Evaluation Of Ifraz Water Treatment Plants In Erbil City-Iraq

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ABSTRACT

With the increasing interest and care to Erbil province related with the priority for producing and supplying of potable water, three water treatment plants (WTP) were constructed during the last decades. Water quality for physical, chemical and bacteriological parameters were monitored in 15 sampling sites of three WTPs (Ifraz 1, 2 and 3) in Erbil governorate from May 2008 to Jan. 2009 at monthly interval period, each WTPs were divided in to five sampling sites according to treatment units. Results of water sample analysis were as follow: Turbidity values ranged between 0.2 to 29 NTU, while pH values ranged from 7 to 8.3, and electrical conductivity were ranged from 340 to 773 µS.cm⁻¹, total alkalinity and chloride ion were ranged from 92 to 181 mg CaCO₃.l⁻¹ and 8 to 28 mg.l⁻¹ respectively. Total hardness for the studied sites were 128 to 308 mg CaCO₃.l⁻¹, magnesium hardness is sure asses on calcium hardness. Dissolved oxygen (DO) values were ranged from 3.2 to 11.6 mg.l⁻¹. High BOD₅ values were recorded in raw water and sedimentation units in all WTPs, while the low values were recorded in filtration and storage units of all WTPs at different times. Nitrite concentrations at the major treatment units estimated to be between (0.006 to 2.96 µg at.N-NO₂.l⁻¹). Generally, potassium concentrations were lower than sodium. Sulphate concentration showed a range of 191 to 541 mg.l⁻¹. The range of reactive phosphorus was between 0.15 to 10.5 µg.at.P-PO₄.l⁻¹, and Jar test results was between 4 and 28 ppm. Bacteriologically, MPN for coliform.100ml⁻¹ in treated waters were safe for drinking purposes according to WHO reports.

Keywords: Evaluation, water treatment plants, Erbil

Introduction

In most parts of the world, from long time ago when rivers, lakes, springs, and wells from which one can directly drink; most of the water are used for drinking, irrigation, and industries, not supporting habitat for natural flora and fauna, but also needs treatment to become suitable for drinking and other purposes. The quality of water in a river might be considered suitable for irrigation but not for drinking, and to determine water quality, one must first determine purposes for using the water and treated according to standards for important parameters of the water that will support and protect the designated water uses (1). Water treatment plant (WTP) is a part of urban water supply system. The principle unit processes
involved in conventional water purification system includes sedimentation, filtration and chlorination (2).

Water purification originally focused on improving the aesthetic qualities of drinking water. Methods for improving taste and odor of drinking water have been recorded as early as 4000 B.C. Ancient Sanskrit and Greek writings mentioned water treatment methods such as filtration through using charcoal, exposing to sunlight, boiling, and straining. Visible cloudiness (later termed turbidity) was the reason behind the earliest water treatments. To clarify water, the Egyptians reportedly used the alum as early as 1500 B.C. During the 1700s, filtration was established as an effective means for removing particles from water. By the early 1800s, slow sand filtration was beginning to be used regularly in Europe. During the mid to late 1800s scientists studied sources and contaminants of drinking water. In 1855, epidemiologists proved that some diseases linking with the contamination of river by sewage, before the use of sands for filtration (3).

Freshwater resources around the world are decreased, demands for drinking, irrigation and industries were increased and their evaluation (physically, chemically and bacteriologically) was necessary (4). In Iraq there are 218 urban water treatment plants (5). Construction of water treatment plants (WTPs) in Erbil city like other parts of Iraq (Nasiriyah in 2006 and Sulaymaniyyah in 2009 etc.) was necessary to supply their population with clean drinking water. To evaluate WTPs in Erbil city some researchers conducted their studies on water quality for these treatment plants among them, (6) who conducted her study on old project of Ifraz, while (7) studied water quality for Ifraz treatment plants 1st and 2nd. After construction of 3rd Ifraz project at Greater Zab River in 2004, evaluation of all WTPs together was necessary to reduce the problem of water deficiency in Erbil city.

A holistic approach to drinking-water supply, risk assessment and risk management increase confidence in the safety of drinking-water. Water treatment is a process of making water suitable for its application or returning its natural state (4).

The aims of this study were to assess the quality of water resources during and after treatment within treatment plant projects; based on certain physical, chemical and bacteriological characteristics, studying the hygienic status of available drinking water and suggesting solutions and recommendations.

Description of the studied area

Three water treatment projects were selected for physico-chemical assessment and bacteriological analysis. First and third projects, locally known as Ifraz 1 and 3 are established in 1968 and 2004 respectively at Ifraz village about 32 Km north-west of Erbil city (Plate 1). While the second
Evaluation Of Ifraz Water Treatment Plants In Erbil City-Iraq.

The project known as Ifraz 2 which is located on the Erbil-Ankawa road at the right side, and established in 1982 (Plate 2). These projects collectively supply Erbil city with about 10500m3/hour of potable water. Each water treatment plant is divided into five sampling sites, raw water (River water), flash mixer (in which Alum, polymer (to increase weight of pellets), and chlorine gas were added and mixed), Sedimentation unit, filtration unit and high left (Storage unit) after second chlorination, which are ready for drinking.
Methodology

Water samples from fifteen sites located at water treatment projects were collected monthly for physical, chemical and bacteriological analysis from May 2008 to January 2009. Each site was visited on nine occasions during the period of the study. On the other hand, each water treatment project (Ifraz 1, 2 and 3) is divided into 5 sampling sites (Raw water, flash mixer, sedimentation, filtration and Storage tank). Water samples were collected in polyethylene bottle and following standard methods described by (8 and 9) for water analysis. All water samples analyzed within first 4-6 hours. Alkalinity, chloride, total and calcium hardness were measured by titration method, while magnesium hardness measured by calculation. EC and pH were measured using (pH-EC-TDS meter, HI 9812, Hanna instrument). Nitrite and phosphate were determined according to the (9). Sulfate was determined by turbidimetric method and Jar test conducted for raw water according to (8). Sodium and potassium cations measured using Flame Emission Photometer technique. Turbidity was measured using Turbidimeter (HF scientific, inc. model BRF- 15 CE). Dissolved oxygen measured by azide modification of Winkler method, BOD₅ and Most probable number (MPN) determined according to (8). Statistical analysis RCBD design Duncans multiple range tests were used to evaluate differences between sampling sites and sampling dates at (P<0.05) in addition to mean and standard error (SE) to find significant differences between sites or dates.
Results and Discussion

Turbidity measurements were used for aesthetic purposes and removal of undesirable particles by water treatment processes. The turbidity in water of WTPs must be less than or equal to 1 NTU in at least 95% of the measurements taken each month, but in potable water usually less than 5 NTU. Turbidity values at Ifraz water treatment plant (IWTP) units ranging from (0.2 to 29 NTU). The minimum value recorded at (St.5) of Ifraz 1 during June, 2008, whereas, maximum value recorded in (St.1) during Dec. 2008. Turbidity results of the present study in Ifraz 3 agreed with (6 and 10). While results in Ifraz 1 and 2 agreed with (7) (Table 1).

