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# Monitoring and Modeling of Fayoum Distribution Networks According to Trihalomethanes Formation

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**Abstract**

This paper aimed to predict THMs con. in water networks having multiple feeding sources. Results showed that the THMs con. in all the selected points in the distribution network of Fayoum, Egypt was less than the maximum acceptable con. A statistically-based empirical models were developed for predicting THMs formation under different condition. The first model was developed to predict THMs con. at the exit of the conventional WTPs with $R^2$ = 0.83. The second model was developed to predict THMs con. at the exit of the Direct filtration WTPs with $R^2$= 0.842. The third model was developed to predict THMs con. for water supply networks having one feeding source with $R^2$ = 0.856. The fourth model was developed to predict THMs con. for water supply networks having multi-feeding sources with $R^2$ = 0.555. Furthermore, WaterCad program was used to predict THMs con. at FWSN with 1.55 $day^{-1}$ THMs growth rate.

**Keywords:** Trihalomethanes, Disinfections by-products, Distribution networks

## 1. Introduction

Water disinfection with chlorine to improve the hygienic quality of water by eliminating waterborne bacterial pathogens such as dysentery and diarrheal diseases, cholera, typhoid fever, hepatitis A, etc. has been the major disinfection process for municipal drinking water since the early twentieth century. However, in 1976, it was discovered that disinfections by-products (DBPs) were produced during the disinfection process (Marhaba and Washington 1998). Chlorine, which exists as hypochlorous acid and hypochlorite in water reacts with natural organic compounds such as humic and fulvic acids to form a wide range of undesired halogenated organic compounds, including trihalomethanes (THMs), haloacetic acids, chlorophenols, chloral hydrate and haloacetonitriles (Gallard and von Gunten 2002). THMs have been found to be the most prevalent organic contaminants in drinking water and typically occur at higher concentrations than other disinfection by-products. The four THMs (chloroform, dichloro-bromomethane, dibromo-chloromethane and bromoform) are formed when chlorine based disinfectants are added to source waters. Previous investigations have shown that the major variables that affect THM formation are chlorine dose and residual, concentration and type of TOC, contact time, pH, temperature of water, and the presence of inorganic compounds such as bromide (Najm et al. 1994). In general, higher THM concentrations are expected if the parameters above are higher (Nikolaou and Lekkas 2001; Nikolaou et al. 2004a, b; USEPA 1999 b). Chloroform is usually the most widespread by-product formed in drinking water after chlorination processes, although brominated THMs can occur at higher concentrations when waters with high bromide concentrations are chlorinated (Najm et al. 1994). The concern of DBPs formed during disinfection processes is based on the evidence that they have some adverse health effects, in particular cancer and reproductive disorders (Arora et al. 1997; Woo et al. 2002). Research on health effects showed a relationship between THMs exposure and bladder cancer. Recently, THMs were suspected to cause not only cancer but also liver and kidney damage, retarded foetus growth, birth defects and possibly miscarriage (Wright et al. 2004). The US Department of Health and Human Services has determined that chloroform ($CHCl_3$) may be anticipated to be a carcinogen (USEPA 2001a). Also, it has been shown that dibromochloromethane ($CHClBr_2$) and bromoform ($CHBr_3$) could damage the nervous system. Disinfected

drinking water from surface waters generally contains higher concentrations of DBPs than groundwater due to the higher concentration of natural organic material (NOM). The objective of this study presented in this paper is to evaluate of Fayoum water distribution networks (Egypt) according to THMs formation and develop a statistically-based empirical models that expresses THMs concentration and use WaterCad software developed by Haestad Methods to predict TTHM concentrations at different locations of Fayoum water distribution networks and then compare predicted concentrations to actual measurements.

## 2. Fayoum water distribution networks

The water utilities taken as a case study are those supplying the province of Fayoum. The distribution networks is a mixing of tree and grid types and it has more than one source for the feeding in the same pipe line. The lengths of the carrier and distribution networks about 4180 km with diameters from 100 mm to 1000 mm (17% carrier lines with diameter from 300 mm to 1000 mm and 83% distribution line with diameter from 100 mm to 300 mm). The network consists of more than one type of pipes such as ( PVC – DI – AC – CI – PRC – HDPE ) and it had been constructed 1926 until now. The source of water for Fayoum Water Supply Network are Four conventional and Seventeen direct filtration water treatment plants. Fig (1) illustrates the FWDN .

