water

Article

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

Shwan Seeyan [1,*], Ammar Adham [2], Karrar Mahdi [3] and Coen Ritsema [3]

[1] Soil and Water Department, Agricultural Engineering Science College, Salahaddin University, Erbil 44002, Iraq
[2] Dams and Water Resources Engineering Department, Engineering College, University of Anbar, Ramadi 31001, Iraq; engammar2000@uoanbar.edu.iq
[3] Soil Physics and Land Management Group, Wageningen University & Research, 6700 AA Wageningen, The Netherlands; Karrar.mahdi@wur.nl (K.M.); coen.ritsema@wur.nl (C.R.)
* Correspondence: shwan.seeyan@su.edu.krd; Tel.: +964-750-4487884

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

check for updates

Citation: Seeyan, S.; Adham, A.; Mahdi, K.; Ritsema, C. Water Quality, Availability, and Uses in Rural Communities in the Kurdistan Region, Iraq. *Water* **2021**, *13*, 2927. https://doi.org/10.3390/w13202927

Academic Editor: Antonio Lo Porto

Received: 8 September 2021
Accepted: 17 October 2021
Published: 18 October 2021

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 km^2 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.

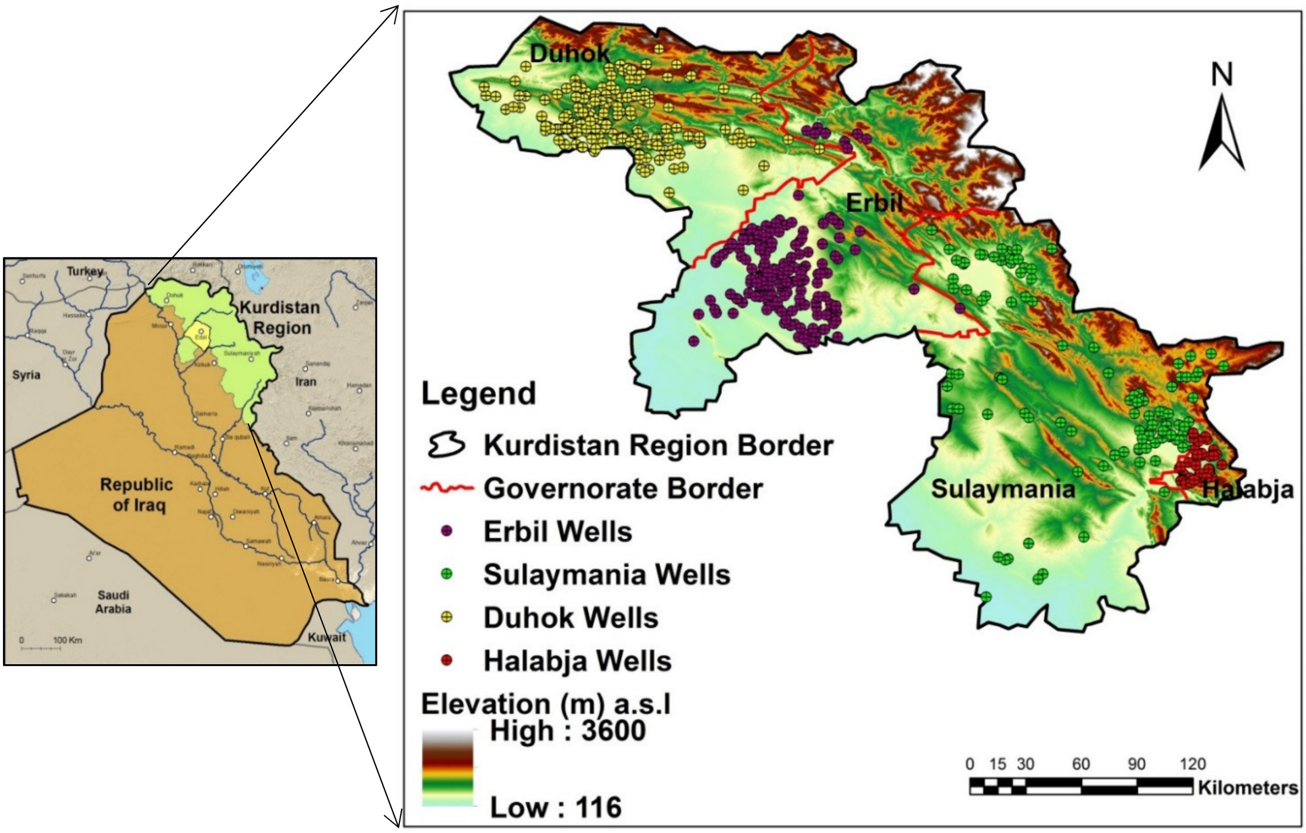

Figure 1. Map showing the origin of the groundwater samples taken across the Kurdistan Region.

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).

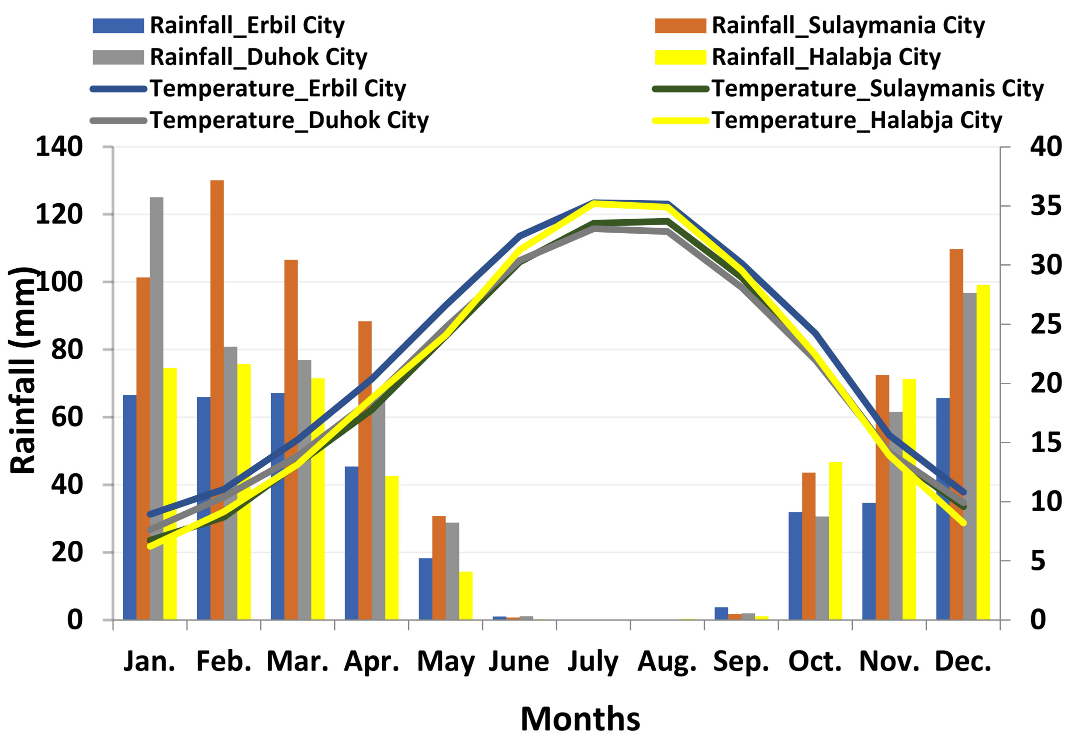

Figure 2. Mean monthly rainfall and temperature in the study area for the period 2005–2019.

