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Physicochemical and Bacteriological Assessment of Groundwater Quality in the Nalut Region, Libya

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ABSTRACT

This study aimed to evaluate the chemical and bacteriological characteristics of groundwater in the Nalut region. Thirty groundwater samples were collected from Wadi Nalut, Takut, and Wadi Al-Thulth, and analyzed for key chemical parameters, including pH, total dissolved solids (TDS), total hardness, and major ions. Bacteriological analyses were also conducted on 12 samples to determine the total bacterial count, total coliforms, and the presence of *Escherichia coli*. The results showed elevated levels of some chemical parameters compared with the adopted standards, with maximum values of **5453.5 mg/L** for TDS and **1619.6 mg/L** for total hardness. Bacteriological results showed that all samples were free of *E. coli*, while **25% of the samples** showed the presence of total coliforms and elevated total bacterial counts. According to local and international standards, groundwater from Wadi Al-Thulth wells exhibited the best quality, followed by Wadi Nalut wells, whereas groundwater from Takut wells was classified as highly saline and unsuitable for human consumption.

Keywords: Groundwater, chemical analyses, bacteriological analyses, Nalut, standard criteria.

التقييم الفيزيائي والكيميائي و البكتريولوجي لجودة المياه الجوفية في منطقة نالوت، ليبيا

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ملخـــــص البحـــــث

هدفت الدراسة لتقييم الخصائص الكيميائية والبكتريولوجية للمياه الجوفية في منطقة نالوت، إذ تم جمع 30 عينة مياه جوفية من مناطق وادي نالوت، تكوت، ووادي الثلث، وأجرت التحاليل الكيميائية اهمها الأس الهيدروجيني، والمواد الصلبة الذائبة الكلية، والعسر الكلي، والأيونات الرئيسية. كما أُجريت التحاليل البكتريولوجية على 12 عينة لتحديد العدد الكلي للبكتيريا والبكتيريا القولونية الكلية والكشف عن بكتيريا *Escherichia coli.*؛ أظهرت النتائج ارتفاع بعض القيم الكيميائية مقارنة بالمعايير المعتمدة، وبلغت القيم القصوى للمواد الصلبة الذائبة الكلية **5453.5ملغم/لتر**، والعسر الكلي **1619.6 ملغم/لتر**، وأظهرت النتائج البكتريولوجية خلو جميع العينات من بكتيريا *E. coli*، في حين سجلت **25%من العينات** وجود بكتيريا قولونية كلية وارتفاعًا في العدد الكلي للبكتيريا. ووفقًا للمعايير المحلية والدولية، كانت مياه آبار وادي الثلث الأفضل جودة، تليها مياه آبار وادي نالوت، بينما صُنفت مياه آبار تكوت بأنها عالية الملوحة وغير صالحة للاستهلاك البشري.

الكلمات المفتاحية: المياه الجوفية، التحاليل الكيميائية، التحاليل البكتيرية، نالوت، المعايير القياسية.

1. Introduction

Groundwater is the primary source of freshwater in Libya, accounting for more than 98% of the country's total water consumption due to the scarcity of surface water resources under arid and semi-arid climatic conditions [1]. In the Nalut region, groundwater is extracted mainly from the Upper Cretaceous Nalut Aquifer and the Kiklah Sandstone Aquifer, which supply domestic, agricultural, and industrial water demands [2].

Groundwater quality is influenced by geological formations, water–rock interactions, climatic conditions, and human activities such as agricultural expansion and excessive groundwater abstraction. It is commonly assessed using physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), and major cations and anions, together with bacteriological indicators to determine its suitability for drinking and other uses [3,4,5]. Rapid socioeconomic development, climate change, and increasing water demand have led to extensive groundwater exploitation in Libya. As a result, groundwater quality has deteriorated, particularly due to increased salinity and hardness. [6].

Previous studies conducted in the Nafusa uplift reported elevated electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), chloride, sulfate, and sodium concentrations, as well as bacteriological contamination in some groundwater sources [7, 8, 9, and 10]. However, these studies were limited to specific locations and did not provide a comprehensive comparison of groundwater quality among Wadi Nalut, Takout, and Wadi Al-Thulth. Therefore, the present study aims to evaluate and compare the physicochemical and bacteriological characteristics of groundwater in these three areas and assess their compliance with the Libyan Drinking Water Standard (LDWS) and the World Health Organization (WHO)

1.1 Location of Study Area

The study area is located in the western part of the Nafusa Uplift in northwestern Libya, approximately 270 km southwest of Tripoli, and includes Wadi Nalut, Takout, and Wadi Al-Thulth. It extends between 31°45′–32°05′ N and 10°42′–11°56′ E Figure 1. The groundwater wells are distributed across an area characterized by diverse topography and geological formations [11],which play a major role in controlling groundwater quality.

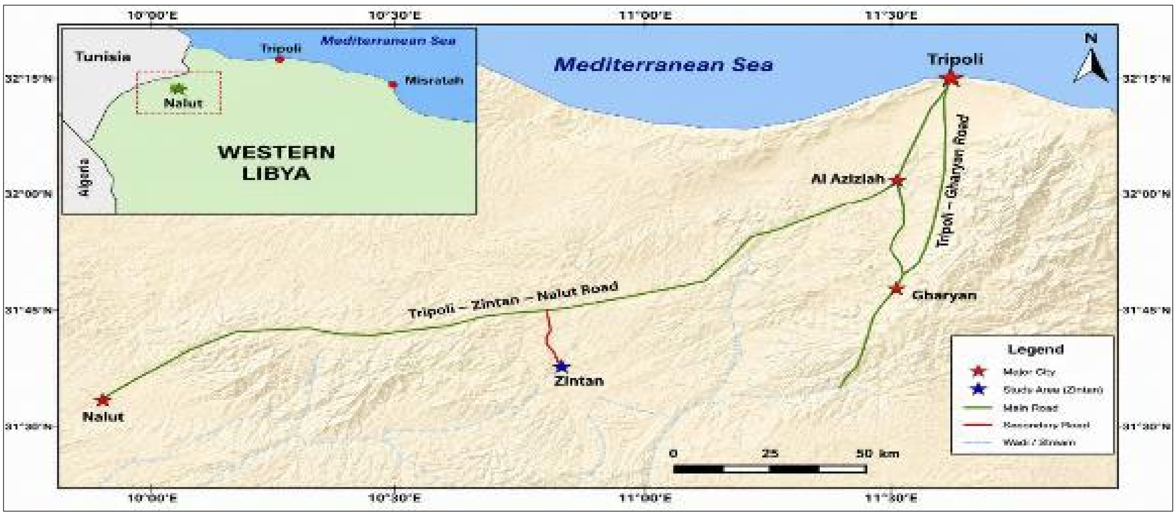


Figure 1: Location of the study area [11]

1.2 Geology of the Study Area

Geologically, the study area forms part of the Nafusa uplift succession, extending from the Kurush Formation (Lower Triassic) to the Zmam Formation (Early Cenozoic) [12]. The region comprises three main geomorphological units: the Jifarah Plain, the mountain escarpment, and the Nafusa Plateau. The geology is dominated by limestone, dolomite, sandstone, marl, and clay, with Upper Cretaceous carbonate rocks widely exposed across the plateau [13]. These lithological formations play a major role in controlling groundwater occurrence, flow, and Hydrochemical characteristics through water–rock interactions, thereby influencing groundwater quality throughout the study area [13].