Figure 1. Illustrates the FWDN

## 3 Methodology

The study presented in this paper consists of three parts; the first part is a sampling program that aims at measuring THMs concentrations throughout FWDN over time, from treated water to the extremities of the distribution systems. The second part is the development of three mathematical models, The first model uses for predict the THMs concentration at the exit of the conventional WTPs , the second model uses for predict the THMs concentration at the exit of the Direct filtration WTPs , the third model uses for predict the THMs concentration for water supply networks having one feeding source, and finally, the fourth model uses for predict the THMs concentration for water supply networks having multi-feeding sources . The third

part utilizes THMs growth rate and THMs concentration at the exit of WTPs along with WaterCad to predict THMs concentrations throughout Fayoum water supply. After that predicted THMs concentrations are compared to actual concentrations obtained by the sampling program.

## 4 Experimental

### *4-1 Sampling*

Samples were collected monthly from different sampling points at four WTPs (New Azab, Old Azab, El Rayan, and Kasr El Basil WTP) in raw water and at the exit of WTPs before distribution, these samples were taken to characterize the quality of treated water leaving the plant as well as initial formation of THMs, and ten samples were taken at the distribution systems for each feeding before any mixing and in the distribution systems after mixing at different distance from the origin in order to represent water with moderate and high residence time within the distribution system. The water samples were quenched with sodium thiosulfate ($Na_2S_2O_3$) and stored in 40-mL vials closed with Teflon-lined screw caps at 4 ℃ until the analysis. Table (1) represents the nomenclature, the location of the sampling points and the travel time from the plant to the sampling points along the distribution network.

Table 1. Represents the nomenclature and the location of the sampling points.

| Sample code | Location | travel time (min.) | Sample code | Location | travel time (min.) |
|---|---|---|---|---|---|
| $NAT_w$ | Treated water (before distribution) At New Azab plant (Conventional TP.) | 0.00 | NOAd2 | (Abo-Shaqura) Sample2 at New Azab & Old Azab dist. network | 93.66-NATP<br>52.02-OAT |
| NAd1 | (Mosque in Alquases-Algindy) Sample1 at New Azab dist. network | 45.06 | $KBT_w$ | Treated water (before distribution) At Kasr El Basil plant (Direct filtration TP.) | 00.00 |
| NAd2 | (Rstom Dala) Sample2 at New Azab dist. network | 82.98 | NAKBd1 | (Kasr El Basil) Sample1 at New Azab & Kasr El Basil dist. network | 379.2-NATP<br>2.00-KBTP |
| NAd3 | (Alshawashna) Sample3 at New Azab dist. network | 524.28 | KBd1 | (Alsareria) Sample1 at Kasr El Basil dist. network | 85.00 |
| NAd4 | (Klamchah) Sample4 at New Azab dist. network | 307.50 | $RT_w$ | Treated water (before distribution) At EL-Rayan plant (Direct filtration TP.) | 0.00 |
| NAd5 | (Ebshwaye) Sample4 at New Azab dist. network | 480.65 | Rd1 | (AL-Hosynia) Sample2 at EL-Rayan distribution network | 100.08 |
| $OAT_w$ | Treated water (before distribution) At Old Azab plant (Conventional TP.) | 0.00 | Rd2 | (AL-Moqurany) Sample1 at EL-Rayan distribution network | 143.64 |
| NOAd1 | (Army stores) Sample1 at New Azab & Old Azab dist. network | 42.72-NATP<br>00.00-OAT | | | |

### *4-2 Measured parameters*

The parameters measured were pH, Free Chlorine, Bromine, Temperature, Travel Time, TOC and THMs (and its component)

*4-3 Equipment*

The following equipment were used:

HANNA – HI83200 Multi parameter Ion Specific Meter, was used for measuring pH value, Residual Chlorine, and Bromine concentration for each sample at the site.

APOLLO 9000 TOC analyzer, was used for measuring TOC concentration for each sample at Central Laboratory of Fayoum.