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, Kurrachina, 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

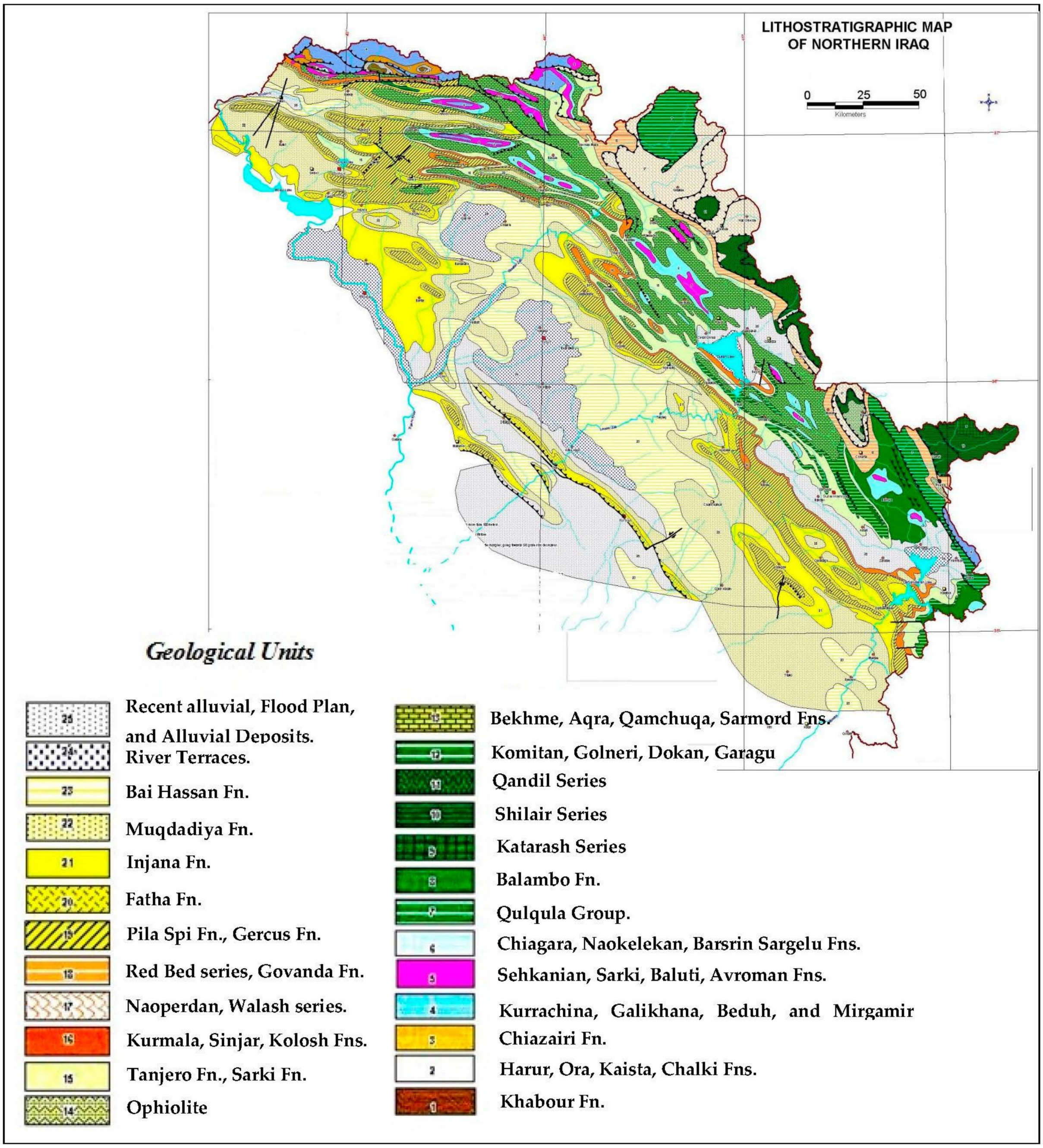

Figure 3. Geological map showing the lithological units of the study area (After Stevanovic and Marcovich, 2003).

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 Baluti, Kurrachina, 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).

Table 2. Classifications of water according to TDS in (mg/L).

Water Class	Gorrell (1958)	Altoviski (1962)	Drever (1997)	Hillel (2000)
Fresh water	0–1000	0–1000	<1000	<500
Slightly brackish water (Marginal)	—	1000–3000	—	500–1000
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).

Table 3. Classifications of water according to EC in (µS/cm).

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).

Table 4. Water classification according to Todd [23].

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.

