An-Najah National University

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The Effects of Pipe Material and Age on the Formation of Disinfection By – Products (DBP) In Nablus Water Network

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Dedicated to

My parents and wife

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إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

تأثير نوع وعمر الأنبوب على تشكل النواتج الثانوية في شبكة مياه نابلس

The Effects of Pipe Material and Age on the Formation of Disinfection By – Products (DBP) In Nablus Water Network

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LIST OF ABBREVIATIONS

Symbols	Definition
ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
CBDA	Chemical, Biological and Drugs Analysis Center at An-Najah National University
DBP	Disinfection By – Products
DBPR	Disinfectants/Disinfection By-Products Rule
EOSQ	Egyptian Organization for Standardization and Quality
GC-MS	Gas Chromatograph- Mass Spectrometer
HDPE	High Density Poly Ethylene
JISM	Jordan Institution for standards and Metrology
MCL	Maximum Contaminant Levels
NOM	Natural Organic Matter
PCBS	Palestinian Central Bureau of Statistics
PP	Polypropylene Pipe
PPb	Part Per Billions
PSI	Palestinian Standards Institution
SPME	Solid-Phase Microextraction
TOC	Total Organic Carbon
TTHM	Total trihalomethanes
UFW	Unaccounted for Water
USEPA	United States Environmental Protection Agency
UV	Ultra Violet light
WESI	Water and Environmental Studies Institute at An-Najah National University
WHO	World Health Organization

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Abstract

In the City of Nablus which is located in the northern West Bank-Palestinian Territory, a water system network serves about 177,000 people in Nablus and some of the surrounding localities, consist of, five wells, five springs, 13 operating storage tanks,13 pump stations, distribution network consists of about 304 km of water pipes of different diameter, material and ages. The treatment process used for disinfecting drinking water is chlorination, using sodium hypochlorite, the Unaccounted for Water (UFW) is 29 % in the year of 2010, and the supply is intermittent due to water shortages, so contaminants can intrude into the pipe network and the rooftop storage tanks and react with chlorine to form disinfection by – products (DBPs), which may cause cancer and some other diseases.

In this research, samples representing Nablus water system in coordination with Nablus Water Supply and Sanitation Department were taken and analyzed for content of DBPs as THM. Results show all TTHM values of the field survey samples were less than PSI MCL (250 ppb) and the USEPA MCL (80 ppb), except one value from Al Qwareen Spring-trading centre at 153 ppb, which is more than the MCL set by the USEPA.

This mean it is very necessary to monitor continuously TTHM in this supply node and the water system and ensure not to exceed the MCL value.

Pipe segments of different materials and ages were installed at the WESI laboratory and filled with water obtained from the taps at WESI, different chlorine doses, contamination loads and different incubation periods were applied to the different segments. Samples from the entire water volume incubated in the pipe segments were analyzed for their content of TTHM. Results were statistically analyzed using SPSS statistical package. Results show that TTHM values increased with increasing chlorine dose, BOD loading, and incubation time. TTHM concentration for new steel pipe samples was more than that in Polypropylene pipe samples, and increased with increasing age of pipe, but the different is not significant.

Based on the results obtained, it was found that:

- There is presence of TTHM in Nablus water supply system.
- There are clear relationships between TTHM in water supply system with chlorine dose and residual concentration, BOD concentration and incubation period.
- Old steel pipes need to be replaced.
- Incubation period need to be reduced by increasing water availability and pumping durations.
- Chlorine dose and residual need to be more closely monitored.
- UFW must be reduced to reduce biological contamination of water.

CHAPTER ONE

INTRODUCTION

1.1 Background

The City of Nablus, located in the West Bank - Palestinian Territory, has at present a water network composed of pipes of different ages and materials (steel, polypropylene (PP), ductile, and high density polyethylene (HDPE)). The water network serves about 177,000 people in Nablus and some of the surrounding localities using multiple ground water sources of varying quality. The Unaccounted for Water (UFW) reported by Nablus municipality is 29 % in the year of 2010, and the supply is intermittent due to water shortages. Thus contaminants can intrude into the pipe network and the rooftop storage tanks.

The treatment process used for disinfecting drinking water in Nablus City is chlorination, which is used to inactivate (or kill) pathogens (i.e., disease causing organisms) that may be found in the water supply (i.e., reservoir, ground water aquifer, or water from springs). Disinfection reduces the risk of waterborne disease and protects the public against disease.

But, the use of chlorine creates new potential risks, because compounds known as disinfection by-products (DBPs) can be formed during the disinfection process by the reaction of disinfectants used in a water treatment with bromide and/or natural organic matter (i.e., decaying vegetation or wastewater contamination) present in the water.

Several epidemiological studies reported the association between the ingestion of chlorinated drinking water with risk of bladder and rectal cancer followed by mortality (IARC, 1991). There is an association between bladder cancers, reproductive disorders and trihalomethane (THM) occurrence (Bielmeier et. al., 2001). Cancer of the colon, rectum, and urinary bladder was linked with water sources containing an elevated level of chlorine by-products. In addition, several other cancer sites namely stomach, brain, pancreas, lung and liver were also found to be linked with chlorinated byproducts. There is some epidemiological evidence of a relationship between the exposure to DBPs and adverse reproductive outcomes in human beings and animal studies (Keegar et. al., 2001, Morris et. al., 1992). Studies have reported an increased incidence of decreased birth weight, prematurity, intrauterine growth retardation, and neural tube defects with chlorinated water and, in some cases, trihalomethanes (U.S. Environmental Protection Agency, 1994, 1998a, 1998b).

Knowing that:

- there are currently no data available on DBPs in the Nablus system,
- the location and extent of DBPs in the Nablus system problem is not identified and/or quantified,
- the effects of pipe material and age on the formation of DBPs was not evaluated,
- There are no clear references for decision makers to:
  a) Understand DBPs and reduce their occurrence while ensuring the public health benefits afforded by disinfection of drinking water.
  b) Monitor DBP levels and report the level of DBPs in drinking water each year.
  c) Ensure that DBP levels meet regulations.

d) If there is an effect of pipe material on the formation of DBPs, then consider using the type of material which has less DBP formation.

e) If there is an effect of the pipe age on the formation of DBP, and the effect is fewer DBPs produced by new pipes, the recommendation is to replace the old pipes with new ones.

It is our intention in this study to discuss, investigate, evaluate and address the above concerns.

1.2 Research question

The key research questions of this study are: do DBPs occur in Nablus water supply system? to what extent? and what factors influence this occurrence?

1.3 Research objectives

The following are the research objectives:

1. To check the occurrence of DBPs in the water of Nablus City.
2. To identify the effects of pipe material on the formation of DBPs.
3. To identify the effects of pipe age on the formation of DBPs.
4. To identify the effects of soluble organic matter concentrations on the formation of DBPs.
5. To identify the effects of chlorine dose concentrations on the formation of DBPs.
6. To identify the effects of incubation period of the water in pipes due to intermittent pumping on the formation of DBPs.
7. To give the decision maker some recommendations regarding the disinfection process followed.

1.4 Motivations

The following are the research motivations:

1. Water quality affects the health of about 177,000 people served by the water system in Nablus City, so it is a vital issue.
2. There is no similar study done in Palestine in the past.
3. Poor sanitation leads to biological contamination of water, so disinfection is very important. However, disinfection must be balanced by minimizing DBP formation.
4. Using plastic pipes instead of iron pipes is controversial among engineers and people of concern and needs field as well as lab experiments to justify its usage and water quality.
5. Because of poverty, resources shortage, and occupation conditions, many pipes are very old (installed since 1950, 1960, 1970, and 1980), so we need to study the relation between pipe age and formation of DBP.
6. The high UFW (Unaccounted for Water) rate, which is the difference between the water production and water sold to consumers, gives an indication that there's leakage in the network. Leaking pipes may be subject to wastewater intrusion, which provides a source of organic material for DBP formation.

1.5 Thesis outline

The general structure of the thesis goes as follows. Chapter one is background about the study, research question, research objectives and motivations. Chapter two furnishes related literature review. Chapter three provides the description of the study area. Chapter four shows the research methodology. Chapter five presents the research results and discussion. The conclusions and recommendations are furnished in chapter six.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Disinfection through inactivation usually involves the use of disinfectants such as chlorine, ozone, chlorine dioxide, or a combination of chlorine and ammonia (chloramines) which can render many pathogenic organisms harmless. Other materials that can act as disinfectants include potassium permanganate, iodine, bromine, ferrate, silver, hydrogen peroxide, and ultraviolet (UV) light (Cohn et. al., 1999)

The Table 2.1 below lists some of the major tradeoffs associated with various disinfection technologies (ACC, 2010)

Disinfectant	Advantages	Limitations
Chlorine Gas	- Highly effective against most pathogens - Provides "residual" protection required for drinking water -Operationally the most reliable - Generally the most cost-effective option	- Byproduct formation (THMs, HAAs[1]) - Special operator training needed - Additional regulatory requirements (EPA's Risk Management Program) - Not effective against Cryptosporidium
Sodium hypochlorite	- Same efficacy and residual protection as chlorine gas - Fewer training requirements than chlorine gas - Fewer regulations than chlorine gas	- Limited shelf-life - Same byproducts as chlorine gas, plus bromate and chlorate - Higher chemical costs than chlorine gas - Corrosive; requires special handling
Calcium hypochlorite	- Same efficacy and residual protection as gas - Much more stable than sodium hypochlorite, allowing long-term	- Same byproducts as chlorine gas - Higher chemical costs than chlorine gas - Fire or explosive hazard

	storage - Fewer Safety Regulations	if handled improperly
Chloramines	- Reduced formation of THMs, HAAs - More stable residual than chlorine - Excellent secondary disinfectant	- Weaker disinfectant than chlorine - Requires shipments and use of ammonia gas or compounds - Toxic for kidney dialysis patients and tropical fish
Ozone	- Produces no chlorinated THMs, Haas Fewer safety regulations - Effective against Cryptosporidium - Provides better taste and odor control than chlorination	- More complicated than chlorine or UV systems - No residual protection for drinking water - Hazardous gas requires special handling - Byproduct formation (bromate, brominated organics and ketones) - Generally higher cost than chlorine
UV	- No chemical generation, storage, or handling - Effective against Cryptosporidium - No known byproducts at levels of concern	- No residual protection for drinking water - Less effective in turbid water - No taste and odor control - Generally higher cost than chlorine
Chlorine dioxide	- Effective against Cryptosporidium - No formation of THMs, Haas - Provides better taste and odor control than chlorination	- Byproduct Formation (chlorite, chlorate) - Requires on-site generation equipment and handling of chemicals - Generally higher cost than chlorine

[1]Trihalomethanes (THMs), Haloacetic Acids (Haas)

The application of disinfection agents to drinking water reduces the microbial risk but poses chemical risk in the form of their by-products. A semi-quantitative presentation of risks associated with disinfection was first attempted by (Morris, 1978) and is given in Figure 2.1. The figure shows that the microbiological risk is very high when no chlorination is used, and drops sharply to a low value when even minimal levels of chlorination are maintained. As the level of chlorination is increased the risk continues to drop slightly, but never quite reaches zero, for no system is perfect. At very high levels of chlorine, the microbial risk increases as taste and odor may cause the use of unsafe supplies (Gorchev, 1998).

The chemical risk decreases initially because destruction of chemicals by oxidation more than compensates for the formation of new chemicals at low levels of chlorination. Because of the formation of by-products, the chemical risk increases with increasing level of chlorination (Gorchev, 1998).

The benefits of water chlorination(see Figure 2.1), are laying in keeping chlorination dose within the limits of microbial risk avoidance.

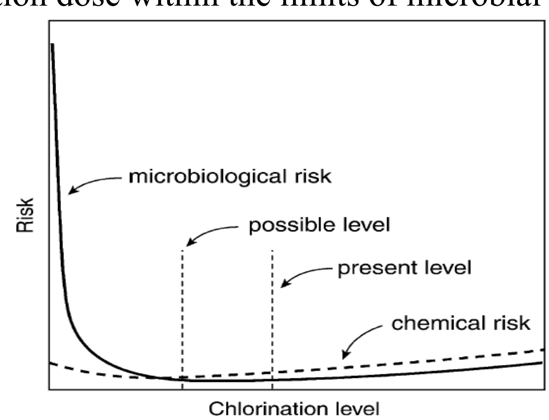


Figure 2.1: Risks and benefits of water chlorination (Morris, 1978)

2.2 Chlorination

It is a chemical disinfection process by which chlorine is added to water; the two most common compounds of chlorine used are calcium hypochlorite ($Ca(ClO)_2$) and sodium hypochlorite ($NaOCl$).

When chorine is added to water containing reducing agents and ammonia, residuals develop which yield the curve in Figure 2.2.

Chlorine first reacts with reducing agents present in water and develops no appreciable residual (0-A in Fig. 2.2). The dose at point A is therefore that required to meet the demand exerted by reducing agents. These include nitrites, ferrous ions, and hydrogen sulfide. Chloramines are formed when chlorine is added in excess at point A. Mono and dichloramines are considered together since there is little control over which is formed. When all the ammonia has been reacted, free available chlorine begins to develop (point B).

$HOCl + NH_3 \rightarrow H_2O + NH_2Cl$ (monochloramine)

$HOCl + NH_2Cl \rightarrow H_2O + NHCl_2$ (dichloramine)

$HOCl + NHCl_2 \rightarrow H_2O + NCl_3$ (trichloramine)

As free available chlorine residual increases, the previously produced chloramines are oxidized. This results in the creation of oxidized nitrogen compounds such as nitrous oxide, nitrogen and nitrogen trichloride, which in turn reduce the chlorine residuals as seen on the curve from point B to the breakpoint.

$2NH_3+3Cl_2 \rightarrow N_2+6HCl$

When all chloramines are oxidized, additional chlorine added creates an unequal residual known as the breakpoint (that limit beyond which all residual is free available chlorine) (Alley, 2007).

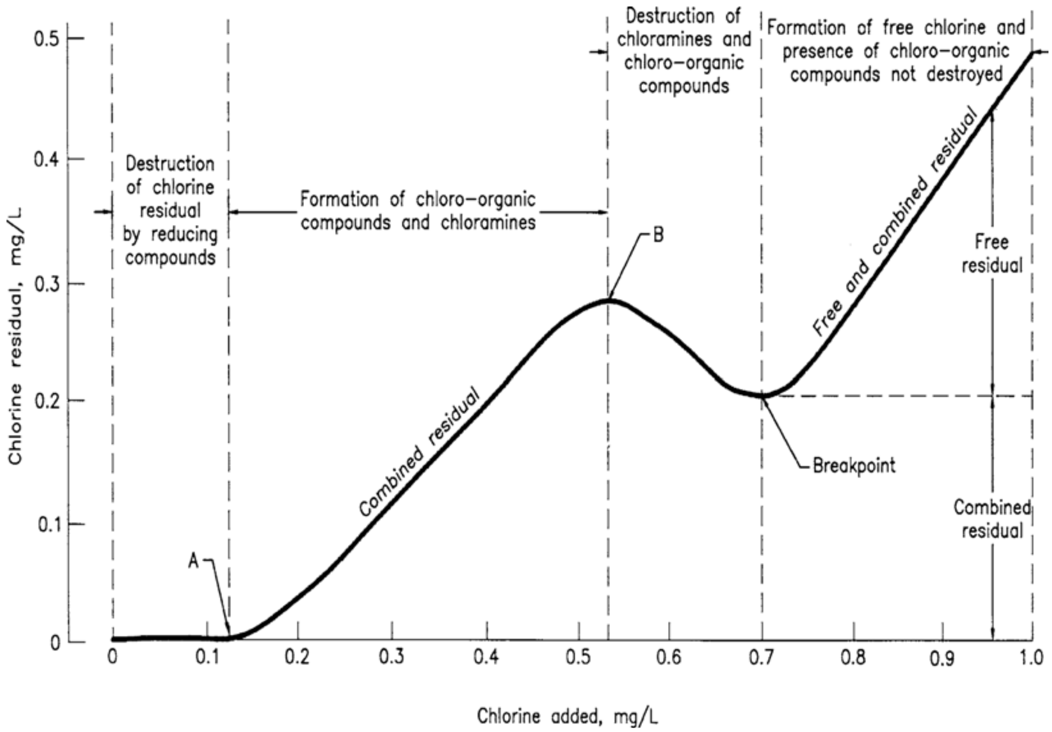


Figure 2.2 Generalized curve obtained during breakpoint chlorination (Alley, 2007)

2.3Disinfection By-Product(DBP)

2.3.1 Introduction

The DBPs are formed when the disinfectant reacts with natural organic matter (NOM) and/or inorganic substances present in water. More than 250 different types of DBPs have already been identified (Sadiq and Rodriguez, 2004).

In 1974, chloroform, a product of the reaction of chlorine and naturally occurring organic matter, was identified in disinfected drinking water (Bellar et. al., 1974; Rook 1974; Symons et. al., 1975, 1981). Since that time, a number of other chlorinated DBPs have been identified, including trihalomethanes, haloacetic acids, bromate, and chlorite; in this research only trihalomethanes will be considered and focused on.

2.3.1.1 Halomethanes

Halomethanes are chemical compounds in which a number of hydrogen atoms of methane (CH_4) are replaced by halogen atoms (fluorine (F), chlorine (Cl), bromine (Br) or iodine (I)).

Trihalomethanes (THMs) are trisubstituted halomethanes in which three of the four hydrogen atoms of CH_4 are replaced by halogen atoms.

Table 2.1 shows the different types of halomethanes classified according to number of the four hydrogen atoms of methane replaced by halogen atoms.

Table 2.2 Halomethanes(Wikipedia, 2010)

No	Group Name	Group Compounds
1	Monosubstituted	CH_3F , CH_3Cl , CH_3Br , CH_3I
2	Disubstituted	CH_2F_2 , CH_2ClF , CH_2BrF , CH_2FI , CH_2Cl_2 , CH_2BrCl , CH_2ClI , CH_2Br_2 , CH_2BrI , CH_2I_2
3	Trisubstituted	CHF_3 , $CHClF_2$, $CHBrF_2$, CHF_2I , $CHCl_2F$, C*HBrClF , C*HClFI , $CHBr_2F$, C*HBrFI, $CHFI_2$, $CHCl_3$, $CHBrCl_2$, $CHCl_2I$, $CHBr_2Cl$, C*HBrClI , $CHClI_2$, $CHBr_3$, $CHBr_2I$, $CHBrI_2$, CHI_3
4	Tetrasubstituted	CF_4 , $CClF_3$, $CBrF_3$, CF_3I , CCl_2F_2 , $CBrClF_2$, $CClF_2I$, CBr_2F_2 , $CBrF_2I$, CF_2I_2 , CCl_3F , $CBrCl_2F$, CCl_2FI , CBr_2ClF , C*BrClFI , $CClFI_2$, CBr_3F , CBr_2FI , $CBrFI_2$, CFI_3 , CCl_4 , $CBrCl_3$, CCl_3I , CBr_2Cl_2 , $CBrCl_2I$, CCl_2I_2 , CBr_3Cl , CBr_2ClI , $CBrClI_2$, $CClI_3$, CBr_4 , CBr_3I , CBr_2I_2 , $CBrI_3$, CI_4
	* Chiral compound	

Chiral compound is a type of molecule that lacks an internal plane of symmetry and has a non-superposable mirror image. The feature that is most often the cause of chirality in molecules is the presence of an asymmetric carbon atom.

Many trihalomethanes find uses in industry as solvents or refrigerants. THMs are also environmental pollutants, and many are considered carcinogenic. Trihalomethanes with all the same halogen atoms are called haloforms (Wikipedia, 2010)

2.3.2 Regulations

It is impossible to talk about controlling any chemicals in drinking water or in general ensuring drinking water quality without the existence of certain regulations which are needed to address the required issues.

For this reason, regulations such as Maximum Contaminant Levels (MCL) are enacted. An MCL is the maximum allowable concentration of a contaminant in drinking water, as established by the country regulations.

The Stage 1 Disinfectants/Disinfection By-products rule (Stage 1 DBPR) was published by United States Environmental Protection Agency (USEPA) in December 1998 (USEPA 1998c). Its purpose was to reduce the formation of DBP and to meet the standard summarized in Table 2.2.

Table 2.3 The maximum contaminant level (MCL) of TTHM (USEPA 1998c)

DBP	MCL
total trihalomethanes (TTHM) (measured as the sum concentration of chloroform ($CHCl_3$), bromoform ($CHBr_3$), bromodichloromethane ($CHBrCl_2$), and dibromochloromethane ($CHBr_2Cl$))	80 parts per billion (ppb)

The Stage 2 Disinfection Byproducts Rule (Stage 2 DBPR) supplements Stage 1 Rule by requiring water utilities a) to identify monitoring sites where DBP levels are most likely to be high, and b) to meet MCL requirements at those sites. Its purpose is to reduce potential cancer and reproductive and developmental health risks resulting from exposure to DBPs in drinking water.

The last Palestinian standard for drinking water was published by Palestinian Standards Institution (PSI) in 2005. Table 2.3 shows the MCL of THM, which is much higher than that of the USEPA standards.