Agilent (7890A) Gas Chromato-graphy , was used for measuring THMs concentration for each sample and each components at Central Laboratory of Fayoum.

*4-4 Computer program*

The following software were used:

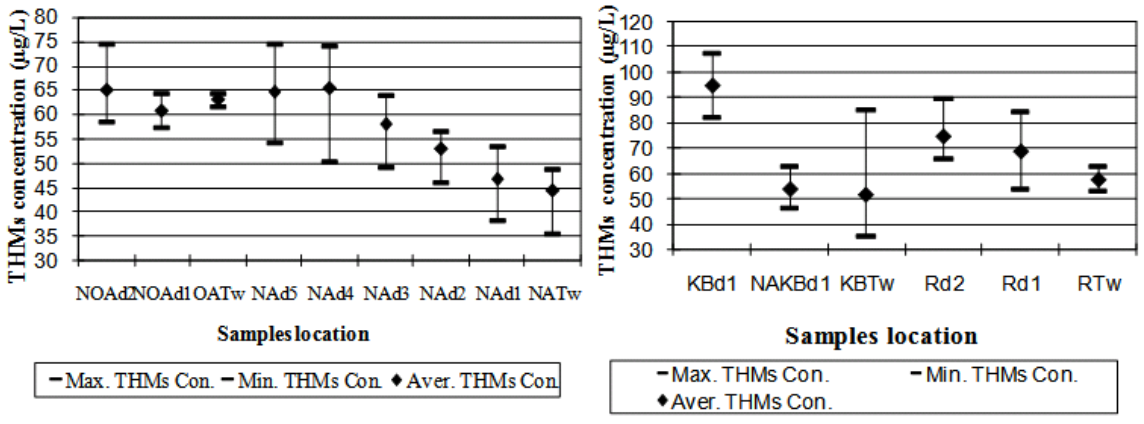
Statistical Package for Social Sciences (SPSS) , was used for developing mathematical models for predict THMs at FWDN.

WaterCad , is a software developed by Haestad Methods (Bentley WaterCad V8, 2007). WaterCad simulates flow, pressure, water age, and constituent concentration throughout distribution systems as a result of transport, mixing, and growth or decay of the constituent. Input to WaterCad includes network connectivity, pipes characteristics such as length, diameter, and frictio n coefficient, nodal elevations, nodal demands, demand patterns, reservoir elevations, and characteristics of any other devices such as pumps and valves.

## 5 Results and discussion

*5-1 THMs concentration*

Figures 2,3 shows the variations in THMs concentration for each sample in plant effluent and the distribution system. Generally, higher THMs formation occurred in spring and summer for all the four plants. On the average, in-plant THMs levels for the four plants ranged from 44.2 to 61.4 μg L−1, while distribution system THMs levels ranged from 46.5 to 95.2 μg L−1. It is noted that THMs levels in the distribution system increased from less than 140% to more than 180% compared to the in-plant THMs levels. The increases in the distribution system were not directly correlated with the total travel/residence times. TOC, Br, Temperature, and the mixing between two feeding sources all influence this disparity.




Figures 2,3. Illustrates THMs concentration

*5-2 Empirical modeling of THMs formation*

In this study, multiple linear regression analysis was used to model THMs formation during enhanced coagulation process. The general strategy adopted to develop model equation was to describe the roles of TOC, chlorine dose, residual chlorine, temperature , pH, Bromine and travel time in formation of THMs. The model coefficients obtained were used to predict THMs formation. The concentrations of THMs are expressed as (µg/L), the TOC, chlorine dose, residual chlorine, Bromine as mg/L, the coagulant and chlorine dose as mg/L, while the travel time as hour (hr.). The model development was based on the THMs concentrations from chlorination of coagulated water. A multiple linear regression model for THMs formation was created using statistical package for social sciences (SPSS) software. In order to estimate the best representation for THMs concentration at FWDN, the samples in distribution networks were divided into point having one feeding source and other having multi feeding sources. Also the effluent water from the treatment plant divided according to type of treatment plant conventional or direct filtration plants. Table 2 lists the models formulated by the different regression structures, and specifies the sample size (n), significance (p), and coefficient of correlation ($R^2$) for each model.