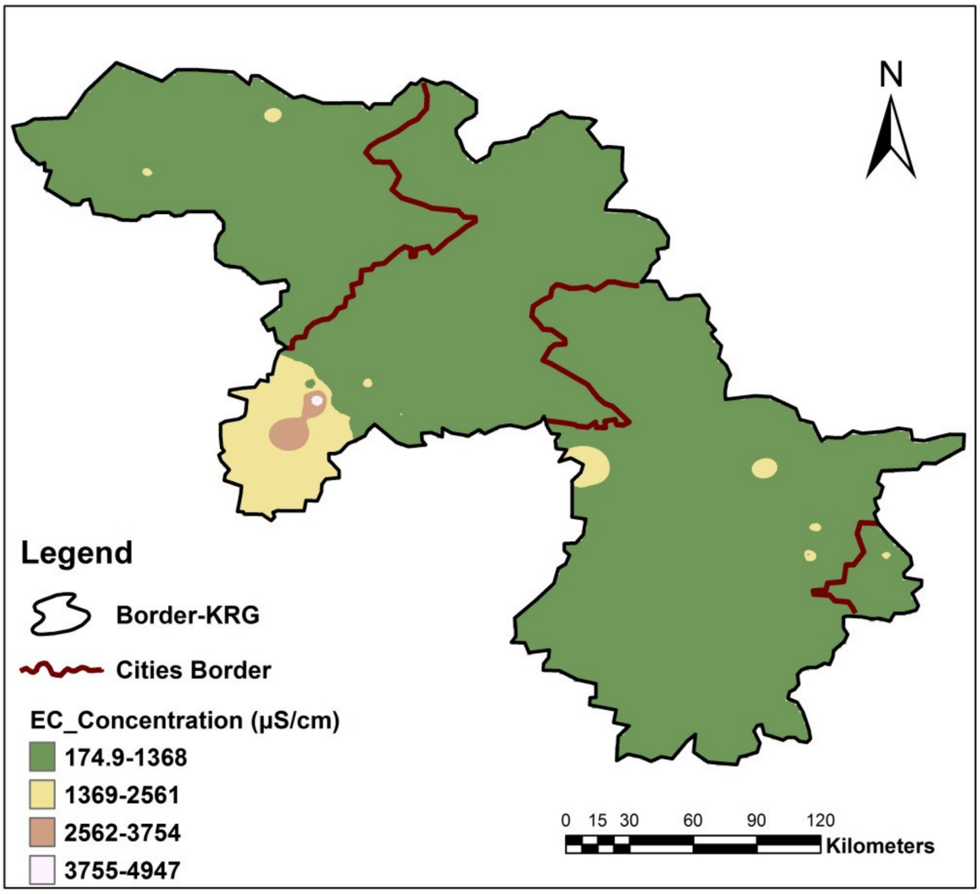

Figure 4. Distribution of the electrical conductivity of groundwater across the Kurdistan Region.

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).

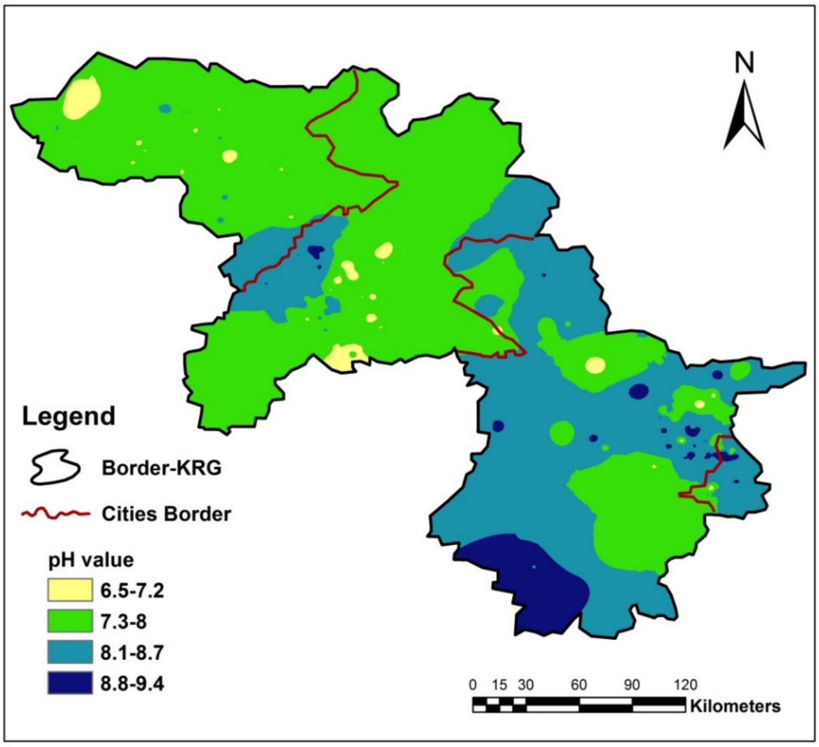

Figure 5. Distribution of the pH of groundwater across the Kurdistan Region.

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).

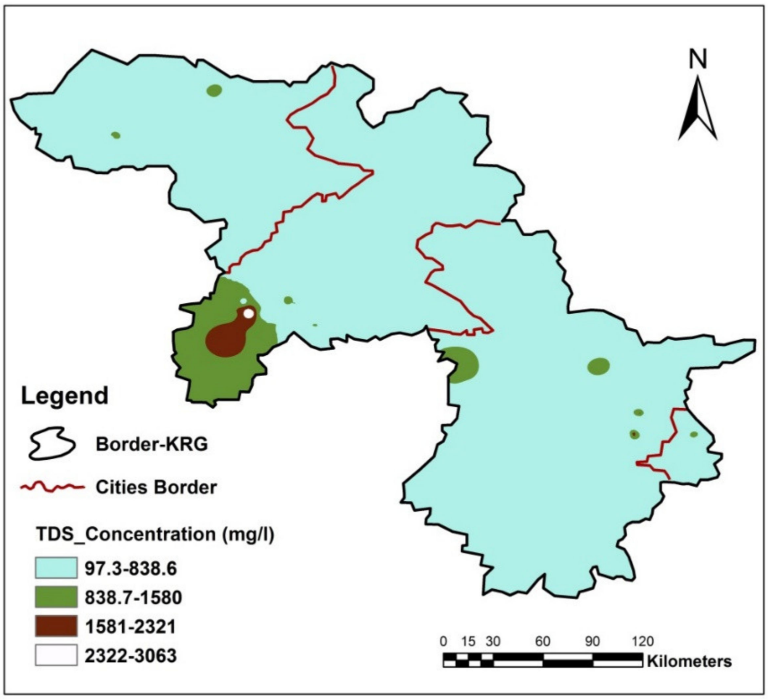

Figure 6. Distribution of the TDS of groundwater across the Kurdistan Region.

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).

