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Potential of Trihalomethanes formation in the Domestic water sources of Jericho area / West Bank

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Abstract

The process of water chlorination to the water contains a considerable amount of TOC can lead to the figuration of some π-products that are highly harmful to human health. Among all the chlorination π-products, trihalomethanes (THMs) is exhibit highly carcinogenic activity. This study tries to identify the main factors that play a critical role in the THM formation and control its mechanisms at different stages. (WHO) usually measure free residual chlorine values at levels less than the recommended values. The concentrations of THMs formed in the water network vary depending on the concentration of TOC in the discharged spring water, and the chlorine dose plays an important role in this process by increasing the contact time. The THM levels in the tap water of Jericho and Aqbat Jabber camp are at levels below the USEPA limit of 80µg/L, as well as the WHO limit of 100 µg/L. $CHBr_3$ was found to be the major contributor to the total THMs. $CHCl_3$ found to be the dominant sort detected after the chlorination of each sample in the experiment. The THM detected at high-temperature incubation were higher than the low-temperature ones for all of the samples.

Keywords: *Total Organic Carbon, Chlorination, Halogenated Hydrocarbons, Sultan Spring.*

1. Introduction

Groundwater quality could be influenced by many factors, including climate, topography, aquifer lithology, the zone of recharge, and human activities (Abu-Khalaf N. et al., 2013). TOC is considered an indicator of natural organic matter (NOM) in groundwater such as humic acid, fulvic acid. The process of water chlorination to the water contains a considerable amount of TOC can lead to the formation of many by-products that are potentially harmful to human health (Reckhow D.A. et al., 1990). Among all the chlorination by-products, trihalomethanes (THMs) is exhibit carcinogenic activity. Classical trihalomethanes consist of $CHCl_3$, $CHCl_2Br$, $CHBr_2Cl$ and $CHBr_3$. They are produced via reactions of HOCl with (NOM) natural organic matter in the absence or presence, of Br^- (Gallard H. and von Gunten U., 2002). In the past 3 decades, many studies have been performed on the health effects of Disinfection By-Products (DBPs) in drinking water supplies (Morris R.D. et al., 1992). Although THMs are, suspected probable carcinogenic and their concentration in water should be monitored. Surrogate parameters such as TOC, UV (A) 254 nm, and THMFP are used to predict or monitor them. In 1999 TOC was selected by (US.EPA) as a surrogate measurement to control (DBPs) in drinking water, to protect consumers from the potentially carcinogenic by-product of disinfection processes of drinking water. To minimize the formation of such harmful (DBPs), the parameters affecting their formation should be understood. THM formation is a function of many water quality parameters, including TOC, pH of chlorination, temperature, and contact time, as well as Bromide and chlorine dose. In the Jericho area, spring water is the major source of drinking and agricultural use. Ein-Sultan Spring is the main source of drinking water in Jericho. High concentrations of TOC were measured in the water from Sultan and Dyouk springs (Khayat S. et al., 2008; Marei A. et al., 2013). No further studies, in this study area, were performed to study the effect of chlorination on the formation potential of THM and related factors that play a role in the process of its formation in the distribution system. Chlorine doses, and concentration of free chlorine residues, nature of NOM (mainly humic substances), contact time, pH, the temperature of the water and the presence of inorganic ion like bromide (Amy G.L. et al.,1987; Golfinopoulos S.K., 2000). The previously mentioned studies show that: the presence of bromide ion shifts the speciation of DBPs to more brominated analogs. Moreover, chlorination, which is a widely used disinfection process, in 1972, was first reported by Rook to cause the formation of (THMs) (Rook J., 1972). In this study, the potential of THMs formation (THMFP) in the water networks drained from Jericho springs and related factors are evaluated in term of availability, mechanism, and stage of interaction. These factors include:

Natural Organic Matter and UV Absorbance at 254nm: The general equation for the formation of DBPs is

$HOCl + Br^- + NOM \rightarrow DBPs$

Where NOM is the primary precursors of DBPs, NOM is composed of hydrophilic and hydrophobic organic materials found by the decay of vegetation in the watershed surrounding the water source (Singer P.C., 1994).

Bromide Concentration: is the second factor, where the presence of bromide ion during water treatment disinfection can lead to the formation of DBPs, such as brominated organics and bromate ion. Brominated compounds may occur in the drinking water source, as a result of pollution and saltwater intrusion that has been reported as common phenomena in previous studies (Khayat S. et al., 2010), in addition to bromide from a natural source. The impact of bromide on the speciation of DBPs within a class of compound such as THMs and HAAs has been also discussed by many previous studies (Amy G.L. et al., 1987; Rook J.J. et al., 1978) .

Temperature: is the third factor, so the formations of THM and HAAs have been shown to increase with temperature (Amy G.L. et al., 1987). On a conceptual basis, it may be that rapidly forming compounds are more reactive and form

DBPs, regardless of temperature. (Golfinopoulos S.K., 2000) reported that DBPs concentrations are higher in summer than in winter. In winter months and in some cases where ice covers surface raw waters, the THM concentration is lower due to lower water temperature and lower NOM.

Effect of Chlorine Dose: is a fourth factor, where studies have shown that, as the disinfectant concentration increases, DBPs formation also increases (Singer P.C. et al., 1995).

Effect of pH: is a five-factor when the pH of the water greatly influences both the rate and equilibrium set point of THM formation. The higher the water pH is, the greater the THM formation (Krasner S.W. et al., 1989; Singer P.C., 1994; Urano K. et al.,1983) .

Effect of Reaction Time: is a six-factor, where the residence time affects DBPs. Studies have shown that as residence time increases, the concentration of TTHMs increases, and the concentration of HAAs decreases (Chen W. & Weisel C., 1998; LeBel G.L. et al.,1997) .