Table 2. The models for predict of THMs concentration at FWDN

| Use for | Formulated model | $R^2$ | P | n |
|---|---|---|---|---|
| initial THMs at each type of treatment | 1) $-0.0007x^5 + 0.1818x^4 - 19.052x^3 + 992.45x^2 - 25693x + 264481$ | 0.789 | | |
| | Where x = $CHCL_3 + CHCL_2Br + CHBr_2CL$ | 0.868 | <0.0006 | 37 |
| | 1-1)$CHCL_3 = 2.7545 * (CL_2) + 1.7946 * (TOC) + 0.5345 * (T)$ | 0.938 | < 0.09 | 37 |
| | 1-2)$CHCL_2Br = 0.679*(CL_2) + 0.487 *(TOC) + 0.362*(T) + 1.13*(Br)$ | | | |
| | 1-3)$CHBr_2CL = 2.28*(CL_2) + 0.514*(TOC) + 0.1366*(T)$ | 0.961 | < 0.010 | 37 |
| initial THMs at conv. WTP | 2) $- 565.886 + 1.451*(Time) + 0.710 * (T)$ | 0.83 | <.001 | 25 |
| initial THMs at direct filtra.WTP | 3) $(CL_2)^{1.312} * (TOC)^{1.611} * (pH)^{6.995} * (T)^{-1.923} * (Br)^{-1.090} *(time)^{-1.257}$ | 0.842 | <0.015 | 19 |
| THMs at the FWDN having one source | 4) $0.0018 * THM_{in.}^3 - 0.3086 * THM_{in.}^2 + 17.949 * THM_{in.} - 281.95$ | 0.582 | <0.217 | 32 |
| | 5) $-29.06 * (CL_2) -0.366* (TOC) + 3.35 * (T) + 10.1* (Br) -3.516 (pH) -0.01* (time)+ 0.336 * (THM_{initial})$ | 0.856 | <0.363 | 32 |
| | 6) $-37.364 (CL_2) + 0.262(TOC) -1.469 (pH) +3.849(T) + 11.461 (Br) -0.048 (time)$ | 0.882 | <0.361 | 32 |
| THMs at mixing point** | 7) $THMs_{effl.} = (THMs_{inf1} * Q_{infl1} + THMs_{inf2} * Q_{infl2})/ Q_{eff.}$ | 0.756 | <0.015 | 19 |
| THMs at all location at | 8) $-11.19 * (CL_2) - 0.14 * (TOC) + 7.3135 * (pH) +4.99* (Br) - 0.959$ | 0.555 | <0.000 | 80 |

Description for the above table.

$CL_2$ (Free Chlorine-mg/L), TOC (Total Organic Carbon-mg/L), T (Water Temperature-$^0$C ), Br (Bromine-mg/L), Time (Travel Time-hour) , $THM_{in.}$ ( Initial THMs concentration at WTP-µg/L ) and THMs (THMs concentration - µg/L ). ** Show figures 4

As shown in figures 2,3 and equation 8, the mixing between two feeding sources is better for the distribution network not only for the flexibility in operation, but also for the quality of the water as the THMs concentration decrease at the mixing points due to the equilibrium balance happens at these junctions fed from two different sources, one of them has THMs concentration less than the other. The THMs concentration at the mixing point depend on the mixing ratio from different sources and the water quality for each source.

Predict of THMs concentration at any location of water distribution networks having water feed from point having mixing between two sources can be determined by using equation 5, by consider the THMs concentration at mixing point is the initial THMs for this point and the travel time calculated from the mixing point to this point (THMs concentration at mixing point can be calculated by using equation 7).

The correlation coefficient for equation eight (used for predict THMs concentration at all location of FWDN) equal 0.555 is small that because FWDN having more than one source of water and more than one type of treatment, also some point having more than one feeding source of water. So the samples in distribution networks were divided into point having one feeding source and other having multi feeding sources, also the effluent water from the treatment plant divided according to type of treatment plant conventional or direct filtration plants before formulated the models.

Figures 5:9, illustrate the concentration of the measured and estimated THMs for each previous models.