2. Materials and Methods

2.1 Groundwater Sampling

A total of 30 groundwater samples were collected from wells distributed across three locations in the Nalut region: Wadi Nalut (12 wells), Takout (14 wells), and Wadi Al-Thulth (4 wells) Table 1 and Figure 2. The sampling sites were selected to ensure adequate spatial coverage and to represent the hydrogeological variability of the study area. The geographic coordinates of each well were recorded using a Global Positioning System (GPS) Table 1. These coordinates were used to prepare the sampling location map and to support the spatial analysis of groundwater quality using a Geographic Information System (GIS).

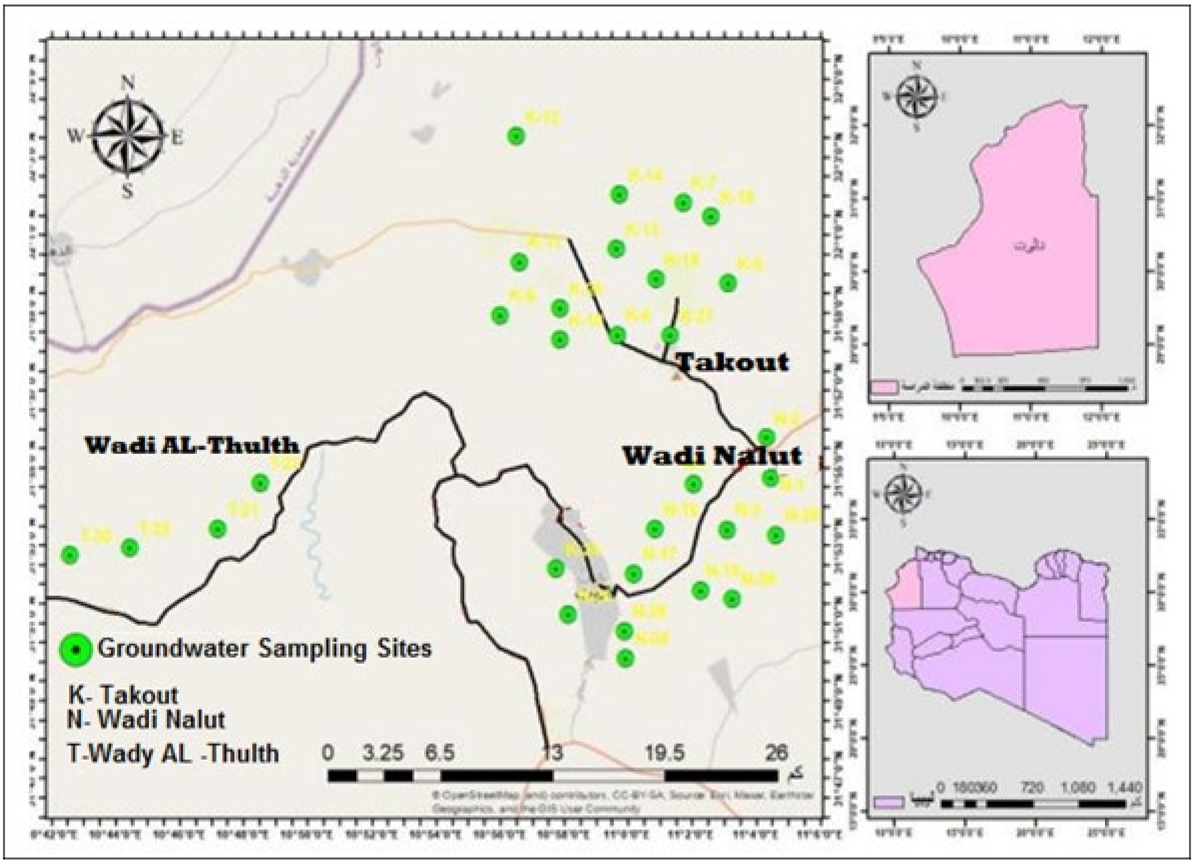


Figure 2: Location and Spatial Distribution of Groundwater Wells *Source: Google Earth Pro, ArcGIS 10.8*

Table 1: Groundwater Sampling Locations in the Study Area

No.	Sample ID	Study Area	Latitude (°N)	Longitude (°E)
1	N-1	Wadi Nalut	31.904944	11.053268
2	N-3	Wadi Nalut	31.897529	11.043393
3	N-4	Wadi Nalut	31.897099	11.022415
4	N-5	Wadi Nalut	31.925079	11.063945
5	N-15	Wadi Nalut	31.873000	11.028774
6	N-16	Wadi Nalut	31.875102	11.027390
7	N-17	Wadi Nalut	31.871147	11.022360
8	N-20	Wadi Nalut	31.856871	11.006140
9	N-24	Wadi Nalut	31.855405	11.010281
10	N-25	Wadi Nalut	31.861972	11.013037
11	N-28	Wadi Nalut	31.874220	11.034060
12	N-29	Wadi Nalut	31.895627	11.046086
13	K-2	Takout	31.874269	10.975146
14	K-6	Takout	31.973988	10.994197
15	K-7	Takout	32.023104	11.018515
16	K-8	Takout	31.990636	10.953296
17	K-9	Takout	32.014691	11.020741
18	K-10	Takout	31.989248	10.956016
19	K-11	Takout	31.991846	10.957707
20	K-12	Takout	32.059076	10.941931
21	K-13	Takout	32.013553	11.019487
22	K-14	Takout	32.016080	11.019612
23	K-18	Takout	32.005007	11.022771
24	K-19	Takout	32.020841	11.025284
25	K-26	Takout	31.990005	10.958293
26	K-27	Takout	31.973833	11.021804
27	T-21	Wadi Al-Thulth	31.914540	10.780369
28	T-22	Wadi Al-Thulth	31.910608	10.808742
29	T-23	Wadi Al-Thulth	31.889616	10.735974
30	T-30	Wadi Al-Thulth	31.882406	10.721661

Source / site Study

Groundwater samples were collected following standard sampling procedures to ensure representative water quality. Before sampling, each well was pumped for 5–10 min to remove stagnant water from the pipes and obtain fresh groundwater directly from the aquifer Figure 3. Samples were then collected in sterile 500 mL polyethylene bottles Figure 4, sealed immediately, and transported in an ice-filled cooler to preserve their physicochemical and bacteriological characteristics until laboratory analysis. Each sample was labeled with a unique identification code, sampling location, and collection date to ensure proper traceability throughout the analytical process.

