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EVALUATION OF SEASONAL A SPATIAL VARIATION OF GROUNDWATER QUALITY BY DETERMINING FACTORS ASSOCIATED WITH WATER QUALITY USING MULTIVARIATE ANALYTICAL METHODS, ERBIL CENTRAL SUB-BASIN

Masoud H. Hamed[1*], Erkan Disli[2], and Jawhar Shukur[3]

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ABSTRACT

The study area is located in the northern Iraqi province of Erbil, covering a total area of about 1400 Km^2 (3.5% of Iraq). The Erbil basin is mostly covered by Quaternary sediments, with only a few outcrops of Miocene – Pliocene formations in the east and northeast of Sharabot-Dedawan highlands, Avanah Mountain in the west and southwest in narrow strips, and Damirdagh in the north. The lithology of sediments ranges from clay, silt, sand, and gravel (sandstone, clay stone, and conglomerate). Erbil Basin, also known as Dashty Hawler Basin, Erbil provinces is the largest groundwater reservoir, with a surface area of 3200 Km^2 and a depth of approximately 800 meters. Erbil Basin, one of the Middle East's most important groundwater basins, is bounded on the north by the Greater Zab River and on the south by the Lesser Zab River. Thirty water samples (27 samples of groundwater wells, and 3 samples of wastewater channels) were collected during May (Water surplus period) and September (Water deficit period) 2020 in Erbil central sub-basin and analyzed. Physical analyses include temperature (T), pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD5), Chemical oxygen demand (COD), Dissolved oxygen (DO), Total Suspension sediments (TSS), whereas the geochemical analysis included concentration determination of the major, minor and trace elements. This article aims to evaluate the pollution in groundwater of the Erbil central sub-basin due to different kinds of wastewater, the samples of water in the study area were collected from different locations and sources, deep wells, and waste. all chemical, physical, and trace elements parameters are presented in this work, the pollution has been founded in the study area due to waste water by Kahrez (old groundwater distribution in Erbil basin), cesspools, and septic tanks.

INTRODUCTION

Groundwater resources have been under rapidly increasing stress in large parts of the world due to pollution by human activity. Pollution is primarily the result of irrigated agriculture, industrialization, and urbanization, which generates diverse wastes, with the attendant impact on the ecosystem and the growth of groundwater. With a rapid increase in population and growth of industrialization, groundwater quality and quantity are being increasingly threatened by the disposal of urban and industrial solid waste. Groundwater is a major source of water supply for domestic, recreational, and industrial purposes in Erbil City

[1] Department of Geology, College of Science, Salahaddin University, Erbil, Iraq,
e-mail: masoud.hamed@su.edu.krd
[2] Departments of Environmental Engineering, Faculty of engineering Van Yüzüncü Yıl University, Van, Turkey.
[3] Erbil Water Directorate, Ministry of Municipality.

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and around it. Consequently, the adequacy of groundwater resources, both in quality and quantity, is essential for socioeconomic sustainability in the area. Groundwater resources are very important for public water supply (Dişli, 2017) and (Dişli and Gülyüz, 2020). Many of the environmental problems are directly or indirectly related to the location of groundwater and its protection from contamination sources of various kinds (Toma, 2006). The environment in which waste is disposed of poses a major problem for groundwater. Solid wastes are produced every day in urban societies as a result of human activities and in an attempt to dispose of these materials; man has carelessly polluted the environment (Badmus *et al*., 2014). The study aims to determine the pollution of groundwater and the source of pollutants in Erbil city which is located in the central sub-basin, as well as to evaluate their suitability for drinking consumption according to Iraqi standards for drinking and the World Health Organization (WHO). The main sources of groundwater pollution in this sub-basin are:

1- Municipal (wastewater).
2- Domestic (Cesspools, Septic tank).
3- Agricultural activities
4- Industrial wastes
5- Natural pollution (Lithology).

The wastewater comes from, domestic (house wastewater), industrial wastewater, and street wastewater. But the cesspools and septic tank wastes are filtered into the groundwater directly.

The problem with the study is that there is an academic gap in the research of the Erbil central sub-basin, where there is no new research on water quality in the last few years. Erbil city is a highly populated governorate in the region, they are for water quality is important for the population more than quantity. Urbanization causes fluctuation in the quantity and quality of groundwater.

DESCRIPTION OF THE STUDY AREA

The study area is situated in Erbil governorate, in the northern part of Iraq and the total area of the region is about 1400 Km^2 (3.5% of Iraq). The study area lies between latitude 36º 08' 30'' – 36º 14' 15'' N on the east by longitude 43° 51' 20'' – 44° 12' 28'' E (Figure 1) and with an elevation range between 415 m to 600 m above sea level.

GENERAL GEOLOGY OF THE STUDY AREA

Erbil basin is mostly covered by the Quaternary sediments with relatively small areas of outcrops of Miocene – Pliocene formations in the east and northeast of Sharabot – Dedawan highlands, the Avanah Mountain in the west and southwest in narrow strips, and Damirdagh in the north. The lithology of the sediments varies from clay, silt, sand, and gravel (sandstone, claystone, conglomerate) (Dizayee, 2010). Recent sediments in the basin cover the rock units in the Shamamik basin, these sediments are non-effected by Alpine orogeny and consist of clay, loam silt, sand, and gravel. The stratigraphy of the Quaternary sediments is unconformable with the underlying unit (vertically and horizontally appeared gravel alternative (repeat) coarse, medium, and fine grain size) (Gardi and Jamal, 2019). The age of Quaternary sediments is Pleistocene to Holocene. These sediments were divided according to our field expert:

River terraces were produced by recent flood plain exposed along each side of the valley, produced by variation in the base level or by climate variation in the area along the valley. The age is Pleistocene; consists of rock fragment limestone, fragment, gravel (silica), and little amount of igneous and metamorphic rock fragments. Floodplain sediments originate as a result of river erosion during flood periods (Hameed, 2013). They consist of clay, silt, sand, and gravel with some fine pebbles and rock fragments. The age of this sediment is Holocene. Geomorphologically, the area is located in Erbil Plain, the highest point in the Sharabot area. It reaches about 600 m above sea level and the lowest point located in the west of the area reaches 415 m above sea level. The drainage type in the study area is dendritic.

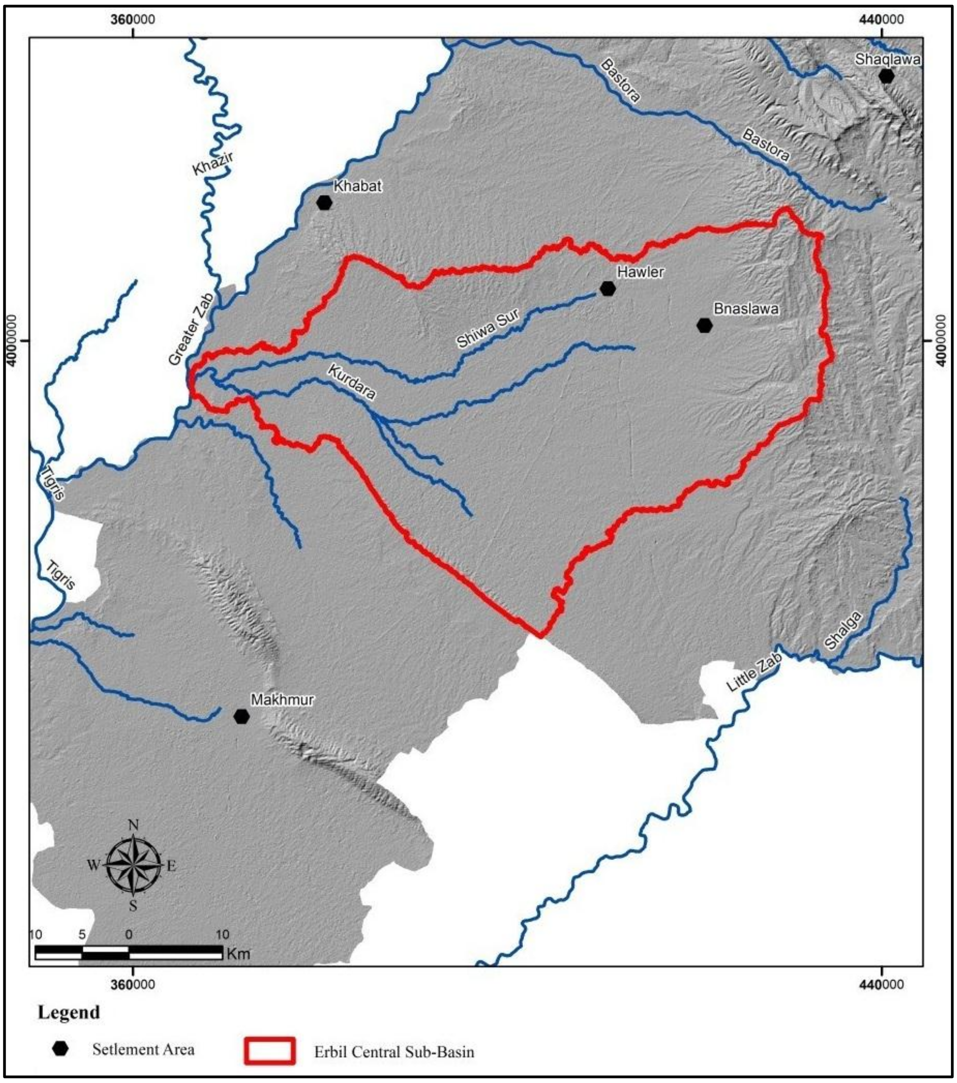

Figure 1: Erbil central sub-basin map.

HYDROGEOLOGY OF ERBIL BASIN AND CENTRAL SUB-BASIN

The Erbil Basin, also known as the Dashty Hawler Basin, is the largest groundwater reservoir in Erbil province, with a surface area of 3200 Km^2 and a depth of roughly 800 meters. The Erbil Basin, one of the most significant groundwater basins in the Middle East, is bounded on the north by the Greater Zab River and on the south by the Lesser Zab River. The Erbil Basin is a huge depression region that lies between the Pirmam anticline's southern limb and the Dibaga hill zone, giving it a semi-circular form (Hassan, 1998). The Bakhtiary Formation, in particular, is a prominent aquifer in the Erbil Basin, consisting mostly of soils, gravels, and conglomerates with occasional sands, clay, and silt (Quaternary sediments) and thickly-bedded conglomerates, sandstones, and shale (the Bakhtiary Formation) (Figure 2).

While Quaternary sediments (alluvium and terraces) are mainly unconfined aquifers across the study region, the Bakhtiary Formation is typically semi-confined to the confined aquifer (Figure 2). The water table in Erbil City and its environs, according to the Erbil water directorate (2020), is between 50 and 160 meters deep.

- **Erbil Wastewater Channels**

The Erbil sewer system is built for stormwater and in most cases, domestic sewers are illegally connected with storm sewer, both (combined rainwater and sanitary sewer) from the Erbil wastewater channel. The extension of this wastewater channel is from the southwest of Erbil city with an extension of about 50 Km that passes through vast farmlands, orchards, and several villages, wastewater effluent discharges into the Greater Zab after Gameshtape village. The Erbil Wastewater Channel consists of three different wastewater channels: the Bnaslawa Wastewater Channel, the Zhyan Wastewater Channel, and the Turaq Wastewater Channel (Figure 1). The Zhyan wastewater channel effected directly on the groundwater of the water well and caused pollution in the area (Figure 3).

MATERIALS AND METHODS

Surface water (Zhyan, Bnaslawa, and Turaq Wastewater Channels) and groundwater (well) samples in the vicinity of the study area were analyzed by the water quality control unit in Erbil Water Quality Control Department (EWCD) and Erbil Environment Directorate Water Quality Control Unit (Iraq) and Van Yüzüncü Yıl University-Science Application and Research Centre (Turkey). The hydrogeochemistry study was undertaken by randomly collecting from 30 samples in the vicinity of the study area between May 20, and September 2020 including 27 groundwater (deep wells) samples, and 3 surface water samples from channels. Locations of the samples (coordinates in UTM system) were recorded with a GARMIN GPS 78s using WGS84 reference and are shown in (Table 1). All water sample locations were shown in Figure 2. During the sampling, in-situ measurements of physicochemical parameters, such as temperature and DO were immediately measured in the field by multipara meters. Also, values of pH and EC were measured immediately in the field using calibrated EC-pH meter with standard solutions, while the levels of TDS were measured in the laboratory (Table 2). The major cat ions and anions of all water samples were chemically analyzed in EWCD and Erbil Environment Directorate Water Quality Control Unit (Erbil, Iraq). The trace elements were analyzed at Van Yüzüncü Yil University (Turkey). Before sampling, all sampling containers are thoroughly washed and rinsed with groundwater or surface water, depending on the sampling location. Then the water samples were collected from the wells and wastewater channels using polyethylene bottles with a volume of 1.5 litter for physicochemical parameter tests, trace elements tests, and glass bottles that had been cleaned with acid for the biological test, during the transportation of all samples were refrigerated (about at 4 °C).

In addition, statistical analyses were done using the SPSS statistical program (version 23.0 for Windows). The Pearson correlation matrix was used to analyze the similar/ different sources for physicochemical qualities in the sampled water well samples using the measure of the probable linear connection between two continuous variables (Ahmed *et al*., 2019). Principal component analysis (PCA) or factor analysis (FA) is a widely used statistical method for determining which factors, such as natural and anthropogenic processes affecting surface water and groundwater quality, are primarily involved/ impacted in the creation of chemical variation in groundwater (Wu *et al*., 2014). Cording to the basic geochemical parameters of the constituent ionic concentrations (Papatheodorou *et al*., 2007).

Table 1: Elevation and groundwater level data (in meters) of the study area.