Table 2.4 Palestinian standard of THM, (PSI, 2005)

DBP	MCL
THM	0.25 mg/L = 250 parts per billion (ppb)

Table 2.5 Comparison of the PSI standards with United States Environmental Protection Agency (USEPA), World Health Organization(WHO), Jordan Institution for standards and Metrology(JISM), and Egyptian Organization for Standardization and Quality (EOSQ)

	Regulation				
	PSI, 2005	USEPA, 1998c	WHO, 2006	JISM, 2008	EOSQ, 1995
TTHM MCL (mg/L)	0.25	0.08	<1	0.15	0.10

2.3.3 Factors affecting the formation of DBP in drinking water

The type and amount of DBPs formed are a function of many factors including chlorine dose and residual concentration, concentration and characteristics of precursors, water temperature, water chemistry (including pH, bromide ion concentration, organic nitrogen concentration, and presence of other reducing agents such as iron and manganese), contact time, pipe material, and pipe age.

2.3.3.1 Chlorine dose and residual concentration

Halogenated byproducts are formed when free chlorine reacts with natural organic matter. In addition, brominated byproducts are formed when source water containing bromide is chlorinated.

Chlorine reacts with natural organic matter in the water to form THMs.

As the concentration of chlorine or chloramines increases, the production of DBPs increases. Formation reactions continue as long as precursors and disinfectant are present (Krasner, 1999 and references therein).

2.3.3.2 Concentration and characteristics of precursors

Total organic carbon (TOC), dissolved organic carbon (DOC) and UV absorption at 254 nm [UV254] are often used as surrogate parameters for monitoring precursor levels. In general, greater DBP levels are formed in waters with higher concentrations of precursors (EPA, 2006).

2.3.3.3 Temperature

DBP concentrations tend to increase and to form more rapidly with increasing temperature (Clark et. al., 2001). The disinfectant residuals deplete rapidly when the water temperature is high. Also, microbial activity within distribution systems is higher in warm than in cold waters (Sadiq and Rodriguez, 2004). Temperature increases within the distribution system would tend to accelerate THM formation (Brereton and Mavinic, 2002).

2.3.3.4 Water chemistry

Aqueous bromine reactions with NOM are much faster than aqueous chlorine, so the speciation and concentrations of DBP formation in chlorination processes are mainly dominated by the ratio of bromide to reactive NOM as well as the ratio of bromide to chlorine concentrations. (Westerhoff et. al., 2004)

The rate of THM formation increases with the pH (Stevens et. al., 1976).

2.3.3.5 Time dependency of DBP formation

The longer the contact time between disinfectant/oxidant and precursors, the greater the amount of DBPs that can be formed. High THM levels usually occur where the water age is the oldest.

2.3.3.6 Pipe material

The occurrence of DBPs at consumers' taps may be influenced by pipe material; there is an interaction between residual disinfectant and the internal pipe material. One study found that the increased chlorine demand of unlined cast-iron results in lower levels of trihalomethanes than those dictated by testing the finished water alone (Brereton and Mavinic, 2002). In contrast, other studies have found that DBPs are increased in iron pipes.

Tuovinen et. al., (1984) demonstrated the potential of iron tubercles, common to unlined cast-iron distribution pipes, for chloroform formation when exposed to chlorinated water. The presence of organic material, associated with ubiquitous biofilms and resulting from the interaction of aqueous humic substances with iron corrosion products, is well documented (Adams and Kingsbury, 1937; Allen et. al., 1980; Ridgway and Olson, 1981; Ahmadi 1981).

Goethite, which is the predominant iron oxide of pipe deposits, affects both chlorine decay and DBP formation and should be always taken into consideration. Chlorine consumption always increased in the presence of goethite and is attributed to an increase in the reactivity and/or modification of adsorbed NOM which led to an overall increase in TTHM (Hassan et. al., 2006).

2.3.4 Models used to predict the occurrence of DBPs in drinking water

In order to predict the occurrence of DBPs in drinking water, a lot of models have been developed. These DBP models can be useful to estimate the occurrence of DBPs in drinking water, for exposure assessment in epidemiological studies and health risk assessment, and for estimating the benefits and impacts of DBP regulations.

Various models and approaches have been used for predicting DBPs' occurrence in drinking water. Some researchers used an entirely empirical approach and some introduced kinetics into the modeling process. Multiple linear and non-linear regression techniques are found to be the most common in developing DBP predictive models. Other methods like ridge, logistic regression and artificial neural networks have also been employed. Most of the predictive models are based on laboratory-scale studies, but some models have been proposed based on actual water distribution sampling as well (Sadiq and Rodriguez, 2004).

One mathematical model expresses total trihalomethane (TTHM) concentration in terms of initial chlorine concentration, total organic carbon, bromide ion concentration, contact time, pH, temperature, and water age. A lot of factors affect the reaction rates of chlorine such as source water characteristics, treatment type (which can affect the amount and type of reactive material available for reaction), contact time (both in the treatment plant and distribution system), and the characteristics of the distribution system (e.g. pipe material, pipe age)

The model is of the following form:

$TTHM = 4.527\ t^{0.127}\ [Cl_2]^{0.595}\ [TOC]^{0.596}\ [Br]^{0.103}\ [pH]^{0.66}$,

Where:

TTHM is total trihalomethane concentration in μg/l,

t is contact time inminutes,

Cl_2 is chlorine concentration in mg/l,

TOC is total organic carbon in mg/l,

Br is bromide ion concentration in mg/l. (Al-Omari et. al., 2004)

TTHM formation was accurately simulated by a chlorine demand model that predicted an average TTHM as a function of Cl_2 consumed (weight of TTHM / weight of Cl_2 consumed) for both raw surface water and water subjected to alum coagulation. Alum treatment reduced chlorine demand by removing organic matter (Gang et. al., 2002).

Another model predicts both TTHMs and chlorine residuals based on the consumption of chlorine. The parameters of the model are functions of total organic carbon, pH, temperature, and initial chlorine residual level. Based on the analysis, it has been shown that the formation of TTHMs is a direct result of the consumption of chlorine (Clark and Sivaganesan, 1998).

Finally, a model that can be used to predict the formation of chlorinated, brominated, and mixed species compounds based on initial chlorine concentration, chlorine consumption, bromide ion concentration, and pH was developed. The model clearly showed that higher levels of bromide in the water favor the formation of brominated compounds. Brominated compounds also formed faster than chlorinated compounds. The model:

$$\text{TTHM} = D\left[C_{A_0} - \left(\frac{C_{A_0}(1-K)}{1-Ke^{-ut}}\right)\right]$$

Where:

D = ratio of TTHM formed (mg/L) to chlorine consumed (mg/L).

C_A = concentration of free chlorine

K = dimensionless constant

C_{A0} = initial concentration of chlorine (mg/L) at time = 0

u = rate constant (min21)

t = time (min). (Clark et. al., 2001).

CHAPTER THREE
DESCRIPTION OF THE STUDY AREA

3.1 Location

Nablus is a Palestinian city in the northern West Bank, approximately 63 kilometers (39 mi) north of Jerusalem. Located in a strategic position between Mount Ebal and Mount Gerizim, it is the capital of the Nablus Governorate and a Palestinian commercial and cultural center (Wikipedia, 2010).

Nablus is located at the crossroads of the Jerusalem-Jenin road running north to south and Tulkarem – Jordan Valley running east to west (Fig 3.1). This location gives the city a significant position in any future development. Most of the Nablus area is built-up areas with multistory buildings.

Nablus lies in synclinal area extending west to east with an altitude varying from 440 m above sea level in the bottom of the valley to about 900 m above sea level in the hills. The north Ebal Mountain is 940 m high and the south Gerizim Mountain is 881 m high. Nablus is located at the northern latitude earth grid 32º13̀ 13″ and east longitude earth grid 35º16̀ 44″. It has hot, dry summers and a moderate, rainy winter. The total area of Nablus is 30.58 km^2.

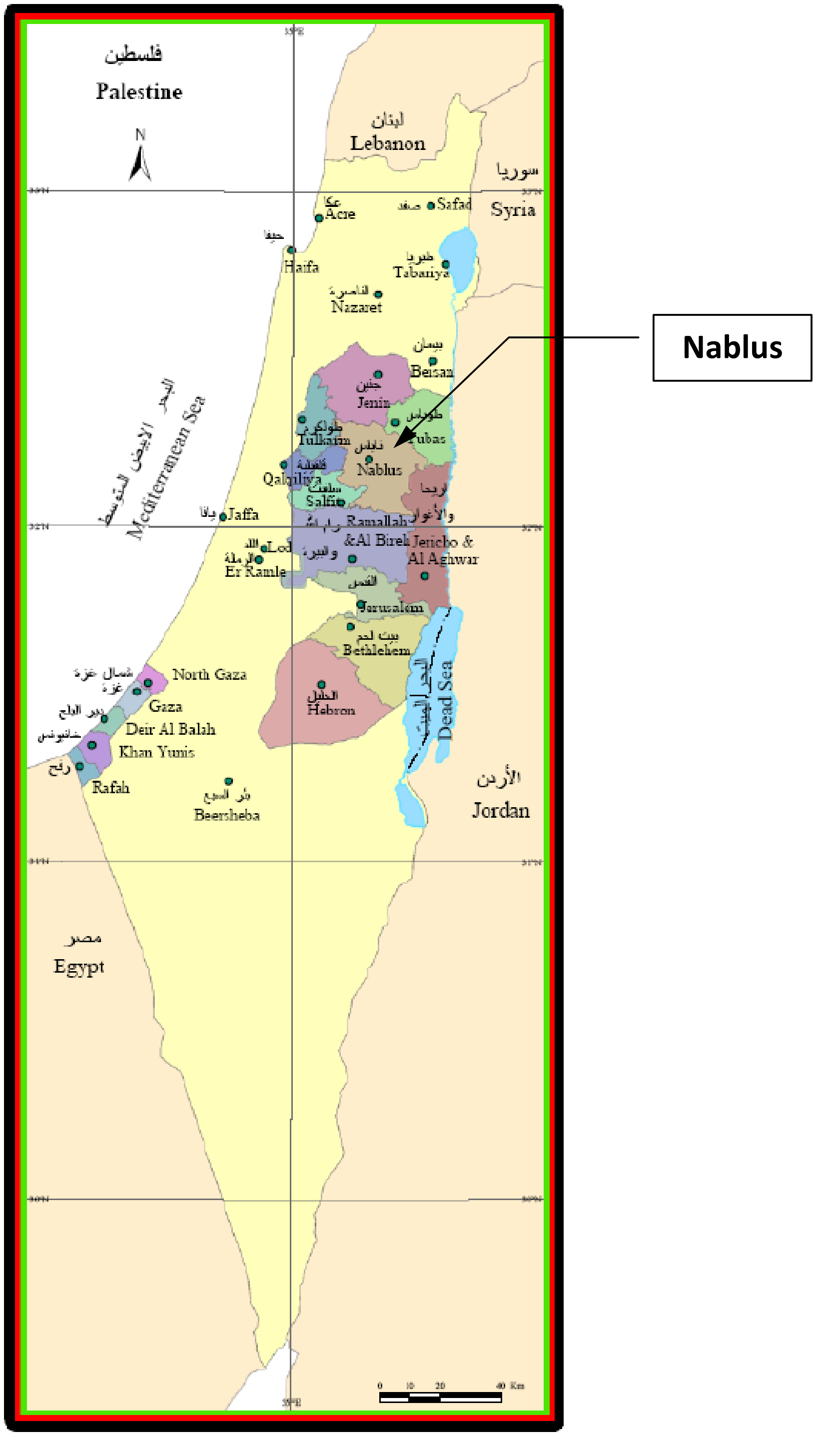


Figure 3.1:- Palestine map showing the location of Nablus City (PCBS, 2008).

3.2 Water supply system

The hydraulic details of the Nablus water supply system are shown in Fig 3.2

3.2.1 Water sources

The water sources of Nablus are five ground aquifer wells: (Deir Sharaf, Al-Badan, Al Far'a and Sabastia well), and five springs (Ein Beit El Ma, Al-Qaryon, Ras Al-Ein, Ein Al-Assal and Ein Dafna).

The capacities of the four wells and the five springs are given in the Table 3.1.

Table 3.1: The water sources of Nablus and its capacity (WWSD, 2010)

No	Source	Average yield (m^3/day)
1	Audala well	5,280
2	Al-Badan well	4,800
3	Al Far'a well	4,320
4	Deir Sharaf well	4,320
5	Sabastia well	8,160
6	Ein Beit El Ma spring	1,574
7	Al-Qaryon spring	1,447
8	Ras Al-Ein spring	1,169
9	Ein Al-Assal spring	457
10	Ein Dafna spring	340
	Total (m3/day)	31,867

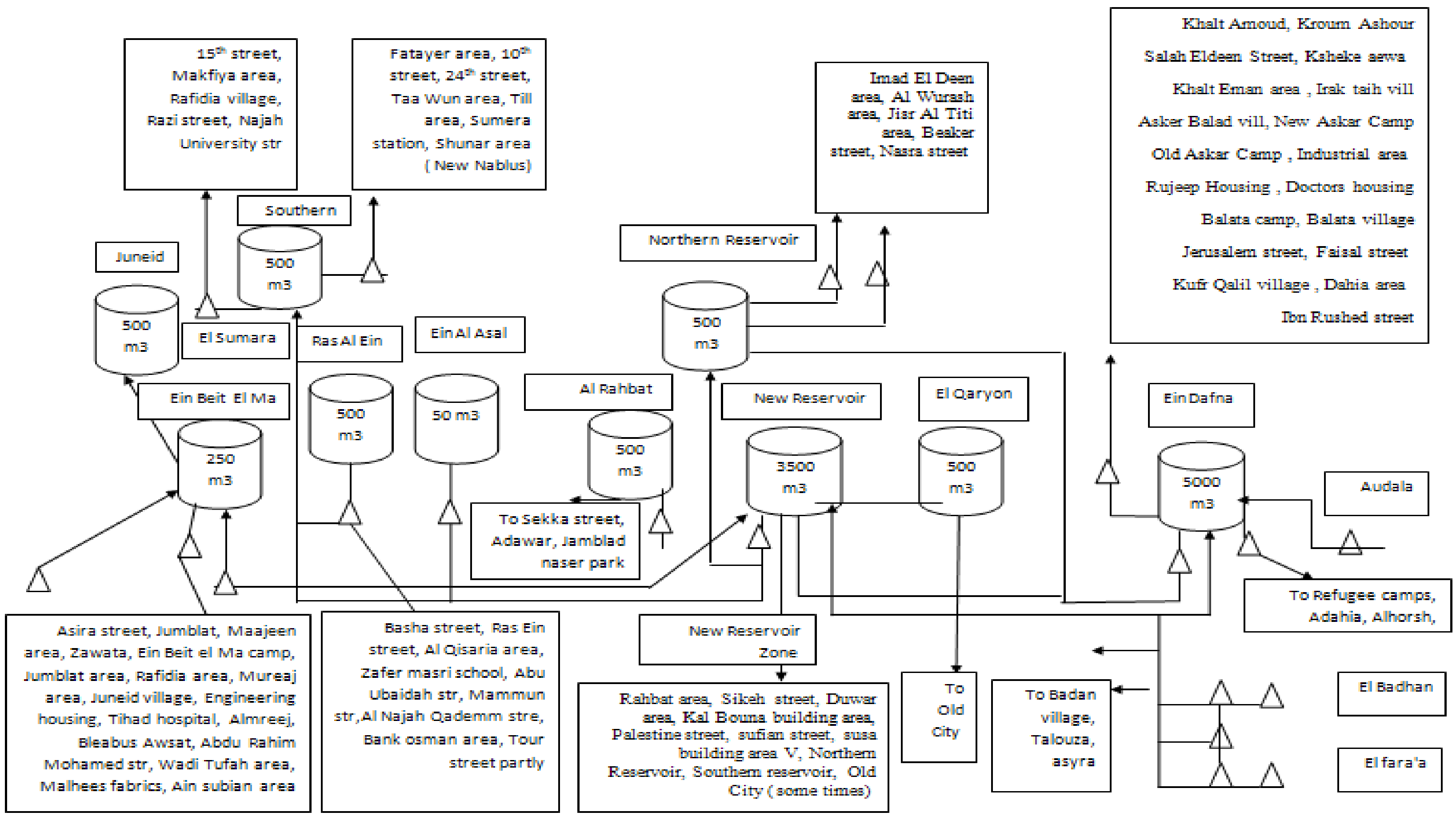


Fig 3.2 Nablus water supply system schematic diagram(WWSD, 2008)

3.2.2 Storage facilities and pumping stations

Nablus is divided into nine individual service zones, but some interconnections exist between these zones. In the lower situated parts of service areas, the pressure in the distribution network reaches extremely high values due to the differences in altitude within the supply zone. Also houses located near the pumping stations that receive water directly are subjected to problems with high pressure.

The Municipality supplies the zones intermittently by opining and closing various valves during a number of hours. Due to this intermittent supply system, most of the houses are equipped with roof storage tanks up to several cubic meters capacity. Tables shows the pumping days and period in the months of January, and August in the year of 2010 (see Appendix 3).

There are 13 operating storage tanks, and 13 pump stations located inside Nablus. Reservoirs, capacity, year of construction and pumping stations are given in Table 3.2.

Table 3.2: Storage facilities and pumping stations in Nablus City(WWSD,2010)

No	Reservoir name	Capacity (m^3)	Year of construction	Pumping station
1	Ein Dafna	5000	1979	3 booster pumps
2	New reservoir	3500	1997	2 booster pumps
3	Northern	500	1958	2 pumps
4	Southern	500	1956	2 pumps
5	Ras Al Ein	500	1953	2 pumps
6	Ein Al Assal	50	1952	1 pump
7	Qaryon	500	1935	2 pump +1 pump standby

No	Reservoir name	Capacity (m^3)	Year of construction	Pumping station
8	Juneid	500	2000	1 pump +1 pump standby
9	Ein Beit Elma	250	1960	5 booster pumps
10	Al-Worash reservoir	2000	2006	By gravity
11	Kamal Junblat Reservoir	800	2007	By gravity
12	Ta'ta Reservoir	900	2007	By gravity
13	Al-Fara' Reservoir well	300	1977	1pump +3 booster pumps
14	Al-Badan well	Without reservoir	1977	1pump +3 booster pumps
15	Deir Sharaf well	Without reservoir	1994	1pump +4 booster pumps
16	Al Somara pumping station			1 pump +1 pump standby

3.2.3 Water distribution network

The distribution network consists of about 304 km of water pipes ranging in diameter from 2 to 12 inches. The existing system consists of a variety of pipe types: steel, polypropylene (PP), ductile, and high density polyethylene (HDPE) pipes, and there is a variety in pipe ages. Figure 3.3 and Figure 3.4 show pipe material and pipe age of Nablus City water network.

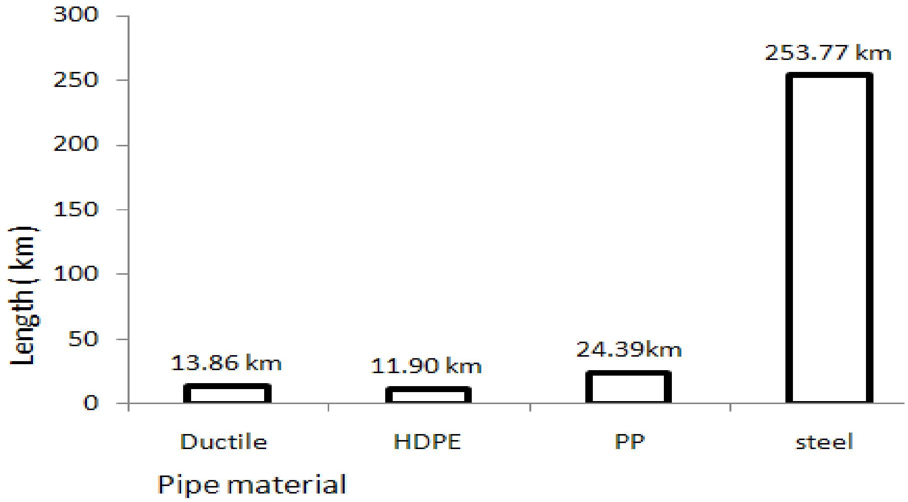


Figure 3.3:- Pipe materials of Nablus City water network(WWSD, 2010)

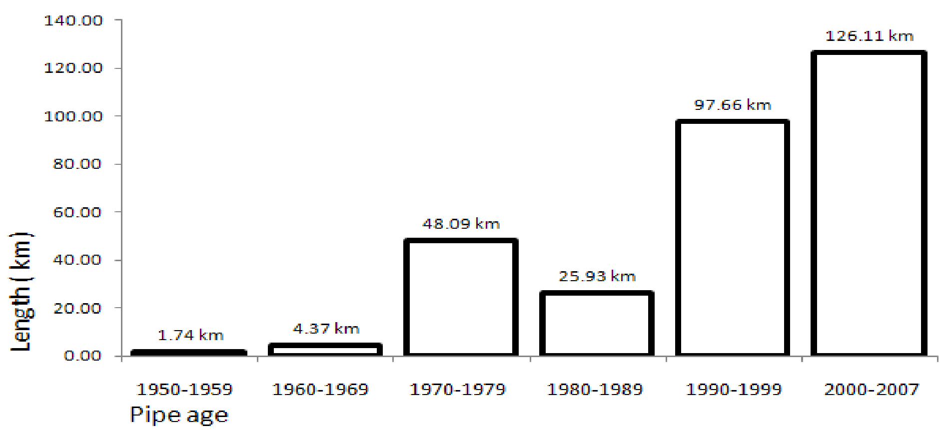


Figure 3.4:- Pipe ages of Nablus City water network (WWSD, 2010)

3.3 People served and water consumption

Figure 3.5 shows Nablus City boundary, water sources and served villages.

