

Assessing Risks to Human Health from Potentially Toxic Elements in Drinking Water of Duhok Province/ Kurdistan Region of Iraq

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Received June 11, 2014; Revised June 20, 2014; Accepted June 26, 2014

Abstract The monitoring and assessment of water has become an environmental concern due to contamination caused by man-kind. The main aim of this study is to evaluate the levels of As and some other heavy metals in the pre and post treated water of the projects in Duhok province and to assess the efficiency of these water projects for filtration and purification of drinking water in terms of potentially toxic metals. This study covers the water purification projects of the entire Duhok governorate areas (Semel, Chambarkat, Zakho, Akre, Shekhan and Amedy). Water samples were collected monthly from August 2008 to July 2009. The results indicated that the As concentration in pretreated water from the Duhok and zakho water project was higher than the WHO guide lines for drinking water (10µg.L-1), whereas in the treated water from the Duhok project its concentration remains above guideline levels. Other metals such as Cd, Pb and Ni at all of the studied projects were higher than the permissible limits in both pre and post treated water, according to the WHO guideline values (3,10 and 20 µg.L-1) respectively, while Cr and Zn were lower than the permissible limit. The values of combined HQ were >1 for all PTEs in drinking water of Duhok, Chamberkat, Zakho and Amedy samples indicating health hazards for the local population. To conclude, the consumption of drinking water may pose high risk to the local population.

Keywords: assessing risks, drinking water, Potentially Toxic Elements (PTEs), Hazar Quotient (HQ), Duhok province

Cite This Article: Karzan. Hawrami, and Hassan. Mezuri, "Assessing Risks to Human Health from Potentially Toxic Elements in Drinking Water of Duhok Province/ Kurdistan Region of Iraq." *Journal of Environment Pollution and Human Health*, vol. 2, no. 2 (2014): 44-51. doi: 10.12691/jephh-2-2-2.

1. Introduction

Water is the "Elixir of Life" but it is facing a severe threat due to an increase in pollution. Water, because of its great solvent power, is constantly threatened with pollution easily. The requirement for water by all forms of life, from microorganisms to human beings, has become a serious issue today since all water resources have reached a point of crisis due to unplanned urbanization and industrialization [1].

One of the most serious problems facing the world today is contamination by potentially toxic elements (PTEs) because it has become a global phenomenon and may become a major stress factor in the next few decades [2]. The main reason for this, is that, metals cannot be biologically decomposed so they accumulate in living organisms, food chains and the ecosystem [3]. One of the most important environmental issues of today is drinking water contamination. It is a serious environmental problem as it adversely affects human health and the biodiversity of the aquatic ecosystem [4]. As is the king of poisons, has probably influenced human history more than any other element or toxic compounds. It is a ubiquitous

toxicant and carcinogenic element associated with a wide range of adverse effects on human health effects [5]. Exposure to inorganic As via drinking water is a major public health concern [6]. Recent studies indicate that As and Cd are carcinogenic, mutagenic, and teratogenic if used in high environmental doses Cr (IV), Pb, and Ni are also extremely toxic and carcinogenic even at very low levels [7].

The major sources of drinking water in the Duhok province are ground water wells and springs) with some sources coming from surface water Khapor River (main river in the area).The main objectives of this study are to evaluate As and some PTE contamination in drinking water in the Duhok province and to assess the efficiency of water projects for the filtration and purification of water.

2. Description of the Area

Duhok province is located in the Kurdistan region of Iraq between the Bekhir Mountain in the north and the White Mountain in the south. Its boundaries extend from longitude (20- 42°) (10-44°)E and from latitude (40-36°) (20-37°) and the elevation at sea level for the Duhok

province varies from 445 m to 1215 m. The climate for the Duhok area is similar to that of the other parts of the Kurdistan region other parts in the northern parts of Iraq, in that it is semi-arid and characterized by hot summers and moderately rainy, cold winters. The total rainfall value for the area during the period of the study, as obtained from Duhok metrological office, was 193.1 mm. The average annual temperature recorded during 2000–2008, ranged from -11.1 to 41°C. The monthly average humidity values recorded for the Duhok province during 2001 to 2004 was 43%.

The study area has marked similar (Northern Iraq) tectonic forms. The tectonically point can be divided into three zones, the thrust zone, the high folded zone and the third region is the alluvial plain (non folded zone) [8]. All geological formation in northern Iraq is sedimentary origin with the rare exception of some rocks in the thrust zone. The area is divided into separate stations, the whole

area in general is located within the folded zone, deposits of the Eocene and Quaternary participate in the geological structure of the area and it was represents by several formations. The geological formation of the studied area have a great effect on water quality due to erosion action or leaching land crust or during percolation toward different aquifers [9].