Higher turbidity values were observed in raw water of WTPs (Figure 2) which may be due to sewage water effluents of neighbor village and erosion effects of rainfall. The maximum value of turbidity in raw water of Ifraz 1 was in Dec. 2008 because of dusty storm and dust falls. The turbidity of raw water increased toward winter season due to the soil run off by rain fall, which accepted with results obtained by (6, 11 and 12). The minimum values of turbidity were found in storage tanks due to the remove of undesirable particles in treatment processes (sedimentation and filtration) of IWTPs (13). These results agreed with results of (6 and 7).

pH values of the major treated units were ranging from (7.0 to 8.4) which are the optimum pH values of drinking water and they are within normal range of drinking water 6.5-8.5 (8 and 14). The lowest values were recorded at flash mixer and sedimentation units of Ifraz 1 during Dec. 2008. While the highest values were measured in filtration unite of Ifraz 1 and raw water of Ifraz 2 during June and May 2008 respectively (Table 2).

In the results of current study, slight decrease in pH values observed from St. 1 toward St. 5 in WTPs which may be due to the salts of Aluminum (Al₂SO₄), which are used today as coagulant for reacting in water with chemicals, macromolecules and particles then precipitate them, which intern reduce the pH of water. In addition, removal of algae from water during treatment, and chlorination has a role in this process (15 and 16). However, these values were come in accordance with results obtained by (6 and 7) on WTPs of Erbil and (16) on Ivedik WTP in Turkia.

The EC value is an indicator of the amount of dissolved salts in the water (17). Results showed that EC values in raw water increased in dry season because of evaporation, while in wet season their values decreased because of dilution by rainfall (11 and 17) and controversy with results of (6 and 18).

The EC values in raw water of WTPs were ranging from minimum of 351 μs.cm⁻¹ and maximum of 773 μs.cm⁻¹ during Dec. and Aug. 2008.
respectively (Figure 3), while in treated water units the EC values varied between the maximum value of (757 µs.cm⁻¹) recorded at the (St. 2) of Ifraz 1 during the Aug. 2008, and the minimum value of 340 µs.cm⁻¹ measured in Ifraz 2 at (St. 5) during Dec. 2008 (Table 3). Values of EC in 56% of sites increased about 14 µs.cm⁻¹ as average during treatment at flash mixer of WTPs because of adding alum and polymer, while in 96% of sedimentation tanks about 10 µs.cm⁻¹ of EC reduced due to the precipitation of soil particles in the form of pellets after binding with coagulants (coagulation and flocculation), while in storage units, EC values were increased because of second chlorination and this accepted with results of (6 and 7).

The minimum value of alkalinity in the studied WTPs was 92 mg. CaCO₃.L⁻¹ recorded in Ifraz 1 at filtration unit in May. 2008, while the maximum value was 181 mg CaCO₃.L⁻¹ observed in raw water of old Ifraz during Aug. 2008 (Table 4). Generally, the alkalinity levels in sites of raw water ranged between 100-190 mg CaCO₃.L⁻¹ that is similar with results obtained by (7 and 18). These results were within the permissible levels of WHO (4). Alkalinity in Northern part of Iraq is due to the presence of bicarbonates and carbonate (19).

As stated by (20), the variation in alkalinity may be related to various factors, among them dissolved Carbon dioxide (CO₂) concentration, rainfall and runoff the catchment basin, microorganisms activity, and hydrolysis of bicarbonate ions. Total alkalinity values reduced in flash mixer of all WTPs by the effects of coagulant, sedimentation which intern minimize pH values and then alkalinity , k and this accepted with (6 and 7) results.

The lowest value of total hardness (TH) recorded was (116 mg.CaCO₃.L⁻¹) at (St. 3) of Ifraz 2 in June 2008, while the highest value was (308 mg.CaCO₃.L⁻¹) recorded at (St. 4) of Ifraz 2 in Dec. 2008 (Table 5). In 70% of sites about 19 mg.CaCO₃.L⁻¹ of Ca hardness increased, while in 30% of sites only 1.25 mg.CaCO₃.L⁻¹ was decreased as average. In 66% of WTPs about 30 mg.CaCO₃.L⁻¹ of Mg hardness was decreased, while in other sites, Mg hardness was increased about 27 mg.CaCO₃.L⁻¹ as average. Total hardness values in raw water of present study come in accordance with results mentioned by (7 and 18) and ranged between 146 and 284 mg.CaCO₃.L⁻¹ (Figure 4). High concentrations of hardness observed in wet season because of erosion effects of rainfall (21). The quality of water in this survey is classified as moderately hard to hard water (8).

The principle water hardness cause ions are Ca⁺² and Mg⁺², which originated from the sedimentary rocks like limestone and chalk (4). The calcium hardness concentrations for the studied sites were ranged from the maximum value of (220 mg CaCO₃.L⁻¹) at (St.3) of new Ifraz project during
Dec. 2008, to the minimum value of (32 mg CaCO₃.l⁻¹) in (St. 2) of old Ifraz project during Aug. 2008 (Table 6). High values of total hardness in old Ifraz project at Nov. 2008 may be related to the waste water effluents of neighbor village in to the River at that time (11).

The lowest value of magnesium hardness was (42 mg CaCO₃.l⁻¹) noted at (St.3) of Ifraz 2 during June 2008, while the highest value was (228 mg CaCO₃.l⁻¹) recorded at St.1 of new Ifraz project during Aug. 2008 (Table 7). The dominancy of magnesium hardness on calcium recorded in different sites during the present study, which may be related with geological formation of the catchments area (21).

The dissolved oxygen (DO) concentration in water depends on the physical, chemical, and biochemical activities in the water body, and its levels provides a good indication of water quality (22). Dissolved oxygen values were ranging from 3.2 to 10.9 mg.l⁻¹ for raw water, while in storage tank ranged from 4.4 to 12 mg.l⁻¹. Similar results were obtained by (6 and 7).

Variations in DO concentrations were observed throughout the entire sampling periods among sampling sites of WTPs, with low concentrations in dry season and high values in wet season that closely related with the temperature, dissolved salts, partial pressure of gasses, inputs of organic matters, climatic factors, light transparency and phytoplankton contents (23). During treatment process, water was aerated and DO values were increased, as obtained by (7 and 16). On the raw water of Greater Zab River showed lower DO values than that of treatment units due to aeration in treatment units. Similar to results obtained by (6).

