Water Quality, Availability, and Uses in Rural Communities in the Kurdistan Region, Iraq

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Abstract: Water resource management and the investigation of the quality and quantity of groundwater and surface water is important in the Kurdistan Region of Iraq. The growing population, as well as agricultural and industrial projects, consume huge amounts of water, especially groundwater. A total of 572 ground and surface water samples were collected for physicochemical analysis to determine the availability and quality of the water in the Kurdistan region. The physicochemical parameters such as pH, electrical conductivity, and total dissolved solids were analyzed to evaluate the suitability of the water for different purposes like livestock, irrigation, and agriculture. GIS-based multi-criteria decision analysis (MCDA) was used to determine the suitability map of water for irrigation purposes. Most of the groundwater samples were suitable for irrigation except for some samples from Erbil City, especially those taken in the Makhmur district, and samples from some small areas in the cities of Sulaymania and Duhok. All groundwater samples were acceptable for all types of agricultural crops, except for 15 well samples that were determined not to be usable for fruit crops. However, this water was acceptable for livestock and poultry. Most of the water wells provided freshwater except for 36 deep wells, which supplied slightly brackish to brackish water. Water samples were found to have low to medium salinity levels except for 26 well samples and one spring sample that had high salinity levels, and 2 well samples with very high salinity levels. Most of the samples had an excellent to good water classification except for 85 samples classified as permissible, 8 classified as doubtful, and 4 classified as unsuitable for irrigation according to the Todd classification. According to the Rhoades classification, all water samples were non-saline to slightly saline except for 11 samples that were moderately saline.

Keywords: water quality; suitability map; water classification and uses; Kurdistan Region

1. Introduction

Water is considered the most important resource to consider when trying to achieve sustainable agricultural development worldwide. Improving the management of water supplies and concentrating on reducing water consumption are both necessary in order to establish sustainable and efficient agricultural systems, especially more efficient irrigation systems. Agricultural activities must concentrate on both the quantity and quality of water to prevent water contamination, unsustainable usage, land loss, and desertification.

The Mediterranean region is one of the most sensitive areas in the world, with significant decreases in rainfall and increases in temperature expected in the future [1,2]. Climate conditions greatly affect crop production. Due to water shortages, especially during the dry season, surface water and groundwater are used more frequently to increase crop production. Improvements in water management are necessary to increase and diversify...
food production in order to meet the needs of a growing population while simultaneously reducing crop vulnerability to droughts, floods, and climate change.

To ensure food security and sustainable water management for agriculture, more crops need to be irrigated drop by drop to ensure improvements in water use without negative impacts on the quantity and quality of downstream water supplies. Given the present and future food demands, increasing water scarcity will put a range of stresses on agricultural productivity and exacerbate sustainability problems [3]. Water demands in the urban, industrial, and commercial sectors increasingly exceed acceptable water supply limits, resulting in local depletion of surface and groundwater resources. An accurate assessment of water demand and supply outside the agricultural sector is a prerequisite to effective water management [4]. The study of chemical characteristics of groundwater is very important for municipal, commercial, industrial, agriculture, and drinking water supplies. Development can contribute to the pollution of groundwater, and consideration must be given to the protection of water quality. Physicochemical parameters were analyzed in this study, including the temperature of water well samples (T °C), salinity in terms of total dissolved solids (TDS), electrical conductivity (EC), and reactivity in terms of (pH). One of the most conservative properties of groundwater is temperature. It is a standard physical characteristic that is important in the concentration of the chemical properties of water. Temperature is an important factor for geochemical reactions and organism life [5]. TDS is defined by the content of all dissolved solids in water, ionized or non-ionized, but does not include colloidal materials, suspended sediment, and dissolved gasses [6]. EC, or the conductance of groundwater, is a function of temperature, the type of ions present, and the concentration of various ions’ specific conductance. Readings are usually adjusted to 25 °C so that variations in conductance are a function only of the concentration and type of dissolved constituents present [7]. pH is the negative logarithm of hydrogen ion activity, and its value expresses the intensity of activity or alkalinity of water under normal temperature (T °C) and pressure conditions [8]. Water quality is typically calculated by comparing the measurements of physicochemical parameters to standard measurements, which provides an estimation of possible pollutants without providing any precise data on the quality of groundwater [9,10]. Improper management of groundwater resources results not only in a scarcity of water, but also in a change in water quality [11]. The multi-criteria decision approach (MCDA) is a decision-making technique that integrates qualitative and quantitative data by decomposing problems into systematic orders based on a set of criteria [12]. Irrigation of cropland has become a widely used practice and has greatly increased the productivity of farmland. Irrigation has made it possible to farm in regions that otherwise would not be farmable. There were several objectives of this research: to give some first information of the groundwater quality; to assess the quality of water for different purposes; to classify groundwater and irrigation water using different methods; to determine water needs for drinking, livestock, irrigation, and agriculture; and to create a suitability map for irrigation using MCDA for the Kurdistan Region in northern Iraq.

2. Materials and Methods

2.1. Study Area Description

The Kurdistan Region is located in northern Iraq. It covers an area of 40,643 km² and has a population of about 5.1 million people. Kurdistan is bordered by Turkey in the north, the Republic of Iran in the east, the Mosul province in the west, and the Kirkuk province in the south (Figure 1). The area includes two main rivers: the Greater Zab and the Lesser Zab, which flows from the Tigris river.
Figure 1. Map showing the origin of the groundwater samples taken across the Kurdistan Region.

This area is known for its semi-arid Mediterranean-type climate. Most places in this region experience cold, rainy winters and long, hot, dry summers. Meteorological data were collected from different meteorological ground stations in the Kurdistan region between 2005 and 2019.

Meteorological data obtained from different meteorological stations in the cities of Erbil, Sulaymania, Duhok, and Halabja show that the annual precipitation was about 400.3 mm in Erbil, 685.3 mm in Sulaymania, 569 mm in Duhok, and 497.7 mm in Halabja. The maximum and minimum mean monthly relative humidity were 69.9% in January and 27.7% in July in Erbil, 70.3% in January and 24.01% in August in Sulaymania, 67.4% in January and 26.7% in August in Duhok, and 67.7% in January and 13.7% in July in Halabja. The maximum monthly temperature in Erbil was 35.3 °C in July, and the minimum monthly temperature was 8.9 °C in January. In Sulaymania, the maximum monthly temperature was 33.7 °C in July, and the minimum was 6.8 °C in January. In Duhok, the maximum monthly temperature was 33.1 °C in July, and the minimum was 7.7 °C in January. In Halabja, the maximum monthly temperature was 35.2 °C in July, and the minimum was 6.2 °C in January (Figure 2). In terms of evaporation, in Erbil City, the maximum mean monthly evaporation was 13.4 mm in July, and the minimum monthly evaporation was 1.8 mm in January. In Sulaymania City, the maximum monthly mean evaporation was 11.8 mm in July, and the minimum was 2.3 mm in January. For Duhok City, the maximum was 11.1 mm in July, and the minimum was 1.4 mm in December. In Halabja City, the maximum mean evaporation was 11.9 mm in July, and the minimum was 2.3 mm in December. The mean annual sunshine duration was 8.5 h/day in Erbil City, 7.4 h/day in Sulaymania City, 7.6 h/day in Duhok City, and 7.5 h/day in Halabja City. The annual mean wind speed was 1.7 m/s in Erbil City, 1.3 m/s in Sulaymania City, 1.12 m/s in Duhok City, and 0.81 m/s in Halabja City (Appendix A).
2.2. Geological and Tectonic Setting

The exposed geological units in the Kurdistan Region are represented by formations that date from the Ordovician to the Tertiary period (Table 1 and Figure 3).

Table 1. Age and lithological description of the geological units.

| Age               | Geological Unit                     | Lithological Description                                                                 |
|-------------------|-------------------------------------|------------------------------------------------------------------------------------------|
| Holocene          | Recent alluvial deposits             | Different sized clastics, mixture of clay, sand, and pebbles                             |
| Pleistocene       | River Terraces                      | Mixture of clay, sand, and pebbles                                                      |
| Pliocene          | Bai Hassan and Muqdadiya formation  | Thick sandstone, siltstone, and conglomerate                                             |
| Late Miocene      | Injana formation                    | Red sandstone, siltstone, and intercalations of red clay and pebbly sandstone            |
| Middle Miocene    | Fatha formation                     | Layers of red claystone, limestone, marl, and lenses of gypsum with some thin layers of siltstone |
| Middle-Late Eocene| Pila Spi formation                  | Well-bedded, recrystallized limestone, dolomite, and marly limestone                    |
| Early Eocene      | Gercus formation                    | Red mudstone, sandstone, and shale, with rare conglomerates                              |
| Paleocene         | Kolosh and Khurmala formations      | Mainly clastics: shale, limestone, marl, and mudstone with tongues of white limestone   |
| Late Cretaceous   | Dokan, Gulneri, Komitan, Aqra, Bekhme, Shiranish, and Tanjero formations | Limestone, grey dolomite-containing bituminous limestone, blue-grey marl, and beds of marly limestone |
| Early Cretaceous  | Chiagara, Balambo, Sarmord, Garagu, and Qamchuqa formations | Dolostone, dolomitic limestone, some calcareous marl, and limited shale                 |
| Late Jurassic     | Naokelekan and Barsrin formations   | Limestone, dolomitic limestone, shaley limestone, carboniferous shale, and bituminous dolomitic shales |
### Table 1. Cont.

| Age            | Geological Unit                          | Lithological Description                                                |
|----------------|------------------------------------------|--------------------------------------------------------------------------|
| Middle Jurassic| Sargelu formation                        | Thin bedded shaley black limestone and shale with black chert and brown dolomitic marl, highly fossiliferous |
| Early Jurassic | Sarki and Sehkanian formations           | Dolomitic limestone with splintery fractures, which are generally bituminous and fossiliferous |
| Late Triassic  | Baluti, Kurrrachina, Beduh, and Avroman formations | Alternations of shales, limestone, dolomites, and dolomitic limestone |
| Late Permian   | Chaizairi formation                      | Beds of shale, limestone, and some evaporates                           |
| Ordovician     | Khabourr formation                       | Thick sandstone-shale cyclic alternations                                |

![Geological map showing the lithological units of the study area (After Stevanovic and Marcovich, 2003).](image-url)
The oldest unit from the Ordovician is the Khabour formation which is comprised of thick sandstone-shale cyclic alternations. The Late Permian period is represented by the Chaizairi formation, which includes shale, limestone, and some evaporates. The Late Triassic period is represented by Balut, Kurachina, Beduh, and Avroman formations which are generally composed of alternations of shales, limestone, dolomites, and dolomitic limestone. The Early Jurassic period is represented by Sarki and Sehkanian formations which consist of dolomitized limestone with splintery fractures, which are generally bituminous and fossiliferous. The Middle Jurassic period is represented by the Sargelu formation, which consists of thinly bedded shaley black limestone and shale with black chert and brown dolomitic marl, and is highly fossiliferous. The Late Jurassic period is represented by Naokelekan and Barsrin formations which consist of limestone, dolomitic limestone, shaley limestone, carboniferous shale, and bituminous dolomitic shales. The Early Cretaceous period is represented by Chiagara, Balambo, Sarmord, Garagu, and Qamchuqa formations which include dolostone, dolomitic limestone, some calcareous marl, and limited shale. The Late Cretaceous period is represented by Dokan, Gulneri, Komitan, Aqra, Bekhme, Shiranish, and Tanjero formations which include limestone, grey dolomite-containing bituminous limestone, blue-grey marl, and beds of marly limestone. The Paleogene period is represented by Khurmala, Kolosh, Pila Spi, and Gercus formations which include interchanging layers of grey claystone, shale, silt, and sandstone with conglomerate lenses. Tongues of white limestone can be found in the Kolosh and Khurmala formations. Red clay, siltstone, and sandstone, as well as a tongue of limestone, can be found in the Gercus formation. Well-bedded, recrystallized limestone, dolomite, and marly limestone can be found in the Pila Spi formation. The Neogene period is represented by Fatha, Injana, Muqdadeya, and Bai Hassan formations. The Fatha formation includes layers of red claystone, limestone, marl, and lenses of gypsum with some thin layers of siltstone. The Injana formation includes red sandstone, siltstone, and intercalations of red clay and pebbly sandstone. The Muqdadeya and Bai Hassan formations include sandstone, siltstone, and conglomerate. The youngest units are represented by Quaternary deposits, which include river terraces, the flood plain, and recent alluvial deposits, which include poorly cemented conglomerate, muddy sandstone, and a cover of pebbly clay [13,14].

2.3. Data Collection and Water Sample Analysis

The physicochemical properties for the analysis of 572 water samples, including 535 deep well samples (169 wells in Erbil, 119 wells in Sulaymania, 209 wells in Duhok, and 18 wells in Halabja), 33 spring samples, and 4 river water samples in the study area were collected from the database of Ministry of Agriculture and Water Resources—Groundwater Directorate in the Kurdistan Region and field work carried out during 2020–2021. The parameters for the samples included temperature, pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS); all these parameters were measured in situ in the field by the portable device (HANNA instrument model Hi8314).

2.4. Interpolation and Statistical Analysis

The interpolation was done in ArcGIS 10.1 using the Kriging method to plot the parameter distribution for the well samples. Kriging spatial interpolation assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variations in the surface. This approach is an efficient geostatistical interpolation technique focused on the special correlation of sampled points [15]. Statistical analysis of the analyzed parameters was carried out using the SPSS program.

2.5. Geo-Information Technique

GIS-based multi-criteria decision analysis (MCDA) was used to create a suitability map for using groundwater and surface water for irrigation purposes based on water availability and quality. The criteria layers were assessed using the multi-criteria decision
approach combined with the weighted overlay function in ArcGIS 10.1. This process was used to evaluate the suitability of a specific area for a specific purpose.

