm. Each of these ranges was represented by a color as shown on Figure 5.18.

Table 5.11 Ranges of all measured chlorine values

CL2 ppm				
0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5
15	20	23	23	3

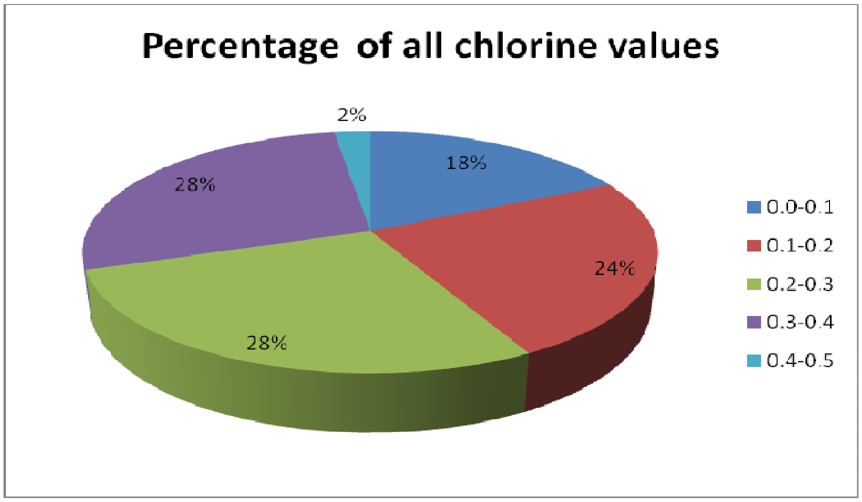


Figure 5.18 Percentages of all measured free Cl_2 values.

The measurements covered all the selected points, which give a real perception of the percentage of free chlorine residual in drinking water in this part of the network. Through the measured values, we find there is great variation in these values where the highest value was 0.44 mg/l, while the lowest one was 0.03 ppm, which was much less than the minimum international specification, a 0.2 ppm.

Therefore, we find that there is no problem in the upper limit to the proportion required of free chlorine in drinking water. This is a good sign to exclude a hazardous compounds associated with the chlorination process, the most important trihalomethan compounds that have been shown in studies of many serious impact on health in terms of the occurrence of diseases caused by cancer, and genetic effects and their impact on fertility.

But on the other hand there are more than 35 (40%) values did not reach to the lower limit of the required standard and 23 value very close to the lower limit which may affect disinfection efficiency by causing re-growth of microorganisms.

Figure 5.18 shows that about 40% of the values did not meet WHO standards for drinking water and approximately 28% of the points very close to the minimum limit for chlorine residual in the water network of Kufor Malek.

5.3.2 Chlorine Decay

5.3.2.1 Effect of Pipe Diameter

Chlorine values of the pipes with the same age but different diameters (Tracks 1, 2) arranged in Table 5.12

The chlorine decay rate is inversely proportional to the diameter of the pipe as shown in Figures above. Figure 5.19 and Figure 5.20 show that the measured free chlorine values vary through track 1 which consists of different pipe diameters with same age. The values of free chlorine that measured on 4" pipe diameter are higher than those measured on 3" and 2″ pipe diameter2".

When drinking water flows through the pipe with a diameter 4" the decay of free chlorine seems to be too small. On the other hand, the decay becomes significant when water flows through the pipes with smaller diameter (2").

Blue series represent the values of free chlorine at node 1, which is located on the pipe with diameter 4" where the water flow towards the node 2, located on the same pipe, which is represented by the red series of chlorine values as shown in Figure 5.20 where no big difference appears between these two series. But when water flows through 3" pipe diameter the decay of chlorine values seems significant which is represented by the green series. More significant chlorine decay appears when the drinking water flows within smaller pipe diameter as shown on the last series of values.

Table: 5.12 Values of free Cl_2 through track 1

		Cl 2(free) ppm			
time	Time (accumulated)	Old (15-20 years) T1,T2 4” (node1)	Old (15-20years)T1 ,T3 4”(node2)	Old (15-20years) T1,T3” (node3)	Old (15-20 years)T1 2” (node4)
6:00AM	0.00	0.32	0.29	0.12	0.08
7:00	1	0.35	0.30	0.15	0.11
8:30	2.5	0.44	0.36	0.34	0.15
10:00	4	0.42	0.38	0.28	0.12
11:00	5	0.40	0.35	0.28	0.08
12:00	6	0.30	0.25	0.18	0.05
1:00pm	7	0.38	0.32	0.27	0.25
2:00	8	0.40	0.38	0.26	0.20
3:00	9	0.32	0.28	0.17	0.10
4:00	10	0.41	0.37	0.28	0.22
5:00	11	0.39	0.33	0.22	0.18
6:00	12	0.40	0.38	0.28	0.27

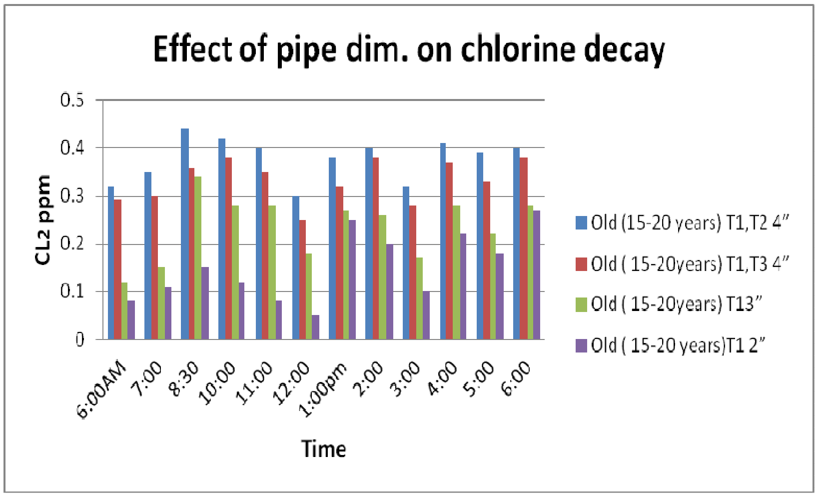


Figure 5.19 Values of free Cl_2 through track 1

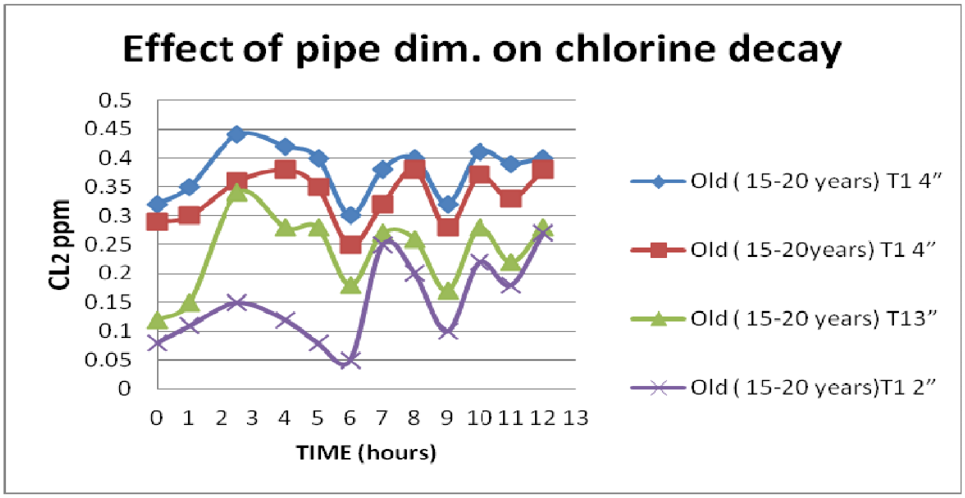


Figure 5.20 Effect of pipe diameter on the residual chlorine

5.3.2.2 Effect of Pipe Age

Chlorine values of the pipes with the same diameter but different ages (Track 3) are shown in Table 5.13.