Generally, biochemical oxygen demand (BOD₅) values for non seeded samples were ranging between (0.1 mg.l⁻¹) at (St. 5) for each of WTPs, and the highest value was (5.4 mg.l⁻¹) observed in (St.4) at old Ifraz project in Nov. 2008 (Table 9), this may be due to low filtration efficiency of old Ifraz project and low chlorination of water during treatment. The chlorine gas action for killing of microorganisms will complete after one hour (24) in spite, some organisms remain in water and consume small amount of oxygen during incubation period, which may supported by fecal coliform results in most sites of WTPs which contain less than 2.2 MPN.100ml. This means that some bacteria still exist in water, even after chlorination and consume dissolved oxygen during incubation, or by chemical oxidation. Results of present study agreed with (6 and 7). On the other hand, Greater Zab River sites showed higher BOD₅ values than treatment units, due to the chlorination and filtration.

Nitrite concentrations at the major treatment units located between (0.006 to 2.96 µg at. N-NO₂⁻¹l⁻¹). The lowest level was measured at storage
unit of Ifraz 2 during June 2008, while the highest level was recorded for sedimentation unit of the Ifraz 2 during June 2008 (Table 10). These results were come in accordance with results obtained by (6). The low Nitrite values in present study related to aeration of water during processes and converted to NO₃ (25).

Sodium salts are generally highly soluble in water and are leached from the terrestrial environment to the ground and surface water. Most water supplies contain less than 20 mg of sodium per liter, but in some countries, the levels can exceed 250 mg.l⁻¹ (4). During the present investigation, fluctuations in Sodium concentration were noticed (Table 11). The dusty storm in Aug. 2008 was behind the high levels of Sodium in water samples particularly in raw water of greater Zab River (Figure 5). While during rainfall season sodium levels reduced by dilution of water as stated by (26). After treatment processes, sodium concentrations increased, because sodium ions are available in alternate forms (ex. Organic compound), and degraded after treatment processes and oxidized by aeration to form soluble sodium (27).

Potassium cation K⁺ occurs in water as a result of mineral dissolution, from decomposing plant material, and from agricultural runoff (8). Generally, K⁺ concentrations were lower than the sodium levels during the entire sampling periods may possibly related to soil formation of Erbil province (7). Potassium concentrations in WTPs were ranged between the minimum value (0.2 mg.l⁻¹) measured in raw water of Ifraz 3, and the maximum value (4.9 mg.l⁻¹) recorded in filtration unit during May 2008 of Ifraz 2 (Table 12). These results agreed with the results obtained by (7), who stated that potassium values were high in dry season and low in wet season.

Chlorides (Cl⁻) occur in natural water, causes a salty taste when combined with sodium and forming sodium chloride (20). However, Cl⁻ range were 8 to 28 mg. l⁻¹ observed at filtration unit of Ifraz 3 during June 2008 and flash mixer in Ifraz 2 and 3 during Oct. and Sept. 2008 (Table 13). The high levels of chlorides in flash mixer and storage units for all WTPs may come from the disinfection of water by chlorine gas which produces hypochlorous and hydrochloric acid which in turn increase Cl⁻ ions in water or the effect of other ions in water which interfere with the results of (25).

Sulphate is an abundant ion on the earth's crust and its concentration in water range from few milligrams to several thousand milligrams per liter (22). Sulphate concentration relatively was within the permissible and desirable standards given for natural waters.

Sulphate concentrations showed a range of 191 to 541 mg.l⁻¹. The lowest value was noticed in (St.4) of Ifraz 2 during Jun. 2008, due to sedimentation, filtration processes and the distance between raw water of Greater-Zab and Ifraz 2, which minimize their values. The higher level was
measured at (St.1) of Ifraz 1 during Aug. 2008 (Table 14) because of dusty storm weather (Figure 6). These results agreed with the results obtained by (6). Clear seasonal fluctuations in Sulphate concentration were observed throughout entire sampling periods and increased with electrical conductivity values (25). Sulphate values in flash mixer of WTPs are lower than values in raw water, due to the binding of Alum with suspended particles in water (naturally SO₄ exists in earth crust) that clumped together via the processes of coagulation and settled faster before sedimentation process, thereby minimizing sulphate concentrations in flash mixer of WTPs during the periods of study (27).

Phosphorus is commonly found in soil, rocks, and plants. It is an essential nutrient for plants growth and important contaminants of surface water, even when low (25). The ranges of reactive phosphorus concentration were ranged between 0.15 µg.at.P-PO₄.L⁻¹ at (St. 3) of Ifraz 1 during Aug. 2008 and 10.5 µg.at.P-PO₄.L⁻¹ at (St.1) in Ifraz 1 during Sept. 2008 (Table 15). The high values of PO₄ in raw water of Greater Zab may come from the pollution of water with fertilizer that used in neighbor villages. The obtained results by (6 and 18) confirm the results of the current study. While in other units of treatment, PO₄ concentrations were decreased due to the treatment process.

Alum was needed for sedimentation of suspended particles from raw water and their concentration depends on the jar test results, to determine an optimum dose of Alum. Minimum Jar test result was 4ppm in Ifraz 2 at Jan. 2009 and their turbidity was 1.5NTU and maximum Jar test result was 28ppm in Ifraz 1 at Dec. 2008 when turbidity was 29 NTU (Table 16).

Fecal coliform bacteria originate from intestinal tracts of animal and human indicate the possible presence of pathogenic organisms. In the present study, the recorded value for the fecal coliform bacteria was >16 MPN.100 mL⁻¹ in raw water of all WTPs, all units of Ifraz 1 in Dec. 2008 and flash mixer of Ifraz 1 in Aug. 2008 considered unsatisfied for drinking according to guidelines (4). Also it indicates that Greater Zab river water is polluted due to the effects of sewage effluents of nearby villages (6, 7 and 18). While in other sites of WTPs have less than 2.2 MPN.100 mL⁻¹ and in the safe side for drinking purposes due to the chlorination effects and filtration (4).

Conclusions and Recommendations
1) Adequate chlorine adding is essential for successful operating WTPs.
2) Rapid sand filters should be checked, and regulating their back washes.
3) Continuous maintenance and analysis will lead to precise evaluation of plant performance and required modifications.
4) The performance of Ifraz 3 is higher than other WTPs (This concludes that the 1st and 2nd treatment plants needs more necessary repairs in their unites especially in filtration and sedimentation process).
### Table (1): Turbidity values (NTU) recorded for sampling sites with mean and SE for WTPs in Erbil Governorate.