2.6. Water Use and Suitability for Different Purposes

The suitability of the water for any particular use is determined by comparing the calculated and measured physical, chemical, and biological parameters with set standards for a particular use. In this study, the physicochemical parameters were used to compare the calculated and measured analysis. Train classification [16] was used to determine the suitability of the water for irrigation purposes based on the total dissolved solid (TDS).

2.7. Water Type Classification

2.7.1. Classification According to TDS

Water samples classified according to Hillel [17], Drever [18], Altoviski [19], and Gorrell [20], depending on TDS (Table 2).

| Water Class                        | Gorrell (1958) | Altoviski (1962) | Drever (1997) | Hillel (2000) |
|-----------------------------------|---------------|-----------------|---------------|--------------|
| Fresh water                       | 0–1000        | 0–1000          | <1000         | <500         |
| Slightly brackish water (Marginal)|               |                 |               |              |
| Brackish water                    | 1000–10,000   | 3000–10,000     | 1000–20,000   | 1000–2000    |
| Salty water                       | 10,000–100,000| 10,000–100,000  |               |              |
| Saline water                      |               |                 | 35,000        | 5000–10,000  |
| Highly Saline Water               |               |                 |               | 10,000–35,000|
| Brine water                       | 100,000       | >100,000        | >35,000       | >35,000      |

2.7.2. Classification According to EC

Water samples classified according to USDA [21] and Mayer et al. [22], depending on the EC parameter (Table 3).

| Water Class                        | USDA (1954)   | Mayer et al. (2005) |
|-----------------------------------|---------------|---------------------|
| Low salinity water                | 100 < EC < 250| 550–1200            |
| Medium salinity water             | 250 < EC < 750| 1200–2200           |
| High salinity water               | 750 < EC < 2250| 2200–5000          |
| Very high salinity water          | 2250 < EC < 5000| —                  |

2.8. Classification of the Irrigation Water

2.8.1. Todd Classification (1980)

This classification depends on electrical conductivity (Table 4).

| EC (µS/cm)                  | Water Class       |
|-----------------------------|-------------------|
| <250                        | Excellent         |
| 250–750                     | Good              |
| 750–2000                    | Permissible       |
| 2000–3000                   | Doubtful          |
| >3000                       | Unsuitable        |

2.8.2. Rhoades Classification (1992)

Rhoades classified irrigation water into six types based on TDS and EC (Table 5).
Table 5. Water classification according to Rhoades [24].

| Water Class       | EC (µS/cm) | TDS (mg/L) |
|-------------------|------------|------------|
| Non-saline        | <700       | <500       |
| Slightly-saline   | 700–2000   | 500–1500   |
| Moderately saline | 2000–10,000| 1500–7000  |
| Highly-saline     | 10,000–25,000 | 7000–15,000 |
| Very highly saline| 25,000–45,000 | 1500–35,000 |
| Brine             | >45,000    | >35,000    |

2.8.3. Don Classification (1995)

This classification depends on electrical conductivity and total dissolved solid. Don classified irrigation water into five types (Table 6).

Table 6. Irrigation water classification according to Don [25].

| Water Quality   | EC (µS/cm) | TDS (mg/L) |
|-----------------|------------|------------|
| Excellent       | 250        | 175        |
| Good            | 250–750    | 175–525    |
| Permissible     | 750–2000   | 525–1400   |
| Doubtful        | 2000–3000  | 1400–2100  |
| Unsuitable      | >3000      | >2100      |

3. Results and Discussion

3.1. Physicochemical Parameters

The physicochemical characteristics are shown in Table 7 and Appendices B–H. The electrical conductivity for the water well samples ranged between 134 and 5090 µS/cm, the spring samples ranged between 196.6 and 796.5 µS/cm, and the river samples ranged between 297 and 480 µS/cm. The highest concentration was measured in Erbil City in the Said-Ubaid village well, while the lowest concentration was measured in Sulaymania City in the Qalaga village well (Figure 4).

Table 7. Basic statistics of the physicochemical parameters of water samples in the study area.

| Sample          | Parameters | EC (µS/cm) | pH   | TDS (mg/L) | Temperature °C |
|-----------------|------------|------------|------|------------|----------------|
| Wells Erbil City| Maximum    | 5090       | 9.1  | 3309       | 31             |
|                 | Minimum    | 286        | 6.5  | 186        | 17             |
|                 | Mean       | 643.9      | 7.7  | 419        | 23             |
|                 | SD *       | 560        | 0.5  | 365        | 1.9            |
| Wells Sulaymani City | Maximum | 3290       | 9.5  | 2139       | 31             |
|                 | Minimum    | 134        | 6.8  | 87         | 13             |
|                 | Mean       | 563.2      | 8.2  | 366.1      | 20             |
|                 | SD *       | 447.5      | 0.6  | 290.8      | 3.4            |
| Wells Duhok City| Maximum    | 2400       | 8.6  | 1560       | 29             |
|                 | Minimum    | 220        | 6.3  | 143        | 14             |
|                 | Mean       | 687.5      | 7.5  | 446.9      | 20.4           |
|                 | SD *       | 256.6      | 0.3  | 166.8      | 2.2            |
| Wells Halabja City | Maximum | 2540       | 9.6  | 1651       | 29             |
|                 | Minimum    | 304        | 6.5  | 198        | 18             |
|                 | Mean       | 530.3      | 8.3  | 344.7      | 21.9           |
|                 | SD *       | 373.4      | 0.7  | 242.7      | 2.1            |
Table 7. Cont.

| Sample          | Parameters | EC (µS/cm) | pH | TDS (mg/L) | Temperature °C |
|-----------------|------------|------------|----|------------|----------------|
| Spring Samples  | Maximum    | 796.5      | 8.2| 509.8      | 26.5           |
|                 | Minimum    | 196.6      | 7.4| 128        | 16.5           |
|                 | Mean       | 432.4      | 7.7| 280.3      | 20.4           |
|                 | SD *       | 138.3      | 0.2| 88.9       | 3.1            |
| River Samples   | Maximum    | 388.5      | 8.2| 252.5      | 22.9           |
|                 | Minimum    | 361        | 8  | 234.7      | 22.2           |
|                 | Mean       | 371.5      | 8.2| 241.5      | 22.5           |
|                 | SD *       | 12.7       | 0.1| 8.3        | 0.3            |

* SD Standard Deviation.

Figure 4. Distribution of the electrical conductivity of groundwater across the Kurdistan Region.

The pH for the deep wells ranged between 6.5 and 9.6, the samples from the springs ranged between 7.4 and 8.2, and the samples from the river ranged between 7.9 and 8.4. The highest concentration was measured in a deep well in Amura located in Halabja City, and the minimum concentration was measured in a deep well in Chrostana in Halabja City (Figure 5).
Figure 5. Distribution of the pH of groundwater across the Kurdistan Region.

Total dissolved solids in the deep wells ranged between 87 and 3309 mg/L, the spring samples ranged between 128 and 509.8 mg/L, and the river samples ranged between 193 and 312 mg/L. The highest concentration of TDS was found in a well in the village of Said-Ubaid in Erbil City, while the lowest concentration was measured in a well in Sulaymania City in the village of Qalaga (Figure 6).

Figure 6. Distribution of the TDS of groundwater across the Kurdistan Region.
The temperature in the deep wells ranged between 10 and 31 °C, the spring samples ranged between 16.5 and 26.5 °C, and the river samples ranged between 21.4 and 23.3 °C. The highest value was measured in Erbil City in the Chamadubz village well, and the lowest value was also measured in Erbil City in the Hasarok village well (Figure 7).

![Figure 7. Distribution of the temperature of groundwater across the Kurdistan Region.](image)

3.2. Water Uses and Suitability Analysis

3.2.1. Water Use for Livestock Purposes

In order to determine water quality for livestock purposes, the water samples were compared with the Ayers and Westcot classification of groundwater suitability for livestock and poultry according to electrical conductivity concentration (Table 8) [26]. All the water samples were acceptable for livestock and poultry purposes because the electrical conductivity fell within acceptable ranges except for the Said-Ubaid water well sample taken from Erbil city. This water was acceptable for livestock but unacceptable for poultry because the EC concentration was more than 5000 µS/cm which has been shown to reduce growth and increase mortality in poultry (Figure 8).
Figure 8. Suitability map for livestock and poultry according to Ayers and Westcot (1989).

Table 8. Water quality for livestock and poultry compared with Ayers and Westcot (1989) standards.

| EC (µS/cm) | Specifications | Remarks | Water Samples |
|------------|----------------|---------|---------------|
| <1500      | Excellent      | This water has a relatively low level of salinity and should present no serious burden to any livestock or poultry | Erbil City 286–5090 (µS/cm) |
| 1500–5000  | Acceptable     | This water should be satisfactory for all classes of livestock and poultry. It may cause temporary and mild diarrhea in livestock not accustomed to it or watery droppings in poultry (especially at the higher levels) but should not affect health or performance | Sulaymania City 134–3290 (µS/cm) |
| 5000–8000  | Acceptable for livestock, unacceptable for poultry | Causes temporary diarrhea in livestock and reduced growth and death in poultry | |
| 8000–11,000 | Limited for livestock, unacceptable for poultry | Avoid use for pregnant and lactating animals as levels increase Not acceptable water for poultry | Duhok City 220–2400 (µS/cm) |
| 11,000–16,000 | Limited | Not acceptable for animals | |
| >16,000    | Not used       | The risks posed by highly saline waters are so great that they cannot be recommended for use under any circumstances | Halabja City 304–2540 (µS/cm) |

3.2.2. Water Use for Agricultural Purposes

The properties of Todd’s classification [23] for Agricultural crops depending on total dissolved solids were applied for assessing water use purposes. This assessment showed that nearly all water samples were acceptable for all types of agricultural crops barring a few exceptions. Specifically, 16 well samples from Erbil City, 8 well samples from Sulaymania
City, 14 well samples from Duhok City, and 2 wells from Halabja City were not suitable for fruit crops (Table 9, Figure 9 and Appendices B–H).

![Suitability map for livestock and poultry according to [19].](image)

**Figure 9.** Suitability map for livestock and poultry according to [19].

**Table 9.** Todd classification (1980) for agricultural crops compared with water samples from the study area.

| Crop Divisions | Low TDS Endurance | Medium TDS Endurance | High TDS Endurance | Water Samples |
|----------------|-------------------|----------------------|--------------------|---------------|
| Fruit          | <300 µS/cm        | 300–400 µS/cm        | 400–1000 µS/cm     | Erbil City    |
|                | Avocado, lemon,   | Olive, date, fig     | Palm               | 286–5090 (µS/cm) |
|                | orange, apple     | cantaloupe, pomegranate | Sulaymania City   |
|                | strawberry, picot prune |                 | 134–3290 (µS/cm)  |
|                | plum              |                      |                    |               |
| Vegetable      | 300–400 µS/cm     | 400–1000 µS/cm       | 1000–12,000 µS/cm  | Duhok City   |
|                | Green bean, celery, | Spinach, kale,       | 220–2400 (µS/cm)  | 304–2540 (µS/cm) |
|                | radish            | asparagus            |                    |               |
| Field crops    | 400–600 µS/cm     | 600–1000 µS/cm       | 1000–10,000 µS/cm  | Halabja City |
|                | Field bean        | Sunflower, corn, rice,| Cotton, sugar beet,|                |
|                |                   | flax, castor bean, wheat | barley            |               |

3.2.3. Water Use for Irrigation Purposes

One problem caused by irrigating cropland is the possibility of groundwater contamination. Fertilizer and pesticide use need to be more carefully restricted in order to reduce the risk of contamination [27]. The suitability of irrigation water is dependent on the effects of its mineral content on both plants and soil, as well as the effect of salts which could cause changes in soil structure. Infiltration increases with increasing TDS, which is used for evaluating soil permeability [28]. Most of the water samples were acceptable for irrigation and would not have detrimental effects on crops. Several samples of well
water proved that the water was not suitable for irrigation, including 17 well samples from Erbil City, 7 well samples from Sulaymania City, 52 well samples from Duhok City, and 2 well samples from Halabja City that could potentially have harmful effects on crops that are sensitive to salinity. Additionally, 4 well samples from Erbil City, 4 well samples from Sulaymania City, 2 well samples from Duhok City, and 1 well sample from Halabja City could be harmful to sensitive crops. Only 4 well samples (3 wells in Erbil City and 1 well in Sulaymania City) could be used for highly tolerant crops (Table 10 and Appendices B–H).

### Table 10. Train classification (1979) for irrigation water and compared with water samples from the study area.

| TDS (mg/L) | Specifications | Water Samples TDS Range |
|------------|----------------|-------------------------|
| 500        | Used for irrigation; does not cause harmful effects | Erbil City 186–3309 mg/L |
| 500–1000   | Used for irrigation but causes harmful effects on crops sensitive to salinity | Sulaymania City 87–2139 mg/L |
| 1000–2000  | Causes harmful effects on crops, so use carefully | Duhok City 143–1560 mg/L |
| 2000–5000  | Used only for irrigating highly tolerant crops | Halabja City 198–1651 mg/L |

### 3.3. Suitability Analysis

A suitability map was created by combining the derived layers to define suitable groundwater locations for irrigation purposes. The steps for this procedure started with reclassifying datasets using a model in ArcGIS to reclassify the interpolation maps of the physicochemical parameters into relative classes. In this approach, for every criterion input, each cell in the study area has a different value for each layer. To determine irrigation suitability, the suitability map was created by integrating the derived layers. Because combining these layers in this format is not possible, the next step was to reclassify the previous maps into a relative four classes with a common value. In the resulted maps, the suitable locations are referred to as number one, while number four indicates unsuitable locations (Figure 10). After reclassification, the weighted overlay analysis was used to create an integrated study of common values for a variety of dissimilar and miscellaneous inputs and to produce a final suitability map for groundwater irrigation.

