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Assessing Aluminum Concentration in Alum-Based Water Treatment Residuals in Halabja, Kurdistan Region of Iraq

Tareq Hamah-ameen Abdullah

Sulaimani Polytechnic University, Halabja Technical Institute /Halabja, Medical Laboratory Technique, Kurdistan region of Iraq.

Abstract

Background & Objectives: The use of alum in the water purification process increases the residual aluminum content in water and potentially has adverse effects on people's health, and considering the water source of Halabja city and the efficiency of the Halabja water treatment plant in purifying or filtering aluminum concentration, this study aims to the study of aluminum concentration in the drinking water treatment plant of Halabja, Iraq.

Method: In order to assessment of water, 3 sites were chosen for sample collection in the study including raw water directly from Sirwan River, treated water from treatment plant and tap water from households during the period from July to December 2023. Water samples were collected in pre-cleaned, sterilized glass bottles of 500 ml capacity and transported to the Atmosphere Company for Environmental and Laboratory Services in ice-cooled containers. Analysis was done for chemical parameters including Aluminum (Al), pH, temperature (CO) total dissolved solids (TDS), turbidity, and total Alkalinity.

Result: The amount of aluminum in Raw, Treated and Tap water was higher than the health and healthy water standards. Although the amount of aluminum residuals in the treated water was very low in the last analysis of sample, and despite being low, it was not in accordance with international standards. Other physicochemical variables, pH, Turbidity, Temperature, Alkalinity and T.D.S, although they were associated with fluctuations and increases in the examined samples, but their values were in the optimal and standard range.

Conclusion: The use of alum in the purification process and the effect of other factors, the concentration of aluminum remaining in the investigated waters is high and it is not safe and sanitary water according to the standards, and this issue can have harmful effects on the consumers of these waters.

Keywords: Aluminum residual, Alum, Alzheimer’s disease, Coagulation, Turbidity

Corresponding author: Tareq Hamah-ameen Abdullah

Contacts: Email: Tareq.abdullah@spu.edu.iq

1.1ntroduction:

Internationally acknowledged as a fundamental human right, safe drinking water is necessary for human survival, health, development, and necessity. A previous WHO/UNICEF report revealed that approximately 663 million people worldwide lack access to clean drinking water [1].

Most surface water treatment facilities use aluminum in the form of alum (aluminum sulfate) to aid in the removal of dangerous waterborne microorganisms, turbidity, color, and other particles by causing them to (coagulate) into larger particles which are then easily removed, by filtration and sedimentation. Additionally, this method eliminates naturally occurring organic debris from the water, which lessens the production of disinfection byproducts [2]. Aluminum concentrations in treated water are frequently higher than in the raw water itself when alum is used as a coagulant for water treatment [3]. All naturally occurring waterways and water systems include aluminum. Most of the aluminum in the treated water, [4]. It can exist as dissolved or undissolved organic and inorganic compounds, and the pH level is a significant component that affects the form of aluminum [5]. pH regulation and effective filtration were key factors in reducing the residual aluminum concentration in water [6].

For the majority of people, food is the main source of aluminum exposure. Water consumption is another exposure source. These exposures came from the water used to prepare meals and drinks, cooking utensils, and antacid preparation [7]. According to a European study, less than 5% of the daily intake of aluminum comes from sources other than food, utensils, pharmaceuticals, etc. [8]. Worldwide drinking water quality guidelines for aluminum (Al) were developed with a range of acceptable concentrations. For aluminium in drinking water, the Environmental Protection Agency suggested a secondary maximum contaminant level of 0.05–0.2 mg/dm^3 [9]. Less than 0.2 mg/L of residual Aluminum (Al) is what the World Health Organization demands [10],

