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RECEIVED :21 /04/2025

ACCEPTED :13/07/ 2025

PUBLISHED :15/10/ 2025

Assessment of Surface and Groundwater Quality of the Alana River Basin Northeast of Erbil City

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Abstract

The water quality assessment of the Alana River Basin is crucial for ensuring the safe use of surface and groundwater for drinking, industry, and agricultural purposes. This study assesses the water quality parameters in the basin through various sources, including surface and groundwater, by examining the biological, chemical, and physical characteristics of the water while considering factors that influence them. Fifteen surface water and three groundwater samples were collected from the Alana River extending to the confluence of the Bekhal, Balakian, and Khalifan Rivers during the dry season (October 2024). Total coliforms, thermotolerant bacteria, and E. coli were evaluated as microbiological parameters. The results of this study show that all surface and groundwater samples conformed to the acceptable limits for drinking set by comparison with WHO and IQS, based on chemical and physical criteria. Additionally, the suitability of water based on average Total Dissolved Solids (TDS)- 237.7mg/L for surface water and 247.3mg/L for groundwater samples, along with the average Total Hardness (T.H.) of 263.6mg/L and 261.9mg/L for surface and groundwater, respectively, suggested that water samples can be classified as harsh freshwater. Surface water and groundwater are classified as Ca-bicarbonate according to Piper and Chadha diagrams. Microbiological indicators revealed that all surface and groundwater samples collected during dry seasons did not comply with WHO guidelines, hence proving their contamination. Consequently, the water in this basin is unfit for direct consumption and necessitates treatment before use.

Keywords:

suitability of water, quality assessment, water resource management, microbiological indicators, contamination.



About the Journal

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1. Introduction

Rivers are the most important natural resources for human life, but they are being polluted by some factors like sewage, industrial, and other human activities (Mandal et al., 2010). Surface water supplies are essential for the advancement of human settlements, industries, and agriculture in societies worldwide. Globally, previous studies have connected the accessibility and allocation of freshwater in river systems to social, economic, and political advancement (Chapman, 1996). The particular characteristics of water, regarding its functional abilities, affect its quality (Tchobanoglous and Schroeder, 1987). Metrics frequently associate these qualities with chemical, physical, and biological aspects. Nowadays, due to environmental pollution and climate change, many countries throughout the world suffer from water supply problems (Hameed et al., 2025). The quality of water in many rivers worldwide has substantially deteriorated in recent decades, perhaps due to human activities (Ochir and Davaa, 2011).

Greater Zab is like a vital lifeline for the Kurdistan region and Iraq, playing a crucial role in supporting local communities, ecosystems, and agriculture. It provides essential water resources for drinking and domestic use. It maintains wetland areas and sustains biodiversity. Agriculture sectors are benefiting from the Greater Zab by ensuring water availability for crops and pastureland (Dilekoğlu et al., 2024). The Alana River is one of the tributaries that feeds into the greater Zab, playing a significant role in maintaining overall health and ecosystem habitats. Because this basin is a tourism area, it can face different environmental challenges, such as pollution from various sources and the effects of climate change, which can directly impact the quality and quantity of water reaching the Greater Zab. Due to this reason, the quality assessment of this river is critical for ensuring that surface water remains safe for drinking, recreation, sustaining aquatic life, maintaining the river's long-term sustainability, and better water resource management in the Kurdistan region. Consequently, evaluating the quality of water resources is an essential procedure for enhancement (Toma, 2012, Al-Timimi and Baktash, 2024). In this study, the water quality index was used to evaluate pollution in surface water and groundwater in Alana River Basin. The index tool seeks to convert complex water quality data into clear and comprehensible information that is both accessible and utilitarian (Toma, 2012).

The quality of most water sources in the Kurdistan region is assessed by various research studies, such as Qader and Rasul (2023), which analyzed the water quality of the Sidakan-Balakyian River, which was of good to excellent quality and was suitable for irrigation according to the physical and chemical properties of river water, and Sh et al. (2024), which assessed surface, subsurface, and groundwater quality of the Balak River, which was of good quality. Moreover, Jirjees (2015) investigated a hydrochemical analysis of the Gibbel Stream in Dinarta / Akre area, to evaluate its quality for drinking water based on WHO and Iraqi standards. Additionally, irrigation suitability was assessed using TDS values, with results indicating that the water is suitable for both domestic and agricultural uses. While Toma (2012) investigated that the water quality of Duhok Lake was poor based on several water samples during three years. Acknowledge the gap in research in the Kurdistan region about water quality is due to minimal studies on how urbanization and tourism affect different water resource quality.

The primary aims of this study are to evaluate the quality of various water resources within the cross-Alana River basin and to ascertain the water quality index.

2. Study Area

The Alana River originates from the mountainous area's northeast of the basin, primarily fed by rainfall and snowmelt. It flows southwest and ultimately drains into the Greater Zab River, acting as a significant tributary in the regional hydrological network. The Alana River Basin (ARB) is in the Kurdistan region, located in the northeast of the Erbil (Hawler) governorate, and lies between N36° 36' 31.88" N and 44° 24' 28.39" E. It belongs to the Khalifan sub district within the Soran district area, figure 1. Generally, Alana Valley is a mountainous area with elevations range from 650 m to more than 2200 m above mean sea level. The approximated total catchment area is about 231 km² this sub-catchment is called Malaccan's Valley. Totally, there are 63 villages in the ARB

with a population of about 28,573 people during 2016; 72% of the population gathered in Khalifan, and 10% of the rest were distributed in 11 villages of sub-catchment and 18% in 20 villages of the main catchment (Sharef et al., 2021). This area contains a lot of beautiful scenes and has many tourism areas with excellent recreational locations, like the well-known one (Fall of Gali Ali). The Alana River plays a crucial role, acting as a vital lifeline for all villages within the basin and providing water resources for economic activity and domestic use. Also, this river helps with industrial, agricultural, recreational, and drinking water demand.

The climate of the study area has been defined by warm summers and cold winters. The mean temperature at winter is 1.6°C, while in the summertime it is 27.8°C. Typically, precipitation occurs from the October until the end of April, subject to climatic change. Precipitation ranges from 600 to 1000 mm, with snowfall measuring between 0.5 and 1 meter (Sharef et al., 2021). The peak temperature in this region surpasses 40 °C throughout the summer, and dust storms are prevalent occurrences. Evaporation rates are elevated in summer owing to elevated temperatures, the lack of cloud cover (intense radiation), and low humidity levels.

Alana River basin is laid within the High Folded Zone (HFZ) (Figure 2), part of an unstable shelf of the Arabian plate formed due to tectonic activity. This zone is one part of the larger Zagros fold-thrust belt (ZFTB), characterized by a series of anticlines and synclines resulting from the collision between the Arabian and Eurasian tectonic plate. The Korek Anticline represents one of the highest and complex structures in the high folded zone, which is trending northwest – southeast direction in accordance with the main trends of Zagros folds (Omar and Othman, 2018).

The various geological formations in the Alana basin, including the sedimentary sequence of the Cretaceous to Tertiary periods (Table 1). The Tertiary deposit includes the Gercus, Khurmala, and Kolosh formations, while the cretaceous deposit consists of the Qamchuqa, Aqra-Bekhma, Shiranish, Balambo, and Tanjero formations (Sissakian, 2013).