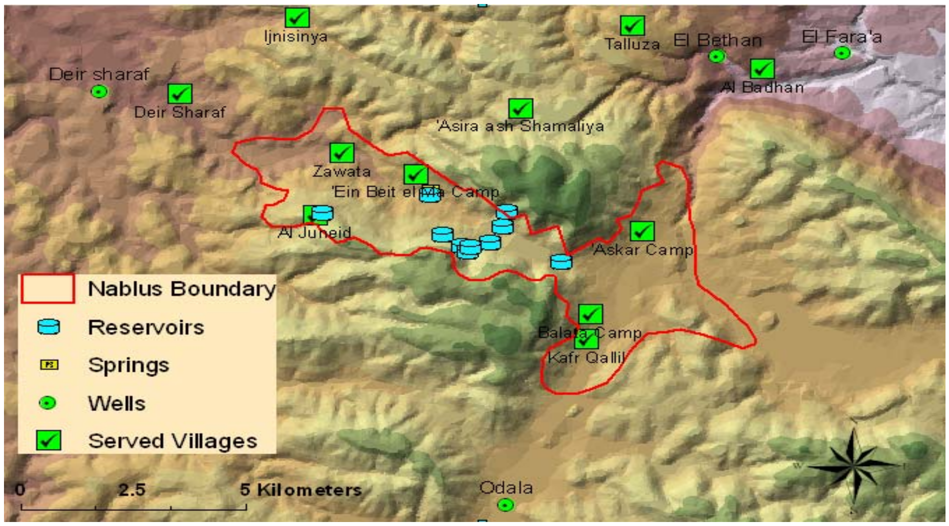


Figure 3.5:- Nablus City boundary, main water sources (wells and springs) and served villages (Water and Environmental Studies Institute at An-Najah National University, 2007).

The water system in Nablus serves the city itself and some of the surrounding localities. Table 3.3 shows served areas and number of people.

Table 3.3:- Number of peoples served by Nablus water system. (PCBS, 2008).

Number	Locality name	Number of people
1	Nablus	126,132
2	Asira ash Shamaliya	7,556
3	Zawata	1,875
4	Ein Beit el Ma Camp	3,979
5	Askar Camp	11,607
6	Balata Camp	15,247
7	Kafr Qallil	2,451
8	Deir Sharaf	2,460
9	Al Badhan	2,485
10	Talluza	2,375
11	Ijnisinya	505
Total people served		176,672

WWSD categories the land use and consumers of water as follows:

Table 3.4: Housing and consumers categories

Name of category	Description
A	2 story buildings/ villas
B	Up to 7 story buildings
C	Up to 4 story buildings
D	7-10 floors, commercial areas
E	Industrial areas
F	Old City
G	Camps, Villages

As a next step the population densities have been estimated for each individual area, the area of each category multiplied by the density gives the population.

The average water consumption in the year of 2010 is 72 l/c/d(WWSD, 2010).

Non domestic includes: hospitals, schools, public buildings/banks, recreation centers/ social centers, work chop/retailers, hotels (business and tourism), industries/commercial.

3.4 Water quality

The treatment process used for disinfecting drinking water in Nablus City is chlorination, by using sodium hypochlorite, which is manufactured as bleach under the brand name Clorox. Sodium hypochlorite reacts in water as follows as a disinfectant:

$NaOCl + H_2O \rightarrow HOCl + NaOH$

Sodium hypochlorite is produced in a clear liquid form and is completely soluble in water. The municipality obtains this disinfectant from a sub-contractor. It comes in 250 kg containers, with a concentration of 12 percent by weight. The dose used is 1 kg of chlorine per 200 m^3 of water (personal communication, Ali Qarqash, responsible for the disinfection process in Nablus Water Supply and Sanitation Department, 2009).

The Water and Environmental Studies Institute (WESI) at An-Najah National University performs periodic water quality tests on behalf of Nablus Municipality. Samples are taken randomly from points in the water distribution network and at house connections. In addition, periodic chemical water tests are performed on the wells and springs. The results of water chemical analysis for samples collected from utilized wells and springs all over Nablus City in the year 2009 showed that all measured parameters are within the acceptable Palestinian standard level. However, the amount of organic matter in the water is unknown. There are occasional detections of total and fecal coliforms in the pipe network, which could indicate contamination.

Results of water chemical analysis for samples collected from utilized wells and springs all over Nablus City, (see Appendix 1), and bacteriological analysis in the months of January and July in the year of 2009 were tabulated (see Appendix 2).

CHAPTER FOUR

RESEARCH METHODOLOGY

Methodology:

To fulfill the objectives of this study and answer the research questions set, two experimental activities were conducted: a field survey and a laboratory pipe experiment. The following chart (Figure 4.1) illustrates the research methodology.

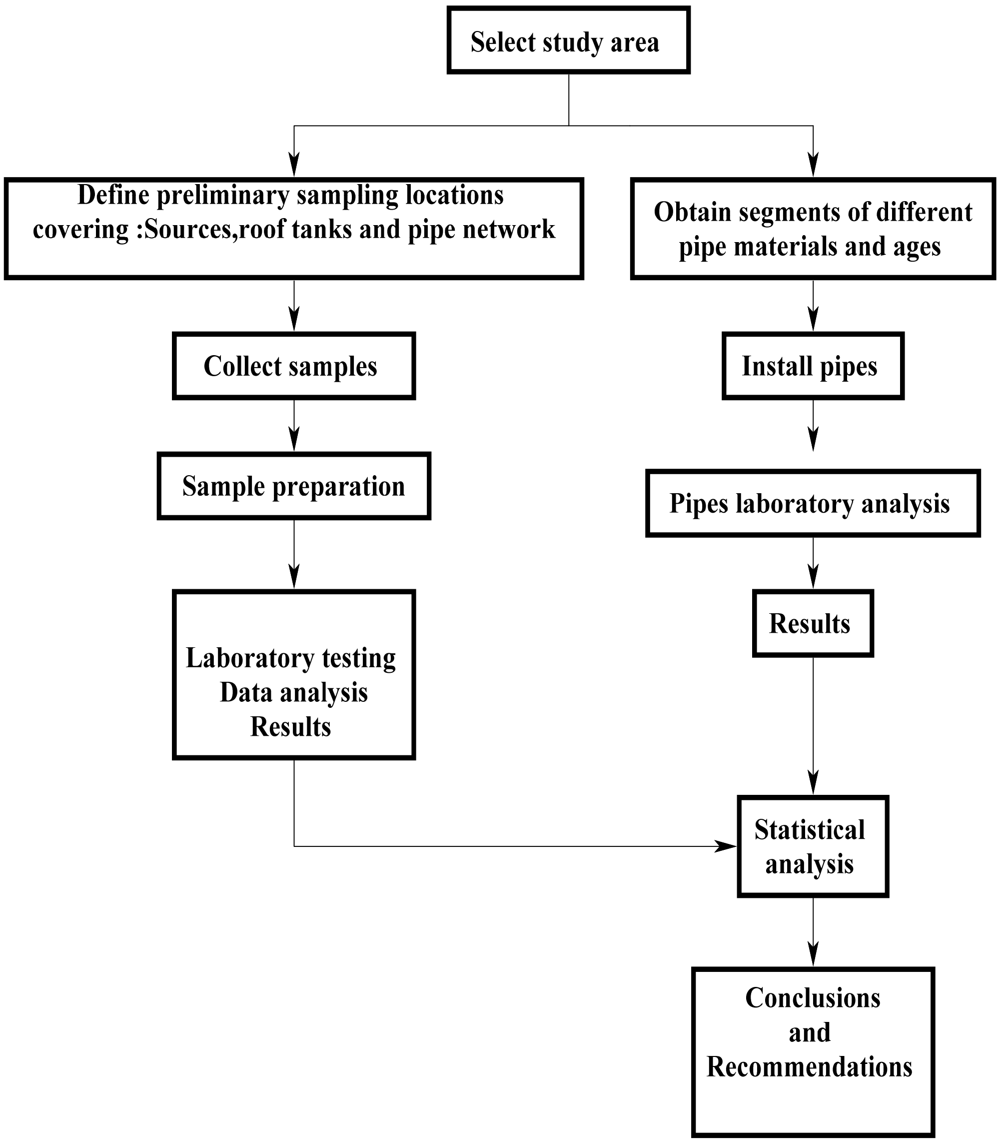


Figure 4.1:- Methodology chart

4.1 Field survey

4.1.1 Field survey plan

The field survey is aimed at evaluating the occurrence of DBPs in the Nablus water supply system. The field survey consisted of the following steps:

- Defining preliminary sampling locations in coordination with Nablus Water Supply and Sanitation Department
- Samples cover different water sources, roof tanks and water pipe networks with different materials and ages
- Collected samples were analyzed for content of DBPs as THM. Samples were prepared and analysis was conducted in the Chemical, Biological and Drugs Analysis Center (CBDAC) at An-Najah National University according to Standard Methods for the Examination of Water and Wastewater (1996) or by methods accepted by USEPA.
- For measurement of THM, samples were analyzed by a Perkin Elmer Clarus 500 Gas Chromatograph with a Perkin Elmer Clarus 560D Mass Spectrometer (GC-MS), using USEPA Method 524.2 (USEPA, 1995).

4.1.2 Sampling locations

To cover the water system of Nablus City, and in coordination with Nablus Water Supply and Sanitation Department the following locations were defined (Table 4.1)

Table (4.1) Field survey sampling locations

Sample no	Sample location
1	Alhaj Nimer reservoir
2	Al Watani Hospital- network
3	Amman Street- network
4	Dafna spring
5	Ein Dafna old reservoir
6	Ein Beit Elma new reservoir
7	Ein El Asal spring reservoir
8	Ras El Ein spring reservoir
9	Ein Beit Elma old reservoir
10	Qaryon spring reservoir
11	Askar Camp- plastic roof tank
12	Askar Camp-steel roof tank
13	Old City- network
14	Old City- plastic roof tank
15	Rafidia Al Balad- plastic network
16	Rafidia Al Balad- plastic roof tanks
17	Sayel Fuel Station- Alquds street –steel network
18	Sayel Fuel Station- Alquds street –plastic roof tank
19	AlQatoni Taxi- Almaajeen- steel network
20	AlQatoni Taxi- Almaajeen- plastic roof tank
21	Al Qwareen spring-trading centre

4.1.3 Sampling procedure

The following steps were done:

1) Sampling vials (glass bottles of 1 liter volume) were obtained.

2) Each sample vial was labeled including sample ID, Sample location, Sample date and time.

3) The water tap which represents the sampling location (water network, water tank, reservoir, and source) was opened about 3-5 minutes and the system allowed to flush until the water temperature

has stabilized to ensure the sample does not represent stagnant water that has set for a long time in the water line or reservoir.

4) Bottles were rinsed with water from the sampling location before sampling.

5) Slowly, the sample vial was filled to the mark of 1L.

6) Samples were capped and taken to the lab and preserved in a refrigerator at 4°C until analysis.

4.2 Laboratory experiment

4.2.1 Laboratory pipe experiment

The laboratory pipe experiment is aimed at studying the impact of pipe material, pipe age, pollution load, and chlorine dose on the formation of DBPs. The laboratory pipe experiment consists of the following steps:

- Pipe segments of different materials used in Nablus water supply system were installed at the WESI laboratory.
- Pipes were filled with water obtained from the taps at WESI which was analyzed before use for pH and chlorine residual concentration.
- Polypropylene new pipe, new steel pipe and old steel pipe were used.
- Different chlorine doses with different contamination loads (soluble organic matter concentrations) were applied to the different segments.
- The pipes with the water, chlorine dose and pollution load were incubated for 72 hours and 120 hours (the periods used in Nablus water supply system for intermittent pumping)
- The experiment was kept at a constant temperature value (26°C).

Samples from the entire water volume were taken out of the pipe and immediately placed in the refrigerator for THM analysis.

- THM concentrations were measured for each case.
- Results were statistically analyzed using SPSS statistical package.

4.2.2 Experiment setting and description

The following Fig 4.2 shows the experiment setup of the pipes, which were installed by Nablus Municipality water systems technicians.

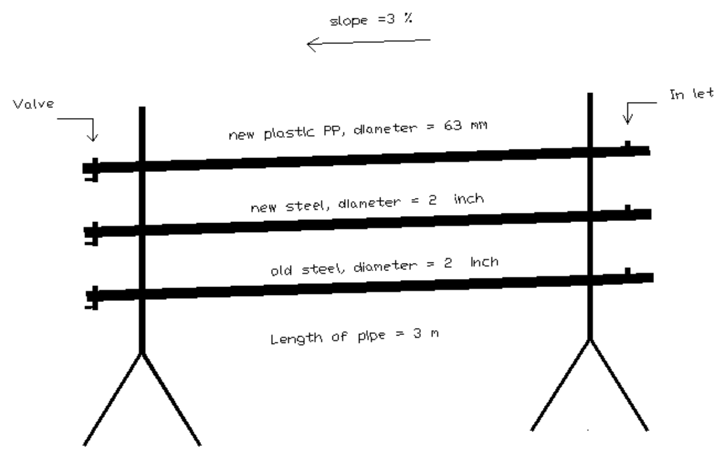


Fig 4.2 Experimental setup of pipes

- Three pipes were obtained in coordination with the Nablus Water and Wastewater Sanitation Department from their stores; new steel and new plastic pipe were purchased and stored to be used when needed, and old steel pipe was taken out of the network and replaced by new one.
- Three pipes were installed: new steel pipe of 3 m length and 2 inch diameter, old steel pipe of the same length and diameter, and polypropylene new pipe of 63 mm diameter and 3 m length.

- A slope in pipes was made maximum of 3% in order to facilitate sample withdrawal.
- Three chlorine concentrations were used to represent the range of chlorine doses typically encountered in the Nablus network: 0.3 mg/l, 0.6 mg/l and 0.9 mg/l.

  First the residual chlorine of the tap water was measured, and then chlorine was added as required to achieve the required dose; the residual chlorine was measured again after chlorine addition to ensure the value needed.
- Three soluble organic concentrations represented as BOD concentrations were used: 0 mg/l, 10 mg/l and 30 mg/l.

For BOD preparation, solid waste was obtained from a chicken farm in Nablus City, dried by sunlight and ground to the size of a sesame seed (approximately 1 mm). One gram of waste was soaked in one liter of water for two days; the BOD measured after five days was 100 mg/L.

In order to confirm the dilution, a tenfold amount of waste was soaked in the same amount of water (10 gm of waste from the same source in 1 L of water for two days), and then 0.25 L of the solution was added to 25L of water. After five days, the sample measured 10 mg/L BOD, the same value calculated by using the dilution formula:

1 g/L gives 100 mg/L BOD (measured)

10 g/L expected to give 1000 mg/L BOD

$C1xV1=C2xV2$

Where:

C1: initial concentration in milligrams/liter (mg/l)

V1: initial volume in liter (L)

C2: final concentration in milligrams/liter (mg/l)

V2: final volume in liter (L)

1000 mg/Lx0.25 L= C2x25L

C2= 10 mg/L (calculated)

So we have 250 mL of pollutant when added to 25 L water sample, gives 10 mg/L BOD.

The same method was used to prepare BOD of 30 mg/L. To prepare 0.5 L of pollutant to give 25 L of water sample with 30 mg/L BOD:

x mg/Lx0.5 L= 30 mg/Lx25 L

x=1500 mg/L achieved when 15 g of waste from the same source was soaked in 1 L of water for two days, and then 0.5 L of the solution was added to 25 L of water to give 30 mg/L BOD.

- Two incubation periods were used, 72 hours and 120 hours (the periods used in Nablus water supply system for intermittent pumping).
- Constant temperature in the lab was controlled at 26 ^{o} C (a preset for the lab).
- pH is started at 7 and we assumed it remained constant.

The following Table 4.2 shows all samples which have been collected and sample descriptions.

Table 4.2: Experiment samples description

No	Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	BOD (mg/l)	Incubation period (hr)
1	OS1/1	Steel	Old	0.3	0	72
2	OS3/1	Steel	Old	0.6	0	72
3	OS2/1	Steel	Old	0.9	0	72
4	OS1/3	Steel	Old	0.3	10	72
5	OS3/3	Steel	Old	0.6	10	72
6	OS2/3	Steel	Old	0.9	10	72
7	OS1/5	Steel	Old	0.3	30	72
8	OS3/5	Steel	Old	0.6	30	72
9	OS2/5	Steel	Old	0.9	30	72
10	OS1/2	Steel	Old	0.3	0	120
11	OS3/2	Steel	Old	0.6	0	120
12	OS2/2	Steel	Old	0.9	0	120
13	OS1/4	Steel	Old	0.3	10	120
14	OS3/4	Steel	Old	0.6	10	120
15	OS2/4	Steel	Old	0.9	10	120
16	OS1/6	Steel	Old	0.3	30	120
17	OS3/6	Steel	Old	0.6	30	120
18	OS2/6	Steel	Old	0.9	30	120
19	NS 1/1	Steel	New	0.3	0	72
20	NS 3/1	Steel	New	0.6	0	72
21	NS 2/1	Steel	New	0.9	0	72
22	NS 1/3	Steel	New	0.3	10	72
23	NS 3/3	Steel	New	0.6	10	72
24	NS 2/3	Steel	New	0.9	10	72
25	NS 1/5	Steel	New	0.3	30	72
26	NS 3/5	Steel	New	0.6	30	72
27	NS 2/5	Steel	New	0.9	30	72
28	NS 1/2	Steel	New	0.3	0	120
29	NS 3/2	Steel	New	0.6	0	120
30	NS 2/2	Steel	New	0.9	0	120
31	NS 1/4	Steel	New	0.3	10	120
32	NS 3/4	Steel	New	0.6	10	120
33	NS 2/4	Steel	New	0.9	10	120
34	NS 1/6	Steel	New	0.3	30	120
35	NS 3/6	Steel	New	0.6	30	120

No	Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	BOD (mg/l)	Incubation period (hr)
36	NS 2/6	Steel	New	0.9	30	120
37	P 1/1	PP	New	0.3	0	72
38	P 3/1	PP	New	0.6	0	72
39	P 2/1	PP	New	0.9	0	72
40	P 1/3	PP	New	0.3	10	72
41	P 3/3	PP	New	0.6	10	72
42	P 2/3	PP	New	0.9	10	72
43	P 1/5	PP	New	0.3	30	72
44	P 3/5	PP	New	0.6	30	72
45	P 2/5	PP	New	0.9	30	72
46	P 1/2	PP	New	0.3	0	120
47	P 3/2	PP	New	0.6	0	120
48	P 2/2	PP	New	0.9	0	120
49	P 1/4	PP	New	0.3	10	120
50	P 3/4	PP	New	0.6	10	120
51	P 2/4	PP	New	0.9	10	120
52	P 1/6	PP	New	0.3	30	120
53	P 3/6	PP	New	0.6	30	120
54	P 2/6	PP	New	0.9	30	120

Note: PP means polypropylene pipe

4.2.3 Experiment sampling

1) Sampling vials (glass bottles of 1 liter volume) were obtained.
2) Each sample vial was labeled including Sample ID, Sample location, Sample date and time.
3) Slowly, the sample vial was filled by opening the water tap at the end of each pipe to the mark of 1 L.
4) Samples were capped and taken to the lab and preserved in a refrigerator at 4 ^{o}C until analysis.

4.3 Sample analysis

4.3.1 Sample collection

Finished drinking water samples (1000 cm^3) were collected for analysis from both 21 field survey samples and 54 pipe experiment samples, (see Tables 4.1 and 4.2). The samples were taken in a standard way after running a few liters of water from the tap for the field samples (but not the pipe experiment samples). 0.1 g of sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$ analytical grade POCH SA, Gliwice) was added to each sample to quench any remaining chlorine residual and stop formation of THMs.

The containers had teflon-lined screw caps. The water samples were kept no longer than three days at + 4°C.

Materials standards of chloroform ($CHC1_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), bromoform ($CHBr_3$) (each 5000 μg/mL in MeOH, J.T. Baker) were used. The suitable solutions of the standards were prepared in methanol (Suprasolv, Merck) by dilution in volumetric flasks.

4.3.2 Solid-Phase Microextraction (SPME)

The compounds were separated from the water samples by SPME technique (Luks-Betlej and Bodzek, 2000). During extraction the fiber was directly immersed in the aqueous solution. The extraction was carried out in 3 ml screw cap vials fitted with silicone/PTFE septa, (Supelco Corp.), to which the sample was being poured underneath the seal. The microextractor fibers coated with 100 μm film of poly(dimethylsiloxane) PDMS (Supelco Corp.) phase were introduced into the vessel with the sample of water and during the fiber exposure the sample was stirred with a magnetic stirrer. Micro extraction conditions were selected experimentally, based on previous studies (Luks-Betlej and Bodzek, 2000). A micro extraction time of 8 min and mixing the sample at 400 rpm achieved equilibrium conditions. After the set time of the micro extraction the fibers were immediately inserted into the injector of GC/MS of Perkin Elmer Clarus 500 Gas Chromatograph-Mass Spectrometer, where the desorption took place within 2 min at 170°C. The time of thermal desorption was verified by fiber purity control by blank test; moreover, the fibers were cleaned at 250°C, before each extraction. 200 extractions were performed with the PDMS fibers.