According to the results, the region was divided into three classes: high suitability, low suitability, and unsuitable with respect to the input factors using the weight overly method. In the resulting maps, the suitable locations are referred to as number one, while the number four indicates unsuitable locations. Figure 8 shows the reclassified map of the four criteria used in this study. High suitability defines water samples that have parameters and concentrations within the acceptable limit, and unsuitable defines the water samples that have concentrations over the standard or acceptable limit. Most of the groundwater samples were suitable for irrigation except for some samples from the Makhmur district in Erbil City, the Chamchamal and Kfri districts in Sulaymania City, and the Zawita district in Duhok City (Figure 11).
Figure 10. Reclassified map of the studied criteria; (a) Reclassified electrical conductivity, (b) Reclassified total dissolved solid, (c) Reclassified pH value, and (d) Reclassified temperature value.
3.4. Water Type and Classification of the Irrigation Water

Most of the well water samples were freshwater except for 36 deep well samples that ranged from slightly brackish to brackish water. Considering TDS results, all the spring samples were considered freshwater according to [17–20] (Appendices B–H).

According to the [21,22], based on the EC, most of the water samples had low to medium salinity except for 26 well samples and one spring sample that had high salinity, and 2 well samples that had very high salinity (Appendices B–H).

Most of the samples had an excellent to good water classification except for 85 samples that were classified as permissible, 8 samples that were classified as doubtful, and 4 samples that were classified as unsuitable for irrigation according to the Todd classification based on EC. According to the Rhoades classification, all water samples were non-saline to slightly saline except for 11 samples that were moderately saline. According to the Don Classification, most of the samples were excellent to good except for 85 samples that were permissible, 8 samples that were doubtful, and 4 samples that were unsuitable for irrigation (Appendices B–H).

4. Conclusions

This study examined water quality and availability as well as water use for different purposes and the suitability of water for irrigation in the Kurdistan Region, Iraq. The water samples were acceptable for all types of agricultural crops with the exception of 16 well samples from Erbil City, 8 well samples from Sulaymania City, 14 well samples from Duhok City, and 2 well samples from Halabja City, which should not be used for fruit crops. Most water samples were acceptable for livestock and poultry purposes except for a well water sample from the Said Ubaid area of Erbil city that was acceptable for livestock but unacceptable for poultry because of its high electrical conductivity which causes reduced growth and increased mortality in poultry. Most of the water samples were acceptable for irrigation and would not cause detrimental effects on crops except for 17 well samples from Erbil City, 7 well samples from Sulaymania City, 52 well samples
from Duhok City, and 2 well samples from Halabja City that could be harmful to crops that are sensitive to salinity. Additionally, 4 well samples from Erbil City, 4 well samples from Sulaymania City, 2 well samples from Duhok City, and 1 well sample from Halabja City could be harmful to crops. A total of 4 well samples (3 wells in Erbil city and 1 well in Sulaymania city) could be used for irrigating highly tolerant crops.

Most of the deep well and spring samples were considered freshwater except for some deep well samples that contained slightly brackish to brackish water according to the total dissolved solids. Most samples contained water with low to medium salinity except for some wells and one spring sample that contained water with high salinity, and two well samples that had water with very high salinity. Suitability analysis shows that most of the groundwater samples were suitable for irrigation except for the samples taken from the Makhmur District in Erbil City, the Chamchamal and Kfri districts in Sulaymania City, and the Zawita district in Duhok City.

Agricultural activities may have adverse effects on water quality due to the release of nutrients (as a result of soil management and fertilizer application) and other chemicals like pesticides into aquatic environments. Biological contamination (e.g., from microbiological organisms in manure), soil erosion, and sediment burdens may increase due to poor farming practices. As a result, farmers and other water users should try to reduce negative effects on water quality.

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## Appendix A

**Table A1.** Mean Monthly Climatic Parameters of the study area for the period 2005–2019 in Erbil, Sulaymania, Duhok, and Halabja.

| Meteorological Station | Parameter                  | Months |                |                |                |                |                |                |                |                |                |                |                |                |                |
|------------------------|----------------------------|--------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                        |                            | Jan.   | Feb.           | Mar.           | Apr.           | May            | June           | July           | Aug.           | Sep.           | Oct.           | Nov.           | Dec.           |                |                |
| Erbil City             | Rainfall (mm)              | 66.6   | 65.9           | 67.1           | 45.4           | 18.3           | 1              | 0              | 0.1            | 3.7            | 32             | 34             | 34.7           | 65.6           |                |
|                        | R.H%                       | 69.9   | 67.3           | 61.2           | 54.4           | 40.7           | 30.9           | 27.7           | 29             | 34             | 45.3           | 59             | 66.4           |                |
|                        | Temp. (°C)                 | 8.9    | 11             | 15.3           | 20.4           | 26.6           | 32.5           | 35.3           | 35.2           | 30.2           | 24.2           | 15.6           | 10.8           |                |
|                        | Sunshine Duration (h/day)  | 5.4    | 6.1            | 6.6            | 7.9            | 9.2            | 11.9           | 12             | 11.6           | 10.5           | 8.1            | 7.2            | 5.9            |                |
|                        | Wind Speed (m/s)           | 1.7    | 1.8            | 2              | 2.1            | 1.9            | 1.9            | 1.6            | 1.6            | 1.4            | 1.7            | 1.4            | 1.5            |                |
|                        | Evaporation (mm)           | 1.8    | 2.5            | 4.4            | 6              | 9.3            | 12.7           | 13.4           | 12.6           | 9.5            | 6.3            | 3.2            | 2              |                |
| Sulaymania City        | Rainfall (mm)              | 101.3  | 130            | 106.5          | 88.4           | 30.8           | 0.7            | 0              | 0.01           | 1.8            | 43.6           | 72.5           | 109.7          |                |
|                        | R.H%                       | 70.3   | 66.8           | 58.9           | 55.7           | 41.7           | 27             | 24.9           | 24             | 30.1           | 44.1           | 59.7           | 65.5           |                |
|                        | Temp. (°C)                 | 6.8    | 8.7            | 13.2           | 17.8           | 24             | 30.3           | 33.5           | 33.7           | 29             | 22.3           | 14.1           | 9.6            |                |
|                        | Sunshine Duration (h/day)  | 4.8    | 5.2            | 5.6            | 7.1            | 7.9            | 9.9            | 10.5           | 10.4           | 9.3            | 7.3            | 6              | 5.1            |                |
|                        | Wind Speed (m/s)           | 1.1    | 1.1            | 1.4            | 1.2            | 1.2            | 1.7            | 1.6            | 1.6            | 1.4            | 1.3            | 1.2            | 1.1            | 0.8            |
|                        | Evaporation (mm)           | 2.3    | 2.6            | 3.3            | 4.7            | 7              | 10.8           | 11             | 11             | 7.9            | 4.9            | 2.9            | 2.3            |                |
| Duhok City             | Rainfall (mm)              | 125    | 80.9           | 77             | 65             | 28.8           | 1.1            | 0.1            | 0.1            | 2              | 30.6           | 61.7           | 96.8           |                |
|                        | R.H%                       | 67.4   | 66.5           | 59.8           | 54.3           | 43.1           | 30.9           | 26.8           | 26.7           | 31.8           | 43             | 58.3           | 64.8           |                |
|                        | Temp. (°C)                 | 7.7    | 10.4           | 13.9           | 18.6           | 24.7           | 30.4           | 33.1           | 32.8           | 28.1           | 22             | 14.2           | 9.9            |                |
|                        | Sunshine Duration (h/day)  | 4.2    | 5.2            | 5.7            | 7              | 9.1            | 11.2           | 11.5           | 11.1           | 9.2            | 7              | 5.5            | 4.4            |                |
|                        | Wind Speed (m/s)           | 1.3    | 1.1            | 1.3            | 1.2            | 1.3            | 1.2            | 1.1            | 1              | 1              | 0.9            | 1              |                |                |
|                        | Evaporation (mm)           | 1.4    | 1.9            | 3.2            | 4.9            | 7.5            | 10.3           | 11.1           | 10.5           | 7.82           | 4.6            | 2.1            | 1.4            |                |
### Table A1. Cont.

| Meteorological Station | Parameter                  | Months          |
|------------------------|---------------------------|-----------------|
|                        |                           | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
|                        | Rainfall (mm)             | 74.6 | 75.7 | 71.5 | 42.7 | 14.3| 0.3  | 0    | 0.4  | 1.1  | 46.7 | 71.3 | 99.2 |
|                        | R.H%                      | 67.7 | 57.6 | 56.1 | 48.9 | 32  | 15.9 | 13.7 | 13.9 | 18.6 | 32.7 | 57.9 | 64.3 |
| Halabja City           | Temp. (°C)                | 6.2  | 9.1  | 13.2 | 18.7 | 24.1| 31.3 | 35.2 | 34.9 | 29.6 | 22.4 | 13.9 | 8.2  |
|                        | Sunshine Duration (h/day) | 4.7  | 5.4  | 5.5  | 7.1  | 7.6 | 10   | 10.7 | 10.5 | 9.3  | 7.3  | 6.2  | 5.2  |
|                        | Wind Speed (m/s)          | 0.7  | 0.7  | 0.8  | 0.8  | 1   | 0.9  | 0.9  | 0.8  | 0.75 | 0.7  | 0.6  | 1.1  |
|                        | Evaporation (mm)          | 2.3  | 2.6  | 3.5  | 4.8  | 7   | 10.8 | 11.9 | 11.4 | 7.97 | 5    | 2.9  | 2.5  |