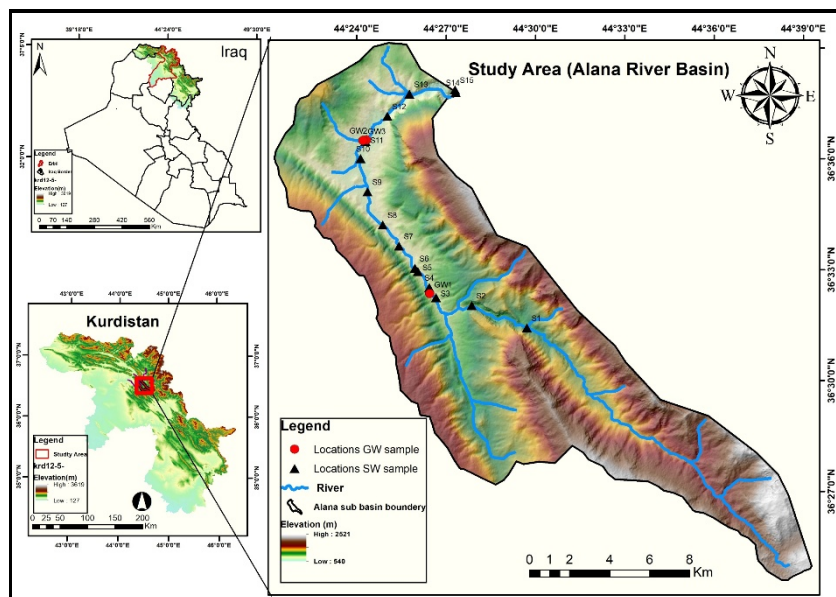
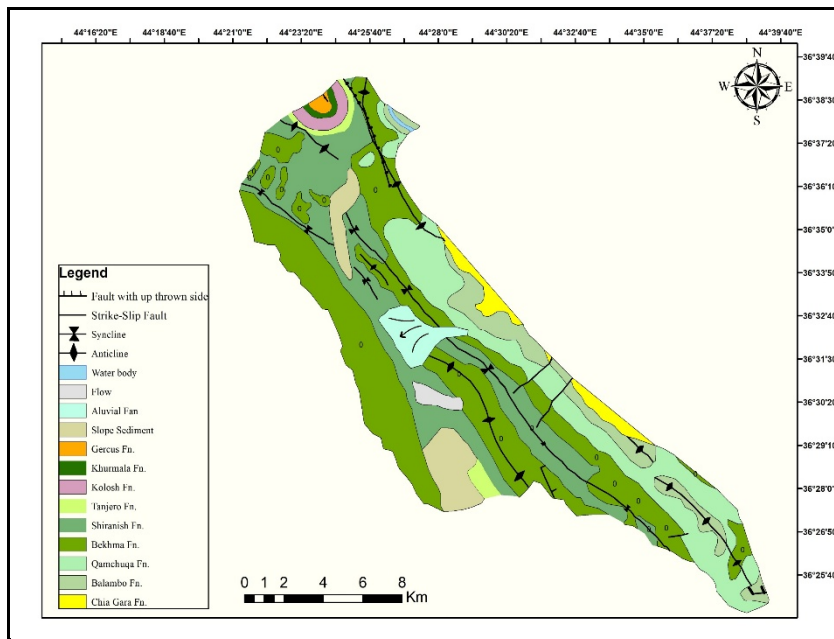


Figure 1. The Location map of the Alana River Basin



**Figure 2. Geological map of the study area, modified after (Omar and Othman, 2018).
Table 1. Descriptions of geologic rock units of Alana River Basin (Sissakian, 2013, Jassim and Goff, 2006).**

Formation	Age	Description
Balambo Formation	Lower Cretaceous	Consists of thinly bedded limestones with intercalations of green marl and blue shales, upwards changes to thinly bedded limestones only
Qamchuqa Formation	Early Cretaceous	Consists of massive limestones and dolomites, usually dark grey.
Aqra-Bekhme Formation	U. Cretaceous	Consists of well bedded limestones and dolostones, locally bituminous, coralline and recrystallized, very hard, light grey in color.
Shiranish Formation	U. Campanian-Maastrichtian	The formation includes of white, yellowish white, and greyish white marly and chalky limestones. This is upwards by thinly bedded or papery marl, blue and grey in color, with minor marly limestone strata (Jassim and Goff, 2006).
Tanjero Formation	U. Campanian-Maastrichtian	The formation consists of alternating dark green and yellowish green shale, claystone, sandstone and siltstone. Some conglomerates occur in the upper part, and some marly limestones in the lower part.
Kolosh Formation	Paleocene	Consists of fairly hard, black claystone, sandstone, with subordinate shales and conglomerate.
Khurmala Formation	Paleocene	Consists of well thickly bedded and hard limestones.
Gercus Formation	Eocene	Consists of fairly hard red claystones, sandstones with subordinate conglomerates.

3. Methodology and Data Collection

3.1 Sampling

Water samples were collected from eighteen different stations across the study area. Fifteen water samples from surface water, two groundwater wells with depths of 5 m, 75 m, and one water treatment project were sampled indicating the presence of both shallow and deep flow zones within the karstified carbonate aquifer. Such variability is characteristic of karst terrains, where conduit flow and fracture networks create irregular groundwater movement. (Table 2). At each station, 500 ml and 250 ml for chemical and biological tests were collected, respectively, to assess water quality. Before sampling, all containers and equipment were washed with doubly deionized distilled water

and then used. Also, for biological analysis, all glass was dried in an autoclave before use to ensure it was free from contaminants. An icebox full of ice was used to store all collected water samples until transport to the laboratory and water tests within 48 hours of sample collection.

3.2 Analysis

Each of (Potential hydrogen (pH), Electrical conductivity (EC), Total Dissolved Solid (TDS), Temperature (T°C) and Dissolved Oxygen (DO) were recorded in the field by using a Function Water Quality Testing Meter Salinity EC Tester with Backlight 5 in 1 Meter (model EZ 9909) and a dissolved oxygen analyzer (model BLE-9100). A buffer standard solution was used for calibration to accurate measurements. Cations, anions, and biological parameters were analyzed for each water sample at Quality Control—Ministry of Municipality & Tourism Directorate of Water & Sewerage, Erbil.

The total hardness, HCO_3^- , Cl^- , and SO_4^{2-} were examined using the EDTA Titrimetric Method, as well as the Ca^{2+} , Na^+ , and K^+ ion concentrations, which were examined using digital flame analyses. Turbidity was examined by using a turbidity meter. Also, Mg^{2+} was examined by equation in relation to total hardness and the calcium. By utilizing a spectrophotometer instrument, the concentration of NO_3^- ions was determined. Also, for detection of total coliform and E. coli, the most probable number, which is a statistical method, is used by utilizing multiple fermentation tubes to estimate bacterial concentration, while using membrane fecal coliform (mFC) agar, which is like a selective medium and blue colony, to detect thermotolerant coliform ((APHA), 2017).