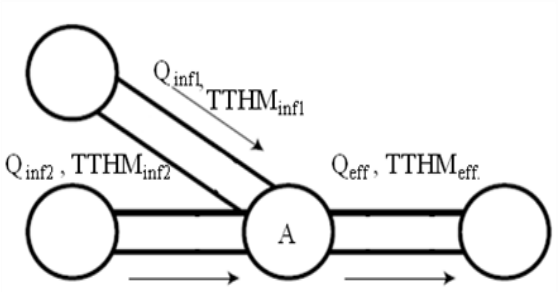
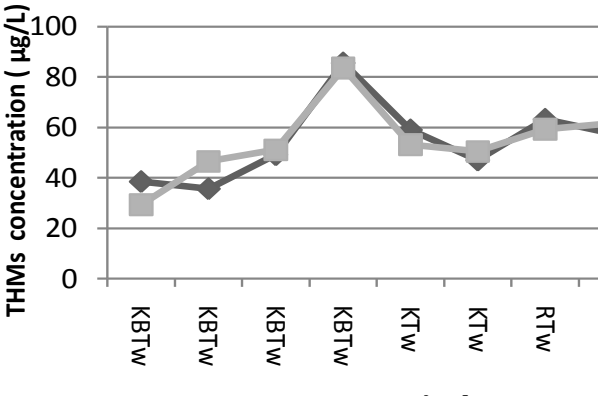



Figure 4. Illustrates the mixing point



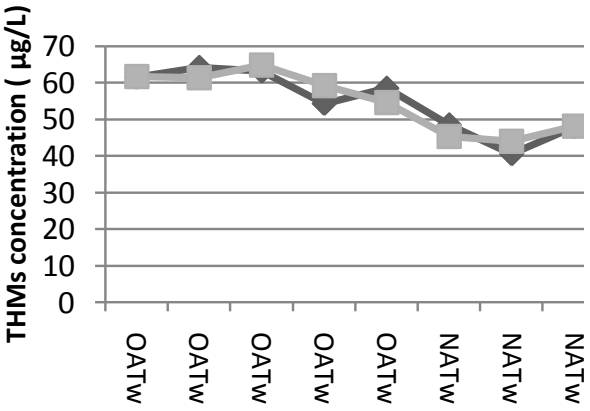




Figure 5. Illustrates the concentration of the measured and estimated THMs by equ.2

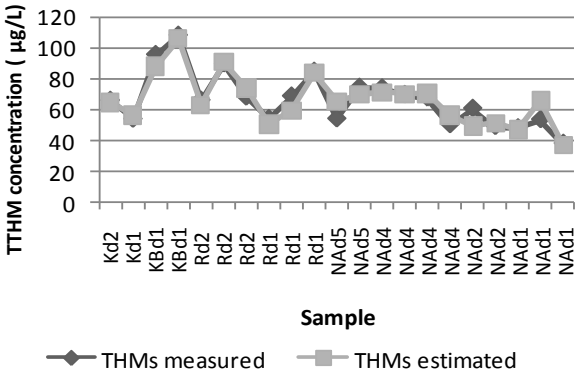



Figure 7. Illustrates the concentration of the measured and estimated THMs by equ.6