### Appendix B

#### Table A2. Physicochemical Parameter Analysis for the Deep Wells in Erbil City, UTM-WGS84 Coordination System.

| SN | Well Name          | X       | Y       | Z       | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|--------------------|---------|---------|---------|----------------|------------|----------|----|------------|
| 1  | Tendura            | 395413  | 3993026 | 335    | 180            | 709        | 24       | 7.3| 461        |
| 2  | Siaw               | 387823  | 3986646 | 294    | 135            | 522        | 25       | 7.8| 339        |
| 3  | Mastawa            | 395425  | 3989611 | 313    | 110            | 2380       | 22       | 7.1| 1547       |
| 4  | Chiman             | 398291  | 3992781 | 332    | 140            | 701        | 25       | 7.6| 456        |
| 5  | Sirawa             | 390621  | 3991566 | 288    | 170            | 684        | 25       | 7.2| 445        |
| 6  | Surbash kakalla   | 399116  | 3986546 | 328    | 150            | 1440       | 22       | 7.3| 936        |
| 7  | Surbash Hawez      | 399119  | 3990618 | 342    | 50             | 1090       | 24       | 7.8| 709        |
| 8  | Sorizha            | 399758  | 3984480 | 327    | 160            | 685        | 24       | 7.6| 445        |
| 9  | Shekh Sherwan      | 385648  | 3988509 | 297    | 112            | 492        | 25       | 8  | 320        |
| 10 | Delogoli Khwaru    | 396086  | 3995879 | 339    | 162            | 706        | 23       | 7.8| 459        |
| 11 | Duldaghan          | 399945  | 3992666 | 339    | 140            | 771        | 24       | 7.4| 501        |
| 12 | Dustapa            | 399176  | 3995794 | 325    | 124            | 576        | 25       | 7.9| 374        |
| SN | Well Name          | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|-------------------|-------|-------|-------|----------------|------------|----------|----|------------|
| 13 | Shekh Sherwan    | 385318| 3988765| 296   | 200            | 508        | 25       | 7.9| 330        |
| 14 | Yadiqizlar       | 398385| 3982621| 322   | 200            | 960        | 25       | 7.4| 624        |
| 15 | Mastawa          | 393502| 3989935| 314   | 132            | 1160       | 24       | 7.3| 754        |
| 16 | ArabKand         | 401207| 4000412| 348   | 135            | 686        | 23       | 7.6| 446        |
| 17 | Binberzi Gichka  | 396837| 4001782| 342   | 200            | 534        | 25       | 7.9| 347        |
| 18 | Binberz          | 395933| 4001268| 352   | 180            | 452        | 24       | 7.9| 294        |
| 19 | Binberz          | 396224| 4000855| 345   | 153            | 455        | 25       | 7.6| 296        |
| 20 | Jimka            | 395878| 4000194| 326   | 100            | 608        | 24       | 7.4| 395        |
| 21 | Yarmja           | 394854| 3999461| 331   | 120            | 362        | 24       | 8.2| 235        |
| 22 | SwarayGawra      | 396326| 3998153| 374   | 110            | 670        | 23       | 7.9| 436        |
| 23 | Khazna           | 391529| 3997369| 311   | 142            | 713        | 23       | 8  | 463        |
| 24 | Lajan Harki      | 391734| 3999080| 335   | 175            | 1200       | 25       | 8.5| 780        |
| 25 | Dusara Harki     | 400708| 3990293| 341   | 170            | 970        | 24       | 8.3| 631        |
| 26 | Qoritan Chukil   | 405209| 3992905| 357   | 240            | 442        | 24       | 8.4| 287        |
| 27 | SwarayGichka     | 401598| 4004542| 401   | 250            | 646        | 24       | 8.1| 420        |
| 28 | Beryat           | 404024| 3996473| 342   | 173            | 467        | 23       | 7.8| 304        |
| 29 | ArabKand         | 400867| 400423 | 352   | 128            | 681        | 22       | 7.6| 443        |
| 30 | Awena            | 382629| 3991199| 290   | 101            | 940        | 26       | 8.4| 611        |
| 31 | Deologoli Khwaru | 394152| 3997089| 325   | 120            | 356        | 23       | 8.3| 231        |
| 32 | Turaq            | 404792| 4002899| 376   | 200            | 578        | 24       | 7.8| 376        |
| 33 | SwarayGichka     | 402800| 4004166| 370   | 240            | 714        | 23       | 8.1| 464        |
| 34 | Tobzawa          | 410115| 3997736| 398   | 170            | 365        | 23       | 8.1| 237        |
| 35 | Traspasion       | 403751| 3983092| 336   | 174            | 660        | 22       | 8.2| 429        |
| 36 | Pirdaud          | 403042| 3986933| 348   | 150            | 613        | 23       | 7.8| 398        |
| SN | Well Name         | X    | Y    | Z   | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|-------------------|------|------|-----|----------------|------------|----------|----|-------------|
| 37 | Serkarez         | 406857 | 3998106 | 377 | 245            | 386        | 25       | 8.2 | 251        |
| 38 | Gird Muhammad    | 407322 | 3997855 | 383 | 249            | 438        | 24       | 8.5 | 285        |
| 39 | Serkarez         | 406998 | 3997742 | 376 | 240            | 430        | 25       | 7.9 | 280        |
| 40 | TimaryGawra      | 408089 | 3996528 | 374 | 204            | 501        | 24       | 8.4 | 326        |
| 41 | Mizahmed         | 405693 | 3996774 | 370 | 164            | 450        | 23       | 7.8 | 293        |
| 42 | qatawy           | 406891 | 3997283 | 376 | 208            | 412        | 25       | 8   | 268        |
| 43 | Serkeez          | 407100 | 3997486 | 388 | 200            | 496        | 24       | 8.4 | 322        |
| 44 | Baghlominara     | 405721 | 4001433 | 378 | 160            | 499        | 21       | 8.3 | 324        |
| 45 | Dugirdkan        | 405002 | 3981465 | 357 | 170            | 740        | 24       | 7.3 | 481        |
| 46 | Elinjagh         | 420484 | 3979467 | 429 | 180            | 410        | 24       | 7.5 | 267        |
| 47 | BerAraban        | 410425 | 3974764 | 360 | 125            | 670        | 25       | 7.3 | 436        |
| 48 | Qushtapa         | 412908 | 3984905 | 398 | 60             | 470        | 24       | 7.4 | 306        |
| 49 | SebiranyAdo      | 409447 | 3981910 | 378 | 185            | 530        | 25       | 7.5 | 345        |
| 50 | Doshewan         | 426219 | 3982081 | 496 | 175            | 480        | 25       | 7.4 | 312        |
| 51 | DolazayNawand    | 412989 | 3972710 | 334 | 180            | 620        | 25       | 7.2 | 403        |
| 52 | QaziKhana        | 408707 | 3973989 | 343 | 205            | 1600       | 23       | 7   | 1040       |
| 53 | SurbashKhidr     | 406064 | 3975330 | 346 | 50             | 1300       | 25       | 7.5 | 845        |
| 54 | OmerMamka        | 416194 | 3969285 | 317 | 160            | 710        | 24       | 7.4 | 462        |
| 55 | GirdMala         | 415049 | 3985162 | 421 | 100            | 470        | 23       | 7.5 | 306        |
| 56 | Aliawa           | 412033 | 3967864 | 331 | 160            | 600        | 24       | 7   | 390        |
| 57 | Omaraway Gawra   | 419638 | 3968151 | 319 | 140            | 630        | 23       | 7.1 | 410        |
| 58 | Rolka            | 428855 | 3980903 | 517 | 200            | 460        | 26       | 7.3 | 299        |
| 59 | KanyBizra        | 426232 | 3985419 | 538 | 108            | 440        | 24       | 7.3 | 286        |
| 60 | Rolka            | 426608 | 3977937 | 458 | 200            | 530        | 26       | 7.3 | 345        |
| SN | Well Name         | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|------------------|-------|-------|-------|----------------|------------|----------|-----|------------|
| 61 | Aziana           | 427596| 3974853| 443   | 180            | 380        | 25       | 7.3 | 247        |
| 62 | Pongena Mantik   | 428654| 3976444| 485   | 126            | 430        | 21       | 7.5 | 280        |
| 63 | Dokala           | 406733| 3977235| 357   | 150            | 660        | 26       | 7.4 | 429        |
| 64 | Qashqa           | 429168| 3967811| 273   | 82             | 440        | 25       | 7.5 | 286        |
| 65 | Seequchan        | 419075| 3964982| 299   | 186            | 680        | 21       | 7   | 442        |
| 66 | Sinala           | 418483| 3972394| 349   | 198            | 570        | 24       | 7.1 | 371        |
| 67 | Shekhan          | 416152| 3964799| 309   | 153            | 440        | 24       | 7   | 286        |
| 68 | Omerawa Bichuk   | 417486| 3965549| 303   | 150            | 690        | 24       | 7.3 | 449        |
| 69 | GirdaSor         | 423034| 3971717| 361   | 200            | 360        | 23       | 7.3 | 234        |
| 70 | Girdasor         | 423584| 3971885| 362   | 200            | 360        | 23       | 7.4 | 234        |
| 71 | Mirakany Afandi  | 424219| 3979606| 458   | 153            | 540        | 28       | 7.2 | 351        |
| 72 | Mirakany khedr   | 428579| 3984536| 520   | 254            | 490        | 24       | 7.2 | 319        |
| 73 | GirdLanka        | 414267| 3966889| 301   | 200            | 560        | 27       | 7.2 | 364        |
| 74 | Qarajnagha       | 413443| 3992743| 398   | 190            | 330        | 24       | 7.6 | 215        |
| 75 | Aliawa mardon    | 407215| 3991827| 380   | 50             | 510        | 23       | 7.8 | 332        |
| 76 | Aliawa mardon    | 406343| 3990223| 354   | 220            | 560        | 22       | 7.4 | 364        |
| 77 | Mortka shahab    | 412765| 3988467| 408   | 194            | 330        | 24       | 7.7 | 215        |
| 78 | Kardiz           | 420011| 3983698| 452   | 50             | 400        | 23       | 7.6 | 260        |
| 79 | Majidawa         | 373717| 3988067| 244   | 206            | 928        | 21.8     | 7.8 | 603        |
| 80 | Garasor          | 366198| 3966290| 236   | 123            | 3100       | 21       | 7.3 | 2015       |
| 81 | Hasarok          | 383687| 3980931| 320   | 111            | 400        | 20       | 7.9 | 260        |
| 82 | Milhurt          | 368641| 3980649| 259   | 143            | 2220       | 23       | 7.4 | 1443       |
| 83 | Said Ubaid       | 376313| 3981264| 265   | 143            | 5090       | 20       | 7.6 | 3309       |
| 84 | shorazartka      | 375605| 3983239| 259   | 157            | 3770       | 20       | 7.7 | 2451       |
Table A2. Cont.

| SN | Well Name      | X    | Y    | Z   | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|----------------|------|------|-----|----------------|------------|----------|-----|------------|
| 85 | Gomaspan       | 437276 | 4014456 | 817 | 160           | 697        | 21       | 7.7 | 453        |
| 86 | Almawani khwaru | 430030 | 4028563 | 773 | 120           | 1850       | 21       | 7.2 | 1203       |
| 87 | SaryBlind      | 430375 | 4020969 | 829 | 103           | 640        | 21       | 7.2 | 416        |
| 88 | Dawdawa        | 430149 | 4028189 | 797 | 145           | 723        | 18       | 6.5 | 470        |
| 89 | Shekhan Harki  | 423363 | 4028611 | 589 | 100           | 577        | 20       | 7.5 | 375        |
| 90 | Azhga          | 426637 | 4031996 | 761 | 121           | 676        | 20       | 7.4 | 439        |
| 91 | Zagros         | 427847 | 4030919 | 783 | 100           | 585        | 20       | 7.6 | 380        |
| 92 | Qalasini Saru  | 439237 | 4024471 | 1195| 130           | 456        | 20       | 7.8 | 296        |
| 93 | Tobzawa        | 414660 | 4024692 | 484 | 50            | 405        | 20       | 7.8 | 263        |
| 94 | Harbo          | 434247 | 4069154 | 650 | 175           | 331        | 20       | 7.8 | 215        |
| 95 | Khardan        | 442530 | 4074013 | 812 | 255           | 442        | 20       | 7.4 | 287        |
| 96 | Kalak          | 382135 | 4015828 | 287 | 112           | 330        | 24       | 8.4 | 215        |
| 97 | Konakalak      | 379603 | 4012701 | 320 | 105           | 512        | 22       | 7.9 | 333        |
| 98 | Malaomer       | 386802 | 4015630 | 242 | 102.8         | 1150       | 25       | 8   | 748        |
| 99 | Khabat         | 376462 | 4008393 | 246 | 170           | 950        | 25       | 8.4 | 618        |
| 100| Chamadubz      | 376782 | 4010057 | 252 | 180           | 1270       | 31       | 8.8 | 826        |
| 101| Bastam         | 378033 | 4011366 | 261 | 180           | 1150       | 25       | 8.5 | 748        |
| 102| KonaSekhora    | 397099 | 4005687 | 409 | 160           | 526        | 24       | 8.6 | 342        |
| 103| Kany Qirzhal  | 397768 | 4007730 | 450 | 220           | 545        | 25       | 8.5 | 354        |
| 104| Sebirani Gaura| 387589 | 4011243 | 402 | 143           | 542        | 24       | 8   | 352        |
| 105| Kawraban       | 389545 | 4009579 | 420 | 160           | 452        | 24       | 8.3 | 294        |
| 106| Qariatagh      | 399065 | 4002583 | 355 | 117           | 678        | 24       | 8.3 | 441        |
| 107| Qalatga        | 398014 | 4012250 | 381 | 200           | 448        | 25       | 8.3 | 291        |
| 108| Satooor        | 392155 | 4004737 | 446 | 160           | 391        | 25       | 8.4 | 254        |
| SN  | Well Name               | X    | Y    | Z    | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|-----|-------------------------|------|------|------|----------------|------------|----------|----|------------|
| 109 | Girdarasha zab         | 383730 | 4018266 | 277 | 120           | 434       | 24       | 8.3 | 282        |
| 110 | Kawr Gosk              | 389147 | 4023536 | 297 | 100           | 1210      | 24       | 8.5 | 787        |
| 111 | Gainji Gaura           | 393451 | 4020664 | 314 | 100           | 447       | 24       | 8.1 | 291        |
| 112 | Agholan Assad          | 390878 | 4020421 | 298 | 155           | 386       | 24       | 8.5 | 251        |
| 113 | Agholan bichuk         | 388452 | 4020472 | 321 | 160           | 474       | 21       | 8.2 | 308        |
| 114 | Girdasor               | 396053 | 4017280 | 325 | 150           | 511       | 23       | 7.9 | 332        |
| 115 | Shewarash Kon          | 391955 | 4025303 | 282 | 150           | 930       | 23       | 8.7 | 605        |
| 116 | Shewarash              | 394680 | 4025042 | 365 | 136           | 419       | 24       | 8.5 | 272        |
| 117 | Shewarash Diwan        | 392407 | 4026303 | 291 | 99            | 605       | 23       | 8.6 | 393        |
| 118 | mamalok                | 395288 | 4023005 | 355 | 88            | 286       | 24       | 8.3 | 186        |
| 119 | Kharaba Draw           | 398390 | 4018460 | 369 | 100           | 411       | 22       | 8.2 | 267        |
| 120 | Smailawa               | 395643 | 4014878 | 345 | 140           | 583       | 23       | 8.4 | 379        |
| 121 | Halajay gaura         | 423849 | 3989468 | 534 | 120           | 360       | 23       | 7   | 234        |
| 122 | Palany                 | 419985 | 3986363 | 461 | 114           | 380       | 23       | 7.5 | 247        |
| 123 | Sablagh                | 420927 | 3989485 | 506 | 125           | 340       | 23       | 7.4 | 221        |
| 124 | Baghmera shahab        | 420519 | 3996696 | 476 | 136           | 330       | 23       | 7.3 | 215        |
| 125 | Daratoo                | 414839 | 3998493 | 430 | 154           | 289       | 23       | 7.3 | 188        |
| 126 | Girdarashay Mufti     | 411909 | 3997991 | 413 | 100           | 340       | 22       | 7.4 | 221        |
| 127 | Kasnazan               | 422851 | 4007170 | 581 | 182           | 390       | 22       | 7.5 | 254        |
| 128 | Mam choghan            | 429660 | 4009737 | 867 | 130           | 360       | 21       | 7.7 | 234        |
| 129 | Sharaboty Gichka      | 428527 | 4011232 | 850 | 75            | 390       | 21       | 7.6 | 254        |
| 130 | Mala Omar              | 422978 | 4017757 | 635 | 122           | 360       | 23       | 7.7 | 234        |
| 131 | Tobzawa                | 462649 | 3993215 | 723 | 115           | 507       | 17       | 7.9 | 330        |
| 132 | Shiwashan              | 482780 | 3982821 | 702 | 281           | 504       | 21       | 7   | 328        |
Table A2. Cont.

| SN  | Well Name       | X     | Y     | Z   | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|-----|-----------------|-------|-------|-----|----------------|------------|----------|----|------------|
| 133 | Sarkarezy zrary | 404494| 4030763| 378 | 185            | 420        | 22       | 8  | 273        |
| 134 | Sarkawr Harky   | 402843| 4029145| 389 | 98             | 378        | 20       | 9.1| 246        |
| 135 | Qafar           | 407471| 4028044| 438 | 111            | 430        | 21       | 8  | 280        |
| 136 | Rashkin         | 406162| 4007467| 385 | 200            | 505        | 23       | 7.5| 328        |
| 137 | Przin           | 416741| 4013421| 493 | 160            | 412        | 22       | 7  | 268        |
| 138 | Bahirka         | 413063| 4019111| 464 | 168            | 370        | 21       | 7  | 241        |
| 139 | Bahirka         | 414097| 4020895| 494 | 300            | 375        | 23       | 7  | 244        |
| 140 | Bark Bichuk     | 412902| 4012230| 469 | 240            | 381        | 24       | 7.3| 248        |
| 141 | ShekhaShil      | 411314| 4017350| 436 | 145            | 436        | 23       | 7.4| 283        |
| 142 | Grdachal        | 404224| 4024290| 389 | 134            | 433        | 23       | 8  | 281        |
| 143 | Qalanchoghan    | 400623| 4016125| 357 | 240            | 398        | 24       | 8.3| 259        |
| 144 | Shakhson        | 398649| 4027829| 359 | 138            | 420        | 20       | 9  | 273        |
| 145 | Barhushter      | 400202| 4024210| 357 | 150            | 568        | 23       | 9  | 369        |
| 146 | Saidan          | 398445| 4021755| 347 | 56             | 468        | 22       | 8  | 304        |
| 147 | Daraban         | 401047| 4018612| 348 | 240            | 440        | 24       | 9  | 286        |
| 148 | Darashakran     | 409834| 4029370| 409 | 180            | 590        | 20       | 7.5| 384        |
| 149 | Hababan         | 412796| 4043905| 597 | 145            | 360        | 21       | 8  | 234        |
| 150 | Binaslawa       | 420902| 4001510| 525 | 136            | 370        | 21       | 7  | 241        |
| 151 | Binaslaway Bchuk| 424875| 4001969| 581 | 120            | 360        | 22       | 7  | 234        |
| 152 | Binaslaw        | 421933| 4001655| 533 | 147            | 370        | 22       | 8  | 241        |
| 153 | Ankawa          | 409437| 4010729| 421 | 132            | 379        | 21       | 7  | 246        |
| 154 | Serwaran Qtr    | 415487| 4005967| 454 | 200            | 350        | 22       | 7.7| 228        |
| 155 | Nawand          | 413828| 4003996| 444 | 170            | 423        | 21       | 7.7| 275        |
| 156 | Polisan         | 413679| 4004401| 435 | 300            | 370        | 20       | 7.5| 241        |
Table A2. Cont.