3.3 Hydrochemical analysis & Quality assessment

In this study, the Grapher software was used to create the Piper and Schoeler diagram, which was used to classify water type based on the relationship of ions. The Statistical Package for the Social Sciences (SPSS) was used for performing the correlation coefficient of hydrochemical parameters. While, Microsoft Excel was used for statistical analysis and data visualization. Additionally, this software was utilized to generate several diagrams, including T.H. with TDS (for water quality and usability) Todd and Mays (2004), Chadha diagrams (types of water), and Gibbs diagrams (dominance process control in water chemistry)(Gibbs, 1970). Water Quality Index (WQI) to assess water quality for drinking water (Krishna Kumar et al., 2015), sodium percentage (Na%) and electrical conductivity (EC) based on (Wilcox, 1955), sodium adsorption ratio (SAR) following Richards (1954), permeability index (PI) according to Doneen (1964), residual sodium bicarbonate (RSBC) based on Gupta and Gupta (1987), magnesium adsorption ratio (MAR)(Raghunath, 1987), Kelly's ratio (KR) depend on Kelley (1963), and irrigation water quality index (IWQI) based on Batarseh et al. (2021) to assess the suitability of water for irrigation were employed in this study (Table 3).

Table 2. Sampling locations in Alana River Basin area.

Station	Name	Elevation (m)	Long.	Lat.
1	First water source	957	E 44° 29' 46.1''	N 36° 31' 22.7''
2	Second source (Gurgar) up stream Bnawi	855	E 44° 27' 54.8''	N 36° 31' 59.2''
3	Downstream of Bnawi village	796	E 44° 26' 42.9''	N 36° 32' 11.7''
4	Up stream of Alana village	787	E 44° 26' 29''	N 36° 32' 28''
5	Downstream of Alana River	777	E 44° 26' 06''	N 36° 32' 54''
6	Up stream of Rumawezh	779	E 44° 26' 00''	N 36° 32' 59''
7	Downstream of Rumawezh	751	E 44° 25' 28''	N 36° 33' 35''
8	Up stream of Sharkan	733	E 44° 24' 55''	N 36° 34' 09''
9	Downstream of Sharkan	707	E 44° 24' 24''	N 36° 35' 03''
10	Beginning of Khalifan sub.d	680	E 44° 24' 09.5''	N 36° 35' 56.5''
11	Middle Khalifan	677	E 44° 24' 19''	N 36° 36' 25''
12	End of Khalifan	676	E 44° 25' 02.8''	N 36° 37' 05.4''
13	Up stream of Gali Ali Bag	639	E 44° 25' 47''	N 36° 37' 42''
14	Downstream of Gali Ali Bag	529	E 44° 27' 20''	N 36° 37' 45''
15	Mixing all rivers	592	E 44° 27' 19''	N 36° 37' 49''
16	Ground water well(75m)	811	E 44° 26' 30''	N 36° 32' 18''
17	Ground water well (5m)	678	E 44° 24' 21''	N 36° 36' 27''
18	Water treatment of Khalifan	680	E 44° 24' 14''	N 36° 36' 26''

Table 3: Equations and classifications used for assessing of Alana River Basin

Quality Index (Reference)	Categories	Ranges
Total Hardness (TH) (Todd and Mays, 2004) $TH = 2.497 Ca^{2+} + 4.115Mg^{2+}$	Soft	$0 < TH \leq 60$
	Moderate	$61 < TH \leq 120$
	Hard	$121 < TH \leq 180$
	Very hard	> 181
Electrical Conductivity (EC) (Wilcox, 1955) ($\mu\text{s}/\text{cm}$)	Excellent	$< 250 \mu\text{s}/\text{cm}$
	Good	250 – 750
	Permissible	750-2250
	Doubtful	2250 – 5000
	Unsuitable	> 5000
Percent sodium (%Na) (Wilcox, 1955) $Na\% = \frac{Na + K}{Ca + Mg + K + Na}$	Excellent	< 20
	Good	20.1-40
	Permissible	40.1-60
	Doubtful	60.1-80
Sodium Adsorption Ratio (SAR) (Richards, 1954) $SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$	Very low	< 2
	Low	2.1–12
	Medium	12.1–22
	High	22.1–32
	Very high	32
Permeability index (PI) (Doneen, 1964) $\frac{Na^{+} + \sqrt{HCO_3^{-}}}{Na^{+} + Mg^{2+} + Ca^{2+}} \times 100$	Suitable	$< 75\%$
	Unsuitable	≥ 75
Residual sodium bi-carbonate (RSBC) (meq/L)(Gupta and Gupta, 1987) $RSBC = (HCO_3^{-} - Ca^{2+})$	Satisfactory	< 5
	Marginal	5 – 10
	Unsatisfactory	≥ 10
Magnesium adsorption ratio (MAR) (Raghunath, 1987) $MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	Permissible	0–50
	Unsuitable	> 50
Kelly's ratio (Kelley, 1963) $KR = \frac{Na^{+}}{Mg^{2+} + Ca^{2+}}$	Suitable	< 1
	Unsuitable	≥ 1
Irrigation Water Quality Index (IWQI) (Batarseh et al., 2021) $IWQI = \sum_{i=1}^n qiwi$	No restriction (NR)	$85 \leq 100$
	Low restriction (LR)	$70 \leq 85$
	Moderate restriction (MR)	$55 \leq 70$
	High restriction (HR)	$40 \leq 55$
	Severe restriction (SR)	$0 \leq 40$
Water quality index (WQI)(Krishna Kumar et al., 2015) $RW = \frac{wi}{\sum_i^n wi}$, $Qi = \left(\frac{Ci}{Si}\right) \times 100$, $Qi pH = \left[\frac{Ci - Vi}{Si - Vi}\right] \times 100$, $SI = RW \times Qi$, $WQI = \sum SI$	Excellent water	< 50
	Good water	50.1-100
	Poor water	100.1-200
	Very poor water	200.1-300
	Water unsuitable for drinking purposes	> 300

4. Results and Discussion

4.1 Physicochemical Properties

The results of the physical and chemical analysis of the surface and groundwater samples collected in October (2024) are shown in Table 4a and Table 4b. This outcome is ascribed to dispersed particulates from agricultural land transported by runoff water. Human action is the origin of all these disparities.

Table 4a. Comparison of physicochemical variables of the surface water from the studied area with the international ((WHO), 2017), and Iraqi Standard of Drinking Water (IQS, 2009).

Parameters	Units	Range	Average	SD	Guideline -2011	WHO (2017)	IQS (2009)
T	°C	17-24.9	20.7	2.6	....	....	....
pH	-	6.8 - 7.88	7.5	0.3	6.5-8.5	6.5-8.5	6.5-8.5
EC	µS/cm	370-538	476.1	42.4	2000	1000	2000
TH	Ppm	233.3-314.4	263.6	27.2	450	200	500
DO	Ppm	6.4-8.7	7.5	0.7	....	....	....
Turb.	NTU	0.2-4.5	1.7	1	5	5	5
TDS	Ppm	187-286	237.7	20.4	1000	500	1000
Ca ²⁺	Ppm	30-68	48.9	10	75	100	150
Mg ²⁺	Ppm	29-47	34.4	5.2	50	30	100
Na ⁺	Ppm	0.3-8.6	4.5	2.2	200	200	200
K ⁺	Ppm	0.2-2	1.1	0.4	12	10	12
HCO ₃ ⁻	Ppm	230-310	268.7	22	500	300	600
SO ₄ ²⁻	Ppm	9-19.75	12.2	2.9	250	250	400
Cl ⁻	Ppm	4.0-11	6.5	1.9	250	250	350
NO ₃ ⁻	Ppm	7.3-28	11.0	4.8	50	50	50

Table 4b. Comparison of physicochemical variables of the groundwater from the studied area with the international ((WHO), 2017), and Iraqi (IQS, 2009) standards for drinking water quality.