In general, when adding an aluminum salt during water treatment, a concentration of between 1 and 5 mg/L is preferred. For aesthetic reasons and to reduce turbidity, color, and post-precipitation in the water apportionment system, it has long been advised that the aluminum concentration should be less than 0.2 mg/L and more than 0.05 mg/L for health reasons [11]. Numerous scientific researches have also revealed that aluminium is a risk factor and may have a connection to dementia, osteomalacia [12], encephalopathy [13], and Alzheimer's disease (AD) [, 14-17], as well as total parenteral nutrition (TPN) [18]. Aluminum in drinking water is seen as a danger [19]. It has long been criticized for employing aluminium salts as a flocculant for cleaning drinking water [20]. Due to its ionized form and ease of absorption, aluminum is toxic to living things, especially in acidic but also in alkaline environments. Aluminum compounds are insoluble in inert environments and are eliminated by the body [21]. The created alum sludge may be a source of toxic aluminum, which may lead to a number of major environmental issues such water pollution, modifications in the characteristics of the soil, and changes in leachate chemistry [22].

The study's findings on how aluminum in coagulants affects the amount of aluminum that remains in filtered water and its toxicity to human health are presented and discussed in the article. It should be noted that due to the use of alum in the water treatment process in the Halabja treatment plant as the only source of drinking water for the residents of the city, it is necessary to evaluate the quality of drinking water and the efficiency of the treatment plant in reducing the maximum concentration of aluminum. of this study is to find out how much aluminum is in the water that the people of Halabja in Iraq's Kurdistan Region drink.

2. Matrials And Methods

Halabja is a city in the Kurdistan Region of Iraq and the capital of Halabja Governorate, located about 240 km northeast of Baghdad at 35.1786° North and 45.9853° East with an elevation of 751 meters above the sea level. The primary municipal drinking water for the city is sourced from the Halabja Water Treatment Plant. Following the treatment process, the water is pumped to elevated storage tanks before being distributed to households. In order to assessment of water, three waster types were chosen for sample collection in the study including raw water directly from Sirwan River (raw water), treated water from treatment plant and tap water from households during the period from July to December 2023. Water samples were collected in pre-cleaned, sterilized glass bottles of 500 ml capacity and transported to the Atmosphere Company for Environmental and Laboratory Services in ice-cooled containers. Analysis was done for chemical parameters including Aluminum (Al), pH, temperature (C^O) total dissolved solids (TDS), turbidity, and total Alkalinity(T.Alkalinity) , We used ICP-OES according to US EPA 200.7, ISO 11885, CSN EN 12506, US EPA 6010, SM 3120 for Aluminum, High performing bench-top PH-meter MW151-E – pH/ORP/Temperature for pH and temperature , turbidity-portable-meter-hi98703-02 for turbidity , hi8734-three-range-portable-tds-meter for T.D.S and titratable-alkalinity-mini-titrator-for-water-HI84531U-O1 for T.Alkalinity. All the precautions were taken as given in APHA, AWWA, WPCF (2003), for sampling and analysis.

3.Data Analysis:

To analyze data from IBM Corp. SPSS software. Version 26 (Armonk, NY: IBM Corp) was used. One-Way ANOVA statistical tests were used to check the difference between the investigated variables, and Tukey HSD post hoc test was also used to find the factor of difference between the variables. Mean Difference was presented as effect size. Scatter plot was used to express the concentration of biochemical agents. A significance level of $P \leq 0.05$ was considered.

4.Results:

The results of biochemical analyzes in Raw water, treated water and Tap water are shown in table number (1). The mean concentration of aluminum mg/L in raw water was 0. 9084±0. 149 mg/L, in treated water 1.0442±0.205 mg/L and in tap water 1.0252±0.295 mg/L. The mean concentration

of Turbidity N.T.U in Raw water was 30.333±20.839 mg/L, in Treated water 2.283±2.212 N.T.U and in Tap water N.T.U was 2.666±2.353. The pH of Raw water was equal to 7.558±0.155, the pH of treated water was equal to 7.328±0.180, and the pH of Tap water was 7.606±0.161.
The temperature water showed that the water temperature in Raw water was 26.366±2.212 C^0, the water temperature in Treated water was 24.383±2.270 C^0, and the water temperature in Tap water was 25.700±1.280 C^0. The mean concentration Alkalinity mg/L in Raw water was 128.666±48.161 mg/L, in Treated water 126.833±29.721 mg/L and in Tap water 135.000±33.633 mg/L. The mean concentration of T.D.S mg/L in Raw water was 249.833±20.923 mg/L, in Treated water 255.333±38.365 mg/L and in Tap water 275.333±37.313 mg/L.

