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Research Article

Investigation of Rainwater Quality in Erbil Province and the Feasibility of Various Uses

Shuokr Qarani Aziz[1*], Reem A. Ahmed Alrawi[2], Kasro Kakil Dizayee[1] Carmen Khalil[1], Intisar Majeed Shaheed[1], Jwan Sabah Mustafa[3]

[1]Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq
[2]Department of Water Resources Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq
[3]General Directorate of Dams and Reservoirs, Kurdistan Region, Iraq
E-mail: shoker71@yahoo.com, shuokr.aziz@su.edu.krd

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Abstract: Climate change, industrialization, global warming, dust storms, etc. influence rainfall, and rainwater quality. The current research aimed to examine rainwater quality parameters in Erbil Province, Kurdistan Region, Iraq. Additionally, the evaluation of rainwater quality for various uses and mapping using a Geographic Information System (GIS) were other goals for the present work. Rainwater samples were collected from December 2019 to February 2020. The samples were collected at Erbil City Center and outside of Erbil City Center, which are represented by plain, hilly, and mountain zones. Rainwater samples were collected from Global City Quarter, New Zanco Village Quarter, Qalat (Citadel) Area, Bakhtiyari Quarter, Zamzamok Village, and Hujran Area. 21 rainwater quality parameters were tested for the collected samples. Further, the measured parameters were sulfate, turbidity, total solids, electric conductivity, pH, etc. Maps for the rainwater quality index were illustrated by the Inverse Distance Weighting (IDW) interpolation method using GIS. The findings showed that samples of rainwater taken from outside Erbil City were cleaner than those taken from the center of Erbil City. Furthermore, rainwater from the hills was cleaner than that from plain areas and the city center. The study found that Erbil Province rainwater may often be used immediately for irrigation, fish production, swimming, and building. However, for drinking and domestic purposes, only sedimentation and disinfection are needed.

***Keywords*:** Erbil, quality, rainwater, treatment, water standards

1. Introduction

Water supply is an important factor in the survival of a community. The World Water Council points out that the request for water within the next five decades will increase due to the forecasted 50% population growth associated with industrialization and urbanization [1]. The big population growth rate in Erbil City, the capital of the Kurdistan Regional Government (KRG) in Iraq, during the last two decades, was associated with the rapid increase of activities in the different sectors, which led to an increase in water consumption. In parallel with these changes, there is a fear of decreasing available water sources due to climate change and repeated drought years. All these factors led to looking for new alternative resources, for example, treatment of wastewater and rainwater harvesting, to get a sufficient amount of water with good quality. Consequently, it is essential to study water quality to manage water resources as effectively as possible. Qualitative measurements and experiments with water are challenging, expensive, and time-consuming.

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Artificial intelligence techniques have undergone significant development recently and have been used in numerous situations, including those involving the environment and water quality. Smart maps are now possible thanks to the widespread availability of high-quality geospatial data and technological advancements in hardware and software [2].

In focusing on rainfall, two visions are highlighted: firstly, the quality of the rainwater about currently extended pollutant inspections, and secondly, the efficiency of collecting and harvesting this rainwater. The quality of rainwater is primarily affected by urbanization, different pollutants, and transboundary pollution [3]. Jordan is a clear example of harvesting rainfall in the Middle East. As part of Jordan's water demand management strategy, rainwater collection is one of the extra water sources. Jordan has been using this strategy since 1980 through the collection of rainwater on the roofs of buildings and the saving of the collected rainwater in the cisterns [4]. If the quality of the rainwater is acceptable and safe, it can be used as a useful source for providing water or contributing to other resources. To figure out this application, this can be done by carrying out required water quality tests such as pH, acidity, alkalinity, turbidity, solids, etc. Due to the importance of the collection of rainwater, particularly in arid and semi-arid areas, rainwater harvesting and its quality are the major points of several ongoing types of research. For example, a study in China showed the effect of different types of catchments on rainwater quality. The study indicated that the inorganic compounds in the rainwater matched the World Health Organization (WHO) standards for drinking water [5]. Of course, the increase in industrialization, desertification, air pollution, climate change, drought, etc. in Erbil Province and Iraq had an impact on the quality of the rainwater. On the other hand, rainwater enters surface and groundwater resources and is used directly for irrigation and other purposes. In 2021, the operation of newly constructed water treatment plants on the Greater Zab River in Erbil City was stopped several times due to rainfall in neighboring countries, which increased turbidity in the Greater Zab River.

Thus, observation of rainwater quality at various zones and the use of rainwater for different purposes have not been carried out in Erbil City. Examining the quality of the rainwater is essential. Hence, the objectives of this research were to: 1) examine the quality of rainwater from December 2019 to February 2020 in four different districts in Erbil Province, and 2) study the feasibility of using rainwater for various purposes. To date, this kind of study has not been carried out in Erbil Province.

2. Materials and methods

2.1 *Study area*

Through the rainy season in Erbil City, the researchers divided the study area into four main locations, which include: inside Erbil City, outside the city, high areas (hills and mountains), and flat areas. The inside and flat areas were represented by the New Zanco Village Quarter and Bakhtiyari Quarter. As for the outside city with high levels, it was represented by Global City Quarter (591 m above sea level) and Zamzamok Village, which is located in the Erbil countryside (particularly in Erbil Plain) and is around 35 km south of Erbil City. A mountain area represented by the Hujran Zone, which is located at a distance of 40 km from Erbil's center. The selected high area is represented by Qalat (Citadel; 428 m above sea level), which is located at the center of Erbil City. The collected rainwater samples were taken from the top and bottom of the citadel. These areas were selected to show the variance between inside and outside of Erbil City, taking into consideration the effect of areas with high levels, and to examine the effect of a hilly climate on the rainwater quality. On the other hand, in this research, the authors tried to check the impact of land cover and land use changes in the selected area on the characteristics of rainwater. Figure 1 shows the collected rainwater samples from Global City Quarter, New Zanco Village Quarter, Qalat (Citadel) Area, Bakhtiyari Quarter, Zamzamok Village, and Hujran Area in Erbil Province, and the details of the locations are shown in Table 1.

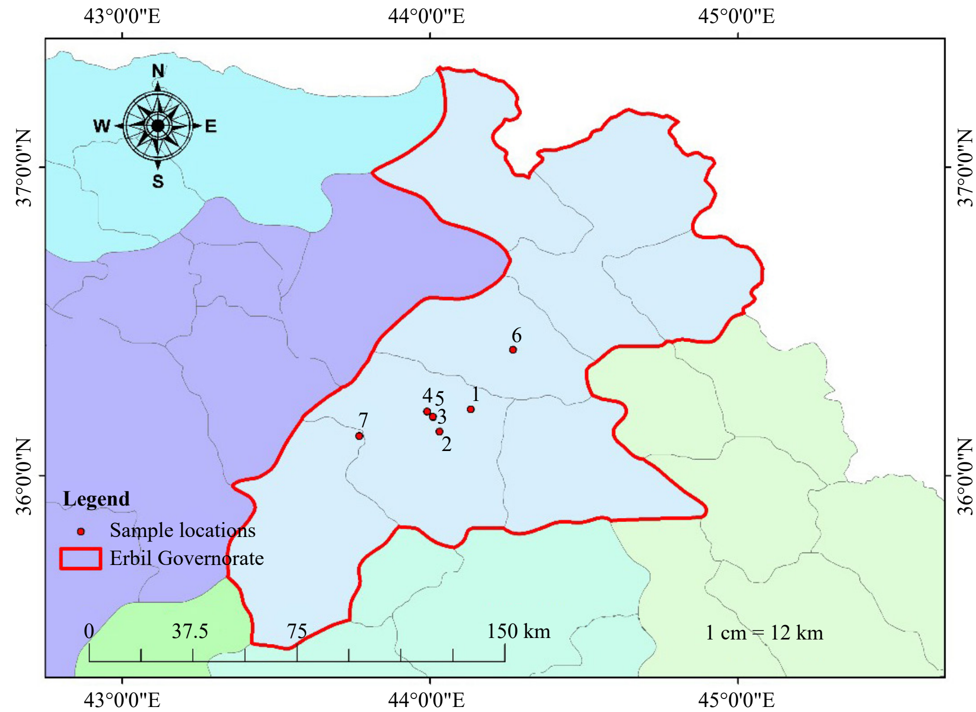


Figure 1. Locations of rainwater sample collection in Erbil Province

Table 1. Details of rainwater collection locations

No.	Sample locations	x	y
1	New Zanco Village Quarter	44.13170	36.21480
2	Global City Quarter	44.02995	36.14279
3	Bakhtiyari Quarter	44.00927	36.19050
4	Qalat Area (Top)	43.98975	36.20764
5	Qalat Area (Bottom)	44.00852	36.19084
6	Hujran Area	44.26878	36.40864
7	Zamzamok Village	43.76928	36.12832

2.2 *Sampling process and analysis*

During rainfalls, four samples at each location were collected in December 2019, January 2020, and February 2020. Plastic containers were used for the collection of the samples. Later, the samples were transported immediately to the laboratory. To prevent changes in their characteristics and any biological activities, the samples were stored at 4 °C. 21 rainwater quality experiments were conducted on the collected samples. The parameters were: pH, electrical conductivity (EC), turbidity, color, total acidity, total alkalinity, total hardness, chloride, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), bicarbonate alkalinity, carbonate alkalinity, non-carbonate alkalinity, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), total non-volatile solids (TnVS), ammonia-nitrogen (NH_3-N), and sulfate. The experiments were carried out in the Sanitary and Environmental Engineering Laboratory, Civil Engineering Department, College of Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq. Tests were carried out according to the Standard Methods for the Examination of Water and Wastewater [6]. Color and NH_3-N tests were done using a spectrophotometer (DR/3900). pH and DO were measured by a Hanna Multiparameter Meter (HI9829-00202). Turbidity and EC experiments were measured with a Hanna Turbidity Meter (LP 200) and Wissenschaftlich-Technische-Werkstätten (LF-42), respectively. TS, TSS, TDS, TVS, and TnVS were carried out using an oven, filter paper, and special weighing instruments. Titration methods were used to measure total alkalinity, total acidity, chloride, and total hardness [6].