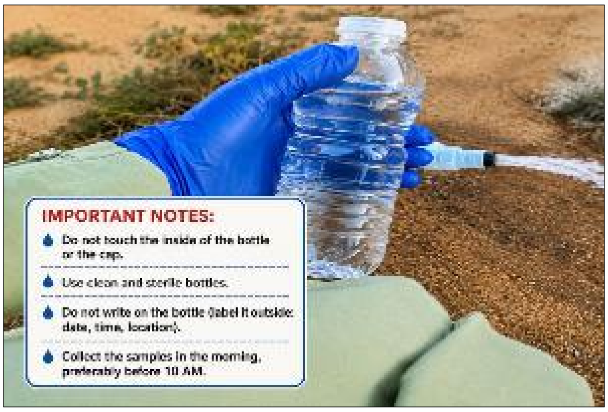


Figure 3: Site Collection of Groundwater Sample

Figure 4: Groundwater Samples Collected

2.2 Physicochemical and Bacteriological Analyses

Physicochemical and bacteriological analyses were performed at the Advanced Chemical Analysis Laboratory, Tripoli, Libya. The physicochemical parameters included pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-}, and SO_4^{2-}. The pH, EC, and TDS were measured using a Hach HQ40d Multi-meter Figure 5, whereas sulfate, nitrate, and chloride concentrations were determined using a DR 3900 Spectrophotometer Figure 5. Sodium and potassium concentrations were measured with a Flame Photometer Figure 5. Total hardness, calcium, magnesium, and bicarbonate were determined by standard titration methods using 0.02 N EDTA and 0.02 N HCl, following the procedures described in the standard methods [14].

Figure 5. Laboratory Instruments Used

Bacteriological analyses were carried out on 12 representative groundwater samples collected from the three study areas. Total Coliforms (TC) and Escherichia coli (E. coli) were determined using the membrane filtration technique with Colony Count Agar as the culture medium. A **100** mL water sample was filtered through a 0.45 µm membrane filter, and the membranes were incubated at 37°C for 24 h. The appearance of bacterial colonies indicated a positive result, whereas the absence of colony growth indicated a negative result [14]. Representative bacteriological results are presented in Figure 6.

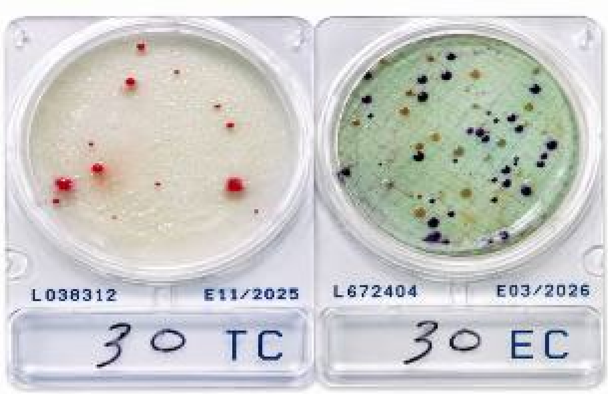


Figure 6. Detection of (TC) and (*E. coli*) in Sample No. 30.

3. Results and Discussion

3.1 Physicochemical Characteristics of Groundwater Samples

Table 2 presents the results of the physicochemical analyses of groundwater samples collected from the three study areas. The analyzed parameters represent the principal indicators used to assess groundwater quality and to compare the obtained values with the Libyan drinking water standards [15] and the World Health Organization (WHO) guidelines [16].

3.1.1 pH of Groundwater Samples

Figure 7 and Table 2 present the pH values of groundwater samples collected from Wadi Nalut, Wadi Al-Thulth, and Takout. The pH ranged from 7.34 (sample N-16) to 8.15 (sample K-27), with an average value of approximately 7.65, indicating that all groundwater samples were neutral to slightly alkaline. All measured pH values were within the permissible limits of both the World Health Organization (WHO) (6.5–9.5) and the Libyan Drinking Water Standard (6.5–8.5), indicating that pH does not pose a concern for groundwater quality in the study area.

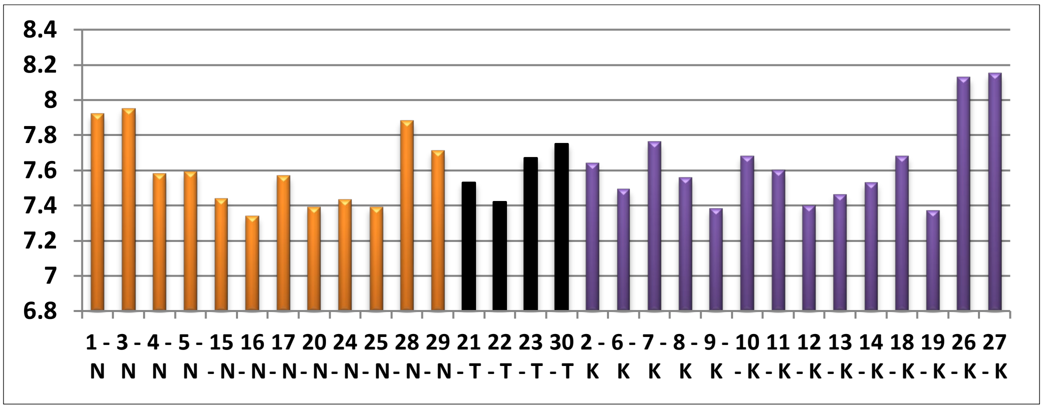


Figure 7*:* pH values of groundwater samples

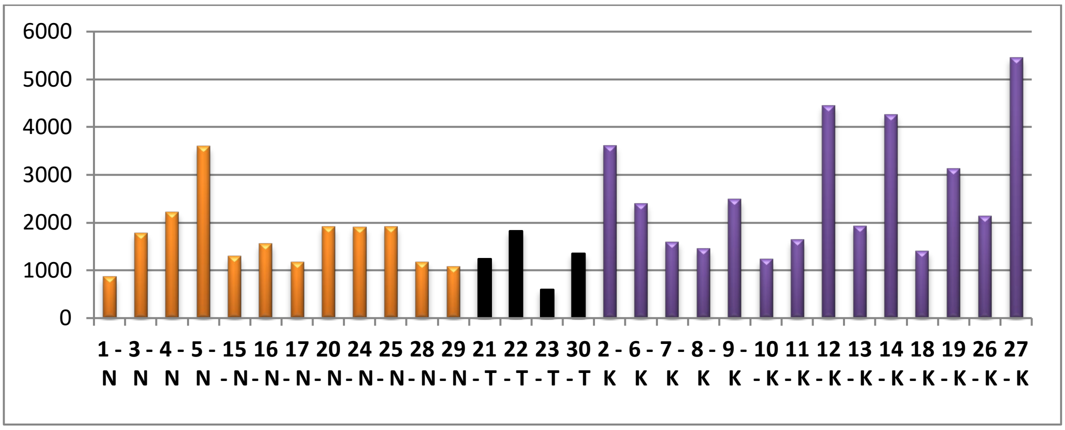
Minor variations in pH were observed among the three study areas, with slightly higher values in Takout than in Wadi Nalut. However, all values remained within the normal range for groundwater.