Parameters	Units	Range	Average	SD	Guideline -2011	WHO (2017)	IQS (2009)
T	°C	20.2-27	23.3	3.4	....	....	....
pH	-	6.9-7.75	7.2	0.5	6.5-8.5	6.5-8.5	6.5-8.5
EC	µS/cm	433-593	497.0	84.7	2000	1000	2000
TH	Ppm	238.5-286.6	261.9	24.1	450	200	500
Turb.	NTU	0.4-1.3	0.7	0.5	5	5	5
DO	Ppm	5.6-7.4	6.7	1.0	....	....	....
TDS	Ppm	218-297	247.3	43.2	1000	500	1000
Ca ²⁺	Ppm	45-67	54.3	11.4	75	100	150
Mg ²⁺	Ppm	27-36	30.7	4.7	50	30	100
Na ⁺	Ppm	2.0-10.4	6.5	4.2	200	200	200
K ⁺	Ppm	0.8-2.7	1.6	1.0	12	10	12
HCO ₃ ⁻	Ppm	250-275	261.7	12.6	500	300	600
SO ₄ ²⁻	Ppm	8.0-30.0	18.7	11.0	250	250	400
Cl ⁻	Ppm	4.0-8.0	6	2.0	250	250	350
NO ₃ ⁻	Ppm	8.0-9.0	8.7	0.6	50	50	50

The results show a clear difference in parameters between surface and groundwater samples. pH and temperature of surface water were lower than in groundwater due to seasonal and atmospheric changes. Surface water has a high value of DO compare with groundwater, consistent with photosynthetic activity and air-water exchange. Also, turbidity of surface water varies with groundwater due to suspended particles or surface runoff. Groundwater has a high concentration of TDS, EC, HCO₃, and Ca; this is due to prolonged water-rock interaction and mineral dissolution. This finding aligns with the interpretation of Abbas and Hassan (2018), which pointed out that Iraq's water system is influenced by a high content of bicarbonate and carbonate. NO₃ of surface water was varied and higher concentration with groundwater, as a result of surface water being impacted by contamination sources such as sewage of domestic use or municipal wastewater. This variability highlights that distinct hydrochemical characteristics are influenced by geological and environmental factors. Adesakin et al. (2020) interpreted that the high value of TDS recorded from

river and reservoir water might be due to agricultural runoff, other human activities like washing.

When comparing the physicochemical variables against the worldwide standards set by World Health Organization (WHO) in 2017, the WHO Guidelines following Edition (2011), and Iraq's IQS in 2009, which are requirements for drinking water. It was discovered that averages of all parameters were within the limits of standards, which means that the surface and groundwater from Alana River Basin are acceptable for human consumption and meet all relevant Iraqi and international standards (Tables 4a and b). This result is associated with the finding of (Alhadithi, 2018). But nitrate levels in surface water require monitoring to avoid health risks because they can cause health issues like blue baby syndrome and can impact aquatic ecosystems by reducing water clarity and oxygen availability.

The common source pollution of DO, turbidity, and nitrate suggests that this pollution comes from agricultural fertilizer, urban wastewater, or atmospheric deposition. While TDS, EC, and mineral content in groundwater could come from anthropogenic activity, leaching of agriculture, or reflect weathering of carbonate rock. Which can cause kidney stress and affect freshwater ecosystems. This pollution should be mitigated by improving treatment facilities to reduce nitrate and organic pollutant discharge or monitoring programs.

Figure 3. Pearson's Correlation Coefficient (r) of the chemical parameters in the study area.

Correlations														
	T	Ph	Ec	TU	TDS	HCO ₃	Cl	SO ₄	Ca	Mg	Na	K	NO ₃	DO
T	1													
Ph	0.136	1												
Ec	0.435	-0.224	1											
TU	0.120	.527*	-0.367	1										
TDS	.493*	-0.208	.991**	-0.356	1									
HCO ₃	-0.303	-0.272	0.013	0.126	-0.076	1								
Cl	0.034	-0.163	0.319	-0.009	0.277	.625**	1							
SO ₄	-0.009	0.236	0.001	0.050	-0.040	0.058	0.063	1						
Ca	0.101	-0.404	0.145	0.162	0.104	.718**	0.419	0.176	1					
Mg	-0.335	0.355	-0.175	-0.015	-0.230	0.162	0.195	0.071	-0.388	1				
Na	0.237	-0.028	0.384	-0.060	0.334	.523*	0.410	.546*	.611**	-0.023	1			
K	0.233	-0.229	.489*	-0.191	0.447	.472*	0.322	0.376	.616**	-0.056	.936**	1		
NO ₃	0.125	0.200	-0.445	.785**	-0.432	0.308	0.190	0.098	0.410	-0.079	-0.013	-0.138	1	
DO	-0.352	0.276	-0.162	0.201	-0.189	0.180	-0.008	-0.228	-0.032	-0.022	-0.344	-.480*	0.069	1

The correlation coefficient (Figure 3) proved that the relationship between TDS and EC was a strong positive correlation. The relations and comparisons presented are based on a Function Water Quality Testing Meter Salinity EC Tester device measured values. This result aligns with (Sh, 2024). (DO and K) and (DO with T) have an inverse correlation, with increasing potassium ions and increasing temperature, dissolved oxygen becoming decreased, which can affect aquatic life. The negative correlation between pH and K in the study area is due to the unique geochemical environment of this region, which may be influenced by Carbonate rock interactions and ion exchange processes, that reduce potassium availability as pH rises. Also, turbidity and nitrate have a possible correlation as a result of higher runoff possibly increasing both parameters in surface water. The relationship between Ca and HCO₃ was a strong positive correlation, suggesting that the presence of bicarbonate might be influencing hardness balance of water.

4.2 Bacteriological Analysis

Figures 4a and b show the results of total coliform, thermotolerant, and E. coli studied at different samples along the study area. The average values of total coliform were 16 MPN/100 ml in surface water and 11.5 MPN/100 ml in groundwater samples. Thermotolerant coliforms, which indicate a greater degree of fecal pollution; the average concentration of this pollutant in surface water was 5.1 MPN/100 ml, whereas in groundwater it was 1.7 MPN/100 ml. Also, demonstrating

concentration levels of *Escherichia coli* were 5.1 MPN/100 mL in surface water and 1.7 MPN/100 mL in groundwater.

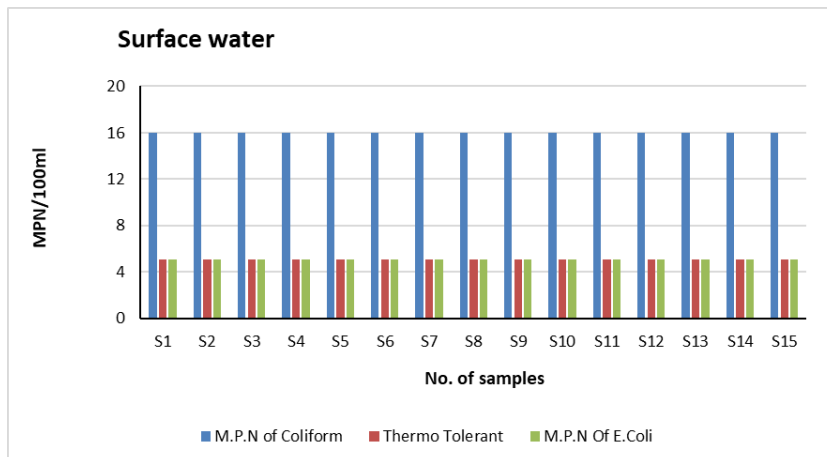


Figure 4a. Microbiological indicators of study area.