Geographic Information System (GIS) maps were used to show the concentration of some rainwater quality parameters such as pH, turbidity, EC, TDS, color, total alkalinity, total acidity, and total hardness. Additionally, GIS maps illustrated the change in rainwater quality values according to the locations.

2.3 *Water quality standards*

To check the suitability of using rainwater in the selected zones, the results were compared with the drinking and domestic, irrigation, fish production, swimming, and constriction water quality standards. The details of the water quality standards are given in Sections 3.2 and 3.3.

3. Results and discussions

3.1 *Amount of precipitation in Erbil Province*

In hilly and mountainous areas, complicated topography has a more significant impact on the spatial distribution of precipitation than it does in plain areas. The distribution of total rainfall throughout time is indicated by the temporal pattern of rainfall. The Agriculture and Environment Statistics Department in the Ministry of Planning-Kurdistan Region Statistics Office presented a report about the weather statistics in Kurdistan Region Governorates for the years 2012 to 2020. The rainfall level (mm) in the Kurdistan Region from 2012 to 2020 is shown in Figure 2 [7].

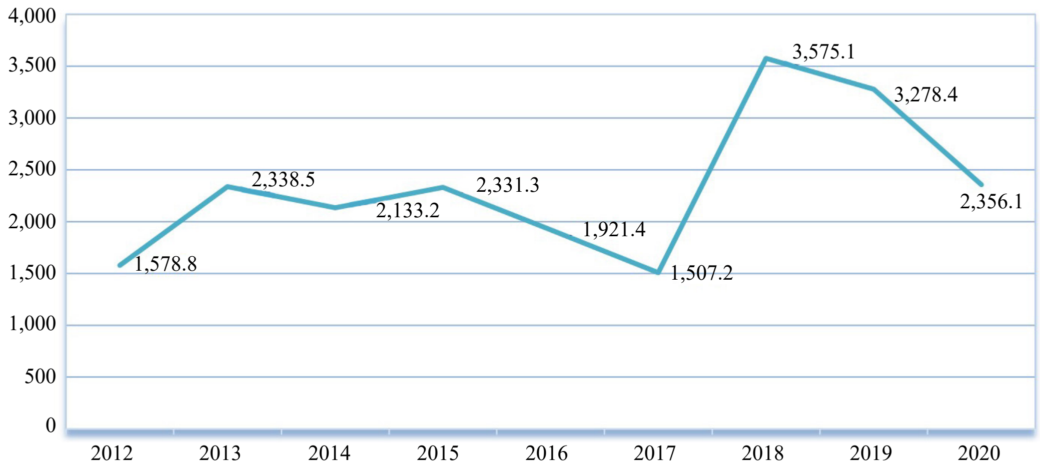


Figure 2. Rainfall level (mm) in the Kurdistan Region for the years 2012 to 2020 [7]

It was found that the rainfall level in Erbil City during December 2019, January 2020, and February 2020 was 45.8 mm, 101.4 mm, and 55.7 mm, respectively. The average temperatures during these months were 12.25 °C, 9.05 °C, and 9.85 °C, respectively, which can be described as cold and comfortable weather, and this range of temperatures is considered the lowest temperature during 2019 and 2020. The rainy days during these months were 14 days in December 2019, 15 days in January 2022, and 14 days in February 2020. There were no hail or snow days, but it was cloudy and partly cloudy between 9 and 20 days.

The reason why data collection was discontinued for a long period is that KRG declared a lockdown in March and April 2020 due to COVID-19. Fully and partially lockdowns continued for several months in 2020.

Table 2 illustrates the average precipitation in Erbil Province from 1941 to 2018. Normally, in Erbil Province, rainfall starts in October and ends in May. The highest values were reported in January, while the lowest figures were registered in July and August. High intensities of rainfall, surface runoff, and floods are affecting surface water sources. Rainfall and surface runoff increase turbidity and solids in surface water sources, such as Greater Zab River water in Erbil Governorate. Many times, the operation of water treatment plants on the Greater Zab River stops due to rainfall and an increase in turbidity and solids in the river [8].

Table 2. Average precipitation in Erbil Province from 1941 to 2018 [9]

Month	Average precipitation (mm)
January	84.8
February	76
March	79.6
April	55.4
May	22.3
June	0.3
July	0.1
August	0.1
September	0.3
October	11.4
November	39.9
December	76.1

3.2 *Rainwater quality*

Apart from those that the rain picks up from the sky, rainwater was originally largely devoid of pollutants. However, when rainwater is collected, stored, and used in homes, its quality may eventually deteriorate. Of course, the availability of smoke for a huge number of cars and electric generators, investment projects, oil and gas production, industrialization, changes in land use and land cover in the area, etc. impact the rainwater characteristics. Consequently, rainwater usually contains a complex chemical composition because it has various properties when collected from different areas in various seasons in the same region. Rainwater contains constituents of local origin from different areas and the atmosphere [10]. Contaminated rainwater can be caused by a variety of factors, including fluttered dirt, leaves, and bird droppings. Various water quality standards are shown in Table 3. In this research, rainwater quality results for seven different locations are illustrated in Table 4. Rainwater samples were collected from December 2019 until February 2020, which is considered the rainfall season inside and outside Erbil City. It can be noticed that there is no data in Qalat Area (bottom) and Zamzamok Village because there was no rain in these areas.

Table 3. Iraqi and WHO drinking water quality standards [11-13]

Parameters	Iraqi drinking water standards	Water quality standard	Suggested value	Health guideline value
pH	6.5 to 9.2	6.5 to 8.5		Not set
Temperature (°C)	20			
EC (µS/cm)	2,000	1,000	1,400	
Total salts (mg/L)	1,000			
Turbidity (NTU)	5 to 25		5	Not set
Color	10 Pt. Co.		15 TCU	There is no WHO health-based guideline value for color
Total acidity (mg/L)	250			
Total alkalinity (mg/L)	200	200		
Total hardness (mg/L)	250	200		Not set
Chloride (mg/L)	200	250		Not set
DO (mg/L)		4 to 6		No health-based guideline value is recommended
TS (mg/L)	1,000			
TSS (mg/L)	60			
TDS (mg/L)	500 to 1,500	1,000		Not of health concern at levels found in drinking water
NH_3-N (mg/L)			1.5	
Sulfate (mg/L)	250	250		Not set

Note: NTU = nephelometric turbidity unit; and TCU = true color unit

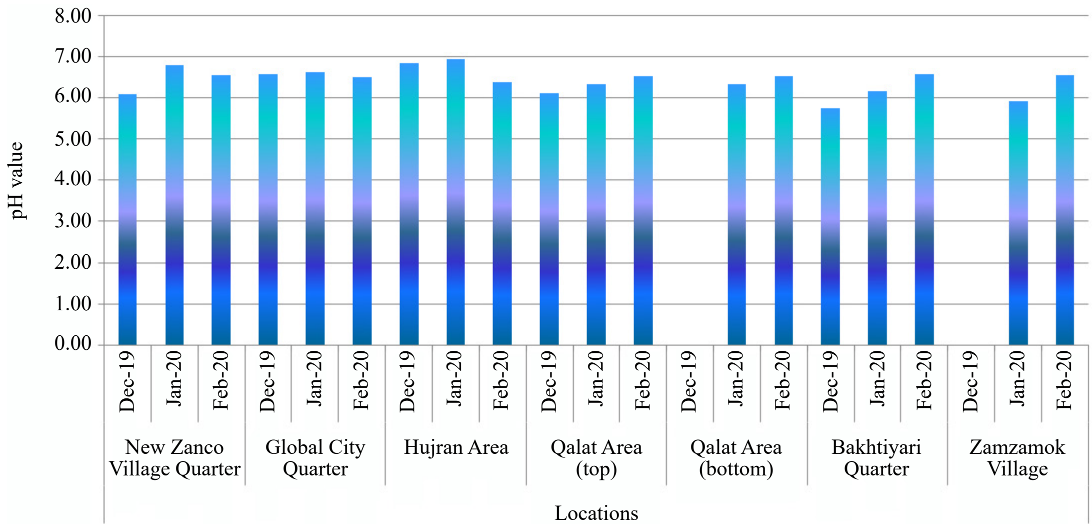
3.2.1 *pH*

In the earlier study, it was assumed that the water in clouds is in equilibrium with atmospheric' carbon dioxide, which leads to a pH of rainwater in equilibrium with atmospheric carbon dioxide at 25 °C of 5.7 [10]. The pH for rainwater samples is shown in Figure 3(a). It was found that the pH figures ranged between 5.92 and 6.94 (average 6.43); this indicates that the rainwater in Erbil City is slightly acidic, which is a little bit out of the acceptable range of the WHO and Iraqi guidelines for drinking water as shown in Table 3 [11-13]. The standard pH values for roof water harvesting, surface runoff, and sand dams are 6.5 to 8.5 [14]. Wu et al. [15] stated that the average value for rainwater samples in China was 7.48, which is higher than the present work. But given the requirements of the water quality standard in Indonesia, which has adopted criteria for water quality based on class, it can be considered that the pH values of the present study meet both classes I and II. Class I is the raw water that has been designated for drinking purposes or for any other use that calls for the water of the same standard as the utility. Water classed as Class II is used for plantation irrigation, freshwater fish farming, infrastructure for water recreation, cattle husbandry, and/or other purposes that call for the water of the same standard [16]. Average pH values were illustrated by the Inverse Distance Weighting (IDW) interpolation method using GIS, as shown in Figure 3(b).