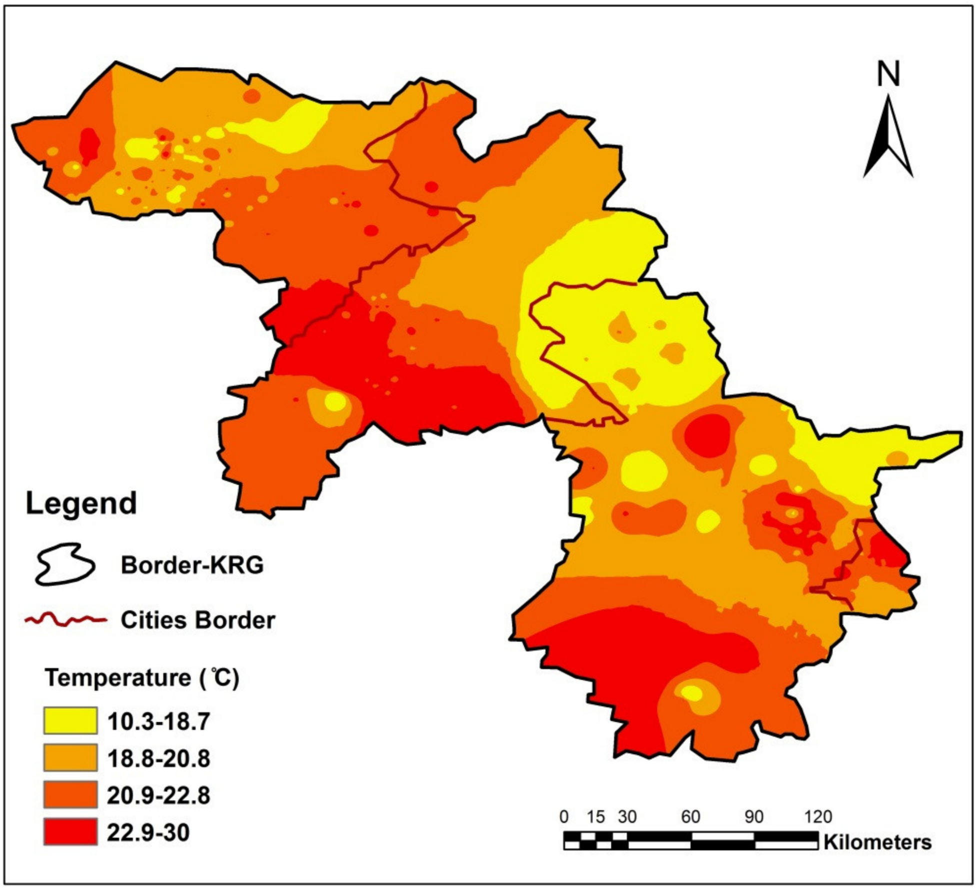

Figure 7. Distribution of the temperature of groundwater across the Kurdistan Region.

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).

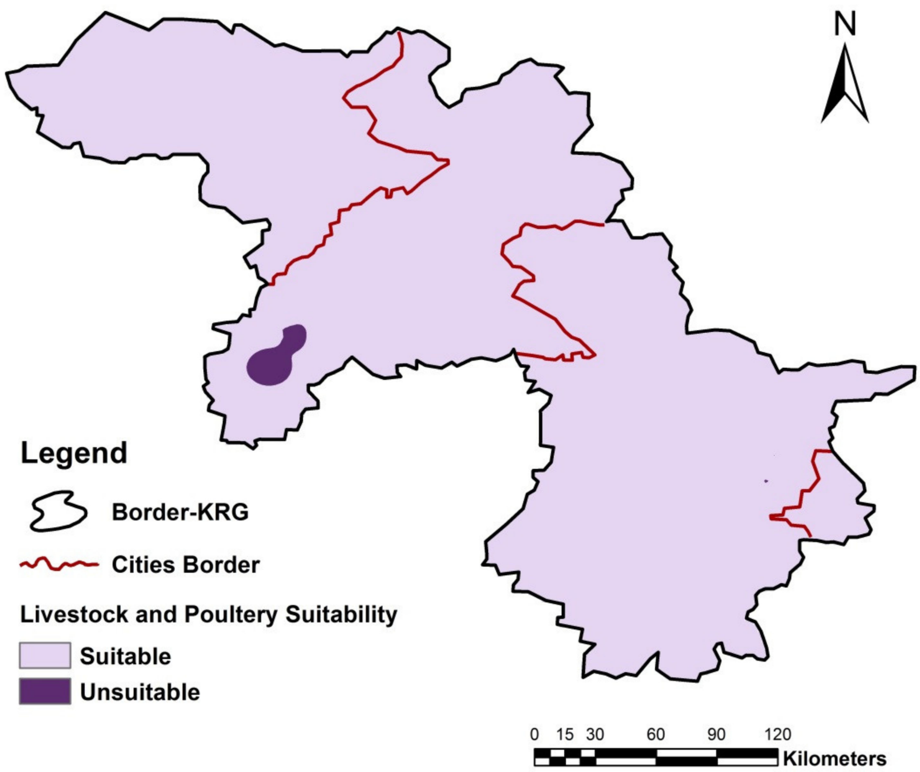

Figure 8. Suitability map for livestock and poultry according to Ayers and Westcot (1989).

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).

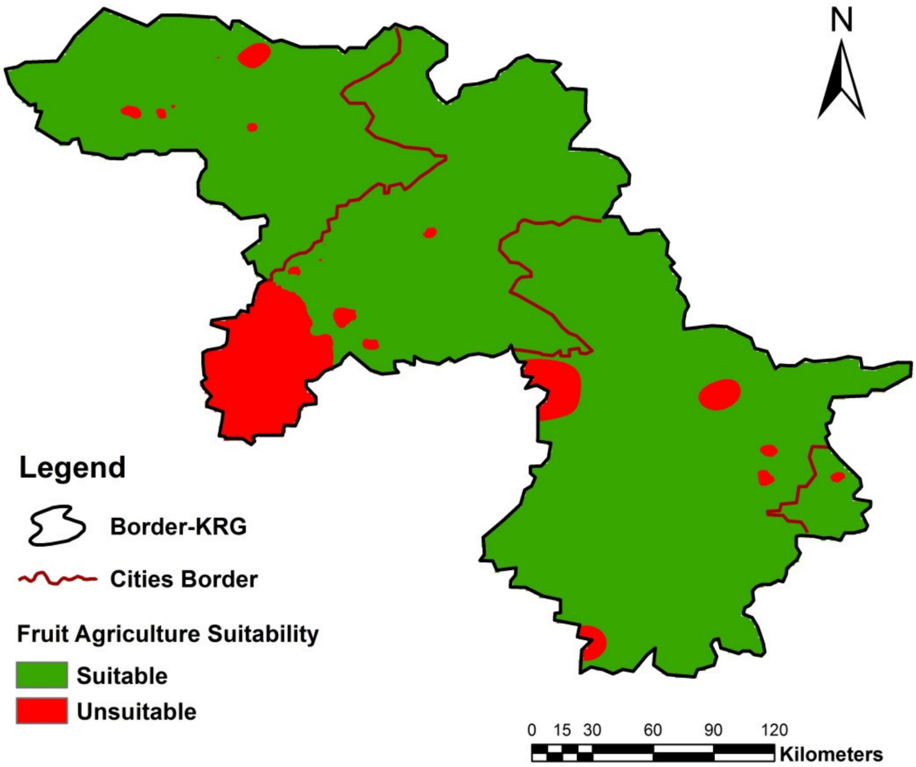

Figure 9. Suitability map for livestock and poultry according to [19].