| WTPs          | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 1.155 |
|---------------|------------------------------|---------|----------------------------|----------------|
| Dates         | 1     | 2     | 3     | 4     | 5     | 1     | 2     | 3     | 4     | 5     | 1     | 2     | 3     | 4     | 5     |                   |
| May           | 3.8   | 2.5   | 2.1   | 1.1   | 0.9   | 3.2   | 2.1   | 1.7   | 1.4   | 0.9   | 4.6   | 1.2   | 1.4   | 0.3   | 0.6   | 1.84 a            |
| June          | 3.5   | 0.2   | 0.5   | 1.0   | 0.2   | 5.6   | 1.2   | 2.7   | 3.0   | 1.7   | 6.3   | 5.2   | 7.3   | 1.3   | 1.1   | 2.7 a             |
| July          | 13.1  | 11.6  | 7.2   | 1.9   | 2.0   | 11.9  | 10.0  | 5.5   | 1.2   | 1.5   | 12.8  | 10.6  | 4.1   | 1.1   | 1.1   | 6.37 b            |
| August        | 28.5  | 20.2  | 7.3   | 21.3  | 17.3  | 25.2  | 31.3  | 19.6  | 17.4  | 4.2   | 27.8  | 19.8  | 8.3   | 1.4   | 1.7   | 15.7 d            |
| September     | 21.2  | 10.5  | 11.2  | 3.2   | 3.3   | 19.5  | 14.5  | 15.0  | 3.2   | 3.2   | 21.4  | 10.5  | 11.5  | 1.2   | 1.2   | 10.0 c            |
| October       | 14.2  | 9.7   | 9.1   | 1.7   | 1.9   | 12.8  | 6.3   | 7.1   | 1.1   | 1.4   | 14.4  | 9.9   | 10.1  | 1.1   | 1.1   | 6.75 b            |
| November      | 10.5  | 3.06  | 1.81  | 2.1   | 1.3   | 9.2   | 5.5   | 2.0   | 0.9   | 1.0   | 10.2  | 4.2   | 1.52  | 0.49  | 0.78  | 3.64 a, b         |
| December      | 29    | 28.4  | 13.42 | 20.1  | 17.1  | 24.7  | 23.7  | 4.55  | 1.32  | 2.08  | 23.1  | 9.8   | 7.6   | 0.25  | 0.57  | 13.7 d            |
| January       | 2.5   | 5.8   | 2.53  | 2.38  | 2.55  | 1.5   | 2.45  | 1.57  | 1.7   | 0.75  | 2.2   | 2.55  | 1.8   | 0.42  | 0.6   | 2.09 a            |
| Mean ±SE      | 14.03 | 10.29 | 6.12  | 5.17  | 1.26  | 12.62 | 10.7  | 6.63  | 3.44  | 1.86  | 13.60 | 8.19  | 5.93  | 0.81  | 0.94  | (P<0.05)          |

*Same letters means significant differences not exist, while different letters means significant difference exist.*

### Table (2): pH values recorded for sampling sites with mean and SE for WTPs in Erbil Governorate.

| WTPs          | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.049 |
|---------------|------------------------------|---------|----------------------------|----------------|
| Dates         | 1     | 2     | 3     | 4     | 5     | 1     | 2     | 3     | 4     | 5     | 1     | 2     | 3     | 4     | 5     |                   |
| May           | 8.11  | 7.16  | 7.34  | 7.5   | 7.39  | 8.43  | 7.78  | 7.8   | 7.87  | 7.53  | 8.03  | 7.6  | 7.62  | 7.73  | 7.62  | 7.701 c         |
| June          | 8.06  | 7.22  | 7.84  | 8.43  | 8.1   | 7.79  | 7.91  | 7.42  | 7.65  | 7.6   | 8.09  | 7.62 | 7.6  | 7.83  | 7.69  | 7.790 c         |
| July          | 8.03  | 7.61  | 7.69  | 7.7   | 7.7   | 8.07  | 7.8   | 7.83  | 7.85  | 7.8   | 8.01  | 7.69 | 7.7  | 7.75  | 7.71  | 7.798 c         |
| August        | 7.01  | 7.05  | 7.43  | 7.54  | 7.49  | 7.75  | 7.26  | 7.36  | 7.47  | 7.36  | 7.14  | 7.32 | 7.43 | 7.66  | 7.52  | 7.386 a         |
| September     | 7.82  | 7.53  | 7.61  | 7.68  | 7.65  | 8.0   | 7.65  | 7.73  | 7.78  | 7.75  | 7.78  | 7.51 | 7.56 | 7.76  | 7.69  | 7.700 c         |
| October       | 7.84  | 7.79  | 7.75  | 7.84  | 7.8   | 8.77  | 8.71  | 7.86  | 7.8   | 7.71  | 7.88  | 7.64 | 7.69 | 7.74  | 7.7   | 7.781 c         |
| November      | 7.81  | 7.05  | 7.09  | 7.23  | 7.27  | 7.84  | 7.69  | 7.72  | 7.76  | 7.72  | 7.71  | 7.45 | 7.48 | 7.57  | 7.53  | 7.528 b         |
| December      | 7.82  | 7.05  | 7.09  | 7.05  | 7.04  | 7.83  | 7.34  | 7.22  | 7.7   | 7.39  | 7.77  | 7.15 | 7.17 | 7.35  | 7.26  | 7.339 a         |
| January       | 8.23  | 8.1   | 8.09  | 8.08  | 8.11  | 8.11  | 7.84  | 7.79  | 7.81  | 7.59  | 8.09  | 7.81 | 7.81 | 7.93  | 7.85  | 7.949 d         |
| Mean ±SE      | 7.859 | 7.859 | 7.54  | 7.67  | 7.61  | 7.97  | 7.68  | 7.64  | 7.74  | 7.61  | 7.83  | 7.53 | 7.56 | 7.70  | 7.6   | 7.949 d         |

*(P<0.05)*
Table (3): Electrical conductivity (µs.cm⁻¹) values recorded for sampling sites with mean and SE for WTPs in Erbil.

| WTPs          | Dates       | Mean±SE | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean±SE |
|---------------|-------------|---------|-----------------------------|---------|----------------------------|---------|
|               |             |         | 1 2 3 4 5                   | 1 2 3 4 5 | 1 2 3 4 5                 |         |
|               | May         | 3.525   | 447 471 456 456 460         | 440 459 455 457 460 | 451 453 452 452 455     | 454.9 d |
|               | June        |         | 536 577 574 540 525         | 542 561 558 490 533 | 544 543 553 543 547     | 544.4 g |
|               | July        |         | 480 493 498 508 511         | 487 496 502 507 514 | 479 486 487 493 495     | 495.7 f |
|               | August      | 768 757 737 740 736         | 738 745 730 746 748 | 773 750 739 733 739     | 745.2 h |
|               | September   | 561 548 528 532 535         | 556 538 532 546 542 | 560 555 547 551 554     | 545.5 g |
|               | October     | 484 490 466 470 479         | 478 483 469 458 467 | 481 493 474 467 478     | 475.8 e |
|               | November    | 437 432 433 427 424         | 430 427 427 420 414 | 421 420 447 417 422     | 426.5 c |
|               | December    | 392 411 407 401 398         | 351 346 342 348 340 | 373 385 389 392 398     | 378.2 a |
|               | January     | 392 390 386 389 392         | 373 402 393 395 401 | 394 382 383 387 385     | 389.6 b |

*Same letters means significant differences not exist, while different letters means significant difference exist.