Table 4. Results of rainwater quality for the collected samples

No.	Parameters	New Zanco Village Quarter			Global City Quarter			Hujran Area			Qalat Area (top)			Qalat Area (bottom)			Bakhtiyari Quarter			Zamzamok Village		
		Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20	Dec-19	Jan-20	Feb-20
1	pH	6.09	6.80	6.56	6.57	6.62	6.49	6.85	6.94	6.37	6.11	6.33	6.52		6.33	6.53	5.74	6.17	6.57		5.92	6.55
2	Temperature (°C)	14.5	10.3	11.3	13.2	10.5	11.0	14.4	11.6	11.0	13.4	14.1	12.6		14.1	12.6	13.4	14.7	12.7		14.4	12.7
3	EC (µs/cm)	34.10	33.11	40.86	36.54	60.21	39.60	48.62	21.10	41.08	24.36	27.83	97.05		29.04	98.32	54.81	24.20	57.45		60.50	54.91
4	Total salts (mg/L)	21.83	21.19	26.15	23.39	38.53	25.34	31.12	13.50	26.29	15.59	17.81	62.11		18.59	62.92	35.08	15.49	36.77		38.72	35.14
5	Turbidity (FTU)	1.86	1.21	2.34	1.15	1.34	7.49	5.26	1.43	2.19	2.20	1.75	8.21		1.80	8.31	5.16	2.30	7.81		1.80	7.75
6	Color (Pt. Co.)	13	15	36	12	30	75	24	17	31	3	29	72		31	83	33	19	60		30	78
7	Total acidity (mg/L)	8	8	4	8	8	8	8	8	4	12	10	8		10	8	8	10	8		12	8
8	Total alkalinity (mg/L)	36	28	24	36	36	32	32	24	24	24	32	28		34	28	32	20	32		28	28
9	Total hardness (mg/L)	12	12	16	28	20	20	12	12	15	8	8	26		14	26	28	12	30		22	24
10	Chloride (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
11	DO (mg/L)	7.50	8.40	8.20	7.00	8.20	8.30	7.80	8.60	8.70	8.10	9.10	9.30		8.90	9.10	6.20	8.10	8.30		8.80	8.50
12	Hydroxide alkalinity (mg/L)	24	16	8	8	16	12	20	12	9	16	24	2		20	2	4	8	2		6	4
13	Carbonate alkalinity (mg/L)	12	12	16	12	20	20	12	12	15	8	8	26		14	26	28	12	30		0	0
14	Bicarbonate alkalinity (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	24
15	TS (mg/L)	100	0	0	100	0	0	100	0	0	100	0	100			100	100	0	60		0	60
16	TSS (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0		0	0
17	TDS (mg/L)	100	0	0	100	0	0	100	0	0	100	0	100			100	100	0	60		0	60
18	Fixed residue (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0		0	0
19	Volatile residue (mg/L)	100	0	0	100	0	0	100	0	0	100	0	100			100	100	0	60		0	60
20	NH_3-N (mg/L)	0.82	0.56	0.71	0.55	0.46	1.02	0.51	0.28	0.58	0.34	0	1.01		0	1.07	1.91	0.6	0.77		0.58	0.7
21	Sulfate (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0		0	0

Note: FTU = formazine turbidity unit



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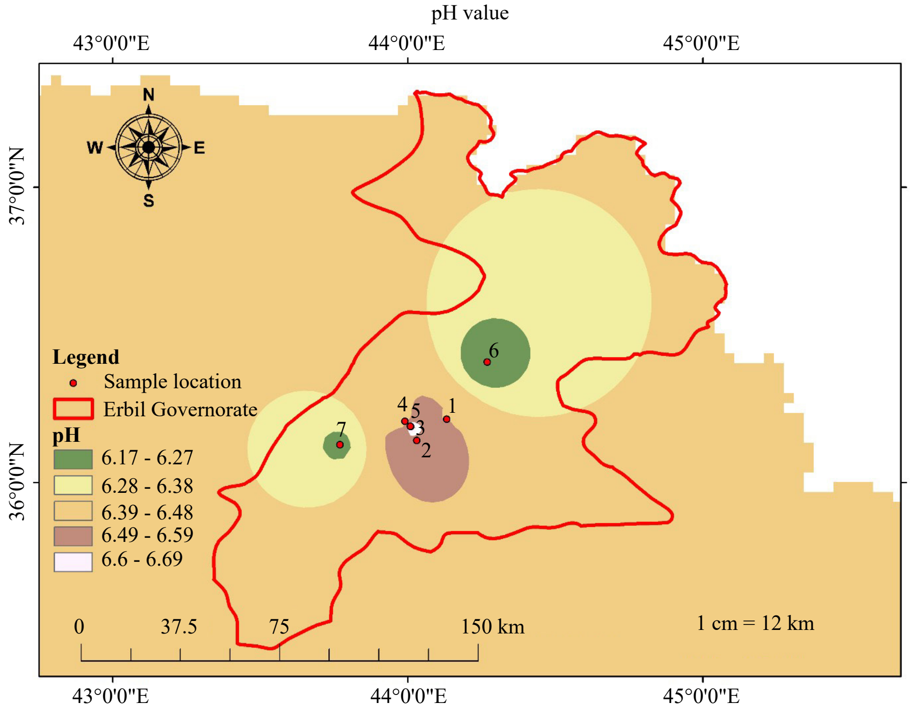


(b)

Figure 3. (a) pH values and (b) pH map of rainwater samples at different locations in Erbil Province

3.2.2 *Total salts*

As known, the rainwater compositions vary geographically, and since Erbil City's location is not near any ocean or a coastal area, it was found that the total salt results in all areas range between 13.5 mg/L and 38.75 mg/L (Figure 4). The obtained results were lower than drinking water standards issued by the Iraqi Central Organization for Standardization and Quality Control, as shown in Table 3 [11]. Rainwater is the cleanest natural water source. Water evaporates from lakes, rivers, and oceans. Later, the evaporated water condenses in the presence of the sun and becomes precipitation. During the vaporization process, all the pollutants are eliminated, and the rain then falls directly to the ground. Since rainwater doesn't contain any ions, it may be utilized in laboratories.

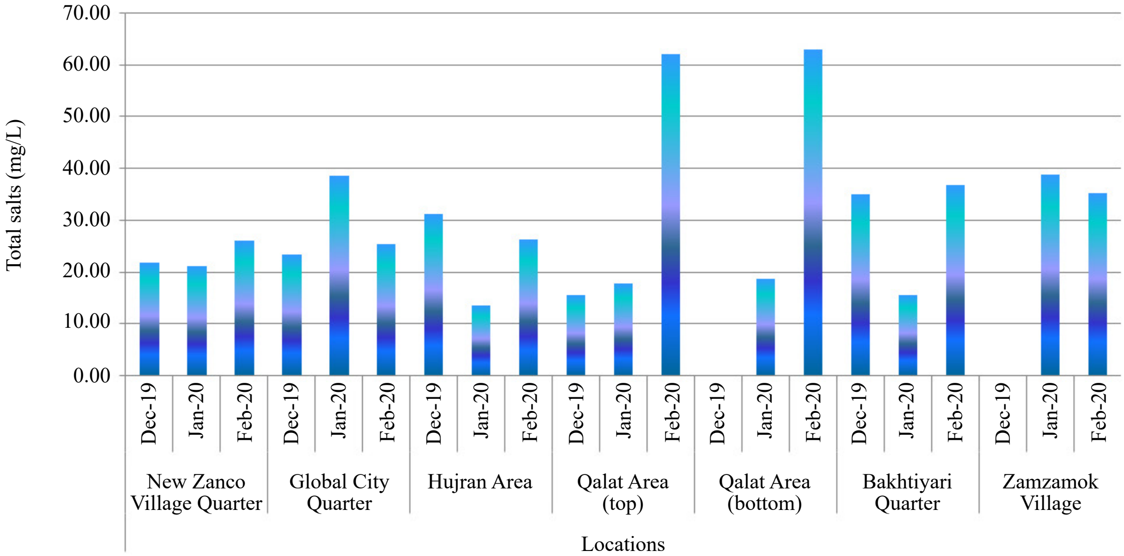


Figure 4. Total salts of rainwater samples at different locations in Erbil Province

3.2.3 *Turbidity*

As a result of suspended particles, water turbidity measures how cloudy a sample of water is. It is crucial to note that the same standard suspensions are used to define the turbidity units: the NTU, the FTU, and the formazine nephelometric unit (FNU), which are considered to be equivalent in value but different in the method of measurement. Hydrazine sulfate and hexamethylenetetramine are present in solutions of 1 NTU (FTU or FAU) at a rate of 1.25 mg/L [17]. The collected data at all locations in the present research agreed with the standards for surface runoff (< 15 NTU or FTU) [11]. Figure 5(a) shows the turbidity values in all areas. It can be noticed that the turbidity of New Zanco Village ranged between 1.8 FTU and 2.3 FTU. In Global City, Qalat Area (top and bottom) and Zamzamok Village had the same result patterns, which started below 2.5 FTU and rapidly increased to more than 7.5 FTU. This sharp increase happened as a result of heavy rain in February; it can be predicted that the wind may have carried the loose soil to the rainwater drops. Turbidity values for all locations ranged from 1.15 FTU to 8 FTU. The top and bottom of the Qalat Area, which is considered an old urban region, had the highest level of rainwater turbidity of 8.3 FTU. A previous study mentioned this type of pollution and showed that the highest level of rainwater pollution usually happens in urban areas, and this is mostly caused by emissions from industry, nearby boiler plants, and power plants [18]. Figure 5(b) illustrates mean turbidity values using GIS.