| SN | Well Name         | X      | Y      | Z      | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|-------------------|--------|--------|--------|----------------|------------|----------|----|------------|
| 157| Badawa            | 413828 | 4003167| 432    | 151           | 310        | 21       | 7.6| 202        |
| 158| Zanko             | 413428 | 4001349| 429    | 150           | 330        | 21       | 7.7| 215        |
| 159| Park              | 409071 | 4006018| 401    | 171           | 490        | 22       | 7.5| 319        |
| 160| Nawand            | 406202 | 4005323| 383    | 250           | 475        | 21       | 7  | 309        |
| 161| Taajil            | 410466 | 4005273| 410    | 166           | 585        | 21       | 7.6| 380        |
| 162| Nawroz            | 408067 | 4003647| 397    | 156           | 661        | 21       | 7.3| 430        |
| 163| Sarkavr Well      | 416765 | 4078678| 637    | 139           | 489        | 21       | 7.3| 318        |
| 164| Fakiran village well | 421428 | 4080281| 478    | 123           | 436        | 23       | 7.5| 283        |
| 165| Shuri Village Well| 420125 | 4076941| 619    | 104           | 457        | 22.4     | 7.4| 297        |
| 166| Pirasal Village Well | 424872 | 4077161| 492    | 100           | 400        | 21       | 7.8| 260        |
| 167| Havendika Village | 433114 | 4072683| 452    | 100           | 414        | 21.2     | 7.2| 269        |
| 168| Harbo Village Well | 434247 | 4069154| 650    | 175           | 331        | 20       | 7.8| 215        |
| 169| Mergasor well 2   | 438635 | 4076840| 1101   | 113           | 850        | 21.5     | 7.6| 553        |

Appendix C

Table A3. Physicochemical Parameter Analysis for the Deep Wells in Sulaymani City, UTM-WGS84 Coordination System.

| SN | Well Name        | X      | Y      | Z      | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|------------------|--------|--------|--------|----------------|------------|----------|----|------------|
| 1  | Bosken           | 492819 | 4011595| 501    | 94            | 380        | 21       | 7.6| 247        |
| 2  | saidawa          | 491491 | 4011704| 563    | 130           | 620        | 21       | 7.4| 403        |
| 3  | Hartal           | 470555 | 4024921| 1255   | 102           | 310        | 13       | 8.5| 202        |
| 4  | Sarwchawa        | 478114 | 4014519| 586    | 100           | 580        | 17       | 7.5| 377        |
| 5  | awazhe           | 514478 | 3986624| 1179   | 95            | 520        | 16       | 7.9| 338        |
| 6  | Nolichka         | 511480 | 3989031| 937    | 63            | 370        | 18       | 8.1| 241        |
| SN | Well Name          | X    | Y    | Z    | Well Depth (m) | EC (µS/cm) | Temp. ºC | pH  | TDS (mg/L) |
|----|--------------------|------|------|------|----------------|------------|----------|-----|------------|
| 7  | Yoliana            | 483853 | 4007714 | 549  | 85            | 350        | 16       | 7.8 | 228        |
| 8  | Sarbasti Quarter   | 483804 | 4007117 | 557  | 92            | 350        | 15       | 7.8 | 228        |
| 9  | Rizgari Quarter    | 484297 | 4006723 | 550  | 88            | 350        | 15       | 7.8 | 228        |
| 10 | For Collective     | 484834 | 4007381 | 556  | 90            | 360        | 17       | 7.7 | 234        |
| 11 | Girdaspian         | 510816 | 4004613 | 672  | 155           | 279        | 19       | 8.4 | 181        |
| 12 | khirajo            | 500642 | 4008443 | 524  | 116           | 378        | 18       | 8.5 | 246        |
| 13 | sultanadei taza    | 503697 | 4008416 | 545  | 103           | 279        | 18       | 8.6 | 181        |
| 14 | Qalaway New        | 503690 | 4013512 | 607  | 125           | 225        | 19       | 8.8 | 146        |
| 15 | Bastaseny Khwaroo  | 503424 | 4011839 | 578  | 105           | 248        | 17       | 8.6 | 161        |
| 16 | Kanjaray New village | 502202 | 4010943 | 564  | 130           | 237        | 16       | 8.4 | 154        |
| 17 | Banwaqal           | 497550 | 4010438 | 549  | 85            | 284        | 20       | 8.5 | 185        |
| 18 | zorkani khwaroo    | 528219 | 4014921 | 637  | 111           | 269        | 17       | 8.6 | 175        |
| 19 | Qadirawa           | 501068 | 4014722 | 617  | 130           | 299        | 17       | 8.5 | 194        |
| 20 | haji awa           | 481268 | 4008715 | 566  | 120           | 440        | 17       | 7.7 | 286        |
| 21 | Hanarok            | 514012 | 4003962 | 720  | 120           | 465        | 19       | 8.3 | 302        |
| 22 | binawshan          | 509246 | 4001922 | 602  | 164           | 367        | 19       | 8.3 | 239        |
| 23 | Sedallan           | 507569 | 4014372 | 628  | 150           | 416        | 20       | 8.1 | 270        |
| 24 | karsonan           | 505069 | 4007123 | 543  | 119           | 260        | 17       | 8.6 | 169        |
| 25 | Dolla Bfra         | 504867 | 4009490 | 553  | 120           | 312        | 17       | 8.4 | 203        |
| 26 | Zharawa collective | 506231 | 4008932 | 559  | 45            | 265        | 17       | 8.5 | 172        |
| 27 | Kawibabasan        | 508161 | 4009222 | 575  | 145           | 285        | 19       | 8.5 | 185        |
| 28 | Tagaran            | 547775 | 3948290 | 894  | 129           | 1960       | 17       | 9   | 1274       |
| 29 | Kele               | 541286 | 3962029 | 833  | 180           | 230        | 19       | 7.5 | 150        |
| 30 | Chokhakh           | 527503 | 3962832 | 1054 | 154           | 599        | 30       | 7   | 389        |
| SN | Well Name          | X   | Y   | Z   | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|--------------------|-----|-----|-----|----------------|------------|----------|----|------------|
| 31 | Shewashan          | 485615 | 3992677 | 630 | 117            | 350        | 22       | 7.7 | 228        |
| 32 | Kani watman        | 479968 | 3993488 | 871 | 153            | 361        | 16       | 8.1 | 235        |
| 33 | Kwna mare          | 505221 | 3986108 | 586 | 99             | 283        | 18       | 7.6 | 184        |
| 34 | Merzarostami Gawra | 493836 | 3989437 | 531 | 162            | 334        | 20       | 8.6 | 217        |
| 35 | Kani bnaw          | 492351 | 3986961 | 685 | 151            | 537        | 18       | 8.28 | 349       |
| 36 | Nuraden            | 514021 | 3998667 | 553 | 107            | 454        | 19       | 8.4  | 295        |
| 37 | Palkarash          | 478870 | 3947771 | 674 | 150            | 2000       | 21       | 8.3  | 1300       |
| 38 | Gazalan            | 482058 | 3947557 | 636 | 90             | 2150       | 23       | 8.2  | 1398       |
| 39 | Sadun awa          | 494714 | 3925980 | 621 | 38             | 234        | 23       | 8.5  | 152        |
| 40 | Kani Shaitan       | 500018 | 3945710 | 901 | 96             | 590        | 22       | 7.9  | 384        |
| 41 | Chalaw             | 477100 | 3941102 | 697 | 100            | 1420       | 22       | 8.4  | 923        |
| 42 | Sofi Hassan        | 511080 | 3926397 | 848 | 92             | 450        | 22       | 7.8  | 293        |
| 43 | Zhallay Darband    | 512901 | 3924145 | 750 | 82             | 840        | 22       | 7.7  | 546        |
| 44 | Kani shaitan       | 500819 | 3944918 | 884 | 80             | 410        | 17       | 8.3  | 267        |
| 45 | Kani shaitan       | 501257 | 3944696 | 873 | 80             | 490        | 17       | 8.4  | 319        |
| 46 | Bani maqan         | 501125 | 3944744 | 877 | 200            | 320        | 17       | 8.4  | 208        |
| 47 | Banimaqan          | 479218 | 3928952 | 870 | 110            | 470        | 15       | 8.6  | 306        |
| 48 | Qalaga             | 482100 | 3928926 | 875 | 65             | 134        | 20       | 8.8  | 87         |
| 49 | Sewsenan           | 534547 | 3895245 | 992 | 300            | 177        | 20       | 7.4  | 115        |
| 50 | Garazil            | 545864 | 3898366 | 1000| 28             | 590        | 19       | 7.5  | 384        |
| 51 | Tangisar           | 531698 | 3916913 | 938 | 108            | 380        | 20       | 7.9  | 247        |
| 52 | Tatan              | 526853 | 3921515 | 912 | 80             | 305        | 17       | 8.8  | 198        |
| 53 | Masydar            | 583659 | 3957601 | 1206| 87             | 329        | 16       | 9    | 214        |
| 54 | Kanisef            | 592707 | 3958965 | 1248| 40             | 458        | 16       | 7.5  | 298        |
| SN | Well Name                      | X      | Y      | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|--------------------------------|--------|--------|-------|----------------|------------|----------|----|------------|
| 55 | Kanimasian                     | 579488 | 3946254| 1322  | 133            | 400        | 19       | 7.5| 260        |
| 56 | Sarkan                         | 582093 | 3946353| 1260  | 150            | 444        | 17       | 7  | 289        |
| 57 | Kura mewy saroo                | 575665 | 3941050| 1238  | 23             | 447        | 13       | 7  | 291        |
| 58 | Kani merani Komary             | 585024 | 3935339| 1249  | 54             | 485        | 16       | 7.8| 315        |
| 59 | Kullo                          | 578390 | 3953483| 1290  | 65             | 463        | 16       | 8.4| 301        |
| 60 | Nizara                         | 586038 | 3946372| 1290  | 60             | 511        | 14       | 8.2| 332        |
| 61 | Gokhlan                        | 587028 | 3949089| 1279  | 63             | 530        | 19       | 8.4| 345        |
| 62 | Uch tapan                      | 598197 | 3952425| 1280  | 70             | 472        | 20       | 8.4| 307        |
| 63 | Nawgirdan                      | 580542 | 3915229| 542   | 125            | 448        | 19       | 8.6| 291        |
| 64 | Said sadiq center              | 581926 | 3909386| 518   | 110            | 602        | 21       | 8.3| 391        |
| 65 | Sara Quarter/Said sadiq        | 577757 | 3912741| 515   | 100            | 555        | 20       | 8.4| 361        |
| 66 | Hassar Project                 | 577930 | 3912496| 524   | 40             | 496        | 20       | 8.5| 322        |
| 67 | Haji Qadr                      | 579461 | 3912956| 528   | 68             | 531        | 21       | 8.6| 345        |
| 68 | Hassar Water Project           | 580321 | 3912476| 520   | 80             | 552        | 21       | 8.6| 359        |
| 69 | Moryas                         | 579245 | 3912385| 524   | 88             | 445        | 20       | 9.3| 289        |
| 70 | Mayawa                         | 565778 | 3925360| 1071  | 107            | 790        | 24       | 8.1| 514        |
| 71 | Geldara                        | 559294 | 3926455| 1236  | 92             | 473        | 18       | 8.8| 307        |
| 72 | Kazhaw                         | 560580 | 3932330| 1226  | 84             | 600        | 27       | 8.4| 390        |
| 73 | Tapi karam                     | 557295 | 3933568| 1128  | 120            | 429        | 24       | 8.7| 279        |
| 74 | Qalijo                         | 568567 | 3910902| 507   | 152            | 518        | 21       | 8.7| 337        |
| 75 | Bard Bard                      | 564676 | 3914456| 550   | 300            | 1140       | 31       | 8.3| 741        |
| 76 | Sarawy Khwaroo                 | 572066 | 3927602| 836   | 167            | 544        | 22       | 8.4| 354        |
| 77 | Greza village                  | 574837 | 3914244| 512   | 90             | 350        | 21       | 8.1| 228        |
| 78 | Sherabara Village              | 566765 | 3917246| 613   | 120            | 601        | 22       | 8.6| 391        |
| SN | Well Name               | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. ºC | pH | TDS (mg/L) |
|----|------------------------|-------|-------|-------|----------------|------------|----------|----|------------|
| 79 | Qawela Village/3       | 567313| 3920629| 742   | 265            | 2730       | 24       | 6.8| 1775       |
| 80 | Qawela                 | 571488| 3925050| 837   | 183            | 613        | 23       | 8.8| 398        |
| 81 | Mirmam                 | 571620| 3926245| 774   | 199            | 454        | 21       | 9.4| 295        |
| 82 | Hozy Khwaja            | 570526| 3927690| 799   | 260            | 445        | 23       | 8.8| 289        |
| 83 | Mizgawta               | 574270| 3926586| 750   | 88             | 483        | 22       | 8.7| 314        |
| 84 | Kani Pankai Khwaroo    | 578970| 392647 | 617   | 95             | 465        | 19       | 8.9| 302        |
| 85 | Qumashy Saroo          | 564686| 3915211| 552   | 83             | 739        | 20       | 8.6| 480        |
| 86 | Barda Rash             | 571627| 3913618| 498   | 132            | 436        | 24       | 8.9| 283        |
| 87 | Wandarena              | 573438| 3920197| 645   | 110            | 708        | 21       | 8  | 460        |
| 88 | Shoke                  | 561237| 3937364| 1320  | 55             | 678        | 17       | 8.2| 441        |
| 89 | Barzinja               | 559097| 3936440| 1202  | 151            | 650        | 22       | 7.3| 423        |
| 90 | Barzinja               | 562508| 3934493| 1307  | 115            | 650        | 21       | 7.3| 423        |
| 91 | Gelara                 | 563283| 3933352| 1308  | 100            | 500        | 22       | 7.3| 325        |
| 92 | Kani Panka             | 560518| 3932550| 1279  | 90.5           | 480        | 24       | 8.7| 312        |
| 93 | Kani Spika             | 565734| 3914671| 542   | 133            | 515        | 22       | 8.5| 335        |
| 94 | Kani Spekae            | 572643| 3917416| 563   | 75             | 556        | 22       | 9.3| 361        |
| 95 | Kani Speka             | 571821| 3916995| 562   | 55             | 500        | 22       | 7.3| 325        |
| 96 | Sarawy saro            | 571962| 3917302| 570   | 63             | 673        | 23       | 8.5| 437        |
| 97 | Be rashka              | 575575| 3915205| 513   | 52.6           | 485        | 19       | 8.5| 315        |
| 98 | Auch quba village      | 580698| 3908617| 502   | 115            | 382        | 23       | 8.1| 248        |
| 99 | Shanadary Kon          | 583202| 3922138| 616   | 127            | 630        | 21       | 7.7| 410        |
| 100| Warmawa                | 581302| 3919741| 583   | 120            | 413        | 21       | 7  | 268        |
| 101| Warmawa                | 561452| 3907065| 587   | 133            | 448        | 21       | 7.2| 291        |
| 102| Jollana                | 561420| 3907764| 560   | 116.7          | 424        | 19       | 7.5| 276        |
Table A3. Cont.