Table (1). Concentrations of Aluminum and physicochemical properties of raw, treated and tap water samples in Halabja province with mean, SD

Parameters	Source Of Sample	Mean	Std.Dev.
Aluminum Mg/L	Raw Water	0.9084	0.149
	Treated Water	1.0442	0.205
	Tap Water	1.0252	0.295
Turbidity N.T.U	Raw Water	30.333	20.839
	Treated Water	2.283	2.212
	Tap Water	2.666	2.353
Ph	Raw Water	7.558	0.155
	Treated Water	7.328	0.180
	Tap Water	7.606	0.161
Temperature C^0	Raw Water	26.366	2.212
	Treated Water	24.383	2.270
	Tap Water	25.700	1.280
Alkalinity Mg/L	Raw Water	128.666	48.161
	Treated Water	126.833	29.721
	Tap Water	135.000	33.633
T.D.S Mg/L	Raw Water	249.833	20.923
	Treated Water	255.333	38.365
	Tap Water	275.333	37.313

The results of this study showed that the amount of Aluminum remaining in Raw, Treated and Tap water was not significantly different. Turbidity value was significantly different in Raw, Treated and Tap water, which showed that the turbidity value in one of the samples is different from the other ($P \leq 0.001$). Also, there was a significant difference in the pH value of Raw, Treated and Tap water, which indicates that the pH value in one of the water samples is different from the other one

(P ≤ 0.001). Temperature, T. Alkalinity and T.D.S remaining in Raw, treated and Tap water have no significant difference (Table 2).

Table (2). Analyses of Variance (one way ANOVA) of water samples showing interaction between variables

Variable	Sum Of Squares	Df	Mean Square	F	P-Value*
Aluminum Mg/L (Raw &Treated &Tap Water)					
Between Groups	.074	2	.037	.471	.633
Within Groups	1.178	15	.079		
Total	1.252	17			
Turbidity N.T.U (Raw &Treated &Tap Water)					
Between Groups	3104.788	2	1552.394	10.473	.001
Within Groups	2223.495	15	148.233		
Total	5328.283	17			
Ph (Raw &Treated &Tap Water)					
Between Groups	.241	2	.120	4.827	.024
Within Groups	.374	15	.025		
Total	.615	17			
Temperature (C0) (Raw &Treated &Tap Water)					
Between Groups	12.223	2	6.112	1.569	.241
Within Groups	58.422	15	3.895		
Total	70.645	17			
T. Alkalinity Mg/L (Raw &Treated &Tap Water)					
Between Groups	220.333	2	110.167	.076	.927
Within Groups	21670.167	15	1444.678		
Total	21890.500	17			
T.D.S Mg/L (Raw &Treated &Tap Water)					
Between Groups	2161.000	2	1080.500	.982	.397
Within Groups	16509.500	15	1100.633		
Total	18670.500	17			

*P-value one-way ANOVA

Based on the ANOVA test, there was a significant difference in Turbidity and pH of the investigated waters, while no difference was seen in Aluminum, Temperature, T. Alkalinity and T.D.S. The results of the Tukey HSD test, which was used to determine the factor of difference, showed that the mean Turbidity between Raw Water and Treated Water has a significant difference (Mean Difference: 28.050, CI 95%: 9.79 - 46.31, P ≤ 0.003). Also, the mean Turbidity between

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Raw Water and Tap Water has a significant difference (Mean Difference: 27.667, CI 95%: 9.41-45.93, P ≤ 0.004) and based on this, the reason for the Turbidity difference is Raw Water. Based on the results, it was shown that the pH of water between Tap Water and Treated Water has a significant difference (Mean Difference: 0.27833, CI 95%: 0.5152-.0415, P ≤ 0.021). The reason for the difference in PH was tap water (Table 3).