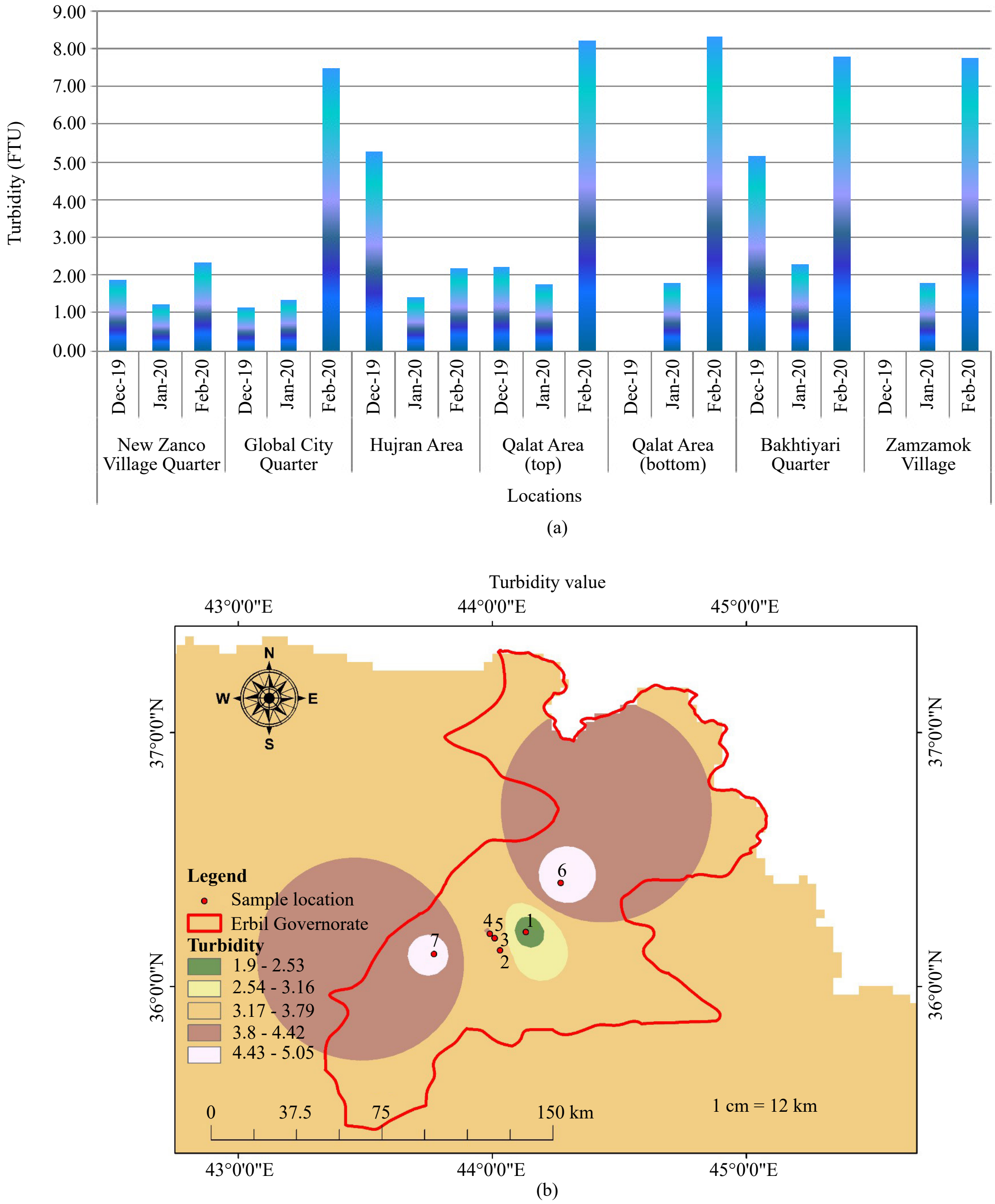


Figure 5. (a) Turbidity values and (b) map of rainwater samples at different locations in Erbil Province

3.2.4 *Color*

In this study, a wide range of color from 3 Pt. Co. to 83 Pt. Co. was reported, as shown in Figure 6(a). It means the rainwater has a trace of color in all areas and is never totally clear; sometimes it looks cloudy and sometimes it looks brown, especially after heavy rain. It can be noticed that all areas in February had out-of-range results, especially in Qalat Area (top and bottom). The change in rainwater color could be an indicator of present pollution because the rainwater color has values of less than 10 units. The pollution happened either naturally, such as through dust, or man-made activities, like smoke and fumes. The allowable accepted value for color in the Iraqi Drinking Water Standard is

5 Pt. Co. There is no color-based WHO health recommendation value. Consumer acceptance may vary; however, it is generally accepted that color levels below 15 TCU are acceptable [12]. Commonly, the Erbil City Center had higher color values when compared with the countryside. Average color values using GIS are shown in Figure 6(b).

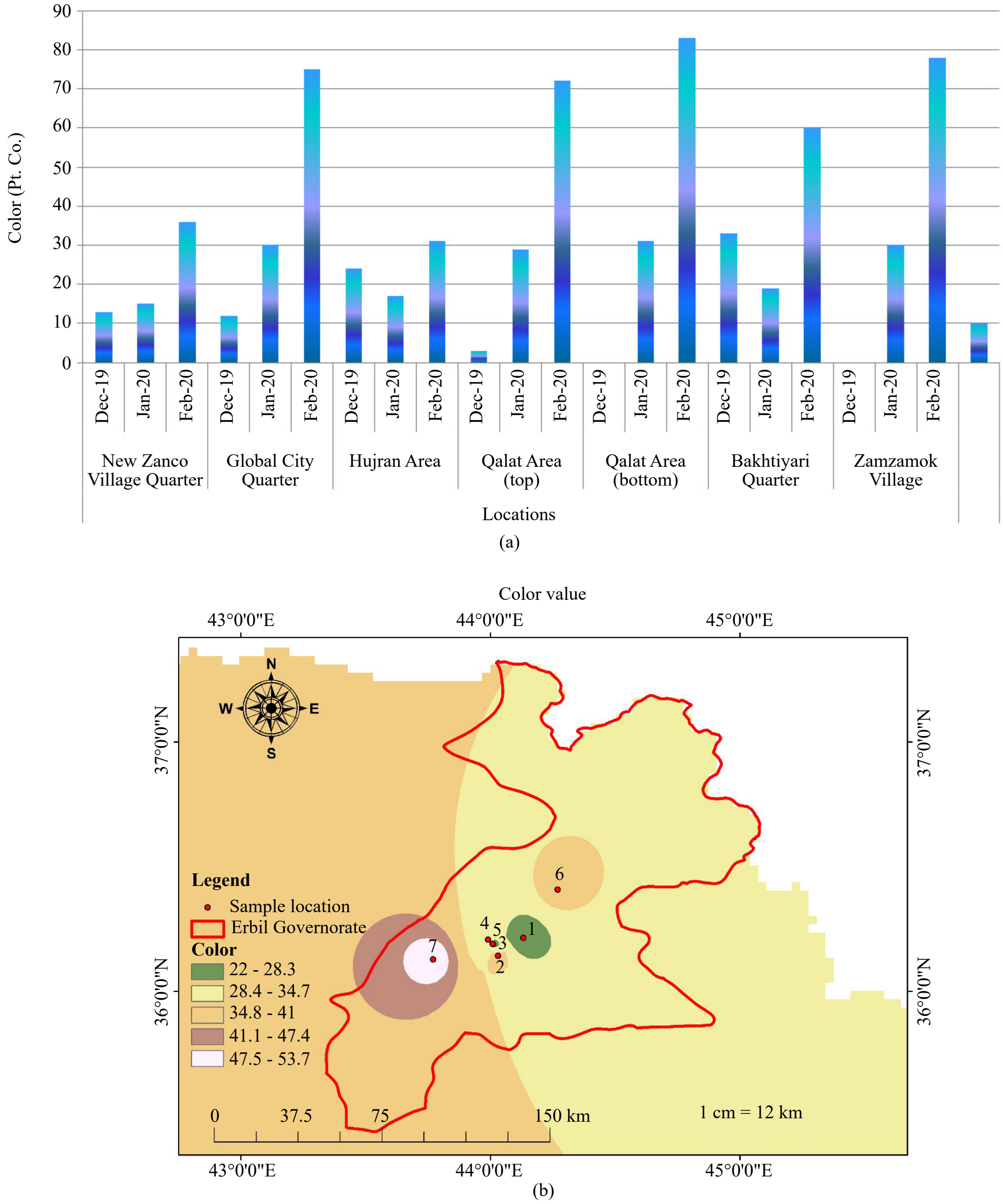
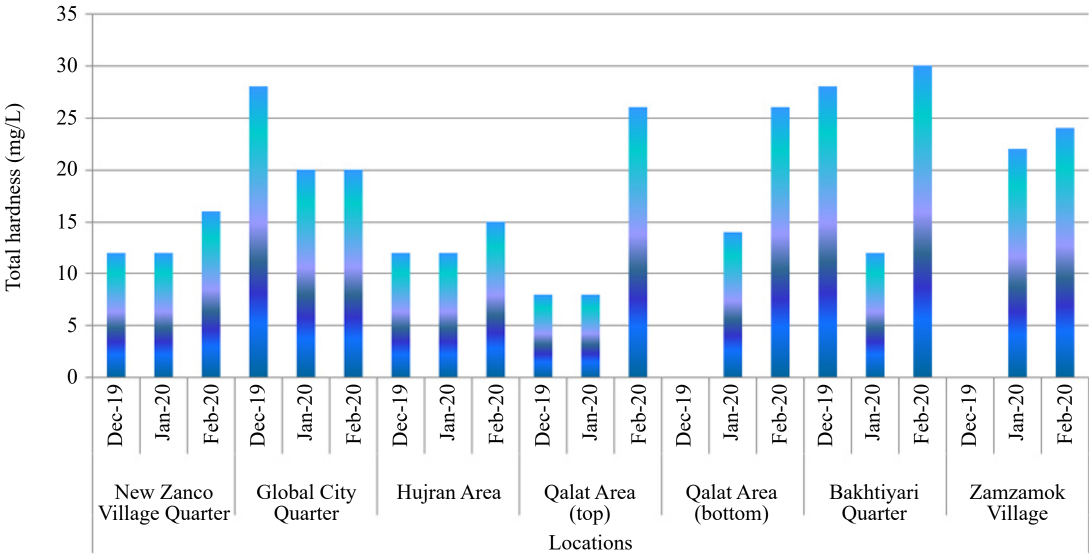


Figure 6. (a) Color values and (b) map of rainwater samples at different locations in Erbil Province

3.2.5 *Total hardness*

Rainwater is naturally soft since its hardness is less than 60 mg/L [19]. The major causes of hardness include calcium and magnesium compounds, as well as a variety of other metals. Figure 7(a) shows that the water was classified as soft since the hardness readings were between 8 mg/L and 30 mg/L. However, it should be noted that Bakhtiyari Quarter and the Qalat Area (top and bottom) both recorded high values of hardness of 26 mg/L and 30 mg/L, respectively. Within the boundaries of Erbil City are these two zones. These locations are heavily populated and congested with automobiles. The mean total hardness values are illustrated in Figure 7(b). In general, hardness in drinking water is not given a specified health-based recommendation value. Also, it was noticed that the degree of water hardness that the general public will tolerate will vary greatly from community to community [12].