Chlorine decay rate is directly proportional to the age of the pipe as shown in the above figures. Figure 5.21 shows that the measured free chlorine values vary through track 1 which consists of different pipe diameters with same age. The values of free chlorine that appear on new pipe higher than those that appear on old pipe although they have the same diameter. When the drinking water flows in a new pipe, the decay of free chlorine seems too small, but becomes significant when the transmission of water through the old pipe.

Blue series represents the values of free chlorine at node 2, which is the beginning of new pipe on track 3 where the water flows towards the node 6, located on the same pipe, which is represented by the red series of chlorine values as shown Figure 5.22 where no big difference appears between these two series. More significant chlorine decay appears when the drinking water flows within the older pipe that goes to node 7 where the values represented by the green series as shown in Figure 5.22.

Table: 5.13 Values of free Cl_2 through track 3

		Cl 2(free) ppm		
time	Time (accumulated)	*new (15-20years) T1,T3 2” (node 2)*	new (15 years)T3 2” (node 6)	Old (15 years)T3 2” (node 7)
6:00AM	0.00	0.29	0.24	0.1
7:00	1	0.30	0.30	0.16
8:30	2.5	0.36	0.33	0.03
10:00	4	0.38	0.38	0.09
11:00	5	0.35	0.31	0.21
12:00	6	0.25	0.21	0.15
1:00pm	7	0.32	0.27	0.20
2:00	8	0.38	0.32	0.11
3:00	9	0.28	0.29	0.09
4:00	10	0.37	0.33	0.15
5:00	11	0.33	0.28	0.10
6:00	12	0.38	0.35	0.14