Table (3). **Comparison of Aluminum and Physicochemical Characteristics between Raw, Treated, and Tap Water Samples using Post Hoc Analysis Results**

Multiple Comparisons						
(I) Group	**(J) Group**	**Mean Difference (I-J)**	**Std. Error**	**P-Value****	**95% Confidence Interval**	
Dependent Variable: Aluminum Mg/L (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**.02772167**	**0.16178600**	**0.984**	**-0.3925127**	**0.4479560**
	Tap Water	**-.11999000**	**0.16178600**	**0.743**	**-.05402243**	**0.3002443**
Treated Water	**Raw Water**	**-.02772167**	**0.16178600**	**0.984**	**-0.4479560**	**0.3925127**
	Tap Water	**-.14771167**	**0.16178600**	**0.641**	**-0.5679460**	**0.2725227**
Tap Water	**Raw Water**	**0.11999000**	**0.16178600**	**0.743**	**-0.3002443**	**0.5402243**
	Treated Water	**0.14771167**	**0.16178600**	**0.641**	**-0.2725227**	**0.5679460**
Dependent Variable: Turbidity N.T. U (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**28.050***	**7.029**	**0.003**	**9.79**	**46.31**
	Tap Water	**27.667***	**7.029**	**0.004**	**9.41**	**45.93**
Treated Water	**Raw Water**	**-28.050***	**7.029**	**0.003**	**-46.31**	**-9.79**
	Tap Water	**-.383**	**7.029**	**0.998**	**-18.64**	**17.88**
Tap Water	**Raw Water**	**-27.667***	**7.029**	**0.004**	**-45.93**	**-9.41**
	Treated Water	**.383**	**7.029**	**0.998**	**-17.88**	**18.64**

Dependent Variable: Ph (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**0.18500**	**0.09118**	**0.139**	**-0.0518**	**0.4218**
	Tap Water	**0-.09333**	**0.09118**	**0.574**	**-0.3302**	**0.1435**
Treated Water	**Raw Water**	**-0.18500**	**0.09118**	**0.139**	**-0.4218**	**0.0518**
	Tap Water	**-0.27833***	**0.09118**	**0.021**	**-0.5152**	**-0.0415**
Tap Water	**Raw Water**	**.09333**	**0.09118**	**0.574**	**-0.1435**	**0.3302**
	Treated Water	**0.27833***	**0.09118**	**0.021**	**0.0415**	**0.5152**
Dependent Variable: Temperature (C0) (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**1.9833**	**1.1394**	**0.223**	**-.976**	**4.943**
	Tap Water	**0.6667**	**1.1394**	**0.830**	**-2.293**	**3.626**
Treated Water	**Raw Water**	**-1.9833**	**1.1394**	**0.223**	**-4.943**	**0.976**
	Tap Water	**-1.3167**	**1.1394**	**0.496**	**-4.276**	**1.643**
Tap Water	**Raw Water**	**-.6667**	**1.1394**	**0.830**	**-3.626**	**2.293**
	Treated Water	**1.3167**	**1.1394**	**0.496**	**-1.643**	**4.276**
Dependent Variable: T. Alkalinity Mg/L (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**1.833**	**21.944**	**0.996**	**-55.17**	**58.83**
	Tap Water	**-6.333**	**21.944**	**0.955**	**-63.33**	**50.67**
Treated Water	**Raw Water**	**-1.833**	**21.944**	**0.996**	**-58.83**	**55.17**
	Tap Water	**-8.167**	**21.944**	**0.927**	**-65.17**	**48.83**
Tap Water	**Raw Water**	**6.333**	**21.944**	**0.955**	**-50.67**	**63.33**

	Treated Water	**8.167**	**21.944**	**0.927**	**-48.83**	**65.17**
Dependent Variable: T.D.S Mg/L (Raw &Treated &Tap Water)						
Raw Water	**Treated Water**	**-5.500**	**19.154**	**0.956**	**-55.25**	**44.25**
	Tap Water	**-25.500**	**19.154**	**0.400**	**-75.25**	**24.25**
Treated Water	**Raw Water**	**5.500**	**19.154**	**0.956**	**-44.25**	**55.25**
	Tap Water	**-20.000**	**19.154**	**0.562**	**-69.75**	**29.75**
Tap Water	**Raw Water**	**25.500**	**19.154**	**0.400**	**-24.25**	**75.25**
	Treated Water	**20.000**	**19.154**	**0.562**	**-29.75**	**69.75**

* The mean difference is significant at the 0.05 level.