Table 2: Physicochemical Properties of Groundwater Samples

Samples	pH	TDS	EC	TH	Ca^{2+}	Mg^{2+}	HCO_3^-	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
//	//	mg/L	µS/cm	(mg/L)								
N-1	7.92	868.4	1016	322.5	65.1	38.83	199.2	60.42	10.19	97.412	14	111
N-3	7.95	1777.1	2410	901	230	80.9	305	154.6	31.5	487	18	243
N-4	7.58	2213.5	3090	780.7	160.3	92.35	326	310.7	53.69	521.85	11.6	408
N-5	7.59	3595	5220	912	189	107	402	386	29.1	626	5.9	424
N-15	7.44	1291	1672	425	114	34.02	183	63.44	11.75	243.53	10.8	113
N-16	7.34	1558.9	2083	500.45	88.16	68.04	366	120.92	23.22	243.53	4.9	122
N-17	7.57	1160.5	1470	391	90.2	40.23	280	57.28	18	170	8.7	100
N-20	7.39	1915	2510	887	240	70	320	40.6	27.2	310	4.5	340
N-24	7.43	1902	2490	866	215	80.2	315	136	28.31	325	3.6	408
N-25	7.39	1908	2500	540.9	150	40.4	396.5	300	27.9	521	12.2	126
N-28	7.88	1171	1535	500.45	112.21	53.46	305	137.6	17.73	313	3.5	126
N-29	7.71	1074	1417	490.44	120.22	46.15	240	104.4	15.01	340.5	5.7	104
T-21	7.53	1238.5	1590	394.8	71.12	52.74	320	108.48	26.93	240.1	5.3	102
T-22	7.42	1823.5	2490	540.48	104.19	68.04	305	221.92	31.38	313.11	5.3	296
T-23	7.67	595.4	916	256.23	63.12	23.32	152	97.37	14.54	195	6.8	50
T-30	7.75	1351	1770	590.53	128.24	65.66	305	200	20.4	452.27	3.9	122
K-2	7.64	3604.5	5230	900	210.9	90.5	422	330	20.31	734.96	8.2	180
K-6	7.49	2392	3680	987.3	225.5	103	386	340.52	29.6	626.22	8.3	448
K-7	7.76	1586	2440	712.5	120.5	100	305	250	32.21	420.5	6.9	408
K-8	7.56	1456	2600	400.3	88.18	43.74	280	200.04	19.04	300.2	12.6	240
K-9	7.38	2480.8	4430	641	140.5	70.52	488	235	15.22	430.5	19.2	77
K-10	7.68	1227.1	2193	457.7	100.5	50.5	244	99.5	13.2	250	10.8	170
K-11	7.6	1630.5	2193	360.32	80.15	38.88	306	307.02	27.86	347.9	10.8	280
K-12	7.4	4446	7940	1189	260.5	130.6	336	360.5	32.51	700	12.8	680
K-13	7.46	1926	3440	467	120.4	40.5	360	215	28.22	340	6.2	240
K-14	7.53	4261.6	7610	1071	230.1	120.5	488	420	16.21	1020	10.5	94
K-18	7.68	1403.8	1832	420.38	80.15	53.46	300	57.88	29.03	140.5	4.6	120
K-19	7.37	3130	4500	760.6	176.3	77.7	366	320.5	17.19	500.5	5.1	416
K-26	8.13	2138.5	3290	847	140.5	120.6	305	250	23.26	510	2.6	416
K-27	8.15	5453.5	8390	1619.6	400.5	150.5	610	550	30.42	1391.6	10.5	150
WHO	**6.5-9.5**	**1000**	**2300**	**500**	**75-200**	**30-150**	**350**	**20-200**	**12**	**400**	**50**	**250-500**
(LDWS)	**6.5–8.5**	**500–1000**	**500–1500**	**500**	**75-200**	**30-150**	**250-400**	**20–250**	**12**	**20–250**	**10–45**	**200–400**
Percentage Exceeding (LDWS) Limits (%)												
(%)	**0.0**	**93.3**	**86.7**	**63.3**	**26.7**	**3.3**	**16.7**	**33.3**	**93.3**	**73.3**	**0.0**	**26.7**

Note: *Percentage exceedance values were calculated based only on samples exceeding the maximum permissible limits specified by the Libyan Drinking Water Standards (LDWS). Samples falling below the minimum acceptable limits were not included in the exceedance calculations.*

3.1.2 Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Total Hardness (TH)
Electrical conductivity (EC) is directly related to the concentration of dissolved ions in water and generally increases with increasing salinity. As shown in Table 2, EC values ranged from 916 µS/cm in sample T-23 to 8390 µS/cm in sample K-27. High EC values were also recorded in samples K-12 (7940 µS/cm), K-14 (7610 µS/cm), K-2 (5230 µS/cm), and N-5 (5220 µS/cm). Overall, 86.7% of the samples exceeded the upper EC limit specified by the Libyan Drinking Water Standards (LDWS) (1500 µS/cm), indicating elevated ionic concentrations and mineralization in the groundwater. EC values increased concurrently with total dissolved solids (TDS). TDS ranged from 595.4 mg/L in sample T-23 to 5453.5 mg/L in sample K-27. Most samples exceeded the upper permissible TDS limit specified by the LDWS (1000 mg/L), with 93.3% of the samples exceeding this limit, indicating high levels of dissolved salts in the groundwater.



.**Figure 8:** Total dissolved solids (TDS) in groundwater samples

Total hardness (TH) ranged from 256.2 to 1619.6 mg/L (Table 2). Approximately 63.3% of the samples exceeded the permissible limit of 500 mg/L (Figure 9), indicating high water hardness. This may be attributed to the dissolution of carbonate minerals, particularly limestone and dolomite, as well as gypsum-bearing formations within the aquifer.