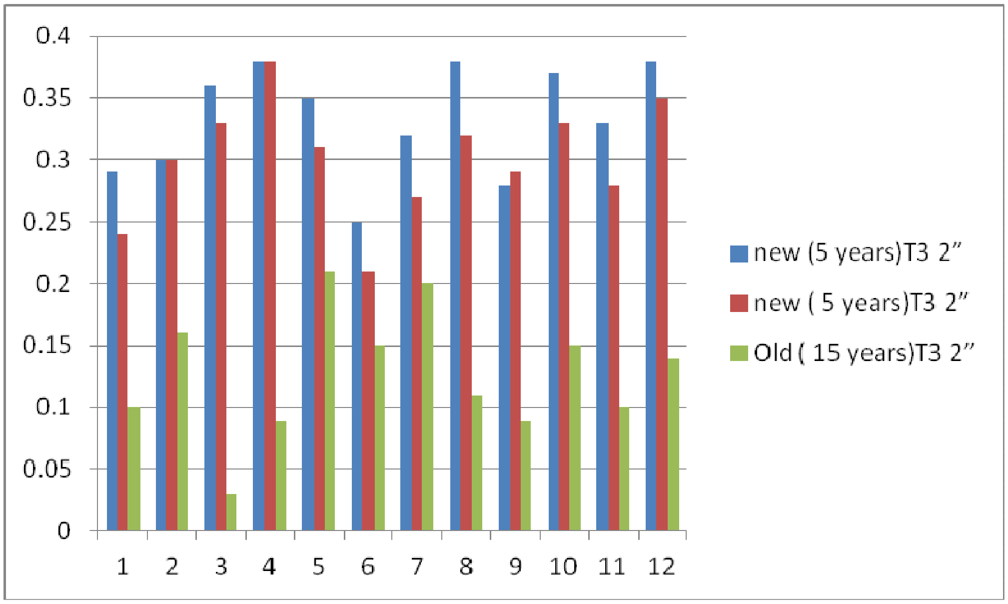


Figure 5.21 Values of free Cl_2 through track 3

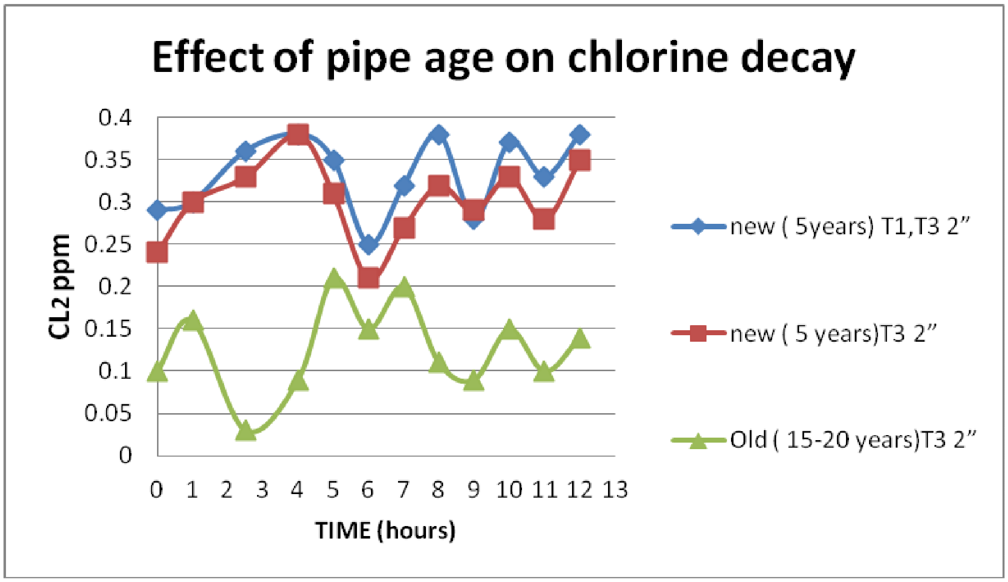


Figure 5.22 Effect of pipe age on the residual chlorine

5.4 Using EPANET

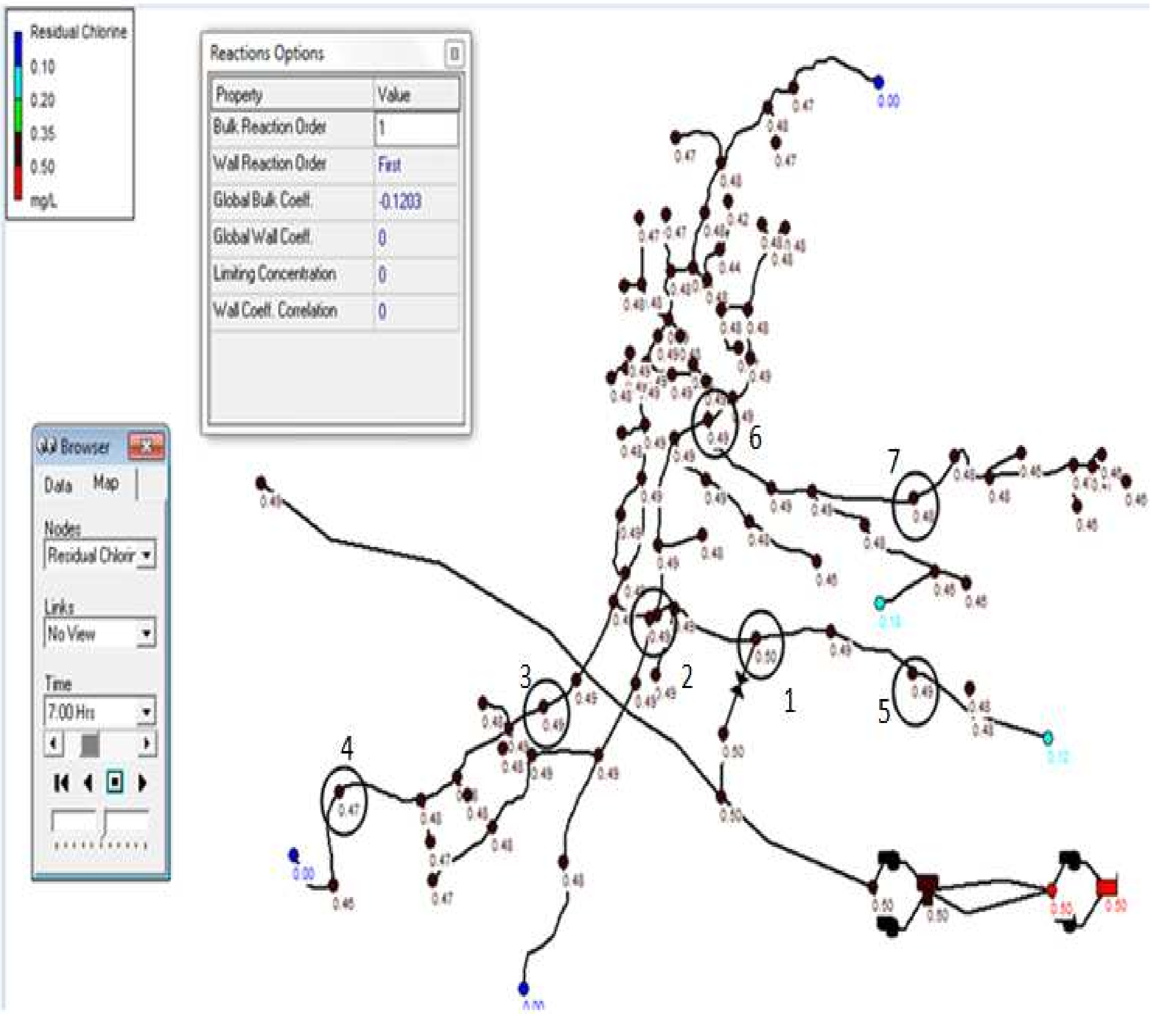
Hydraulic modeling

To conduct a quality simulation in a given distribution system, one must have a hydraulic model on which to apply the EPANET quality model.

Water quality modeling

Since the Kb coefficient was determined in laboratory, it will be directly introduced into the software to check the effect of the water by its bulk phase on the residual chlorine. The Kb coefficient is denominated as bulk reaction coefficient and will have the value of -0.1203 hour^{-1}. The value must be proceeding by a minus sign in order to indicate a disappearance coefficient. We will not enter the value of K_f at this phase, because its calibration will occur later.

The simulation's preliminary data can be presented by EPANET in the shape of a map of concentration isolines. In a first approach, we only used the K_b value to characterize the chlorine decay, getting the data presented in Figures 5.30 and 5.31.



Reactions Options

Property	Value
Bulk Reaction Order	1
Wall Reaction Order	First
Global Bulk Coeff.	-0.1203
Global Wall Coeff.	0
Limiting Concentration	0
Wall Coeff. Correlation	0

Figure 5.23 Chlorine values according to the bulk effect

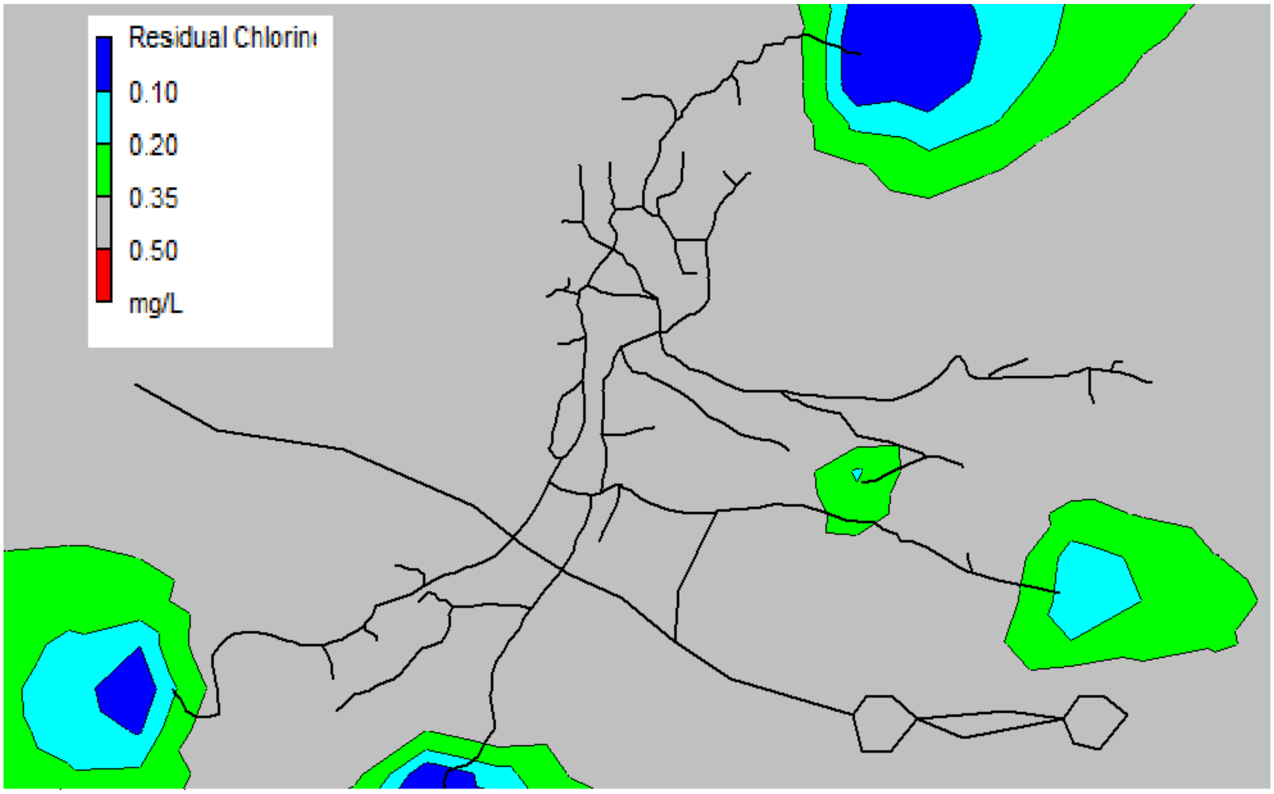
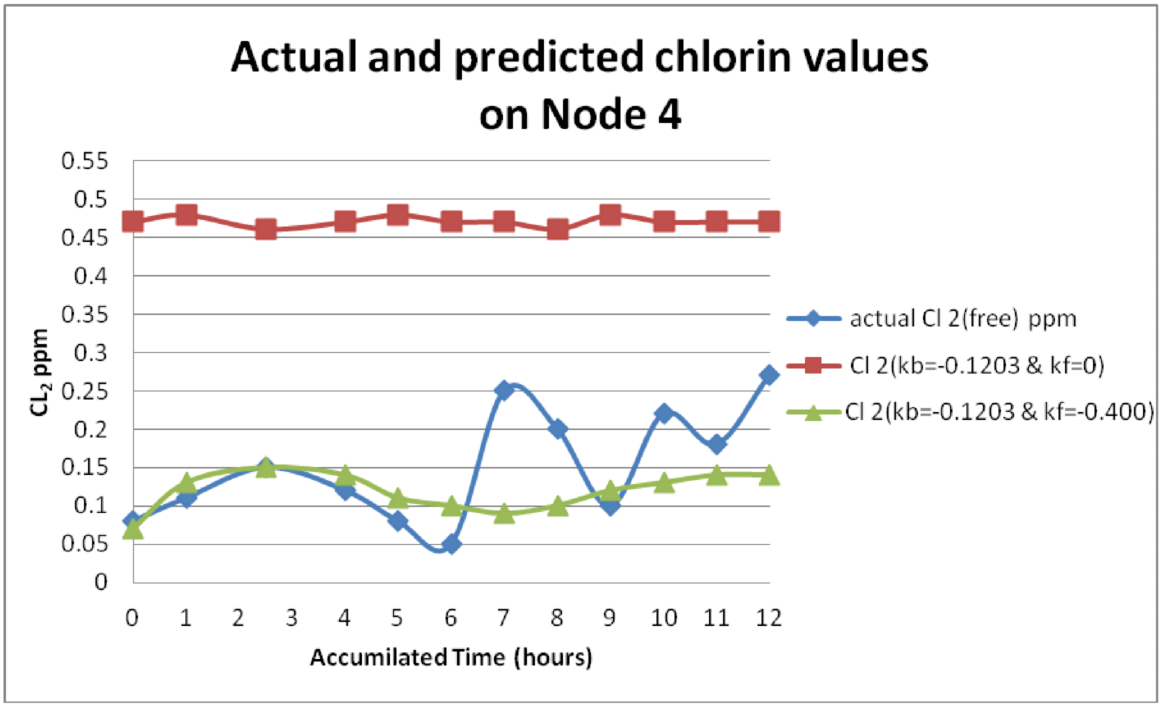