Table (4): Total alkalinity (mg CaCO₃.L⁻¹) values recorded for sampling sites with mean and SE for WTPs in Erbil.

| WTPs          | Dates       | Mean±SE | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean±SE |
|---------------|-------------|---------|-----------------------------|---------|----------------------------|---------|
|               |             |         | 1 2 3 4 5                   | 1 2 3 4 5 | 1 2 3 4 5                 |         |
|               | May         | 3.211   | 113 120 98 92 104           | 117 126 109 107 116 | 120 136 138 110 140     | 116.4 a |
|               | June        |         | 118 113 107 119 110         | 123 116 112 114 111 | 127 121 128 123 131     | 118.2 a |
|               | July        |         | 142 127 140 144 138         | 142 131 137 126 112 | 161 148 149 131 128     | 137.0 b |
|               | August      | 181 142 160 166 162         | 164 154 156 162 164 | 186 160 168 158 160     | 162.8 d |
|               | September   | 170 138 144 148 144         | 176 140 146 152 148 | 168 132 138 142 140     | 148.4 c |
|               | October     | 148 122 128 130 126         | 156 128 132 134 128 | 150 132 134 138 132     | 134.5 b |
|               | November    | 136 96 128 116 114          | 146 137 140 132 124 | 140 132 122 126 130     | 127.9 b |
|               | December    | 144 128 126 120 126         | 160 168 184 196 192 | 148 128 130 130 136     | 147.7 c |
|               | January     | 190 182 174 178 168         | 166 170 190 186 178 | 194 170 192 176 170     | 178.9 c |
|               | Mean±SE     | 4.14    | 149 130 134 135 132         | 150 141 145 145 141     | 155 140 144 137 141     | (P<0.05) |
Table (5): Total hardness (mg CaCO₃.l⁻¹) values recorded for sampling sites with mean and SE for WTPs in Erbil.

| Dates   | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE |
|---------|-----------------------------|---------|----------------------------|----------|
|         | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  |         |
| May     | 221| 206| 227| 186| 211| 186| 174| 178| 178| 180| 194| 192| 208| 228| 182| 186 a,b |
| June    | 200| 212| 200| 192| 208| 148| 212| 116| 160| 128| 192| 194| 198| 222| 202| 186 a   |
| July    | 218| 204| 198| 204| 192| 192| 174| 174| 182| 220| 196| 204| 208| 214| 198 a,b |
| August  | 262| 240| 208| 192| 148| 146| 192| 196| 196| 192| 276| 244| 222| 220| 224| 211 b,c |
| September | 266| 238| 240| 212| 220| 168| 182| 186| 180| 184| 266| 232| 236| 238| 244| 219 b,c |
| October | 254| 215| 222| 210| 181| 176| 184| 186| 190| 192| 248| 200| 214| 218| 224| 210 b,c |
| November | 262| 276| 276| 276| 288| 208| 216| 192| 184| 190| 256| 268| 256| 296| 256| 249 d,e |
| December | 244| 268| 282| 244| 268| 236| 264| 288| 308| 300| 248| 276| 272| 232| 252| 265 e   |
| January  | 240| 232| 292| 260| 224| 200| 244| 212| 202| 240| 284| 248| 220| 244| 260| 240 d   |
| Mean ±SE | 241| 232| 239| 219| 221| 184| 205| 192| 197| 199| 243| 228| 229| 229| 234| 240 d   |

*Same letters mean significant differences not exist, while different letters mean significant difference exist.

(P<0.05)

Table (6): Calcium hardness (mg CaCO₃.l⁻¹) values recorded for sampling sites with mean and SE for WTPs in Erbil.

| Dates   | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE |
|---------|-----------------------------|---------|----------------------------|----------|
|         | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  |         |
| May     | 90 | 98 | 84 | 90 | 92 | 102| 114| 106| 104| 114| 118| 130| 118| 116| 126| 107 d   |
| June    | 64 | 84 | 62 | 120| 112| 92 | 64 | 52 | 60 | 56 | 100| 132| 68 | 132| 112| 87 c    |
| July    | 54 | 68 | 62 | 66 | 76 | 46 | 54 | 52 | 50 | 58 | 54 | 62 | 60 | 62 | 68 | 59 b    |
| August  | 46 | 32 | 40 | 36 | 36 | 48 | 52 | 52 | 44 | 52 | 48 | 44 | 44 | 44 | 40 | 44 a    |
| September | 54| 44 | 48 | 48 | 52 | 54 | 62 | 60 | 56 | 62 | 54 | 58 | 58 | 52 | 58 | 55 a,b  |
| October | 110| 122| 108| 102| 112| 94 | 104| 100| 96 | 102| 114| 120| 114| 108| 116| 108 d   |
| November | 180| 172| 168| 160| 144| 132| 148| 150| 122| 130| 164| 132| 168| 172| 168| 154 f   |
| December | 132| 140| 144| 156| 160| 68 | 92 | 152| 152| 154| 88 | 160| 220| 160| 168| 143 e,f |
| January  | 134| 140| 136| 148| 112| 120| 120| 116| 110| 128| 184| 160| 162| 140| 164| 138 e   |
| Mean ±SE | 96 | 100| 95 | 103| 100| 84 | 90 | 93 | 88 | 95 | 103| 111| 112| 110| 113 c   |

(P<0.05)
### Table (7): Magnesium hardness (mg CaCO$_3$.l$^{-1}$) values recorded for sampling sites within WTPs during periods of study in Erbil Governorate.

| WTPs     | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean $\pm$SE |
|----------|-----------------------------|---------|----------------------------|--------------|
|         | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 7.03 |
| May      | 131| 108| 143| 96 | 119| 84 | 60 | 72 | 74 | 66 | 76 | 62 | 90 | 112| 56 | 90 a |
| June     | 136| 128| 138| 70 | 96 | 36 | 148| 64 | 100| 72 | 92 | 62 | 130| 90 | 90 | 97 a |
| July     | 164| 134| 146| 132| 134| 146| 120| 118| 124| 124| 166| 134| 144| 144| 146| 139 b|
| August   | 216| 208| 168| 156| 112| 98 | 140| 144| 152| 140| 228| 200| 178| 176| 184| 167 c|
| September| 212| 194| 192| 164| 168| 114| 120| 126| 124| 122| 212| 174| 178| 186| 226| 167 c|
| October  | 144| 93 | 114| 108| 106| 82 | 80 | 86 | 94 | 90 | 134| 80 | 94 | 106| 112| 101 a|
| November | 82 | 104| 108| 116| 144| 76 | 68 | 42 | 62 | 60 | 92 | 136| 128| 86 | 128| 95 a |
| December | 112| 128| 138| 88 | 108| 168| 172| 136| 156| 146| 160| 116| 52 | 72 | 84 | 122 b|
| January  | 106| 92 | 156| 112| 112| 80 | 124| 96 | 92 | 112| 100| 88 | 58 | 104| 94 | 102 a|
| Mean $\pm$SE 9.07 | 145 | 132| 145| 116| 122| 98 | 115| 98| 109| 104| 140| 117| 117| 120| 124| 124 a,b,c |

*Same letters means significant differences not exist, while different letters means significant difference exist.