The whole of the Duhok province includes Duhok city and its five districts (Semel, Zakho, Shekhan Akre and Amedy). The sources of drinking water and their distribution has been studied by many authors [10,11,12] during the last decade, 80% of the Duhok city depends on the Mosul and Duhok dam for its drinking water and the other 20% depends upon groundwater (drilled wells). Zakho city depends upon surface water (Khapor River) and other cities (Semel, Shekhan Akre and Amedy) depend 100% upon groundwater wells and springs Figure 1 shows the satellite image of the studied sites.

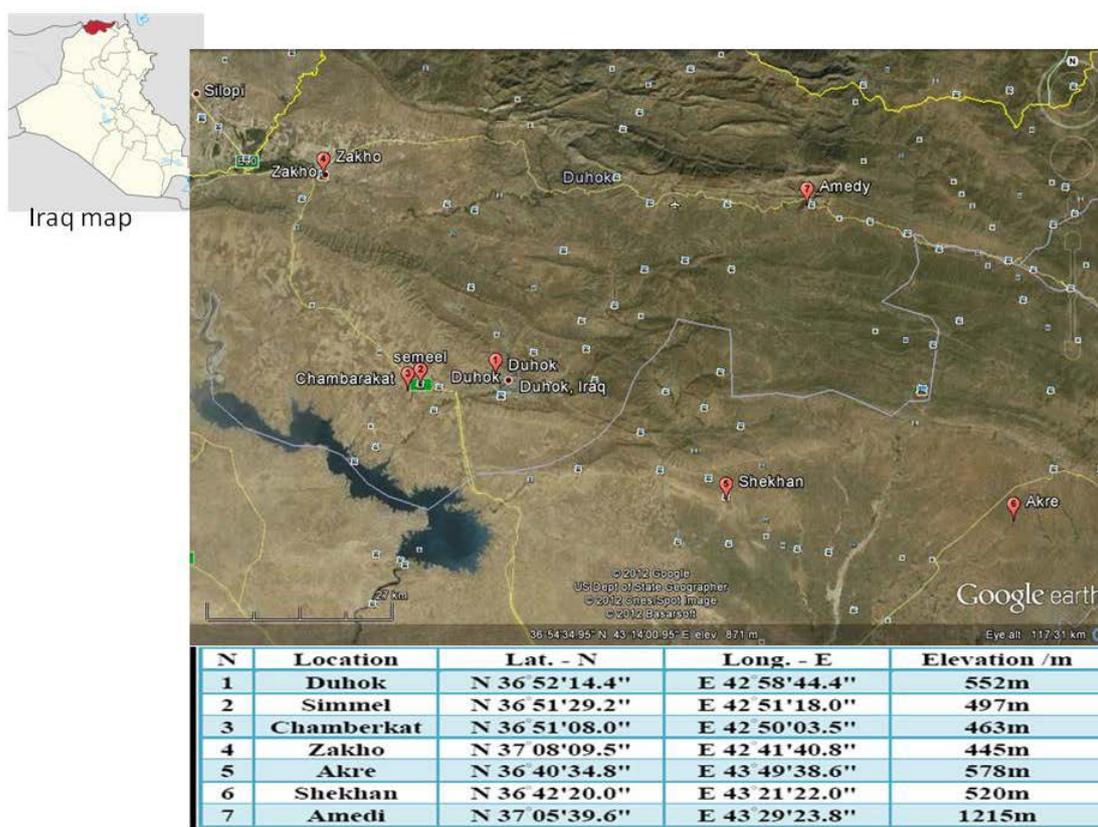


Figure 1. satellite image illustrates all studied sites

3. Material and Method

Water treatment methods are generally divided into chemical, mechanical and microbiological processes which include aeration, flocculation, sedimentation and filtration and disinfection but in the current projects the only treatment which used for purification of water is disinfection.