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 Avocado, lemon, orange, apple strawberry, picot prune, plum	300–400 µS/cm Olive, date, fig cantaloupe, pomegranate	400–1000 µS/cm Palm	Erbil City 286–5090 (µS/cm) Sulaymania City 134–3290 (µS/cm)
Vegetable	300–400 µS/cm Green bean, celery, radish	400–1000 µS/cm Cucumber, onion, peas carrot, potato, cauliflower lettuce, squash	1000–12,000 µS/cm Spinach, kale, asparagus	Duhok City 220–2400 (µS/cm)
Field crops	400–600 µS/cm Field bean	600–1000 µS/cm Sunflower, corn, rice, flax, castor bean, wheat	1000–10,000 µS/cm Cotton, sugar beet, barley	Halabja City 304–2540 (µS/cm)

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).

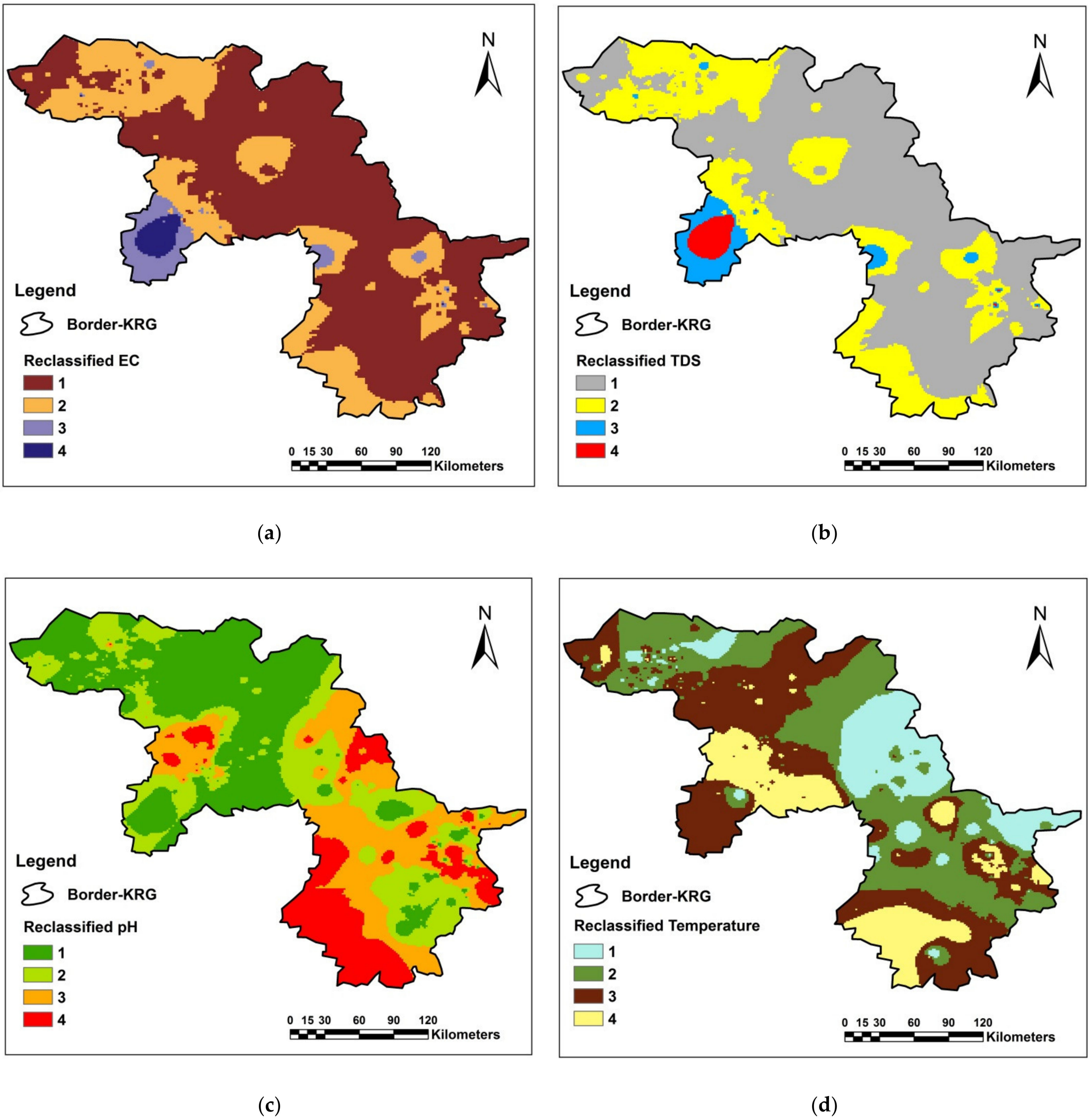

Figure 10. Reclassified map of the studied criteria; (**a**) Reclassified electrical conductivity, (**b**) Reclassified total dissolved solid, (**c**) Reclassified pH value, and (**d**) Reclassified temperature value.