4.3.3 Quantitative analysis

GC/MS analysis was performed in the gas chromatograph of Perkin Elmer Claurus 500 type. The chromatograph was equipped with 560D MS detector, and a column of Elite 5MS with poly(dimethylsiloxane) phase (30 m x 0.25 mm x 0.25 μm film thickness) dimensions. The parameters of chromatographic analysis were as follows:

Temperatures: split/splitless injector 170°C, detector 250°C; programme: 30°C (5 min), 30-120°C (9°C min,), 120°C (10 min). Carrier gas He: 20 cm s-1; desorption time from the fibers: 2 min.

To make calibration curves, aliquots dissolved in methanol with concentration of 5000 μg/mL of all standards were applied. The solutions were kept refrigerated in amber-coloured vials. The basic aliquots were dissolved with methanol in order to prepare spiked water solutions for making calibration curves.

Calibration curves for chloroform were made for the concentration range 5-30 μg/L, for bromodichloromethane 0.25-4 μg/L, dibromochloromethane 0.5-5 μg/L, bromoform 0.05-0.1 μg/L, respectively. Calibration curves details are shown in Table 4.3.

Table 4.3. The calibration curves correlation coefficients of compounds determined by the SPME-GC/MS method at a range of concentrations: Bromodichloromethane ($CHBrCl_2$) 0.25-4.0 μg/L, Dibromochloromethane ($CHBr_2Cl$) 0.5-5.0 μg/L, Bromoform ($CHBr_3$) 0.05-0.5 μg/L, Chloroform ($CHC1_3$) 5-30 μg/L.

Compound	b*	a*	r^2	R.S.D %	Detection limit ppb
$CHBrCl_2$	145.7	1212.3	0.998	6-10	2.1
$CHBr_2Cl$	414.7	1220.8	1	3-5	3.1
$CHBr_3$	-10.36	782.4	0.999	3-12	3.2
$CHC1_3$	-22.82	308.9	0.999	3-10	2.5

* = Linear regression y=ax+b
n = number of determinations (5-7)

4.4 Statistical analysis

Data were statistically analyzed using the SPSS statistical software program (SPSS Inc, Chicago Illinois).

Significance of effects of pipe material, pipe age, chlorine concentration, pollution load, and incubation period on the formation of DBP were analyzed with the help of the analysis of variance (ANOVA), which is a well-known statistical technique. Because only single data points were collected for each condition, data were pooled for ANOVA tests.

CHAPTER FIVE
RESULTS AND DISCUSSION

5.1 Results

The results were measured separately for each single compound, and then added together as a total THM.

5.1.1 Field survey results

The following Table (5.1) shows the field survey sample locations and TTHM results.

Table (5.1) Field survey sample locations and results

Sample no	Sample location		TTHM (ppb)
1	Reservoir	Alhaj Nimer reservoir	14
2	Network	Al Watani hospital	26
3	Network	Amman street	27
4	Source	Dafna spring	6
5	Reservoir	Ein Dafna old reservoir	8
6	Reservoir	Ein Beit Elma new reservoir	34
7	Reservoir	Ein El Asal spring reservoir	13
8	Reservoir	Ras El Ein spring reservoir	14
9	Reservoir	Ein Beit Elma old reservoir	18
10	Reservoir	Qaryon spring reservoir	31
11	Roof tanks	Askar Camp- plastic roof tank	52
12	Roof tanks	Askar Camp-steel roof tank	41
13	Network	Old City	53
14	Roof tanks	Old City- plastic roof tank	48
15	Network	Rafidia Al Balad- plastic	38
16	Roof Tanks	Rafidia Al Balad- plastic	29
17	Network	Sayel Fuel Station- Alquds street –steel	37
18	Roof tank	Sayel Fuel Station- Alquds street – plastic	28
19	Network	AlQatoni Taxi- Almaajeen- steel	23
20	Roof tank	AlQatoni Taxi- Almaajeen- plastic	37
21	Source	Al Qwareen spring-trading centre	153

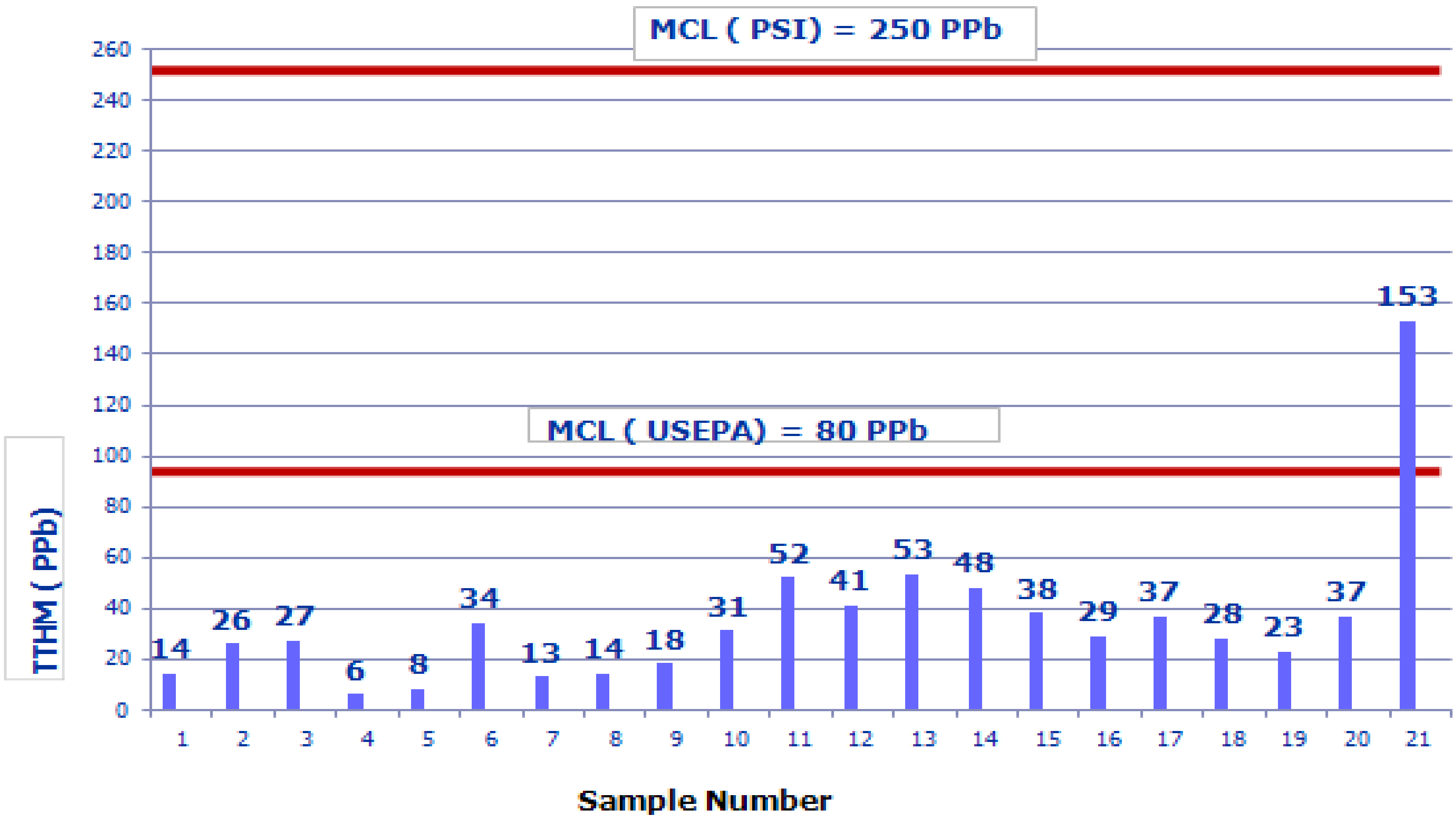


Fig 5.1 TTHM values of Nablus City water system and MCL values according to PSI and USEPA are shown for reference.

5.1.2 Pipe experiment results

5.1.2.1 Case one

Description: Zero BOD, seventy two hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.2) shows case one sample and results.

Table 5.2 Case one of experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/1	Steel	Old	0.3	111
OS3/1	Steel	Old	0.6	118
OS2/1	Steel	Old	0.9	123
NS1/1	Steel	New	0.3	88
NS3/1	Steel	New	0.6	89
NS2/1	Steel	New	0.9	94
P1/1	Plastic	New	0.3	63
P3/1	Plastic	New	0.6	81
P2/1	Plastic	New	0.9	72

5.1.2.2 Case two

Description: Zero BOD, one hundred and twenty hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.3) shows case two samples and results.

Table 5.3: Case two experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/2	Steel	Old	0.3	131
OS3/2	Steel	Old	0.6	211
OS2/2	Steel	Old	0.9	169
NS1/2	Steel	New	0.3	92
NS3/2	Steel	New	0.6	187
NS2/2	Steel	New	0.9	114
P1/2	Plastic	New	0.3	74
P3/2	Plastic	New	0.6	163
P2/2	Plastic	New	0.9	89

5.1.2.3 Case three

Description: 10 mg/L BOD, seventy two hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.4) shows case three samples and results.

Table 5.4: Case three of experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/3	Steel	Old	0.3	121
OS3/3	Steel	Old	0.6	160
OS2/3	Steel	Old	0.9	188
NS1/3	Steel	New	0.3	93
NS3/3	Steel	New	0.6	151
NS2/3	Steel	New	0.9	162
P1/3	Plastic	New	0.3	74
P3/3	Plastic	New	0.6	138
P2/3	Plastic	New	0.9	157

5.1.2.4 Case four

Description: 10 mg/L BOD, one hundred and twenty hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.5) shows case four samples and results.

Table 5.5: Case four of experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/4	Steel	Old	0.3	148
OS3/4	Steel	Old	0.6	215
OS2/4	Steel	Old	0.9	298
NS1/4	Steel	New	0.3	136
NS3/4	Steel	New	0.6	201
NS2/4	Steel	New	0.9	276
P1/4	Plastic	New	0.3	111
P3/4	Plastic	New	0.6	193
P2/4	Plastic	New	0.9	259

5.1.2.5 Case five

Description: 30 mg/L BOD, seventy two hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.6) shows case five samples and results.

Table 5.6: Case five of experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/5	Steel	Old	0.3	176
OS3/5	Steel	Old	0.6	288
OS2/5	Steel	Old	0.9	326
NS1/5	Steel	New	0.3	156
NS3/5	Steel	New	0.6	262
NS2/5	Steel	New	0.9	302
P1/5	Plastic	New	0.3	141
P3/5	Plastic	New	0.6	238
P2/5	Plastic	New	0.9	287

5.1.2.6 Case six

Description: 30 mg/L BOD, one hundred and twenty hours incubation period, different pipe material and age, different chlorine concentration.

The following Table (5.7) shows case six samples and results.

Table 5.7: Case six of experiment results

Sample no	Pipe material	Pipe age	Cl_2 concentration (mg/l)	TTHM (ppb)
OS1/6	Steel	Old	0.3	193
OS3/6	Steel	Old	0.6	298
OS2/6	Steel	Old	0.9	357
NS1/6	Steel	New	0.3	171
NS3/6	Steel	New	0.6	281
NS2/6	Steel	New	0.9	319
P1/6	Plastic	New	0.3	159
P3/6	Plastic	New	0.6	273
P2/6	Plastic	New	0.9	307

5.2 Statistical analysis

5.2.1 Analysis of Variance (ANOVA)

In its simplest form, the ANOVA can be viewed as a hypothesis test of group means by applying six steps.

5.2.1.1 Test of pipe materials means

To check the effect of pipe material on the formation of DBP, data of new steel and poly propylene pipe were analyzed using ANOVA (see Appendix 4).

The following Table 5.8 shows the SPSS output of comparing means by one way ANOVA.

Report

TTHM

PipeMaterial	Mean	N	Std. Deviation
1.00	176.3333	18	79.76510
2.00	159.9444	18	81.87973
Total	168.1389	36	80.09857

ANOVA

TTHM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2417.361	1	2417.361	.370	.547
Within Groups	222134.9	34	6533.381		
Total	224552.3	35			

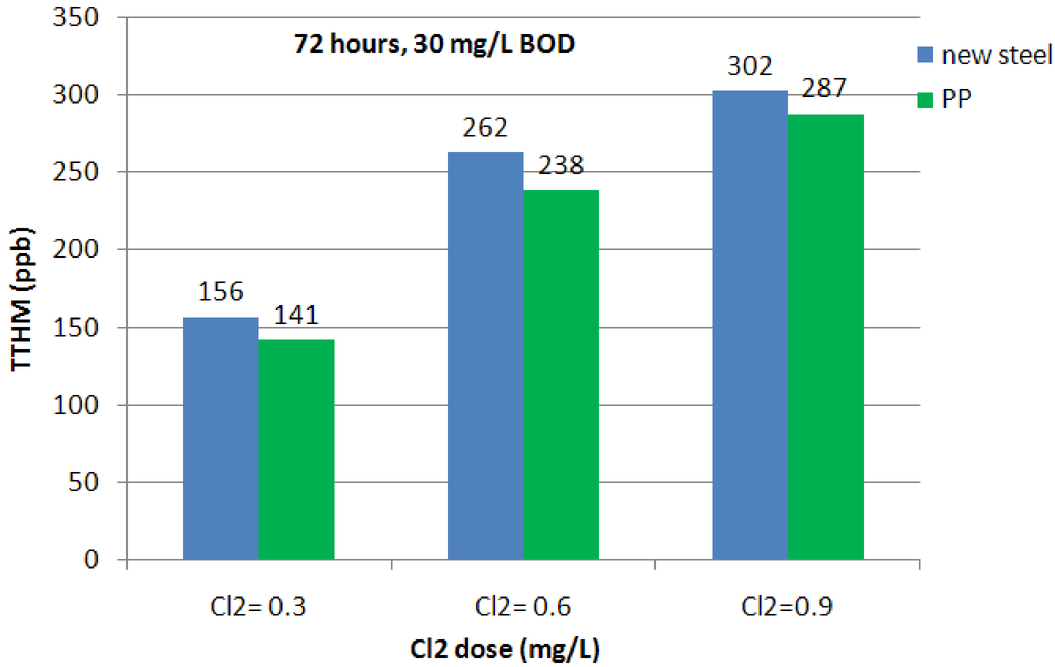


Fig 5.2 The effect of pipe material on the formation of TTHM

5.2.1.2 Test of pipe ages means

To check the effect of pipe age on the formation of DBP data of new steel and old steel pipe were analyzed using ANOVA (see Appendix 5).

The following Table 5.9 shows the SPSS output of comparing means by one way ANOVA.

Report

TTHM

PipeMaterial	Mean	N	Std. Deviation
1.00	176.3333	18	79.76510
2.00	201.7222	18	78.73246
Total	189.0278	36	79.16402

ANOVA

TTHM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5801.361	1	5801.361	.924	.343
Within Groups	213541.6	34	6280.636		
Total	219343.0	35			

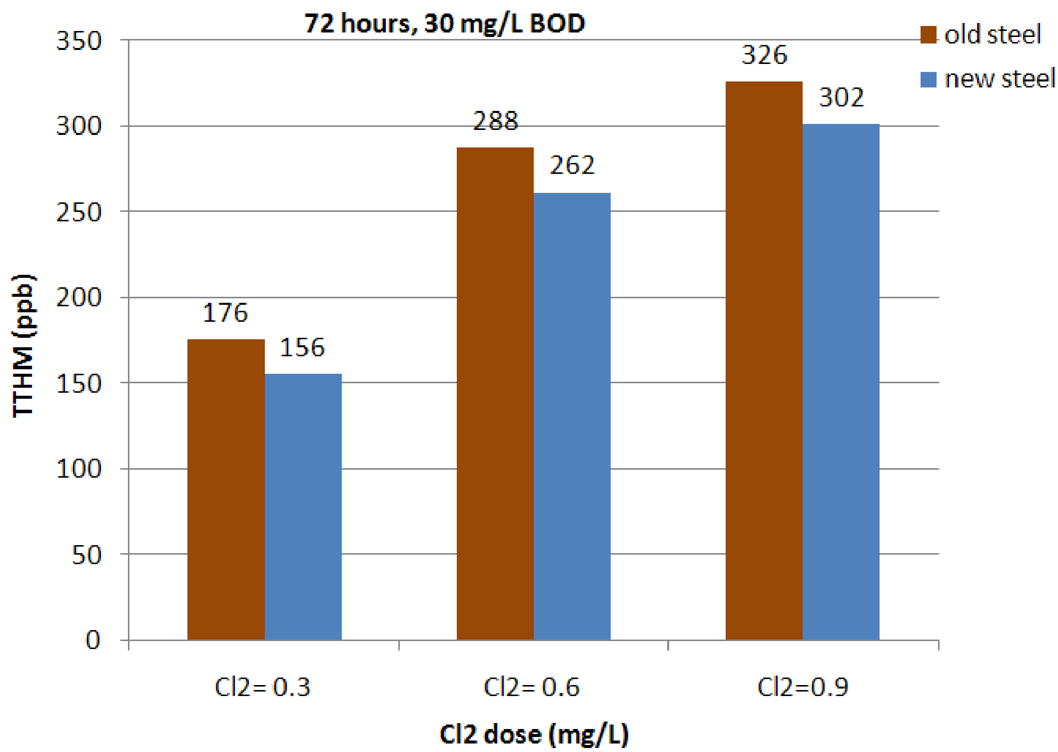


Fig 5.3 The effect of pipe age on the formation of TTHM

5.2.1.3 Test of chlorine concentrations means

To check the effect of chlorine concentration on the formation of DBP data of TTHM under the application of 0.3, 0.6, or 0.9 mg/L of Cl_2 were analyzed using ANOVA (see Appendix 6).

The following chart (Fig 5.4) shows the effect of chlorine concentration.

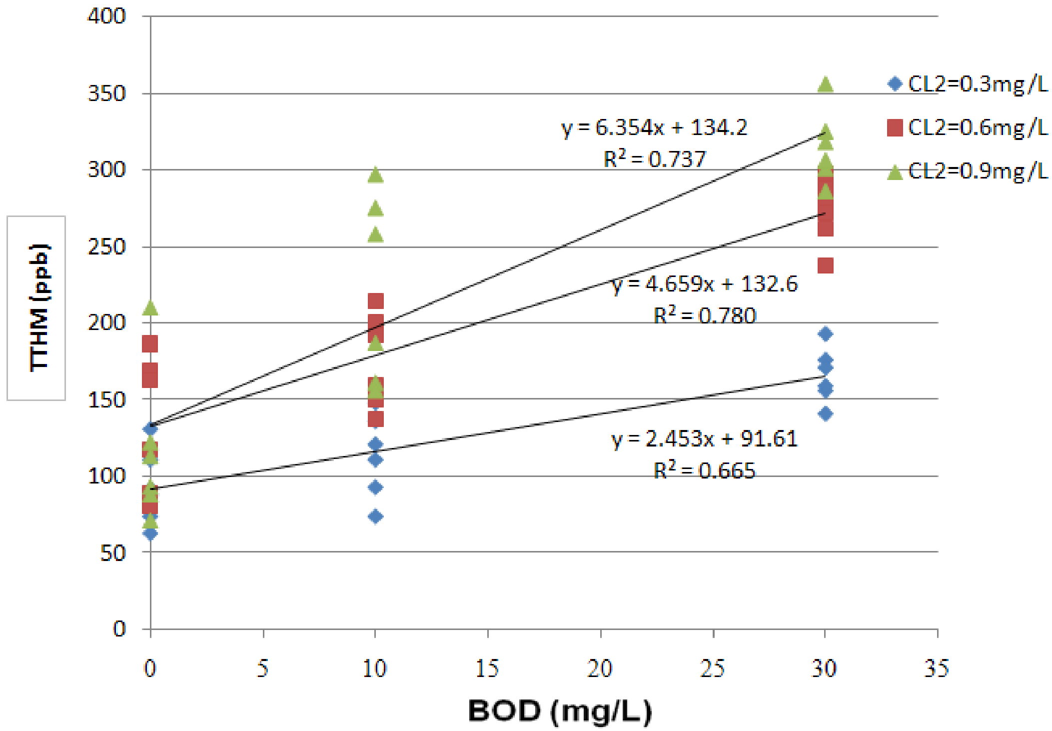


Fig 5.4 TTHM values versus BOD at different chlorine concentration.

The following Table 5.10 shows the SPSS output of comparing means by one way ANOVA.

ANOVA

TTHM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	85116.778	2	42558.389	8.401	.001
Within Groups	258349.2	51	5065.671		
Total	343466.0	53			

Multiple Comparisons

Dependent Variable: TTHM

	(I) CL	(J) CL	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Scheffe	1.00	2.00	-72.72222*	23.72451	.013	-132.5419	-12.9026
		3.00	-92.27778*	23.72451	.001	-152.0974	-32.4581
	2.00	1.00	72.72222*	23.72451	.013	12.9026	132.5419
		3.00	-19.55556	23.72451	.714	-79.3752	40.2641
	3.00	1.00	92.27778*	23.72451	.001	32.4581	152.0974
		2.00	19.55556	23.72451	.714	-40.2641	79.3752

*. The mean difference is significant at the .05 level.