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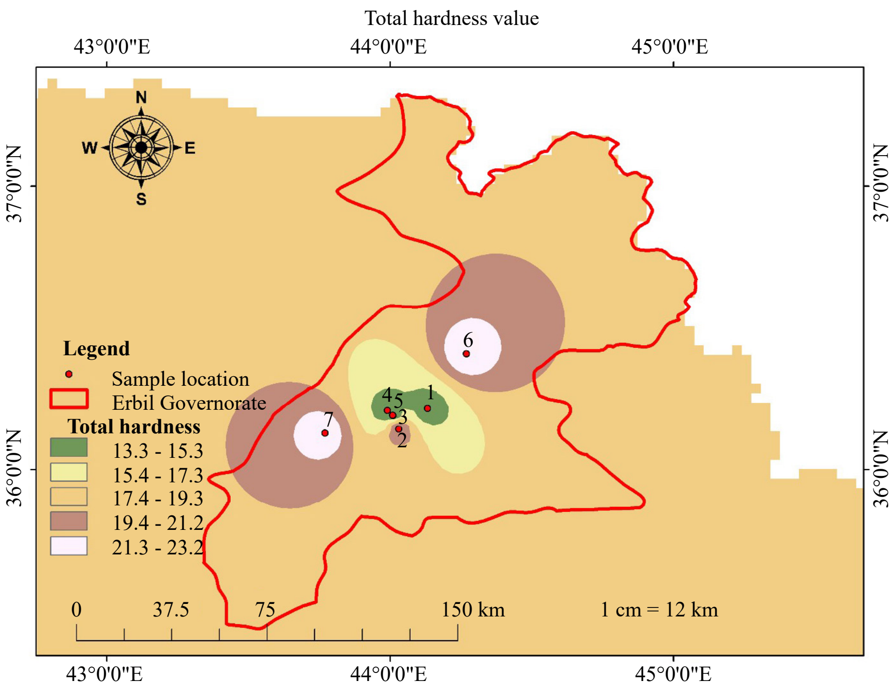
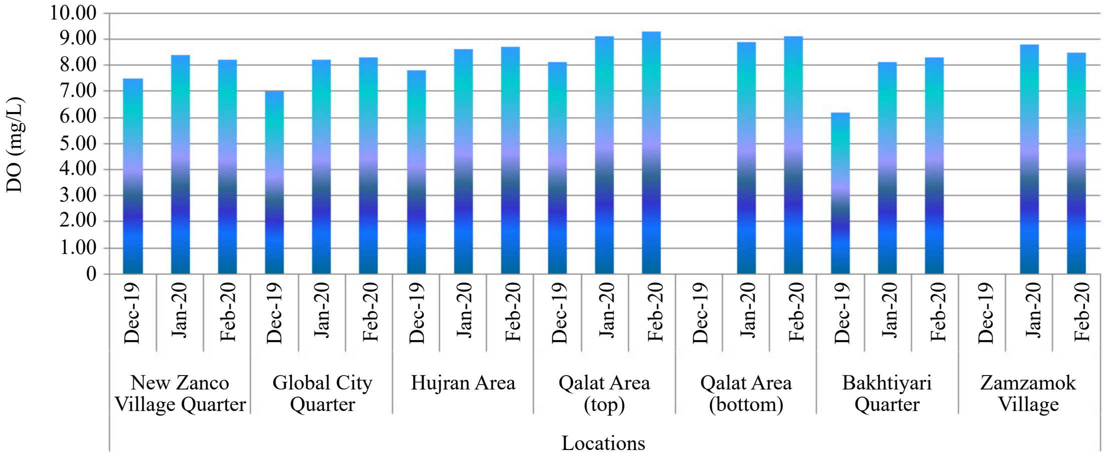


(b)

Figure 7. (a) Total hardness values and (b) map of rainwater samples at different locations in Erbil Province

3.2.6 *DO*

Rainfall can increase the quantity of DO in water, but the amount of oxygen added is dependent on several factors, including the type of rainfall, its intensity, and the temperature of the water. The minimum and maximum values of DO for the collected rainwater samples were 6.2 mg/L and 9.30 mg/L, respectively, as shown in Figure 8(a). It can be seen that the DO values were near saturation. The range for saturated is 6 mg/L to 9.2 mg/L. Rainwater receives DO from the atmosphere, resulting in a high concentration of DO. There were significant connections discovered between variations in average DO and cumulative rainfall. DO values during the rainy season were significantly higher than those during the dry season. It is found that DO and temperature are connected and that rainfall has a favorable impact on DO levels in rivers [20]. Average DO figures are shown in Figure 8(b). No health-based guideline value is recommended [12, 13].



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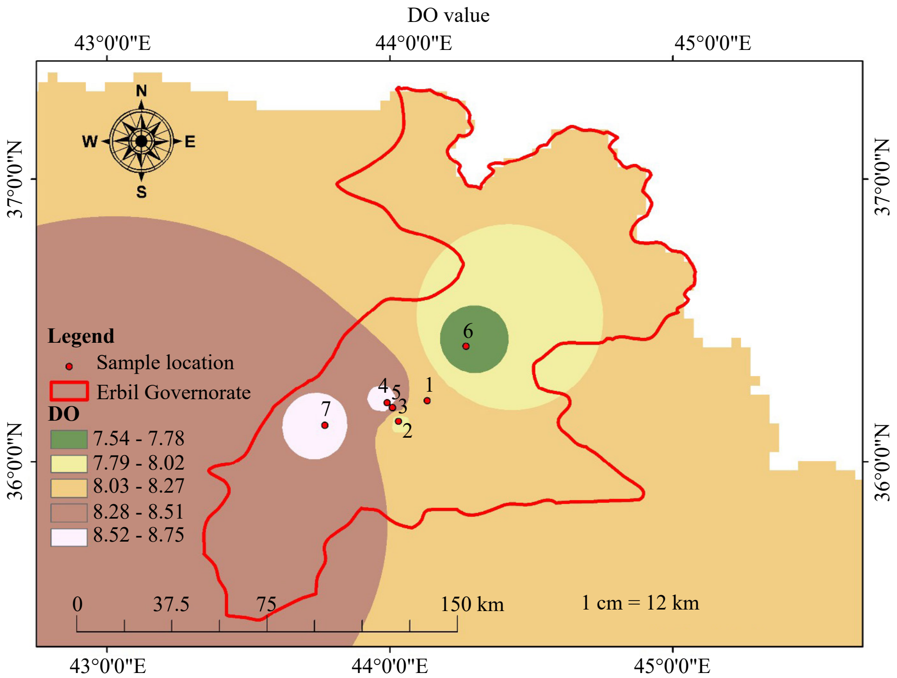
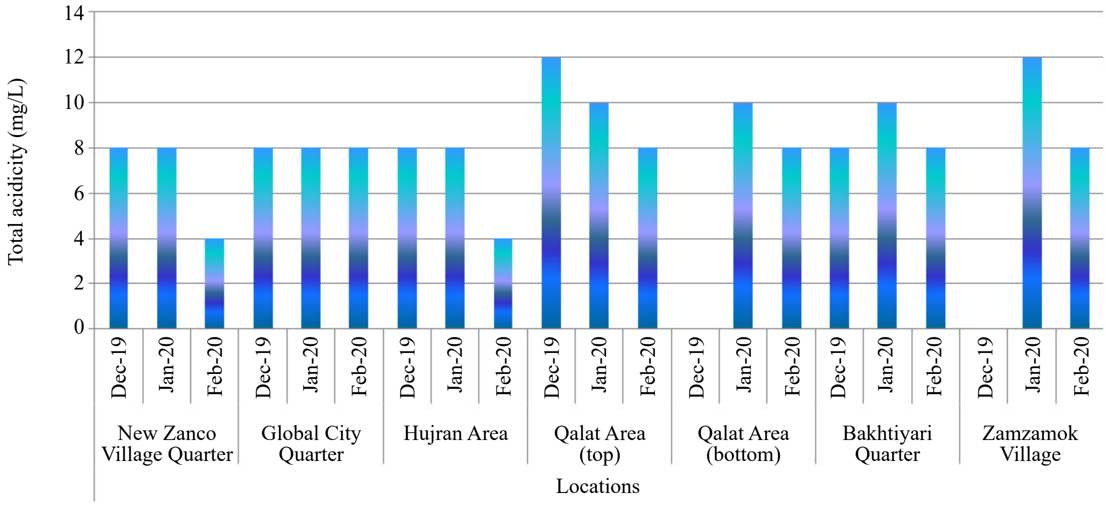


(b)