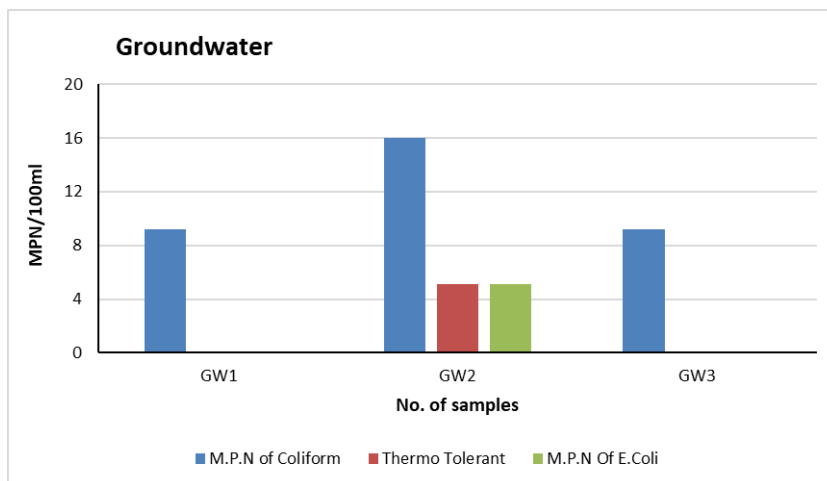


Figure 4b. Microbiological indicators of study area.

The high levels of Total coliform, thermotolerant, and *E. coli* that were marked in the Alana water basin compared with WHO guidelines for drinking safe water indicate that this water is contaminated with fecal matter. This is due to the many municipal waste water sources discharged directly into these bodies of water without treatment. This result is associated with Páll et al. (2013), which states that human activity plays a significant role in this category of contamination. To protect water bodies from this pollution, wastewater should be treated with modern technology, better management of sanitation systems, and education awareness about wastewater treatment. Because this pollution in water directly impacts human health, such as causing hepatitis and cholera. Also, it can decrease DO, which is harmful for aquatic life and has a negative environmental impact. Additionally, it can affect the ecosystem balance by disrupting natural microbial populations. Similar studies, like Elahcene et al. (2019), show that the presence of these indicators in water poses severe health risks to consumers and should not be used for direct human consumption without treatment. Also, Nduka et al. (2008) reported that DO oxidizes both organic and inorganic substances, thereby interfering with their capacity to constitute a nuisance to the consumer. Dissolved oxygen may not have a direct health hazard to humans, but it could have effects on other chemicals in the water (Olajire and Imeokparia, 2001). Dissolved oxygen is an important water quality parameter and has special significance for aquatic organisms in natural waters (Wilcock et al., 1981).

4.3 Hydrochemical Formula and Type of Water

According to the results of the hydrochemical formula of water (Table 5), the Piper (Figure 5) and Chadha diagrams (Figure 6) detect that the surface and groundwater from this river basin are Ca-bicarbonate. This is due to the water in this region flowing through these different geological formations, which consist of limestone or dolomite rocks. Also, both water resources in the Alana basin are distributed in rock dominance from the Gibbs diagram which align with founding Dara et al. (2024) (Figure 7a and b). This result means that the water chemistry of this basin is influenced by the weathering of minerals or the dissolution of minerals from the surrounding rock. This finding was associated with the study of (Sh et al., 2024), which suggested that this distribution was more a result of water interaction with rock and soil than due to precipitation.

Table 5. Hydrochemical formula of difference source of Alana River Basin.

Water resources	Hydrochemical Formula	Type of water
Surface water	TDS (235mg/l) $\frac{HCO_3^- (87.75).SO_4^{2-} (5.47).Cl^- (3.61).NO_3 (3.50)}{Mg^{+2} (52.41).Ca^{+2} (43.44).Na^+ (3.46).K^+ (0.52)}$ pH(7.53)	Mg, Ca-Bicarbonate
Groundwater	TDS(257mg/l) $\frac{HCO_3^- (82.54).SO_4^{2-} (5.55).Cl^- (3.41).NO_3 (2.81)}{Ca^{+2} (53.03).Mg^{+2} (42.36).Na^+ (4.84).K^+ (0.62)}$ pH(6.94)	Ca, Mg-Bicarbonate

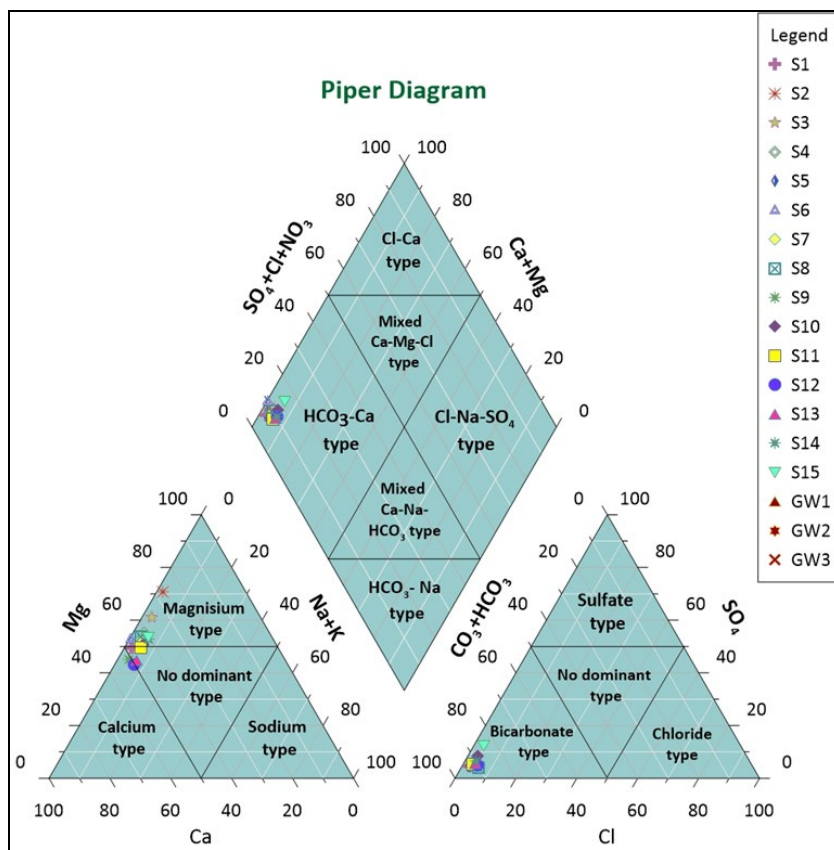


Figure 5. Piper diagram of surface and ground water samples (Piper, 1944).