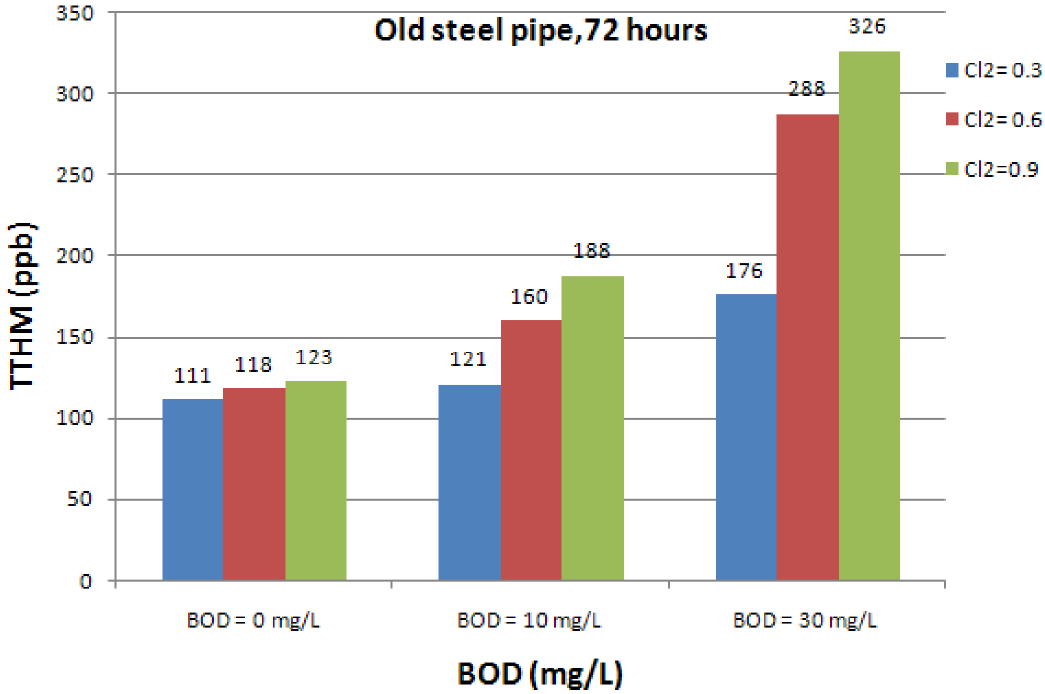


Fig 5.5 The effect of Cl_2 on the formation of TTHM

Linear regression:

When applying linear regression using SPSS to see the TTHM trend under the variable values of chlorine concentration the following results obtained

Linear regression equation

TTHM= 46.139X CL_2 + 87.056

R^2= 0.223

Sig ‹ 0.05

Scatter shape is linear

The results of linear regression (see Appendix 7)

5.2.1.4 Test of BOD concentrations Means

To check the effect of BOD concentration on the formation of DBP data of TTHM under the application of 0, 10, or 30 mg/L BOD were analyzed using ANOVA (see Appendix 8).

The following chart (Fig 5.6) shows the effect of BOD loading.

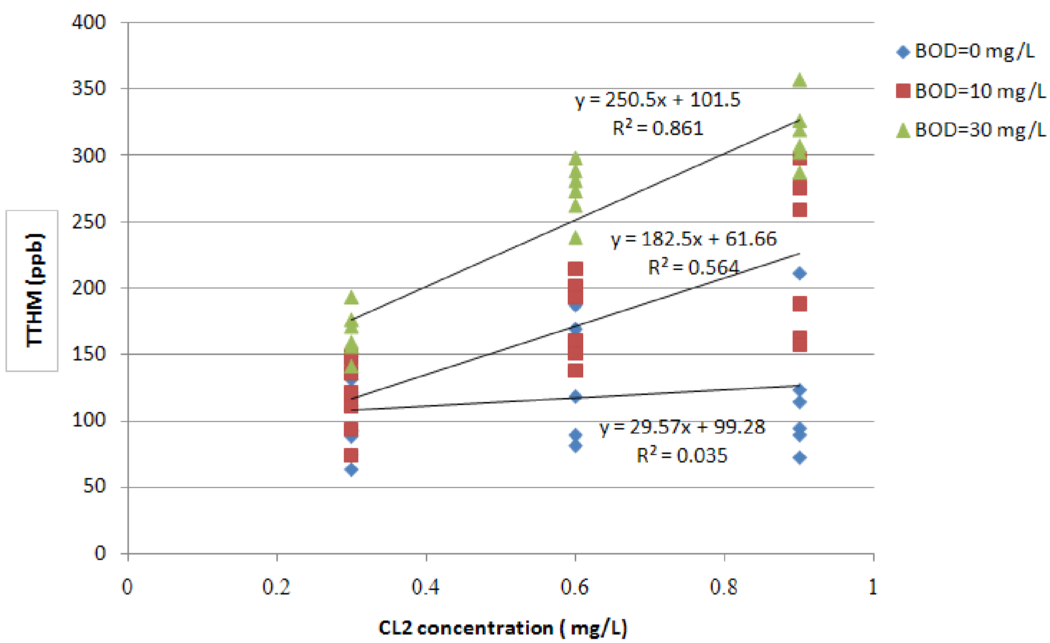


Fig 5.6 TTHM values versus chlorine concentration at different BOD concentration.

The following Table 5.11 shows the SPSS output of comparing means by one way ANOVA.

ANOVA

TTHM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	170584.8	2	85292.389	25.161	.000
Within Groups	172881.2	51	3389.828		
Total	343466.0	53			

Multiple Comparisons

Dependent Variable: TTHM

	(I) BOD	(J) BOD	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Scheffe	1.00	2.00	-56.22222*	19.40741	.021	-105.1566	-7.2878
		3.00	-136.94444*	19.40741	.000	-185.8788	-88.0101
	2.00	1.00	56.22222*	19.40741	.021	7.2878	105.1566
		3.00	-80.72222*	19.40741	.001	-129.6566	-31.7878
	3.00	1.00	136.94444*	19.40741	.000	88.0101	185.8788
		2.00	80.72222*	19.40741	.001	31.7878	129.6566

*. The mean difference is significant at the .05 level.

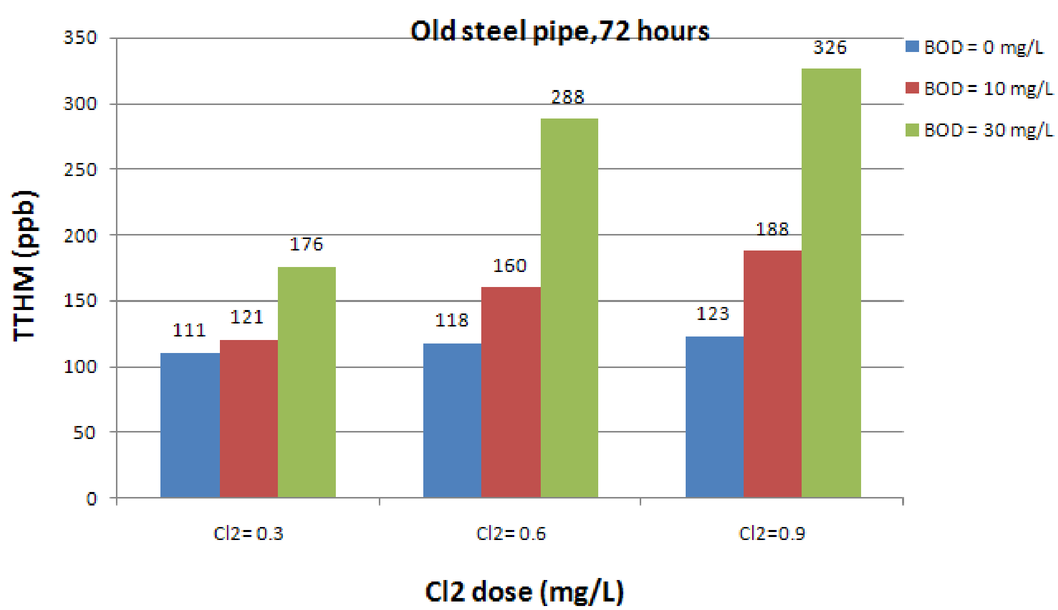


Fig 5.7 The effect of BOD on the formation of TTHM

Linear regression

When applying linear regression using SPSS to see the TTHM trend under the variable values of BOD concentration the following results obtained

- Linear regression equation

  TTHM= 68.472X BOD + 42.389
- R^2= 0.491
- Sig ‹ 0.05
- Scatter shape is linear

The results of linear regression (see Appendix 9)

5.2.1.5 Test of incubation periods Means

To check the effect of incubation period on the formation of DBP, data of TTHM after 72 and 120 hours were analyzed (see Appendix 10).

The following Table 5.12 shows the SPSS output of comparing means by one way ANOVA.

Report

TTHM

PipeMaterial	Mean	N	Std. Deviation
1.00	157.7407	27	77.33374
2.00	200.9259	27	79.12888
Total	179.3333	54	80.50149

ANOVA

TTHM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25176.963	1	25176.963	4.113	.048
Within Groups	318289.0	52	6120.943		
Total	343466.0	53			

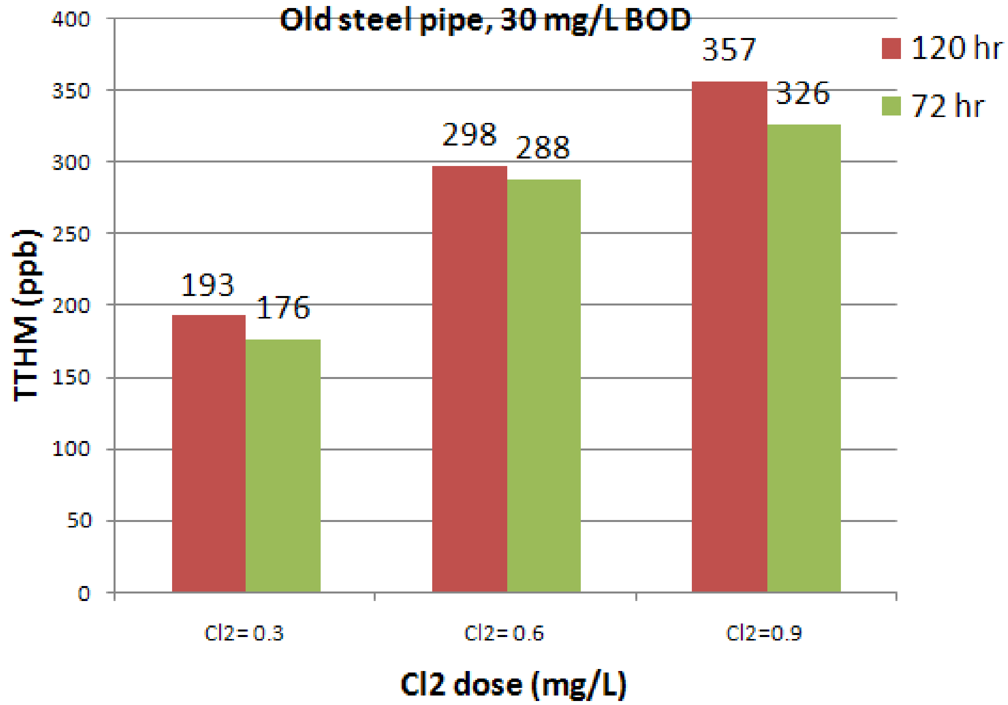


Fig 5.8 The effect of incubation period on the formation of TTHM

5.3 Non linear modeling

In order to predict the occurrence of DBPs in drinking water, non-linear regression techniques used in developing DBP predictive model.

The model expresses Total Trihalomethane (TTHM) concentration in terms of BOD, Cl_2 concentrations and incubation time.

The proposed model is:

$$\mathbf{TTHM=K\times BOD^{x1}\times Cl_2^{x2}\times t^{x3}}$$

After making simulation on results by SPSS

$$\boxed{\mathbf{TTHM=24.758\times BOD^{0.3292}\times Cl_2^{0.5579}\times t^{0.3386}}}$$

Where:

TTHM: trihalomethane in mg/l

BOD: Biological Oxygen Demand in mg/l

Cl_2: chlorine concentration in mg/l

t: incubation period in hours

The following figure 5.9 shows the relation between measured and predicted TTHM

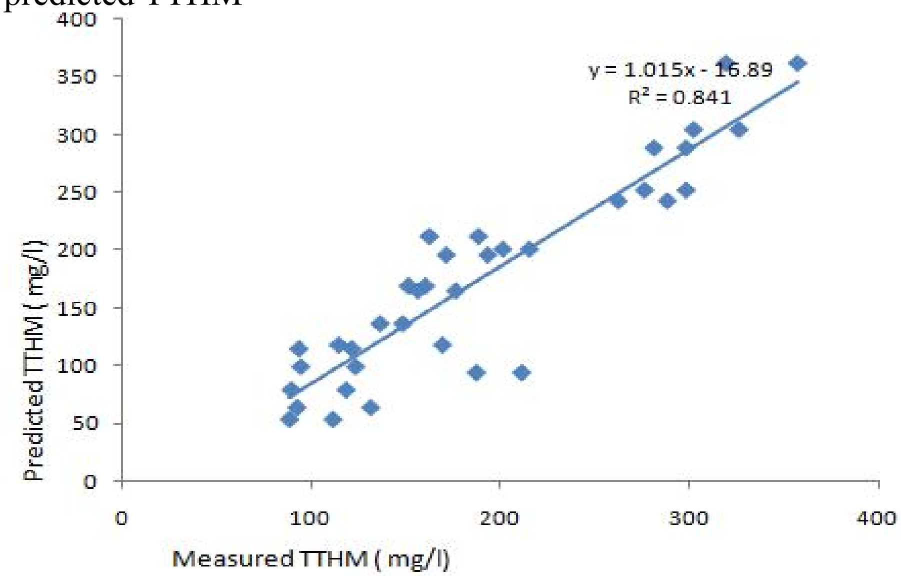


Fig 5.9 Relation between measured and predicted TTHM

To check the effect of chlorine, BOD concentrations and incubation period on the formation of DBP data of TTHM by using the predictive model, the following figures 5.10, 5.11 and 5.12 respectively shows the results

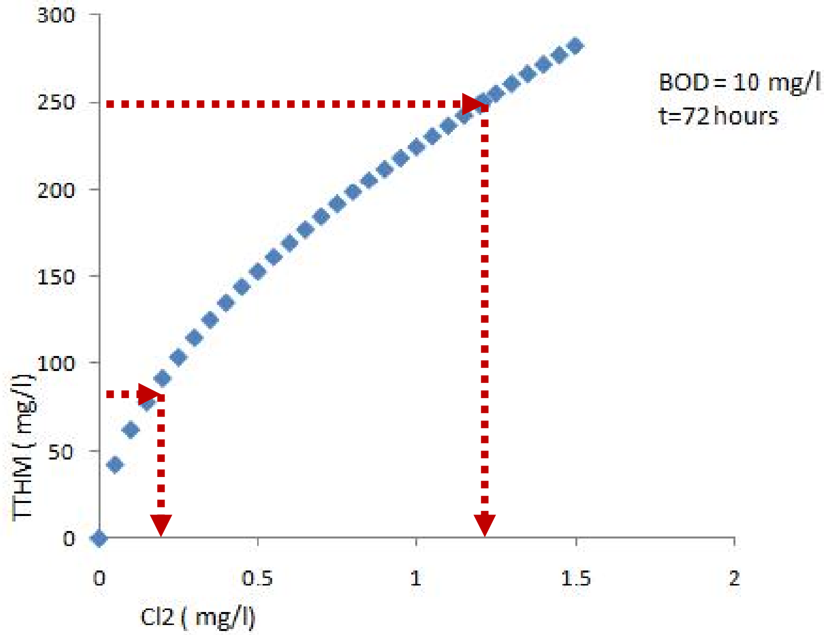


Fig 5.10 Chlorine concentration versus TTHM using the predictive model

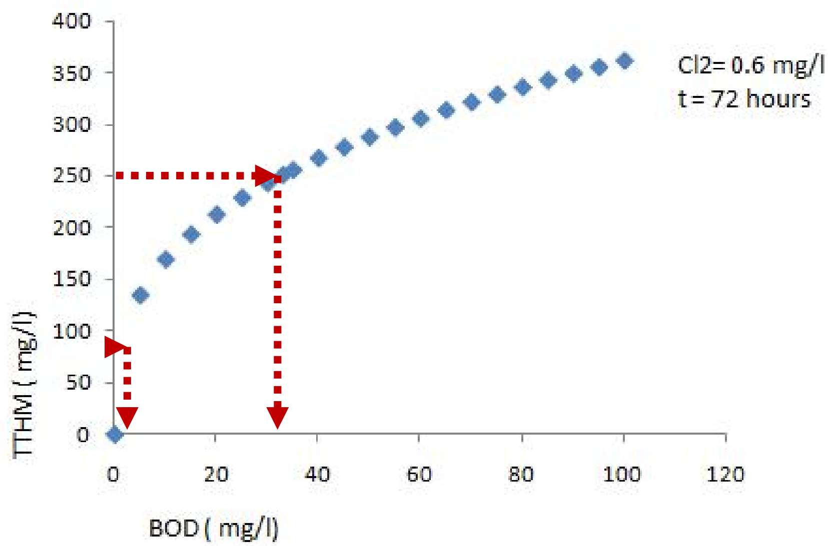


Fig 5.11 BOD concentration on TTHM using the predictive model

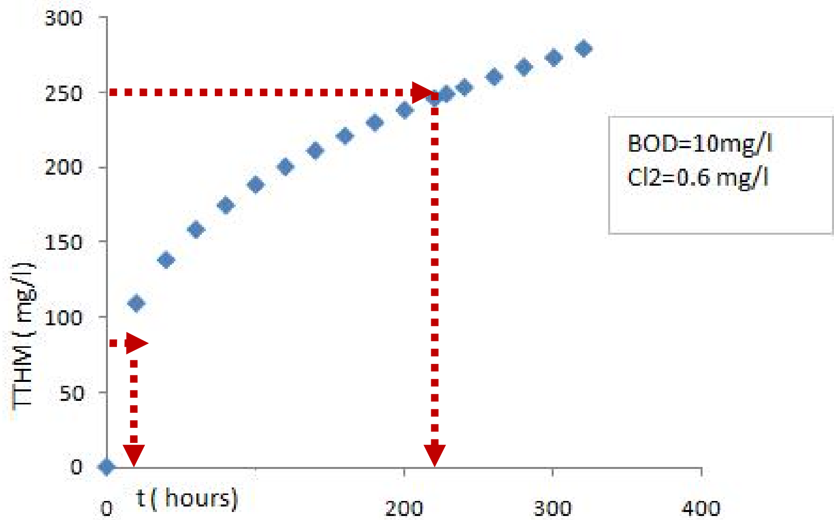


Fig 5.12 The effect of incubation period on TTHM using the predictive model

From the above charts, Predicted TTHM reaches PSI MCL (80 ppb) at the following:

- Cl_2= 0.16 mg/l at BOD= 10 mg/l, t=72 hours.
- BOD = 1 mg/l at Cl_2= 0.6 mg/l, t=72 hours.
- t= 8 hours at Cl_2= 0.6 mg/l, BOD= 10 mg/l.

From the above charts, Predicted TTHM reaches the USEPA MCL (250 ppb) at the following:

- Cl_2= 1.21 mg/l at BOD= 10 mg/l, t=72 hours.
- BOD = 33 mg/l at Cl_2= 0.6 mg/l, t=72 hours.
- t= 228 hours at Cl_2= 0.6 mg/l, BOD= 10 mg/l.

5.4 Discussion

5.4.1 Field samples

The results show detectable levels of TTHM in all 21 samples. The TTHM concentrations in 20 samples were below the USEPA and PSI MCL (80 ppb and 250 ppb, respectively). Sample 21 (Al Qwareen Spring-trading centre) measured 153 ppb, which is above the USEPA MCL but still less than the MCL according to PSI. This high level of TTHM was expected by the Nablus water and wastewater department. In fact, they don't use this water directly, but instead they dilute it with water from other sources.

Field results indicate that TTHM PSI standard level (250ppb) is not appropriate since some of the TTHM in samples for the field survey were approaching the EPA standard of 80 ppb. It is important that PSI to revise the TTHM level set and modifies it or justify why it should be over 80 ppb. This is of importance because, in Egypt this limit was set to 100 ppb (see table 2.5)

5.4.2 Pipe experiment samples

5.4.2.1 The effect of pipe material on the formation of DBP

Results of TTHM for the new steel pipe were compared with TTHM for new plastic pipe, and analyzed using ANOVA (see Appendix 4), the results of comparison and analysis were:

- At the same chlorine dose concentration, BOD loading, and incubation period, the TTHM concentrations in steel pipes were greater than concentrations in plastic pipes.
- Applying ANOVA shows that TTHM means of steel and plastic pipe were significantly not different because, the significant is 0.547 which is more than the level of 0.05 at which the mean difference is significant.