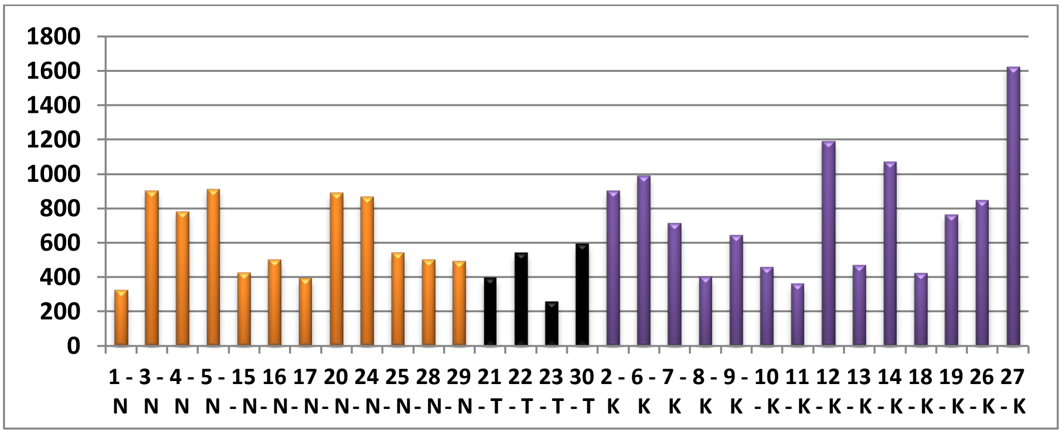


Figure 9: Total hardness (TH) of groundwater samples.

The obtained results are generally consistent with previous studies conducted in the Nafusa foothill region, which also reported elevated EC, TDS, and TH values due to similar hydrogeological and geological conditions [7,8,9,10].

3.1.3 Major Anions (SO_4^{2-}, NO_3^-, Cl^-, and HCO_3^-)

Sulfate (SO_4^{2-}) concentrations exceeded the LDWS permissible limit (400 mg/L) in 26.7% of the groundwater samples (Figure 10). The highest concentration (680 mg/L) was recorded in sample K-12. Elevated sulfate levels are mainly attributed to the dissolution of sulfate-bearing minerals, particularly gypsum and anhydrite, as well as chemical weathering processes.

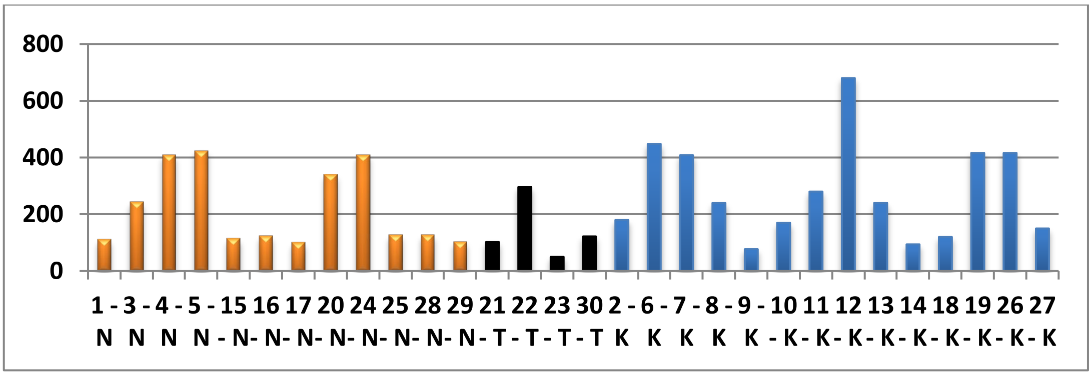


Figure 10: Sulfate (SO_4^{2-}) concentrations in groundwater samples.

Nitrate (NO_3^-) concentrations ranged from 2.6 to 14.0 mg/L, and all samples complied with both the LDWS and WHO guideline values (Figure 11), indicating no significant nitrate contamination from sewage or agricultural activities.

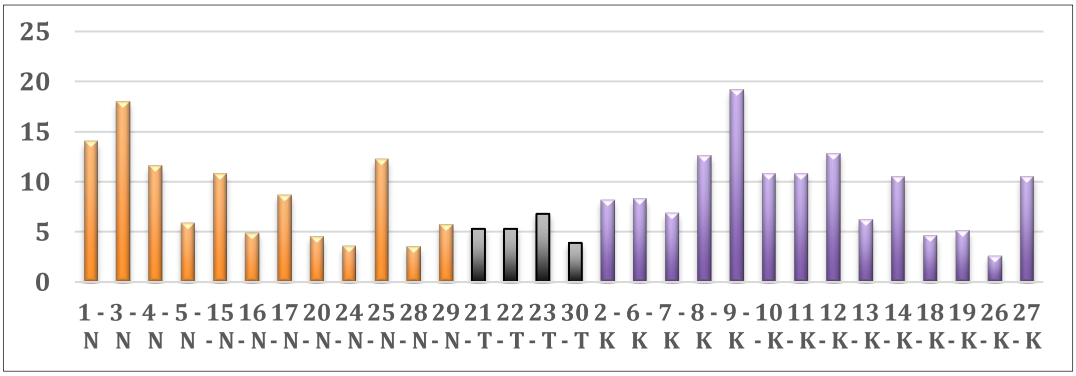


Figure 11: Nitrate (NO_3^-) concentrations in Groundwater Samples.

Chloride (Cl^-) concentrations exceeded the LDWS permissible limit (250 mg/L) in 73.3% of the groundwater samples (Figure 12). The highest concentrations were recorded in samples K-27 (1391.6 mg/L), K-14 (1020 mg/L), K-2 (734.96 mg/L), K-12 (700 mg/L), and K-19 (626.22 mg/L). The elevated chloride concentrations are mainly associated with the dissolution of chloride-bearing minerals and the geological characteristics of the aquifer.