Sampling Location	Well code	Surface elevation (m)	Total depth of the well (m)	Static groundwater level depth (SWL)		Groundwater level (water table)	
				May.20	Sept.2020	May.20	Sept.2020
Kasnazan, 15	Ka-15	612	250	165	180	447	432
Bnaslawa, 43, cemetery	Bn-43	537	320	115	123	422	414
Hawlery new, 7	Ha-7	485	300	110	120	375	365
Kwestan, 1	Kw-1	473	300	93	102	380	371
Bnaslawa, 19	Bn-19	466	320	105	125	361	341
Badawa, 37	Ba-37	464	350	104	118	360	346
Iskan, 1	Is-1	463	180	89	97	374	366
North Industry, 6	No-6	456	250	94	105	362	351
Gullan, 8, cemetery	Gu-8	446	300	86	98	360	348
Daratu, 4	Da-4	443	330	92	108	351	335
Sharawani, 4	Sh-4	434	250	75	80	359	354
Daratu, 23, cemetery	Da-23	433	300	95	108	338	325
Zhyan, 11	Zh-11	424	330	93	110	331	314
Roshanbeery, 12	Ro-12	415	300	96	115	319	300
Kurani Ainkawa, 2	Ku-2	415	250	90	95	325	320
Roshanbeery, 7	Ro-7	415	300	98	105	317	310
Erbil great cemetery	Er-Gr	411	300	87	105	324	306
Zhyan, 13	Zh-13	406	330	95	108	311	298
Ashty, 2	As-2	403	200	60	68	343	335
Gilkand, 3	Gl-3	401	200	48	57	353	344
Nawroz, 16	Na-16	395	200	55	62	340	333
South Industry (Shadi, 13)	So-13	393	250	91	103	302	290
Sarbasty, 10	Sa-10	391	250	56	68	335	323
Kurdistan, 11	Ku-11	390	160	73	79	317	311
Mardeen, 3	Ma-3	389	250	80	88	309	301
Gerd Muhamad, 2	Gr-2	385	240	73	82	312	303
Turaq, 4	Tu-4	380	200	50	55	330	325

Table 2: Analytical techniques used in measuring the various parameters.

Parameter	Analytical method
Temperature c°	Field thermometer
pH- value	Field pH- meter
Total hardness (T.H)	Titration with EDTA (0.01N)
Calcium & magnesium	Titration with EDTA (0.01N)
Sodium& Potassium (Na and K)	Flame photometer
Nitrate, Nitrite, and phosphor	spectrophotometer
Sulphate (SO_4)	Titration with EDTA (0.02N)
Hydrogen-sulphide (H_2S)	Titration with sodium thiosulfate
Chloride (Cl)	Titration with $AgNO_3$ (0.01N)
Bicarbonate (HCO_3)	Titration with HCl (0.01N)
Turbidity	Turbidity meter
Trace element	Atomic absorption spectrophotometer
Chemical oxygen demand (COD)	Titration with sodium thiosulfate
Dissolved oxygen and biological oxygen demand (Do and BOD_5)	Titration with sodium thiosulfate
Total dissolved solids (TDS)	TDS meter portable
Acidity	Titration with (0.01 NaOH)

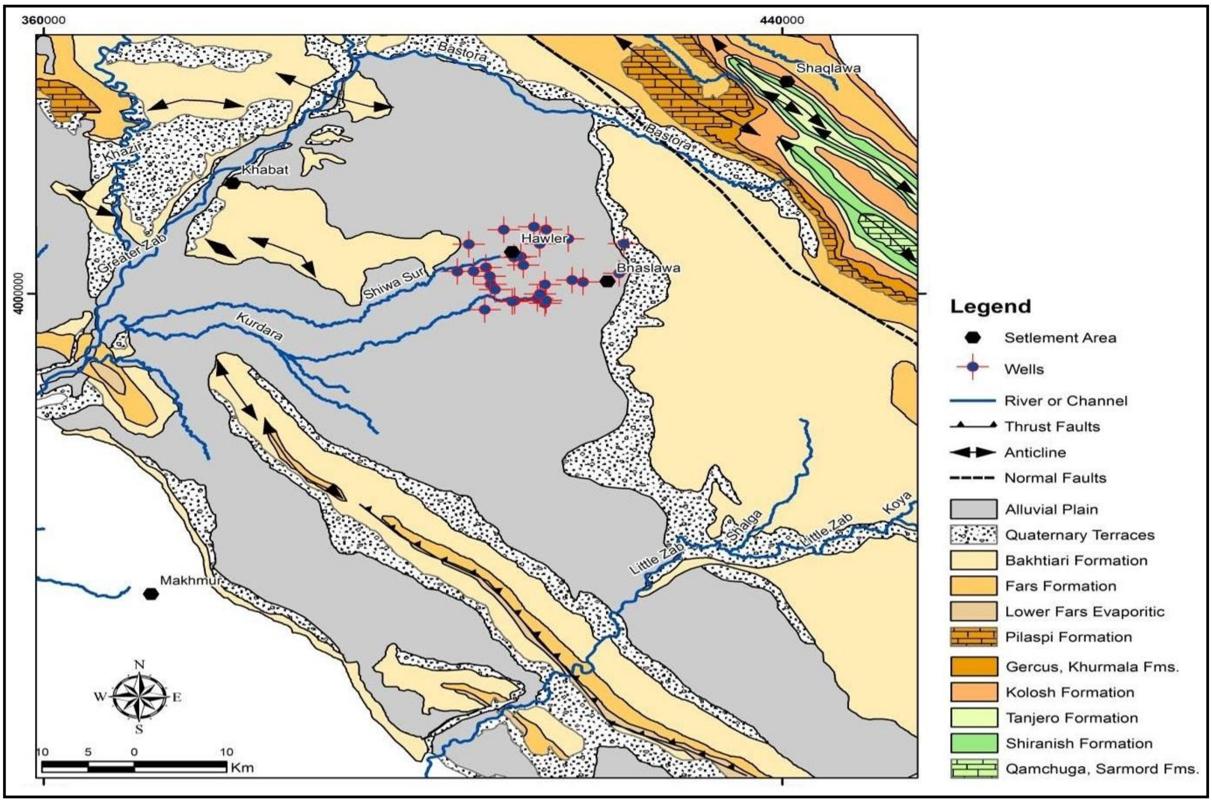

Figure 2: Geological map of the study area.

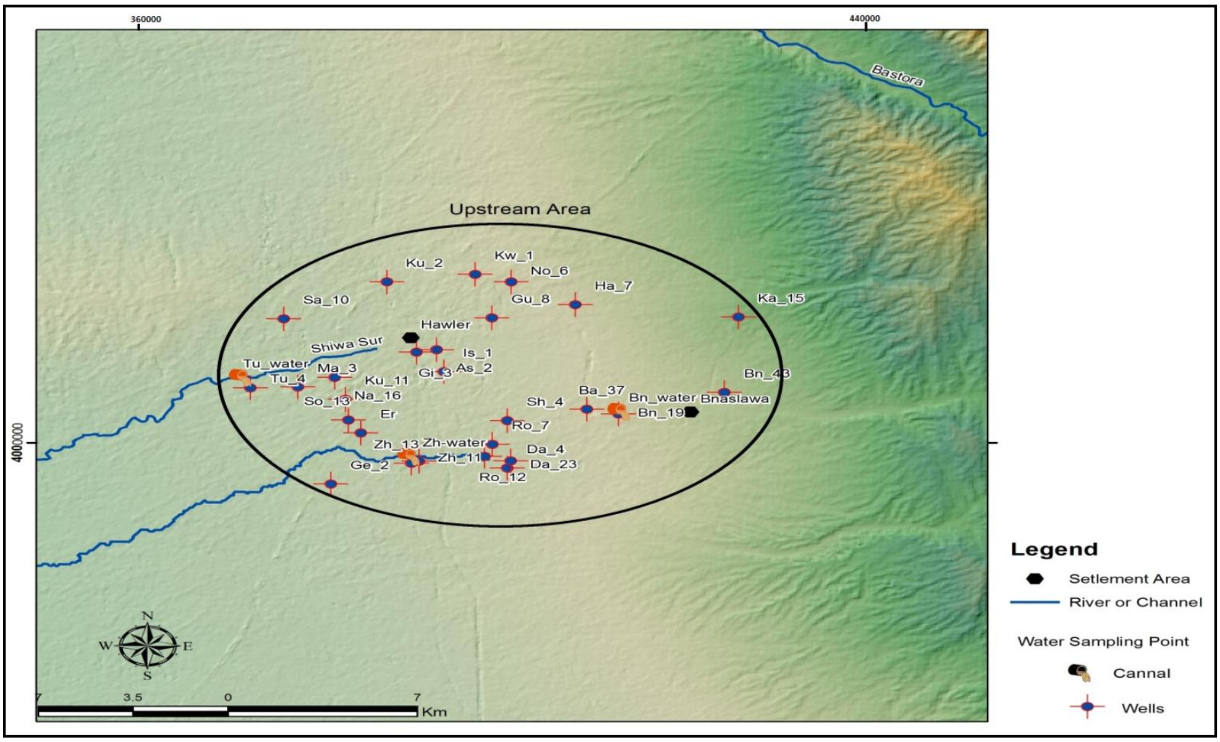

Figure 3: Sampling location map of the study area.

RESULT AND DISCUSSION

- **Physical Parameters**

Groundwater well and surface water geochemistry are largely controlled by aquifer lithology, the dissolution of the minerals forming the bedrock, oxidation/ reduction, residing time within the porous media, ion exchange, the leaching and transport of natural, sewage from both cesspool and the wastewater channels, and through many other activities (ATSDR., 2000). The results of the major cations and anions concentrations of the groundwater and wastewater channels samples, which were collected from the study and field measurements, such as temperature, pH, EC, TDS, and DO are presented in Tables 3, 4, 5, and 6. The physicochemical parameters of the groundwater and wastewater channel samples were compared to the standards for drinking water limits indicated by the guideline values of the World Health Organization (WHO) and IQWS (Table 7).

Water temperature was lower during the wet season (May 2020) with an average value of 21.73 °C (ranging between 21.10 to 22.00 °C) and higher during the dry season (September 2020) with an average value of 21.90 °C (ranging from 21.00 to 23.00 °C) in the water well samples (see Tables 3 and 4, Figures 4a, and 4b). However, it was higher during the dry season with an average value of 35.00 °C (ranging between 34.00 to 36.00 °C) and lower during the wet season with an average value of 28.66 °C (ranging between 28.00 to 29.00 °C) in the wastewater channel samples, respectively (see Tables 3 and 4). Since pH is an important water quality parameter, pH measurement is an indispensable parameter in the evaluation of water quality since it indicates the acidity or alkalinity degree of the water system. The pH values in the water well samples were higher, ranging from 7.10 to 8.00 with an average of 7.53 in the wet season, and from 7.10 to 7.90 with an average of 7.38 in the dry season (see Tables 3 and 4, Figures 4a and 4b). Besides, in the wastewater channel samples, the pH values ranged between 7.02 and 8.00 with an average value of 7.67 during the wet season, whereas during the dry season, the range was between 6.90 and 7.02 with an average value of 7.10, respectively (see Tables 3 and 4). The maximum value of pH i.e., 8.00 was recorded at Erbil great cemetery well (Er-Gr) during the wet season and 7.90 during the dry season at South Industry Well (So-13), situated between the wastewater channels. The level of pH in water sources especially waters well samples are controlled by nature such as water mineralization probably coming from dissolved sedimentary minerals, domestic waste from humans or household activity, and waste generated by industrial and agricultural area. The average pH of the water samples indicates neutral to slightly alkaline water. While the pH value throughout the study area takes a minimum value at the Erbil-Central in both sampling periods, it increases slightly depending on the rock-water interaction, short groundwater residence times, and groundwater level changes in the Quaternary sediments. From the above results, all of the water samples are within the permissible limits compared to the specifications of WHO and IQWS (Table 7). The EC values of water well samples varied from 366.00 to 917.00 µS/cm during the wet season, and from 346.00 to 882.00 µS/cm during the dry seasons, respectively (see Tables 3 and 3 and Figure 3). In addition, in the studied wastewater channel waters, the EC values were in the range of 389.00 – 785.00 µS/cm in the wet season while it was in the range of 864.00 – 1231.00 µS/cm in the dry season, respectively (see Tables 3 and 4, Figures 4a and 4b). The average EC values were 533.815 µS/cm and 524.963 µS/cm for the water well in the wet and dry seasons, respectively, indicating that the EC values of the water well in the wet season were higher than the dry season. On the other hand, wastewater channel waters collected in the dry season have higher EC values (average value, 1021.6 µS/cm), as compared to those collected in the wet season (average value, 549.4 µS/cm). As seen in the spatial distributions of the EC values of the water well samples in Erbil Central Sub-Basin during both wet and dry seasons, it is seen that in general, anthropogenic activities are more dominant than the geochemical processes prevailing in the region. As seen in the spatial distributions of EC concentrations in Figures (4a and b), the EC concentrations were increasing from the northeast to the southwest direction for both wet and dry seasons, and the EC concentration value in all wells was generally below 1000 µS/cm. The EC values in the water samples were below the value of 2000 µS/cm specified by IQWS (2010) and the value of 1500 µS/cm specified by WHO (2011) (Table 7). The average value of DO (mg/L) in wells was 12.65 mg/L in the wet season (high infiltration of rainwater), but in the dry season 11.76 mg/L, because of the high temperature in the dry season, and in the wastewater 4.95 mg/L and 4.18 mg/L in the wet and dry season, respectively. The spatial distribution of DO concentrations in Figures 4a and b indicated that they were high DO concentrations in the south (Ro-7) and low concentrations in the west (Tu-4) of the study area for both wet and dry seasons.

TSS concentration ranged from 2.00 to 5.30 and 2.30 to 6.80 mg/L in the dry and wet seasons for water well samples, respectively, while in the wastewater channels samples, it ranged from 35.00 to 69.16 and 39.00 to 68.20 mg/L in the wet season and dry season, respectively (Table 3 and 4).

- **Chemical Parameters (Cation And Anion)**

The concentrations of dissolved ions, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), and anions (Cl^{-}, SO_4^{2-}, HCO_3^{-}) in water samples taken from wells and wastewater channels throughout the study area are shown in Tables 5 and 6, Figures 5a and b. All dissolved ions analyzed in the well and wastewater channel samples have low concentrations during both seasons. From Tables 5 and 6, it can be observed that mean cation concentrations (in mg/L) occur in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ - $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and anions in the order $HCO_3^{-} > NO_3^{-} > SO_4^{2-} > Cl^{-}$ - $HCO_3^{-} > SO_4^{2-} > NO_3^{-} > Cl^{-}$ during the wet and dry seasons for water well samples respectively. The relative concentrations of the cations and anions of the wastewater channel ranked in the order of $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$ in the wet season, and $Na^{+} > Ca^{2+} > Mg^{2+} > K$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$ in the dry season, respectively.