| SN  | Well Name           | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|-----|---------------------|-------|-------|-------|----------------|------------|----------|-----|------------|
| 103 | Daq                 | 554720| 3905994| 674  | 146            | 510        | 20       | 7.1 | 332        |
| 104 | Cham w Zhala        | 568733| 3901292| 667  | 60             | 322        | 21       | 7.9 | 209        |
| 105 | Awakala             | 561888| 3900517| 705  | 68             | 560        | 19       | 7.7 | 364        |
| 106 | Yakhshee khwaro     | 550792| 3904199| 890  | 31             | 562        | 19       | 7.8 | 365        |
| 107 | Ashtokan            | 564619| 3907908| 545  | 72             | 3290       | 24       | 8.8 | 2139       |
| 108 | Jabara              | 494074| 3827861| 149  | 100            | 1270       | 25       | 8.9 | 826        |
| 109 | Khidran             | 479803| 3998683| 552  | 127            | 387        | 19       | 8.4 | 252        |
| 110 | Warmin              | 572771| 3884546| 415  | 42             | 550        | 19       | 7.4 | 358        |
| 111 | Saedawa             | 519335| 3840306| 305  | 86             | 500        | 15       | 7.6 | 325        |
| 112 | Saeeda              | 517150| 3837429| 293  | 120            | 620        | 23       | 8.8 | 403        |
| 113 | Fatah homar         | 503774| 3848391| 348  | 120            | 570        | 23       | 9.4 | 371        |
| 114 | Bakrashal           | 502589| 3847738| 345  | 197            | 630        | 25       | 9.1 | 410        |
| 115 | Homar bli gawra     | 499503| 3849244| 336  | 100            | 820        | 27       | 8.6 | 533        |
| 116 | Chanakhchian        | 561631| 3917366| 645  | 129            | 351        | 22       | 8.9 | 228        |
| 117 | Kullaji Hama jan    | 512916| 3856680| 513  | 108            | 517        | 25       | 8   | 336        |
| 118 | Zangi Gawra         | 537252| 3860126| 561  | 147            | 537        | 24       | 7.4 | 349        |
| 119 | Zerinjo Khwaro      | 562798| 3913032| 549  | 111.3          | 787        | 29       | 7.5 | 512        |
Appendix D

Table A4. Physicochemical Parameter Analysis for the Deep Wells in Duhok City, UTM-WGS84 Coordination System.

| SN | Well Name     | X     | Y     | Z   | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|---------------|-------|-------|-----|----------------|------------|----------|----|------------|
| 1  | Avrik         | 332933| 4078301| 862 | 180            | 862        | 21       | 7.5 | 560        |
| 2  | Ekmale        | 326002| 4085892| 730 | 184            | 864        | 21       | 7.7 | 562        |
| 3  | Gre Qesrok    | 323283| 4084514| 673 | 107            | 857        | 19       | 7.8 | 557        |
| 4  | Etot          | 327324| 4080718| 580 | 191            | 785        | 18       | 7.7 | 510        |
| 5  | Bade          | 329095| 4086427| 8190| 302            | 835        | 23       | 7.7 | 543        |
| 6  | Banye         | 341132| 4087887| 850 | 210            | 783        | 21       | 7.6 | 509        |
| 7  | Duhok         | 325430| 4086000| 591 | 131            | 1200       | 22       | 7.3 | 780        |
| 8  | Bagerat       | 336632| 4090235| 8310| 150            | 745        | 23       | 7.7 | 484        |
| 9  | Botya         | 323524| 4089547| 763 | 160            | 1300       | 21       | 7.5 | 459        |
| 10 | Berebhar      | 330449| 4083264| 742 | 153            | 755        | 20       | 7.4 | 491        |
| 11 | Malta Saro    | 316261| 4081602| 512 | 153            | 680        | 20       | 7.8 | 442        |
| 12 | Malta Khwaro  | 316028| 4080686| 492 | 200            | 1100       | 23       | 7.5 | 715        |
| 13 | Zawite        | 335164| 4088211| 790 | 134            | 845        | 21       | 7.7 | 549        |
| 14 | Sindor        | 326803| 4085922| 7280| 203            | 768        | 20       | 7.6 | 499        |
| 15 | Shakhke       | 319249| 4083645| 671 | 220            | 700        | 21       | 7.8 | 455        |
| 16 | linava        | 319127| 4089788| 6720| 194            | 687        | 21       | 7.5 | 447        |
| 17 | Duhok         | 317032| 4080858| 498 | 186            | 600        | 21       | 7.2 | 390        |
| 18 | Shakhke       | 319426| 4083407| 6750| 200            | 625        | 21       | 7.5 | 406        |
| 19 | Zirka         | 315728| 4084302| 599 | 180            | 620        | 21       | 7.3 | 403        |
| 20 | Warmele       | 336886| 4115352| 1169| 67             | 860        | 21       | 7.9 | 559        |
| 21 | Gjabara       | 322976| 4081776| 656 | 232            | 451        | 21       | 7.9 | 293        |
| 22 | Nizarke/10    | 327177| 4078190| 700 | 150            | 545        | 20       | 7.5 | 354        |
| SN | Well Name       | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|----------------|-------|-------|-------|----------------|------------|----------|----|------------|
| 23 | Bakoze         | 313436| 4089081| 757  | 141            | 2400       | 22       | 7.2 | 1560       |
| 24 | Baroshke       | 324248| 4080204| 584  | 140            | 780        | 17       | 7.9 | 507        |
| 25 | Gaverke        | 316818| 4080277| 492  | 200            | 550        | 18       | 7.5 | 358        |
| 26 | Qarqarava      | 324757| 4086611| 705  | 155            | 1500       | 23       | 8.1 | 975        |
| 27 | Segirka        | 322038| 4079194| 625  | 240            | 682        | 18       | 7.3 | 443        |
| 28 | Nezarke        | 323178| 4078768| 665  | 152            | 700        | 19       | 7.6 | 455        |
| 29 | Bagera Khwaro  | 336388| 4090200| 802  | 106            | 600        | 21       | 7.6 | 390        |
| 30 | Eminke         | 329887| 4081165| 859  | 174            | 750        | 21       | 7.3 | 488        |
| 31 | Koret Gavana   | 335110| 4088056| 818  | 165            | 585        | 18       | 7.6 | 380        |
| 32 | Berebuhar      | 330356| 4083178| 712  | 172            | 790        | 18       | 7.8 | 514        |
| 33 | Khrabiya       | 340713| 4090371| 921  | 112            | 500        | 18       | 7.8 | 325        |
| 34 | Ronahi         | 323086| 4078936| 674  | 220            | 520        | 14       | 7.9 | 338        |
| 35 | Serhildan      | 325542| 4081164| 757  | 260            | 562        | 16       | 7.4 | 365        |
| 36 | Zari land      | 317834| 408218 | 569  | 200            | 1410       | 18       | 7.9 | 917        |
| 37 | Shakhki        | 319424| 4083645| 686  | 190            | 490        | 15       | 7.7 | 319        |
| 38 | Shindokha      | 318237| 4092506| 571  | 90             | 650        | 19       | 7.4 | 423        |
| 39 | Mezringan      | 408599| 4073901| 839  | 71             | 500        | 22       | 7.4 | 325        |
| 40 | Nihawe         | 321642| 4081097| 547  | 124            | 672        | 23       | 7.5 | 437        |
| 41 | Gondik         | 392620| 4072732| 736  | 89             | 785        | 23       | 7.4 | 510        |
| 42 | Jem Sine       | 387615| 4077588| 594  | 180            | 783        | 23       | 7.4 | 509        |
| 43 | Tobzawe        | 388907| 4047021| 457  | 146            | 585        | 21       | 7.2 | 380        |
| 44 | Drin Khaje      | 398058| 4059939| 557  | 126            | 524        | 23       | 7.3 | 341        |
| 45 | Shoshe         | 388592| 4072203| 759  | 195            | 496        | 23       | 7.3 | 322        |
| 46 | Meroke         | 422094| 4068676| 798  | 115            | 569        | 23       | 7.3 | 370        |
| SN | Well Name       | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|----------------|-------|-------|-------|----------------|------------|----------|----|------------|
| 47 | Serderava      | 348867| 4098992| 1099  | 232            | 738        | 19       | 7.4| 480        |
| 48 | Miska          | 348098| 4115084| 979   | 188            | 650        | 19       | 8  | 423        |
| 49 | Syretika       | 342060| 4098101| 1141  | 225            | 580        | 20       | 7.6| 377        |
| 50 | Barashe        | 348006| 4094969| 1228  | 136            | 700        | 20       | 8  | 455        |
| 51 | Bibava         | 347129| 4100414| 811   | 150            | 550        | 19       | 7.4| 358        |
| 52 | Dihe           | 338122| 4111800| 980   | 130            | 580        | 19       | 7.4| 377        |
| 53 | Dokare         | 332058| 4112710| 720   | 200            | 980        | 20       | 7.5| 637        |
| 54 | Bamerne        | 345738| 4109899| 1139  | 130            | 540        | 18       | 7.4| 351        |
| 55 | Shrti          | 343173| 4108183| 1009  | 200            | 965        | 19       | 7.6| 627        |
| 56 | Teni           | 343807| 4106965| 1017  | 166            | 970        | 19       | 8  | 631        |
| 57 | Dokary         | 332058| 4112710| 720   | 200            | 980        | 18       | 7.9| 637        |
| 58 | Zewa shikh pirmos | 340849| 4110891| 1196  | 128            | 520        | 19       | 7.6| 338        |
| 59 | Hloora         | 381168| 4101451| 625   | 158            | 850        | 19       | 7.6| 553        |
| 60 | Kanya mala     | 366482| 4107925| 1205  | 100            | 437        | 15       | 7.7| 284        |
| 61 | Khlibish       | 340747| 4107188| 853   | 135            | 500        | 16       | 8  | 325        |
| 62 | Qadish         | 357073| 4108234| 1233  | 100            | 485        | 16       | 7.2| 315        |
| 63 | Kerbraski      | 340985| 4100222| 828   | 170            | 600        | 19       | 7.9| 390        |
| 64 | Hdene          | 353749| 4123526| 1514  | 112            | 460        | 22       | 7.7| 299        |
| 65 | Pase           | 332028| 4113791| 7175  | 174            | 510        | 19       | 7.5| 332        |
| 66 | Ekmale         | 361241| 4114833| 1161  | 102            | 2015       | 20       | 7.9| 1310       |
| 67 | Bilminde       | 381566| 4079678| 512   | 145            | 549        | 21       | 7.6| 357        |
| 68 | Jimbilke       | 348070| 4115396| 954   | 120            | 1300       | 20       | 7.2| 845        |
| 69 | Baretin        | 346145| 4076550| 640   | 157            | 732        | 22       | 7.5| 476        |
| 70 | Dize           | 343544| 4079892| 637   | 195            | 784        | 24       | 7.5| 510        |
| SN | Well Name     | X    | Y    | Z     | Well Depth | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|----|---------------|------|------|-------|------------|------------|----------|----|------------|
| 71 | Mersida       | 36653 | 4076234 | 656   | 144        | 748        | 23       | 7.2 | 486        |
| 72 | Shkeft hindiyan | 349332 | 4072117 | 750   | 130        | 618        | 22       | 7.6 | 402        |
| 73 | Shlya         | 356012 | 4080442 | 873   | 150        | 930        | 22       | 7.7 | 605        |
| 74 | Shehiya       | 353080 | 4075300 | 528   | 180        | 645        | 21       | 7.6 | 419        |
| 75 | Der khidre    | 354326 | 4075470 | 564   | 205        | 655        | 21       | 7.4 | 426        |
| 76 | Mkirs         | 351824 | 4075092 | 544   | 170        | 930        | 22       | 7.7 | 605        |
| 77 | Baratin       | 345076 | 4076563 | 624   | 90         | 658        | 21       | 7.2 | 428        |
| 78 | Avriva        | 355110 | 4068857 | 570   | 167        | 543        | 22       | 7.9 | 353        |
| 79 | Khinis        | 358591 | 4069166 | 461   | 91         | 548        | 23       | 7.5 | 356        |
| 80 | Geli roman    | 343896 | 4078297 | 772   | 162        | 540        | 18       | 7.6 | 351        |
| 81 | Migara        | 352123 | 4071416 | 778   | 134        | 657        | 20       | 7.9 | 427        |
| 82 | Badinava      | 356927 | 4075417 | 568   | 230        | 552        | 20       | 7.8 | 359        |
| 83 | Mam yezdin    | 343619 | 4072331 | 760   | 146        | 745        | 23       | 7.8 | 484        |
| 84 | Ba’adre       | 344241 | 4067121 | 549   | 94         | 758        | 21       | 7.7 | 493        |
| 85 | Basewa        | 334650 | 4073729 | 650   | 177        | 650        | 24       | 7.7 | 423        |
| 86 | Jeman         | 337429 | 4076432 | 783   | 70         | 689        | 22       | 7.5 | 448        |
| 87 | Brifka        | 341464 | 4075308 | 1010  | 86         | 765        | 22       | 7.7 | 497        |
| 88 | Shekh Hesen   | 339922 | 4073189 | 755   | 178        | 602        | 24       | 7.1 | 391        |
| 89 | Ba’adre       | 344234 | 4064329 | 465   | 200        | 520        | 20       | 7.2 | 338        |
| 90 | Esyan         | 347180 | 4065072 | 548   | 86         | 397        | 21       | 7.5 | 258        |
| 91 | Beroshka Sa’adon | 328933 | 4103109 | 999   | 194        | 600        | 22       | 7.4 | 390        |
| 92 | Beshinke      | 324021 | 4094686 | 747   | 176        | 925        | 18       | 7.5 | 601        |
| 93 | Mangesh       | 330420 | 4099214 | 1002  | 180        | 600        | 21       | 7.8 | 390        |
| 94 | Majilmakht    | 337016 | 4097365 | 1035  | 95         | 700        | 23       | 7.5 | 455        |
| SN | Well Name         | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|------------------|-------|-------|-------|----------------|------------|----------|-----|------------|
| 95 | Besifke alsufla | 331784| 4095148| 885 | 161 | 510 | 18 | 7.3 | 332 |
| 96 | Besifke          | 331016| 4095108| 880 | 115 | 548 | 18 | 7.3 | 356 |
| 97 | Kamaka           | 329540| 4092271| 834 | 198 | 1300 | 21 | 7.3 | 845 |
| 98 | Ekmala khabor    | 319632| 4104534| 824 | 175 | 600 | 29 | 7.5 | 390 |
| 99 | Alkish           | 339549| 4097669| 1040| 86  | 879 | 23 | 7.9 | 571 |
| 100| Zeka abu         | 321969| 4100997| 825 | 150 | 898 | 22 | 7.9 | 584 |
| 101| Dilya            | 315739| 4095946| 895 | 148 | 550 | 18 | 7.4 | 358 |
| 102| Shawreke         | 320859| 4097417| 682 | 169 | 380 | 26 | 7.8 | 247 |
| 103| Gre pete         | 327983| 4096002| 794 | 116 | 410 | 21 | 7.8 | 267 |
| 104| Gond kose        | 317281| 4107436| 558 | 124 | 786 | 21 | 7.3 | 511 |
| 105| Kovle            | 334505| 4101971| 897 | 184 | 500 | 20 | 7.4 | 325 |
| 106| Rostinke         | 344994| 4098613| 990 | 182 | 765 | 22 | 7.3 | 497 |
| 107| Navishke         | 319951| 4103261| 899 | 196 | 480 | 16 | 7.4 | 312 |
| 108| Ozmana           | 317377| 4103967| 772 | 180 | 472 | 16 | 7.6 | 307 |
| 109| Koreme           | 332693| 4104079| 1032| 125 | 450 | 17 | 7.9 | 293 |
| 110| Milhimban        | 325857| 409653 | 904 | 198 | 448 | 15 | 7.4 | 291 |
| 111| Alindke          | 317491| 4098277| 704 | 157 | 590 | 17 | 7.8 | 384 |
| 112| Derke            | 334586| 4093466| 942 | 150 | 573 | 17 | 7.6 | 372 |
| 113| Grepte           | 328133| 4095997| 824 | 182 | 420 | 15 | 7.7 | 273 |
| 114| Zinava           | 309400| 4099865| 826 | 130 | 832 | 16 | 7.8 | 541 |
| 115| Ashanke          | 313466| 4102931| 633 | 201 | 520 | 18 | 7.4 | 338 |
| 116| Dergijnik        | 328190| 4096028| 834 | 198 | 555 | 19 | 7.4 | 361 |
| 117| Kerble           | 325584| 4095738| 719 | 105 | 620 | 21 | 7.5 | 403 |
| 118| Qesrok           | 364315| 4352009| 432 | 200 | 539 | 22 | 7.8 | 350 |
| SN  | Well Name               | X      | Y      | Z      | Well Depth (m) | EC (µS/cm) | Temp. ºC | pH  | TDS (mg/L) |
|-----|-------------------------|--------|--------|--------|----------------|------------|----------|-----|------------|
| 119 | Mitka Seri              | 370774 | 4072489| 489    | 140            | 465        | 23       | 7.6 | 302        |
| 120 | Selke                   | 361728 | 4067073| 443    | 162            | 560        | 22       | 7.4 | 364        |
| 121 | Baviyan                 | 357519 | 4066265| 432    | 173            | 529        | 21       | 7.6 | 344        |
| 122 | Mitka alsufli           | 370535 | 4072636| 485    | 73             | 612        | 20       | 7.3 | 398        |
| 123 | Piran                   | 363081 | 409678 | 404    | 169            | 520        | 21       | 7.5 | 338        |
| 124 | Hinjirok                | 356781 | 4046063| 484    | 182            | 366        | 21       | 8   | 238        |
| 125 | Mam Reshan              | 359131 | 4058926| 398    | 180            | 459        | 23       | 8.1 | 298        |
| 126 | Shekhan                 | 352873 | 4063659| 554    | 120            | 452        | 21       | 7.9 | 294        |
| 127 | Doshivan                | 348219 | 4058619| 408    | 190            | 570        | 21       | 7.5 | 371        |
| 128 | Almeman                 | 344915 | 4058922| 412    | 180            | 598        | 22       | 7.5 | 389        |
| 129 | Shiv shrin              | 346445 | 4057335| 395    | 190            | 570        | 22       | 7.6 | 371        |
| 130 | Said Zari               | 303956 | 4081666| 439    | 200            | 822        | 21       | 7.5 | 534        |
| 131 | Sertank                 | 311095 | 4081010| 482    | 155            | 700        | 19       | 7.3 | 455        |
| 132 | Sumail                  | 308642 | 4081337| 464    | 200            | 1020       | 20       | 7.3 | 663        |
| 133 | Sershor                 | 303855 | 4080492| 483    | 220            | 650        | 17       | 7.8 | 423        |
| 134 | Sertank                 | 310616 | 4081046| 475    | 180            | 600        | 19       | 7.3 | 390        |
| 135 | Domize                  | 311857 | 4072838| 420    | 200            | 670        | 20       | 7.7 | 436        |
| 136 | Khorshinia              | 317072 | 4072797| 479    | 130            | 450        | 19       | 7.4 | 293        |
| 137 | Qasreen                 | 322750 | 4088132| 520    | 190            | 750        | 19       | 7.9 | 488        |
| 138 | Sharya                  | 319509 | 4071272| 469    | 190            | 650        | 20       | 7.2 | 423        |
| 139 | Sharia                  | 319509 | 4071272| 469    | 190            | 620        | 20       | 7.2 | 403        |
| 140 | Sharya complex          | 324681 | 4068938| 588    | 151            | 710        | 19       | 7.2 | 462        |
| 141 | Upper Deleb             | 313919 | 4080894| 507    | 192            | 600        | 18       | 7.6 | 390        |
| 142 | Bakhtme                 | 311877 | 4073095| 426    | 204            | 935        | 20       | 7.7 | 608        |
### Table A4. Cont.