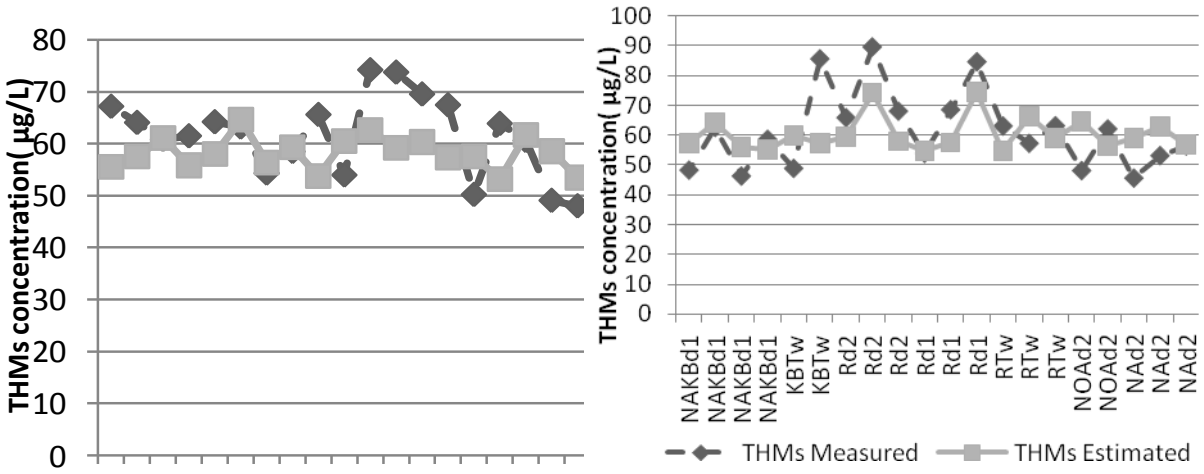



Figure 5. The measured and estimated THMs by equ.8

*5-3 Predict of THMs concentration by using WaterCad program.*

In order to predict THMs concentration at the FWDN by using WaterCad program, the next data were entered to the program, the overall THMs growth constant and the initial THMs concentration (Treated water before distribution) at New Azab treatment plant (the least value between all WTPs) and generalized it for all WTPs, that because no more than one initial THMs concentration can be input to the program at the same time.

The overall THMs growth constant was determined by using the following equations

$$C = Co + (F - Co)(1 - \exp(-kt)) \quad (9)$$

* (IDSE Guidance Manual for the Final Stage 2 DBPR, 2006)

Where :- C = THMs con.(µg/L) , Co = initial THMs con. (µg/L), F= ultimate THMs formation (110 µg/L) , k= growth constant (1/days), t = time in days and exp = natural log ( e ) , and the next table 3. illustrate the overall THMs growth constant between each sample and its source.

Table 3. The overall THMs growth constant

| Sample | THMs conc. | Initial THMs at New Azab | Travel Time | Growth Coeff. | Sample | THMs conc. | Initial THMs at New Azab | Travel Time | Growth Coeff. |
|---|---|---|---|---|---|---|---|---|---|
| | µg/L | µg/L | Minute | 1/Sec | | µg/L | µg/L | Minute | 1/Sec |
| NAd1 | 38.03 | 35.33 | 45.06 | 1.36E-05 | NAd3 | 63.9 | 48.46 | 524.28 | 9.18E-06 |
| NAd1 | 53.48 | 40.53 | 45.06 | 7.63E-05 | NAd4 | 50.21 | 48.79 | 307.5 | 1.27E-06 |
| NAd2 | 56.48 | 48.79 | 82.98 | 2.70E-05 | NAd4 | 67.48 | 47.963 | 307.5 | 2.05E-05 |
| NAd2 | 53.21 | 47.963 | 82.98 | 1.78E-05 | NAd4 | 69.57 | 40.53 | 307.5 | 2.93E-05 |
| NAd2 | 45.71 | 40.53 | 82.98 | 1.56E-05 | NAd4 | 73.78 | 48.46 | 307.5 | 2.87E-05 |
| NAd2 | 56.23 | 48.46 | 82.98 | 2.71E-05 | NAd5 | 74.24 | 48.79 | 440.8 | 2.03E-05 |
| NAd3 | 49.08 | 35.33 | 524.28 | 6.47E-06 | NAd5 | 53.97 | 40.53 | 440.8 | 8.13E-06 |
| NAd3 | 60.62 | 40.53 | 524.28 | 1.09E-05 | NAd5 | 65.62 | 48.46 | 440.8 | 1.24E-05 |
| Average (the input to WaterCad) | | | | 1.79E-05 | | | | | |

The output data from WaterCad calibrated by using actual concentration for each plants and the mixing ratio at point having more than one source to get the better relation used to predict THMs concentration at FWDN. And the table (4) illustrate the average THMs concentration at each point from field data and from WaterCad program before and after calibration.