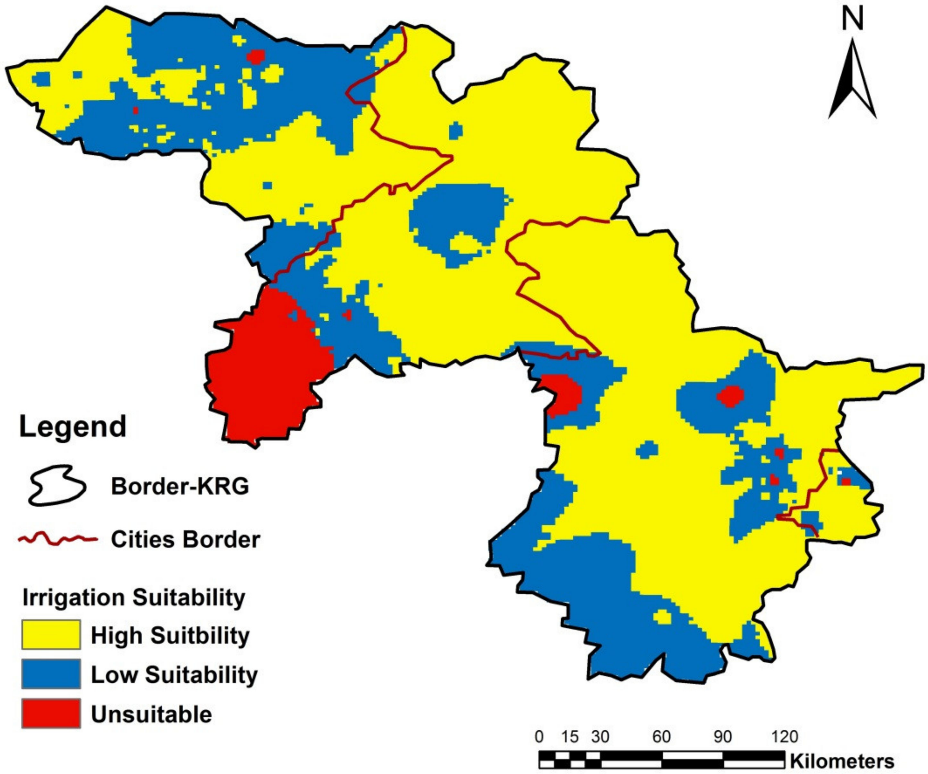

Figure 11. Irrigation water suitability map of the Kurdistan Region.

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.

Author Contributions: Conceptualization, S.S. and C.R.; methodology, S.S.; software, S.S.; validation, S.S., C.R. and K.M.; formal analysis, S.S.; investigation, S.S., C.R., A.A.; resources, S.S.; data curation, S.S.; writing—original draft preparation, S.S.; writing—review and editing, C.R. and K.M.; visualization, S.S., A.A. and K.M.; supervision, C.R.; project administration, C.R. and K.M.; funding acquisition, C.R. All authors have read and agreed to the published version of the manuscript.

Funding: This Research is fully funded by NUFFIC Orange Knowledge Programme OKP-IRA-104278.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Some data in this manuscript obtained from Ministry of Agriculture and Water Resources-Groundwater Directorate, Kurdistan Region, Iraq and the other data from the field work during 2020–2021 and analyzing the parameters.

Acknowledgments: This study was funded by the NUFFIC Orange Knowledge Programme (OKP-IRA-104278) and coordinated by Wageningen University & Research, The Netherlands. The authors thank the Ministry of Agriculture and Water Resources and Groundwater Directorate in the Kurdistan Region for making data available for this study.

Conflicts of Interest: The authors declare no conflict of interest.

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	34.7	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	1.4	1.3	1.2	1.1	0.8
	Evaporation (mm)	2.3	2.6	3.3	4.7	7	10.8	11.8	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	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.
Halabja City	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
	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	Daldaghan	399945	3992666	339	140	771	24	7.4	501
12	Dustapa	399176	3995794	325	124	576	25	7.9	374

Table A2. *Cont.*

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 Jabar	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	4000423	352	128	681	22	7.6	443
30	Awena	382629	3991199	290	101	940	26	8.4	611
31	Delogoli 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	Trpaspian	403751	3983092	336	174	660	22	8.2	429
36	Pirdaud	403042	3986933	348	150	613	23	7.8	398

Table A2. *Cont.*

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	Dolazay Nawand	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

Table A2. *Cont.*

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 mardan	407215	3991827	380	50	510	23	7.8	332
76	Aliawa mardan	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	Qalasinji 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 Qirzhala	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	Satoor	392155	4004737	446	160	391	25	8.4	254

Table A2. *Cont.*

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	Bahrka	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	Shakholan	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	Binaslawa	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

Table A3. *Cont.*

SN	Well Name	X	Y	Z	Well Depth (m)	EC (μS/cm)	Temp. °C	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	522819	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	Chokhmakh	527503	3962832	1054	154	599	30	7	389

Table A3. *Cont.*

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

Table A3. *Cont.*

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	Keloo	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	3912596	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

Table A3. *Cont.*

SN	Well Name	X	Y	Z	Well Depth (m)	EC (μS/cm)	Temp. °C	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	3920647	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	Kullajoi 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	8	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	845
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	7.2	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

Table A4. *Cont.*

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	4082918	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

Table A4. *Cont.*

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	Shrty	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	Khlbish	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

Table A4. *Cont.*

SN	Well Name	X	Y	Z	Well Depth (m)	EC (µS/cm)	Temp. °C	pH	TDS (mg/L)
71	Mersida	366533	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	407379	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

Table A4. *Cont.*

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	40959446	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	4099653	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	328113	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

Table A4. *Cont.*

SN	Well Name	X	Y	Z	Well Depth (m)	EC (µS/cm)	Temp. °C	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	4059678	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	44099441	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	Avzorok 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

Table A4. *Cont.*

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	Qeshefre	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	455	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	4088211	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

Table A4. *Cont.*

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 Khwaroo	586841	3902459	533	105	387	23	8.4	252
20	Kagrdal	583261	3900444	513	110	452	22	8.1	294
21	Ghwlami khwaroo	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

Table A5. *Cont.*

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	526	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	Mortka Spring	505940	3936511	935	335	16.7	218.0	7.7
14	Zekan Spring	510020	3934824	811	346	17.2	225.1	7.6
15	Khaldan Spring	510846	3936146	823	253	18.7	164.3	7.9
16	Alibzaw Spring	513125	3933774	826	293	18.5	190.6	7.8
17	Qushqaya Spring	519069	3935353	827	197	18.8	127.8	8.2
18	Kani shaya Spring	519303	3933194	783	250	19	162.2	7.7
19	Warmziar Spring	522429	3930660	805	406	19.6	263.6	7.6
20	Barowi gawra Spring	526007	3926479	937	463	17.6	301.1	7.7
21	Darikali Spring	523300	3924898	957	371	17.6	241.3	7.8
22	Halai sarwchawa Spring	518219	3932409	793	367	18.3	238.3	7.7
23	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	Siyara 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