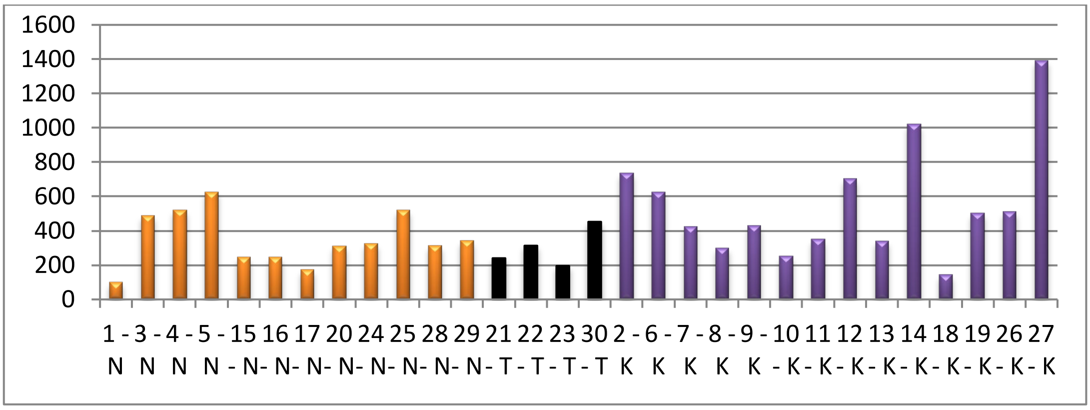


Figure 12: Chloride (Cl^-) concentrations in groundwater samples.

Bicarbonate (HCO_3^-) concentrations were generally within the permissible limits, with 16.7% of the samples exceeding the LDWS upper limit (400 mg/L) (Figure 13). The highest concentration (610 mg/L) was recorded in sample K-27, reflecting enhanced dissolution of carbonate rocks, particularly limestone and dolomite.

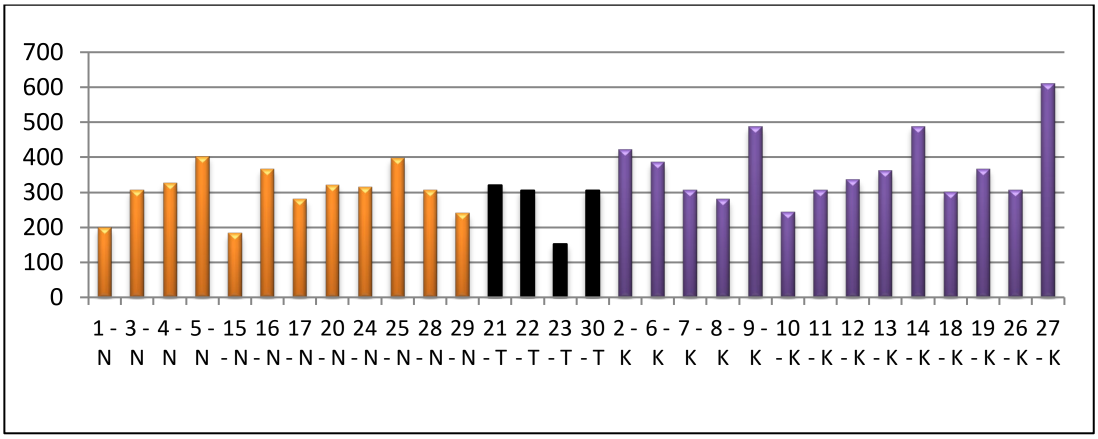


Figure 13: Bicarbonate (HCO_3^-) concentrations in groundwater samples

Overall, elevated sulfate and chloride concentrations were observed in several groundwater samples, whereas nitrate concentrations remained within the permissible limits in all samples. These findings suggest that the hydrochemical composition of the groundwater is strongly influenced by the geological characteristics of the aquifer. The results are generally consistent with previous studies conducted in the Nafusa region [7,8,9 and10].

3.1.4 Major Cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+)

As shown in Figure 14, 26.7% of the groundwater samples exceeded the LDWS permissible limit for calcium (200 mg/L). The highest concentration (400.5 mg/L) was recorded in sample K-27, followed by K-12 (260.5 mg/L), K-14 (230.1 mg/L), K-6 (225.5 mg/L), and K-2 (210.9 mg/L). The remaining samples were within the permissible limit.

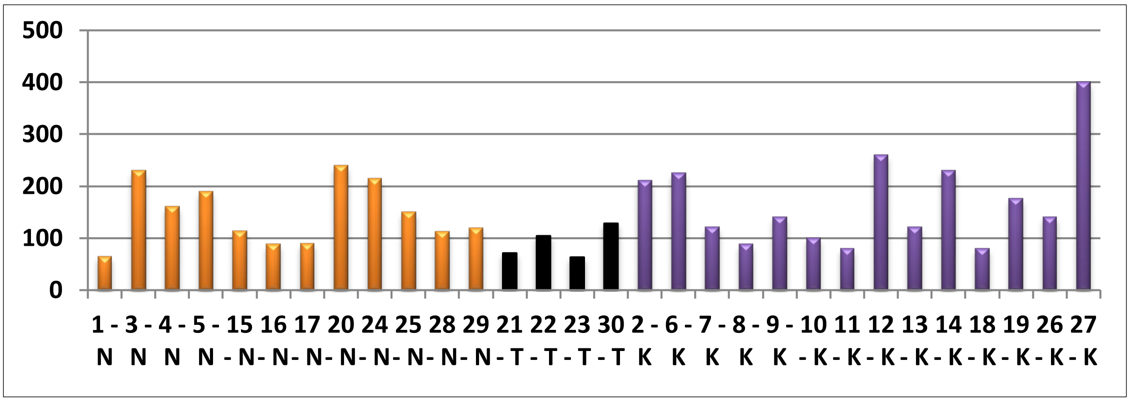


Figure 14: Calcium (Ca^{2+}) concentrations in groundwater samples.

Magnesium (Mg^{2+}) concentrations ranged from 23.32 mg/L in sample T-23 to 150.5 mg/L in sample K-27 (Figure 15). Only sample K-27 exceeded the permissible limit of 150 mg/L, while all other samples complied with the LDWS. Elevated magnesium concentrations are primarily associated with the dissolution of carbonate rocks, particularly dolomite and limestone.

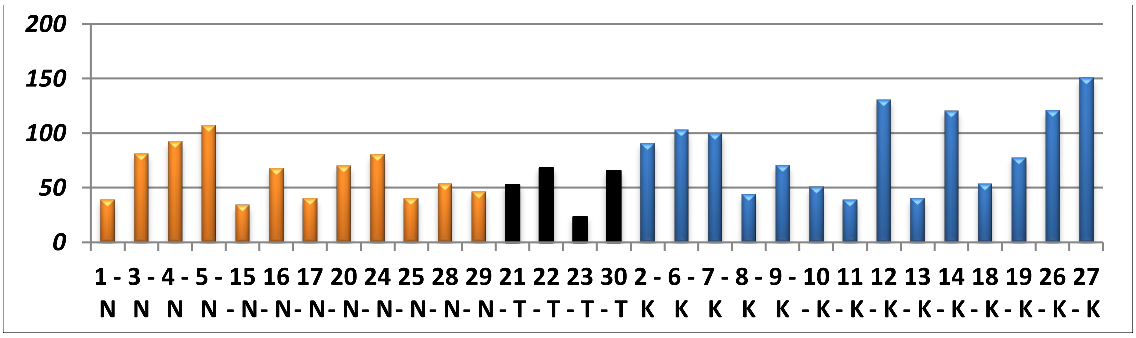


Figure 15: Magnesium (Mg^{2+}) concentrations in groundwater samples.