Figure 5.24 Concentration tie-lines of chlorine throughout the system (12 hours). Kb = -0.1203hour-1; Kf = 0.00 m.s-1.

As noted from the values on the network that appear on Figure 5.23 where these values do not differ from the initial dosage (0.5 ppm), where all the noted values are ranging as 0.5-0.42 ppm on all nodes (Appendix 2). Figure 5.24 shows that the concentration tie-lines map has almost the same value of residual chlorine, which appears by the gray color when introducing just the Kb value.

That means there are other factors that have a significant effect on the decay of chlorine through the water network. As literature, the reaction of the chlorine with the pipe wall has a main role to decrease the amount of chlorine in the distribution systems. On the other hand, as shown in Figure 5.26, introducing a K_f value alters the concentration tie-lines map significantly. In this case, the chlorine reaction with pipe walls contributes 77% to total chlorine decay values on track 1 and 88% on track 2.



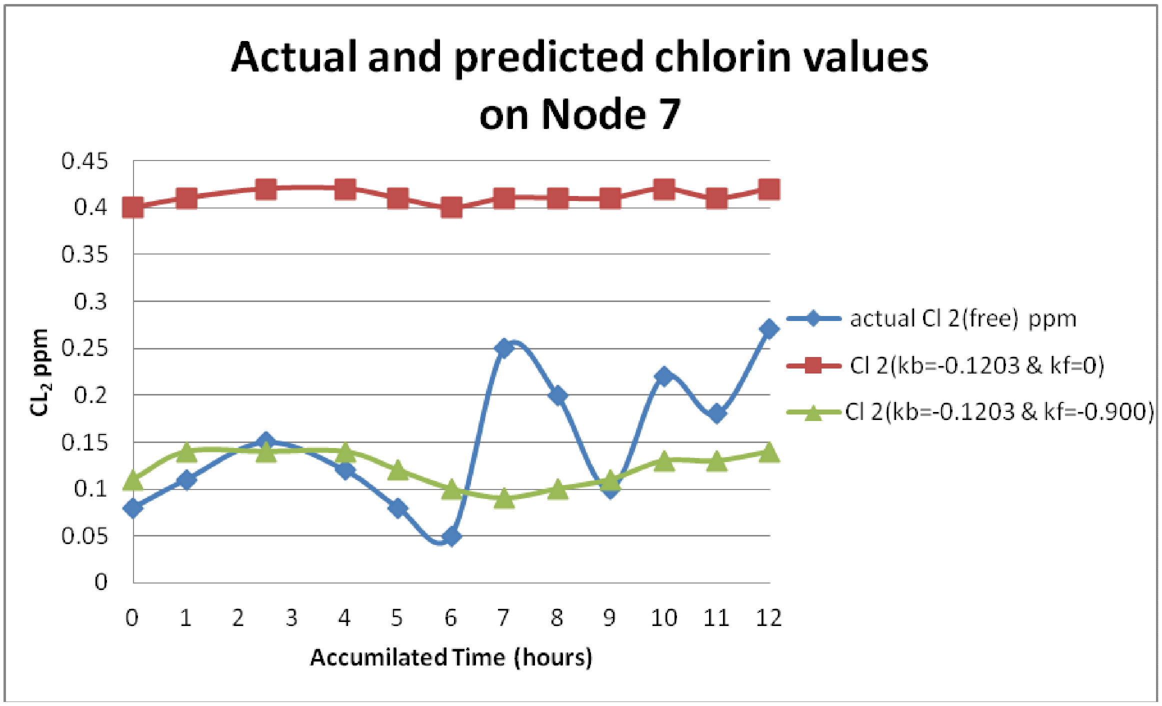


Figure 5.25: Simulation results of residual chlorine for nodes 4 and 7, before and after Kf calibration

Figure 5.25 represents the result of K_f coefficient calibration through the trial-error method. As shown above, the effect of the pipes wall appear when the wall coefficient applied to the model. There is no significant effect of the bulk coefficient on the residual chlorine values (Figure 25) that monitored on the node no. 4 which is located on track 1, while the effect seems significant when the wall coefficient applied on the same track. The same thing applies for the node no.7 which is located on track 3.