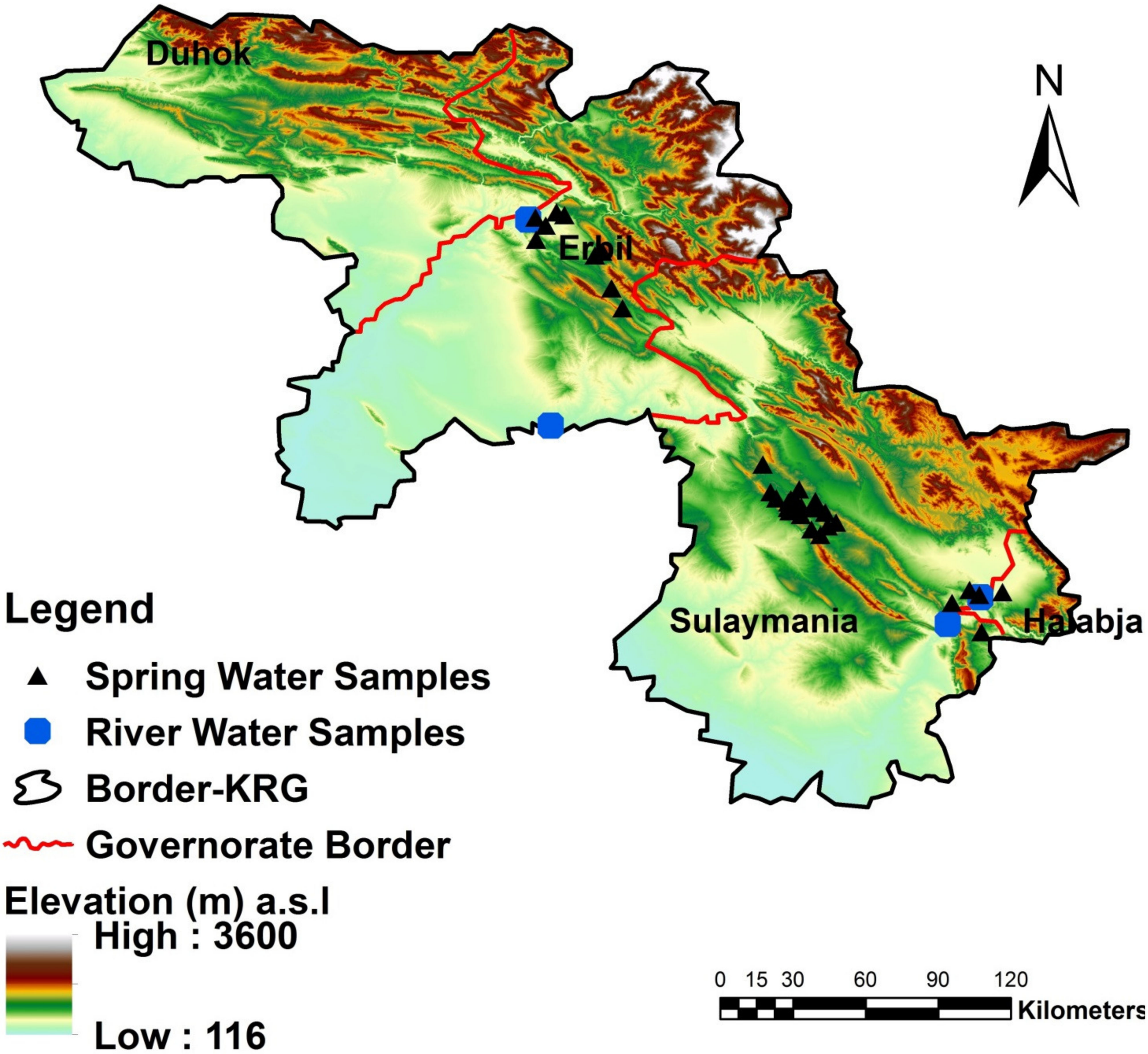

Figure A1. Location Map Showing the Spring and River Samples of the Study Area.

Appendix H

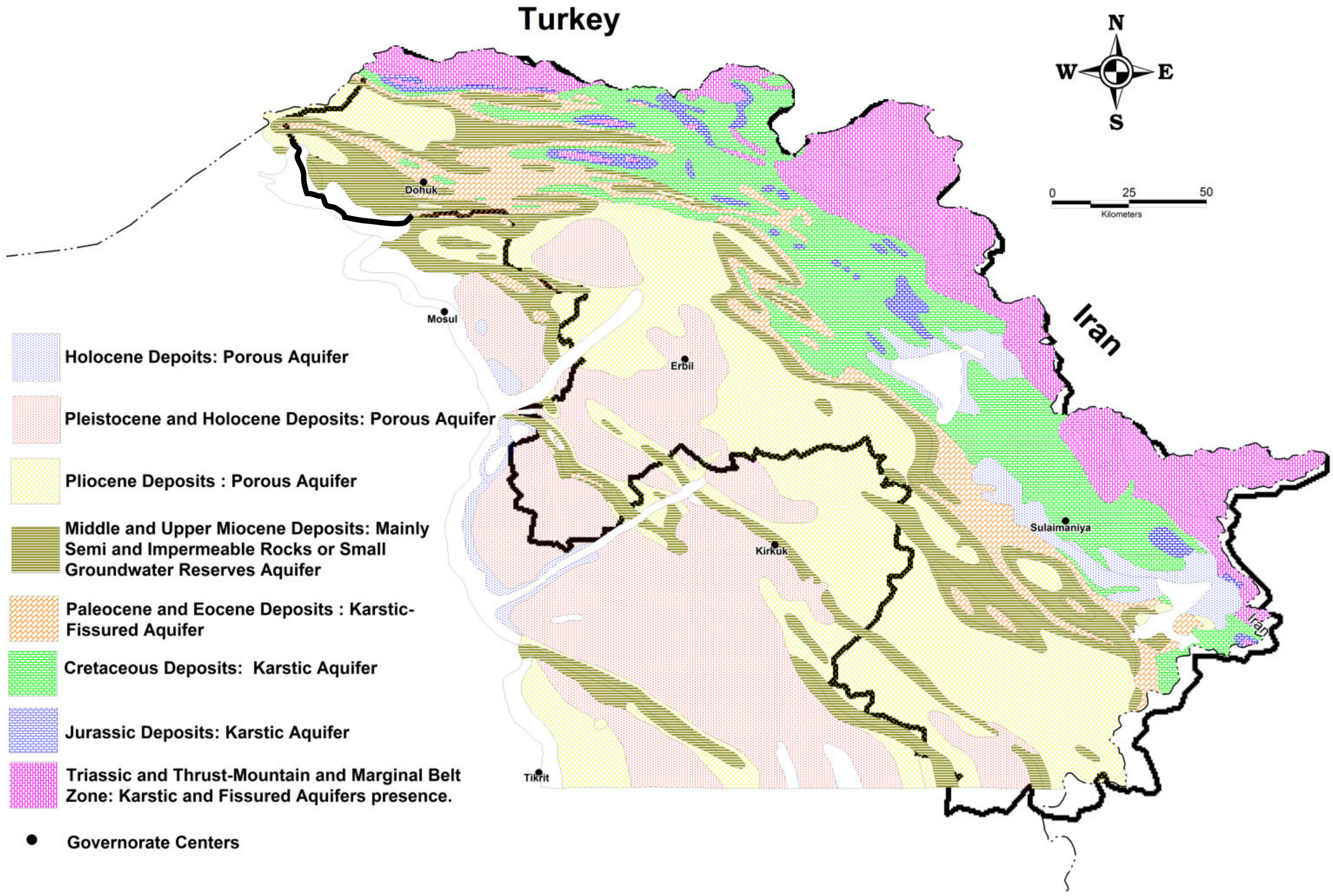

Figure A2. Hydrogeological Map (Aquifer System) across the Kurdistan Region (after Stevanovic and Marcovich, 2004).