Sodium (Na^{+}) concentrations exceeded the LDWS permissible limit (250 mg/L) in 33.3% of the groundwater samples (Figure 16), ranging from 40.6 to 550 mg/L, with the highest concentration recorded in sample K-27. The elevated sodium levels are mainly attributed to mineral dissolution, weathering processes, and groundwater interaction with geological formations.

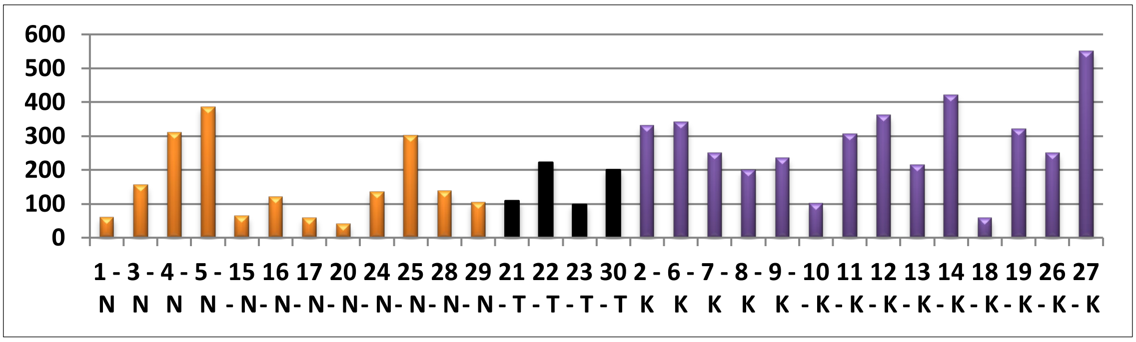


Figure 16: Sodium (Na^{+}) concentrations in groundwater samples.

Potassium (K^{+}) concentrations exceeded the permissible limit (12 mg/L) in approximately 93.3% of the groundwater samples (28 out of 30), with concentrations ranging from 10.19 to 53.69 mg/L, as presented in Table 2 and Figure 17. Only samples N-15 (11.75 mg/L) and N-4 (11.60 mg/L) remained within the permissible limit.

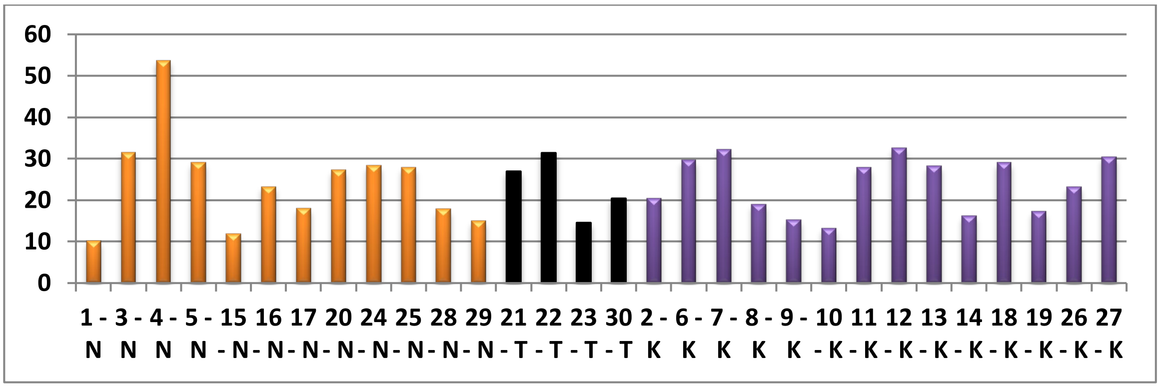


Figure 17: Potassium (K^+) concentrations in groundwater samples.

Overall, the elevated concentrations of Ca^{2+}, Mg^{2+}, Na^+, and K^+ in several groundwater samples reflect the influence of carbonate and sedimentary formations that dominate the study area. These findings are generally consistent with previous studies conducted in the Nafusa region [7, 8, 9 and10]

3.2 Bacteriological Analysis of Groundwater Samples

Table 3 and Figure 18 present the bacteriological analysis results of the groundwater samples, including Total Bacterial Count (TBC), Total Coliforms (TC), and Escherichia coli (E. coli). The results showed that no E. coli was detected in any of the analyzed samples, indicating the absence of recent fecal contamination in the groundwater of the study area.

Table 3: Bacteriological Analysis Results of Groundwater Samples

Location	Sample ID	T- Bacterial (CFU/100 mL)	Total Coliform (CFU/100 mL)	*E. coli* (CFU/100 mL)
Wadi Nalut	N-1	3	Nil	Nil
Wadi Nalut	N-5	1	Nil	Nil
Wadi Nalut	N-16	Nil	Nil	Nil
Wadi Nalut	N-24	13	30	Nil
Wadi Nalut	N-25	Nil	Nil	Nil
Wadi Nalut	N-28	Nil	Nil	Nil
Takout	K-2	3	Nil	Nil
Takout	K-26	5	Nil	Nil
Takout	K-27	17	250	Nil
Wadi Al-Thulth	T-23	Nil	Nil	Nil
Wadi Al-Thulth	T-29	8	Nil	Nil
Wadi Al-Thulth	T-30	3	25	Nil
WHO Drinking Water Guidelines	—	0	0	0
Libyan Drinking Water Standard	—	0	0	0

Low Total Bacterial Count (TBC) values, ranging from 1 to 17 CFU/100 mL, were detected in a limited number of samples. The highest count (17 CFU/100 mL) was recorded in sample K-27, followed by N-24 (13 CFU/100 mL) and T-29 (8 CFU/100 mL), whereas no bacterial growth was observed in the remaining samples.