**P-value Tukey HSD

Figures:

Mean value of aluminum, turbidity and pH of Raw water, treated water and Tap water are shown in figure number (1).

The analysis of aluminum concentration and turbidity in the water samples reveals noteworthy findings. The minimum aluminum values in both treated water and tap water surpass the standard range, indicating an elevated concentration compared to the established norms. Specifically, the aluminum concentrations are as follows: 0.205 mg/L in treated water and 0.295 mg/L in tap water, both exceeding the acceptable standard range. On the other hand, the minimum turbidity values in treated water and tap water fall within the standard range of less than 5 NTU, with values of 2.212 NTU and 2.353 NTU, respectively. These turbidity levels are considered acceptable, falling within the recommended range of 6.5 to 8.5 degrees. In summary, while the minimum aluminum concentrations in both treated and tap water are higher than the standard, the minimum turbidity values adhere to the established guidelines.

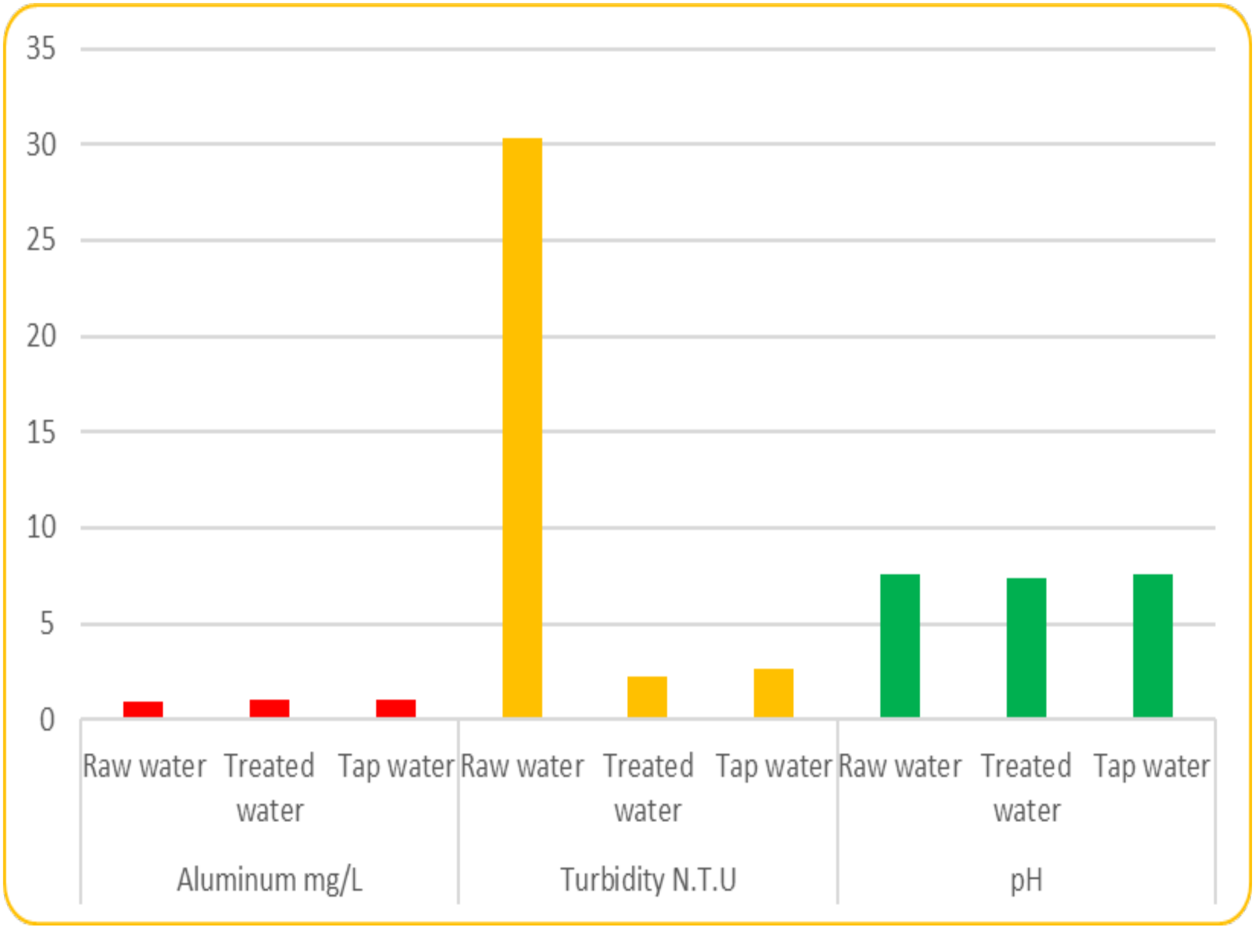

Figure (1). Mean value of aluminum, turbidity and pH of Raw water, treated water and Tap water

The amount of aluminum present in Raw, Treated and Tap water in 6 water samples is shown in Figure 2. The first sampling of every month was done in the designated places mentioned in the work method. The amount of aluminum in the first sample in all three waters (Raw, Treated and Tap) was higher than the standard. The amount of aluminum in the second sample increased in all three investigated waters and was much higher than the standard. In the third, fourth and fifth samples, although the amount of aluminum has decreased, but its amount is more than the standard. In the sixth sample, the amount of aluminum in Raw and Tap water has increased significantly, but the amount of aluminum in treated water was between 0.05-0.2 ppm and despite being low, it was not in accordance with international standards.

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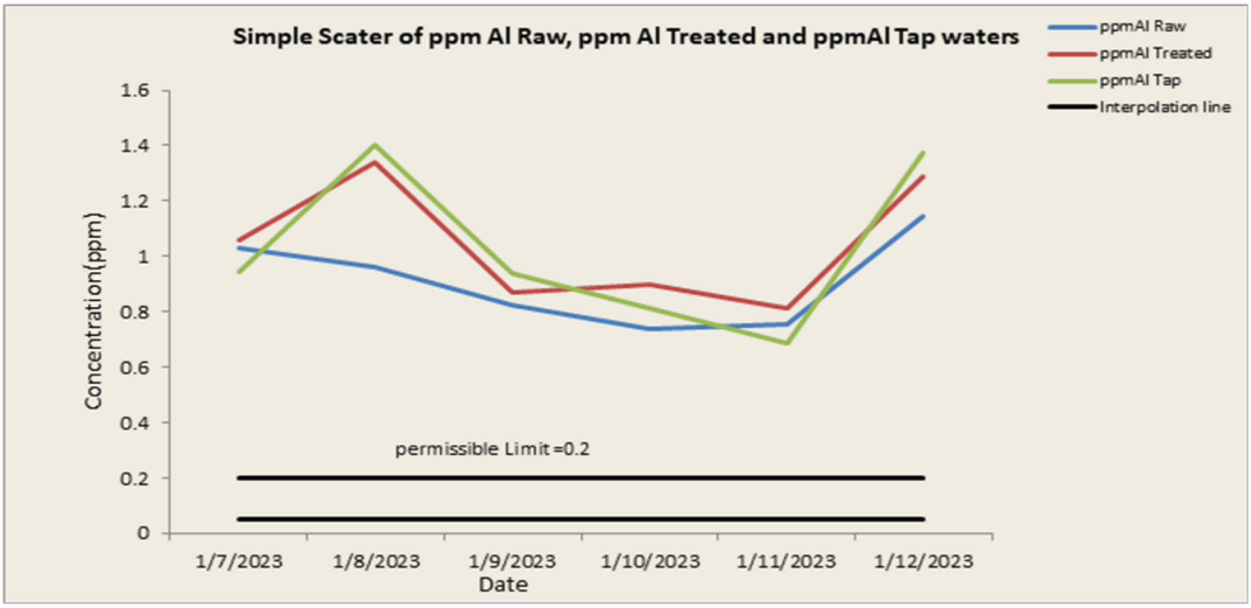