The water samples were collected monthly from August 2009 to July 2010 at all the selected projects. They were taken carefully to prevent any contamination of samples with metals. Water samples were taken at all water projects in pre and post treated water and three replicate water samples were taken at five (5) minute intervals. [13] The samples were filtered through Watman No. 41 filter

paper, 0.45- μ m pore size. The pH of the filter was adjusted to 2 ± 0.2 with 1M HNO₃ then the samples were acidified with 1 ml of concentrated HNO₃ per 500 ml of sample in order to minimize the precipitation and adsorption into the container walls. Each sample was then stored in a refrigerator for later heavy metal determination. Water samples were digested before analysis according to [14] for a more accurate determination of trace metals. The 500 ml water sample was placed in a 600 ml Pyrex-glass beaker, 5 ml of concentrated HNO₃ for each 100 ml sample was added and slowly boiled on a hotplate (60–80°C). The evaporation process was carried out in a dust free room until reaching a final sample volume of 15–20 ml. The heating process continued by adding drops of concentrated HNO₃ until digestion was complete, as

shown by the bright color, clear solution, and the digested samples were completed using 50 ml of deionized water in 50 ml volumetric flasks.

The water temperature was measured in the field at the time of sampling using a precise mercury thermometer (0 to 50°C) graduated at 0.1 intervals. Hydrogen ion concentration was measured directly after transporting the samples to the laboratory with an electrometric method using a pH-meter model (Inolab. WTW) [14].

Electrical conductivity was measured in the laboratory using EC-meter model (Inolab. WTW). [14]. Metal analysis was carried out using a flame atomic absorption spectroscopy (AAS) which determined the total content of As, Cd, Cr, Pb, Ni, Cu and Zn. The instrument used was an Analyst 200 (Perkin-Elmer) spectrophotometer. Measurements for Cr, Ni, Cu and Zn were taken using a hollow cathode multi-element lamp, while, for As, Cd and Pb an Electrode Less Discharge Lamps (EDL System 2), was used, which used acetylene gas as fuel and air as an oxidizer.

3.1. Health risk Assessment

3.1.1. Hazard Quotient (HQ) Indices

The HQ for non-carcinogenic risk can be calculated by the following equation [15]:

$$HQ = CDI / RfD \quad (1)$$

$$CDI = C \times DI = BW \quad (2)$$

Where, C, DI and BW represent the concentration of PTE in water ($\mu\text{g/L}$), average daily intake rate (2 L/day) and body weight (72 kg), respectively [16]. According to USEPA database the oral toxicity reference dose values (RfD) are $3.0\text{E}-04$, $5.0\text{E}-04$, 1.5, $3.7\text{E}-02$, $2.0\text{E}-02$, $3.6\text{E}-02$, $3.0\text{E}-01$ mg/kg-day for Cd, Cr, Cu, Ni, Pb and

Zn, respectively [17]. The exposed population is assumed to be safe when $HQ > 1$ [18].

4. Statistical Analysis

Randomize Complete Block Design (RCBD) was used for statistical analysis by using Microsoft (SPSS Ver. 17). Analysis of Variance (ANOVA), Duncan multiple range tests were employed to examine the statistical significance difference in the mean concentration of PTEs with location, months and their interaction; the probable level of ($P < 0.01$) was conceded to be statistical significant. Multiple correlation models were used to measure the correlation coefficient values between each calculated pairs of the studied variables.

5. Results

Figure 2 shows the physical properties of both pre and post treated water within each water purification project. The pH values of pretreated water was higher than the post treated water except for the Shekhan project, where the post treated water was slightly higher than the pretreated water. While, EC results showed that there was no significant difference between pre and post treated water throughout all studied projects.

As concentration increased and decreased according to the treatment process. Figure 3 shows that, As concentration at post treated water at the Chambarakat and Zakho water projects were significantly high. While, As concentrations in the post treated water were high at the Duhok Dam and Shekhan. The general mean concentration of As concentration decreased during the treatment process.

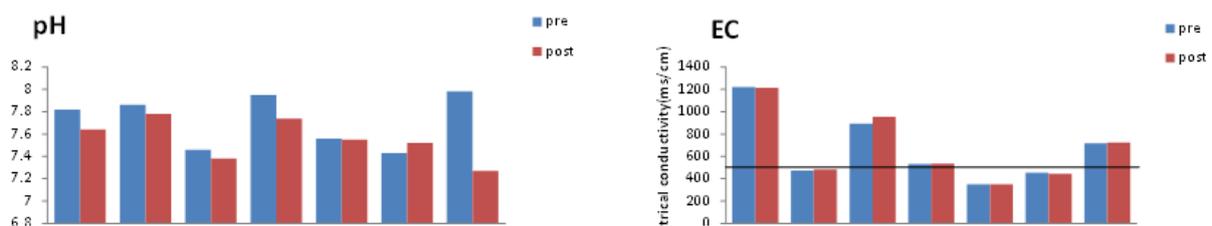


Figure 2. Physical properties in pre and post water treatment at each studied water purification project. Different letters are significantly difference at $p < 0.01$, while same letters are not significantly difference. The straight line denotes WHO guideline value