5.4.2.2 The effect of pipe age on the formation of DBP

Results of TTHM for the new steel pipe were compared with TTHM for old steel pipe, and analyzed using ANOVA (see Appendix 5), the results of comparison and analysis were:

- At the same chlorine dose concentration, BOD loading, and incubation period, the TTHM concentrations in old steel pipes were greater than concentrations in new steel pipes.
- Applying ANOVA shows that TTHM means of new steel and old steel pipe were significantly not different, because, the significant is 0.343 which is more than the level of 0.05 at which the mean difference is significant.

5.4.2.3 The effect of chlorine concentration on the formation of DBP

Results of TTHM for different pipe materials and ages (old steel, new steel and new plastic pipe) under the application of 0.3 mg/l chlorine concentration were compared with TTHM at the application of 0.6 mg/l and 0.9 mg/l chlorine concentration, and analyzed using ANOVA (see Appendix 6), the results of comparison and analysis were:

- At the same pipe material, pipe age, BOD loading, and incubation period, TTHM concentrations increased with increasing chlorine dose.
- TTHM at 0.9 mg/l CL_2 › TTHM at 0.6 mg/l › TTHM at 0.3 mg/l.

- Applying linear trend on the graph of TTHM versus Cl_2 concentration, the slope is positive, which means that the trend is increasing TTHM with increasing Cl_2.
- Applying ANOVA shows that:

- Comparing TTHM at 0.3 mg/l Cl_2 with TTHM at 0.6 mg/l Cl_2, TTHM means were significantly not different, because, the significant is 0.013 which is less than the level of 0.05 at which the mean difference is significant.
- Comparing TTHM at 0.3 mg/l Cl_2 with TTHM at 0.9 mg/l Cl_2, TTHM means were significantly different, because, the significant is 0.001 which is less than the level of 0.05 at which the mean difference is significant.
- Comparing TTHM at 0.6 mg/l Cl_2 with TTHM at 0.9 mg/l Cl_2, TTHM means were significantly not different, because, the significant is 0.714 which is more than the level of 0.05 at which the mean difference is significant.

  - Applying linear regression using SPSS (see Appendix 7) shows that:

- The coefficient of determination (R^2) is 0.223 which means low correlation between the outcomes and their predicted values.
- The significance of the equation is less than 0.05.

5.4.2.4 The effect of BOD concentration on the formation of DBP

Results of TTHM for different pipe materials and ages (old steel, new steel and new plastic pipe) under the application of 0 mg/l BOD concentration were compared with TTHM at the application of 10 mg/l and 30 mg/l BOD concentration, and analyzed using ANOVA (see Appendix 8), the results of comparison and analysis were:

- At the same pipe material, pipe age, chlorine concentration, and incubation period, TTHM concentrations increased with increasing BOD concentration.
- TTHM at 30 mg/l BOD › TTHM at 10 mg/l › TTHM at 0 mg/l.
- Applying linear trend on the graph of TTHM versus BOD concentration, the slope is positive, which means that the trend is increasing TTHM with increasing BOD.
- Applying ANOVA shows that:

• Comparing TTHM at 0 mg/l BOD with TTHM at 10 mg/l BOD, TTHM means were significantly different, because, the significant is 0.021 which is less than the level of 0.05 at which the mean difference is significant.

• Comparing TTHM at 0 mg/l BOD with TTHM at 30 mg/l BOD, TTHM means were significantly different, because, the significant is 0.000 which is less than the level of 0.05 at which the mean difference is significant.

• Comparing TTHM at 10 mg/l BOD with TTHM at 30 mg/l BOD, TTHM means were significantly different, because, the significant is 0.001 which is less than the level of 0.05 at which the mean difference is significant.

- Applying linear regression using SPSS (see Appendix 9) shows that:

- The coefficient of determination (R^2) is 0.491 which means low correlation between the outcomes and their predicted values.
- The significance of the equation is less than 0.05.

5.4.2.5 The effect of incubation periods on the formation of DBP

Results of TTHM for different pipe materials and ages (old steel, new steel and new plastic pipe) under the condition of 72 hours incubation period, were compared with TTHM under the condition of 120 hours incubation period, and analyzed using ANOVA (see Appendix 10), the results of comparison and analysis were:

- At the same pipe material, pipe age, chlorine concentration, and BOD concentration, the TTHM concentrations at 120 hours incubation period were greater than concentrations at 72 hours incubation period.
- Applying ANOVA shows that TTHM means were significantly different, because, the significant is 0.048 which is less than the level of 0.05 at which the mean difference is significant.
- TTHM means of 72 hours and 120 hours incubation period were significantly different.(TTHM at 120 hours › TTHM at 72 hours)

The following Table **(Table 5.13) shows the variables and which had a statistically significant effect on TTHM concentrations.**

Variables		TTHM means	
First	Second	Significantly different	Significantly not different
Old steel	New steel		√
New steel	Plastic pipe		√
Cl_2=0.3	Cl_2=0.6	√	
Cl_2=0.3	Cl_2=0.9	√	
Cl_2=0.6	Cl_2=0.9		√
BOD=0	BOD=10	√	
BOD=0	BOD=30	√	
BOD=10	BOD=30	√	
t=72	t=120	√	

5.4.3 Non linear modeling

Because the pipe material and pipe age as a factor were not significant, a model for the TTHM formation was build as a factor of chlorine dose concentration, BOD concentration and incubation time these factor have significant effect on TTHM formation.

The coefficient of determination (R^2) is 0.841 which means high correlation between the measured and their predicted values.

The DBP predictive model indicates:

- BOD and t, have equal effect on predicted TTHM (the power of BOD is 0.3 and the power of t is 0.3) while the chlorine concentration has higher impact (the power of Cl_2 is 0.5).
- The high constant value which is 25 indicates the important of the three factors together.

- BOD, Cl_2 and incubation period are directly proportional to the formation of DBP as TTHM.

The benefit of this model, that we can predict the concentration of TTHM.

By using the model, TTHM concentration based on the three factors can be predicted; this enables decision makers in the field of water in Nablus City to ensure TTHM not to increase more than MCL.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Based on the results obtained and their discussion, the following concluding remarks were reached:

- There is presence of TTHM in Nablus water supply system.
- TTHM PSI standard level (250ppb) is not appropriate.
- At the same chlorine dose concentration, BOD loading, and incubation period, the TTHM concentrations in steel pipes were greater than concentrations in plastic pipes.
- At the same chlorine dose concentration, BOD loading, and incubation period, the TTHM concentrations in old steel pipes were greater than concentrations in new steel pipes.
- At the same pipe material, pipe age, BOD loading, and incubation period, TTHM concentrations increased with increasing chlorine dose.
- At the same pipe material, pipe age, chlorine concentration, and incubation period, TTHM concentrations increased with increasing BOD concentration.
- At the same pipe material, pipe age, chlorine concentration, and BOD concentration, the TTHM concentrations at 120 hours incubation period were greater than concentrations at 72 hours incubation period.
- Model for the TTHM formation was build as a factor of chlorine dose concentration, BOD concentration and incubation time these factor have significant effect on TTHM formation.

6.2 Recommendations

- It is very necessary to monitor continuously the value of TTHM in the water system and ensure not to exceed the MCL value.
- Old steel pipes need to be replaced.
- Incubation period need to be reduced by increasing water availability and pumping durations.
- Chlorine dose and residual need to be more closely monitored.
- UFW must be reduced to reduce biological contamination of water.

Recommendations for further research

It is recommended to:

- Repeat the experiment with different segments of pipes to cover different ages.
- Repeat the experiment with different pipe material.
- Studying the feasibility of declining Cl_2 as disinfectant and using other alternatives.
- Studying the effects of other water quality parameters on the formation of TTHM.

REFERENCES

Adams, G.O., and Kingsbury, F.H.: "***Experiences with chlorinating new water mains***", **Journal of the New England Water Works Association**, 51,1937/ 60–68.

Ahmadi, A.B.: **Effects of water quality parameters on corrosion of mild steel, copper, and zinc**(Ph.D. thesis). University of Florida. Miami. Fla. 1981.

Allen, M.J., Taylor, R.H., and Geldreich, E.E.: ***"The occurrence of microorganisms in water main encrustations***", **Journal of the American Water Works Association**, 72**,**1980/ 614–625.

Al-Omari, A., Fayyad, M. and Qader, A.: ***"Modeling trihalomethane formation for Jabal Amman water supply in Jordan"***, **Environmental Modeling and Assessment** , 9,2004/245–252.

American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF).: **Standard Methods for the Examination of Water and Wastewater**. 1996

American Chemistry Council(ACC).: **Water Disinfection: Evaluating Alternative Methods In Light of Heightened Security Concerns**,2010

Bielmeier, S.R., Best, D.S., Guidici, D.L., Narotsky, M.G.: ***"Pregnancy loss in the rat caused by bromodichloromethane***", **Toxicol. Sci**, 59,2001/ 309–315.

Brereton, J.A. and Mavinic, D.S: "***Field and material-specific simulated distribution system testing as aids to understanding***

trihalomethane formation in distribution systems", **Can. J. Civ. Eng.,** 29,2002/ 17–26**.**

Clark, R.M. and Sivaganesan, M.: "***Predicting Chlorine Residuals and Formation of TTHMs in Drinking Water***", **Journal of Environmental Engineering**, 124,December, 1998/1203–1210.

Clark, R.M., Thurnau, R.C., Sivaganesan, M. and Ringhand, P.: "***Predicting the Formation of Chlorinated and Brominated By-Products***", **Journal of Environmental Engineering**, 127, June, 2001/ 493–501.

Cohn, P. D, Cox, M. and Berger, P. S., ***"Health and Aesthetic Aspects of Water Quality*, In: *Water Quality and Treatment*", Ed. American Water Works Association, McGraw-Hill, Inc***,1999/2.1-2.86.

Egyptian Organization for Standardization and Quality (EOSQ). **Drinking Water Regulation.**Egypt.26, February 1995.

EPA.: **Initial Distribution System Evaluation Guidance Manual for the Final Stage 2 Disinfection Byproducts Rule**, Appendix A, EPA 815-B-06-002, January 2006

E. Roberts Alley, P.E**.: Water Quality Control Handbook,** Mc Graw Hill Companies, Second edition, 2007**.**

Gang, D.D., Segar Jr, R.L., Clevenger, T.E. and Banerji, S.K.: ***"Using chlorine demand to predict TTHM and HAA9 formation"*,** **Journal Am. Water Works Assn.**, 94,2002/ 76-86.

Gorchev, H.G.: **Disinfection of Drinking Water and By-products of Health Concern**, World Health Organization**,** December,1998.

Hassan, K.Z.A.; Bower, K.C. and Miller, C.M.: "***Iron Oxide Enhanced Chlorine Decay and Disinfection By-Product Formation Journal*** *of Environmental Engineering***", Journal of Environmental Engineering,** 132,2006 / 1609–1616.

Hua, G. and Reckhow, D.A.: ***"Comparison of disinfection byproduct formation from chlorine and alternative disinfectants",*** **Water Research,** 41,2007/ 1667 – 1678.

IARC: **Monograph on the Evaluation of Carcinogenic Risk to Humans: Chlorinated Drinking Water, Chlorination Byproducts, Some Other Halogenated Compounds; Cobalt and Cobalt Compounds**, 52 Lyon IARC, 1991.

Jordan Institution for standards and Metrology(JISM):**Technical Regulation, water-drinking water**,23 January, 2008

Krasner S. W.: **Chemistry of disinfection by-product formation. In Formation and Control of Disinfection By-products in Drinking Water**. Singer, P.C. (editor). American Water Works Association, Denver, CO, 1999.

Keegar, T., Whitaker, H., Nieuwenhuijsen, M.J., Toledano, M.B. Elliott, P.,Fawell, J., Wilkinson, M., Best, N.: ***"Use of routinely collected data on trihalomethane in drinking water for epidemiological purposes"***, **Occup. Environ. Med**., 58 ,2001/ 447–452.

Luks-Betlej K and Bodzek D.: ***"Determination of Tri,-Tetrachloromethanes and Trichloroethane by Using Microextraction with GC-ECD Detection"***, **Chem. Anal. (Warsaw) 45**, **2000.**

Morris, R.D., Audet, A.M., Angelillo, I.F., Chalmers, T.C., Mosteller, F.: ***"Chlorination, Chlorination By-products, and Cancer—a meta analysis***", **Am. J. Public Health**, 82,1992/ 955–963.

Morris J.C.: ***Conference summary. In: Water chlorination environmental impact and health effects***. Volume 2. Jolley RL, Gorchev H., Hamilton D.H. eds., Ann Arbor Science, Ann Arbor, Michigan, 1978.

Palestinian Standards Institution: **Drinking Water**, 2005.

Palestinian Central Bureau of Statistics, **Census 2007, Census final results in the west bank-summary (population and housing)**, 2008

Ridgway, H.F., and Olson, B.H.: "***Scanning electron microscope evidence for bacterial colonization of a drinking water distribution system"***, **Applied Environmental Microbiology**, 41,1981/ 274–287.

Sadiq, R. and Rodriguez, M.J.: ***"Disinfection by-products (DBPs) in drinking water and predictive models for their occurrence: a review"***, **Science of the Total Environment**, 321,2004/ 21–46.

Stevens AA, Slocum CJ, Seeger DR, & Robeck GG.: **Chlorination of organics in drinking water**. J Am Water Works Assoc, 1976.

Tuovinen, O.H., Mair, D.M., and Banovic, J.: "***Chlorine demand and trihalomethane formation by tubercles from cast-iron water mains"***, **Environmental Technology Letters**, 5,1984/ 97–108.

U.S. Environmental Protection Agency: **Draft Drinking Water Health Criteria Document for Chloramines**, Washington,D.C:Office of Science and Technology, Office of Water,1994.

U.S. Environmental Protection Agency: **EPA Panel Report and Recommendation for conducting Epidemiological Research on Possible Reproductive and Developmental Effects of Exposure**

to Disinfected Drinking Water, Washington, D. C: Office of Research and Development, 1998a.

U.S. Environmental Protection Agency: **Integrated Risk Information System**. Cincinnati, OH: Office of Research and Development, Office of Health and Environmental Assessment, 1998b.

U. S. Environmental Protection Agency (USEPA): **The Stage 1 Disinfectants/Disinfection Byproducts (Stage 1 DBPR)**, December 1998c.

Water and Environmental Studies Institute at An-Najah National University: **Map of Nablus City boundary, main water sources (wells and springs) and served villages**, 2007.

Westerhoff, P., Chao, P. and Mash, H.: ***"Reactivity of natural organic matter with aqueous chlorine and bromine*", Water Research,** 38,2004/ 1502–1513.

World Health Organization.: **Guidelines for drinking-water quality,** 3rd ed, 2006.

Appendix 1

Water Chemical Analysis results for Samples collected from Utilized wells and springs all over Nablus City,(WESI, 2009)

Sample No.	Description	Sampling Date	pH Unit	Turbidty (NTU)	NO3 (mg/l)	SO4 (mg/l)	PO4 (mg/l)	Cl (mg/l)	Total Alkalinity (mg/l)	Total Hard mg/l CaCo3	TDS (mg/l)
1	Odala well	22/6/2009	7.1	0.24	17	7.5	0.0	55	230	239	356
2	Alfar'a well	22/6/2009	7.3	0.21	14	7.8	0.0	80	290	299	435
3	Al-Badan well	22/6/2009	7.4	0.2	16.8	9.5	0.0	70	230	252	377
4	Alqaryoon spring	22/6/2009	7.1	0.26	21	7	0.0	50	210	216	307
5	Ein Defna	22/6/2009	7.3	0.19	35.8	9	0.0	65	207	232	370
6	Ein Al-Asal	22/6/2009	7.35	0.23	18	9	0.0	50	170	188	264
7	Ras Al Ein spring	22/6/2009	7.4	0.19	17	8	0.0	40	190	186	270
Standard level			6.5-8.5	<1	50	200	6	250	NGL	500	1000
Method of determination			Meter		Spectrophotometer			Titrarion			Gravimetric

Continue…

Sample No.	Description	Sampling Date	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	k (mg/l)	Fe (mg/l)	Zn (mg/l)	Pb (mg/l)	Cr (mg/l)	Cd (mg/l)	Cu (mg/l)
1	Odala well	22/6/2009	63	20	20	1.6	0.12	0.21	0.0	0.0	0.0	0.0
2	Alfar'a well	22/6/2009	82	23	32	1.5	0.11	0.18	0.0	0.0	0.0	0.0
3	Al-Badan well	22/6/2009	68	20	26	1.7	0.12	0.2	0.0	0.0	0.0	0.0
4	Alqaryoon spring	22/6/2009	62	15	23	1.6	0.09	0.19	0.0	0.0	0.0	0.0
5	Ein Defna	22/6/2009	65	17	30	1.4	0.08	0.19	0.0	0.0	0.0	0.0
6	Ein Al-Asal	22/6/2009	49	16	20	1.1	0.1	0.15	0.0	0.0	0.0	0.0
7	Ras Al Ein spring	22/6/2009	53	13	21	1.5	0.08	0.18	0.0	0.0	0.0	0.0
Standard level			100	50	200	10	0.300	5	0.01	0.05	0.005	1
Method of determination			Flame Atomic Abs.									

- All measured parameters are within the acceptable Palestinian standard levels.

Appendix 2

Bacteriological Analysis results of Nablus water system(WESI, 2009).

							Bacteriological Analysis	
Date of Sampling	**Sample #**	**Time**	**Sample Point**	**Location**	**Exact Location**	**Res. Cl2 mg/l**	**T.coliform cfu/100ml**	**F.coliform cfu/100ml**
4/1/2009	209	09:20	Reservoir	New Fire Station	Tap	0.4	Nil	Nil
	210	09:30	House tap	Ad-Dawwar	Abaza Sweets	0.2	Nil	Nil
	211	09:35	House tap	Ad-Dawwar	Basuni Restaurant	0.4	Nil	Nil
	212	09:50	House Tap	Masakin	Zakat Dairy Factory	0.3	Nil	Nil
	213	10:00	Well	Audalah	line at dafnah	UNCL	Nil	Nil
	214	10:10	Well	Deir Sharaf	Line at Beit Al Ma'	0.5	Nil	Nil
5/1/2009	215	08:30	Spring	Qaryoun	Before Chlorination	UNCL	360	250
6/1/2009	216	07:20	Reservoir	New Fire Station	Tap	0.4	Nil	Nil
	217	08:20	House Tap	Khallet Al Amoud	House	0.4	Nil	Nil
	218	09:05	Reservoir	Beit Al Ma'	Tap	0.5	Nil	Nil
	219	09:10	Well	Deir Sharaf	Line at Beit Al Ma'	UNCL	Nil	Nil
	220	08:00	Reservoir	Ain Dafnah	Tap	0.4	Nil	Nil
	221	08:10	Spring	Ain Dafnah	Before Chlorination	UNCL	5	3
7/1/2009	222	09:45	Reservoir	New Fire Station	Tap	0.4	Nil	Nil
	223	09:50	Reservoir	Qawareen	Tap	0.4	Nil	Nil
	224	10:00	Reservoir	Beit Al Ma'	Tap	0.5	Nil	Nil
	225	10:10	P.station	Ras Al Ain	Tap	0.6	Nil	Nil

	226	**10:20**	**P.station**	**Ain Al Asal**	**Tap**	**0.4**	**Nil**	**Nil**
	227	**10:30**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.5**	**Nil**	**Nil**
11/1/2009	**228**	**09:45**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	229	**10:00**	**House Tap**	**Masakin**	**Zakat Dairy Factory**	**0.5**	**Nil**	**Nil**
	230	**10:10**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.5**	**Nil**	**Nil**
	231	**10:25**	**Reservoir**	**Jabal Janoubi**	**Tap**	**0.5**	**Nil**	**Nil**
	232	**10:30**	**House Tap**	**Ta'awon street**	**shop**	**0.4**	**Nil**	**Nil**
	233	**10:40**	**P.station**	**As-Sumara**	**Tap**	**0.3**	**Nil**	**Nil**
12/1/2009	**234**	**08:30**	**Spring**	**Qaryoun**	**After chlorination**	**1.0**	**Nil**	**Nil**
	235	**08:40**	**Spring**	**Qaryoun**	**Before Chlorination**	**UNCL**	**Nil**	**Nil**
13/1/2009	**236**	**07:20**	**Reservoir**	**New Fire Station**	**Tap**	**0.3**	**Nil**	**Nil**
	237	**07:40**	**Reservoir**	**Beit Al Ma'**	**Tap**	**0.6**	**Nil**	**Nil**
	238	**07:50**	**Spring**	**beit Al Ma'**	**Before Chlorination**	**UNCL**	**7**	**3**
	239	**07:55**	**House Tap**	**Al Ain camp**	**Butcher**	**0.6**	**Nil**	**Nil**
	240	**08:05**	**House Tap**	**Al Basha street**	**shop**	**0.5**	**Nil**	**Nil**
	241	**08:15**	**House Tap**	**Qawareen**	**Restaurant**	**0.5**	**Nil**	**Nil**
	242	**08:45**	**House Tap**	**Rafidia**	**Restaurant**	**0.3**	**Nil**	**Nil**
	243	**10:45**	**House Tap**	**Al Basha street**	**Okasha house**	**0.4**	**Nil**	**Nil**
	244	**11:00**	**P.station**	**Qaryoun**	**Tap**	**0.5**	**Nil**	**Nil**
14/1/2009	**245**	**09:40**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	246	**09:50**	**House Tap**	**Khallet Al Amoud**	**House**	**0.4**	**Nil**	**Nil**
	247	**10:00**	**House Tap**	**Maa'jeen**	**House**	**0.4**	**Nil**	**Nil**
	248	**10:05**	**House Tap**	**Tulkarm street**	**Azzouni Gas station**	**0.5**	**Nil**	**Nil**
	249	**10:10**	**Reservoir**	**Beit Al Ma'**	**Tap**	**0.6**	**Nil**	**Nil**
	250	**10:15**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**