References

1. Erol, A.; Randhir, T.O. Climatic change impacts on the Ecohydrology of Mediterranean watersheds. *Clim. Chang.* **2012**, *114*, 319–341. [CrossRef]
2. Christensen, J.H.; Kumar, K.K.; Aldria, E.; An, S.-I.; Cavalcanti, I.F.A.; De Castro, M.; Dong, W.; Goswami, P.; Hall, A.; Kanyanga, J.K.; et al. Climate Phenomena and Their Relevance for Future Regional Climate Change Supplementary Material. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2013, Climate Change 2013: The Physical Science Basis 62. Available online: http://www.climatechange2013.org (accessed on 29 January 2013).
3. Booker, J.F.; Trees, W.S. Implications of Water Scarcity for Water Productivity and Farm Labor. *Water* **2020**, *12*, 308. [CrossRef]
4. Habib, Z.; Wahaj, R. *Water Availability, Use and Challenges in Pakistan—Water Sector Challenges in the Indus Basin and Impact of Climate Change*; FAO: Islamabad, Pakistan, 2021. [CrossRef]
5. Seather, O.M.; Caritat, P.D. *Geochemical Processes, Weathering and Groundwater Recharge in Catchments*; A. A. Balkama: Rotterdam, The Netherlands, 1997; 400p.
6. Davis, S.N.; Dewiest, R.J. *Hydrology*; John Wiley & Sons. Inc.: New York, NY, USA, 1966; 463p.
7. Walton, C.W. *Groundwater Resource Evaluation*; McGraw Hill Co.: New York, NY, USA, 1970; 664p.
8. Langmuir, D. *Aqueous Environmental Geochemistry*; Prentice Hall: Hoboken, NJ, USA, 1997; 600p.
9. Houatmia, F.; Azouzi, R.; Charef, A.; Bédir, M. Assessment of groundwater quality for irrigation and drinking purposes and identification of hydrogeochemical mechanisms evolution in northeastern, Tunisia. *Environ. Earth Sci.* **2016**, *75*, 746. [CrossRef]
10. Chakraborty, S.; Kumar, R.N. Assessment of groundwater quality at a MSW landfill site using standard and AHP based water quality index: A case study from Ranchi, Jharkhand, India. *Environ. Monit. Assess.* **2016**, *188*, 335. [CrossRef] [PubMed]
11. Xu, P.; Zhang, Q.; Qian, H.; Zheng, L. Spatial distribution characteristics of irrigation water quality assessment in the Central-Western Guanzhong Basin, China. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *647*, 012143. [CrossRef]
12. Chan, F.; Kumar, N.; Tiwar, M.; Lau, H.; Choy, K. Global supplier selection: A fuzzy-AHP approach. *Int. J. Prod. Res.* **2008**, *46*, 3825–3857. [CrossRef]
13. Stevanovic, Z.; Markovic, M. *Hydrogeology of Northern Iraq, Climate, Hydrology, Geomorphology & Geology*; FAO: Rome, Italy, 2003; Volume 1, pp. 1–122.

14. Stevanovic, Z.; Markovic, M. *Hydrogeology of Northern Iraq, Hydrogeology and Aquifer System*; Specific edition; FAO UN: Rome, Italy, 2004; Volume 2, pp. 1–175.
15. Vajsáblová, M. Variograms and regression methods of their creation. *Acad. J.* **2013**, *8*, 1998–2007.
16. Train, R.E. *Quality Criteria for Water*; Castle House Publication, Ltd.: London, UK, 1979; 256p.
17. Hillel, D. *Salinity Management for Sustainable Irrigation Integrating Science, Environment, and Economics, Environmentally and Socially Sustainable Development: Rural Development*; The World Bank: Washington, DC, USA, 2000.
18. Drever, J.I. *The Geochemistry of Natural Water, Surface and Groundwater Environment*, 3rd ed.; Prentice Hall: Hoboken, NJ, USA, 1997; 436p.
19. Altoviski, M.E. *Hand Book of Hydrogeology*; Gosgeolitzda Moscow, USSR: Moscow, Russia, 1962; 614p. (In Russian)
20. Gorrell, H.A. *Classification of Formation Waters Based on Sodium Chloride Content*; American Association of Petroleum Geologists Bulletin: Tulsa, OK, USA, 1958; Volume 42, No. 10.
21. U.S.D.A. *USDA Census of Agriculture*; United State Department of Agriculture: Washington, DC, USA, 1954.
22. Mayer, X.M.; Ruprecht, J.K.; Bari, M.A. *Stream Salinity Status and Trends in South-West Western Australia*; Report No. SLUI 38; Department of Environment, Salinity and Land Use Impacts Series; Department of Environment, Government of Western Australia: Perth, WA, Australia, 2005.
23. Todd, D.K. *Groundwater Hydrology*, 2nd ed.; John Wiley & Sons, Inc.: New York, NY, USA, 1980; 535p.
24. Rhoades, J.D.; Kandiash, A.; Mashali, A.M. *The Use of Saline Water for Crop Production*; Irrigation and Drainage paper No. 48; FAO: Rome, Italy, 1992.
25. Don, C.M. *A Grows Guide to Water Quality*; University College Station: College Station, TX, USA, 1995.
26. Ayers, R.S.; Westcot, D.W. *Water Quality for Agriculture. Irrigation and Drainage Paper 29*; Rev.1; FAO: Rome, Italy, 1989; 174p.
27. Grossman, Z. International Environmental Problems & Policy, a Class Website on Water Privatization and Commodification. Produced by Students of Geography at the University of Wisconsin-Eau Claire, USA. 2004. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fkuliah.rizaldi.web.id%2FESL%2520223_Ekonomi%2520Sumber%2520Daya%2520Air%2FWater%2520is%2520Life.doc (accessed on 8 September 2021).
28. Leavy, D.B.; Kearney, W.F. Irrigation of Native Rangeland Using Treated Waste Water From Institute Uralian processing. *J. Environ. Qual.* **1999**, *28*, 208–217. [CrossRef]