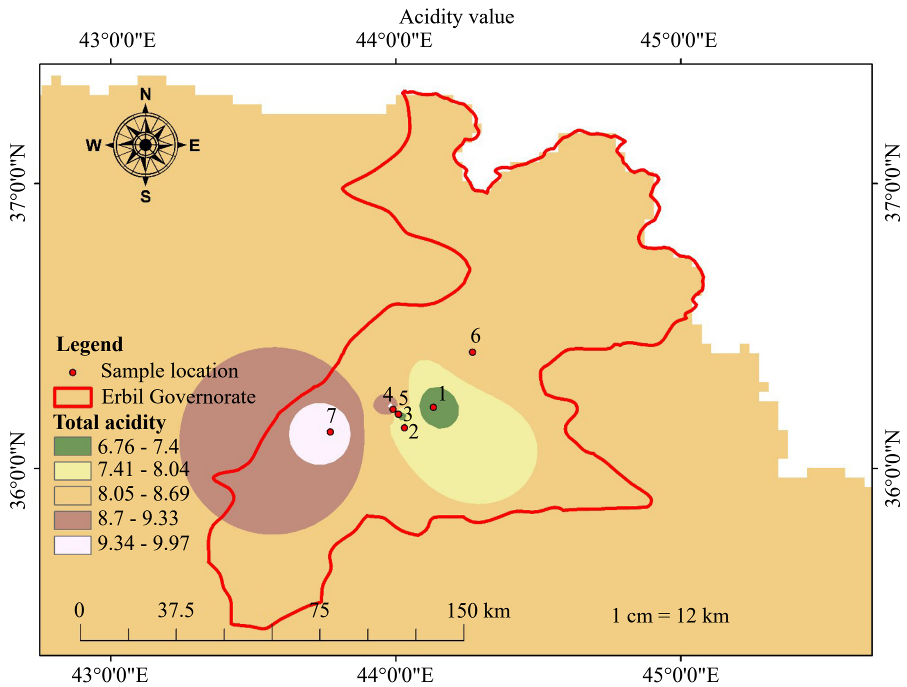
Figure 8. (a) DO values and (b) map of rainwater samples at different locations in Erbil Province

3.2.7 *Total acidity*

Natural rainwater is slightly acidic with an average pH of 5.7. In areas where highly soluble acidic gases such as carbon dioxide, nitrogen dioxide, and sulfur dioxide (both produced by transportation, industrial processes, and fossil fuel generation) are present in the atmosphere, rainwater may be even more acidic. Total acidity in the collected samples varied from 4 mg/L to 12 mg/L (average 6 mg/L). Figure 9(a) shows rainwater samples with low acidity values and Figure 9(b) illustrates average total acidity values. There is no information about the total acidity guidelines for drinking water [12, 13].



(a)



(b)

Figure 9. (a) Total acidity values and (b) map of rainwater samples at different locations in Erbil Province

3.2.8 *Total alkalinity*

As the nature of the rainwater is acidic, where carbon dioxide is dissolved in the rainwater when it falls to the earth's surface, the alkalinity amounts were very low, as shown in Figure 10(a). During the study period, alkalinity readings varied between 20 mg/L and 36 mg/L; these results fall within the WHO and Iraqi standards guidelines for drinking water (200 mg/L), as shown in Table 3 [11-13]. Relations between total alkalinity and total hardness (such as hydroxide alkalinity, carbonate alkalinity, and bicarbonate alkalinity) are given in Table 4. The average total alkalinity figures are shown in Figure 10(b).

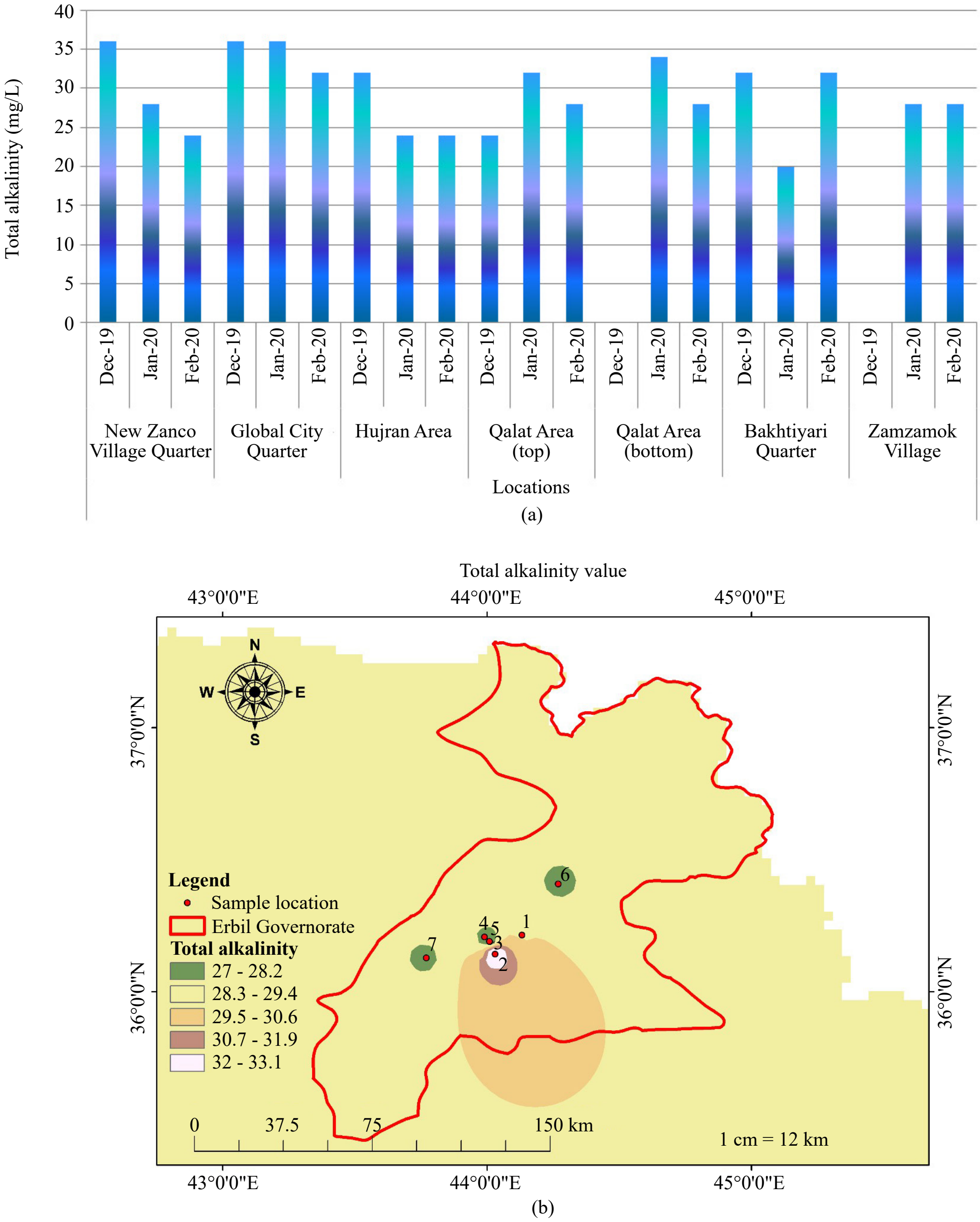


Figure 10. (a) Total alkalinity values and (b) map of rainwater samples at different locations in Erbil Province

3.2.9 *Solids*

TS values for the collected rainwater samples are illustrated in Figure 11. TS includes both TSS and TDS. It can be noticed that TS values were between 60 mg/L and 100 mg/L, which displays the brilliant quality of the TS.

TSS values were not observed in all rainwater samples. The rainwater samples contained TDS only, as shown in Table 4. Figure 12 illustrates TDS values for all locations. Inorganic salts (mostly calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and trace quantities of organic materials are dissolved in water to form TDS [12]. The presence of TDS in rainwater led to pollutants in the atmosphere. It is well known that rainfalls reduce air pollution in the atmosphere because during the falling of raindrops, they capture pollutants and consequently they will be enriched with dissolved ions. Dissolved ions include calcium, magnesium, and potassium ions, which can come from land surfaces or water surfaces. Volatile suspended solids varied from 0 mg/L to 100 mg/L, which meant that low-volatile materials were available in the rainwater samples. Furthermore, total fixed solids were absent in all samples (Table 4). Figure 12(b) shows average TDS values. There are no credible studies on the potential health implications of consuming TDS in drinking water, and no recommended value based on health is available. As a result, there is no WHO recommendation for this criterion. But if we are talking about drinking water, people could find it disagreeable if there are excessive TDS levels in the water they drink [12, 13].