### Table (8): Dissolved oxygen (mg.l$^{-1}$) values recorded for sampling sites with mean and SE for WTPs in Erbil.

| WTPs     | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean $\pm$SE |
|----------|-----------------------------|---------|----------------------------|--------------|
|         | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 1  | 2  | 3  | 4  | 5  | 0.18 |
| May      | 7  | 6.4| 7.6| 6.8| 8  | 7.8| 7  | 7.4| 7.2| 8.2| 7.2| 6  | 7.6| 3.2 | 6  | 6.9 c |
| June     | 3.6| 5.2| 4.4| 5.2| 5.2| 6  | 6.4| 6  | 4  | 4.4| 4.5| 4.4| 5.2| 4.4 | 4.4| 4.9 a |
| July     | 5.2| 5.8| 6  | 6  | 6.4| 5.4| 5.5| 5.2| 5  | 5.6| 5  | 5.3| 5.5| 5.9 | 6  | 5.6 b |
| August   | 5.9| 6.8| 6  | 6  | 6.9| 7.1| 7.4| 6.5| 6.2| 6.9| 6.2| 6.7| 7.8| 6.9 | 6.9 | 6.7 c |
| September| 6  | 6.5| 6.3| 6  | 5.7| 6.3| 6.7| 6  | 6  | 5.8| 6.1| 6.4| 6  | 5.7 | 5.1 | 6.0 b |
| October  | 6.5| 6.9| 6  | 5.5| 5.2| 6.9| 7.2| 7  | 6.9| 6.6| 6.3| 6.9| 7.2 | 7  | 6.6 | 6.6 c |
| November | 10.8| 11.2| 10.8| 11| 9.9| 10 | 10.3| 9.6| 10 | 10.4| 9.6| 10.4| 10.8 | 10 | 10.4 | 10.3 d,e |
| December | 9  | 9.6| 9.6| 10.1| 10 | 10 | 11.6| 10.4| 11.2| 10 | 8.8| 11.2| 10.8 | 10 | 9.8 | 10.1 d |
| January  | 9.7| 10| 10.8| 11.2| 10.8| 10.9| 11.1| 11| 10.4| 10.1| 10.4| 10.3| 10 | 12.8 | 12 | 10.7 e |
| Mean $\pm$SE 0.23 | 7.08 | 7.6| 7.5| 7.5| 7.6| 7.8| 8.1| 7.7| 7.4| 7.5| 7.2| 7.5| 7.8| 7.3 | 7.4 | 7.4 a,b |

(P<0.05)
Table (9): Biochemical oxygen demand for five days incubation (mg.¹⁻), recorded for sampling sites with mean and SE for WTPs in Erbil Governorate.

| WTPs          | Dates | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.18 |
|---------------|-------|------------------------------|---------|-----------------------------|---------------|
|               |       | 1    | 2    | 3    | 4    | 5    | 1    | 2    | 3    | 4    | 5    | 1       | 2       | 3       | 4       | 5       |             |
| May           |       | 1.9  | 0.4  | 2.4  | 1.6  | 0.4  | 1.9  | 0.5  | 2    | 1.2  | 0.2  | 2.2    | 0.4     | 2.6     | 2.4     | 0.2     | 1.35     | b,c       |
| June          |       | 2    | 1.6  | 0.8  | 0.4  | 0.1  | 2.8  | 1.6  | 3.6  | 2.4  | 0.4  | 3.2    | 0.8     | 0.4     | 0.4     | 0.4     | 1.39     | b,c       |
| July          |       | 2    | 1.3  | 1    | 0.9  | 0.5  | 1.5  | 0.6  | 0.5  | 0.4  | 0.1  | 1.5    | 1       | 1.8     | 0.3     | 0.8      | 0.89     | a,b       |
| August        |       | 1.9  | 0.8  | 0.2  | 0.2  | 0.4  | 1.1  | 0.9  | 0.3  | 0.4  | 0.1  | 0.9    | 0.6     | 1.5     | 1       | 0.1      | 0.69     | a         |
| September     |       | 2.5  | 2    | 1.4  | 1    | 0.5  | 3    | 2.2  | 2    | 1.5  | 0.7  | 2.1    | 1.9     | 1.3     | 1       | 0.5      | 1.57     | c         |
| October       |       | 2.9  | 2.4  | 1.9  | 1    | 0.9  | 3.5  | 2.6  | 2    | 1.5  | 0.6  | 3.1    | 1.9     | 1.8     | 1       | 0.6      | 1.84     | c         |
| November      |       | 4.2  | 4.8  | 3.2  | 5.4  | 1.3  | 4    | 3.6  | 3    | 3.2  | 1    | 4.8    | 4.6     | 5.2     | 4       | 2        | 3.62     | d         |
| December      |       | 0.7  | 0.1  | 0.4  | 0.9  | 1.2  | 0.4  | 0.8  | 0.3  | 0.5  | 0.3  | 0.8    | 1.6     | 1.2     | 0.4     | 0.6      | 0.68     | a         |
| January       |       | 0.7  | 0.4  | 0.9  | 0.4  | 0.8  | 1.9  | 0.6  | 0.9  | 0.6  | 0.3  | 0.4    | 0.6     | 0.4     | 2.4     | 1.3      | 0.84     | a,b       |
| Mean ±SE 0.23 |       | 2.09 | 1.5  | 1.36 | 1.3  | 0.68 | 2.2  | 1.49 | 1.6  | 1.3  | 0.4  | 2.1    | 1.49    | 1.7     | 1.49    | 0.67     | (P<0.05) |

*Same letters means significant differences not exist, while different letters means significant difference exist.

Table (10): Nitrite values (µg at. N-NO₂ ¹⁻) recorded for sampling sites with mean and SE for WTPs in Erbil.