The values of Cl- and SO_4^{2-} parameters were within the 250 – 250 mg/L and 250 – 400 mg/L limits, which had been specified by the WHO and IQWS (2010) for all seasons (Tables 5 and 6, Figures 6a and b). However, all of the well water and wastewater channels samples taken from the study area in the wet season were within the permissible limit of 500 mg/L for HCO_{3-} (WHO 2011), whereas all of the samples were above the permissible limit (200 mg/L) of IQWS (2010) (Table 7). In addition, in the dry season, only 59.26 and 100% of the well and wastewater channel samples were within the permissible limit of 200 mg/L for HCO_{3-} (IQWS, 2010) (Table 7). As can be seen in the anion and cation concentration maps (Figures 6a and b), the concentration values of these parameters vary depending on the anthropogenic sources, and the contact time between the rock-water and groundwater flow direction (Adimalla and Qian, 2019) and (Appelo, 1999). Chloride is extremely stable in water resources and is also the most dominant natural form of chlorine. The high concentration of Cl- in the both well and wastewater channels derives mainly from rainwater, natural weathering of bedrock, surface materials or soils and sedimentary deposits, and other anthropogenic sources such as domestic effluents (cesspool). Concentrations of SO_4^{2-} ions in both the well water and wastewater channels samples are caused by the weathering of sedimentary rocks containing sulfate and gypsum, and it is the anthropologic source as a secondary source.

Table 3: Physicochemical parameters in the water samples from the 30 sites during the wet season.

Sampling location	Sampling code	Type location	Sampling date	Coordinate		Temperature (0C)	pH	TDS (mg/L)	EC (µS/cm)	DO (mg/L)	Hardness	BOD5 mg/L	COD mg/L	TSS mg/L
				X	Y									
Sharawani, 4	Sh-4	Water well	May.20	414292	4001174	22	7.5	188	375	-	300.65	-	-	-
Daratu, 4	Da-4		May.20	414291	3998675	21.9	7.6	208	415	-	318.85	-	-	-
Zhyan, 11	Zh-11		May.20	411022	3999028	22	7.6	216	432	-	263.36	-	-	-
Zhyan, 13	Zh-13		May.20	410750	3998917	21.1	7.4	272	543	16.1	295.66	8.1	15.9	3.6
Roshanbeery,12	Ro-12		May.20	413457	3999287	21.6	7.5	216	431	-	277.46	-	-	-
North Industry, 6	No-6		May.20	414428	4008489	22	7.7	201	401	-	265.86	-	-	-
Gerd Muhamad,2	Gr-2		May.20	407770	3997833	21.5	7.8	251	501	-	290.67	-	-	-
South Industry (Shadi,13)	So-13		May.20	408420	4001198	21.8	7.9	206	411	-	295.66	-	-	-
Bnaslawa,19	Bn-19		May.20	418408	4001520	21.8	7.7	200	399	13	330.45	5.4	12.5	2
Kasnazan,15	Ka-15		May.20	422840	4006626	21.9	7.8	247	494	12	337.06	5.6	11.1	2.5
Kwestan, 1	Kw-1		May.20	413106	4008873	22	7.6	265	529	-	274.96	-	-	-
Turaq,4	Tu-4		May.20	404799	4002898	22	7.6	305	610	9.7	404.15	8.2	14.8	4.9
Sarbasty,10	Sa-10		May.20	406028	4006533	21.9	7.2	395	789	-	882.87	-	-	-
Nawroz,16	Na-16		May.20	407908	4003445	22	7.5	368	736	12.3	374.76	5.2	11.8	5.3
Kurdistan, 11	Ku-11		May.20	408306	4002294	22	7.4	377	754	-	497.66	-	-	-
Kirkland,3	Gl-3		May.20	410937	4004782	21.5	7.1	459	917	9.1	547.43	8.3	12.5	4.8
Ashty,2	As-2		May.20	411679	4004901	21.3	7.2	389	778	13.6	570.62	7.9	11.3	4
Kurani Ainkawa,2	Ku-2		May.20	409835	4008483	21.7	7.5	258	515	-	383.45	-	-	-
Hawlery new,7	Ha-7		May.20	416807	4007275	21.6	7.5	246	492	-	260.87	-	-	-
Iskan,1	Is-1		May.20	411941	4003747	21.3	7.1	275	549	-	455.11	-	-	-
Mardin, 3	Ma-3		May.20	406556	4002936	21.9	7.5	293	586	-	327.96	-	-	-
Daratu, 23, cemetery	Da-23		May.20	414413	3999056	22	7.7	229	458	-	258.37	-	-	-
Gullan,8, cemetery	Gu-8		May.20	413722	4006588	21.4	7.5	336	672	-	313.86	-	-	-
Erbil great cemetery	Er-Gr		May.20	408881	4000513	22	8	206	412	-	313.86	-	-	-
Bnaslawa,43, cemetery	Bn-43		May.20	422321	4002665	21.7	7.4	192	383	-	240.17	-	-	-
Badawa,37	Ba-37		May.20	417234	4001777	21.2	7.6	183	366	-	281.57	-	-	-
Roshanbeery,7	Ro-7		May.20	413737	3999916	21.6	7.5	233	465	15.5	337.52	7.6	15.8	3.9
Zhyan wastewater	Zh-W W	Waste Water Channel	May.20	410631	3999252	28	8	200	399	-	339.55	-	-	-
Bnaslawa Wastewater	Bn-W W		May.20	418403	4001635	29	7.2	393	785	5.6	406.36	60	95	35
Turaq wastewater	Tu-W W		May.20	404408	4003425	29	7.8	195	389	4.3	339.55	65.3	126.8	69.2

Table 4. Physicochemical parameters in the water samples from the 30 sites during the dry season.

Sampling location	Sampling code	Type location	Sampling date	Coordinate		Temperature (^0C)	pH	TDS (mg/L)	EC (µS/cm)	DO (mg/L)	Hardness (FS^0)	BOD5 mg/L	COD mg/L	TSS mg/L
				X	Y									
Sharawani - 4	Sh-4	Water well	Sep-20	414292	4001174	22.9	7.2	189	377	-	407.94	-	-	-
Daratu - 4	Da-4		Sep-20	414291	3998675	23	7.4	214	428	-	267.48	-	-	-
Zhyan-11	Zh-11		Sep-20	411022	3999028	21	7.5	212	424	-	255.88	-	-	-
Zhyan -13	Zh-13		Sep-20	410750	3998917	21.3	7.5	253	505	12.1	255.88	9	20.7	4
Roshanbeery-12	Ro-12		Sep-20	413457	3999287	22.1	7.6	202	403	-	269.97	-	-	-
North Industry - 6	No-6		Sep-20	414428	4008489	21.4	7.3	201	402	-	443.60	-	-	-
Grd Muhamad -2	Gr-2		Sep-20	407770	3997833	21.4	7.4	234	467	-	211.71	-	-	-
South Industry (Shadi -13)	So-13		Sep-20	408420	4001198	21.4	7.9	173	346	-	213.88	-	-	-
Bnaslawa -19	Bn-19		Sep-20	418408	4001520	21.6	7.4	207	414	11.8	361.55	6.9	15.87	2.3
Kasnazan -15	Ka-15		Sep-20	422840	4006626	21.3	7.5	253	505	11.3	316.22	6.1	13.5	3.1
Kwestan -1	Kw-1		Sep-20	413106	4008873	21.7	7.6	260	520	-	276.19	-	-	-
Turaq -4	Tu-4		Sep-20	404799	4002898	22	7.2	399	797	8.3	435.57	9.1	20.13	6
Sarbasty -10	Sa-10		Sep-20	406028	4006533	21.9	7.5	319	638	-	303.88	-	-	-
Nawroz -16	Na-16		Sep-20	407908	4003445	21.5	7.3	373	746	10.5	438.06	6	13.8	6.8
Kurdistan - 11	Ku-11		Sep-20	408306	4002294	23	7.1	362	723	-	448.04	-	-	-
Glkand -3	Gl-3		Sep-20	410937	4004782	21	7.3	441	882	11.3	246.78	9.1	14.49	6
Ashty -2	As-2		Sep-20	411679	4004901	21.8	7.1	380	761	13.4	349.92	8.1	12.3	5
Kurani Ainkawa-2	Ku-2		Sep-20	409835	4008483	21.9	7.4	252	503	-	315.48	-	-	-
Hawlery new-7	Ha-7		Sep-20	416807	4007275	22	7.4	254	507	-	422.03	-	-	-
Iskan-1	Is-1		Sep-20	411941	4003747	22.8	7.4	250	500	-	325.46	-	-	-
Mardin-3	Ma-3		Sep-20	406556	4002936	21.5	7.5	294	588	-	306.38	-	-	-
Daratu -23-cemetery	Da-23		Sep-20	414413	3999056	21.6	7.5	231	461	-	276.58	-	-	-
Gullan-8-cemetery	Gu-8		Sep-20	413722	4006588	22	7.3	287	573	-	497.48	-	-	-
Erbil great cemetery	Er-Gr		Sep-20	408881	4000513	22.6	7.2	202	404	-	346.58	-	-	-
Bnaslawa -43-cemetery	Bn-43		Sep-20	422321	4002665	21.9	7.4	195	390	-	250.89	-	-	-
Badawa-37	Ba-37		Sep-20	417234	4001777	21.8	7.1	184	368	-	174.28	-	-	-
Roshanbeery-7	Ro-7		Sep-20	413737	3999916	23	7.2	271	542	15.3	223.58	8.1	18.6	4.1
Zhyan wastewater	Zh-W	Waste Water Channel	Sep-20	410631	3999252	35	7.2	432	864	4.5	359.65	-	-	-
Bnaslawa Wastewater	Bn-W		Sep-20	418403	4001635	36	6.9	615	1231	4.6	449.51	34.3	78.89	39
Turaq wastewater	Tu-W		Sep-20	404408	4003425	34	7.2	459	918	3.6	403.60	79.6	134.3	68.2

Table 5: Chemical parameters in the water samples from the 30 sites during the dry season.

Sampling location	Sampling location	Type location	Sampling date	Cations (ppm)				Anions (ppm)					Water Type	Saturation Indices			
				Na^+	K^+	Ca^{++}	Mg^{++}	$CO_3^=$	HCO_3^-	Cl^-	$SO4^=$	NO_3		Aragonite	Calcite	Dolomite	Gypsum
Sharawani-4	Sh-4	Water well	May-20	14.00	0.80	76.00	27.00	-	211.00	23.00	15.00	35.00	Ca-Mg-HCO3	0.074	0.219	-0.326	-2.400
Daratu-4	Da-4		May-20	28.00	1.10	80.00	29.00	-	220.0	18.00	38.00	34.00	Ca-Mg-HCO3	0.182	0.327	0.539	-1.1995
Zhyan -11	Zh-11		May-20	32.00	1.00	66.00	24.00	-	218.00	18.00	46.00	37.00	Ca-Mg-Na-HCO3	0.116	0.261	-0.419	-1.973
Zhyan -13	Zh-13		May-20	46.00	1.20	74.00	27.00	-	278.00	40.00	13.00	25.00	Ca-Mg-Na-HCO3	0.039	0.185	0.245	-2.488
Roshanbeery-12	Ro-12		May-20	20.00	0.70	70.00	25.00	-	236.00	24.00	15.00	12.00	Ca-Mg-HCO3	0.087	0.232	0.355	-2.428
North Industry-6	No-6		May-20	16.00	0.60	67.00	24.00	-	224.00	18.00	13.00	46.00	Ca-Mg-HCO3	0.277	0.470	0.758	-2.502
Grd Muhamad-2	Gr-2		May-20	52.00	1.60	72.00	27.00	-	219.00	18.00	70.00	40.00	Ca-Na-Mg-HCO3-SO4	0.360	0.503	0.941	-1.788
South Industry (Shadi-13)	So-13		May-20	45.00	1.40	74.00	27.00	-	222.00	12.00	36.00	30.00	Ca-Mg-Na-HCO3	0.489	0.632	1.189	-2.052
Bnaslawa -19	Bn-19		May-20	21.00	0.70	83.00	30.00	-	202.00	15.00	23.00	28.00	Ca-Mg-HCO3	0.281	0.425	0.747	-2.195
Kasnazan -15	Ka-15		May-20	11.00	0.30	84.00	31.00	-	141.00	29.00	5.00	61.00	Ca-Mg-HCO3	0.198	0.345	0.557	-2.834
Kwestan -1	Kw-1		May-20	55.00	1.90	69.00	25.00	-	236.00	42.00	29.00	25.00	Ca-Na-Mg-HCO3	0.193	0.336	0.593	-2.171
Turaq -4	Tu-4		May-20	68.00	1.80	101.00	37.00	-	243.00	40.00	68.00	19.00	Ca-Mg-Na-HCO3	0.051	0.447	0.795	-1.710
Sarbasty -10	Sa-10		May-20	54.00	1.30	222.00	80.00	-	350.00	46.00	40.00	54.00	Ca-Mg-HCO3	0.370	0.513	0.947	-1.768
Nawroz -16	Na-16		May-20	36.00	1.10	20.00	79.00	-	323.00	50.00	26.00	56.00	Mg-HCO3	-0.374	-0.229	0.465	-2.812
Kurdistan - 11	Ku-11		May-20	27.00	0.90	122.00	47.00	-	299.00	55.00	13.00	61.00	Ca-Mg-HCO3	0.250	0.396	0.692	-2.363
Glkand -3	Gl-3		May-20	23.00	1.10	137.00	50.00	-	317.00	48.00	75.00	61.00	Ca-Mg-HCO3	0.016	0.161	0.210	-1.590
Ashty -2	As-2		May-20	20.00	0.80	143.00	52.00	-	361.00	56.00	28.00	60.00	Ca-Mg-HCO3	0.225	0.369	0.651	-2.004
Kurani Ainkawa-2	Ku-2		May-20	19.00	0.70	96.00	35.00	-	251.00	19.00	17.00	29.00	Ca-Mg-HCO3	0.277	0.372	0.644	-2.294
Hawlery new-7	Ha-7		May-20	40.00	1.40	65.00	24.00	-	240.00	65.00	57.00	14.00	Ca-Mg-Na-HCO3-Cl	0.052	0.196	0.308	-1.905
Iskan-1	Is-1		May-20	18.00	0.70	11.00	104.00	-	250.00	36.00	11.00	54.00	Mg-HCO3	-1.138	-0.993	-0.683	-3.464
Mardin-3	Ma-3		May-20	68.00	1.8	82.00	30.00	-	223.00	22.00	91.00	22.00	Ca-Na-Mg-HCO3-SO4	0.113	0.256	-0.434	-1.647
Daratu -23-cemetery	Da-23		May-20	38.00	1.00	64.00	24.00	-	171.00	19.00	50.00	14.00	Ca-Mg-Na-HCO3	0.114	0.258	0.438	-1.946
Gullan-8-cemetery	Gu-8		May-20	9.00	0.70	78.00	29.00	-	190.00	34.00	52.00	40.00	Ca-Mg-HCO3	0.061	0.204	0.340	-2.074
Erbil great cemetery	Er-Gr		May-20	12.00	0.90	78.00	29.00	-	150.00	14.00	34.00	15.00	Ca-Mg-HCO3	0.424	0.568	1.045	-2.038
Bnaslawa-43-cemetery	Bn-43		May-20	26.00	1.70	60.00	22.00	-	134.00	10.00	5.00	30.00	Ca-Mg-Na-HCO3	-0.295	-0.151	-0.399	-2.928
Badawa-37	Ba-37		May-20	20.00	0.80	70.00	26.00	-	200.00	17.00	9.00	31.00	Ca-Mg-HCO3	0.225	0.369	0.651	-2.004
Roshanbeery-7	Ro-7		May-20	47.00	1.40	71.00	39.00	-	244.00	19.00	23.00	22.00	Ca-Mg-Na-HCO3	0.115	0.258	0.618	-2.286
Zhyan wastewater	Zh-W		May-20	53.00	5.10	85.00	31.00	-	321.00	45.00	53.00	24.00	Ca-Mg-Na-HCO3	0.863	1.001	1.998	-1.886
Bnaslawa wastewater	Bn-W	Wastewater channel	May-20	63.00	3.50	92.00	43.00	-	370.00	45.00	36.00	11.00	Ca-Mg-Na-HCO3	0.172	0.310	0.722	-2.049
Turaq wastewater	Tu-W		May-20	53.00	0.90	85.00	31.00	-	389.00	50.00	42.00	13.00	Ca-Mg-Na-HCO3	0.739	0.877	0.743	-1.989