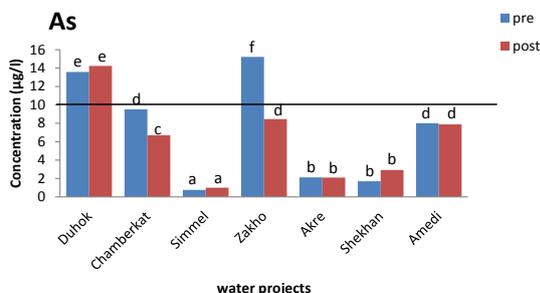


Figure 3. Concentration of As in pre and post in pre and post water treatment at each studied water purification project. Different letters are significantly difference at $p < 0.01$, while same letters are not significantly difference. The straight line denotes WHO guideline value

Figure 4 shows the PTEs concentrations in pre and post water treatment. Cd concentration in post treated water at

the Zakho station had decreased significantly, (13.850 to $7.218 \mu\text{g.L}^{-1}$) while no significant difference was observed in Cd concentrations between the pre and post treated water at each of the Semel, Akre, Shekhan and Amedy water projects. Cr concentration decreased significantly, during water treatment processes at Chambarakat while at the Duhok Dam, Semel and Shekhan its concentration had increased during water treatment processes. Pb concentration slightly decreased during the treatment process at Chambarakat and Zakho while, its concentration increased significantly, during the treatment process at Akre, Semel, Shekhan and Amedy. Ni concentration significantly decreased during the treatment process at the Chambarakat (35.81 to $28.21 \mu\text{g.L}^{-1}$). Cu concentration in post treated water at the Chambarakat and Zakho stations were significantly decreased, whereas it significantly increased in concentration after water process

treatment at the Akre and Shekhan stations. At the Duhok, Semel, Akre and Amedy water projects there were no significant differences observed in Cu concentration between pre and post treated water. Zn concentration significantly decreased during the treatment process at Chamberkat and Zakho stations, while it significantly increased during water treatment process at the Shekhan station.

Figure 5 shows the seasonal variations of physical properties, As and heavy metals, where no significant difference was observed between seasons for pH and EC, a higher value was recorded during the summer and a lower value was recorded during autumn. As well as, seasonal fluctuation for As, and metals concentration the same was shown to have happened for Cd, Cr and Pb. The higher mean value was found during summer which differed significantly from all other seasons while, the lower mean value was recorded during autumn which differed significantly from all other seasons. In contrast for Ni, Cu and Zn the higher mean value was found during

the autumn and differed significantly from all other seasons and the lower mean value was recorded during spring and differed significantly from the autumn and summer.

The correlation analysis provided a preliminary view of the relationship ($r=-1$ to $+1$). A positive correlation between two or more variables suggests that they vary in the same direction, while a negative correlation suggests that two or more variables change reversely. It can be noted that, values of (r) from (0.1- 0.3) suggests that the variables have a slightly Correlation between them, (r) value from (0.4 - 0.6) suggest moderate and an (r) value from (0.7- 0.9) shows a very high correlation. Whereas, $r=1$ shows a perfect correlation between them and $r=0$ means there is no correlation between them at all.

Table 1 shows the results of the correlation analysis between PTEs of the studied sites. It can be seen that there was a significant correlation ($P < 0.01$) between pH with (As and Cd), As with Cd and Cr with Pb.