Table 4. The THMs con. According to WaterCad

| Sample Code | Average THMs con. (µg/L) | Average THMs con. (µg/L) | | Sample Code | Average THMs con. (µg/L) | Average THMs con. (µg/L) | |
|---|---|---|---|---|---|---|---|
| | | WaterCad | | | | WaterCad | |
| | Field data | Before Calibrated | After Calibrated | | Field data | Before Calibrated | After Calibrated |
| NATw | 44.21 | 44.21 | | RTw | 61.22 | 44.21 | 61.22* |
| NAd1 | 46.51 | 47.8 | | Rd1 | 69.04 | 47.8 | 64.81** |
| NAd2 | 52.9 | 51.5 | | Rd2 | 74.51 | 51.6 | 68.61** |
| NAd3 | 57.87 | 73.6 | | KTw | 52.90 | 44.21 | 52.90* |
| NAd4 | 65.26 | 61.5 | | Kd1 | 59.78 | 50.2 | 58.89** |
| NAd5 | 64.61 | 65.5 | | KBTw | 52.08 | 44.21 | 52.08* |
| OATw | 60.35 | 44.21 | 60.35* | NAKBd1 | 54.03 | 53.1 | 57.03*** |
| NOAd1 | 60.71 | 48 | 57.68*** | KBd1 | 95.24 | 57.90 | 65.77** |
| NOAd2 | 64.87 | 51.6 | 64.512*** | | | | |

* THMs concentration calibrated = $THMs_{FD}$

** THMs concentration calibrated = $THMs_{WC} + (THMs_{FDTW} - THMs_{NATW})$

*** THMs concentration calibrated = $THMs_{WC} + (THM_{FDTW} - THMs_{NATW}) * \%M$

Description for the above table.

$THMs_{FD}$ = average THMs con. according to Field data, $THMs_{WC}$ = THMs con. according to WaterCad , $THMs_{FDTW}$ = average THMs con. at WTP source to this point, $THMs_{NATW}$ = average THMs concentration at NATw and % M= percentage of flow at this point according to the second WTP.

In order to overcome that no more than one initial THMs concentration can be input to the program at the same time , additional pipe was insert at the treatment plant (after high left pumps and before the distribution networks) which want to change their initial THMs to be as the measured concentration. The diameter and length of this pipe were calculated to make the THMs concentration at the end of pipe equal to the average THMs concentrated measured at the end of this source before distribution. The length of this pipe can be calculated by using the next equation 10) $L = (4*Q*t) / (\pi*\phi^2)$

Where :- t = time in days (calculated by equation 9 with C = required THMs con. leaving the source, Co = $THMs_{NATW}$ , F =110 µg/L, and k = 1.55 $day^{-1}$), L= length of pipe (m), φ = diameter of pipe assumed (m), and Q = Flow ($m^3$ /d).

The next figure (10) illustrate the concentration of THMs average measured and estimated according to WaterCad.

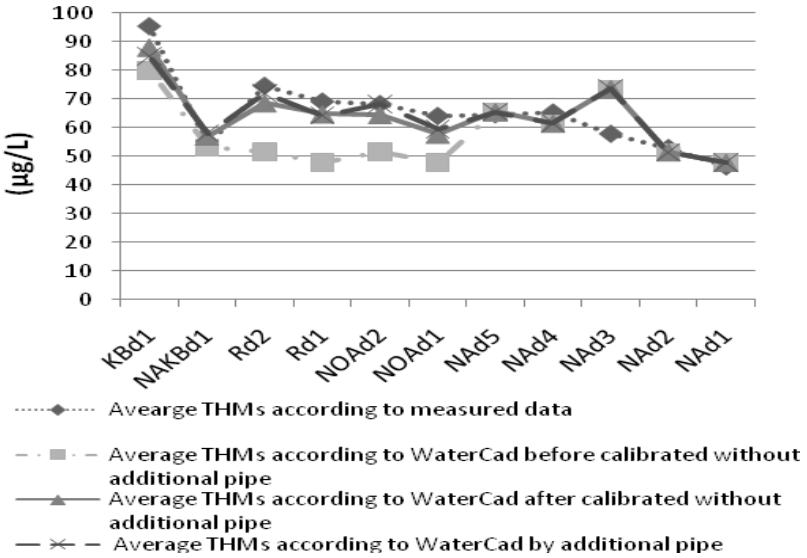



Figure 10. Illustrates the con. of the measured and estimated THMs by using WaterCad program.