2. Study Area

Jericho city locates in the Jordan Rift Valley, which is situated 250 m below sea level and is the lowest living town on the earth. Located on the eastern boundary of the West Bank, Recharge area of the spring groups located in the western mountains of Jerusalem -Ramallah (HWE, 2007) (Figure 1). The area within the municipality borders extends over 45 km^2 with an estimated population of 43.620 (PCBS, 2006). While it has a semiarid climate, Jericho is considered an oasis since it is watered by many springs. This characteristic makes it an important agricultural area, especially for fruits and vegetables (Isaac J. et al., 1995) . The climate of Jericho district is classified as arid, with hot summer and warm winters. The average maximum temperature during January (the coldest month) and August (the hottest month) are around 19^o Cand 38^o C respectively. According to Jericho weather station, the mean annual rainfall of Jericho city is 259 mm; it has little rain and a short rainy season ranging between 20-25 rainy days per year (Ministry of Transportation, 2018). Domestic water resources in Jericho city is mainly water from Jericho spring group (Sultan and Duk), with a monthly average discharge of 2MCM/Yr. Aqbat Jaber Refugee Camp, that locates to the southwest of the city use water from Wadi Quilt Spring group (Fara, Fawae, Quilt Springs). The average monthly discharge for Wadi Quilt group is about 146,775 m^3 (PWA, 2010). Both spring groups drain water from the Upper aquifer system of the Mountain aquifer, that compost of Upper Cretaceous carbonate rock. The main recharge area for this aquifer locates in the mountain area (Ramallah-Jerusalem mountain ridges) as well as through flooding water, and wastewater that infiltrates in the upper part of the catchment area (Khayat S. et al., 2008; Marie A. and Vengosh A., 2001). The groundwater flow in the Eastern Basin of the Mountain Aquifer is generally to the east and southeast, in the direction of the Jordan River and the Dead Sea (Rofe and Raffety, 1963). Domestic uses consume about 30% of the spring water in Jericho group, and 10 % of Wadi Quilt group (Jericho Municipality, 2010). The main water source is the spring Ein-Sultan, with an average discharge of 700 m3⁄h. Over 95% of the population is connected to the water supply network (Sturm C. et al., 1996). Part of the network was constructed in 1963 (steel pipes), the other in 1972 (asbestos-cement pipes). Total losses of both networks, due to leakage, are 60% of the abstracted water (Sturm C. et al., 1996). The length of the distribution network in Jericho is about 45 km. Chlorination is the only technique used for the disinfection of drinking water. Liquid chlorine-sodium hypochlorite with concentration about 12% is the form by which chlorine is added to the system continues at the spring niche. Raw spring water pumped in the network and the total chlorine residual range between 0.3 and 0.5 mg⁄L (Isaac J. et al., 1995; Marei A. et al., 2010; Sturm C. et al.,

1996). The last study done by (Hdaidoun L., 2011) shows that the concentration of DOC fluctuated depending on recharge conditions in the upper mountains area, where the concentration reaches up to 18.4 mg/L in Ein Sultan and 5.2 mg/L in the channel before sand filter and still have the same value arround5.mg/L even after the filter treatment (Hdaidoun L., 2011; Marei A. et al., 2013). In all cases, the study shows that all of these maximum values appear shortly after a thunderstorm event that flushes out all aquifer pollutants including organics as a big shock. However, the potential of DOC reaction with added chloride and the factors that influenced this potential may exceed the amount of DOC in the water resources. Therefore, this study tries to identify the main factors that play a role in the formation of the THM and control its mechanisms at different stages.

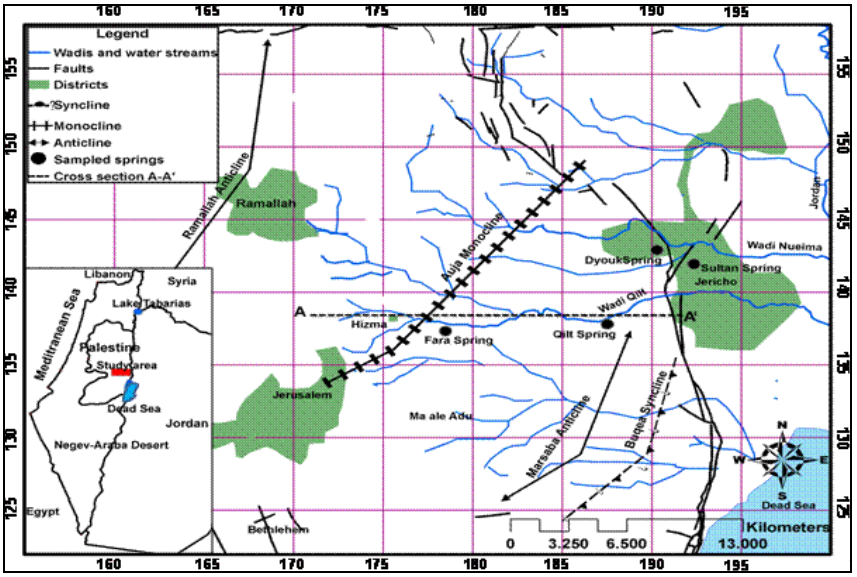

Figure 1: Location map of the studied area.

3. Methodology:

Trihalomethanes formation potential test is conducted to determine the maximum potential of the sample to form trihalomethanes under several conditions. For this purpose, untreated water samples were collected from Ein Sultan spring and Al Quilt canal during October 2018. To perform the THMFP test, some seasonal variable conditions; such as the pH, and water temperature were fixed and one of them was studied at different variable values. The test was started by estimating the chlorine demand of each sample, then the samples were chlorinated with an excess of free chlorine of sodium hypochlorite stock solution (NaOCl). The chlorine demand after 24h incubation, for Ein Sultan and Al Quilt before and after sand filtration, were (13 mg/L), (16 mg/L) and (17 mg/L), respectively. Accordingly, the volumes of chlorine dose, which added for each sample were (130 ml for Sultan water), (160 ml for Al Quilt before sand filtration) and (170 ml for Al Quilt after sand filtration). To study the effect of temperature in THMSP, the chlorinated samples were put in an incubator under different temperatures (25oC, 38oC, and 19oC) to simulate the same conditions in the water networks, and the consequent sampling at the incremental time was carried out for each temperature. At the end of a seven-day reaction period, the free chlorine residual concentrations were found between (4 and 5 mg/L) for the examined samples at all temperatures.