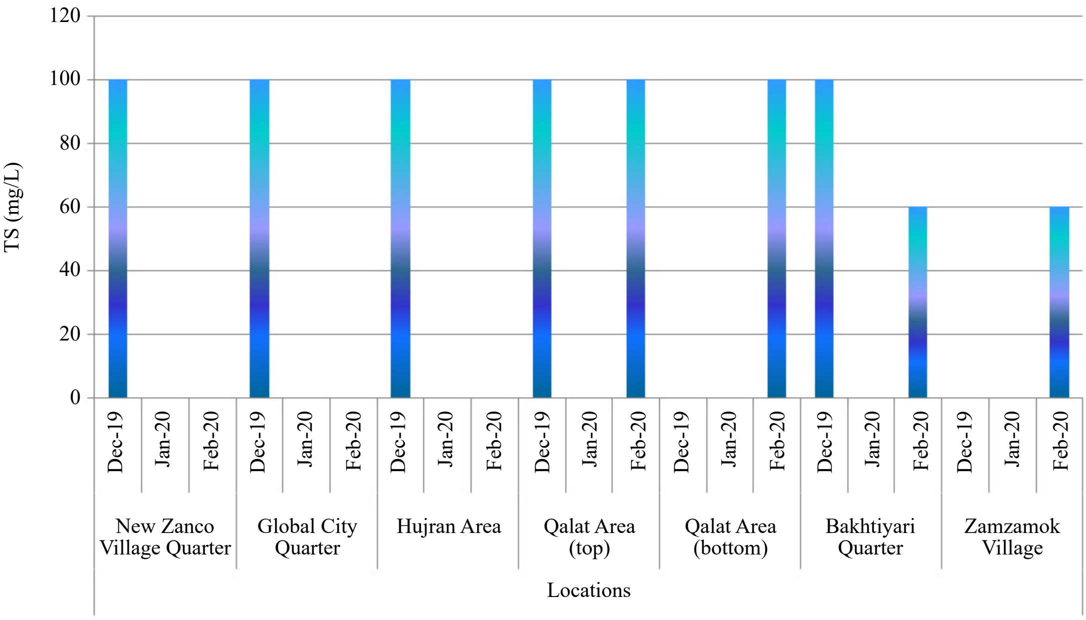
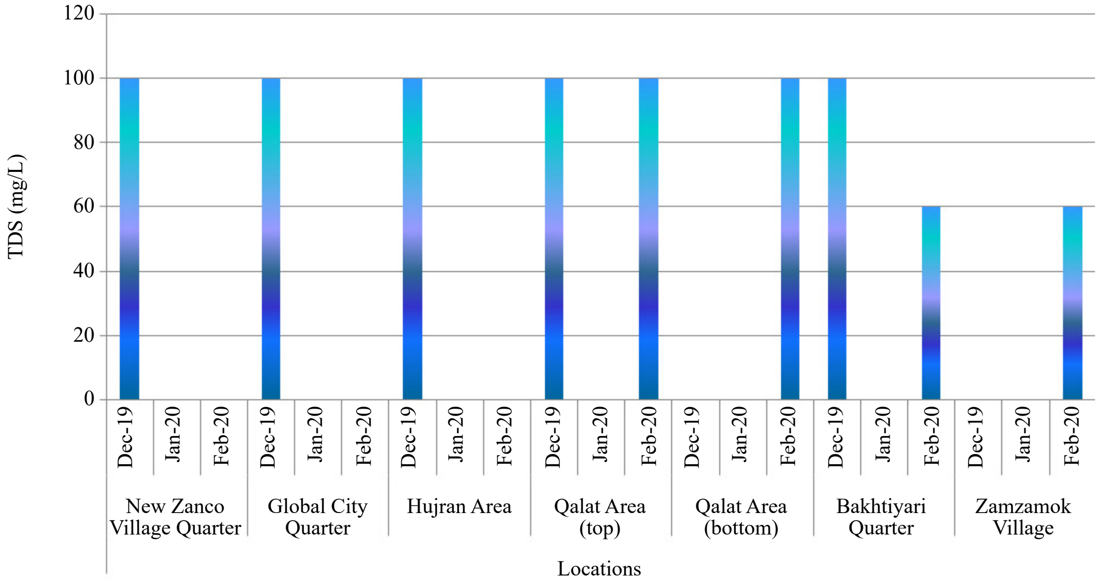
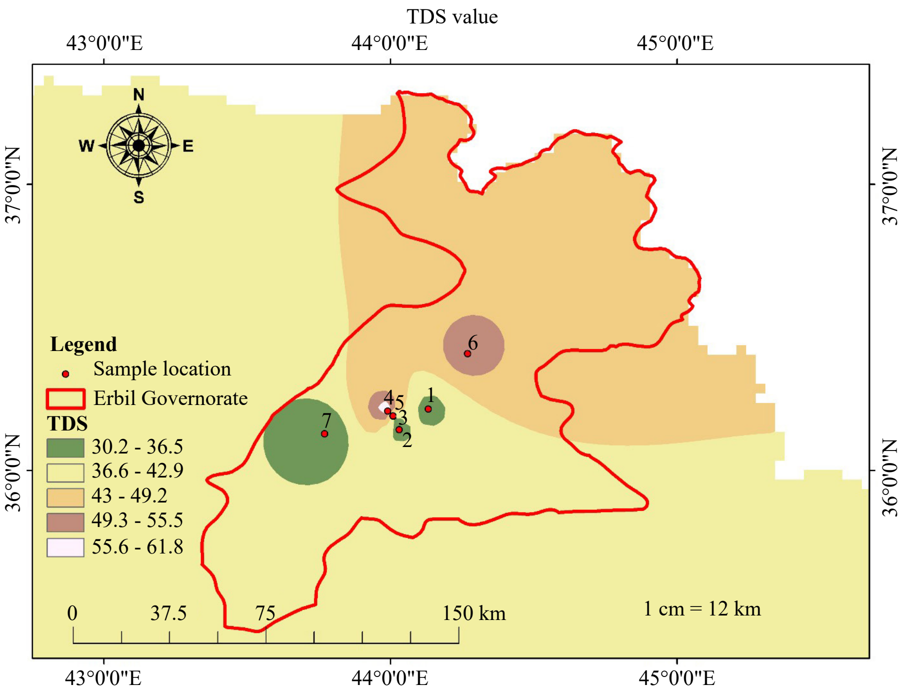


Figure 11. TS values of rainwater samples at different locations in Erbil Province



(a)

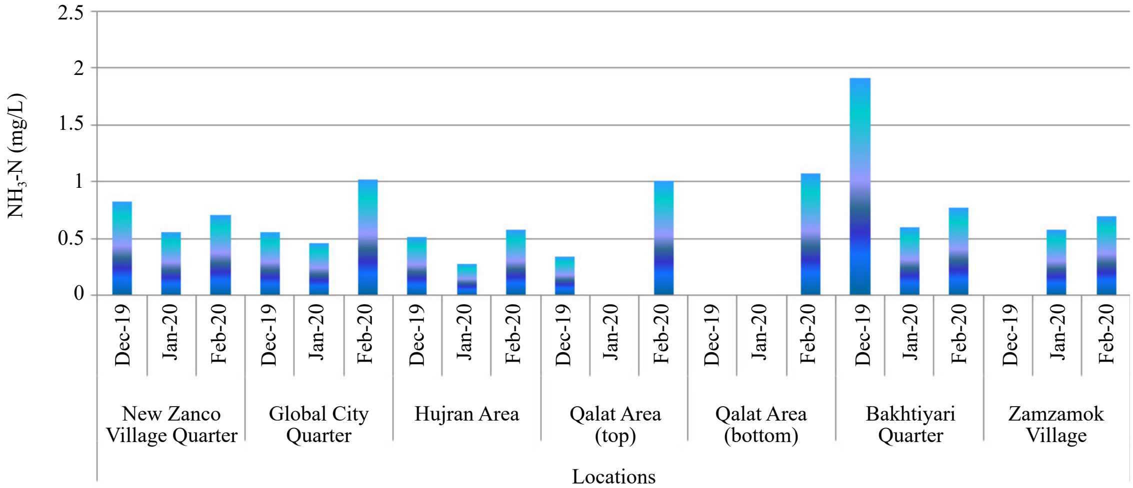


(b)

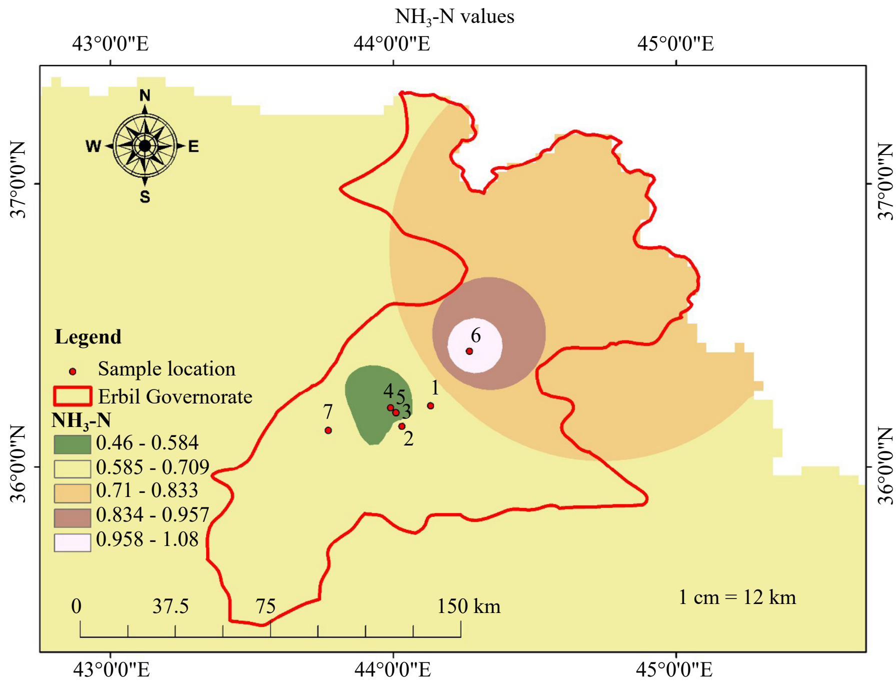
Figure 12. (a) TDS values and (b) a map of rainwater at different locations in Erbil Province

3.2.10 *NH_3-N*

Ammonia does not have a WHO health-based recommendation value. But according to the rainwater quality guidelines [11], the NH_3-N limit should be ≤ 1.5 mg/L because it may cause odor issues. It is not advised to use ammonia in drinking water as a key criterion for first or basic evaluations since it does not immediately affect human health [12, 13]. The values of NH_3-N varied from 0 mg/L to 1.91 mg/L, as shown in Figure 13. It can be seen that ammonia values in the city center were higher than in the countryside and high areas. The authors thought that entering pollutants from the city center into the rainwater led to an increase in NH_3-N in the rainwater samples. All the obtained results were within the limits; only a sample from the Bakhtiyari site exceeded the benchmark.