Table 6: Chemical parameters in the water samples from the 30 sites during the dry season.

Sampling location	Sampling location	Type location	Sampling date	Cations (ppm)				Anions (ppm)					Water Type	Saturation Indices			
				Na^+	K^+	Ca^{++}	Mg^{++}	$CO_3^=$	HCO_3^-	Cl^-	$SO4^=$	NO_3		Aragonite	Calcite	Dolomite	Gypsum
Sharawani-4	Sh-4	Water well	Sep-20	13.00	0.90	119.0	27.00	-	199.0	20.00	8.00	18.00	Ca-Mg-HCO3	-0.043	0.100	-0.081	-2.531
Daratu-4	Da-4		Sep-20	60.00	2.40	66.00	25.00	-	224.0	18.00	23.00	18.00	Ca-Na-Mg-HCO3	-0.067	0.077	0.071	-2.276
Zhyan -11	Zh-11		Sep-20	27.00	1.20	63.00	24.00	-	95.00	18.00	43.00	31.00	Ca-Mg-Na-HCO3	-0.328	-0.184	-0.439	-1.997
Zhyan -13	Zh-13		Sep-20	44.00	1.20	63.00	24.00	-	217.0	24.00	35.00	15.00	Ca-Mg-Na-HCO3	0.027	0.170	0.282	-2.111
Roshanbeery-12	Ro-12		Sep-20	23.00	1.10	67.00	25.00	-	215.0	22.00	132.0	12.00	Ca-Mg-HCO3-SO4	0.110	0.253	0.433	-1.548
North Industry-6	No-6		Sep-20	12.00	0.60	130.0	29.0	-	238.0	18.00	6.00	21.00	Ca-Mg-HCO3	0.176	0.318	0.360	-2.640
Grd Muhamad-2	Gr-2		Sep-20	34.00	1.00	42.00	26.00	-	229.0	16.00	42.00	16.00	Mg-Ca-Na-HCO3	-0.216	-0.073	0.006	2.183
South Industry (Shadi-13)	So-13		Sep-20	36.00	1.10	61.00	15.00	-	160.0	12.00	45.00	18.00	Ca-Na-Mg-HCO3	0.302	0.444	0.651	-1.983
Bnaslawa -19	Bn-19		Sep-20	25.00	0.70	107.0	23.00	-	204.0	19.00	30.00	16.00	Ca-Mg-HCO3	-0.478	-0.335	-0.752	-2.360
Kasnazan -15	Ka-15		Sep-20	38.00	1.30	47.00	32.00	-	202.0	33.00	19.00	57.00	Ca-Mg-Na-HCO3	0.004	0.150	0.250	-2.323
Kwestan -1	Kw-1		Sep-20	54.00	2.20	69.00	25.00	-	206.0	33.00	26.00	25.00	Ca-Na-Mg-HCO3	0.140	0.283	0.493	-2.212
Turaq -4	Tu-4		Sep-20	45.00	1.10	107.0	41.00	-	250.0	51.00	45.00	52.00	Ca-Mg-Na-HCO3	-0.051	0.094	0.109	-1.867
Sarbasty -10	Sa-10		Sep-20	40.00	2.00	47.00	29.00	-	106.0	40.00	65.00	17.00	Ca-Mg-Na-HCO3-SO4	-0.223	-0.080	-0.208	-1.796
Nawroz -16	Na-16		Sep-20	37.00	1.10	108.0	41.00	-	290.0	47.00	45.00	54.00	Ca-Mg-HCO3	0.100	0.245	0.395	-1.863
Kurdistan - 11	Ku-11		Sep-20	25.00	0.80	112.0	41.00	-	273.0	58.00	10.00	58.00	Ca-Mg-HCO3	-0.097	0.048	-0.013	-2.491
Glkand -3	Gl-3		Sep-20	34.00	0.90	61.00	23.00	-	328.0	48.00	70.00	57.00	Ca-Mg-HCO3	-0.106	0.041	-0.043	-1.841
Ashty -2	As-2		Sep-20	17.00	0.70	88.00	31.00	-	120.0	54.00	15.00	60.00	Ca-Mg-HCO3-Cl	-0.478	-0.335	0.752	-2.360
Kurani Ainkawa-2	Ku-2		Sep-20	19.00	0.70	77.00	30.00	-	114.0	18.00	16.00	26.00	Ca-Mg-HCO3	-0.277	-0.133	-0.338	-2.361
Hawlery new-7	Ha-7		Sep-20	43.00	1.50	123.0	28.00	-	239.0	20.00	44.00	12.00	Ca-Mg-Na-HCO3	0.166	0.312	0.295	-1.798
Iskan-1	Is-1		Sep-20	43.00	3.60	81.00	30.00	-	144.0	36.00	6.00	55.00	Ca-Mg-Na-HCO3	-0.164	-0.020	-0.132	-2.783
Mardin-3	Ma-3		Sep-20	29.00	0.9	75.00	29.00	-	106.0	36.00	10.00	16.00	Ca-Mg-Na-HCO3	-0.192	-0.049	-0.148	-2.579
Daratu -23-cemetery	Da-23		Sep-20	16.00	0.30	68.00	26.00	-	198.0	19.00	99.00	14.00	Ca-Mg-HCO3-SO4	-0.002	0.141	0.222	-1.651
Gullan-8-cemetery	Gu-8		Sep-20	42.00	2.00	145.0	33.00	-	248.0	31.00	40.00	34.00	Ca-Mg-Na-HCO3	0.213	0.356	0.442	-1.811
Erbil great cemetery	Er-Gr		Sep-20	34.00	1.10	101.0	23.00	-	208.0	16.00	33.00	14.00	Ca-Mg-Na-HCO3	-0.125	0.019	-0.266	-1.967
Bnaslawa-43-cemetery	Bn-43		Sep-20	47.00	1.60	61.00	24.00	-	208.0	16.00	17.00	27.00	Ca-Na-Mg-HCO3	-0.478	-0.335	-0.752	-2.360
Badawa-37	Ba-37		Sep-20	25.00	0.90	27.00	26.00	-	159.0	16.00	10.00	20.00	Mg-Ca-Na-HCO3	-0.478	-0.335	-0.752	-2.360
Roshanbeery-7	Ro-7		Sep-20	40.00	1.40	55.00	21.00	-	165.0	20.00	12.00	20.00	Ca-Na-Mg-HCO3	-0.421	-0.278	-0.612	-2.594
Zhyan wastewater	Zh-W		Sep-20	97.90	13.2	80.00	38.92	-	210.0	103.20	53.30	41.30	Na-Ca-Mg-HCO3-Cl	-0.060	0.074	0.302	-1.928
Bnaslawa wastewater	Bn-W	Wastewater channel	Sep-20	209.7	16.6	108.8	43.30	-	296.0	119.7	88.80	48.20	Na-Ca-Mg-HCO3-Cl	-0.112	0.022	0.114	-1.653
Turaq wastewater	Tu-W		Sep-20	68.00	14.1	96.00	39.90	-	240.0	186.0	92.30	43.20	Ca-Mg-Na-Cl-HCO3	0.064	0.198	0.483	-1.646

Table 7: Drinking water quality standards of WHO (2011) and IQWS (2010) guidelines.

Water quality parameters	Unit	WHO (2011)	IQWS (2010)	Wet season	Dry season
pH	-	6.5 – 8.5	6.5 – 8.5	7.1 – 8	6.9 – 7.9
EC	µs/cm	1500	2000	366 – 917	346 – 1231
TDS	mg/L	1000	500 – 1500	183 – 459	173 – 615
TH	mg/L	500	100 – 500	240 – 882	174 – 497
BOD5	mg/L	5	<5	5.2 – 65	6 – 79
COD	mg/L	20	-	11.1 – 126	12.3 – 68
Ca^{2+}	mg/L	75 – 200	75 – 200	11 – 222	27 – 145
Mg^{2+}	mg/L	30 – 150	50 – 150	22 – 104	15 – 43
Na^{+}	mg/L	200	200	9 – 68	12 – 209
K^{+}	mg/L	12-20	250	0.3 – 5.1	0.3 – 16
HCO_3^{2-}	mg/L	500	125 – 200	134 – 389	95 – 328
$SO4^{2}$-	mg/L	250	200 – 400	5 – 91	6 – 132
Cl^{-}	mg/L	250	200 – 250	10 – 65	12 – 186
$NO3^{-}$	mg/L	50	50	11 – 61	12 – 60
Al	mg/L	0.1 – 0.2	0.2	ND	0.029 – 0.0040
Zn	mg/L	3 – 5	3	0.0019 – 0.088	0.0073 – 0.0093
Mn	mg/L	0.1 – 0.4	0.1	0.0034 – 0.072	0.012 – 0.041
Cu	mg/L	0.05 – 2	1	0.0003 – 0.020	0.00015 – 0.021
Fe	mg/L	0.1 – 0.3	0.3	0.038 – 0.22	0.050 – 0.90
B	mg/L	0.1 – 0.5	0.5	ND	ND
Pb	mg/L	0.1	0.01	ND	0.00015 – 0.0024
Ni	mg/L	0.02	0.02	ND	ND
Cr	mg/L	0.05	0.05	0.00034 – 0.0077	0.00017 – 0.081
As	mg/L	0.01 – 0.01	0.01	ND	ND

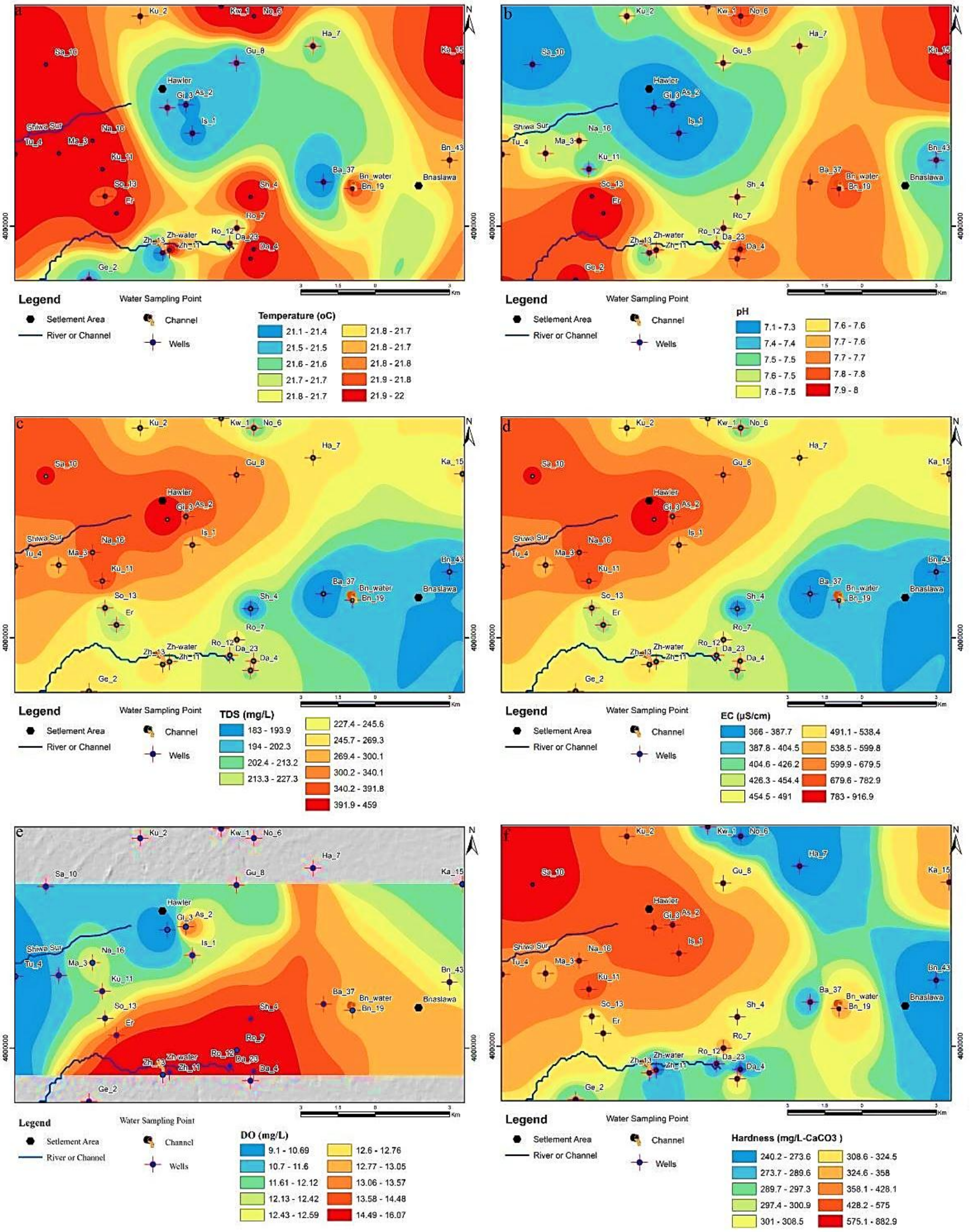

Figure 4a: Spatial distribution maps of the physicochemical parameters in the well water samples during the wet season (May 2020)
a) TC°, **b)** pH, **c)** TDS, **d)** EC, **e)** DO, and **f)** Hardness.