4. Results and Discussion

The results for the THMFP in Ein Sultan and also Al Quilt canal (before and after sand filtration), are shown in (Table 1, 2 and 3), respectively. In most cases, the total Trihalomethanes are exceeded the WHO guideline (100µg/L), and the

maximum contamination level of USEPA (80µg/L) at different periods, for incubation temperature for each sample. For example, for Ein Sultan the TTHMs exceeded the limit of 100 µg/L concentration after (72h at 19°C) and after (24h at 25°C and38°C) of incubation.. Al Quilt canal water (before and after sand filtration), all water samples were exceeded the guideline value after (6h at 19°C and 25°C), and after (2h at 38°C) of incubation, taking into account that previous study for (Hdaidoun L., 2011) shows relatively an enrichment of DOC concentration after sand filter with a value of 3.3 mg/L in April. It was expected that the reaction rates are mainly depending on several factors; these are the type and concentration of organic precursors, pH, chlorine dose, temperature, and bromide concentration. The rates of THMs formation are plotted for the three sampling points (Ein Sultan, Quilt canal before and after) over seven days at different temperature degrees. The results for each sample are shown in (Figures 2 - 5). The THMs were formed rapidly under the chlorine saturated condition. The THMFP formed at a high rate after two days and then the rate of their formation increased then it became constant as time proceeding when organic material is consumed.

Table 1: THMFP in Ein Sultan spring samples at different temperature degree of incubations**.**

	Incubation Temperature 19°C					Incubation Temperature 25°C					Incubation Temperature 38°C				
Time (hr)	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs
0	4.1	1.1	< MRL	< MRL	5.2	12.5	2.2	< MRL	< MRL	14.7	20.1	3.5	< MRL	< MRL	23.6
2	20.1	2.1	< MRL	< MRL	22.2	25.9	3.9	< MRL	< MRL	29.8	40.8	2	< MRL	< MRL	42.8
6	30.2	2.3	< MRL	< MRL	32.5	36.1	4	< MRL	< MRL	40.1	43.4	1.1	< MRL	< MRL	44.5
24	54.7	1.7	< MRL	< MRL	56.4	85.9	4.06	< MRL	< MRL	89.9	96	1.2	< MRL	< MRL	97.2
48	66.1	2.2	< MRL	< MRL	68.3	99.9	4.51	< MRL	7.79	112.2	102	2.1	< MRL	< MRL	104
72	95.9	2.8	< MRL	< MRL	98.7	212	3.62	< MRL	< MRL	215.6	223	3.1	< MRL	< MRL	226
168	109	5.1	< MRL	< MRL	114.1	121.8	7.79	< MRL	5.7	136.3	126	3.1	< MRL	5.7	134.8

MRL: minimal reporting limit.

Table 2: THMFP in Al Quilt canal samples before sand filtration at different temperature degree of incubations.

	Incubation Temperature 19°C					Incubation Temperature 25°C					Incubation Temperature 38°C				
Time (hr)	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs
0	20.1	1.9	< MRL	< MRL	22	106	3.2	< MRL	< MRL	43.6	41.2	8.7	< MRL	< MRL	49.9
2	44.2	2.9	< MRL	< MRL	47.1	106	4.7	< MRL	< MRL	77.6	107	11..2	< MRL	< MRL	118.2
6	106.5	5.7	< MRL	< MRL	112.2	106	6.2	< MRL	< MRL	112.2	207.3	7.5	< MRL	< MRL	214.7
24	151.4	3.6	< MRL	< MRL	154.9	106	6.9	< MRL	< MRL	152.9	250	6.5	< MRL	< MRL	256.6
48	138.7	4.5	< MRL	< MRL	143.2	106	3.9	< MRL	< MRL	245.9	278.3	5.2	< MRL	< MRL	283.5
72	285.3	2.9	< MRL	6.6	291.9	106	4.5	< MRL	4.9	318.4	439	6.7	< MRL	< MRL	445.7
168	321.9	6.3	< MRL	< MRL	328.2	106	5.2	< MRL	< MRL	339.2	434.8	6.3	< MRL	11.5	446.3

MRL: minimal reporting limit.

Table 3: THMFP in Al Quilt canal samples after sand filtration at different temperature degree of incubations**.**

	Incubation Temperature 19°C					Incubation Temperature 25°C					Incubation Temperature 38°C				
Time (hr)	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	TTHMs
0	30.4	5.7	< MRL	< MRL	36.1	12.9	2.1	< MRL	< MRL	15	40.3	2.1	< MRL	< MRL	42.4
2	71..2	4	< MRL	< MRL	75..2	77.1	2.4	< MRL	< MRL	79.5	127	1.2	< MRL	< MRL	128.2
6	101	3.4	< MRL	< MRL	104.4	103	3.3	< MRL	< MRL	106.3	181	1.1	< MRL	< MRL	182.1
24	112	7.1	< MRL	< MRL	119.1	276	6	< MRL	< MRL	282	219	2.5	< MRL	< MRL	221.5
48	141	2.7	< MRL	< MRL	143.7	283	2.8	< MRL	< MRL	285.8	296	4.2	< MRL	< MRL	300.2
72	271	7.3	< MRL	< MRL	278.3	292	2.9	< MRL	< MRL	294.9	336	5.3	< MRL	< MRL	341.3
168	322	4.9	< MRL	< MRL	326.9	398	4.9	< MRL	< MRL	402.9	439	6.3	< MRL	< MRL	445.3

MRL: minimal reporting limit.

In this study, the results reveal an increase in chloroform ($CHCl_3$) over time comparing to other THM species in all samples (Figures 6 - 14). The dominant species of brominated THM was bromodichloromethane ($CHCl_2Br$) while dibromochloromethane ($CHClBr_2$) was not detected in all samples at any temperature or any period. The Bromoform ($CHBr_3$) which was the dominant species formed in the distribution system, was also present only at two temperature degrees of 25°C, 38°C, (24h at 25° C and 72h at 38°C) in Ein Sultan and after (48h at 25°C and after 48h at 38°C) in Al Quilt before sand filtration. (Symon et al., 1993), found that the ratio of bromide to average chlorine (Br^-/Cl_2) controls the percentage of brominated THMs. This indicates that chlorine substitution predominates (more chlorinated THM species) in case of high chlorine dosage. These same results were also shown in this study. This could be due to competition kinetics of chlorine reaction with bromide, simply because the concentration of Cl_2 is normally greater than Br_2.