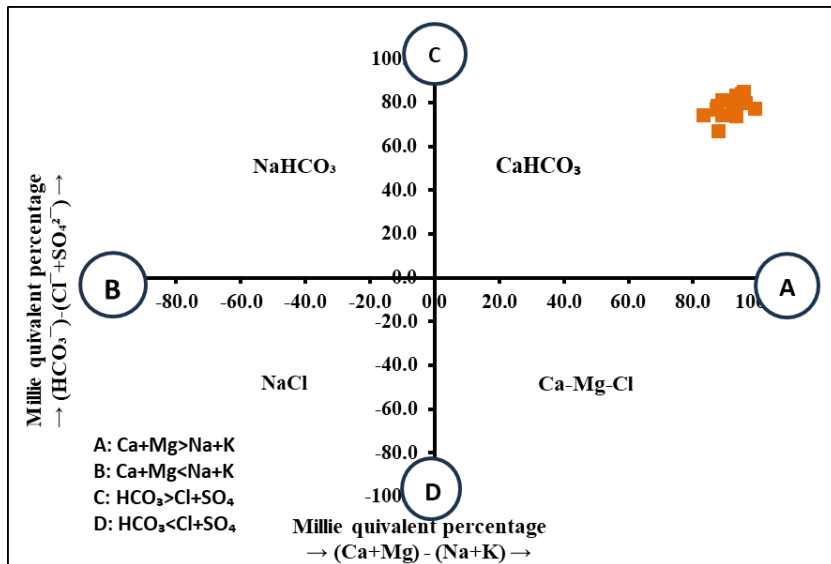


Figure 6. Chadha plot of the surface and groundwater samples from study area.

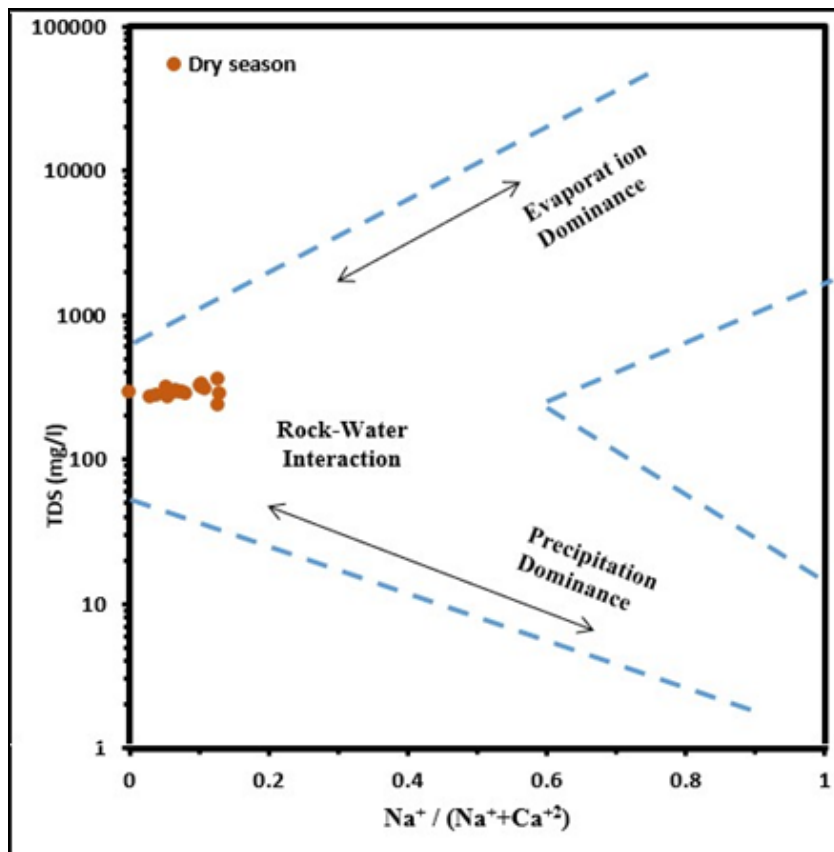


Figure 7a. The geochemical controlling factors for surface and groundwater samples Gibbs (1970) Diagram).

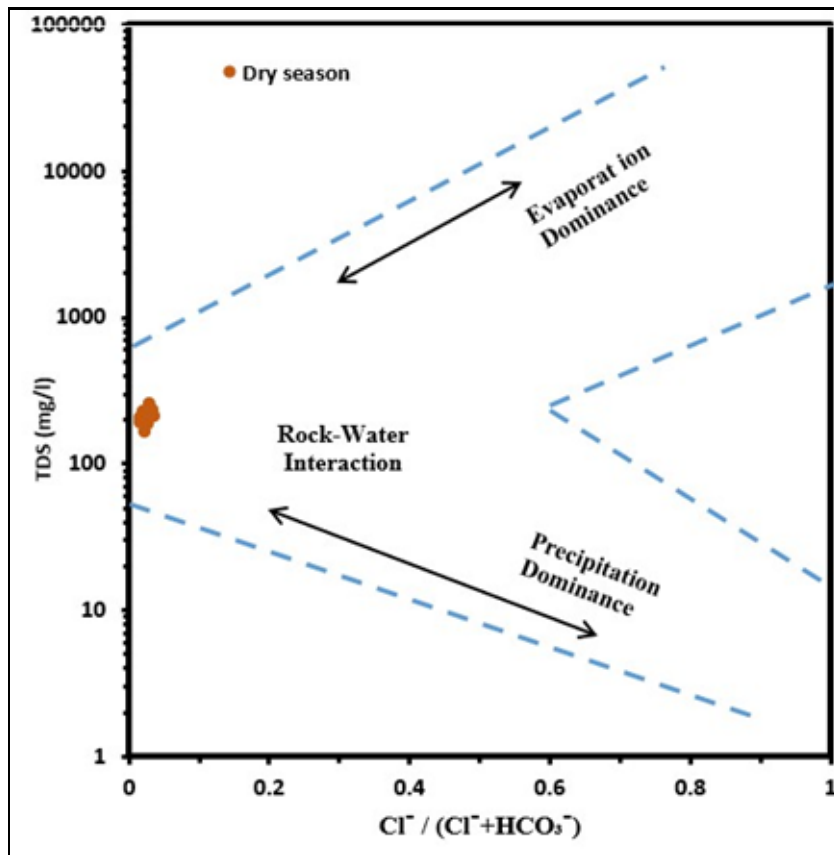


Figure 7b. The geochemical controlling factors for surface and groundwater samples Gibbs (1970) Diagram).

4.4 Drinking Water Suitability

The water quality index (WQI) is a widely accepted composite indicator that simplifies the assessment of water quality for public understanding and policy decision. According to the results of TDS and TH values (Figure 8), like indicators for evaluating water quality by comparing with (WHO) (2017), the quality of surface water of Alana basin is good to excellent quality, and the quality of groundwater is excellent, this outcome corresponds with result of Dara et al. (2024). This finding of WQI (Table 6) reflects low pollutant levels in this catchment, and the observation in this study could be attributed to limited human activity. Additionally, geographical and climate conditions play a role in maintaining the observed water quality. In contrast to research conducted in the Kurdistan regions, the substandard quality of water is attributed to the impact of leachate from landfills and a lot of anthropogenic activity (Todd and Mays, 2004). Those results match with Guenouche et al. (2024), which determined that better environmental conditions, climate, and human activities contribute to better water quality. As the current study offers important insights, future research might examine monthly variations in the Water Quality Index (WQI) to evaluate temporal trends. Furthermore, analyzing specific contaminants, such as heavy metals or pesticides, would improve our understanding of water quality dynamics.