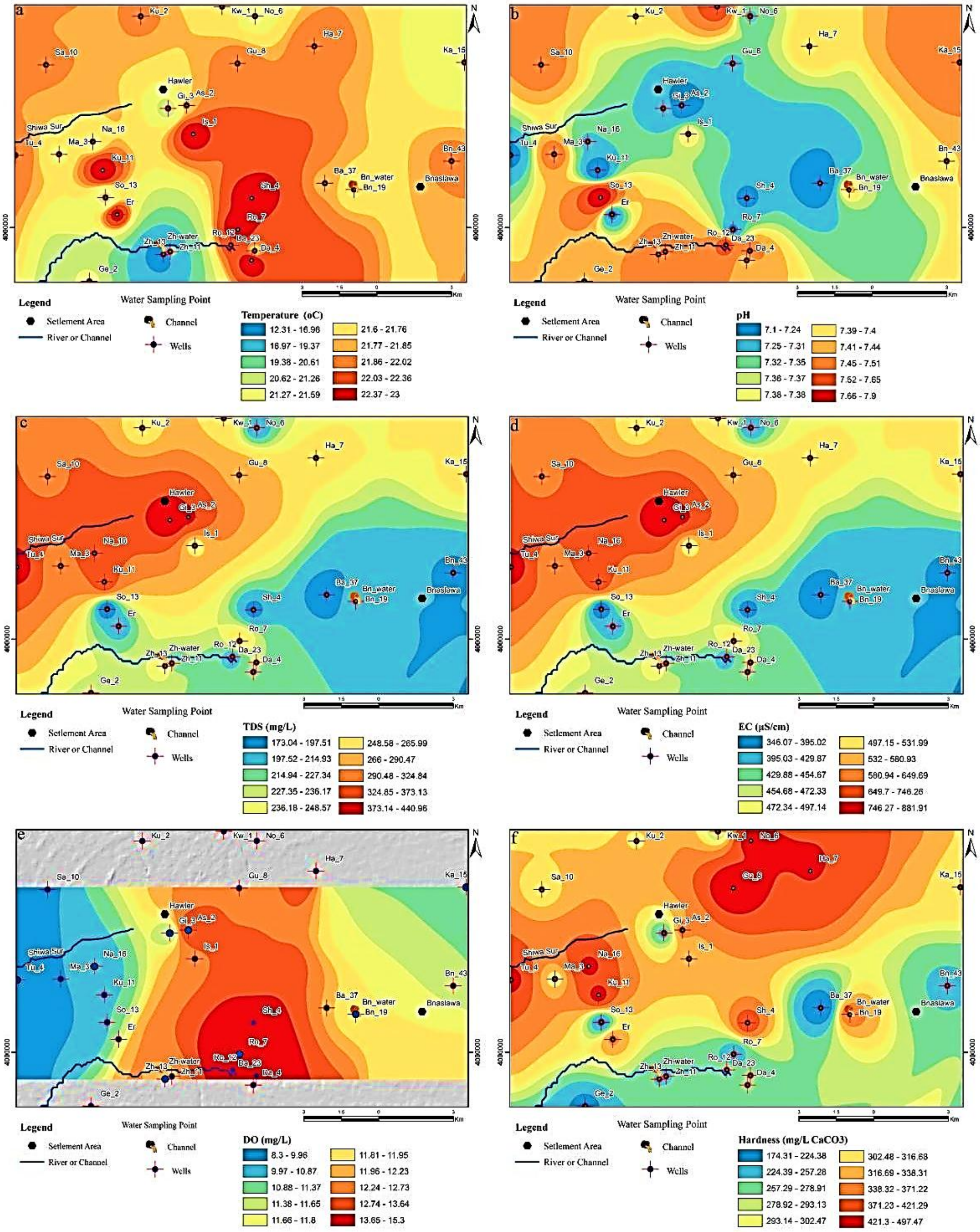

Figure 4b: Spatial distribution maps of the physicochemical parameters in the well water samples during the dry season (September 2020)
a) TC°, **b)** pH, **c)** TDS, **d)** EC, **e)** DO, and **f)** Hardness.

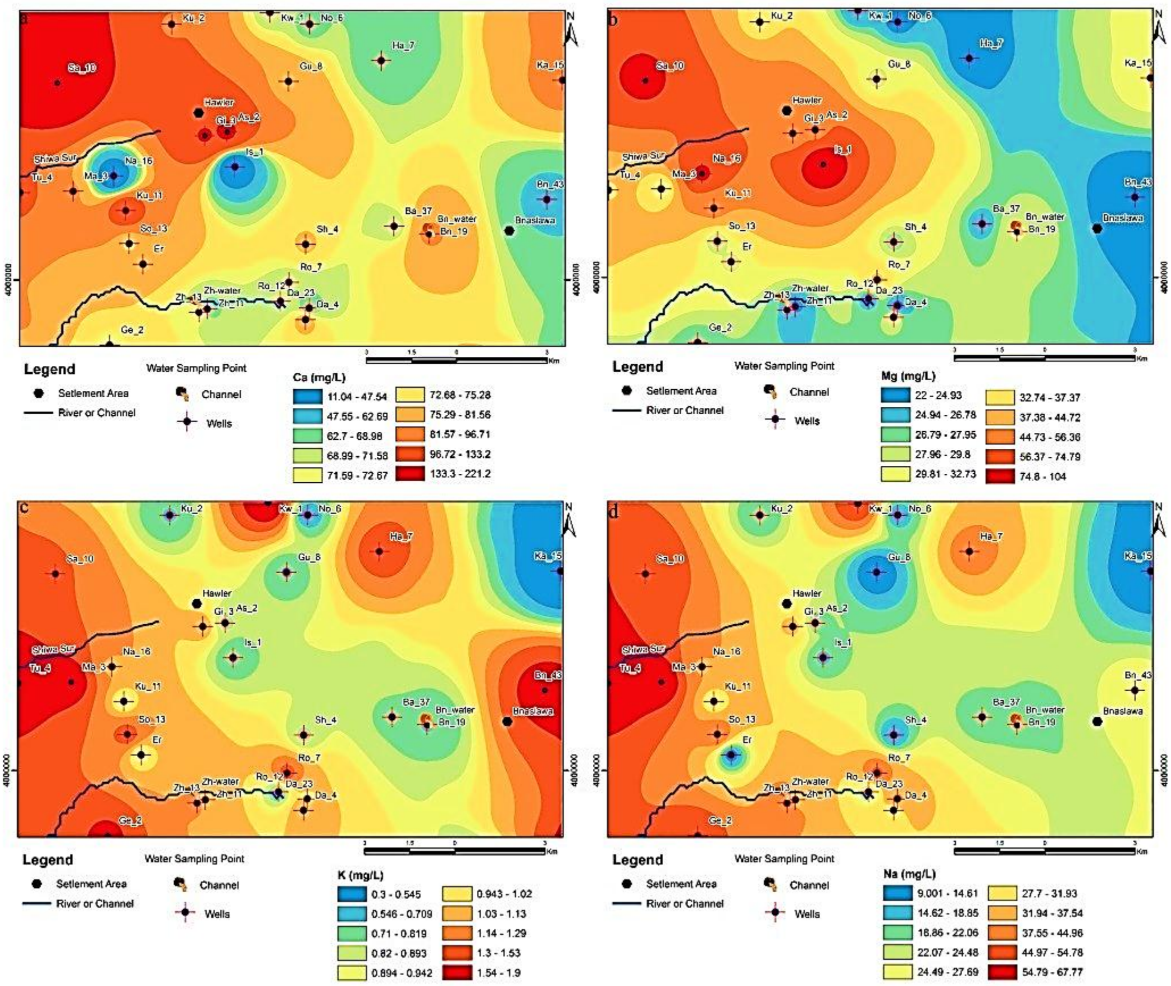

Figure 5a: Spatial distribution maps of the cation parameters in the well water Samples during the wet season (May 2020)
a) Ca^{2+}, **b)** Mg^{2+}, **c)** K^{+}, and **d)** Na^{+}.

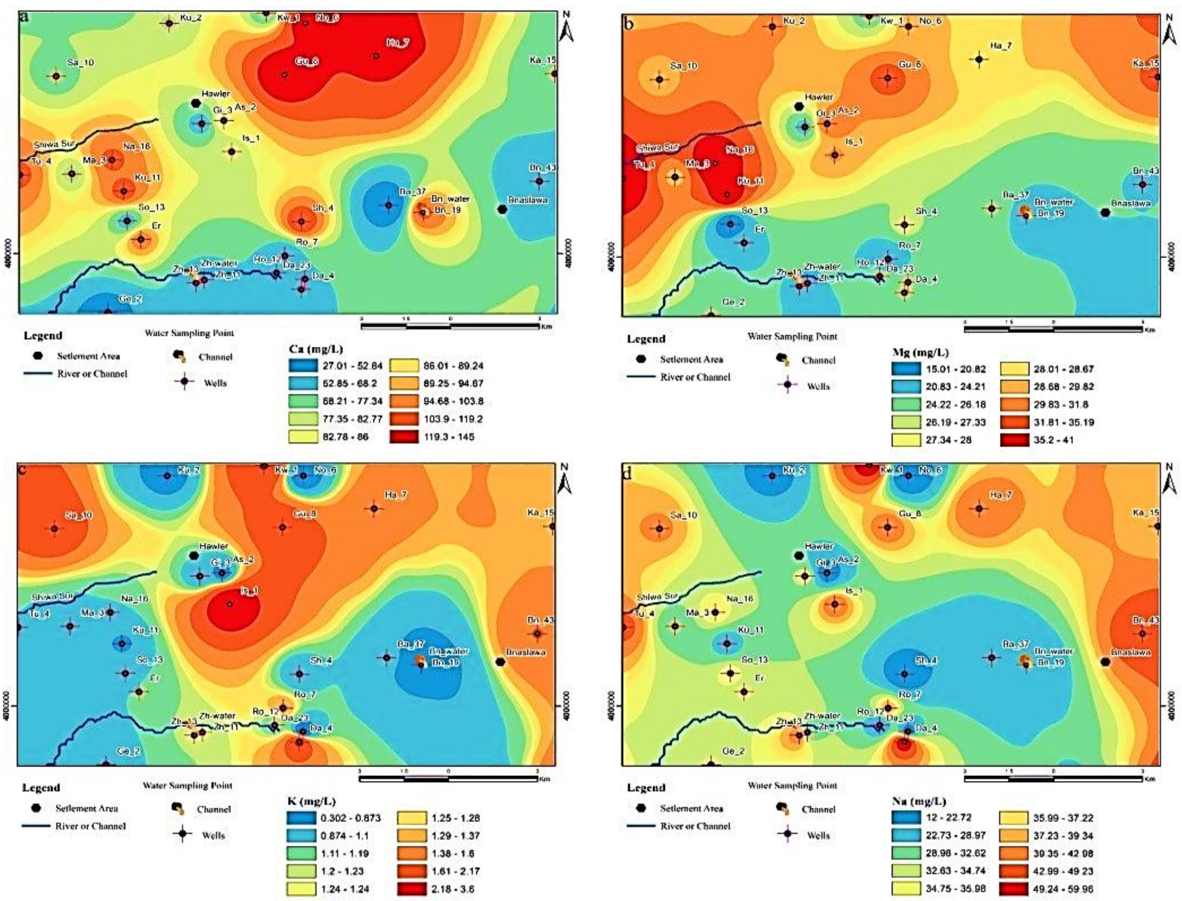

Figure 5b: Spatial distribution maps of the cation parameters in the well water samples during the dry season (September 2020)
a) Ca^{2+}, **b)** Mg^{2+}, **c)** K^{+} and **d)** Na^{+}.