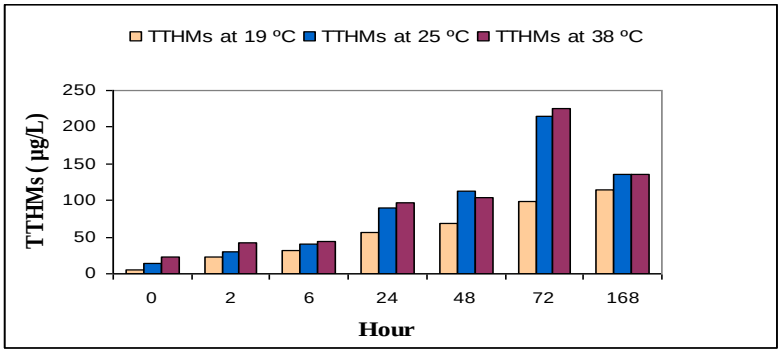

Figure 2: TTHMFP in Ein Sultan at different temperature degrees and periods.

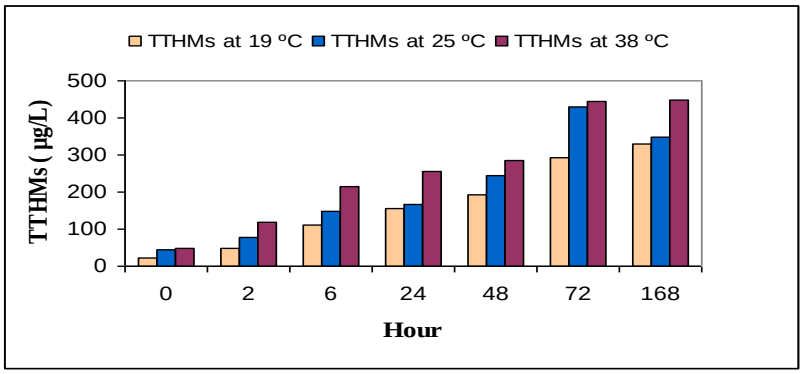

Figure 3: TTHMFP in Al Quilt canal before sand filtration at different temperature degrees and periods.

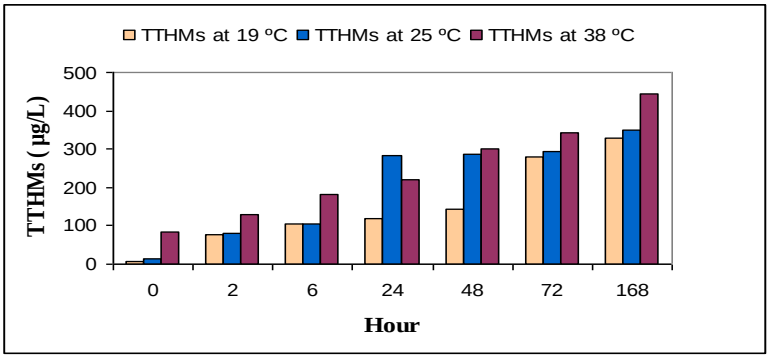

Figure 4: TTHMFP in Al Quilt canal after sand filtration at different temperature degrees and periods.

The results of this study also show that THM formation increases with increasing temperature and contact time. THM formation rate is more likely influenced by temperature more than any other species (Figures 2, 3, and 4). The THM formation is increased also with increasing time and/or higher chlorine dose (Tables 1-3). In this context, reaction time plays an important role that affecting their formation. Further, investigation of the influence of reaction time on THMs formation is critical and not easy, to determine the exact final concentrations to which people could be exposed.

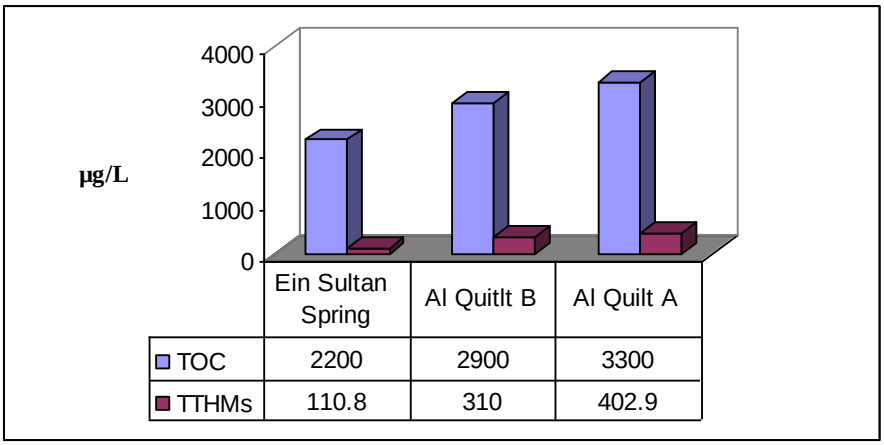

Figure 5: Organic carbon concentration effects on trihalomethane formation (TTHMs at 25 °C).