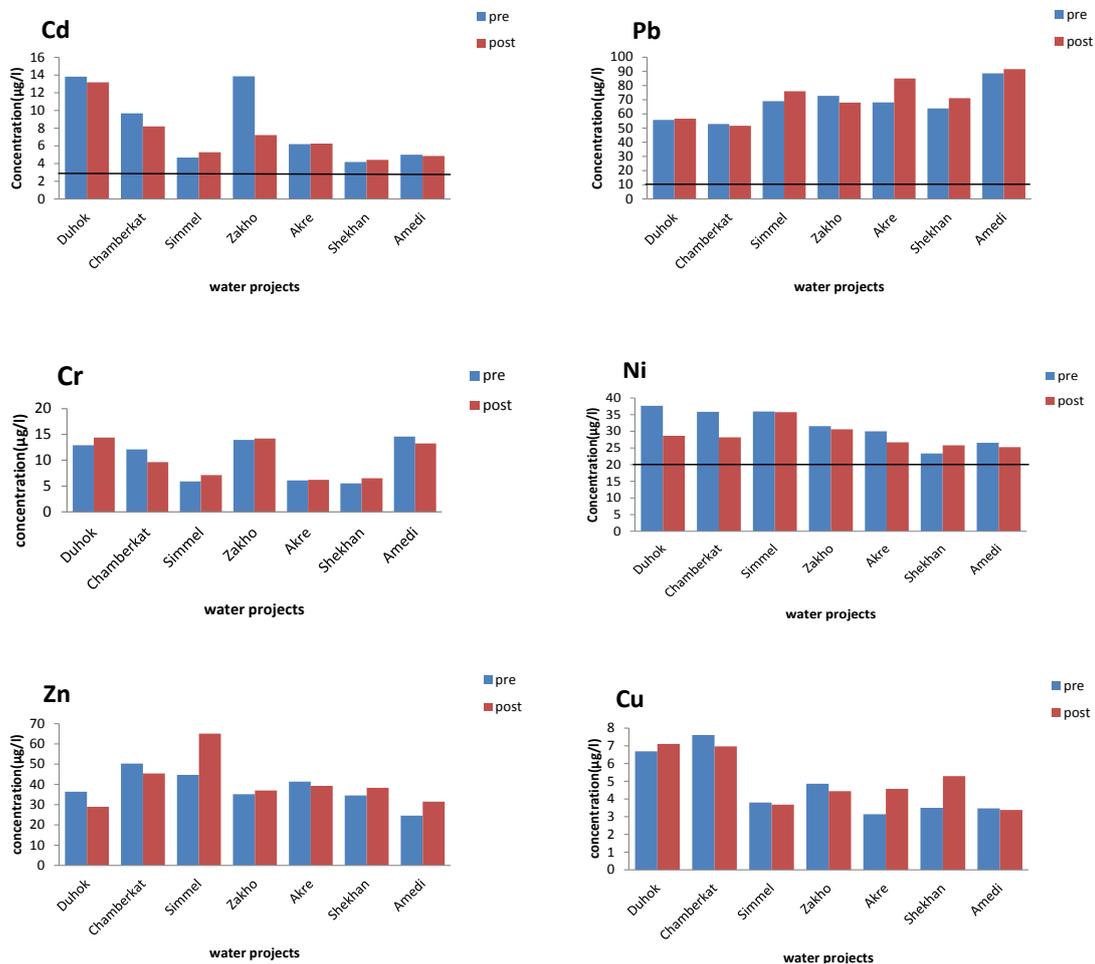


Figure 4. Concentration of PTEs in pre and post water treatment ($\mu\text{g.L}^{-1}$) at each studied water purification project. Different letters are significantly difference at $p < 0.01$, while same letters are not significantly difference. The straight line denotes WHO guideline value

Table 1. Pearson correlation coefficient for physical properties and PTs in drinking water

	EC	pH	As	Cd	Cr	Cu	Ni	Pb	Zn
EC	1								
pH	-0.085	1							
As	0.025	0.637**	1						
Cd	0.009	0.329**	0.754**	1					
Cr	-0.250*	0.052	0.135	0.09	1				
Cu	-0.01	-0.027	0.14	0.211	-0.091	1			
Ni	0.136	0.027	0.132	0.167	-0.14	0.144	1		
Zn	-0.081	-0.01	-0.148	0.094	-0.129	-0.089	0.157	-0.169	1

*Correlation is Significant at the 0.05 level (2 Tailed)