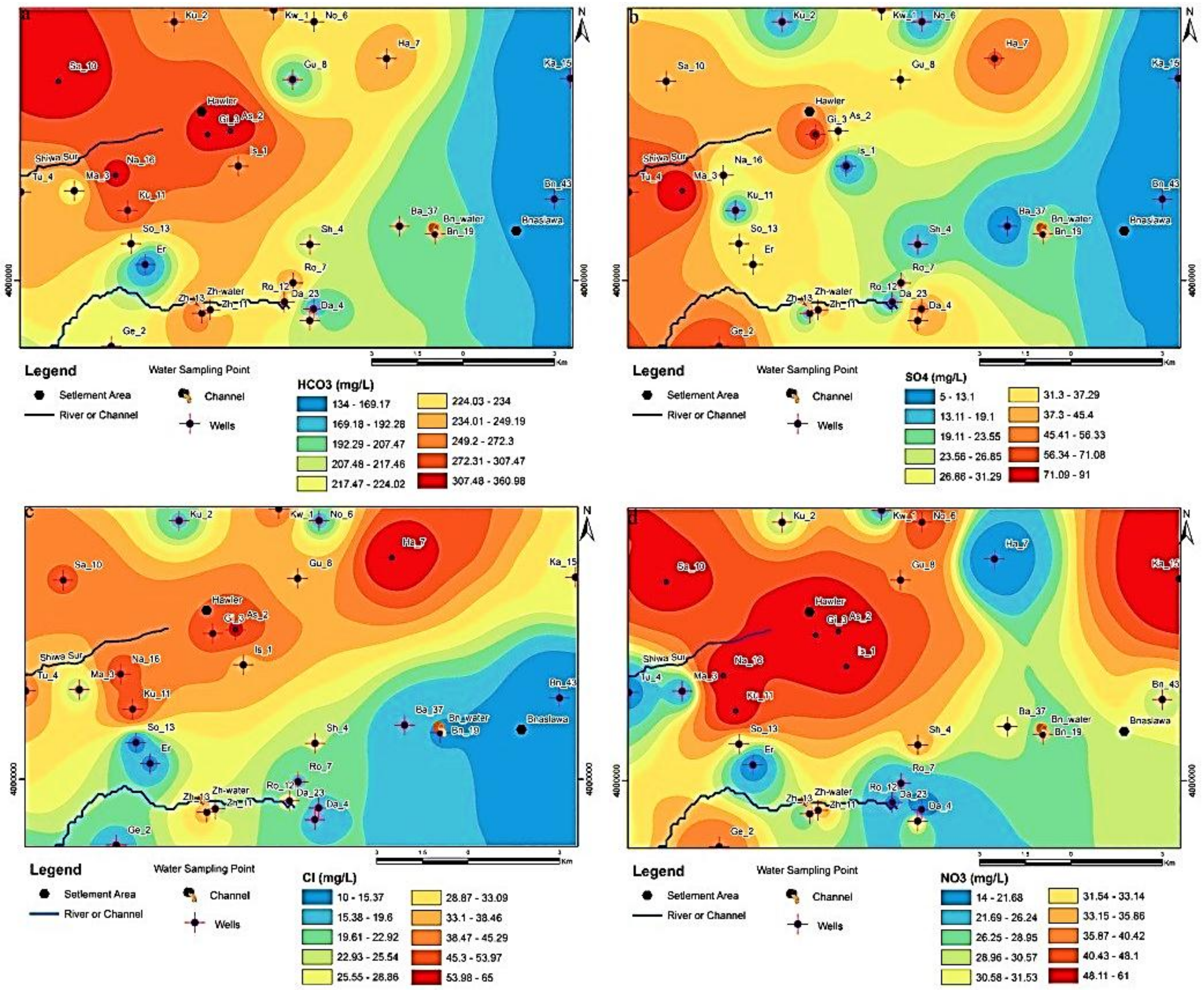

Figure 6a: Spatial distribution maps of the anion parameters in the well water samples during the dry season (September 2020)
a) HCO_3, **b)** SO_4, **c)** Cl, and **d)** NO_3.

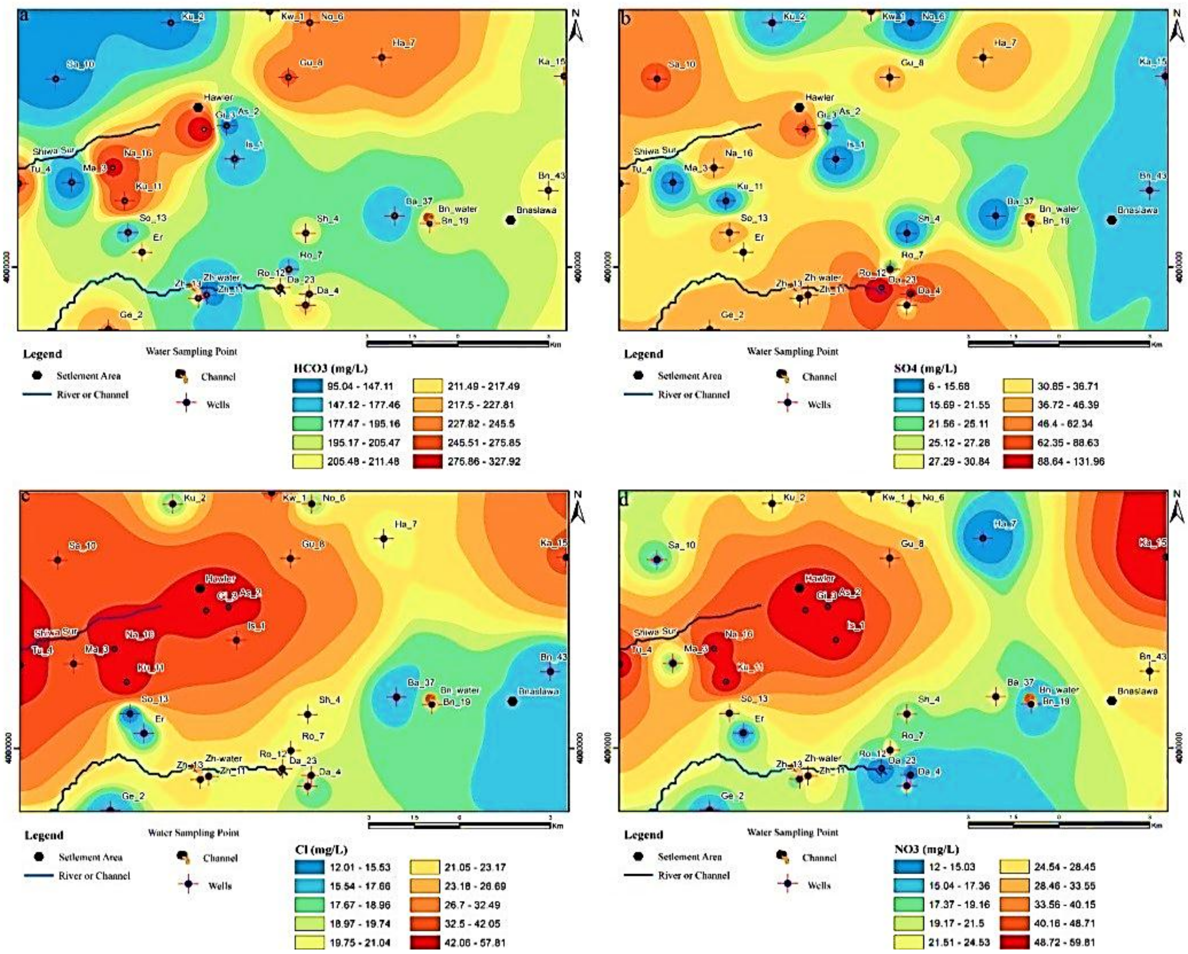

Figure 6b: Spatial distribution maps of the anion parameters in the well water samples during the wet season (May 2020)
a) HCO_3, **b)** SO_4, **c)** Cl, and **d)** NO_3.

Nitrate, generally found in groundwater, refers to one or more of the main pollutants of anthropogenic origin resulting from the contact of soil with nitrate fertilizers, animal wastes, domestic wastes, and human and septic tank leakage (Barakat *et al*., 2016). In the groundwater of the study area, the concentrations of NO_3^- were found in the well water samples from all the sites having a range between 14.00 to 61.00 mg/L with an average value of 35.70 mg/L during the wet season, whereas during the dry season, it varied between 12.00 and 60.00 mg/L with an average value of 29.00 mg/L, respectively (Tables 5 and 6, Figures 6a and b). The maximum value of NO_3^- was (61 mg/L) recorded at Ka-15, Ku-11, and Gl-3 during the wet season, and (60 mg/L) at As-2 during the dry season. In addition, the concentrations of NO_3^- in the wastewater channels samples ranged between 11.00 and 24.00 mg/L, with an average value of 16 mg/L during the wet season, and between 41.30 and 48.20 mg/L with an average value of 44.23 mg/L during the dry season, respectively (Tables 5 and 6, Figures 6a and b). NO_3^- is an important pollutant in both the groundwater well and wastewater channels and has to be predominantly related to the anthropogenic sources, especially from the domestic effluents (cesspools), biological fixation and nitrification of organic N and NH_4, oxidation of organic materials, and from agricultural fertilizers. It causes an increase in nitrate leaching through the "vadose zones" depending on the groundwater level, which generally increases at the end of the wet season in the Erbil Central Sub-Basin and thus an increase in the nitrate concentration in the groundwater.

100% of wastewater samples in the wet and dry period contained NO_{3^-} lower than the permissible limit of WHO (2011) and IQWS (2010) which is 50 mg/L for drinking water. 25.92% of well water samples (Ka-15, Sa-10, Na-16, Ku-11, Gl-3, As-2, Is-1) in the wet season were higher than the permissible limit, also same ratio (25.92%) of the well water samples (Ka-15, Tu-4, Na-16, Ku-11, Gl-3, As-2, and Is-1) in the dry season contained NO_{3^-} concentration higher than permissible limit (Table 7). Excess nitrate in drinking water sources can cause several health disorders in humans, including methemoglobinemia, stomach cancer, goiter, birth malformations, and hypertension. As seen in the distribution map of the nitrate concentration (Figures 6a and b), the fact that NO_3^- concentrations in the sampled well waters vary greatly depends on the sampling locations in both wet and dry seasons. This indicates that the groundwater system consisting of the Quaternary sediments and Bakhtiari Formation in the Erbil Central Sub-Basin is sensitive to the influence of point and non-point pollution.

- **Biological Parameters**

BOD_5 and COD parameters are two important parameters used to measure the organic contamination load in surface and groundwater sources (Aziz and Maulood, 2015). The BOD_5 and COD values in the water well samples were in the range of 5.20 – 8.30 mg/L with an average value of 7.04 mg/L and 11.10 – 15.90 mg/L with an average of 13.21 during the wet season, while in the wastewater channels samples, it ranged from 60.00 to 65.30 mg/L with an average value 62.65 mg/L and 95.00 to 126.80 with an average value of 11.90 mg/L, respectively (Tables 3 and 4, Figures 5a and b). During the dry season, the BOD_5 and COD values ranged between 6.00 – 9.10 mg/L and 12.30 – 20.70 mg/L for the water well samples, and 34.30 – 79.60 mg/L and 78.89 – 134.33 mg/L for the wastewater channel samples, respectively (Tables 3 and 4, Figures 7a and 7b).

COD and BOD_5 parameters in the water well samples may be related to the leaching and transport of natural, sewage from the cesspool, the wastewater channels, the municipal solid waste landfill site, and agricultural and industrial pollution in the study area. In addition, the source of these parameters in the wastewater channels is mainly due to the discharge of untreated wastewater from industries and the surface drainage of chemicals used in agricultural areas (Drever, 1988). The concentration of BOD_5 at all 10 sampling sites (8 from wells and 2 from the wastewater channels) in both two seasons exceeds the maximum allowable limit of 5 mg/L for drinking water (WHO) (see Table 7). According to WHO, the desirable limit of COD in drinking water sources is 20 mg/L. The concentration at all 8 sampling sites from the wells is within the limit of WHO standards, while in wastewater channels, the two sampling sites (the Bn-W W and Tu-W W) exceed the desirable limit of WHO (2011) during the wet season (Table 7). Also, during the dry season, the concentration of COD in the Zh-13 and Sa-10 wells, as well as the wastewater channels, was higher and exceeds the desirable limit of 20 mg/L for drinking water. High BOD_5 in the well and wastewater channel is due to the high decomposition of organic matter at high temperatures, extreme turbidity, and stagnant water conditions. BOD_5 concentrations are relatively high in both seasons, except in areas where some wells, such as Ma 3, Bn 43, and Ka 15 are located (see Figure 7b) However, as seen in the COD concentration map (Figs.7a and 7b), the COD concentration increases depending on the topographic slope and the location of the wastewater channel.

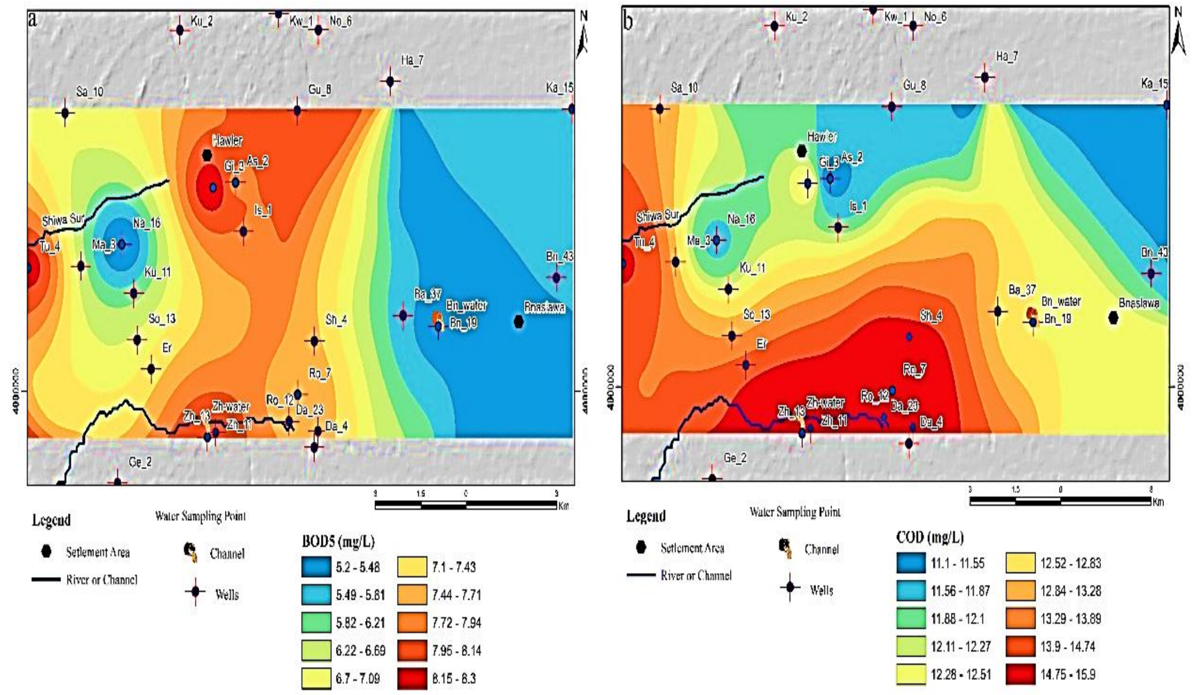

Figure 7a: Spatial distribution maps of the BOD_5 and COD parameters in the well, water samples during the wet season (May 2020), **a)** BOD5, and **b)** COD.