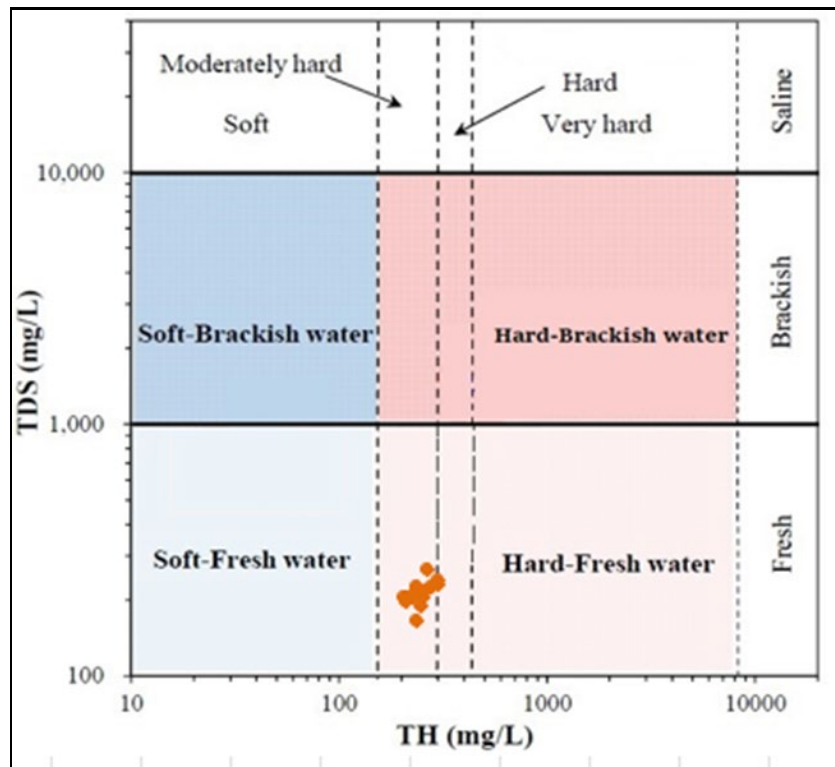


Figure 8. Plot of TDS versus TH after Xiao (2021).

Table 6. Drinking water quality for both surface water and groundwater in ARB.

Sample No.	Location Name	(Oct. 2024)	
		WQI Value	Remark on Quality
S1	First water source	27.24	Excellent
S2	Second source (Gurgar) up stream Bnawi	53.99	Good
S3	Downstream of Bnawi village	53.78	Good
S4	Up stream of Alana village	55.89	Good
S5	Downstream of Alana River	45.87	Excellent
S6	Up stream of Rumawezh	43.18	Excellent
S7	Downstream of Rumawezh	48.10	Excellent
S8	Up stream of Sharkan	47.18	Excellent
S9	Downstream of Sharkan	53.14	Good
S10	Beginning of Khalifan sub. D	53.90	Good
S11	Middle Khalifan	57.28	Good
S12	End of Khalifan	58.14	Good
S13	Up stream of Gali Ali Bag	58.64	Good
S14	Downstream of Gali Ali Bag	53.03	Good
S15	Mixing all rivers	56.12	Good
GW1	Ground water well(75m)	42.70	Excellent
GW2	Ground water well (5m)	36.82	Excellent
GW3	Water treatment of Khalifan	30.16	Excellent

4.5 Irrigation Suitability

The results of the classification of Na%, EC, SAR, PI, RSBC, MAR, KR, and IWQI to assess the suitability of water for irrigation, utilized for evaluating water quality for irrigation purposes. Most of the surface water and groundwater samples were detected as suitable (Tables 7a and b). It generally means that this water is of high quality for irrigation, with minimal risks to soil health and crop growth, except for the results of some water samples like S1 to S6, S9 to S12, and S13 from

surface water and GW1, which have a high magnesium adsorption ratio, meaning they are unsuitable for irrigation. According to DO values from both water resources and comparisons with WHO standards for irrigation suitability, these water sources are good quality for irrigation purposes, with averages of 6 to 7 mg/l from surface and groundwater samples, respectively.

Table.7a Irrigation suitability for surface water in study area.

Quality Index	Categories	Ranges	Range	Sample number
Percent sodium (%Na)	Excellent	<20	0.39- 6.35	All samples
	Good	20.1-40		
	Permissible	40.1-60		
	Doubtful	60.1-80		
	Unsuitable	>80		
Sodium Adsorption Ratio (SAR)	Very low	<2	0.01- 0.21	All samples
	Low	2.1-12		
	Medium	12.1-22		
	High	22.1-32		
	Very high	32		
Permeability index (PI)	Suitable	PI > 75%	38.8 - 46.08	All samples
	Moderate	25 - 75%		
	Unsuitable	PI < 25%		
Residual sodium bi-carbonate (RSBC)	Satisfactory	<5	1.51 - 2.68	All samples
	Margional	5 - 10		
	Unsatisfactory	≥10		
Magnesium adsorption ratio (MAR)	Permissible	0-50	44.8- 72.09	4 samples
	Unsuitable	>50		11 samples
Kelly's ratio	Suitable	<1	0.00-0.09	All samples
	Unsuitable	≥1		
Irrigation Water Quality Index (IWQI)	No restriction (NR)	85 - 100	56.01- 58.79	All samples
	Low restriction (LR)	70 - 85		
	Moderate restriction (MR)	55 - 70		
	High restriction (HR)	40 - 55		
	Severe restriction (SR)	0 - 40		

Table.7b Irrigation suitability for groundwater in study area.

Quality Index (Reference)	Categories	Ranges	Range	Sample number
Percent sodium (%Na)	Excellent	<20	2.20-8.34	All samples
	Good	20.1-40		
	Permissible	40.1-60		
	Doubtful	60.1-80		
	Unsuitable	>80		
Percent sodium (%N)	Very low	<2	0.06-0.27	All samples
	Low	2.1-12		
	Medium	12.1-22		
	High	22.1-32		
	Very high	32		
Permeability index (PI)	Suitable	PI > 75%	41.66- 43.50	All samples
	Moderate	25 - 75%		
	Unsuitable	PI < 25%		
Residual sodium bi-carbonate (RSBC)	Satisfactory	<5	1.16-2.02	All samples
	Margional	5 - 10		
	Unsatisfactory	≥10		
Magnesium adsorption ratio (MAR)	Permissible	0-50	41.64-56.9	2 samples
	Unsuitable	>50		1 sample
Kelly's ratio	Suitable	<1	0.02-0.08	All samples
	Unsuitable	≥1		
Irrigation Water Quality Index (IWQI)	No restriction (NR)	85 - 100	57.16- 57.45	All Samples
	Low restriction (LR)	70 - 85		
	Moderate restriction (MR)	55 - 70		
	High restriction (HR)	40 - 55		
	Severe restriction (SR)	0 - 40		

5. Conclusion

This study is an attempt to assess the water quality of different sources in the Alana River Basin using chemical and biological contaminants. Usually, all physiochemical parameters for surface and groundwater samples were within the WHO standard limit. Based on hydrochemical formulas, Chadha and Piper diagrams have proved that surface and groundwater samples are Ca-bicarbonate types during the dry season. This finding is due to the predominant carbonate rock formations along the outcrops. The Gibbs diagram indicates the distribution of these different sources in terms of rock dominance. Furthermore, this study indicated that the studied water is of good-to-excellent quality for drinking, and almost all samples are suitable for irrigation based on TDS, TH, and WQI values, as well as Na%, EC, SAR, PI, RSBC, MAR, KR, and IWQI results. However, bacteriological analysis revealed that microorganisms polluted both the surface and groundwater in the Alana region, rendering them unsafe for drinking. This contaminant was present due to the infiltration of sewage water from municipal, domestic, or industrial sources. Better water resource management and treatment strategies are crucial for protecting human and environmental health.