18/1/2009	**251**	**08:30**	**Spring**	**Beit Al Ma'**	**After chlorination**	**0.6**	**Nil**	**Nil**
	252	**08:40**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**30**	**20**
	253	**09:00**	**Spring**	**Qaryoun**	**After chlorination**	**0.8**	**Nil**	**Nil**
	254	**09:10**	**Spring**	**Qaryoun**	**Before Chlorination**	**UNCL**	**40**	**26**
	255	**09:45**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	256	**10:00**	**House Tap**	**Masakin**	**Zakat Dairy Factory**	**0.3**	**Nil**	**Nil**
	257	**10:05**	**House tap**	**Ad-Dahia**	**Garage**	**0.2**	**Nil**	**Nil**
	258	**10:10**	**Well**	**Audalah**	**line at dafnah**	**UNCL**	**Nil**	**Nil**
	259	**10:15**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.5**	**Nil**	**Nil**
20/1/2009	**260**	**07:30**	**Reservoir**	**New Fire Station**	**Tap**	**0.5**	**Nil**	**Nil**
	261	**07:50**	**House tap**	**Balata camp**	**House**	**0.4**	**Nil**	**Nil**
	262	**08:40**	**Spring**	**beit Al Ma'**	**After chlorination**	**0.5**	**Nil**	**Nil**
	263	**08:50**	**House Tap**	**Aseera street**	**Al Faris Taxi office**	**0.3**	**Nil**	**Nil**
21/1/2009	**264**	**09:15**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	265	**09:30**	**House Tap**	**Amman street**	**Butcher**	**0.3**	**Nil**	**Nil**
	266	**09:45**	**Reservoir**	**beit Al Ma'**	**New reservoir**	**0.5**	**Nil**	**Nil**
	267	**09:50**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**
	268	**10:00**	**Spring**	**Qaryoun**	**After chlorination**	**0.6**	**Nil**	**Nil**
	269	**10:20**	**Spring**	**Qaryoun**	**Water entering the reservoir**	**UNCL**	**900**	**500**
	270	**10:30**	**Spring**	**Qaryoun**	**Spring itself**	**UNCL**	**900**	**600**
25/1/2009	**271**	**09:25**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	272	**09:40**	**House Tap**	**Masakin**	**Zakat Dairy Factory**	**0.4**	**Nil**	**Nil**
	273	**09:50**	**House Tap**	**Amman street**	**Butcher**	**0.4**	**Nil**	**Nil**
	274	**09:55**	**House Tap**	**Al Quds street**	**Sayel Gas station**	**0.3**	**Nil**	**Nil**

	275	**10:05**	**Well**	**Audalah**	**line at dafnah**	**UNCL**	**Nil**	**Nil**
	276	**10:10**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.4**	**Nil**	**Nil**
	277	**08:40**	**Roof tank**	**Habs Ad-Dam**	**Arafat house**	**0.4**	**Nil**	**Nil**
	278	**11:00**	**Spring**	**Qaryoun**	**After chlorination**	**0.6**	**Nil**	**Nil**
	279	**11:10**	**Spring**	**Qaryoun**	**Water entering the reservoir**	**UNCL**	**400**	**270**
	280	**11:20**	**Spring**	**Qaryoun**	**Spring itself**	**UNCL**	**440**	**270**
27/1/2009	**281**	**07:25**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	282	**07:40**	**House Tap**	**Khallet El Eman**	**Al Eman Taxi office**	**0.4**	**Nil**	**Nil**
	283	**08:15**	**P.station**	**Qaryoun**	**Tap**	**0.8**	**Nil**	**Nil**
	284	**08:20**	**House Tap**	**Street #15**	**Old People's Home**	**0.5**	**Nil**	**Nil**
	285	**08:30**	**House Tap**	**Imraij street**	**Restaurant**	**0.4**	**Nil**	**Nil**
	286	**08:55**	**House Tap**	**Rafidia**	**Restaurant**	**0.4**	**Nil**	**Nil**
28/1/2009	**287**	**09:40**	**Reservoir**	**New Fire Station**	**Tap**	**0.6**	**Nil**	**Nil**
	288	**09:45**	**House Tap**	**Faisal street**	**Restaurant**	**0.4**	**Nil**	**Nil**
	289	**09:50**	**House Tap**	**Maa'jeen**	**Qatouni Taxi office**	**0.5**	**Nil**	**Nil**
	290	**10:00**	**House Tap**	**Tulkarm street**	**Azzouni Gas station**	**0.4**	**Nil**	**Nil**
	291	**10:05**	**Reservoir**	**Beit Al Ma'**	**Old reservoir**	**0.7**	**Nil**	**Nil**
	292	**10:10**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**
1/7/2009	**728**	**09:25**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	729	**09:35**	**House Tap**	**Saladin street**	**Restaurant**	**0.4**	**Nil**	**Nil**
	730	**09:40**	**House Tap**	**Khallet Al Amoud**	**House**	**0.4**	**Nil**	**Nil**
	731	**09:50**	**House Tap**	**Faisal street**	**Restaurant**	**0.4**	**Nil**	**Nil**
	732	**09:55**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**

	733	**10:00**	**Spring**	**Beit Al Ma'**	**After chlorination**	**0.4**	**Nil**	**Nil**
	734	**10:05**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**14**	**8**
5/7/2009	**735**	**09:20**	**Reservoir**	**New Fire Station**	**Tap**	**0.5**	**Nil**	**Nil**
	736	**09:35**	**Spring**	**Ain Al Asal**	**After chlorination**	**0.4**	**Nil**	**Nil**
	737	**09:40**	**Spring**	**Ain Al Asal**	**Before Chlorination**	**UNCL**	**12**	**7**
	738	**09:50**	**House Tap**	**Amman street**	**Butcher**	**0.4**	**Nil**	**Nil**
	739	**10:00**	**Well**	**Audalah**	**Line at Dafnah**	**UNCL**	**Nil**	**Nil**
	740	**10:10**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.4**	**Nil**	**Nil**
	741	**10:15**	**Well**	**Badan**	**Line at Dafnah**	**0.3**	**Nil**	**Nil**
7/7/2009	**742**	**07:30**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	743	**07:45**	**House Tap**	**Balata camp**	**House**	**0.4**	**Nil**	**Nil**
	744	**08:00**	**Spring**	**Ras Al Ain**	**After chlorination**	**0.5**	**Nil**	**Nil**
	745	**08:05**	**Spring**	**Ras Al Ain**	**Before Chlorination**	**UNCL**	**Nil**	**Nil**
	746	**08:20**	**House Tap**	**Old City**	**Sabeel an-Nasir**	**0.4**	**Nil**	**Nil**
	747	**08:35**	**House Tap**	**Aseera street**	**Al Faris Taxi office**	**0.3**	**Nil**	**Nil**
8/7/2009	**748**	**08:30**	**Spring**	**Ain Dafnah**	**After chlorination**	**0.4**	**Nil**	**Nil**
	749	**08:35**	**Spring**	**Ain Dafnah**	**Before Chlorination**	**UNCL**	**5**	**3**
	750	**09:00**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	751	**09:30**	**House Tap**	**Jabal Shamali**	**Restaurant**	**0.4**	**Nil**	**Nil**
	752	**09:40**	**Reservoir**	**Beit Al Ma'**	**Tap**	**0.4**	**Nil**	**Nil**
	753	**09:45**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**
	754	**09:50**	**House Tap**	**Tunis street**	**Shop**	**0.4**	**Nil**	**Nil**
12/7/2009	**755**	**07:45**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**>800**	**>800**
	756	**07:50**	**Reservoir**	**Beit Al Ma'**	**Old reservoir**	**0.2**	**15**	**10**
	757	**07:55**	**Reservoir**	**Beit Al Ma'**	**New reservoir**	**0.4**	**Nil**	**Nil**

	758	**09:25**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	759	**09:35**	**House Tap**	**Iraq At-Tayeh**	**Garage**	**0.4**	**Nil**	**Nil**
	760	**09:50**	**House Tap**	**Masakin**	**Zakat Dairy Factory**	**0.3**	**Nil**	**Nil**
	761	**10:00**	**House Tap**	**Asker Old camp**	**Butcher**	**0.4**	**Nil**	**Nil**
	762	**10:10**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.4**	**Nil**	**Nil**
13/7/2009	**763**	**08:20**	**Spring**	**Beit Al Ma'**	**before Chlorination**	**UNCL**	**220**	**160**
14/7/2009	**764**	**07:25**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	765	**07:40**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**250**	**150**
	766	**07:55**	**Spring**	**Beit Al Ma'**	**After chlorination**	**0.5**	**Nil**	**Nil**
	767	**08:20**	**Spring**	**Qaryoun**	**Before Chlorination**	**UNCL**	**20**	**12**
	768	**08:35**	**Spring**	**Qaryoun**	**After chlorination**	**0.6**	**Nil**	**Nil**
	769	**08:45**	**House Tap**	**Jnaid**	**Jnaid prison**	**0.3**	**Nil**	**Nil**
	770	**08:55**	**Reservoir**	**Jnaid**	**Tap**	**0.3**	**Nil**	**Nil**
15/7/2009	**771**	**08:55**	**House Tap**	**Ad-Dawwar**	**Abu Salha sweets**	**0.3**	**Nil**	**Nil**
	772	**09:20**	**Reservoir**	**Ad-Dawwar**	**Commercial Complex (upper reservoir)**	**0.2**	**Nil**	**Nil**
	773	**09:40**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	774	**09:50**	**House Tap**	**Aseera street**	**Al Faris Taxi office**	**0.3**	**Nil**	**Nil**
	775	**09:55**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**80**	**50**
	776	**10:00**	**Reservoir**	**Beit Al Ma'**	**Old reservoir**	**0.6**	**Nil**	**Nil**
	777	**10:05**	**Reservoir**	**Beit Al Ma'**	**New reservoir**	**0.4**	**Nil**	**Nil**
	778	**10:10**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**
21/7/2009	**779**	**07:15**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	780	**07:40**	**House Tap**	**Qawareen**	**Restaurant**	**0.4**	**Nil**	**Nil**

	781	**07:55**	**House Tap**	**Ad-Dawwar**	**Juice shop**	**0.4**	**Nil**	**Nil**
	782	**08:05**	**House Tap**	**Old City**	**As-Salahi Sabeel**	**0.4**	**Nil**	**Nil**
	783	**08:30**	**Spring**	**Ain Al Asal**	**After chlorination**	**0.5**	**Nil**	**Nil**
	784	**08:40**	**Spring**	**Ain Al Asal**	**Before Chlorination**	**UNCL**	**190**	**120**
	785	**08:50**	**House Tap**	**Maa'jeen**	**Qatouni Taxi office**	**0.4**	**Nil**	**Nil**
22/7/2009	**786**	**09:45**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	787	**10:00**	**Well**	**Deir Sharaf**	**Line at Beit Al Ma'**	**UNCL**	**Nil**	**Nil**
	788	**10:05**	**House Tap**	**Al Ain camp**	**Butcher**	**0.4**	**Nil**	**Nil**
	789	**10:10**	**House Tap**	**Tulkarm street**	**Hawwash Wood Stores**	**0.4**	**Nil**	**Nil**
	790	**10:20**	**House Tap**	**Jnaid**	**Jnaid prison**	**0.4**	**Nil**	**Nil**
	791	**10:30**	**Reservoir**	**Jnaid**	**Tap**	**0.4**	**Nil**	**Nil**
	792	**10:40**	**House Tap**	**Street # 15**	**Old People's Home**	**0.4**	**Nil**	**Nil**
	793	**09:30**	**House Tap**	**Makhfiya**	**H. Istaitiyyeh house**	**<0.1**	**>800**	**>800**
	794	**10:00**	**House Tap**	**Makhfiya**	**M.Yadak house**	**<0.1**	**>800**	**>800**
	795	**10:30**	**House Tap**	**Makhfiya**	**A.Al Ghanamih**	**<0.1**	**>800**	**>800**
26/7/2009	**796**	**09:40**	**Reservoir**	**New Fire Station**	**Tap**	**0.4**	**Nil**	**Nil**
	797	**10:00**	**House Tap**	**Masakin**	**Zakat Dairy Factory**	**0.3**	**Nil**	**Nil**
	798	**10:15**	**House Tap**	**Ad-Dahia**	**Garage**	**0.4**	**Nil**	**Nil**
	799	**10:20**	**Well**	**Audalah**	**Line at Dafnah**	**UNCL**	**Nil**	**Nil**
	800	**10:25**	**Reservoir**	**Ain Dafnah**	**Tap**	**0.4**	**Nil**	**Nil**
	801	**10:30**	**Well**	**Badan**	**Line at Dafnah**	**UNCL**	**Nil**	**Nil**
	802	**10:40**	**House Tap**	**Jnaid**	**Jnaid prison**	**0.3**	**Nil**	**Nil**
28/7/2009	**803**	**07:45**	**Spring**	**Ain Dafnah**	**Before Chlorination**	**UNCL**	**Nil**	**Nil**
	804	**08:00**	**Spring**	**Ain Dafnah**	**After chlorination**	**0.4**	**Nil**	**Nil**

	805	**08:15**	**Spring**	**Ain Al Asal**	**Before Chlorination**	**UNCL**	**46**	**25**
	806	**08:20**	**Spring**	**Ain Al Asal**	**After chlorination**	**0.5**	**Nil**	**Nil**
	807	**08:35**	**Spring**	**Qaryoun**	**Before Chlorination**	**UNCL**	**Nil**	**Nil**
	808	**08:40**	**Spring**	**Qaryoun**	**After chlorination**	0.4	**Nil**	**Nil**
	809	**08:50**	**Spring**	**Beit Al Ma'**	**Before Chlorination**	**UNCL**	**72**	**34**
	810	**09:00**	**Spring**	**Beit Al Ma'**	**After chlorination**	**0.5**	**Nil**	**Nil**
	811	**10:45**	**Seepage**	**Faisal street**	**Hamama House**		**260**	**120**
29/7/2009	**812**	**08:30**	**House Tap**	**Makhfiya**	**H. Istaitiyyeh house**	**0.2**	**420**	**240**
	813	**08:35**	**House Tap**	**Makhfiya**	**A.Al Ghanamih**	**0.2**	**Nil**	**Nil**
	814	**08:40**	**House Tap**	**Makhfiya**	**M.Yadak house**	**0.2**	**740**	**380**
	815	**09:05**	**House Tap**	**Makhfiya**	**GH.mraish house**	**0.3**	**Nil**	**Nil**
	816	**09:20**	**House Tap**	**Al-seka Street**	**Mustafa Dula**	**0.1**	**Nil**	**Nil**

Appendix 3

Pumping days and periods for all water service zones in the months of January and August, 2010(WWSD,2010)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Aseera-Al-Namsawi						18			10					11				11		
Al-Mraij						15		12				15				14				15
Rafedia (W0)	12							12				14				12				14
Old Junblat				12				7.6					10			7.5				12
Ein Beit Elma Camp		8.8		9.3			8.8			5.3			6	11		8.5			8.4	
Aseera	10	15								12				13				11		
Zawata					12				16				13				13			
Al-Ma'ajeen					13				16				13				13			
Haifa Str.	10				11				8					11				12		
Al-Junaid		7.6				7.6				8.2				8.3				8		
New Junblat			8			8.8					18				9.8				9	
Ras Al-Ein				8.3				7.4				7.8				7				7.9
Al-Basha					7.4			7.4				7.4				7				7.9
Abu Obaida			6.5				8.5				7.9				8.8				8.3	
Al-Ta'awon		6.2				7				7.5				7				8.7		
New Nablus		8.2				9				7.5				8.3				8.7		
Till Str.		13					18				16				14				14	

Fatayer+Kshaikeh			7.7								9				9				9.8	
New Fatayer			9.3					8	10			9.5				11				10
Al-Quds Str			12				9.5					15			11				12	
Amman Str.							13					14			13				12	
Iraq Al-Tayeh						12	19							20				21		
Khalet Al-Amoud		9.5				12				11				9.5				11		
Salah Al-Deen Str.		9.5				12				11				12				11		
Al-Dahyeh				14				17					20			16			12	
Balata Camp				9.5				11				9.5				12			10	
Askar Camp		12				14				11				12				11		
Lower Khalet Al-Eman	10				10				8				19				9.2			
Al-Makhfiya				12					15				13				13			
15 St.		15				12				12				12				12		
Imad Al-Deen			11					16				15		16						13
Upper Khalet Al-Eman		13									9				12				16	
Old City		3.7				12	12			12				12				15		
Al-Sikeh Str	10			11				12				12					15			15
Al-Qaruon		4			11	6		12	4		4	5	5.5	2	1.2	3	2			11

	January, 2010											August, 2010									
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aseera-Al-Namsawi		14			12				11				11.3				12.3				12
Al-Mraij		4.4		13			15	15			13				**14.5**				**2**		
Rafedia (W0)		4.3		12			14	15			12				16				13		
Old Junblat		2		12								12				8				8.5	
Ein Beit Elma Camp					9	14								8			8			9.5	
Aseera		13							12					5.5				9			6.3
Zawata	12				10			9.5					16.5			14.5					14.17
Al-Ma'ajeen	12				10			9.5					16.5			14.5					14.2
Haifa Str.		12											12.5				10.5				6
Al-Junaid		9.3				7				11				10.3				11.17			
New Junblat		10				11				7					21				10		
Ras Al-Ein				6.5				7.9							7.17			7			7
Al-Basha				6.5				7.9							7.17			7			7
Abu Obaida														6.5				8.5			
Al-Ta'awon		9.9				7.8				6			6.2				7				7.5
New Nablus		9.9				7.8				6			8.2				9				7.5
Till Str.		15				15				15			13					18			

Fatayer+Kshaikeh			10				9				5			7.7							
New Fatayer			10				9.3				11			9.3					8	10	
Al-Quds Str			6				9				12			12				9.5			
Amman Str.			6				9				17							13			
Iraq Al-Tayeh	13				17				2.5	12							12	19			
Khalet Al-Amoud		9.5				12				10			9.5				12				11
Salah Al-Deen Str.		9.5				12				10			9.5				12				11
Al-Dahyeh			15					12							14				17		
Balata Camp			10					12							9.5				11		
Askar Camp	12				12					12			12				14				11
Lower Khalet Al-Eman	9				9.5							10				10				8	
Al-Makhfiya	13			15					15						12					15	
15 St.	13				11				12				15				12				12
Imad Al-Deen				14			15							11					16		
Upper Khalet Al-Eman			14				15				17		13								
Old City		16			12				15				3.7				12	12			12
Al-Sikeh Str				14				12				10			11				12		
Al-Qaruon	2	1.5		4		6.7	11	5	4	7.5			4			11	6		12	4	

August, 2010

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Aseera-Al-Namsawi	10.5			10								9		12.9				9			11.3
Al-Mraij		**15**				**14.3**					**6.3**		**4.3**	**21.3**				**4**			**4**
Rafedia (W0)		4.5				3.7					6.3			5				5.3			13.17
Old Junblat			9				11					8			10				10.3		
Ein Beit Elma Camp		4			14			8.5				8.17		8			7.17			7.7	
Aseera				2				1.3					4			3				12	
Zawata				4.5			6.5					8				4			10.7		
Al-Ma'ajeen				4.5			6.5					8				4			10.7		
Haifa Str.				2				13								4.3				9	
Al-Junaid					13.5				3				13.5				12.7			10	
New Junblat						13.17					14.7		3.5	3.5				11.17			12
Ras Al-Ein			7.3			8.7			4.5						3.5			6.3			6
Al-Basha			7.3			8.7			4.5						3.5			6.3			6
Abu Obaida	7.9				8.8				8.3												
Al-Ta'awon				7				8.7				9.9				7.8				6	
New Nablus				8.3				8.7				9.9				7.8				6	
Till Str.	16				14				14			15				15				15	

Fatayer+Kshaikeh	9				9				9.8				10				9				5
New Fatayer		9.5				11				10			10				9.3				11
Al-Quds Str		15			11				12				6				9				12
Amman Str.		14			13				12				6				9				17
Iraq Al-Tayeh				20				21			13				17				2.5	12	
Khalet Al-Amoud				9.5				11				9.5				12				10	
Salah Al-Deen Str.				12				11				9.5				12				10	
Al-Dahyeh			20			16			12				15					12			
Balata Camp		9.5				12			10				10					12			
Askar Camp				12				11			12				12					12	
Lower Khalet Al-Eman			19				9.2				9				9.5						
Al-Makhfiya			13				13				13			15					15		
15 St.				12				12			13				11				12		
Imad Al-Deen		15		16						13				14			15				
Upper Khalet Al-Eman	9				12				16				14				15				17
Old City				12				15				16			12				15		
Al-Sikeh Str		12					15			15				14				12			
Al-Qaruon	4	5	5.5	2	1.2	3	2			11	2	1.5		4		6.7	11	5	4	7.5	