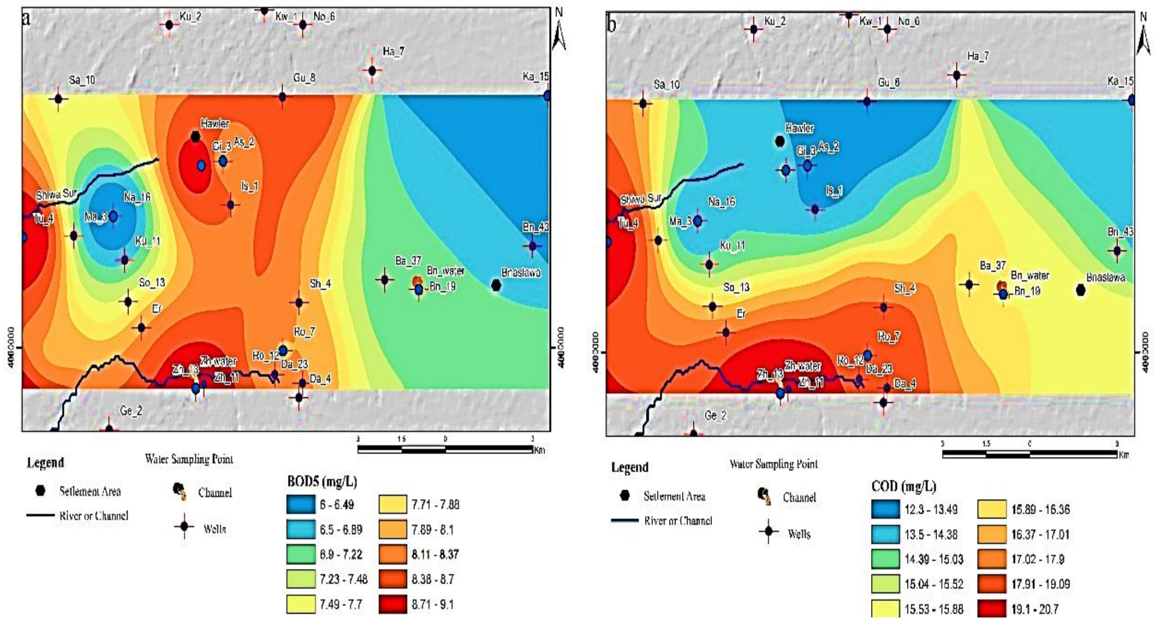

Figure 7b: Spatial distribution maps of the BOD5 and COD parameters in the well water samples during the dry season (September 2020), **a)** BOD5, and **b)** COD.

- **Heavy Metals**

The contamination of both groundwater and surface water resources with heavy metals has gained great importance in recent years due to their toxicity and accumulation behavior in terms of human health (Aslam *et al*., 2021). Unlike most pollutants in water resources, these elements are not biodegradable and enter a global eco-biological cycle since they are on the main pathways of natural waters (Jampani *et al.,* 2018). In particular, major sources of heavy metals in groundwater include the decomposition of rock minerals due to water-rock interaction, drainage of both domestic effluents (cesspools) and sewage, and other wastewater on lands, such as industrial wastes, pesticides, and fertilizers (Al-Mezori and Hawrami, 2013).

Trace metals in natural surfaces and groundwater were grouped into three different groups large, small, and trace levels according to their concentrations (Ma, 2016). In nature, these metals can get into groundwater in a hydrogeological system in many different ways, such as natural (for example chemical weathering and soil leaching) and anthropogenic processes, and cause contamination depending on their concentration (Nienie *et al*., 2017). It was concluded that the heavy metal concentration in groundwater throughout Erbil Central Sub-Basin is attributed to anthropogenic sources such as especially industrial wastes (22 and 23).

Heavy metal concentrations (mg/L) in all water samples collected during the wet and dry seasons are summarized in (Tables 8 and 9, Figure 9), and spatial changes are given in Figures 10 and 11. In the well and wastewater channels water characterization, most trace metals analysis indicates that except Fe, was found below the permissible limits (0.3 mg/L) from IQWS (2010) and WHO guidelines (2011) (Table 7). The concentration of Fe level in groundwater of Erbil Central Sub-Basin was measured at concentrations ranging from 0.0386 to 0.1395 mg/L during the wet season and 0.05020 to 0.10540 mg/L during the dry season. In the wastewater channels, the concentration of Fe varied from 0.1395 to 0.0386 mg/L and 0.902 to 0.1748 mg/L during the wet and dry seasons (Tables 8 and 9, Figures 9a and b are spatial changes are given in Figures 9a and b). The iron concentration in the water resources was found to be almost higher in all samples than in other elements. During the wet season, Cu, Cr, As, Zn, and Mn were generally found in trace levels based on their concentrations in water samples collected from wells with concentrations ranging from 0.0003 – 0.1395 mg/L, 0.00031 – 0.02244 mg/L, 0.00342 – 0.00769 mg/L, 0.0019 – 0.0887 mg/L, and 0.0034 – 00184 mg/L, respectively (Tables 8 and 9, Figures 9a and b). In addition, the concentration values of these heavy metals in the water samples taken from the wastewater channels show a similar change with the values in the well waters, and the Cu, Cr, As, Zn, and Mn varied between 0.0023 and 0.0204 mg/L, 0.0009 and 0.0029 mg/L, 0.0035 – 0.0044 mg/L, 0.0164 – 0.034 mg/L, and 0.0361 – 0.0722 mg/L, respectively (Table 8 and Figures 9a and b). Pb, Al, N, and Ni were not detected in all sampling points during this period (see Tables 8 and 9). During the dry season, all of the well water samples in the investigated area contain values of Pb, Cu, Cr As, Zn, and Mn ranging from 0.00015 to 0.00243 mg/L, 0.00015 to 0.00433 mg/L, 0.00053 to 0.02147 mg/L, 0.00734 to 0.00933 mg/L, 0.02707 to 0.04113 mg/L, and 0.03164 to 0.03409 mg/L, respectively (Table 9, Figures 10a and b). Additionally, in the wastewater channels, they were within the range of 0.00017 – 0.00186 mg/L, 0.00156 – 0.00212 mg/L, 0.00017 – 0.00178 mg/L, 0.00736 – 0.00917 mg/L, 0.01273 – 0.03037 mg/L, and 0.02941 – 0.04019 mg/L, respectively (Tables 4 and 8, Figure 9a and b). B, Al, and Ni were not detected in all sampling points during the dry season (Table 9) It is evident from the Fe results that about 87.5% and 100% of the well water and wastewater channels samples fall within the desirable limit of 0.1 mg/L, 12.5 % of the well water samples (well As-2 in the wet season and Zh-13 in the dry season) exceed the desirable limit of 0.1 mg/L but all samples are within the maximum permissible limit of 0.3 mg/L (Table 9). Ingestion of particularly large amounts of Fe causes a condition known as "hemochromatosis" in humans, which causes tissue damage due to high iron concentration (Azumi and Bichi, 2010) and (Khuddur, 2015). Heavy metal concentrations in water sources vicinity of the study area might have been generally caused by the entry of domestic water and industrial wastes (Figure 8).

CONCLUSION

A total of 30 samples, including 27 groundwater wells samples, and 3 surface water samples from channels, were collected and analyzed to determine the quality of water sources during the wet season (May 2020) and dry season (September 2020). Based on chemical analysis, the concentrations of physicochemical parameters of water samples (wells and wastewater channels) were compared with standard IQWS (2010) and WHO (2011). The general hydrochemical analysis indicates that overall well water quality is suitable for drinking purposes except for the elevated NO_3, concentrations. In the well and wastewater channels water characterization, most trace metals analysis indicates that except Fe, all parameters were found below the permissible limits (0.3 mg/L) of IQWS (2010) and WHO guidelines (2011).

The mean ionic dominance pattern is in the order of so $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ - $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and anions in the order $HCO_3^- > NO_3^- > SO_4^{2+} > Cl^-$ - $HCO_3^- > SO_4^{2+} > NO_3^- > Cl^-$ during the wet and dry seasons for well water, respectively. The Piper plot revealed that the majority (51.85%) of well water samples fall in the field of Ca-Mg-HCO_3 and 25.93% in the Ca-Mg-Na-HCO_3 water type while 7.41% plots in the Ca-Na-Mg-HCO_3-SO_4 and Mg-HCO_3, and 3.70% in the Ca-Mg-Na-HCO_3-C and Ca-Na-Mg-HCO_3 fields during the wet season.

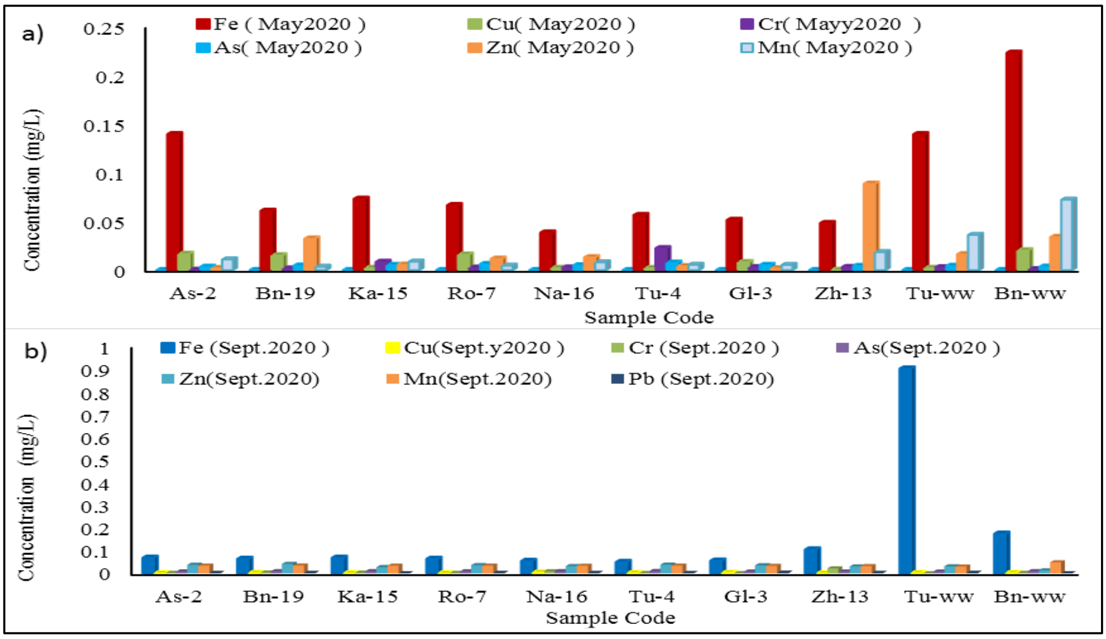

Figure 8: Distribution of heavy metal parameters in the water samples of the study area during the wet and dry season **a)** Fe, Cu, Cr, As, Zn, Mn and **b)** Fe, Cu, Cr, As, Zn, Mn, and Pb.

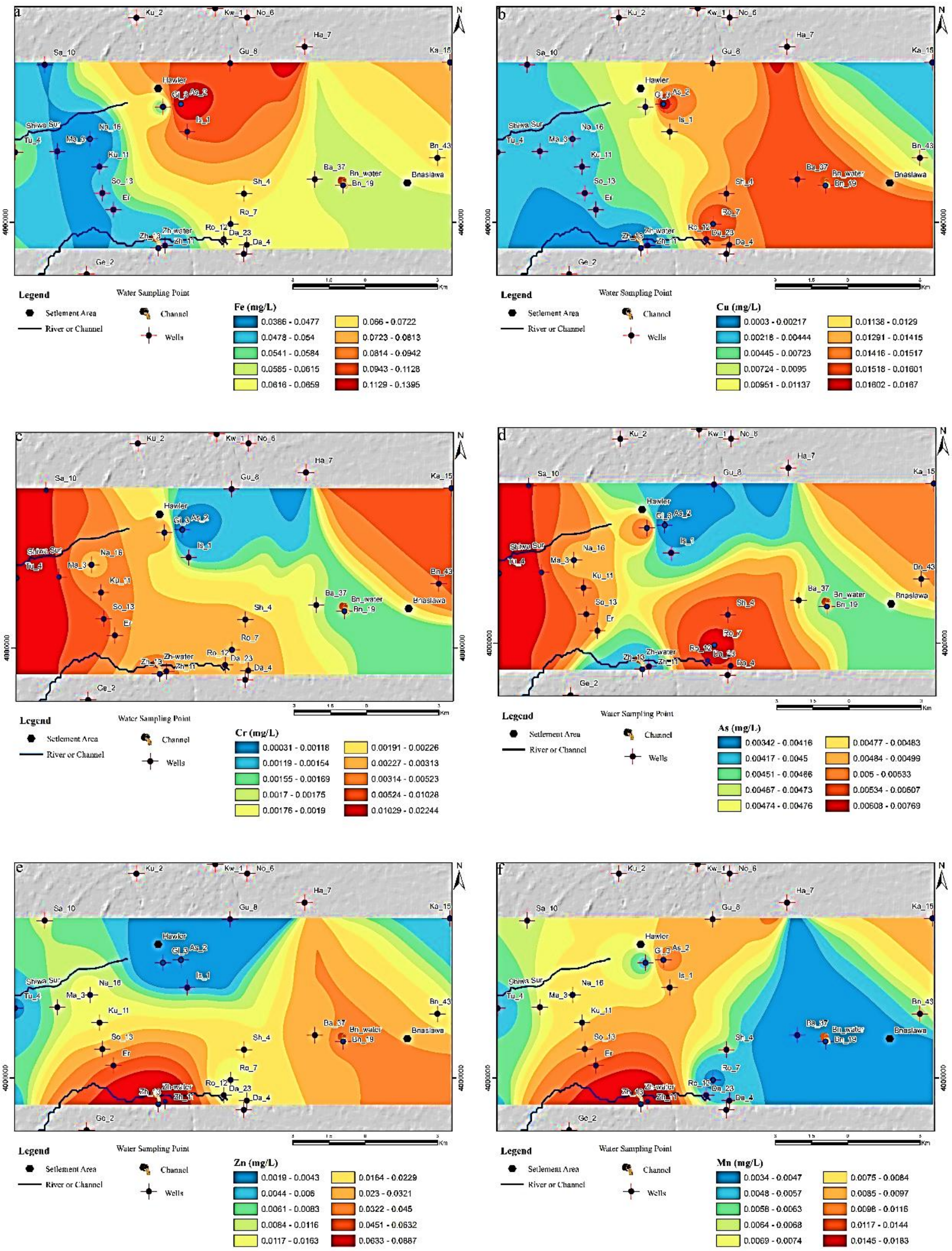

Figure 9a: Spatial variation of 6 heavy metals in the Erbil Central Sub-Basin during the wet season (May 2020) **a)** Fe, **b)** Cu, **c)** Cr, **d)** As, **e)** Zn, and **f)** Mn.