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هه‌لسه‌نگاندنی کوالیتی ئاوی ڤووکار و ژیر زهوی هه‌وزی ڤووباری ئالانا: به‌کارهیتانی ڤیازیکی فیزیایی و کیمیایی و بایؤلۆژی به‌کرتوو

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پوخته

هه‌لسه‌نگاندنی هایدروکیمیایی و بایؤلۆژی هه‌وزی ڤووباری ئالانا زۆر گرنگه بۆ گه‌ره‌نتی کردنی سه‌لامه‌تی ئاوی سه‌رزه‌وی و ژیر زهوی بۆ خواردنه‌وه و پیشه‌سازی و گونجاوی کشتوکال. ئەم تووژینه‌وه‌یه له ڤیگه‌ی سه‌رچاوه جیاوازه‌کانه‌وه، وهک ئاوی سه‌رزه‌وی و ژیر زهوی، پارامیته‌ره‌کانی کوالیتی ئاو له هه‌زه‌که‌دا هه‌له‌سه‌نگینیت، له ڤیگه‌ی هه‌لسه‌نگاندنی تایبه‌تمه‌ندییه بایؤلۆژی و کیمیایی و فیزیاییه‌کانی ئاوه‌که له هه‌مان کاتدا ڤه‌چاوکردنی هۆکاره جیاوازه‌کان که کاریگه‌رییان له‌سه‌ره. به‌گشتی 15 نمونه‌ی ئاوی سه‌رزه‌وی و 3 نمونه‌ی ئاوی ژیر زهوی له ڤووباری ئالانا کۆکرایه‌وه که درێژده‌بیته‌وه بۆ به‌کرتنی ڤووباره‌کانی بیخال، باله‌کیان و خه‌لیفان بۆ وه‌رزنی وشکه‌سالی (ئۆکتۆبه‌ری 2024). کۆی گشتی کولیفۆرمه‌کان، به‌کتریا به‌رگه‌گره‌کانی گه‌رمی، و ئی.کۆلای به‌ پارامیته‌ره‌کانی مایکروبیؤلۆجی هه‌لسه‌نگیندرا. ئەنجامی ئەم تووژینه‌وه‌یه ده‌ریده‌خات که هه‌موو نمونه‌کانی ئاوی سه‌رزه‌وی و ژیر زهوی له‌گه‌ل ئەو سنووره قبولکراوانه‌ی که به‌ به‌راوردکردن له‌گه‌ل ڤیکخواوی تهن‌دروستی جیهانی و IQS دانراون، به‌ پشتیبه‌ستن به‌ ڤۆه‌ره کیمیایی و فیزیاییه‌کان به‌کده‌گره‌نه‌وه. هه‌لسه‌نگاندنی کوالیتی بۆ ئاوی خواردنه‌وه ده‌ریخست که هه‌موو نمونه‌کانی ئاوی سه‌رزه‌وی له کوالیتی باشه‌وه بۆ کوالیتی نایاب، له‌گه‌ل کوالیتییه‌کی نایابی هه‌موو نمونه‌کانی ئاوی ژیر زهوی. سه‌ره‌پای ئەوه‌ش، گونجاوی ئاو به‌پیتی TDS و T.H. پینشنیاری کرد که نمونه‌ی ئاو ئاوی شیرینی سه‌خته. ئاوی سه‌رزه‌وی و ئاوی ژیر زهوی به‌پیتی دیاگرامه‌کانی پایپه‌ر و چاده‌ها به‌ Ca-bicarbonate پۆلین ده‌کرین. نیشاندهری مایکروبیؤلۆجی ده‌ریانخست که هه‌موو ئەو نمونه‌ی ئاوی سه‌رزه‌وی و ژیر زهوی که له وه‌رزنی وشکه‌سالیدا کۆکراونه‌ته‌وه پابه‌ند نه‌ببون به‌ ڤینماییه‌کانی ڤیکخواوی تهن‌دروستی جیهانی، هه‌ر بۆیه پيسیوونیان سه‌لمیتراره. له ئەنجامدا ئاوی ئەم هه‌زه بۆ خواردنی راسته‌وخۆ نییه و ڤیویستی به‌ چاره‌سه‌رکردن هه‌یه پینش به‌کارهیتان. تیکه‌لکردنی به‌های کیمیایی، بایؤلۆژی و فیزیایی تیروانینیکی به‌نرخ ده‌دات بۆ باشترین شیوازه‌کانی به‌ ڤیوه‌بردنی کوالیتی ئاو بۆ به‌ ڤیوه‌بردنی هه‌وزی ڤووباری ئالانا.

وشه سه‌ره‌کیه‌کان: گونجاوی ئاو، هه‌لسه‌نگاندنی کوالیتی، به‌ ڤیوه‌بردنی سه‌رچاوه‌کانی ئاو، نیشاندهری مایکروبیؤلۆجی، پيسیوون.

تقییم جوده‌ المیاه السطحیة والجوفیة لحوض نهر آلانا: باستخدام مناهج فیزیائیة وکیمیائیة و بیولوجیة متکاملة

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المخلص

إن التقییم الهیڈروکیمیائی والبیولوجی لحوض نهر آلانا له أهمية بالغة لضمان سلامة المیاه السطحیة والجوفیة للشرب والصناعة والملاءمة الزراعیة. تقوم هذه الدراسة بتقییم معاییر جودة المیاه في الحوض من خلال مصادر مختلفة مثل المیاه السطحیة والجوفیة، من خلال تقییم الخصائص البیولوجیة والكیمیائیة والفیزیائیة للمیاه مع الأخذ في الاعتبار العوامل المختلفة التي تؤثر علیها. تم جمع ما مجموعه 15 عینة من المیاه السطحیة و 3 عینات من المیاه الجوفیة من نهر آلانا الممتد إلى النقاء أنهار بیخال وبالاکیان وخلیفان خلال موسم الجفاف (أکتوبر 2024). تم تقییم المعاییر المیکروبیولوجیة للکولیفورم الکللی، البکتیریا المقاومة للحرارة والإشریکیة القولونیة. تظهر نتائج هذه الدراسة أن جمیع عینات المیاه السطحیة والجوفیة تتوافق مع الحدود المقبولة التي حدتها منظمة الصحة العالمیة ومعاییر الجودة العراقیة استناداً إلى المعاییر الكیمیائیة والفیزیائیة. أظهر تقییم جودة میاه الشرب أن جمیع عینات المیاه السطحیة تراوحت جودتها من جیدة إلى ممتازة، إلى جانب جودة ممتازة لجمیع عینات المیاه كانت میاه عذبة قاسیة. بالإضافة إلى ذلك، مدى ملاءمة المیاه وفقاً لـ

TDS و T.H. ، اقترح أن عينات المياه كانت مياه عذبة قاسية. يتم تصنيف المياه السطحية والمياه الجوفية على أنها بيكربونات الكالسيوم وفقاً لمخططات باير وتشادها. كشفت المؤشرات الميكروبيولوجية أن جميع عينات المياه السطحية والجوفية التي تم جمعها خلال موسم الجفاف لم تتوافق مع إرشادات منظمة الصحة العالمية، مما يثبت تلوثها. وبالتالي فإن المياه في هذا الحوض غير صالحة للاستهلاك المباشر وتتطلب المعالجة قبل الاستخدام. إن الجمع بين القيمة الكيميائية والبيولوجية والفيزيائية يوفر رؤية قيمة حول أفضل ممارسات إدارة جودة المياه لإدارة حوض نهر آلتا.

الكلمات المفتاحية: ملاءمة المياه، تقييم الجودة، إدارة موارد المياه، المؤشرات الميكروبيولوجية، التلوث.