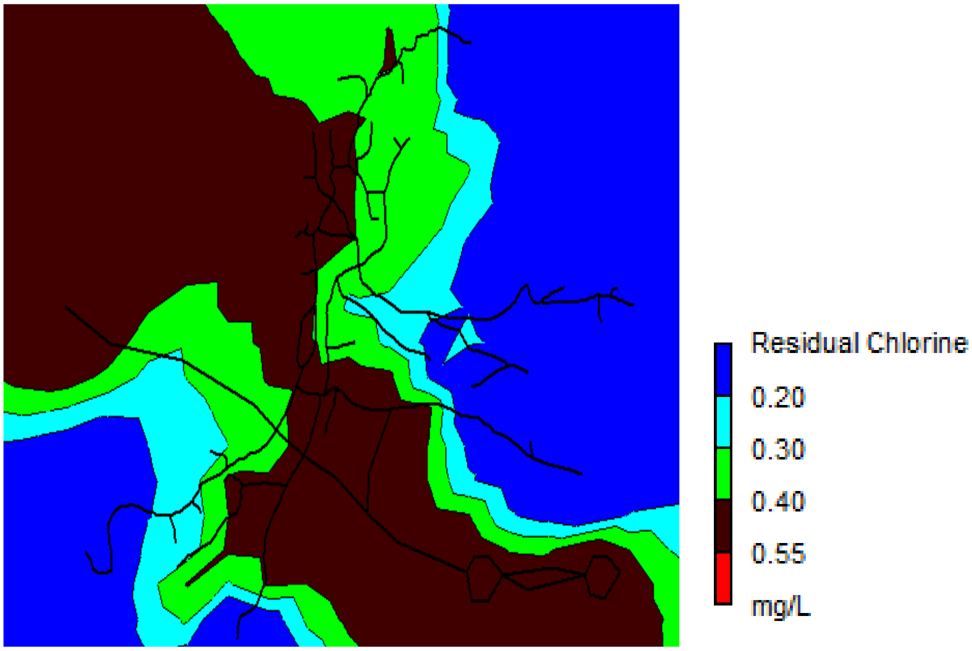


Figure 5.26 Concentration tie-lines of chlorine throughout the system (12 hours). Kb = - 0.1203hour-1; different Kf values

The contribution of pipe wall reaction is more significant than that the chlorine reaction in the bulk phase (Figure 5.26). As shown in (Appendix 3) all the chlorine values range as (0.07-0.4mg/l). One must bear in mind that we are dealing with a rechlorination station and that, at this stage, water has already lost most of its chlorine constituents in its first chlorination step.

Chapter Six
Conclusions and Recommendations

6.1 Conclusions

- The initial chlorine dosage in the Palestinian water distribution networks in general and in the study area in particular is 0.5 ppm which is small as the upper limit of the standard is 0.8 ppm.
- The water quality parameters (pH, turbidity, and temperature, SS, Ammonium, TOC, Faecal coliform, EC, Ca, Mg, Fe and Mn) have values within the limits of WHO standers, which means that this water has a good quality.
- Through the measured values of the residual free chlorine in the water network, it was found there is great variation in these values where the highest value was 0.44 ppm, while the lowest value was 0.03 ppm that was much less than the minimum lower limit of WHO standard which is 0.2 mg/l.
- The efficiency of the chlorination process is not completely effective where more than 35 values (42%) were less than the lower limit of the standard, 23 values (28%) were very close to the lower limit and the rest were within the required range.
- The average of the measured values of residual free chlorine of old steel pipes with small diameters are less than the average values measured on new steel pipes with large diameters and the difference is significant.
- There is a substantial impact of pipe diameter and age on chlorine decay and residual chlorine contraptions in the water supply systems.
- The EPANET molding shows the direct effect of Kb and Kf on the residual chlorine through the network but it does not show the effect of other parameters.
- EPANET might show better results for modeling of chlorine decay in large water networks than small ones as in the study area.

6.2 Recommendations

- We recommend increasing the initial dosage of chlorine at the source, but after doing a comprehensive study of the water network in order to ensure that there is no impact of various levels of chlorine addition, which results in trihalomethane formation.
- We recommend replacing the old pipes, especially with those with small diameters to improve the efficiency of the chlorination process in Kofur Malik network.

- We recommend replacing the old pipes, especially with those with small diameters to improve the efficiency of the chlorination process in Kofur Malik network.

- We suggest adding chlorination stations through the water network, especially on the parts that did not meet the required standards of the World Health Organization.
- We recommend to make molding for a large scale network using the EPANET software so that the effect of other parameters can clearly appear on the residual chlorine.

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Appendixes

Appendix 1: Chlorine values on all selected nodes

Appendix 1.1: Network Chlorine values when (Kb = -0.1203 hour^{-1}and Kf = 0.00 m.s^{-1}) were applied.

	Head	Pressure	Residual Chlorine
Node ID	m	m	mg/L
Junc 2	842.79	78.79	0.42
Junc 3	842.8	49.8	0.48
Junc 4	842.82	60.82	0.49
Junc 5	842.82	61.82	0.48
Junc 6	842.96	54.96	0.49
Junc 7	842.95	62.95	0.47
Junc 8	843.15	54.15	0.49
Junc 9	843.4	57.4	0.49
Junc 10	843.38	57.38	0.49
Junc 11	843.36	55.36	0.48
Junc 12	843.38	65.38	0.49
Junc 13	843.37	75.37	0.48
Junc 15	843.37	80.37	0.48
Junc 16	843.37	78.37	0.49
Junc 17	843.71	63.71	0.49
Junc 18	843.7	62.7	0.49
Junc 19	844.4	62.4	0.49
Junc 20	844.35	78.35	0.49
Junc 21	844.34	77.34	0.49
Junc 22	844.35	87.35	0.49
Junc 23	844.4	62.4	0.49
Junc 24	844.42	63.42	0.49
Junc 25	844.85	62.85	0.49
Junc 26	845.53	58.53	0.49
Junc 27	843.36	54.36	0.49
Junc 28	843.4	77.4	0.49
Junc 29	843.53	74.53	0.49
Junc 30	845.57	59.57	0.49
Junc 31	845.55	59.55	0.49
Junc 32	845.55	65.55	0.49
Junc 33	845.55	69.55	0.49
Junc 34	845.75	54.75	0.49
Junc 35	845.75	54.75	0.49
Junc 36	843.72	76.72	0.49

Junc 37	843.92	67.92	0.49
Junc 38	844.24	59.24	0.5
Junc 39	844.44	68.44	0.49
Junc 40	844.18	55.18	0.49
Junc 41	844.15	46.15	0.49
Junc 42	844.14	37.14	0.48
Junc 43	842.28	76.28	0.49
Junc 44	841.6	75.6	0.49
Junc 45	841.53	72.53	0.49
Junc 46	841.48	72.48	0.48
Junc 47	841.47	41.47	0.46
Junc 48	840.79	89.79	0.49
Junc 49	840.47	93.47	0.49
Junc 50	841.47	72.47	0.48
Junc 51	840.25	98.25	0.49
Junc 52	840.25	108.25	0.48
Junc 53	839.97	88.97	0.48
Junc 54	839.97	78.97	0.48
Junc 55	839.95	84.95	0.48
Junc 56	839.95	84.95	0.48
Junc 57	839.94	84.94	0.48
Junc 58	845.65	33.65	0.5
Junc 59	845.65	40.65	0.49
Junc 60	846.87	21.87	0.5
Junc 61	847.29	21.29	0.5
Junc 62	847.28	20.28	0.49
Junc 63	849	20	0.5
Junc 65	848.84	12.84	0.5
Junc 66	848.72	22.72	0.49
Junc 67	848.68	31.68	0.49
Junc 68	848.67	35.67	0.48
Junc 69	848.68	30.68	0.49
Junc 71	846.78	21.78	0.5
Junc 72	846.42	20.42	0.5
Junc 73	846.28	25.28	0.5
Junc 74	845.95	38.95	0.49
Junc 75	846.06	36.06	0.49
Junc 76	846.21	-13.79	0.49
Junc 77	846.21	-2.79	0.49