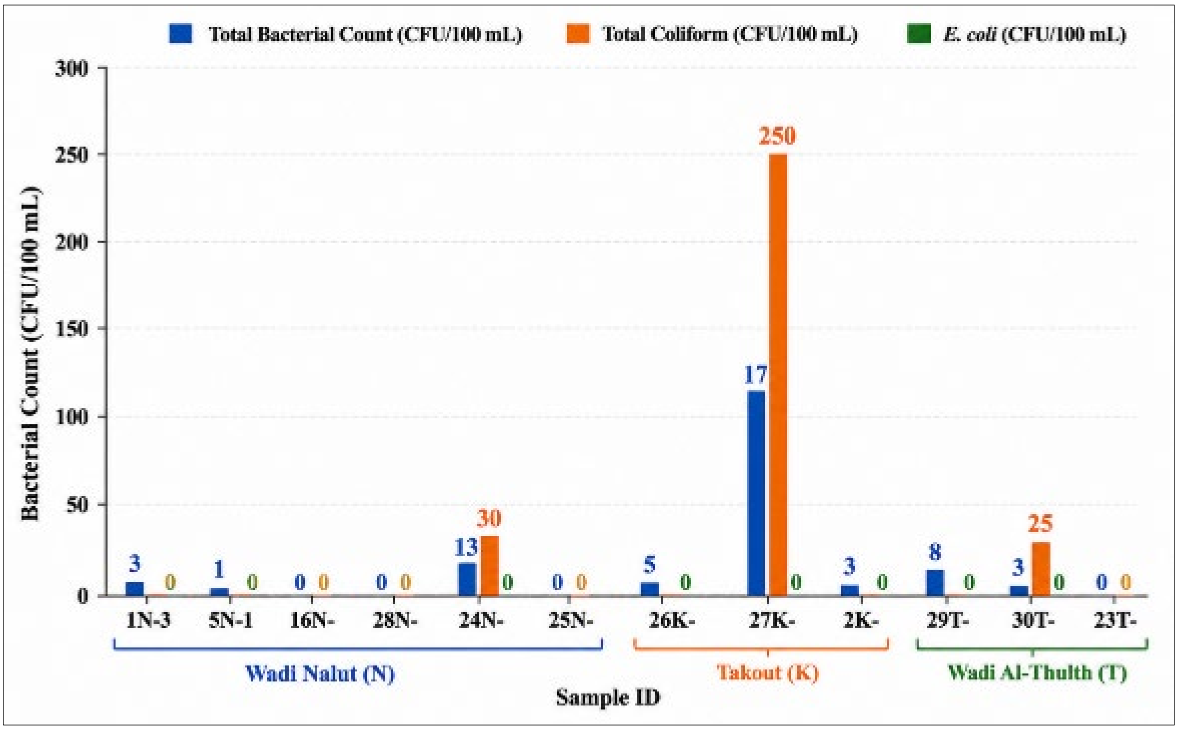


Figure 18: Bacteriological analysis results of groundwater samples.

Total Coliforms (TC) were detected in only three samples: K-27 (250 CFU/100 mL), N-24 (30 CFU/100 mL), and T-30 (25 CFU/100 mL), while all other samples were free of coliform contamination. According to the Libyan Drinking Water Standard (LDWS) and the World Health Organization (WHO) guidelines, which require the absence of TC and *E. coli* in 100 mL of drinking water, samples K-27, N-24, and T-30 were bacteriologically unsuitable for drinking. Overall, the results indicate good microbiological quality in most groundwater samples, with localized contamination in a limited number of wells. These findings are generally consistent with previous studies reporting the absence of *E. coli* and limited Total Coliform contamination in groundwater from similar hydrogeological settings [7].

3.3 Comparison of Groundwater Quality.

Groundwater quality varied considerably among the three study areas, as summarized in Table 4. Takout exhibited the poorest groundwater quality, characterized by the highest levels of most physicochemical parameters, including EC, TDS, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, Na^+, and Cl^-. It also recorded the highest bacteriological contamination, with 250 CFU/100 mL Total Coliforms and 17 CFU/100 mL Total Bacterial Count in sample K-27, indicating substantial deterioration in groundwater quality.

Table 4: Comparative Assessment of Groundwater Quality among the Study Areas

Parameter	Wadi Nalut	Wadi Al-Thulth	Takout
Water Quality	Moderate	Good	Poor
EC	Medium	Low	Very High
TDS	Medium	Low	Very High
TH	Medium	Low	Very High
Ca^{2+}	Moderate	Low	Very High
Mg^{2+}	Moderate	Low	Very High
HCO_3^-	High	Moderate	Very High
Cl^-	High	Moderate	Very High
SO_4^{2-}	Moderate	Low	High
Na^+	Moderate	Low	High
Bacteriological Quality	Good	Good	Moderate
Overall Ranking*	**2**	**1**	**3**

***Note:** *Overall ranking was based on the combined physicochemical and bacteriological water quality assessment. Rank **1** indicates the best groundwater quality, whereas Rank **3** indicates the poorest groundwater quality*

In contrast, Wadi Nalut exhibited moderate groundwater quality. Although several samples exceeded the permissible limits for EC, TDS, TH, Cl^-, Na^+, and SO_4^{2-}, most samples complied with the drinking water standards. Bacteriological contamination was limited to a single sample (N-24), where Total Coliforms and Total Bacterial Count were detected. Wadi Al-Thulth demonstrated the best groundwater quality among the three study areas. Most physicochemical parameters remained within the permissible limits, and only one sample (T-30) showed Total Coliform contamination. No Escherichia coli (E. coli) was detected in any groundwater sample collected from the three study areas.

Based on the integrated assessment of physicochemical and bacteriological characteristics (Table 4), the overall groundwater quality was ranked as follows: Wadi Al-Thulth (best) > Wadi Nalut > Takout (poorest). This ranking indicates that groundwater quality is strongly influenced by the geological and hydrogeological characteristics of the study area, which control water–rock interactions, mineral dissolution, and the susceptibility of groundwater to contamination.

4. Conclusion

The study concluded that there was clear spatial variation in groundwater quality among the three investigated areas in the Nalut region, with noticeable differences in the physicochemical and bacteriological characteristics of the water. Although the pH values were within the acceptable limits, a considerable proportion of the samples showed elevated electrical conductivity, total dissolved solids, and total hardness, together with increased concentrations of some major ions, particularly chloride, sodium, and potassium, compared with the Libyan drinking water standards. In contrast, nitrate concentrations did not exceed the permissible limits. Bacteriological analyses confirmed the absence of E. coli in all samples, while Total Coliform bacteria were detected in a limited number of samples. The comparative assessment showed that Wadi Al-Thulth had the highest groundwater quality, followed by Wadi Nalut, whereas Takout recorded the lowest quality, reflecting differences in salinity and mineralization among the study areas.

Based on these findings, the study recommends:

1. Implementing regular physicochemical and bacteriological monitoring programs for groundwater, with particular attention to wells showing elevated salinity, hardness, and chloride concentrations, especially in Takout.
2. Rationalizing groundwater abstraction and regulating the drilling of new wells according to the water resources and recharge capacity of the area, in order to limit aquifer depletion and protect groundwater quality.
3. Conducting hydrogeological investigations to identify factors controlling groundwater salinity, mineralization, flow paths, and the relationship between geological formations and water quality, while assessing alternative water sources to reduce groundwater dependence

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