(a)

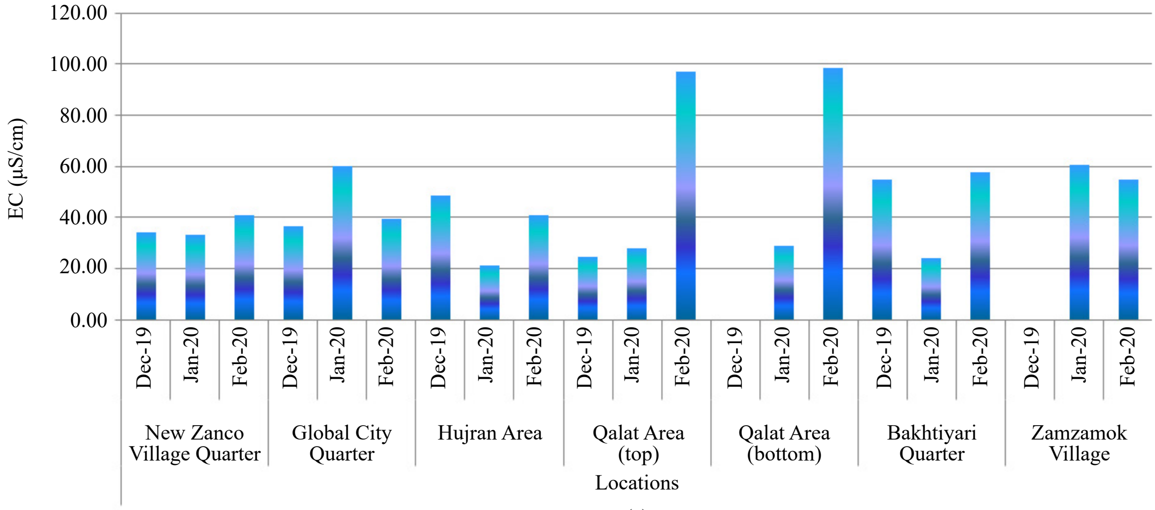


(b)

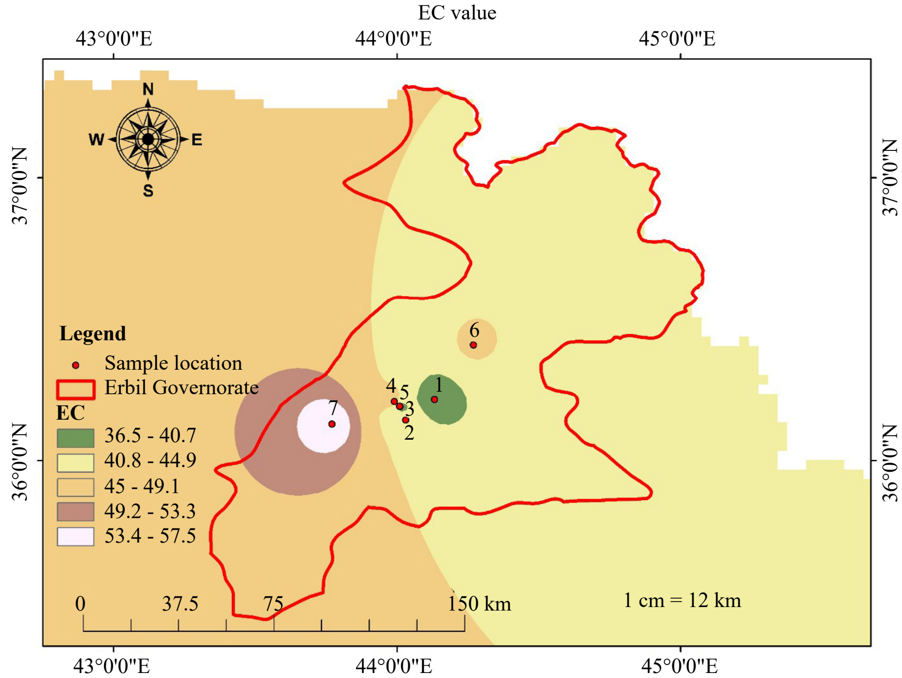
Figure 13. (a) NH_3-N values and (b) maps for rainwater samples at different locations in Erbil Province

3.2.11 *EC*

A proxy indicator of TDS and, consequently, of the taste and salinity of water, which primarily consist of inorganic salts (primarily calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates), is conductivity, the capacity of water to carry an electric charge. Conductivity consequently serves as a proxy for the water's flavor or saltiness. Although no conductivity value is based on WHO health recommendations, it is widely agreed that drinking water becomes noticeably and increasingly unpleasant at levels higher than 1,400 µS/cm (which is similar to a TDS value of about 1,000 mg/L) [13]. Water's capacity to carry electricity is gauged by its EC. The total concentration, mobility, valence, and relative concentration of ions, as well as the water temperature, are all factors that affect EC. In general, a higher EC indicates that the water contains more electrolytes. Figure 14(a) shows the EC values for the seven areas. The EC values ranged from 21.1 µS/cm to 98.32 µS/cm. It can be noticed that rainwater's EC in Erbil City Center was higher than outside the city. Wu et al. reported that the average EC in rainwater in China was less than 100 µS/cm, indicating that the rainwater had a low ion concentration [15]. This confirms that in general, the rainwater samples in this study have low ion concentrations and these levels are somewhat lower than the WHO's recommended standard value (1,000 µS/cm) for drinkable water [12, 13]. Depending on previous studies, if we want to make a comparison between the EC of rainwater, surface water, and groundwater in Erbil Province, it was found that the EC's rainwater quality is lower than the groundwater quality values and the Greater Zab River [20-23]. Average EC values using GIS are illustrated in Figure 14(b).



(a)



(b)

Figure 14. (a) EC values and (b) map for rainwater samples at different locations in Erbil Province

3.3 *The feasibility of using rainwater*

The possibility of rainwater treatment and various uses for drinking, irrigation, fish production, swimming, and construction purposes were discussed.

3.3.1 *Drinking and domestic*

Erbil Province is considered an arid to the semi-arid zone where the average waterfalls between 300 mm and 800 mm with a low risk of flooding and is used for agriculture. Meanwhile, drinking water is derived from surface and groundwater resources (i.e., rivers and wells). Temperature, total EC, salts, total alkalinity, hardness, chloride, solids, and sulfate remained within the allowable limits for the WHO standards [12]. The pH values for rainwater samples were a little bit lower than the limit mentioned for drinking purposes. Based on the pH, turbidity, color, and NH_3-N results obtained in Table 4, rainwater cannot be used directly for drinking purposes [11, 24]. There has been previous research reporting that rainwater in China cannot be used for drinking and this is agreed upon by current research. To minimize the pollutants in the rainwater and make it fit for drinking purposes, the authors suggested simple sedimentation and disinfection processes [15].

3.3.2 *Irrigation*

The common range of pH values for irrigation is 6.5 to 8.4 [25]. The obtained results were a little bit lower than the reported standards; this may be due to the mix of carbon dioxide and other pollutants with the rainwater during rainfall. Regarding chloride concentration, no restrictions were forced on rainwater in Erbil Province for irrigation purposes [26]. Additionally, based on total salt and chloride content, rainwater in Erbil Province areas is considered entirely safe for irrigation [25]. According to EC, total salts, chloride, and sulfate were obtained and rainwater in Erbil Province locations was measured as excellent for irrigation purposes [26, 27]. All EC values were less than 100 µS/cm. So, rainwater samples in Erbil Province are regarded as low-salinity water class C1 and the rainwater is suitable for all kinds of crops and all classes of soils. Allowable under usual irrigation practices except in soils of exceedingly low permeability [26, 28].

3.3.3 *Fish production*

The satisfactory pH limit for fish production in fresh water in Australia, Brunei, Canada, Kenya, Malaysia, and New Zealand varies from 5 to 9 [29]. The pH values achieved for rainwater at Erbil Province locations were acceptable for fish production. Reported data described that the satisfactory DO figure of fresh water in Australia and New Zealand should be greater than 5 mg/L, above 5.5 mg/L in the United Kingdom, and from 3 mg/L to 7 mg/L in Malaysia [29]. The obtained DO values for rainwater samples in Erbil Province varied between 6.2 mg/L and 9.3 mg/L. This outcome shows that rainwater in Erbil Province is aerobic and the environment is appropriate for fish and other aquatic animals.

3.3.4 *Swimming*

The acceptable pH, total alkalinity, total hardness, TDS, and turbidity of water for swimming are 7.2 to 7.8, 60 mg/L to 150 mg/L, 150 mg/L to 1,000 mg/L, 1500 mg/L, and ≤10 NTU, respectively [30]. The pH values of the rainwater were slightly lower than the tolerable limit. The achieved total alkalinity values in rainwater samples at all locations varied from 24 mg/L to 36 mg/L, which remain within the acceptable limit. The obtained figures for total hardness were between 8 mg/L and 30 mg/L, which are regarded as safe for swimming. The TDS values for all samples were less than 1,500 mg/L. Turbidity values ranged from 1.15 NTU to 8.31 NTU. The achieved results indicated that rainwater in Erbil Province was suitable for swimming.

3.3.5 *Construction*

The obtained results for rainwater showed that chloride values were zero. Water standards for fields of construction necessitate chloride concentrations of 500 mg/L for reinforced concrete and 2,000 mg/L for plain concrete [31].

Obtained values of chloride show that water in Lesser Zab can be used for construction purposes as the concentration of chloride is less than 500 mg/L. The maximum TSS for construction is 2,000 mg/L. The water in Lesser Zab is safe for construction because the TSS values range from 200 mg/L to 400 mg/L [31]. Sulfate values were zero and less than the stated standards (400 mg/L). Therefore, rainwater in Erbil Province is safe for construction purposes. The pH values were within neutral conditions and stayed within satisfactory borders.

3.4 *IDW*

The collected data and the results of each sample location are added into GIS to create a map of parameters such as pH, turbidity, EC, TDS, color, total alkalinity, total acidity, and total hardness. To see the change between the values at the locations, the method is based on the degree of similarity between the cells. On the other hand, another study used the same method of interpolation of groundwater tables for the same region and showed the applicability of the method for the study area [32]. IDW determines cell values by using a linearly weighted combination of a set of data. The weight is a function of the inverse distance between points. The surface should be dependent on the location of the variable. The measured data are nearest to the unmeasured locations that have the most influence (values).

4. Conclusion

Rainwater from outside the city was cleaner and had better quality than that inside Erbil City Center. Additionally, the rainwater quality from the mountain zone was better than that of the Erbil City quarters. Investment projects, industrialization, changes in land cover and land use, oil and gas production, smoke from a huge number of cars and electrical generators, etc. impacted the rainwater characteristics in the various zones. Proper water harvesting at different areas and times is necessary. Rainwater from Erbil Province can commonly be used directly for irrigation, fish production, swimming, and construction purposes. For domestic uses, collected rainwater needs some treatment processes, such as plain sedimentation and disinfection. Average rainwater quality parameters were illustrated using GIS. It is recommended to study: 1) rainwater quality in all KRG provinces; 2) snow quality in the KRG; and 3) the impact of climate change and drought years on rainfall intensity, floods, and rainwater quality.

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Conflict of interest

There is no conflict of interest in this study.

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