Figure (2) . Concentration of aluminum in Raw, Treated and Tap water

5. Discussion

This study was conducted with the aim of investigating the effect of aluminum used in coagulants on the amount of aluminum remaining, and investigating its amount in water used for domestic purposes. The results of this study showed that during the study period, the amount of aluminum remaining in the water was higher than the optimal and standard level, although in the last study and sample, the amount of aluminum remaining in the treated water was very low, and despite being low, it was in accordance with It has not been up to global standards. Other biochemical variables pH, Turbidity, Temperature, Alkalinity and T.D.S, although they were associated with fluctuations and increases in the studied samples, but their values were within the optimal and standard range.

The results of this research showed that the use of alum was associated with an increase in the remaining aluminum. A study who aimed to investigate the effectiveness of phosphate compounds in removing residual aluminum from normal and enhanced coagulation in water treatment. They showed that the aluminum compounds used in coagulants and water purification process increase the residual amount of aluminum, which should be reduced by using appropriate methods such as adding phosphate compounds after coagulation.

In the water purification process, various coagulants such as aluminum sulfate (alum) and polyaluminum chloride are used in order to settle colloidal particles and destroy various pathogenic organisms. Using both types of coagulants in the coagulation process causes some aluminum to remain in the water, if its amount exceeds the set standard; It will have destructive effects on human health and the environment [23]. Another study which was conducted with the aim of determining the amount of residual aluminum due to the use of alum and polyaluminum chloride in removing turbidity from turbid waters. They have shown that there is a significant relationship between the amount of aluminum consumed in the water purification process and the amount of residual aluminum, so that with the increase in aluminum consumption, the amount and concentration of its residue in water will increase. [24]

It should be noted that the change of shape of aluminum in water or in some way the speciation of aluminum in drinking water is very important because the solubility, bioavailability and toxicity of aluminum depend on its shape in water. Because the increase of some forms of aluminum such as aluminum salts, which have a low molecular weight and are chemically reactive and easily absorbed by the human body, it will be very important and vital to pay attention in the water purification process to reduce the amount of remaining aluminum in the forms used [25].

In a study conducted in Iraq they examined the data on the concentration of aluminum in raw and drinking water in the city of Baghdad between 2005-2006 and for six treatment plants in the city. The results showed that according to the seasonal changes, the amount of aluminum remaining in the water has undergone changes. It has also been shown that the amount of remaining aluminum, although it was within the desired and standard level in some treatment plants, but it was higher than the standard level in another treatment plant [11].

The increase of aluminum in water may be caused by various factors, such as the type and shape of aluminum used, problems related to the purification process, such as not replacing the filters on time, and the filters being damaged, which should be paid more attention to reduce the amount of aluminum [26,27].

Using the right pH in the coagulation process, avoiding the high use of alum salts, the proper efficiency of filtration to remove aluminum clots, the use of effective methods of removing aluminum during water purification and identifying the factors affecting the remaining aluminum in purified water, are one of the solutions that can be useful in reducing the amount of aluminum remaining in water.

The results of various studies [28, 29] have shown that aluminum in water can be effective in reducing Turbidity, Alkalinity and T.D.S. As shown in the results, the Turbidity, Alkalinity and T.D.S was within the standard and was in accordance with the standards of healthy and hygienic drinking water, which can be due to the use of aluminum and its positive effects.

6. Acknowledgement: Author thanks Halabjah water directorate and Halabjah water treatment plant for institutional facilities and help me.

7. Conclusion

The results of this study showed that the concentration of aluminum remaining in Raw, Treated, and Tap water was high so that the concentration of aluminum remaining in Tap water was higher than in Raw and Treated water. Considering that the remaining aluminum concentration in treated water was lower than Tap and Raw water, this concentration was still higher than the international standard. This high concentration is due to the excessive use of aluminum or the fact that the aluminum regeneration filter does not work properly, which causes the concentration of aluminum in the water to increase and the treatment project cannot completely reduce the incoming aluminum to the standard level. and increased aluminum concentrations in treat water, possibly due to pipelines or reservoirs containing aluminum where the amount of aluminum in the tap water has increased again.

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