Junc 78	845.87	-20.13	0.49
Junc 79	846.01	-10.99	0.49
Junc 80	846.4	3.4	0.5
Junc 81	846.31	6.31	0.49
Junc 82	846.25	-3.75	0.49
Junc 83	845.82	-28.18	0.49
Junc 84	845.47	-37.53	0.49
Junc 85	845.91	-26.09	0.49
Junc 86	845.83	-32.17	0.49
Junc 87	845.91	-27.09	0.49
Junc 88	845.82	-31.18	0.48
Junc 89	845.72	-52.28	0.48
Junc 90	845.68	-72.32	0.48
Junc 91	845.67	-80.33	0.47
Junc 92	845.96	-6.04	0.49
Junc 93	845.94	-6.06	0.46
Junc 94	845.5	60.5	0.49
Junc 96	845.86	-14.14	0.49
Junc 97	843.37	78.37	0.48
Junc 98	695.87	695.87	0.5
Junc 99	959.37	274.37	0.5
Junc 100	953.94	124.94	0.5
Junc 101	947.94	-22.06	0.5
Junc 102	953	124	0.5
Resvr 1	450	0	0.5
Tank 14	694.62	4.62	0.5

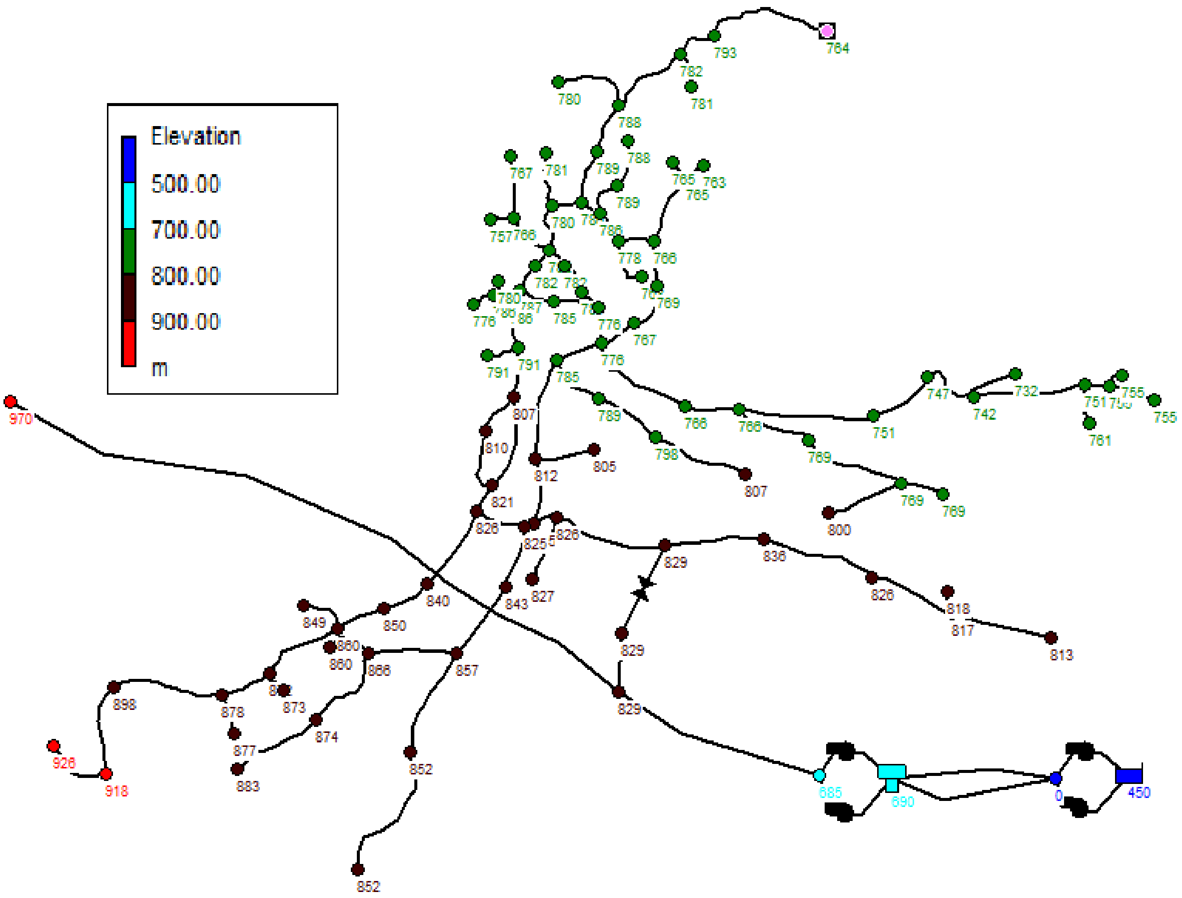
Appendix 1.2: Network Chlorine values when Kb = -0.1203 hour^{-1} and Kf = (-0.4 for track 1 and -0.9 m.s^{-1} for track 3) were applied to show the effect of the wall of pipes .

	Head	Pressure	Residual Chlorine
Node ID	m	m	mg/L
Junc 2	842.79	78.79	0.33
Junc 3	842.8	49.8	0.41
Junc 4	842.82	60.82	0.42
Junc 5	842.82	61.82	0.41
Junc 6	842.96	54.96	0.42
Junc 7	842.95	62.95	0.4
Junc 8	843.15	54.15	0.42
Junc 9	843.4	57.4	0.42
Junc 10	843.38	57.38	0.42
Junc 11	843.36	55.36	0.41
Junc 12	843.38	65.38	0.4
Junc 13	843.37	75.37	0.4
Junc 15	843.37	80.37	0.4
Junc 16	843.37	78.37	0.4
Junc 17	843.71	63.71	0.42
Junc 18	843.7	62.7	0.42
Junc 19	844.4	62.4	0.42
Junc 20	844.35	78.35	0.42
Junc 21	844.34	77.34	0.41
Junc 22	844.35	87.35	0.42
Junc 23	844.4	62.4	0.42
Junc 24	844.42	63.42	0.42
Junc 25	844.85	62.85	0.42
Junc 26	845.53	58.53	0.42
Junc 27	843.36	54.36	0.41
Junc 28	843.4	77.4	0.4
Junc 29	843.53	74.53	0.41
Junc 30	845.57	59.57	0.42
Junc 31	845.55	59.55	0.42
Junc 32	845.55	65.55	0.42
Junc 33	845.55	69.55	0.42
Junc 34	845.75	54.75	0.42
Junc 35	845.75	54.75	0.42
Junc 36	843.72	76.72	0.41