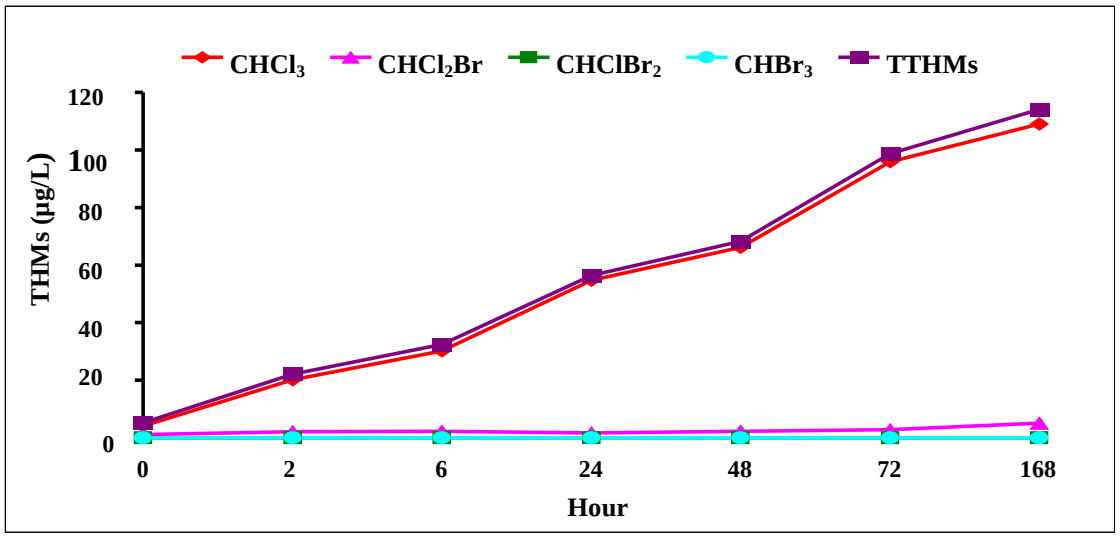

Figure 6: THMFP rate in Ein Sultan spring at 19°C incubation**.**

The results were compared with the DOC concentrations from sampling points at the previous study of (Hdaidoun L.,2011). It was noticed that the high organic matter content the higher chlorine demands, and consequently high THM formation potential. The effect of the organic matter content of the sampled water on the potential formation of trihalomethanes is shown in (Figure 5). The high formation potential of trihalomethanes measured in Al Quilt after sand filtration is explained by the high organic material content accumulates within the sand filter (Table 3) since the organic material is the precursor of the trihalomethane formation after the process of water chlorination. The results reveal also that the THM reaction is slow, taking place over several hours and, in some cases, resulting in a significant increase after 24 hours of contact time. (Figure 7 and 8) show the concentration of each THM compound (chloroform and bromodichloromethane) and TTHMs, all of them increases with running time and temperature. However, the same

figures show that they tend to accelerate the formation of THMs and $CHCl_3$ at a temperature more than 25°C, then the rate of both product formations decrease due to the rapid consumption of either organic matter and/or free chlorine in the samples. This THMFP test was conducted within a seven-day test which determines the THMFP in water sample after a reaction time of seven days. This time is believed to allow the reaction to approach completion with a steady temperature of 19°C. This period was different from the results of study who founded that formations of THMs were completed within 24h reaction (Nikolaou A. et al., 2004) .

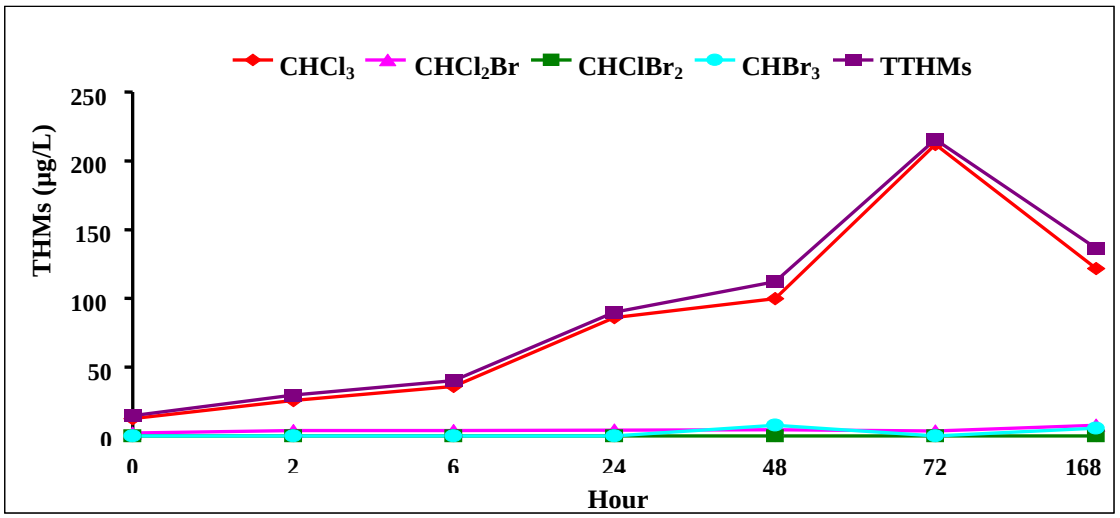

Figure 7: THMFP rate in Ein Sultan spring at 25°C incubation.

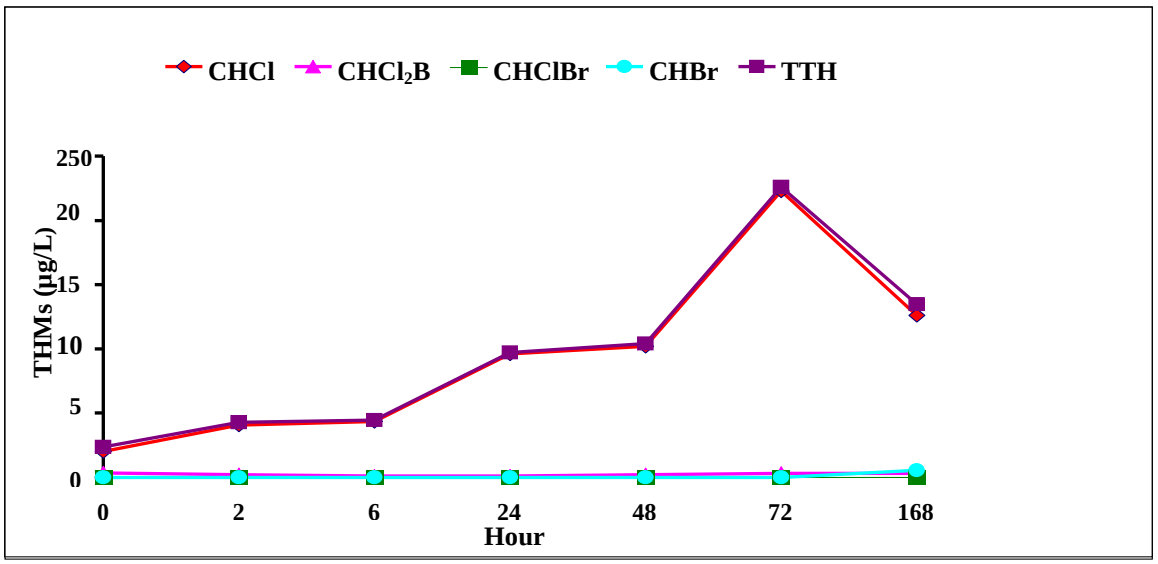

Figure 8: THMFP rate in Ein Sultan spring at 38°C incubation.