| SN  | Well Name         | X    | Y    | Z    | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|-----|-------------------|------|------|------|----------------|------------|----------|-----|------------|
| 143 | Domiz             | 311857 | 4072838 | 420  | 200            | 1000       | 20       | 7.7 | 650        |
| 144 | Bakhetme          | 311877 | 4073095 | 426  | 204            | 935        | 20       | 7.7 | 608        |
| 145 | Dostka            | 328516 | 4073408 | 560  | 70             | 746        | 20       | 7.6 | 485        |
| 146 | Rezgari complex   | 312107 | 4072823 | 422  | 134            | 746        | 16       | 7.6 | 485        |
| 147 | Qsreen            | 321431 | 4065377 | 540  | 232            | 487        | 18       | 7.4 | 317        |
| 148 | Sharya            | 319846 | 4071251 | 485  | 170            | 1085       | 21       | 7.9 | 705        |
| 149 | Shekh Khedre      | 323702 | 4075661 | 605  | 200            | 518        | 18       | 7.5 | 337        |
| 150 | Uppe deleb        | 313919 | 4080894 | 507  | 192            | 220        | 18       | 7.8 | 143        |
| 151 | Meserik           | 305001 | 4082573 | 452  | 162            | 800        | 19       | 7.9 | 520        |
| 152 | Ivzorok Shane     | 278649 | 4100051 | 446  | 170            | 455        | 20       | 7.6 | 296        |
| 153 | Batel             | 293169 | 4093222 | 502  | 195            | 750        | 22       | 8   | 488        |
| 154 | Khrabdem complex  | 287050 | 4092307 | 391  | 180            | 650        | 17       | 7.6 | 423        |
| 155 | Kilke             | 282263 | 4099441 | 451  | 178            | 490        | 21       | 7.6 | 319        |
| 156 | Sershor           | 302376 | 4088065 | 482  | 158            | 766        | 18       | 7.8 | 498        |
| 157 | Ave zerik miri    | 290289 | 4093611 | 500  | 180            | 450        | 23       | 7.6 | 293        |
| 158 | ALasy             | 295729 | 4099390 | 655  | 126            | 600        | 21       | 7.4 | 390        |
| 159 | Pebzne            | 278050 | 4104759 | 561  | 203            | 780        | 22       | 7.4 | 507        |
| 160 | Aloka             | 315966 | 4078631 | 543  | 153            | 620        | 19       | 7.6 | 403        |
| 161 | Sumail            | 309339 | 4081170 | 463  | 190            | 755        | 21       | 7.4 | 491        |
| 162 | Sitke             | 325368 | 4070241 | 464  | 184            | 635        | 23       | 7.7 | 413        |
| 163 | Meserik           | 306104 | 4081504 | 454  | 200            | 740        | 22       | 7.3 | 481        |
| 164 | Azvorok Mere      | 290287 | 4093611 | 500  | 180            | 450        | 24       | 7.6 | 293        |
| 165 | Bakhetme          | 309607 | 4075254 | 357  | 200            | 745        | 23       | 7.5 | 484        |
| 166 | Kilke             | 282813 | 4099445 | 467  | 178            | 430        | 22       | 8.3 | 280        |
| SN  | Well Name    | X      | Y      | Z       | Well Depth (m) | EC (µS/cm) | Temp. °C | pH | TDS (mg/L) |
|-----|--------------|--------|--------|---------|---------------|------------|----------|----|------------|
| 167 | Hajeya       | 293067 | 4099617| 592     | 175           | 430        | 28       | 7.8| 280        |
| 168 | Gre gawre    | 304000 | 4082966| 452     | 200           | 998        | 26       | 7.4| 649        |
| 169 | Tanahi       | 312500 | 4081614| 483     | 200           | 530        | 24       | 7.5| 345        |
| 170 | Qsara        | 316054 | 4078975| 543     | 200           | 802        | 24       | 7.4| 521        |
| 171 | Kwashi       | 303958 | 4096995| 756     | 210           | 571        | 20       | 7.6| 371        |
| 172 | Tenahi       | 313130 | 4081411| 501     | 198           | 414        | 22       | 7.5| 269        |
| 173 | Qeshefere    | 312110 | 4087446| 670     | 143           | 586        | 22       | 7.5| 381        |
| 174 | Tobzawe      | 302558 | 4088235| 486     | 180           | 822        | 23       | 7.2| 534        |
| 175 | Selan Mamik  | 384752 | 4074279| 835     | 164           | 585        | 20       | 7.2| 380        |
| 176 | Sercaf       | 370214 | 4076013| 604     | 210           | 483        | 21       | 7.3| 314        |
| 177 | Basifre      | 365416 | 4076433| 647     | 194           | 595        | 21       | 7.7| 387        |
| 178 | Shekhka      | 360730 | 4069702| 522     | 116           | 390        | 21       | 7.3| 254        |
| 179 | Rkava        | 340688 | 4073959| 453     | 190           | 570        | 21       | 7.8| 371        |
| 180 | Mam Yezdin   | 342976 | 4072779| 738     | 140           | 470        | 21       | 7.9| 306        |
| 181 | Ba'adre      | 344273 | 4066695| 532     | 180           | 470        | 21       | 7.6| 306        |
| 182 | Bakhirnif    | 320421 | 4089908| 676     | 135           | 900        | 21       | 6.7| 585        |
| 183 | Zawite       | 335164 | 4082111| 785     | 165           | 840        | 21       | 7.2| 546        |
| 184 | Memane       | 329270 | 4089449| 963     | 201           | 780        | 20       | 7.7| 507        |
| 185 | Gelbok       | 380339633 | 47090271 | 892 | 237 | 575 | 21 | 7.3 | 374 |
| 186 | Betase       | 334477 | 4075080| 659     | 84            | 545        | 20       | 7.3| 354        |
| 187 | Jeman        | 337061 | 4075691| 746     | 130           | 1460       | 21       | 7.5| 949        |
| 188 | Pishta Gre   | 323350 | 4085115| 683     | 129           | 510        | 21       | 6.3| 332        |
| 189 | Bagera       | 335314 | 4092774| 545     | 200           | 480        | 21       | 7.3| 312        |
| 190 | Rkava        | 340592 | 4073943| 766     | 163           | 540        | 20       | 6.8| 351        |
| SN | Well Name  | X     | Y     | Z     | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|------------|-------|-------|-------|---------------|------------|----------|-----|------------|
| 191| Mangesh    | 330406| 409923| 993   | 210           | 675        | 21       | 7.5 | 439        |
| 192| Tehlava    | 332960| 4109484| 719   | 196           | 490        | 20       | 8.6 | 319        |
| 193| Banka      | 340243| 4113227| 1509  | 245           | 854        | 19       | 7.6 | 555        |
| 194| Shrty      | 341723| 4108183| 1009  | 200           | 770        | 20       | 7.8 | 501        |
| 195| Berashe    | 346381| 4096204| 1327  | 170           | 750        | 20       | 6.8 | 488        |
| 196| Spindare   | 349166| 4094425| 1177  | 86            | 790        | 20       | 7.7 | 514        |
| 197| Siare      | 357226| 4092036| 1043  | 72            | 545        | 20       | 8   | 354        |
| 198| Tazika     | 347020| 4098568| 999   | 92            | 320        | 20       | 7.1 | 208        |
| 199| Rostinke   | 343510| 4098339| 1138  | 290           | 648        | 20       | 7.8 | 421        |
| 200| Kani golan | 367404| 4108752| 1382  | 223           | 582        | 19       | 7.5 | 378        |
| 201| Metin      | 341655| 4112259| 1595  | 242           | 893        | 19       | 7.6 | 580        |
| 202| Sarke      | 395247| 4096108| 598   | 110           | 759        | 19       | 7.5 | 493        |
| 203| Migara     | 347800| 412885 | 1464  | 193           | 913        | 20       | 7.5 | 593        |
| 204| Bircat     | 360549| 4081089| 1045  | 250           | 1250       | 20       | 6.5 | 813        |
| 205| Rkava      | 340494| 4073953| 767   | 220           | 540        | 20       | 6.8 | 351        |
| 206| Baadre     | 317465| 4079326| 570   | 191           | 610        | 21       | 6.8 | 397        |
| 207| Qesrok     | 3643167| 4352016| 446   | 170           | 735        | 22       | 7.3 | 478        |
| 208| Hasan Iva  | 291494| 4107300| 703   | 168           | 660        | 23       | 6.5 | 429        |
| 209| Hezel      | 296303| 4115226| 465   | 160           | 400        | 22       | 6.9 | 260        |
### Appendix E