** Correlation is Significant at the 0.01 level (2 Tailed)

5.1. Hazard Quotient (Hq) Indices

Table 1 summarizes the HQ indices of HM through consumption of drinking water in the study area. In Duhok dam, the mean HQ index values for As, Cd, Cr, Pb and Ni for pretreatment water were 1.256, 0.732, 2.39E-04, 0.043 and 0.52 while that of post treated water were 1.318, 0.732, 2.66E-04, 0.043 and 0.047 respectively. In Chambarakat project, the mean HQ index values for As, Cd, Cr, Pb and Ni for pretreated water were 0.881, 0.538, 2.242E-04, 0.041 and 0.050 while that of post treated water 0.621, 0.455, 1.786E-4, 0.039 and 0.039 respectively (Table 1). Similarly, in Seemel water project the mean HQ index values for Cd, Cr, Pb and Ni for pretreated water were 0.072, 0.232, 1.96E-04, 0.053 and 0.050 while that of post treated water 0.073, 0.263, 1.316E-04, 0.059 and 0.050 respectively (Table 1). Therefore, In Zakho water project, the mean HQ index values for As, Cd, Cr, Pb and Ni for pretreated water were 1.409, 0.769, 2.582E-04, 0.056 and 0.044 while that of post treated water 0.783, 0.401, 2.630E-04, 0.053 and 0.043 respectively. In Akre project, the mean HQ index values for As, Cd, Cr, Pb and Ni for pretreated water were 0.197, 0.313, 1.128, 0.053 and 0.048 while that of post treated water 0.195, 0.317, 1.152E-4, 0.065 and 0.37 respectively. Similarly, in Shekhan water project the mean HQ index values for Cd, Cr, Pb and Ni for pretreated water were 0.159, 0.232, 1.020E-04, 0.060 and 0.032 while that of post treated water 0.208, 0.248, 1.209E-04, 0.066 and 0.036 respectively and in final water project (Amedy) the mean HQ index values for Cd, Cr, Pb and Ni for pretreated water were 0.742, 0.260, 2.698, 0.068 and 0.037 while that of post treated water 0.730, 0.258, 2.456E-04, 0.073 and 0.035 respectively.

6. Discussion

Physical parameters such as pH, and EC are one of the most important ecological features, they control the behavioral characteristics of organisms, solubility of gases and salts in water [19,10,11].

The pH value of the current study lies on the alkaline side above pH 7. For pre and post treated water, the obtained value of pH was considered to be in the usual condition generally because in the Kurdistan region of Iraq the pH of water has been characterized by a shift toward the alkaline side of neutrality due to the geological formation of the area which is composed mainly of CaCO₃ [12,20]. High pH value was recorded at the water projects that are dependent upon surface water, such as River (Zakho) and, Impoundment (Chambarakat and Duhok). This could contribute to increased photosynthetic activity (reducing the CO₂ amount in water), or it may be due to the presence of dissolved carbonate and bicarbonate in the water. Similar results were recorded by [19,21].

The decrease in pH values during the water treatment processes may be due to the release of carbonate and bicarbonate in the water or by the action of precipitation or filtration [22]. The pH values of all the studied samples in pre and post treated water was on the safe side for drinking purposes (6.5-8.5) in accordance with the WHO and Iraqi guidelines for drinking water standards [23,24].

Electrical conductivity is an important measurement of water quality because it gives a good idea of the presence

of the amount of dissolved minerals in the water [25]. The EC values at the Duhok Dam and Semel exceed the WHO guideline for drinking water (700 $\mu\text{S}\cdot\text{cm}^{-1}$) in both pre and post treated water, this may be related to presence of high dissolved ions, input of allochthonous organic material from the catchment areas and high mineral salts concentration from the dissolution of minerals in the soil [26]. These two stations are not suitable for domestic use. The health effects on humans for consuming water with high EC may include disturbances of salt and water balance and adverse effects on certain myocardial patients and individuals with high blood pressure [27]. Similar EC values were recorded at the same area [17,18].

There was no significant differences observed between EC in pre and post treated water, at each of the stations, this may be due to the inactivity of treatment processes in trapping total ions or may it be related to new contamination of water with ions during the treatment process.

Drinking water is a well-recognized pathway for exposure to As. It has been associated with various forms of cancer, nephrotoxicity, central nervous system effects and cardiovascular disease in humans. [28].

The provisional guideline value for As concentration in drinking water has been lowered from 50 to 10 $\mu\text{g}/\text{l}$ in some countries [29] and the maximum admissible concentration value has also been reduced to 10 $\mu\text{g}/\text{l}$ for the people of the United States by the USEPA in 2002 [30]. The results of this study showed that the As concentration in surface water samples (Zakho (River), Duhok Dam and Chambarakat (Impoundment)) from pretreated water, were above maximum allowed concentration according to the WHO Guidelines for drinking water standards [29]. This may be due to the drainage of hydrothermal spring into the impoundment, especially at the Duhok Dam thus leading to an increase the concentration of sulfate, and the high concentration of As found in the samples contain high concentration of sulfate [31], the same results were recorded by [32,33] for ground water and [21,34] for surface water in different parts of the world.

The treatment process at the Duhok dam has not affected the As concentration in the water this, may due to that, in this water project the only way which is used for water purification is chlorination, therefore As concentration will not be treated by only addition of chlorine. At both the Chambarakat and Zakho stations, As concentration significantly decreased during the water treatment process. This may be because of the presence of precipitation and sand filtration units in these projects. These are most important units for removal of excesses PTEs, including As, because dissolved metals ions are absorbed into the sand surface [34].