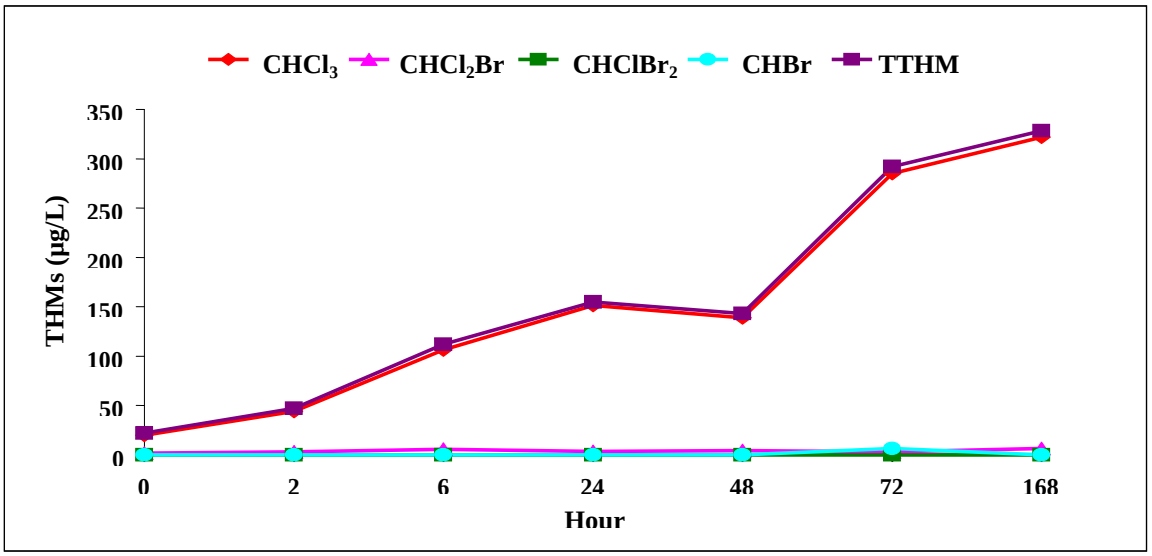

Figure 9: THMFP rate in Al Quilt canal before sand filtration at 19°C incubation.

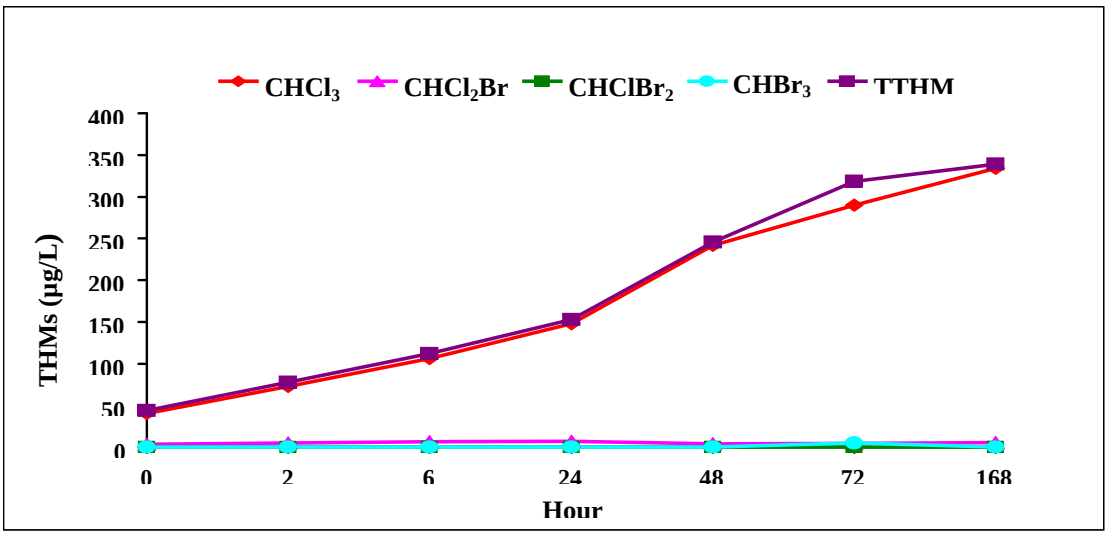

Figure 10: THMFP rate in Al Quilt canal before sand filtration at 25°C incubation.

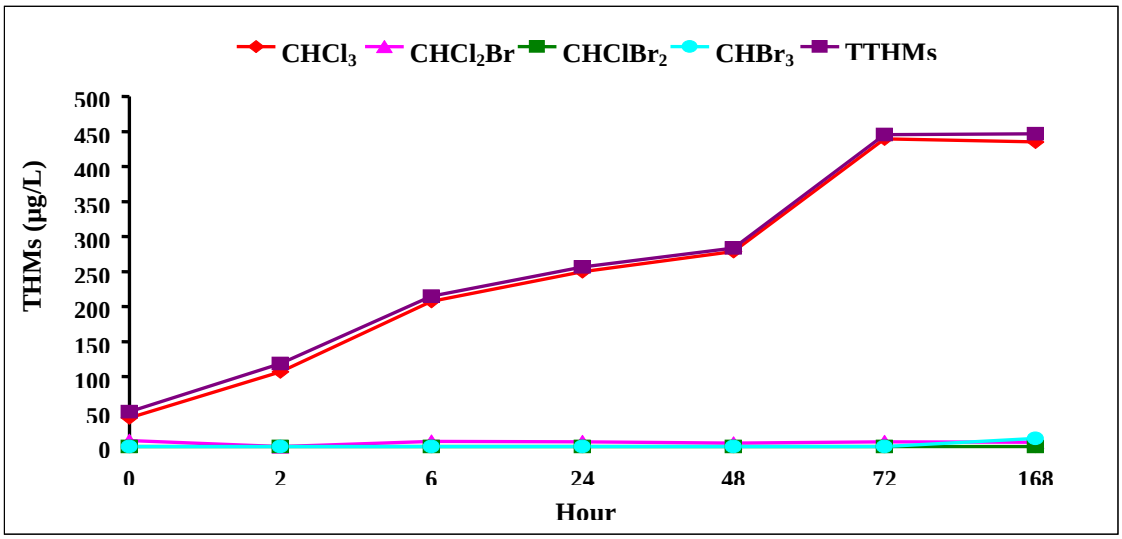

Figure 11: THMFP rate in Al Quilt canal before sand filtration at 38°C incubation.