#### Table A5. Physicochemical Parameter Analysis for the Deep Wells in Halabja City, UTM-WGS84 Coordination System.

| SN | Well Name            | X    | Y    | Z    | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|----------------------|------|------|------|----------------|------------|----------|-----|------------|
| 1  | Bakhtiary            | 592071 | 3892595 | 825  | 163           | 390        | 20       | 8.5 | 254        |
| 2  | Bawakochak           | 588873 | 3890000 | 859  | 134           | 385        | 19       | 8.3 | 250        |
| 3  | Zamaqi               | 588203 | 3894673 | 660  | 120           | 443        | 18       | 8.1 | 288        |
| 4  | Near to ababaile     | 593610 | 3892759 | 943  | 109           | 519        | 20       | 8.5 | 337        |
| 5  | Jalila               | 592722 | 3895712 | 756  | 100           | 348        | 22       | 8.7 | 226        |
| 6  | Anab—Jalila          | 592572 | 3895984 | 765  | 97            | 365        | 22       | 8.3 | 237        |
| 7  | Kishadary            | 586062 | 3907468 | 503  | 115           | 441        | 20       | 8.4 | 287        |
| 8  | Kani Too             | 581276 | 3894130 | 652  | 130           | 304        | 21       | 6.5 | 198        |
| 9  | Belanga              | 583882 | 3892091 | 695  | 61            | 527        | 23       | 8.3 | 343        |
| 10 | Miraelly             | 580016 | 3890642 | 633  | 121           | 623        | 21       | 8   | 405        |
| 11 | Chrostana            | 581313 | 3890799 | 644  | 185           | 1151       | 22       | 7.9 | 748        |
| 12 | Gunda Village        | 582370 | 3890069 | 684  | 126           | 408        | 20       | 8.2 | 265        |
| 13 | Hana Zhalla Village  | 582179 | 3888734 | 675  | 100           | 950        | 23       | 7.5 | 618        |
| 14 | Saraw Village        | 584382 | 3889504 | 786  | 105           | 516        | 19       | 8   | 335        |
| 15 | Presy Saroo          | 585853 | 3891312 | 809  | 95            | 432        | 19       | 8.1 | 281        |
| 16 | Byawella             | 592426 | 3897181 | 734  | 100           | 382        | 22       | 9.1 | 248        |
| 17 | Anab-Byawella        | 592117 | 3897069 | 729  | 89            | 384        | 22       | 8.5 | 250        |
| 18 | Khakukholl           | 586980 | 3904073 | 519  | 129           | 484        | 21       | 7.6 | 315        |
| 19 | Basharaty Kharoo     | 586841 | 3902459 | 533  | 105           | 387        | 23       | 8.4 | 252        |
| 20 | Kagrdal              | 583261 | 3900444 | 513  | 110           | 452        | 22       | 8.1 | 294        |
| 21 | Ghwlamk kharoo       | 579248 | 3897246 | 510  | 99            | 596        | 24       | 8.1 | 387        |
| 22 | Imam zamin           | 579938 | 3898233 | 511  | 120           | 439        | 24       | 8.2 | 285        |
| 23 | Sharazor Project-6   | 586483 | 3899015 | 562  | 128           | 420        | 22       | 8.3 | 273        |
| SN | Well Name       | X       | Y       | Z    | Well Depth (m) | EC (µS/cm) | Temp. °C | pH  | TDS (mg/L) |
|----|----------------|---------|---------|------|---------------|------------|----------|-----|------------|
| 24 | Khurmal        | 594307  | 3907412 | 563  | 98            | 2540       | 29       | 8.4 | 1651       |
| 25 | Amwra          | 591361  | 3912840 | 660  | 112           | 425        | 25       | 9.6 | 276        |
| 26 | Mirt soor      | 590598  | 3914380 | 702  | 95            | 346        | 21       | 6.6 | 225        |
| 27 | Qulkhurd       | 587237  | 3913052 | 826  | 74            | 742        | 22       | 9.3 | 482        |
| 28 | Mala waisa     | 587657  | 3911858 | 531  | 63            | 570        | 22       | 9.3 | 371        |
| 29 | Aliawa         | 585467  | 3913493 | 528  | 160           | 437        | 23       | 9.5 | 284        |
| 30 | Shashki khwaroo| 589662  | 3904454 | 558  | 72            | 360        | 21       | 8.3 | 234        |
| 31 | Rostum bag     | 595651  | 3904943 | 632  | 84            | 351        | 24       | 8.2 | 228        |
| 32 | Gomalar        | 592687  | 3903819 | 609  | 101           | 365        | 24       | 7.8 | 237        |
| 33 | De kon         | 594328  | 3904138 | 627  | 100           | 362        | 21       | 7.5 | 235        |
| 34 | Zardahal       | 598089  | 3899419 | 906  | 181           | 448        | 21       | 7.9 | 291        |
| 35 | Qainaja        | 585183  | 3916320 | 543  | 165           | 520        | 20       | 7.3 | 338        |
| 36 | Tapy safa      | 589053  | 3905505 | 550  | 129           | 514        | 24       | 8.3 | 334        |
| 37 | Dalamar        | 591410  | 3892298 | 798  | 156           | 356        | 20       | 8.5 | 231        |
| 38 | Shakrally      | 587155  | 3904786 | 521  | 164           | 468        | 22       | 8.7 | 304        |
## Appendix F

**Table A6.** Physicochemical Parameter Analysis for the Spring and River Samples in the Study Area, UTM-WGS84 Coordination System.

| SN | Spring Name                  | X  | Y  | Z  | EC (µS/cm) | Temp (°C) | TDS Mg/L | pH  |
|----|------------------------------|----|----|----|------------|-----------|----------|-----|
| 1  | Hiran Spring                 | 454550 | 4014850 | 925 | 536 | 24.5 | 348.4 | 7.5 |
| 2  | Kani Hanjeer Spring          | 445441 | 4036667 | 744 | 525 | 24.3 | 341.3 | 7.6 |
| 3  | Sisawa Spring                | 447906 | 4038217 | 861 | 536 | 24.2 | 348.4 | 7.6 |
| 4  | Amokan Spring                | 435472 | 4053369 | 634 | 507.5 | 24.9 | 329.9 | 7.8 |
| 5  | Kani Chirgan Spring          | 432855 | 4054601 | 556 | 644.5 | 24.6 | 418.9 | 7.8 |
| 6  | Kani Qura Bag Spring         | 425821 | 4052478 | 407 | 469.5 | 24.7 | 305.2 | 7.9 |
| 7  | Graw Spring Spring           | 426026 | 4043286 | 627 | 656 | 24.6 | 426.4 | 7.6 |
| 8  | Kani Khazal Spring           | 429244 | 4049134 | 503 | 571 | 24.8 | 371.2 | 7.8 |
| 9  | Aspendara Spring             | 450966 | 4023173 | 974 | 540 | 24.8 | 351.0 | 7.5 |
| 10 | Gomashin Spring              | 513551 | 3940143 | 889 | 309 | 17.8 | 200.8 | 8.1 |
| 11 | Kanisarwchawa Spring         | 501402 | 3950379 | 939 | 343 | 19.4 | 223.1 | 7.6 |
| 12 | Cholmak Spring               | 503981 | 3939024 | 925 | 349 | 18 | 227.1 | 7.6 |
| 13 | Morkta Spring                | 505940 | 3936511 | 935 | 335 | 16.7 | 218.0 | 7.7 |
| 14 | Zekan Spring                 | 510846 | 3936146 | 823 | 253 | 18.7 | 164.3 | 7.9 |
| 15 | Khalbani Spring              | 513125 | 3933774 | 826 | 293 | 18.5 | 190.6 | 7.8 |
| 16 | Qushqaya Spring              | 519069 | 3953353 | 827 | 197 | 18.8 | 127.8 | 8.2 |
| 17 | Kani shaya Spring            | 519303 | 3933194 | 783 | 250 | 19 | 162.2 | 7.7 |
| 18 | Warmziar Spring              | 522429 | 3930660 | 805 | 406 | 19.6 | 263.6 | 7.6 |
| 19 | Barowi gawra Spring          | 526007 | 3926479 | 937 | 463 | 17.6 | 301.1 | 7.7 |
| 20 | Darikali Spring              | 523300 | 3924898 | 957 | 371 | 17.6 | 241.3 | 7.8 |
| 21 | Halai sarwchawa Spring       | 518219 | 3932409 | 793 | 367 | 18.3 | 238.3 | 7.7 |
| 22 | Shekhmand Spring             | 514267 | 3929614 | 815 | 351 | 26.5 | 228.2 | 8.1 |
Table A6. Cont.

| SN | Spring Name       | X    | Y    | Z    | EC (µS/cm) | Temp (°C) | TDS Mg/L | pH  |
|----|-------------------|------|------|------|------------|-----------|----------|-----|
| 24 | Gomatagach Spring | 514365 | 3933015 | 810 | 353 | 19 | 229.2 | 7.8 |
| 25 | Hanjeera Spring   | 509826 | 3932541 | 890 | 365 | 16.6 | 237.3 | 7.8 |
| 26 | Aligoran Spring   | 510422 | 3931134 | 989 | 510 | 20.5 | 331.6 | 8.1 |
| 27 | Delezha Spring    | 517743 | 3923677 | 791 | 362 | 16.5 | 235.2 | 7.7 |
| 28 | Gurbaz Spring     | 520783 | 3921370 | 803 | 413 | 21 | 268.7 | 7.8 |
| 29 | Azaban Spring     | 571219 | 3898928 | 870 | 345.5 | 18 | 221.1 | 7.6 |
| 30 | Siyarra Spring    | 582344 | 3898235 | 602 | 459 | 20 | 293.8 | 7.4 |
| 31 | Birke Spring      | 574532 | 3896998 | 835 | 704 | 17.6 | 450.6 | 7.5 |
| 32 | Qashti Spring     | 565342 | 3893567 | 699 | 796.5 | 19 | 509.8 | 7.4 |
| 33 | Ahmed Brenda Spring| 575461 | 3881721 | 899 | 342.5 | 18.5 | 219.2 | 7.7 |
| 34 | Greater Zab River | 423363 | 4051506 | 368 | 388.5 | 22.2 | 252.5 | 8.1 |
| 35 | Lesser Zab River  | 430190.4 | 3966505 | 302 | 362.5 | 22.7 | 235.6 | 8.2 |
| 36 | Sirwan River      | 563919.9 | 3884792 | 367 | 374 | 22.9 | 243.1 | 8.2 |
| 37 | Tanjero River     | 574854.6 | 3895831 | 457 | 361 | 22 | 235 | 8 |
Appendix G

Figure A1. Location Map Showing the Spring and River Samples of the Study Area.
Appendix H

Figure A2. Hydrogeological Map (Aquifer System) across the Kurdistan Region (after Stevanovic and Markovic, 2004).

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