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Quality Assessment of Groundwater Resources in the City of Al-Marj, Libya

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Abstract: This study aimed to assess and compare the quality of groundwater in the city of Al-Marj in Libya with the international standard guidelines for drinking water recommended by the World Health Organisation. An evaluation of the groundwater wells in the study area was conducted. Standard techniques, such as Minitab (v. 16) and ArcGIS (v.10.2), were used for the analytics of the physicochemical and biological parameters of the groundwater samples. An assessment of the calculation of groundwater quality was conducted on the basis of temperature, pH, turbidity, electrical conductivity, total dissolved solids, chloride, sulphate, bicarbonate, total hardness, calcium, potassium, magnesium, ammonia, ammoniacal nitrogen, nitrate, sodium, copper, iron, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total suspended solids, *Escherichia coli* and total coliform bacteria. Results indicated that most groundwater wells in the study area display a higher concentration of several parameters compared with the permissible limits of drinking water; thus, the water in these wells is chemically and biologically unsafe for drinking purposes. On the basis of the above results, routine water quality monitoring should be performed and additional water filtration plants should be installed by the local government to obtain safe drinking water.

Keywords: groundwater; physicochemical and biological parameters; water quality index; Al-Marj city

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1. Introduction

Water is a fundamental element in the life of every creature. It is primarily obtained from two sources, surface water and groundwater [1], and roughly one-third of the world's population utilises groundwater for drinking purposes [2]. Groundwater is a valuable natural water reservoir that can be regarded as a safe and accessible water source for residential use [3]. Groundwater has been used as a preferred source of drinking water in arid and semiarid areas [4]. Water sources in Libya come from four sources, with groundwater providing almost 95% of the country's needs; surface water, including rainwater and dam constructions, as well as desalinated seawater and wastewater recycling [5]. Groundwater is the principal source of drinking and irrigation water in the African continent [4,5]. The major livelihood of the residents of the city of Al-Marj is agriculture, and they heavily rely on groundwater for drinking, domestic, livestock, and agricultural purposes [6]. Therefore, with the increasing demand for groundwater, its quality and sustainability have become the focus of public health and food manufacturing industries worldwide. Water contamination is a major issue that occurs in the groundwater of developed and developing countries [7]. Thus, the estimation of groundwater quality is indispensable to define hygienic and appropriate groundwater sources. The human population in numerous areas of the world are facing critical issues of water supply and contamination, African countries confront difficulties in obtaining safe drinking water and satisfactory sanitation [8]. Groundwater contamination is particularly acute in arid or semiarid countries where water supply is scarce [1]. Groundwater quality in Libya is a critical issue that threatens human health due to the high concentration of some chemical and physical parameters [9]. The appropriate grade of water and its permission for drinking and other regional uses rely on its physicochemical and microbiological characteristics [10]. Statistically, 80% of illnesses in developing nations are directly connected with the insalubrious status of drinking water. In addition, the contamination of groundwater is related to unsanitary and polluted drinking water, which causes illnesses, including cholera, diarrhoea, dysentery, and hepatitis. Each year, more than 842,000 people worldwide die from diarrhoea [11]. Therefore, the main aim of this work is to assess groundwater quality by testing 11 groundwater wells in the study area on the basis of physicochemical and bacteriological parameters.

2. Materials and Methodology

2.1. Description of the Study Area

The study was conducted in the city of Al-Marj in Libya. The city is located in the north-eastern part of Libya and lies on the bank of the Mediterranean Sea. It covers an area of approximately 10,000 km^2. The regulatory seat of Al-Marj was known as Barca. Al-Marj is arranged on the Cyrenaica level at the western edge of Jebel Akhdar and had an estimated population of 85,315 at the beginning 2012 with coordinates 32°29′12″ N 20°50′02″ E [12]. The study area is considered one of the most valuable regions in Libya because of its location relative to the Green Mountain, as well as its agricultural activities, including irrigated and non-irrigated cultivation and animal wealth as well as economic activities. The precise locations of the sampling points of the groundwater wells were determined in the field using GARMIN GPSMAP 67CSx (Handheld, Lenexa, MD, USA).