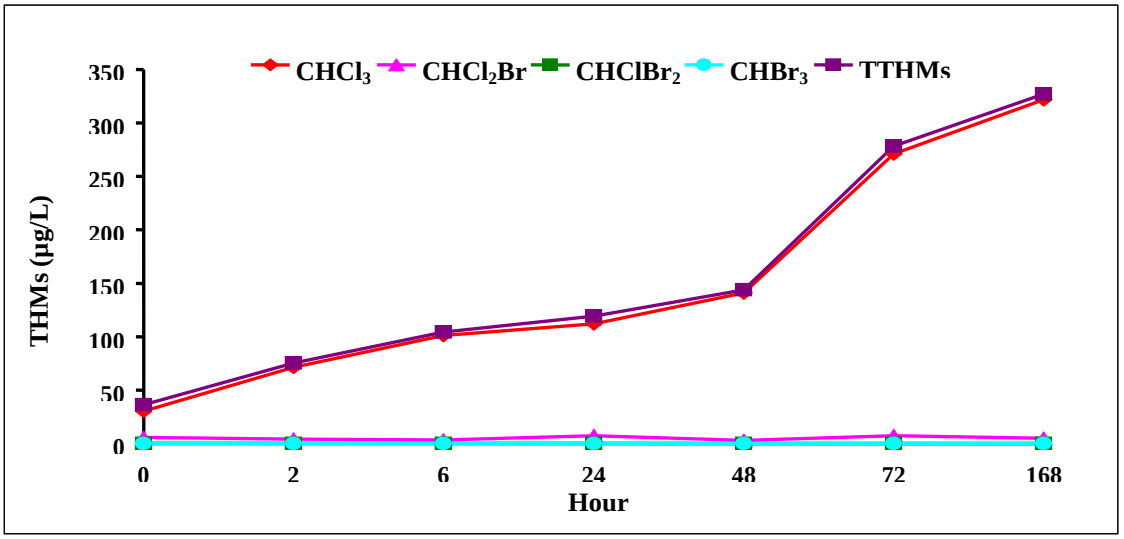

Figure 12: THMFP rate in Al Quilt canal after sand filtration 19°C incubation.

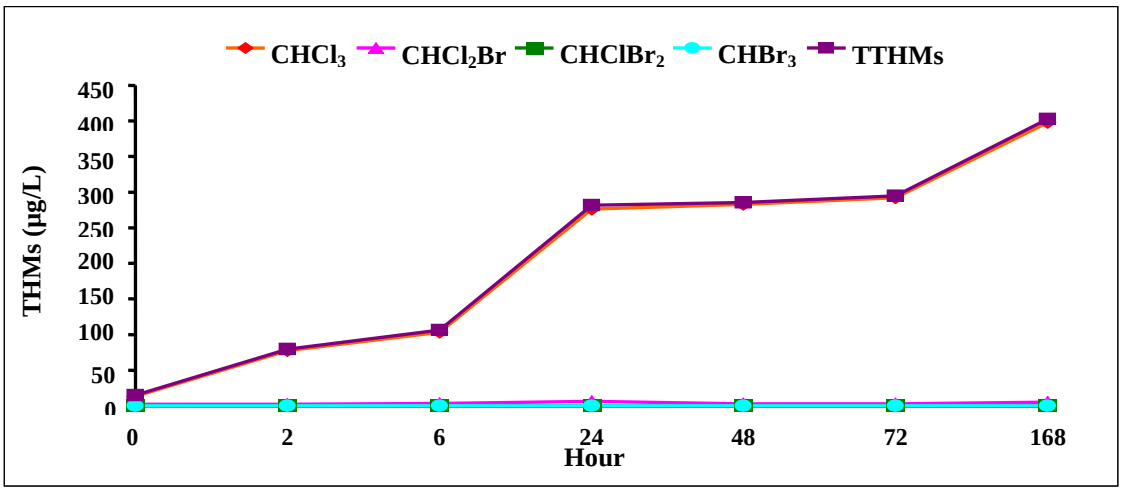

Figure 13: THMFP rate in Al Quilt canal after sand filtration 25°C incubation.

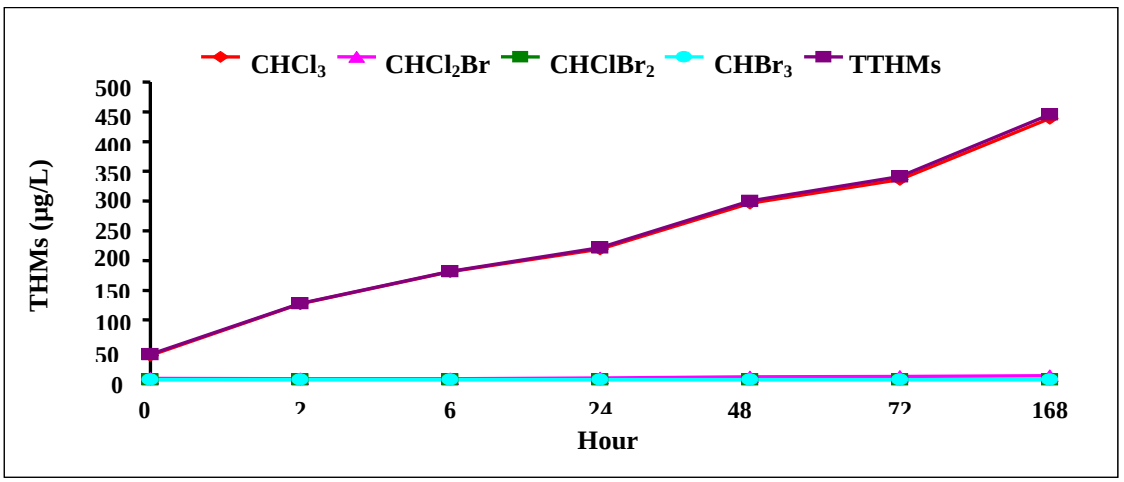

Figure 14: THMFP rate in Al Quilt canal after sand filtration 38°C incubation.