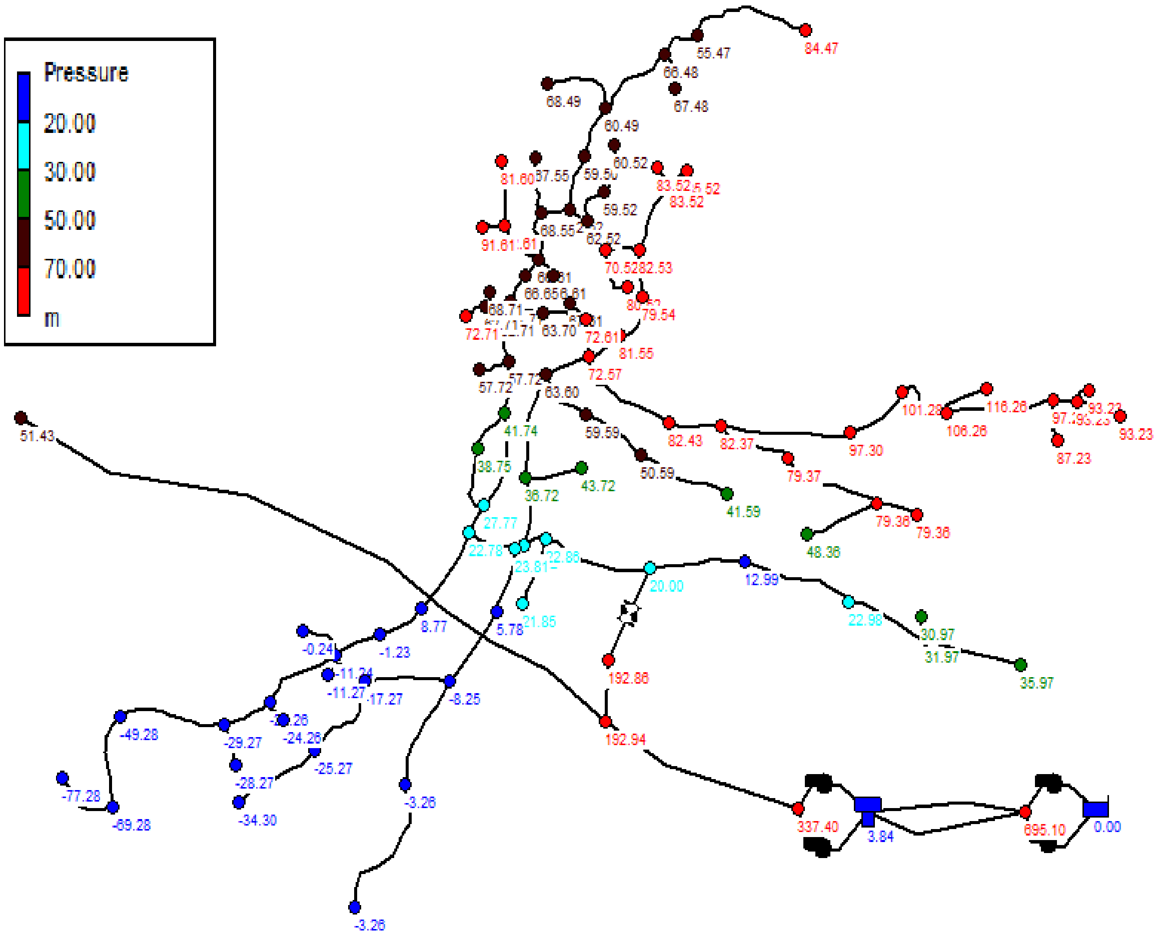
Junc 37	843.92	67.92	0.41
Junc 38	844.24	59.24	0.45
Junc 39	844.44	68.44	0.42
Junc 40	844.18	55.18	0.45
Junc 41	844.15	46.15	0.45
Junc 42	844.14	37.14	0.45
Junc 43	842.28	76.28	0.31
Junc 44	841.6	75.6	0.26
Junc 45	841.53	72.53	0.26
Junc 46	841.48	72.48	0.25
Junc 47	841.47	41.47	0.22
Junc 48	840.79	89.79	0.17
Junc 49	840.47	93.47	0.14
Junc 50	841.47	72.47	0.25
Junc 51	840.25	98.25	0.14
Junc 52	840.25	108.25	0.14
Junc 53	839.97	88.97	0.14
Junc 54	839.97	78.97	0.14
Junc 55	839.95	84.95	0.14
Junc 56	839.95	84.95	0.14
Junc 57	839.94	84.94	0.14
Junc 58	845.65	33.65	0.37
Junc 59	845.65	40.65	0.36
Junc 60	846.87	21.87	0.44
Junc 61	847.29	21.29	0.47
Junc 62	847.28	20.28	0.47
Junc 63	849	20	0.5
Junc 65	848.84	12.84	0.43
Junc 66	848.72	22.72	0.16
Junc 67	848.68	31.68	0.16
Junc 68	848.67	35.67	0.14
Junc 69	848.68	30.68	0.16
Junc 71	846.78	21.78	0.44
Junc 72	846.42	20.42	0.42
Junc 73	846.28	25.28	0.42
Junc 74	845.95	38.95	0.42
Junc 75	846.06	36.06	0.42
Junc 76	846.21	-13.79	0.29

Junc 77	846.21	-2.79	0.29
Junc 78	845.87	-20.13	0.44
Junc 79	846.01	-10.99	0.44
Junc 80	846.4	3.4	0.44
Junc 81	846.31	6.31	0.36
Junc 82	846.25	-3.75	0.32
Junc 83	845.82	-28.18	0.44
Junc 84	845.47	-37.53	0.44
Junc 85	845.91	-26.09	0.24
Junc 86	845.83	-32.17	0.2
Junc 87	845.91	-27.09	0.24
Junc 88	845.82	-31.18	0.2
Junc 89	845.72	-52.28	0.13
Junc 90	845.68	-72.32	0.13
Junc 91	845.67	-80.33	0.09
Junc 92	845.96	-6.04	0.44
Junc 93	845.94	-6.06	0.4
Junc 94	845.5	60.5	0.42
Junc 96	845.86	-14.14	0.44
Junc 97	843.37	78.37	0.4
Junc 98	695.87	695.87	0.5
Junc 99	959.37	274.37	0.5
Junc 100	953.94	124.94	0.5
Junc 101	947.94	-22.06	0.5
Junc 102	953	124	0.5
Resvr 1	450	0	0.5
Tank 14	694.62	4.62	0.5