The study area is influenced by the Mediterranean climate, which is characterised by hot, dry summers and mild, rainy winters. The study area has a dry climate, such as that of a semidesert, showing minimal rainfall and high evaporation rates and a clear appearance of aridity, which prevails over the entire area. The climatic characteristics were obtained from the Al-Marj meteorological station, the nearest to the study area. The average annual rainfall is 380 mm year^{-1}. December, January and February have the highest rates of precipitation and lower temperatures during the year, whereas the average yearly temperature is 18.8 °C. The highest relative humidity appears in January and February, with an average of 71%, and it decreases in May and June, with an average of 50%; the highest wind speed appears in December, January and February, reaching up to 10 km/h, and the average annual wind speed is 8.6 km/h [13]. An assessment of 11 groundwater wells in the study area was conducted to determine the degree of water quality, as shown in Figure 1.

2.2. Description of the Groundwater Wells

Groundwater wells are the primary water source in Libya, including the city of Al-Marj; these wells are used for different purposes, such as drinking and irrigation. Eleven groundwater wells were surveyed in terms of criticality, coordinates, elevation, depth, age, and locality; these wells are situated in the farms around the city with the purpose to determine the water quality at the study area, as shown in Table 1.

2.3. Sample Collection and Analysis

Firstly, data collection mining was performed to obtain the pertinent information needed for this research. The samples for primary information were all gathered from the groundwater wells in the study area. The sampling of data collection and laboratory extraction of primary data started on 1 June 2017 and was completed on 25 August 2017. In accordance with the procedures indicated in [14], water samples from 11 groundwater wells were collected. A total of 33 water samples were collected from the studied groundwater wells.

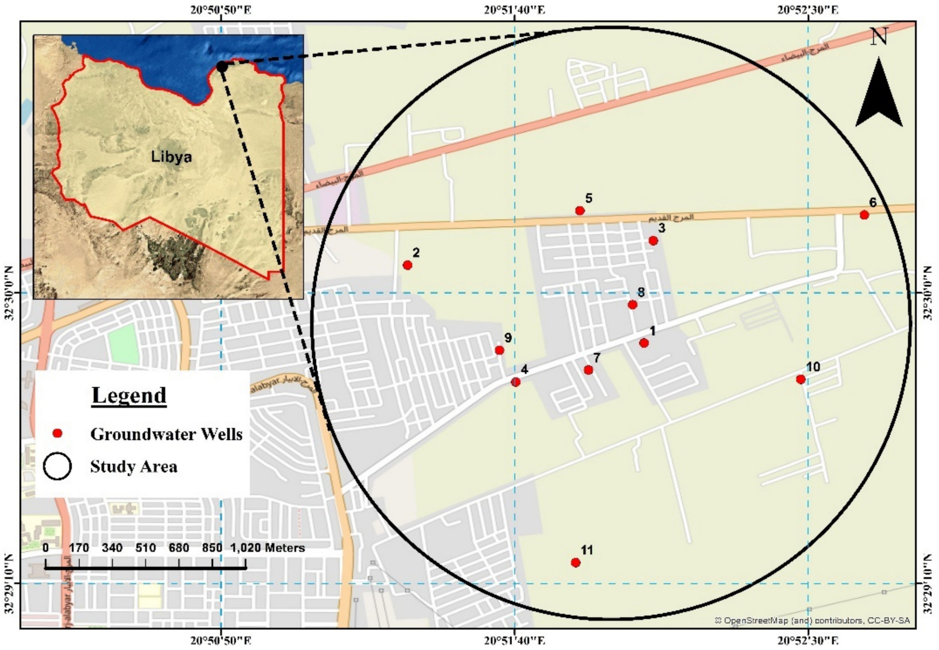

Figure 1. The groundwater wells in the study area.

Table 1. Description of groundwater wells.

No.	Wells Name	Coordinates		Elevation (m)	Depth of wells (m)	Wells Age (Year)
		Latitude	Longitude			
1	Salah Amtaual	32.497556	20.864528	284	280	1978
2	Salam Edaab	32.501167	20.853667	300	472	1979
3	Al Marthi	32.502306	20.864944	292	200	2001
4	Saad Mokhtar	32.495750	20.858639	297	228	1965
5	Al Sahly	32.503694	20.861583	296	200	1978
6	Ali Ibrahim	32.5035	20.874639	288	262	2010
7	Agdora Al Abidi	32.496306	20.861972	295	301	2002
8	Mohamad Abd Raba	32.499333	20.864	296	250	1999
9	Sediq Al Rashed	32.497222	20.857889	314	280	1978
10	Idris Moftah	32.436833	20.882028	356	365	1998
11	Abo Shuisha	32.428333	20.871694	363	300	2008

The coordinates in the decimal degrees system.