**6 Conclusion**

the concentrations of THMs in all locations at the distribution network are less than the allowable limit (100 µg/L) stated by the decision of the Ministry of Health No.458 of 2007. The mixing between two feeding sources is better for the distribution network that because the THMs con. decrease at these point due to the equilibrium balance happens at these junctions . The relation between the exit and inter concentrations depends on the mixing ratio from different sources and the water quality for each source and can be calculated by using equation (7) with $R^2 = 0.756$, $P < 0.015$. A statistically-based empirical models which developed for predicting THMs formation under different condition can be used . The first model was developed to predict the THMs concentration at the exit of the conventional WTPs with $R^2 = 0.83$, $P < 0.001$. The second model was developed to predict the THMs conc. at the exit of the Direct filtration WTPs with $R^2= 0.842$, $P < 0.015$. The third model was developed to predict the THMs concentration for water supply networks having one feeding source with $R^2=0.856$, $P <0.363$. Finally, the fourth model was developed to predict the THMs concentration for water supply networks having multi-feeding sources with $R^2 = 0.555$, $P < 0.0001$. WaterCad program can be used to predict THMs concentration at FWSN with 1.55 $day^{-1}$ TTHM growth rate. This can be obtained by generalizing the THMs concentration at the exit of New Azab WTP for all the other treatment plants and performing additional pipes at the exit of these treatment plants, in order to obtain the original THMs concentrations .

**7 References**

Al-Omari A., et al., (2004). Modeling trihalomethane formation for Jabal Amman water supplyin Jordan. J. Environmental Modeling and Assessment 9:245-252.

Arora H, et al. (1997) DBP occurrence survey. J Am Water Works Ass 89:60–68

Bentley WaterCad V8 XM Edition User's Guide, (2007). Bentley Systems, DAA03758010001.

Chowdhury S., et al., (2009). Models for predicting disinfection byproduct (DBP) formation in drinking waters: A chronological review. J. Science of The Total Environment, Vol.407, Issue 14, Pages 4189-4206.

Gallard H, Von Gunten U (2002) Chlorination of natural organic matter: kinetics of chlorination and of THM formation. Water Res 36:65–74

IDSE Guidance Manual for the Final Stage 2 DBPR, (2006). United States Environmental Protection Agency.

Marhaba TF, Washington MB (1998) Drinking water protection and byproducts: history and current practice. Adv Environ Res 2:103–115

Najm I, et al. (1994) Evaluating surrogates for disinfection by-products. J Am Water Works Ass 86:98–106

Nikolaou AD, et al. (2004a) DBP levels in chlorinated drinking water: effect of humic substances. Environ Monit Assess 93:301–319

Nikolaou AD, Lekkas TD (2001) The role of natural organic matter during formation of chlorination by-products: a review. Acta Hydrochim Hydrobiol 29:63–77

Nikolaou AD, et al. (2004b) Kinetics of the formation and decomposition of chlorination by-products in surface waters. Chem Eng J 100:139–148

Ristoiu D., et al., (2009). Trihalomethane formation during water disinfection in four water supplies in the Somes river basin in Romania. J. Environmental Science and Pollution Research, Vol.16, Pages 55-65.

USEPA (1999b) Alternative Disinfectants and Oxidants Guidance Manual, United States Environmental Protection Agency. EPA 815-R-99-014

USEPA (2001) National Primary Drinking Water Standards. United States Environmental Protection Agency, EPA 816-F-01-007

Wright JM, et al. (2004) The effect of disinfection by-products and mutagenic activity on birth weight and gestational duration. Environ Health Persp 112:920–925

Woo Y-T, et al. (2002) Use of Mechanism-Based Structure-Activity Relationships Analysis in Carcinogenic Potential Ranking for Drinking Water Disinfection By-Products. Environmental Health Perspectives. Supplements Volume 110, No S1, February

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| 7 | Illustrates the concentration of the measured and estimated THMs by equ.6 | 6 |
| 8 | Illustrates the concentration of the measured and estimated THMs by equ.8 | 7 |
| 9 | Illustrates the concentration of the measured and estimated THMs by equ.8 | 7 |
| 10 | Illustrates the con. of the measured and estimated THMs by using WaterCad program. | 9 |