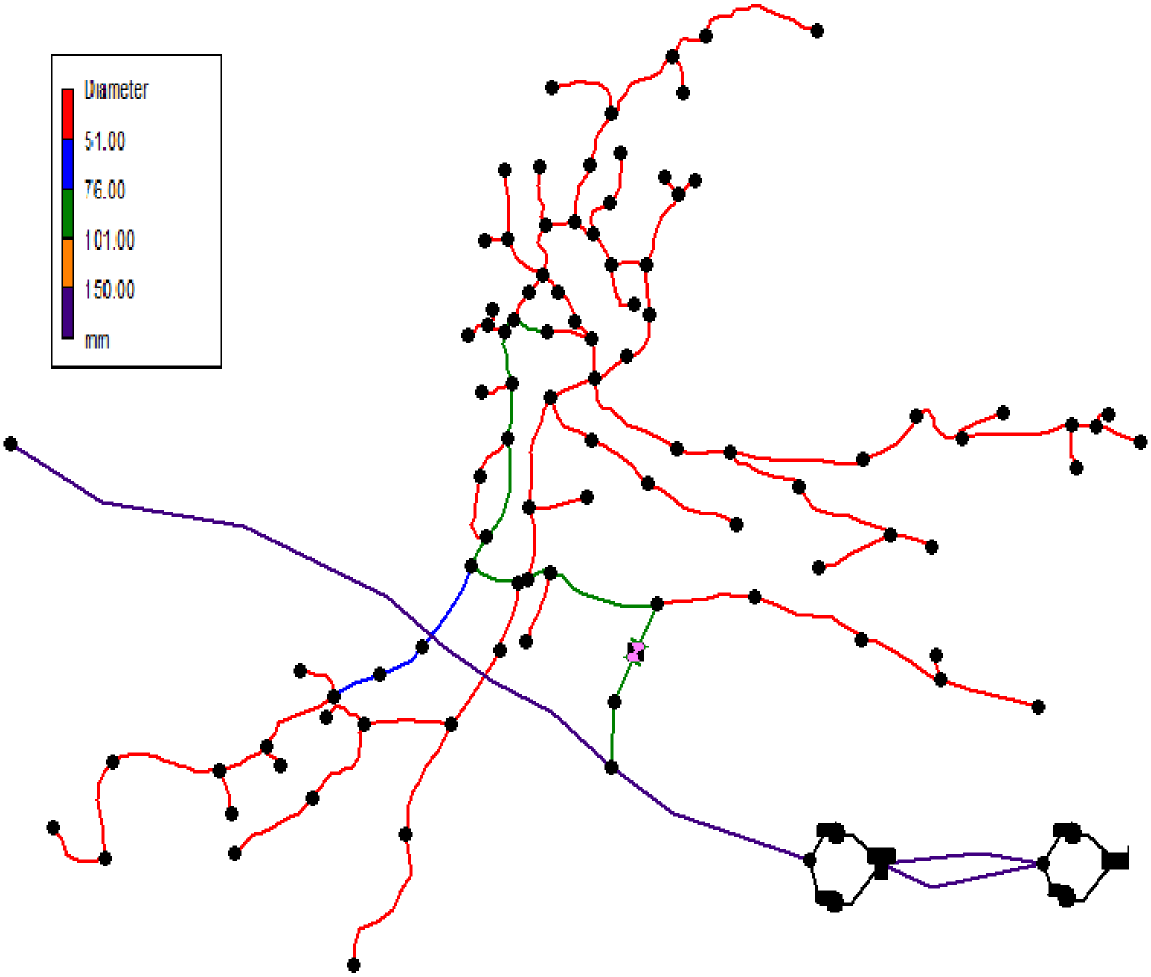
Appendix 4: EPANET model



Appendix 4.1: Elevations of the nodes on the water network



Appendix 4.2: Nodal pressure in the distribution system

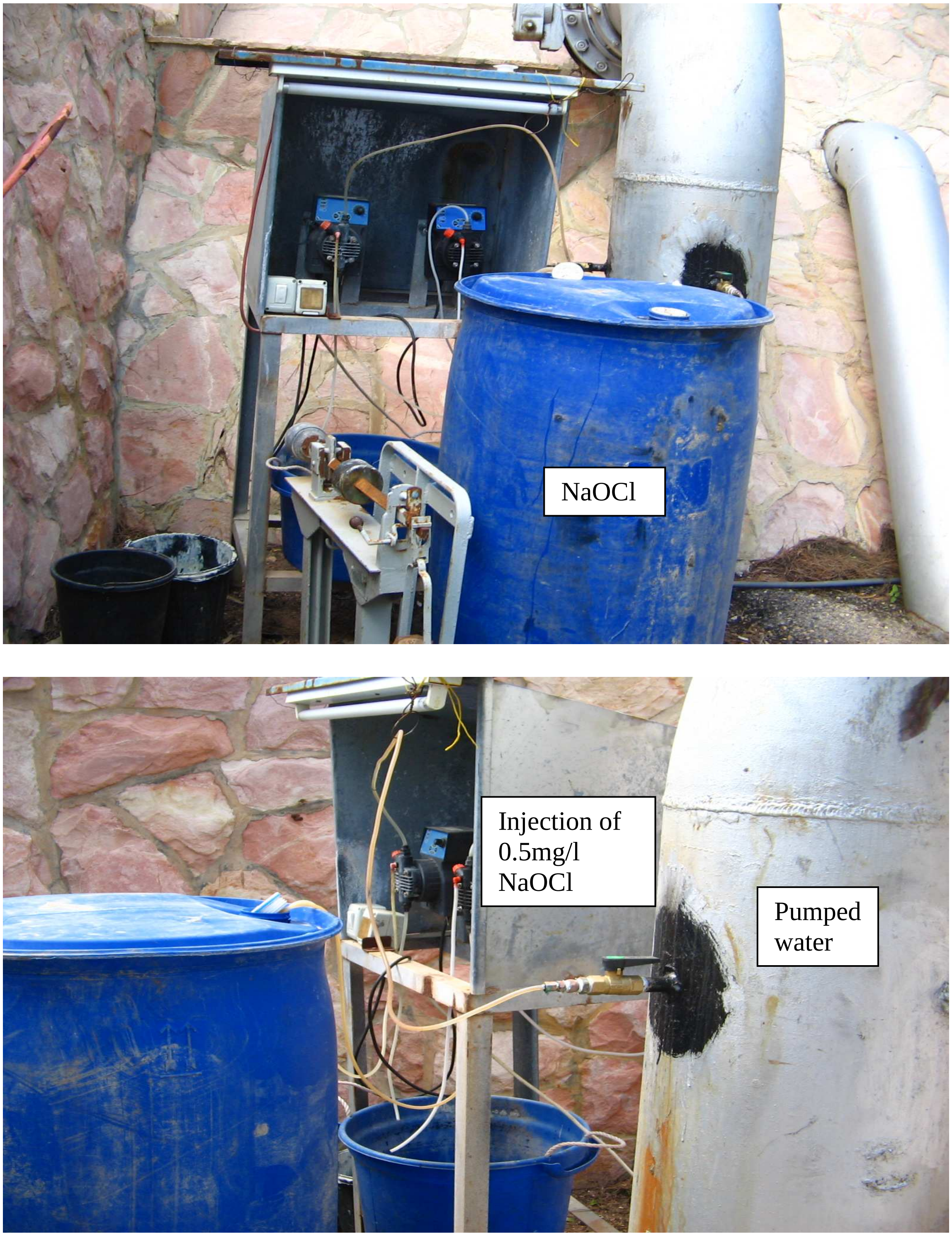


Appendix 4.3: Pipe diameters in the distribution system

Appendix 5: Photos

Appendix 5.1: Ein Samia Wells

Appendix 5.2: Balancing tank which the ground water pumped to with 500 m^3 capacity.



Appendix 5.3: Dosing pump which injected the chlorine to the pumped water to the distribution system

Appendix 5.4: Pumps in series that pump the water to the distribution systems

Appendix 5.5: Trunk lines (16” and 10”) transfer the water to the network

Appendix 5.6: Used instrument for analyses in the lab

Appendix 5.7: Lab analyses process

Appendix 5.8: Field analyses process