APPENDIX 4

Test of Pipe materials Means

To check the effect of pipe material on the formation of DBP the following data were analyzed:

NO	New steel pipe		Polypropylene	
	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)
1	NS1/1	88	P1/1	63
2	NS1/2	92	P1/2	74
3	NS1/3	93	P1/3	74
4	NS1/4	136	P1/4	111
5	NS1/5	156	P1/5	141
6	NS1/6	171	P1/6	159
7	NS2/1	94	P2/1	72
8	NS2/2	114	P2/2	89
9	NS2/3	162	P2/3	157
10	NS2/4	276	P2/4	259
11	NS2/5	302	P2/5	287
12	NS2/6	319	P2/6	307
13	NS3/1	89	P3/1	81
14	NS3/2	187	P3/2	163
15	NS3/3	151	P3/3	138
16	NS3/4	201	P3/4	193
17	NS3/5	262	P3/5	238
18	NS3/6	281	P3/6	273

Step 1: Formulation of hypotheses

Ho: $\mu 1=\mu 2$

HA: at least one pair of group means are not equal

Step 2: Define the test statistic and its distribution

F=MSb/MSw

Step 3: specify the level of significance = 5%

Step4: collect data and compute test statistic

Parameter	$\mu 1$	$\mu 2$	K	N
Value	176.3	159.9	2	36
Parameter	Nj	μt	SSb	SSw
Value	18	168.1	2417.4	222134.9

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between	2417.4	1	2417.4
Within	222134.9	34	6533.4
Total	224552.3	35	----

Step 5: Determination the critical value of the test statistic from F distribution tables

F	F critical
0.37	4.13

Step 6: Make a decision-

F is less than F critical; the null hypothesis should be accepted

APPENDIX 5

Test of Pipe ages Means

To check the effect of pipe age on the formation of DBP the following data were analyzed:

NO	New steel pipe		Old steel pipe	
	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)
1	NS1/1	88	OS1/1	111
2	NS1/2	92	OS1/2	131
3	NS1/3	93	OS1/3	121
4	NS1/4	136	OS1/4	148
5	NS1/5	156	OS1/5	176
6	NS1/6	171	OS1/6	193
7	NS2/1	94	OS2/1	123
8	NS2/2	114	OS2/2	169
9	NS2/3	162	OS2/3	188
10	NS2/4	276	OS2/4	298
11	NS2/5	302	OS2/5	326
12	NS2/6	319	OS2/6	357
13	NS3/1	89	OS3/1	118
14	NS3/2	187	OS3/2	211
15	NS3/3	151	OS3/3	160
16	NS3/4	201	OS3/4	215
17	NS3/5	262	OS3/5	288
18	NS3/6	281	OS3/6	298

Step 1: Formulation of hypotheses

Ho: $\mu 1=\mu 2$

HA: at least one pair of group means are not equal

Step 2: Define the test statistic and its distribution

F=MSb/MSw

Step 3: specify the level of significance = 5%

Step4: collect data and compute test statistic

Parameter	$\mu 1$	$\mu 2$	K	N
Value	176.3	201.7	2	36
Parameter	Nj	μt	SSb	SSw
Value	18	189	5801.4	213542

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between	5801.4	1	5801.4
Within	213541.6	34	6280.6
Total	219343.0	35	----

Step 5: Determination the critical value of the test statistic from F distribution tables

F	F critical
0.92	4.13

Step 6: Make a decision-

F is less than F critical; the null hypothesis should be accepted

APPENDIX 6

Test of chlorine concentrations Means

To check the effect of chlorine concentration on the formation of DBP the following data were analyzed:

NO	Cl1 = 0.3 mg/l		Cl2= 0.6 mg/l		Cl3= 0.9 mg/l	
	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)
1	OS1/1	111	OS3/1	118	OS2/1	123
2	OS1/2	131	OS3/2	211	OS2/2	169
3	OS1/3	121	OS3/3	160	OS2/3	188
4	OS1/4	148	OS3/4	215	OS2/4	298
5	OS1/5	176	OS3/5	288	OS2/5	326
6	OS1/6	193	OS3/6	298	OS2/6	357
7	NS1/1	88	NS3/1	89	NS2/1	94
8	NS1/2	92	NS3/2	187	NS2/2	114
9	NS1/3	93	NS3/3	151	NS2/3	162
10	NS1/4	136	NS3/4	201	NS2/4	276
11	NS1/5	156	NS3/5	262	NS2/5	302
12	NS1/6	171	NS3/6	281	NS2/6	319
13	P1/1	63	P3/1	81	P2/1	72
14	P1/2	74	P3/2	163	P2/2	89
15	P1/3	74	P3/3	138	P2/3	157
16	P1/4	111	P3/4	193	P2/4	259
17	P1/5	141	P3/5	238	P2/5	287
18	P1/6	159	P3/6	273	P2/6	307

Step 1: Formulation of hypotheses

Ho: $\mu 1=\mu 2$

HA: at least one pair of group means are not equal

Step 2: Define the test statistic and its distribution

F=MSb/MSw

Step 3: specify the level of significance = 5%

Step 4: collect data and compute test statistic

Parameter	$\mu 1$	$\mu 2$	$\mu 3$	K	N
Value	124.3	197.1	216.6	3	54
Parameter	Nj	μt	SSb	SSw	
Value	18	179.3	85116.8	258349	

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between	85116.8	2	42558.4
Within	258349.2	51	5065.7
Total	343466.0	53	----

Step 5: Determination the critical value of the test statistic from F distribution tables

F	F critical
8.40	3.18

Step 6: Make a decision-
F is greater than F critical; the null hypothesis should be rejected
Multiple comparisons in the ANOVA test using Duncan Multiple Range Test
Ho: $\mu i=\mu j$
Rm=SX(rm)
SX=(MSw /nj)0.5

SX	rm	Rm
16.78	2.85	47.81

Groups i,j	µi	µj	Range	decision
1,2	124.3	197.1	72.7	reject Ho
1,3	124.3	216.6	92.3	reject Ho
2,3	197.1	216.6	19.6	Accept Ho

The means pair of 1,2 groups are significantly different
The means pair of 1,3 groups are significantly different
The means pair of 2,3 groups are not significantly different

APPENDIX 7

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
TTHM	179.3333	80.50149	54
CL	2.0000	.82416	54

Correlations

		TTHM	CL
Pearson Correlation	TTHM	1.000	.472
	CL	.472	1.000
Sig. (1-tailed)	TTHM	.	.000
	CL	.000	.
N	TTHM	54	54
	CL	54	54

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	CL[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TTHM

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.472[a]	.223	.208	71.63332

a. Predictors: (Constant), CL

b. Dependent Variable: TTHM

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	76636.694	1	76636.694	14.935	.000[a]
	Residual	266829.3	52	5131.333		
	Total	343466.0	53			

a. Predictors: (Constant), CL

b. Dependent Variable: TTHM

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	87.056	25.791		3.375	.001
	CL	46.139	11.939	.472	3.865	.000

a. Dependent Variable: TTHM

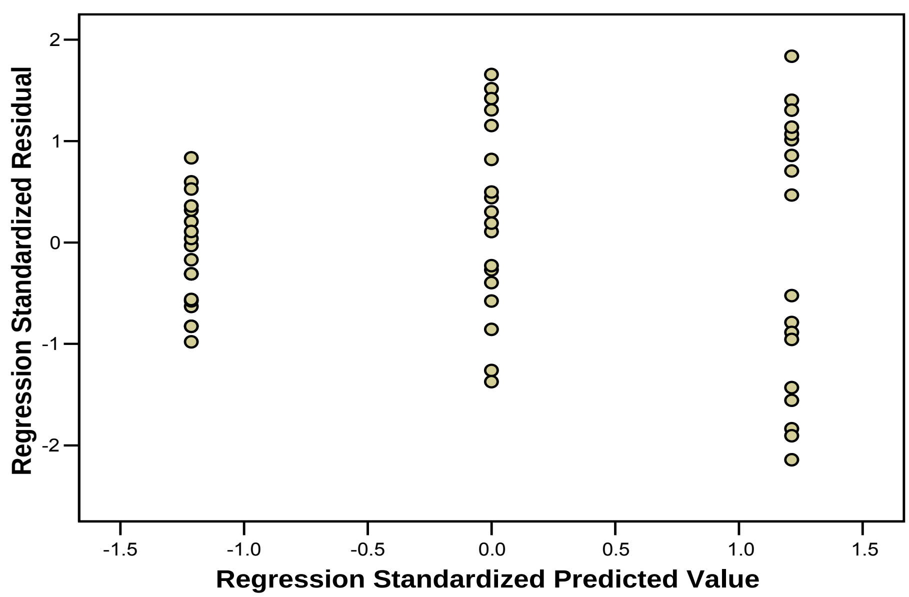
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	133.1944	225.4722	179.3333	38.02598	54
Residual	-153.472	131.52777	.00000	70.95432	54
Std. Predicted Value	-1.213	1.213	.000	1.000	54
Std. Residual	-2.142	1.836	.000	.991	54

a. Dependent Variable: TTHM

Scatterplot

Dependent Variable: TTHM



APPENDIX 8

Test of BOD concentrations Means

To check the effect of BOD concentration on the formation of DBP the following data were analyzed:

NO	BOD1= 0 mg/l		BOD2= 10 mg/l		BOD3= 30 mg/l	
	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)
1	OS1/1	111	OS1/3	121	OS1/5	176
2	OS3/1	118	OS3/3	160	OS3/5	288
3	OS2/1	123	OS2/3	188	OS2/5	326
4	OS1/2	131	OS1/4	148	OS1/6	193
5	OS3/2	211	OS3/4	215	OS3/6	298
6	OS2/2	169	OS2/4	298	OS2/6	357
7	NS1/1	88	NS1/3	93	NS1/5	156
8	NS 3/1	89	NS 3/3	151	NS 3/5	262
9	NS 2/1	94	NS 2/3	162	NS 2/5	302
10	NS 1/2	92	NS 1/4	136	NS 1/6	171
11	NS 3/2	187	NS 3/4	201	NS 3/6	281
12	NS 2/2	114	NS 2/4	276	NS 2/6	319
13	P1/1	63	P1/3	74	P1/5	141
14	P 3/1	81	P 3/3	138	P 3/5	238
15	P 2/1	72	P 2/3	157	P 2/5	287
16	P 1/2	74	P 1/4	111	P 1/6	159
17	P 3/2	163	P 3/4	193	P 3/6	273
18	P 2/2	89	P 2/4	259	P 2/6	307

Step 1: Formulation of hypotheses
Ho: $\mu 1=\mu 2$
HA: at least one pair of group means are not equal
Step 2: Define the test statistic and its distribution
F=MSb/MSw
Step 3: specify the level of significance = 5%
Step4: collect data and compute test statistic

Parameter	$\mu 1$	$\mu 2$	$\mu 3$	K	N
Value	114.9	171.2	251.9	3	54
Parameter	Nj	μt	SSb	SSw	
Value	18	179.3	170584.8	172881	

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between	170584.8	2	85292.4
Within	172881.2	51	3389.8
Total	343466.0	53	----

Step 5: Determination the critical value of the test statistic from F distribution tables

F	F critical
25.16	3.18

Step 6: Make a decision-
F is greater than F critical; the null hypothesis should be rejected
Multiple comparisons in the ANOVA test using Duncan Multiple Range Test
Ho: $\mu i=\mu j$
Rm=SX(rm)
SX=(MSw /nj)0.5

SX	rm	Rm
13.72	2.85	39.11

Groups i,j	μi	μj	Range	decision
1,2	114.9	171.2	56.2	reject Ho
1,3	114.9	251.9	136.9	reject Ho
2,3	171.2	251.9	80.7	reject Ho

The means pair of 1,2 groups are significantly different
The means pair of 1,3 groups are significantly different
The means pair of 2,3 groups are significantly different

APPENDIX 9

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
TTHM	179.3333	80.50149	54
BOD	2.0000	.82416	54

Correlations

		TTHM	BOD
Pearson Correlation	TTHM	1.000	.701
	BOD	.701	1.000
Sig. (1-tailed)	TTHM	.	.000
	BOD	.000	.
N	TTHM	54	54
	BOD	54	54

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	BOD[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TTHM

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.701[a]	.491	.482	57.95920

a. Predictors: (Constant), BOD

b. Dependent Variable: TTHM

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	168784.0	1	168784.028	50.244	.000[a]
	Residual	174682.0	52	3359.269		
	Total	343466.0	53			

a. Predictors: (Constant), BOD

b. Dependent Variable: TTHM

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	42.389	20.868		2.031	.047
	BOD	68.472	9.660	.701	7.088	.000

a. Dependent Variable: TTHM

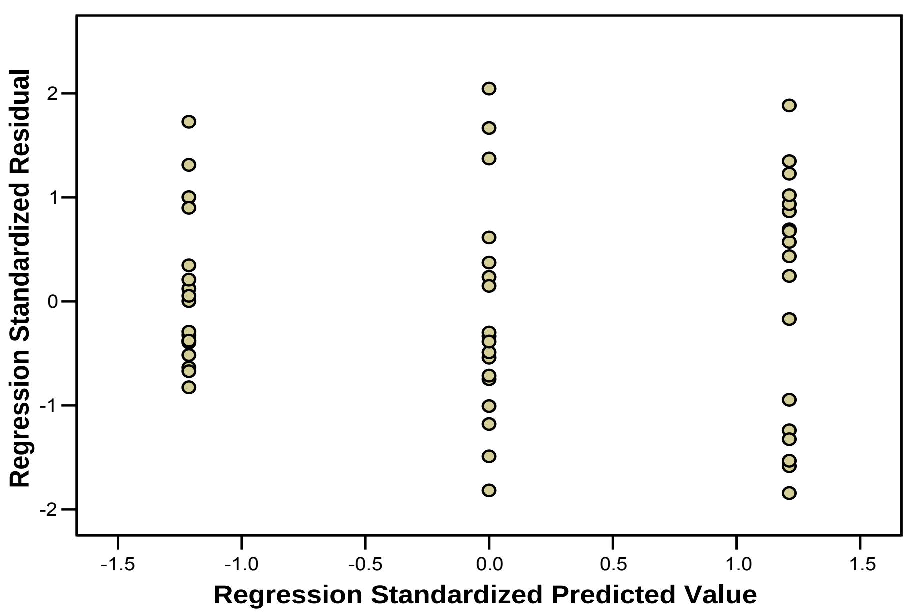
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	110.8611	247.8056	179.3333	56.43230	54
Residual	-106.806	118.66666	.00000	57.40981	54
Std. Predicted Value	-1.213	1.213	.000	1.000	54
Std. Residual	-1.843	2.047	.000	.991	54

a. Dependent Variable: TTHM

Scatterplot

Dependent Variable: TTHM



APPENDIX 10

Test of incubation periods means

To check the effect of incubation period on the formation of DBP the following data were analyzed:

NO	t1= 72 hr		t2= 120 hr	
	Sample No	TTHM (ppb)	Sample No	TTHM (ppb)
1	OS1/1	111	OS1/2	131
2	OS1/3	121	OS1/4	148
3	OS1/5	176	OS1/6	193
4	OS2/1	123	OS2/2	169
5	OS2/3	188	OS2/4	298
6	OS2/5	326	OS2/6	357
7	OS3/1	118	OS3/2	211
8	OS3/3	160	OS3/4	215
9	OS3/5	288	OS3/6	298
10	NS1/1	88	NS1/2	92
11	NS 1/3	93	NS 1/4	136
12	NS 1/5	156	NS 1/6	171
13	NS 2/1	94	NS 2/2	114
14	NS 2/3	162	NS 2/4	276
15	NS 2/5	302	NS 2/6	319
16	NS 3/1	89	NS 3/2	187
17	NS 3/3	151	NS 3/4	201
18	NS 3/5	262	NS 3/6	281
19	P1/1	63	P1/2	74
20	P 1/3	74	P 1/4	111
21	P 1/5	141	P 1/6	159
22	P 2/1	72	P 2/2	89
23	P 2/3	157	P 2/4	259
24	P 2/5	287	P 2/6	307
25	P 3/1	81	P 3/2	163
26	P 3/3	138	P 3/4	193
27	P 3/5	238	P 3/6	273

Step 1: Formulation of hypotheses
Ho: $\mu 1=\mu 2$
HA: at least one pair of group means are not equal
Step 2: Define the test statistic and its distribution
$F=MSb/MSw$

Step 3: specify the level of significance = 5%

Step4: collect data and compute test statistic

Parameter	μ1	μ2	K	N
Value	157.7	200.9	2	54
Parameter	Nj	μt	SSb	SSw
Value	27	179.3	25177.0	318289

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between	25177.0	1	25177.0
Within	318289.0	52	6120.9
Total	343466.0	53	----

Step 5: Determination the critical value of the test statistic from F distribution tables

F	F critical
4.11	4.03

Step 6: Make a decision-

F is greater than F critical; the null hypothesis should be rejected

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قدمت هذه الأطروحة استكمالاً لمتطلبات درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العاليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2010

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الملخص

في مدينة نابلس الواقعة شمال الضفة الغربية المحتلة نظاما مائيا يخدم حوالي 177000 نسمة من مدينة نابلس وبعض التجمعات المحيطة بها، ويتألف من خمسة آبار وخمسة ينابيع وثلاثة عشر خزانا وثلاثة عشر محطة ضخ وشبكة مياه بطول304 كم تقريبا من مواسير مختلفة الأقطار والأنواع والأعمار، يتم تعقيم المياه من خلال الكلورة باستخدام هيبوكلوريت الصوديوم، ومن الملاحظ ان نسبة الفاقد في 2010 بلغت 29%، مما يشير إلى وجود تسرب من الشبكة وان أي تلوث محيط بخطوط الماء التالفة يمكن أن يؤدي إلى دخول الملوثات إلى الشبكة وتلويث المياه، وان وجود الكلور وتفاعله مع الملوثات يؤدي إلى تشكل النواتج الثانوية لاستخدام الكلور في تعقيم المياه والتي أثبتت الدراسات أن وجودها في مياه الشرب يؤدي إلى الإصابة بعدد من الأمراض منها السرطان.

تم من خلال هذا البحث إجراء دراسة مسحية بأخذ عينات ممثلة للنظام المائي في نابلس بالتنسيق مع دائرة المياه والصرف الصحي التابعة لبلدية نابلس وفحص نسبة النواتج الثانوية على شكل ترايهالوميثان الكلي وتبين أن كل العينات تحتوي على الترايهالوميثان الكلي ولكن بنسب ضمن المسموح به باستثناء عينة واحدة، مما يعني ضرورة أن يتم اخذ عينات بشكل دوري من النظام لمراقبة وضبط هذا المصدر بالذات وكذلك النظام المائي. كما تم دراسة عدد من العوامل التي تؤثر على نسبة النواتج خاصة الأوكسجين المستهلك حيويا ونسبة الكلور وفترة الحضانة، حيث تم تثبيت مجموعة من المواسير في المختبر بأنواع وأعمار مختلفة ومن ثم

إضافة نسب مختلفة من الكلور والملوث ولفترات حضانة مختلفة ومن ثم إجراء فحص لنسبة الترايهالوميثان وإجراء تحليلات إحصائية لاستخلاص النتائج.

حيث أثبتت الدراسة أن العلاقة بين تشكل النواتج الثانوية لاستخدام الكلور وكل من تركيز جرعة الكلور والاكسجين المستهلك حيويا وفترة الحضانة (مكوث المياه في الخزانات أو الشبكة) وعمر الماسورة هي علاقة طردية أي أنها تزداد بزيادة أي منها.

كما لوحظ أن نسبة الترايهالوميثان في مواسير الحديد هي أكبر منها في مواسير البلاستيك وكذلك في المواسير القديمة أكبر منها في المواسير الجديدة، ولكن نتائج تحليل البيانات إحصائيا أظهرت أن الفروقات هي ليست كبيرة، مما يجعل هذين العاملين (نوع الماسورة وعمرها) إحصائيا غير مؤثرين على زيادة أو نقصان تشكل النواتج الثانوية لاستخدام الكلور.

مما سبق، وبناءا على النتائج التي تم الوصول اليها، فانه وجد ما يلي:

- يوجد نواتج ثانوية على شكل ترايهالوميثان في النظام المائي في نابلس.
- يوجد علاقة واضحة بين تشكل النواتج الثانوية في النظام المائي في نابلس وكل من تركيز جرعة الكلور والاكسجين المستهلك حيويا وفترة الحضانة.
- يجب ان يتم العمل على استبدال خطوط المياه القديمة وخاصة التالف والمتآكل منها.
- ضرورة السعي الحثيث والمتواصل لإيجاد مصادر مياه إضافية، لحل مشكلة شح المياه وبالتالي ضمان تقليل فترة مكوث المياه في الخزانات والشبكات وتجددها بشكل متواصل.
- يجب أن يتم مراقبة وضبط تركيز جرعة الكلور االمستخدمة لتعقيم المياه وان يتم تحديدها بدقة.
- العمل على تقليل نسبة الفاقد في المياه، وضمان عدم تسرب الملوثات إلى داخل الشبكة.