| WTPs          | Dates | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.10 |
|---------------|-------|------------------------------|---------|-----------------------------|---------------|
|               |       | 1    | 2    | 3    | 4    | 5    | 1    | 2    | 3    | 4    | 5    | 1       | 2       | 3       | 4       | 5       |             |
| May           |       | 0.25 | 0.19 | 0.14 | 0.21 | 0.18 | 0.21 | 0.16 | 0.11 | 0.2  | 0.21 | 0.27    | 0.21    | 0.2      | 0.25     | 0.25     | 0.20     | a         |
| June          |       | 0.8  | 0.82 | 0.64 | 0.82 | 0.6  | 0.1  | 1.84 | 2.96 | 1.8  | 1.68 | 1      | 2.22    | 2.1      | 1.92     | 2        | 1.42     | d         |
| July          |       | 0.31 | 0.17 | 0.15 | 0.21 | 0.12 | 0.26 | 0.13 | 0.12 | 0.16 | 0.21 | 0.37    | 0.22    | 0.17     | 0.2      | 0.14     | 0.19     | a         |
| August        |       | 0.92 | 0.86 | 0.08 | 0.62 | 0.3  | 1.4  | 0.22 | 0.82 | 0.3  | 0.006| 0.9    | 0.4     | 0.28     | 0.42     | 0.22     | 0.51     | a,b       |
| September     |       | 0.83 | 0.76 | 0.41 | 0.5  | 0.21 | 0.49 | 0.17 | 0.04 | 0.2  | 0.37 | 0.6    | 0.47    | 0.3      | 0.39     | 0.4      | 0.40     | a,b       |
| October       |       | 0.49 | 0.32 | 0.15 | 0.19 | 0.33 | 0.21 | 0.14 | 0.09 | 0.25 | 0.3  | 0.56    | 0.41    | 0.19     | 0.2      | 0.52     | 0.29     | a,b       |
| November      |       | 0.29 | 0.21 | 0.04 | 0.52 | 0.7  | 0.25 | 0.19 | 0.08 | 0.35 | 0.4  | 0.46    | 0.46    | 0.14     | 0.02     | 0.06     | 0.28     | a,b       |
| December      |       | 1.2  | 1    | 1.14 | 1.62 | 1.84 | 0.3  | 1.14 | 1.1  | 1.54 | 1.14 | 1.14    | 0.14    | 0.22     | 0.14     | 0.18     | 0.92     | c         |
| January       |       | 0.17 | 0.94 | 0.76 | 0.5  | 1.58 | 1.46 | 0.68 | 0.84 | 0.21 | 1.08 | 0.14    | 0.02    | 0.08     | 0.06     | 0.02     | 0.57     | b         |
| Mean ±SE 0.14 |       | 0.58 | 0.58 | 0.39 | 0.57 | 0.65 | 0.52 | 0.52 | 0.68 | 0.56 | 0.60 | 0.60    | 0.50    | 0.41     | 0.40     | 0.42     | 0.57     | (P<0.05)  |
### Table (11): Sodium ion (mg/l⁻¹) values recorded for sampling sites of WTPs in Erbil Governorate.

| WTPs Dates | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.65 |
|------------|----------------------------|---------|----------------------------|---------------|
| May        | 31 31 33.2 34 36.2 29.2 31.6 36 38.2 39 | 29.5 33 31.2 32 32.5 32.5 | 33.2 d |
| June       | 30 34.5 31.6 26.2 29 | 28.5 30.8 29.1 30 31.5 30.8 31.2 30 30.8 32 30.4 c |
| July       | 41 45 40.4 36.5 39 | 36 38.5 37 32.3 35 40.8 29 33.1 34 34.8 36.8 e |
| August     | 67 70 69.2 72.3 70 70.6 72.4 78 74.2 73 | 70.9 81.7 71.3 71.8 76.5 72.6 f |
| September  | 31 32.5 32 35.5 35.9 35.5 30 29.2 30.2 31 | 31.7 32.5 31 34 34.5 31.9 c,d |
| October    | 21.5 24 22 26.5 29.3 19.9 20 20.2 21 21.8 20 22.2 23 23.5 27 22.8 b |
| November   | 3.4 4 4.3 4.5 4.3 | 3 3.6 3.8 3.9 4.1 | 3.7 4.7 4.3 4.5 4.5 4.3 4.03 a |
| December   | 3.5 3.7 3.6 3.7 3.4 | 2 2.8 2.8 3.5 3.6 | 3.8 4.4 5.5 4.8 4.4 3.7 a |
| January    | 2.8 3 1.9 1.9 2.1 | 2.2 2.6 2 2.4 2.1 | 3 3 3.1 3.5 3.2 2.6 a |
| Mean ±SE 0.84 | 25.7 a,b 27.5 a,b 26.5 a,b 26.8 a,b 27.7 b | 24.3 a 25.8 a,b 26.4 a,b 26.2 a,b 26.8 a,b | 26.0 a,b 26.8 a,b 25.8 a,b 26.5 a,b 27.7 b (P<0.05) |

*Same letters means significant differences not exist, while different letters means significant difference exist.

### Table (12): Potassium ion (mg/l⁻¹) values recorded for sampling sites, with mean and SE for WTPs in Erbil.

| WTPs Dates | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.15 |
|------------|----------------------------|---------|----------------------------|---------------|
| May        | 3.6 3 3.3 4.3 3.1 | 3.3 2.9 3.1 4.9 3.3 | 3.5 3.6 4 3.6 3 | 3.64 c |
| June       | 4.2 4.2 4.4 4.7 4 | 3.6 3.9 4 5.1 3.8 | 4 4.2 4.5 4.2 4.2 | 4.23 d |
| July       | 3.2 3.9 4 4 2.9 | 2 2.1 2.3 4.9 3.1 | 3.3 3.5 3.8 3.2 3.9 | 3.47 c |
| August     | 1.4 2.4 0.6 2.7 0.1 | 2.8 1.7 0.2 2.5 3.7 0.2 | 0.5 2.3 1.4 2.4 1.57 b |
| September  | 1.4 1.7 1 1.6 1.3 | 1.3 1.5 0.9 2.1 1.1 | 1.3 1.4 0.6 1.4 1.7 1.35 a,b |
| October    | 1.2 1.9 1.1 1.7 1.4 | 1.5 1.5 0.9 2.2 1.3 | 1.5 1.7 1.1 1.2 1.9 1.45 a,b |
| November   | 1 1.3 1 1.4 1.7 | 1.1 1.2 1.4 0.9 1.2 | 1 1 1 1 1.3 1.15 a,b |
| December   | 0.9 1 1 0.6 0.8 | 0.7 1 0.9 1.1 1.2 | 1.3 1.4 1.2 0.9 1 | 1.0 a |
| January    | 1.6 1.6 1.6 1.6 1.8 | 1.6 1.5 2.4 0.7 0.9 | 0.9 1 1.1 1.6 1.6 1.45 a,b |
| Mean ±SE 0.19 | 2.68 c 2.01 a,b 2.06 a,b 2.3 a,b,c 2.02 a,b | 2.51 b,c 1.90 a,b 1.92 a,b 1.79 a 2.71 c 2.18 a,b,c 1.89 a,b, 2.03 a,b 2.18 a,b,c (P<0.05) |
### Table (13): Chloride ion (mg.l⁻¹) values recorded for sampling sites of WTPs in Erbil Governorate.

| WTPs            | Dates   | May     | June    | July    | August   | September | October  | November | December | January  | Mean ±SE 0.65 |
|-----------------|---------|---------|---------|---------|----------|-----------|----------|----------|----------|----------|---------------|
|                 | 1       | 2       | 3       | 4       | 5        | 1         | 2        | 3        | 4        | 5        |                |
| Ifraz 1 (Old Ifraz project) | 10      | 12      | 11      | 11      | 12       | 11        | 13       | 11       | 13       | 12       | 11 ± 12± 11± 14± 10± 11.9 a |
| Ifraz 2         | 16      | 13      | 16.1    | 16      | 12       | 23        | 12       | 15       | 18       | 16       | 12 ± 12± 12± 8 ± 16 ± 14.0 b |
| Ifraz 3 (New Ifraz project) | 20      | 25      | 22      | 23      | 23       | 20        | 24       | 23       | 25       | 27       | 21 ± 24± 22± 24 ± 20 ± 23.2 e |
| Mean ±SE 0.84   | 17.0 ± a| 18.7 a,b,c,d| 18.1 a,b,c| 17.8 a,b,c,d| 17.4 a,b,c,d| 19.5 a,b,c,d,e| 21.4 d,c, e| 19.9 b,c,d,e| 20.9 d,e| 22.3 e| 17.3 a,b| 20.1 b,c,d,e| 19.3 a,b,c| 19.5 a,b,c| 19.2 a,b,c, d| (P<0.05) |

*Same letters means significant differences not exist, while different letters means significant difference exist.