The concentration of As was slightly higher in summer season Figure 5, this may be related to the evaporation of water which leads to an increase in the concentration of this element. However, in winter high dilution occurred and similar results were observed by [35,36]

PTEs cause severe threats to humans and the environment [37]. In addition, despite being part of the natural environment, concentrations above a certain threshold are considered toxic materials, dangerous and harmful because of their tissue degradation in nature [2]. Toxic metals are also bioaccumulative and relatively stable as well as, being carcinogenic [38].

In the present study, the concentration of Cd, Cr and Ni at surface water samples (Duhok Dam, Chambarakat and Zakho) were more than the ground water samples from Semel, Akre and Shekhan. This could be that studied surface water is more exposed to anthropogenic pollution than the ground water. For example, effluent of sewage water, atmospheric deposition and disposal municipal waste around the water sources then runoff during the rainy season in to water bodies [39].

In general, decreasing concentration of PTEs at the Chambarakat and Zakho water projects during water treatment processes may be due to the presence of precipitation and the sand filtration unit, in both water projects Cd and Ni still above the acceptable limit because of the effect of solder and galvanized pipes on the treated water [14]. It can be also argued that, paints of water reservoirs and relatively old and poorly maintained pipe distribution systems may have a played a role in elevation of the concentration of PTEs in the drinking water, even after treatment.

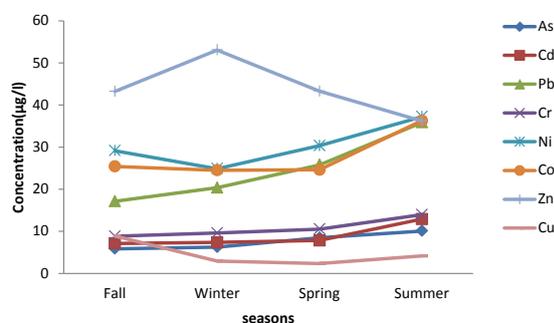


Figure 5. seasonal fluctuation of As and heavy metals in raw water for all studied sites

Unfortunately, the concentration of Pb was significantly increased at (Semel, Akre, Shekhan and Amedy) in post treated water compared with the pre treated water. This may be due to the household plumbing systems in which the pipes solder, fittings, or service connections to homes

contain Pb, PVC pipes also contain Pb that can leach in to drinking-water [38,39].

Generally the concentrations of Cu and Zn in pre and post treated water were detected to be so much lower than the WHO guidelines for drinking water standards (1000 and 3000 µg/L) respectively. Zn concentration seems to be safe if it is water that is only used for domestic purposes but it is not acceptable to aquatic ecosystem because it might be detrimental for fish and other aquatic life [35].

Seasonal variations in Cd, Cr and Pb concentration, shown in Figure 3, significantly increased during the summer and decrease during autumn this agreed with results that were observed by Khan and ASTDR, [40,43]. This may be due to evaporation during hot and dry season and dilution during rainfall or it may be related to an increase dust precipitation during dry months, 26 dusty days were recorded by Duhok Metrological Directorate (DMD) during May, June and July 2009. While, the concentration of nickel significantly increased during autumn this may be due to increase of municipal waste disposal especially, of household appliance near the body of water or atmospheric precipitation due to the first rain. Worldwide there is a release approximately 56 million kg of nickel into the atmosphere each year [44] and the an increase in fertilizer and pesticide in the water sources through surface runoff [33], the same results were recorded [21,36,43].

Concentration of Cu and Zn, were significantly increased during the wet season Figure 5. This may be due to an increase in weathering and erosion caused by heavy rain during the wet season consequently running off in to the near water body or it may be because of transition of metals between water and sediment due to oxidation and reduction condition and change water pH, whereas decrease in their concentration during hot periods may relate to an increase in the abundance of green organisms including phytoplankton growth and other activities throughout summer [43]. The same results were recorded [31,36,43].