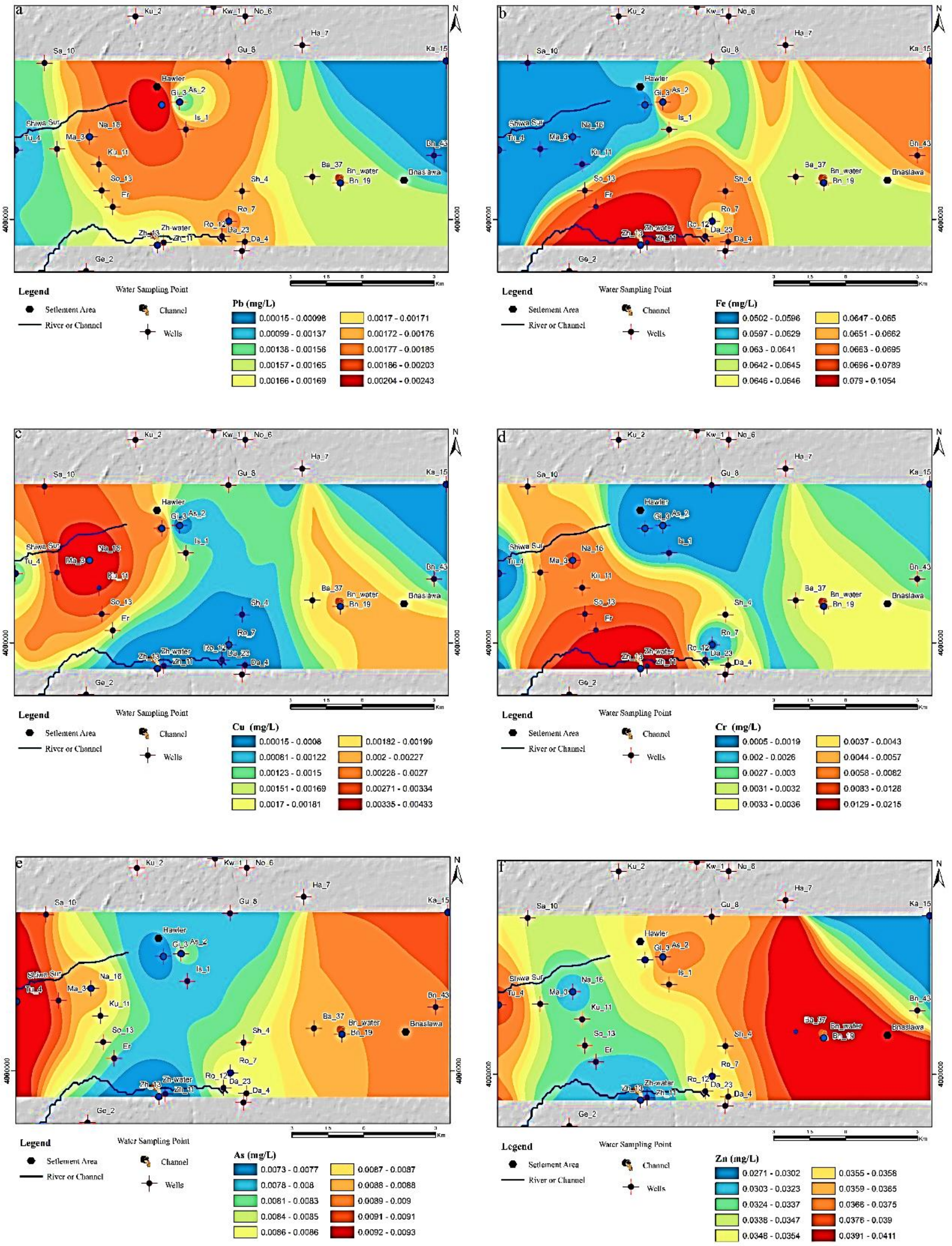

Figure 9b: Spatial variation of 7 heavy metals in the Erbil Central Sub-Basin during the dry season (September 2020) **a)** Pb, **b)** Fe, **c)** Cu, **d)** Cr, **e)** As, **f)** Zn, and **g)** Mn.

Table 8: The concentration of heavy metals in water collected from well and wastewater channels during the wet season (all samples taken on May 20).

Sampling location	**Sampling code**	**Type location**	**Trace Elements (mg/L)**			**Cr**	**As**	**Zn**	**Mn**	**Al**	**B**	**Ni**
			Pb	**Fe**	**Cu**							
Sharawani, 4	Sh-4	Well water	-	-	-	-	-	-	-	-	-	-
Daratu, 4	Da-4		-	-	-	-	-	-	-	-	-	-
Zhyan, 11	Zh-11		-	-	-	-	-	-	-	-	-	-
Zhyan , 13	Zh-13		N.D	0.0483	0.0003	0.0032	0.0043	0.0887	0.0184	N.D	N.D	N.D
Roshanbeery,12	Ro-12		-	-	-	-	-	-	-	-	-	-
North Industry, 6	No-6		-	-	-	-	-	-	-	-	-	-
Gerd Muhamad ,2	Gr-2		-	-	-	-	-	-	-	-	-	-
South Industry (Shadi, 13)	So-13		-	-	-	-	-	-	-	-	-	-
Bnaslawa ,19	Bn-19		N.D	0.0609	0.0152	0.0017	0.0046	0.0324	0.0034	N.D	N.D	N.D
Kasnazan ,15	Ka-15		N.D	0.0732	0.0023	0.0085	0.0053	0.0056	0.0086	N.D	N.D	N.D
Kwestan , 1	Kw-1		-	-	-	-	-	-	-	-	-	-
Turaq ,4	Tu-4		N.D	0.0565	0.0022	0.0224	0.0077	0.0041	0.0054	N.D	N.D	N.D
Sarbasty ,10	Sa-10		-	-	-	-	-	-	-	-	-	-
Nawroz ,16	Na-16		N.D	0.0386	0.0023	0.0027	0.0049	0.0132	0.0079	N.D	N.D	N.D
Kurdistan , 11	Ku-11		-	-	-	-	-	-	-	-	-	-
Girkand ,3	Gl-3		N.D	0.0515	0.0082	0.0030	0.0053	0.0019	0.0053	N.D	N.D	N.D
Ashty, 2	As-2		N.D	0.1395	0.0167	0.0003	0.0034	0.0022	0.0109	N.D	N.D	N.D
Kurani Ainkawa,2	Ku-2		-	-	-	-	-	-	-	-	-	-
Hawlery new,7	Ha-7		-	-	-	-	-	-	-	-	-	-
Iskan,1	Is-1		-	-	-	-	-	-	-	-	-	-
Mardin,3	Ma-3		-	-	-	-	-	-	-	-	-	-
Daratu, 23, cemetery	Da-23		-	-	-	-	-	-	-	-	-	-
Gullan, 8, cemetery	Gu-8		-	-	-	-	-	-	-	-	-	-
Erbil great cemetery	Er-Gr		-	-	-	-	-	-	-	-	-	-
Bnaslawa,43, cemetery	Bn-43		-	-	-	-	-	-	-	-	-	-
Badawa,37	Ba-37		-	-	-	-	-	-	-	-	-	-
Roshanbeery,7	Ro-7		N.D	0.0667	0.0160	0.0025	0.0062	0.0117	0.0045	N.D	N.D	N.D
Zhyan wastewater	Zh-W W	Waste Water Channel	-	-	-	-	-	-	-	-	-	-
Bnaslawa Waste water	Bn-W W		N.D	0.2231	0.0204	0.0009	0.0035	0.0340	0.0722	N.D	N.D	N.D
Turaq wastewater	Tu-W W		N.D	0.1395	0.0023	0.0029	0.0044	0.0164	0.0361	N.D	N.D	N.D

Table 9: The concentration of heavy metals in water collected from well and wastewater channels during the dry season (all samples taken in Sep-20).

Sampling location	Sampling code	Type location	Trace Elements (mg/L)			Cr	B	As	Zn	Mn	Al	Ni
			Pb	Fe	Cu							
Sharawani - 4	Sh-4	Well water	-	-	-	-	-	-	-	-	-	-
Daratu - 4	Da-4		-	-	-	-	-	-	-	-	-	-
Zhyan-11	Zh-11		-	-	-	-	-	-	-	-	-	-
Zhyan -13	Zh-13		0.00165	0.1054	0.00015	0.02147	N.D	0.00734	0.02981	0.03164	N.D	N.D
Roshanbeery-12	Ro-12		-	-	-	-	-	-	-	-	-	-
North Industry - 6	No-6		-	-	-	-	-	-	-	-	-	-
Grd Muhamad -2	Gr-2		-	-	-	-	-	-	-	-	-	-
South Industry (Shadi-13)	So-13		-	-	-	-	-	-	-	-	-	-
Bnaslawa -19	Bn-19		0.00159	0.0643	0.00202	0.0033	N.D	0.00885	0.04113	0.03409	N.D	N.D
Kasnazan -15	Ka-15		0.00015	0.069	0.00046	0.00241	N.D	0.00901	0.02707	0.03343	N.D	N.D
Kwestan -1	Kw-1		-	-	-	-	N.D	-	-	-	-	-
Turaq -4	Tu-4		0.00123	0.0502	0.00144	0.00118	N.D	0.00933	0.03788	0.03382	N.D	N.D
Sarbasty -10	Sa-10		-	-	-	-	-	-	-	-	-	-
Nawroz -16	Na-16		0.00177	0.0549	0.00433	0.00837	N.D	0.00885	0.03167	0.03333	N.D	N.D
Kurdistan - 11	Ku-11		-	-	-	-	-	-	-	-	-	-
Glkand -3	Gl-3		0.00243	0.0561	0.00281	0.00053	N.D	0.00736	0.03501	0.03264	N.D	N.D
Ashty -2	As-2		0.00139	0.069	0.00042	0.0017	N.D	0.00817	0.03729	0.03359	N.D	N.D
Kurani Ainkawa-2	Ku-2		-	-	-	-	-	-	-	-	-	-
Hawlery new-7	Ha-7		-	-	-	-	-	-	-	-	-	-
Iskan-1	Is-1		-	-	-	-	-	-	-	-	-	-
Mardin-3	Ma-3		-	-	-	-	-	-	-	-	-	-
Daratu -23-cemetery	Da-23		-	-	-	-	-	-	-	-	-	-
Gullan-8-cemetery	Gu-8		-	-	-	-	-	-	-	-	-	-
Erbil great cemetery	Er-Gr		-	-	-	-	-	-	-	-	-	-
Bnaslawa -43-cemetery	Bn-43		-	-	-	-	-	-	-	-	-	-
Badawa-37	Ba-37		-	-	-	-	-	-	-	-	-	-
Roshanbeery-7	Ro-7		0.00176	0.0643	0.00028	0.00179	N.D	0.00856	0.03586	0.0339	N.D	N.D
Zhyan wastewater	Zh-W	Waste Water Channel	-	-	-	-	-	-	-	-	-	-
Bnaslawa Wastewater	Bn-W		0.00017	0.1748	0.00212	0.00178	N.D	0.00917	0.01273	0.04019	N.D	N.D
Turaq wastewater	Tu-W		0.00186	0.902	0.00156	0.00017	N.D	0.00736	0.03037	0.02941	N.D	N.D

According to the Davis and De Wiest classification, all of the well water and wastewater channel (100%) samples in the wet season and 100% of the well water and 66.67% of wastewater channel samples in the dry season from the study area belong to a desirable limit category. However, 33.3% of the wastewater channel samples are within the permissible drinking based on the chemical composition category in the dry season. the water samples taken from wells and wastewater channels in the study area are of the freshwater type. The classification of water according to total hardness indicates that the well water samples fall between hard (40.74 and 59.26%) and very hard (55.56 and 44.44%) types of water during the wet and dry seasons. The Schoeller diagram shows that the concentrations of all ions in water samples generally have a similar tendency, with Cl^- and Ca^{2+} concentrations differing in some wells.

The results of the factor analysis for the wet and dry season hydrogeochemical indicate that the first five and six-component extracted have eigenvalues >1 and correspond to approximately 94.844 and 96.26 % of the total variance, respectively. The factor analysis indicates that groundwater quality in the wet and dry season are significantly associated with anthropogenic pollution sources such as leaching from soil layers, cesspools wastes, wastewater channels, industrial wastes, and agriculture activities which fill the drains in the region rather than natural, geogenic processes such as reverse ion exchange, the weathering of carbonate minerals such as dolomite and silicate by carbonic acid from geologic formations outcropping throughout the Erbil Central Sub-Basin. In addition, especially heavy metal variables such as Mn, As, Fe, Cr, and Zn in well water samples may not be associated with geogenic processes (rock/soil decomposition) due to the dominant rock/soil types (soils, gravels, and conglomerates with some sands, clay, and silt) in the study area are not likely to consist of such mineralogy. Therefore, the heavy abundance of trace metal in water can indicate that these factors are attributed to anthropogenic sources such as transportation by leaching from the industrial wastewater in groundwater more than geogenic processes.

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About the author

Dr. Masoud Hussein Hamed graduated from the Geological Department, College of Science at Salahaddin University in 2002. After graduation, He worked as a Demonstrator in the Geology Department from January/19/2003 to Oct/1/2005 in Department. He worked as a laboratory demonstrator at the Department of Geology. In October 2005, He was accepted into the Master's Program at Salahaddin University in the specialty of Environmental. In April 2007, He has gotten a master's degree in Environmental Geology and became an assistant lecturer for an Environmental course in the Department of Geology at Salahaddin University. In 2013, He got PhD in hydrogeology and groundwater modeling, at Salahaddin University. He has 22 years of experience working in the field of Environmental Impact Assessment, Hydrogeology, Hydrochemistry, Water management, and GIS. He has published 6 articles on different geological aspects. He has wide experience in the environmental field. Know He is a lecturer at the University of Salahaddin, College of Science, Department of Earth Sciences and Petroleum for the past 20 years, and supervised 2 M.Sc. students inside Iraq, and 3 students outside Iraq.

e-mail: masoud.hamed@su.edu.krd