### Table (14): Sulphate values (mg.l⁻¹) recorded for sampling sites with mean and SE of WTPs in Erbil Governorate.

| WTPs            | Dates   | May     | June    | July    | August   | September | October  | November | December | January  | Mean ±SE 8.05 |
|-----------------|---------|---------|---------|---------|----------|-----------|----------|----------|----------|----------|---------------|
|                 | 1       | 2       | 3       | 4       | 5        | 1         | 2        | 3        | 4        | 5        |                |
| Ifraz 1 (Old Ifraz project) | 310     | 282     | 242     | 215     | 225      | 288       | 251      | 227      | 206      | 215      | 296 ± 266 ± 241 ± 221 ± 229 ± 247.6 a |
| Ifraz 2         | 324     | 290     | 246     | 209     | 218      | 274       | 244      | 214      | 191      | 193      | 319 ± 268 ± 246 ± 211 ± 217 ± 244.2 a |
| Ifraz 3 (New Ifraz project) | 390     | 326     | 270     | 219     | 234      | 349       | 294      | 274      | 247      | 261      | 385 ± 359 ± 359 ± 317 ± 326 ± 307.3 b |
| Mean ±SE 10.4   | 449 ± e| 387 ± d| 327 ± b,c| 289 ± a| 277 ± a| 377 ± 340 ± 308 ± 283 ± 282 ± 343 ± 389 ± 340 ± 305 ± 303 ± 381.4 a,b | (P<0.05) |
Table (15): Reactive phosphorus (µg.at.P-PO₄.l⁻¹) values recorded for sampling sites in WTPs of Erbil Governorate.

| WTPs       | Dates  | Ifraz 1 (Old Ifraz project) | Ifraz 2 | Ifraz 3 (New Ifraz project) | Mean ±SE 0.309 |
|------------|--------|-----------------------------|---------|----------------------------|----------------|
|            |        | 1   | 2   | 3   | 4   | 5   | 1   | 2   | 3   | 4   | 5   | 1   | 2   | 3   | 4   | 5   |               |
|            |        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |               |
| May        |        | 3.2 | 1.9 | 1.1 | 1.4 | 1.8 | 1.9 | 1   | 0.9 | 1.1 | 1.7 | 2.35| 0.85| 0.4 | 0.45| 0.4 | 1.36 a       |
| June       |        | 4.2 | 2   | 1.3 | 1.7 | 1.8 | 2.7 | 1.8 | 1   | 1.6 | 2   | 5.3 | 1.5 | 1.4 | 1.8 | 1.9 | 2.13 a,b     |
| July       |        | 7.1 | 1.9 | 1.8 | 2   | 2.5 | 5.4 | 3   | 1.9 | 2.4 | 2.8 | 6.8 | 2.2 | 1.8 | 2.2 | 2.4 | 3.08 b,c     |
| August     |        | 7.5 | 2.9 | 0.15| 2.55| 0.4 | 3   | 0.95| 5.35| 1.4 | 1.45| 6.9 | 6.6 | 2.1 | 0.8 | 0.7 | 2.89 b,c     |
| September  |        | 10.5| 3.4 | 2.6 | 1.7 | 2   | 4.7 | 2   | 1.7 | 2   | 2.4 | 10  | 2.1 | 1.2 | 1.8 | 2   | 3.34 C       |
| October    |        | 6   | 1.9 | 1.7 | 2   | 2.5 | 5.1 | 1.6 | 1   | 1.2 | 0.9 | 5   | 2.6 | 2   | 2.2 | 2.7 | 2.56 b,c     |
| November   |        | 6.8 | 1.5 | 1.3 | 2.55| 3.25| 3.6 | 1.2 | 0.94| 1.2 | 1.32| 8.4 | 1.9 | 1   | 1.4 | 1.05| 4.9 b,c      |
| December   |        | 5.2 | 1.9 | 1.25| 1.8 | 2.65| 1.7 | 2.45| 1.25| 1.1 | 2.25| 7.1 | 3.85| 3.55| 2.8 | 1.3 | 2.67 b,c     |
| January    |        | 10.3| 2   | 2.55| 2.15| 1.35| 2   | 3.3 | 2.5 | 1.9 | 2.4 | 11.8| 2.3 | 1.7 | 1.9 | 1.75| 3.32 c       |
| Mean ±SE   |        | 6.76| 2.16| 1.53| 1.99| 2.03| 3.41| 1.92| 1.84| 1.54| 1.91| 7.07| 2.66| 1.68| 1.70| 1.58| 1.32 c       |
|            |        | a   | a   | a   | a   | a   | b   | a   | a   | a   | c   | a,b | a   | a   | a   | a   | (P<0.05)     |

*Same letters means significant differences not exist, while different letters means significant difference exist.

Table (16): Jar test values recorded for sampling sites within WTPs in Erbil Governorate.

| WTPs Dates | Ifraz 1 | Ifraz 2 | Ifraz 3 | Mean ±SE 0.35 |
|------------|---------|---------|---------|---------------|
|            |         |         |         |               |
|            | Ifraz 1 | Ifraz 2 | Ifraz 3  | Mean ±SE 0.35 |
| May        |         |         |         |               |
| June       | 12      | 11      | 12      | 11.7 d        |
| July       | 9       | 9       | 9       | 9.0 b,c       |
| August     | 10      | 10      | 10      | 10.0 c        |
| September  | 14      | 14      | 14      | 14.0 e        |
| October    | 24      | 23      | 24      | 23.7 g        |
| November   | 16      | 16      | 16      | 16.0 f        |
| December   | 8       | 8       | 8       | 8.0 b         |
| January    | 28      | 25      | 25      | 26.0 h        |
| Mean ±SE   | 14.0 b  | 13.3 a  | 13.67 a,b| (P<0.05)      |

Figure (2): Monthly variations in Turbidity of Greater Zab river (raw water).
Figure (3): Electrical conductivity of Greater Zab river

Figure (4): Monthly variations in Total hardness of Greater Zab river during the periods of study.
Figure (5): Sodium concentrations in mg.l⁻¹ for Greater Zab river

Figure (6): Sulphate values in raw water of Greater Zab river
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