Table 2. Hazard quotient indices (HQI) of potentially toxic elements (PTE) in drinking water

Water projects	As		Cd		Cr		Pb		Ni		Hazard Indices	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Duhok dam	1.26	1.32	0.77	0.73	2.39E-04	2.67E-04	0.04	0.04	0.05	0.05	2.12	2.14
Chambarakat	0.88	0.62	0.54	0.46	2.24E-04	1.76E-04	0.04	0.04	0.05	0.04	1.51	1.16
Semeel	0.07	0.07	0.23	0.26	1.10E-04	1.32E-04	0.05	0.06	0.05	0.05	0.41	0.44
Zakho	1.4	0.78	0.77	0.40	2.58E-04	2.63E-04	0.06	0.05	0.04	0.04	2.28	1.28
Akre	0.20	0.19	0.31	0.32	1.13E-04	1.15E-04	0.05	0.07	0.04	0.04	0.60	0.61
Shekhan	0.16	0.21	0.23	0.25	1.02E-04	1.21E-04	0.06	0.07	0.03	0.04	0.48	0.56
Amedy	0.74	0.73	0.26	0.26	2.70E-04	2.46E-04	0.07	0.07	0.04	0.04	1.11	1.10

Generally the concentrations of Cd, Pb and Ni of pre and post treated water were detected to be so much higher than the WHO guidelines for drinking water standards, (3, 10 and 20 µg/L) respectively, the higher concentration of these elements may be due to the discharge of industrial effluents and municipal wastes, geological formation, weathering and the erosion of soil during the rainy seasons [45].

In addition, the usage of chemical fertilizer and agro-chemicals also increase the PTEs pollution of farmland because fertilizers are not sufficiently purified during the process of manufacture, for economic reasons, they contain impurities, such as, trace elements. Also Cd, Pb and Ni often form a part of the active compound in

pesticides [38]. The concentration of these elements in permissible limits except for Cr which was less than the WHO guidelines for drinking water standards, (50 µg.L⁻¹) Therefore, the use of the water for domestic supply is not safe without the proper treatment.

Possible metal-metal, metal-pH and metal-EC relationships were investigated throughout the study, using the Pearson correlation coefficient, r , $p < 0.05$ and 0.01. as Table 1, This correlation is supported by many authors such as Soyalk et al., and Apafilippaki et al, [37,46,47]. A significant correlation between metals may be indicate whether there is any common source of pollution [43] or as a result of co-existence and co-precipitate with each other, as based on the Redox

condition, on the other hand most PTEs in the water are affected by many physico-chemical changes in the environment, such as pH, temperature, DO, COD and the Redox potential [37].

The HQ indices of potentially toxic elements in the water purification projects were found in the order of Duhok dam> zakho> Chamberkat> Amedy> Akre> Shekhan> Semealso for post treated water were found in the same order.

It can be clearly seen from the table that the HQ indeces values based on the trace element concentrations was considerably greater for pretreated water than post treated water (Table 1), treatment processes minimized the HQ values at Chamberkat and Zakho and Amedy by 0.355, 0.999, 0.010, respectively, while in others remain same or slightly higher at pot treated water.

The combined HQ at Duhok dam, Chamberkat, zakho and Amedy water projects were higher than recommended value set by USEPA $HQ \geq 1$ [14] (Table 1), demonstrating drinking water from these water projects is likely to cause a substantial health risks to dwellers and costumers while the HQ indices for all trace elements in drinking water at Seemel, Shekhan and Akre water projects suggest no risk to local population when compared [12,15], but still more attention should be paid to contamination because some of the HQ values were close to guideline value. However, the HQ indices of As, Cd, Ni and Pb metals were tend to be higher than those reported in drinking water by Kavcar et al. [48] in surface water and groundwater by Lim et al [49]

7. Conclusion

The presence of As contamination in the Duhok dam and Zakho station indicates that there is a leaching of this metal from the anthropogenic activity of discharging the waste materials, which contains a high level of As. The remaining of As after treatment at the Duhok dam indicates that the process of purification is in sufficient at this station. The drinking water in most of the purification projects in the Duhok province contains a high level of other PTEs (Cd, Pb and Ni) which exceed the worldwide permissible level. Chamberkat and Zakho are the best water treatment plants for the purification of raw water in the Duhok province All water projects must be continuously monitored as well as proper treatment of water, in order to eliminate the concentration of trace elements before the water enters the aqueduct web, using Granular activated carbon filtration and sand filters inoculated with heavy metal biosorbing and bio precipitating bacteria there is a crucial way for removing excess PTEs.

The health risk assessment indices indicates that potentially toxic elements in drinking water of some water projects (Duhok, Chamberkat, zakho and Amedi) pose hazardous risk to the consumers based on US EPA standards ($HQ > 1$) while in Seemel, Akre and Shekhan the drinking water is safe for human consumption, Therefore, it is strongly recommended that water from contaminated locations should not be used for drinking purposes without proper treatment. The Government of Kurdistan region of Iraq should provide drinking water alternatives to these areas in recognition of the potential health risks associated with Potentially toxic elements.

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