5. Conclusion

Water from springs and Qilt channel have shown a variable level of TOC and TN, along the hydrological year 2018/2019, when THM formed. High levels of TOC and TN in the spring water during the sampling period were closely related to rainfall/runoff events. In addition, the TOC levels were highly variable and were found in response to change from season to season as well as from sampling point to another. Water chlorination is the only treatment measure that takes place before the distribution of water. Within this study, it was reported that the free residual chlorine values are usually measured at levels less than the recommended values required for efficient drinking water disinfection (WHO). The average concentrations for residual free chlorine during the sampling periods (summer and winter), in Jericho were (0.09 and 0.19 mg/L) respectively, while that for Aqbat jabber camp were (0.18 and 0.09 mg/L) respectively. Such low concentrations show that the chlorine dose added to the network through a process of disinfection is not sufficiently effective for disinfection process. High-temperature conditions in Jericho area may properly promote the accelerated depletion of residual chlorine, which mitigates THM formation. The concentrations of THMs formed in the water network vary depending on the concentration of TOC in the discharged spring water, and the chlorine dose plays an important role in this process with increasing the contact time. The study shows that the THM levels in the tap water of Jericho and Aqbat Jabber camp are at levels below the USEPA limit of 80µg/L, as well as the WHO limit of 100 µg/L. In most samples analyzed, $CHBr_3$ was found to be the major contributor to the total THMs. As a summary, the experimental data of THMFP test performed on Ein Sultan spring and Al Quilt canal water show that: The high TOC content leads to a high chlorine demand and, simultaneously, high THM formation potential in Al Quilt canal water more than those values in Sultan spring water. A good observation system should be installed all over the year to mitigate the effect of high TOC content that flushed out 2-3 times along the hydrological year.

Chloroform was the dominant species observed after the chlorination of each sample in the experiment. Therefore, special attention must be drawn for observation of the Chloroform concentration in water network along the year.

As the temperature increased, more THMs are formed. The THM values measured at high-temperature incubation were always higher than the ones measured at low-temperature incubation for all of the samples. This must be controlled by careful observation for temperature and dose of chlorine in the summertime where the temperatures in the Jericho area reach its maximum values.

References

[1] Abu-Khalaf, N., Khayat, S. and Natsheh, B. (2013). Multivariate data analysis to identify the groundwater pollution sources in the Tulkarm area, Palestine. *Science and Technology*, 3, 99-104.

[2] Amy, G.L., Minea, R.A. and Cooper, W.J. (1987). Testing and validation of a multiple nonlinear regression model for predicting trihalomethane formation potential. *Water Research*, 21, 649-659.

[3] Chen, W. and Weisel, C. (1998). Halogenated DBP concentrations in a distribution system *J. Am. Water Works Assoc*. 90, 151–163.

[4] Gallard, H. and von Gunten, U. (2002). Chlorination of natural organic matter: kinetics of chlorination and THM formation. *Water Research*, 36, 65-74.

[5] Golfinopoulos, S.K. (2000). The occurrence of trihalomethanes in the drinking water in Greece. *Chemosphere*, 41, 1761-1767.

[6] Hdaidoun, L. (2011). Tracing the dissolved Organic Carbon (DOC) from Groundwater from Springs and Wells in Jericho Area. *Master Thesis, College of Graduate Studies, Al-Quds University Abu Dees*.

[7] Isaac, J., Qumsieh, V. and Abu-Zahra, B. (1995). Environmental Profile for the West Bank, Jericho District. *Applied Research Institute-Jerusalem (ARIJ)*, 11-26.

[8] Khayat, S., Geyer, S. and Marei, A. (2010). Tracing the inorganic carbon system in the groundwater from the lower Jordan Valley basin (Jericho/Palestine). In P. Birkle & A. I. (Eds.), *In the Water-Rock interaction XIII (ED.)* (pp. 1008): Taylor and Francis Group.
[9] Khayat, S., Möller, P., Geyer, S., Marei, A., Siebert, C. and Hilo, F. (2009). Hydrochemical variation in the springs water between Jerusalem-Ramallah Mountains and Jericho Fault, Palestine. *Environmental Geology*, 57,1739–1751
[10] Krasner, S. W., McGuire, M. J., Jacangelo, J. G., Patania, N. L., Reagan, K. M. and Aieta, E. M. (1989). The occurrence of disinfection by-products in US drinking water. *Journal-American Water Works Association*., 81, 41-53.
[11] LeBel, G. L., Benoit, F. M., and Williams, D. T. (1997). A one-year survey of halogenated disinfection by-products in the distribution system of treatment plants using three different disinfection processes. *Chemosphere*., 34, 2301-2317.

[12] Marei, A., Khayat, S., Weise, S., Ghannam, S., Sbaih, M. and Geyer, S. (2010). Estimating groundwater recharge using the chloride mass-balance method in the West Bank, Palestine. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*., 55, 780-791.
[13] Marei, A., Schmidt, N. and Tiehm, A. (2013). *Evidence of Hydrogeological Connection between the Mountain and Plio-Pleistocene Aquifer Systems, Using Pharmaceutical Residual-case study Jericho area/Lower Jordan Valley*. Paper presented at the EGU General Assembly Conference Abstracts.
[14] Marie, A. and Vengosh, A. (2001). Sources of salinity in groundwater from Jericho area, Jordan Valley. *Ground Water*., 39, 240-248.
[15] Morris, R.D., Audet, A.M., Angelillo, I. F., Chalmers, T.C. and Mosteller, F. (1992). Chlorination, chlorination by-products, and cancer: a meta-analysis. *American journal of public health*., 82, 955-963.
[16] Nikolaou, A., Lekkas, T. and Golfinopoulos, S. (2004). Kinetics of the formation and decomposition of chlorination by-products in surface waters. *Chemical Engineering Journal*., 100, 139-148.
[17] Reckhow, D.A., Singer, P.C. and Malcolm, R. L. (1990). Chlorination of humic materials: byproduct formation and chemical interpretations. *Environmental science & technology*., 24, 1655-1664.
[18] Rofe, and Raffety. (1963). West Bank. The Hashemite Kingdom of Jordan. Central Water Authority. In: Rofe and Raffety Consulting Engineers Westminster, London.15-32.
[19] Rook, J. (1972). Formation of haloform during chlorination of natural water. *Water Treatment and Examination*., 21, 32-36.
[20] Rook, J.J., Gras, A., Van der Heijden, B. and De Wee, J. (1978). Bromide oxidation and organic substitution in water treatment. *Journal of Environmental Science & Health Part A*., 13, 91-116.
[21] Singer, P.C. (1994). Control of Disinfection By-Products in Drinking Water. *Journal of Environmental Engineering – ASCE*, 120, 727-744.
[22] Singer, P.C., Obolensky, A. and Greiner, A. (1995). DBPs in chlorinated North Carolina drinking waters. *Journal-American Water Works Association*., 87, 83-92.
[23] Sturm, C., Ribbe, L. and Schwabe, C. (1996). Water resources management in the West Bank, Palestine-Final Report. ASA Program of 1996. Carl Duisberg Gesellschaft e. V., Berlin.