Water samples were pumped out of boreholes at a fast rate to cool the metal pipe and thus eliminate the influence of water temperature on the pipe. The pumping was sustained for at least 5 min. Generally, water samples were collected from groundwater wells using 500 mL glass bottles. The glass bottles were cleaned with warm water and soap and then rinsed with double distilled water and a few drops of 5% HNO_3 were added to avoid microbial activities. Afterwards, the bottle was rinsed with some of the water and then filled, leaving no air space; then, the bottles were immediately covered. Separate samples were obtained for chemical and biological examination with the appropriate procedures for sampling and protection of the samples. To ensure that the evaluations were accurate and reproducible, after every 10 samples, blank, standard and pre-analysed samples were examined. The standard processes by [15] were used to analysed all of the samples.

Water samples were transported to the laboratory in a cool box with ice and analysed within 6 h. Samples meant for metal analysis were stored in a refrigerator at 4 °C. Then, water samples were carried and analysed carefully in the laboratory of Abutaraba desalination plant, which is located nearly 20 km north of the city of Al-Marj.

The physical parameters of the water samples were determined in accordance with the standard method in [15,16]. The measured physical parameters are as follows:

Temperature was measured using an HI 98517 (Hanna Instruments, Smithfield, RI, USA) and was calibrated and set to 25 °C; whereas pH was measured using an HI 9024-C (Hanna Instruments, Smithfield, RI, USA), and the calibration of the pH meter used the standard buffer solutions of pH 4, 7, and 10. A LaMotte turbidimeter (Model: 2020 we/wi, LaMotte Company, Chestertown, MD, USA) was calibrated by using formazin standards to measure the turbidity of the water samples. Electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were measured using a YSI multiparameter water quality meter (Model: 3100C, Xylem, Westchester County, NY, USA). Measurements were made using the standard methods recommended by [15] and Canada CCME [16]. The mensuration was repeated thrice for each parameter reading, and the average was taken. These six physical parameters were chosen on the basis of their relevance to the general water quality constituents as pollution indicator parameters.

Thirteen chemical parameters were included to examine the quality of water. The parameters are as follows: Chloride was determined by Mercuric Thiocyanate Method (HACH method 8113); detection range 0.1 to 25.0 mg/L Cl^-; wavelength 455 nm reported in [16]. The Turbidimetric Method was used to measure the SO_4^{2-}. The NO_3^- was measured via an Ultraviolet Spectrophotometer Screening Method by (DR 2800, Hach). The MB3000 Fourier Transform Infrared Spectroscopy (Perkin-Elmer, Waltham, MA, USA) was used to measure the HCO_3^- at 2345 wavenumbers. A flame photometer (model CL-360, Elico, Baden, Switzerland) was utilized to measure the Na and K. Ca and Mg were analysed by used the complexometric titration EDTA (ethylenediaminetetraaceticacid) Titration Method as described in [17]. Total hardness was counted by the total of Ca and Mg altogether. The salicylate method of Ammonia Salicylate Powder Pillow (10,205) 0 to 10 mg/L NH_3-N was used to measure NH_3 and NH_3_N by using the Hach DR 2800 spectrophotometer. Biochemical oxygen demand was determined by the 5-day Biochemical Oxygen Demand Dilution Method prescribed by Hach Method 10,230. COD was evaluated using a Hach DRB200 reactor and a Hach DR6000 spectrophotometer (Reactor Digestion Method) with the potassium acid phthalate; determination of COD was detected in limitation of 0.7 to 40.0 mg/L. The photometric method (Hach method 8006; detection range: 5–750 mg/L; wavelength: 810 nm) was used to determine the total suspended solids (TSS). The chemical analysis of the groundwater samples was conducted in accordance with the standard method recommended by Hach [18]. Copper and Iron were examined via ICP-MS (Inductively Coupled Plasma Mass Spectrometry) and Strong Acid (HNO_3/HCL) digestion Method 200.2. *E. coli* and total coliforms (TC) in each sample were determined using the Membrane Filtration Method 8074.

For the statistical analysis, Minitab software version 16 was used to obtain the mean, standard deviation and *p*-value; one-way analysis of variance (ANOVA) was performed to determine the significant difference between each value. Inverse distance weighted interpolation was used to present the quality of water on the basis of each parameter. By using ArcGIS 10.1 software, each physicochemical and biological parameter was interpolated with Inverse Distance Weighting (IDW), and maps were created.

3. Results and Discussions

The physicochemical and biological parameters measured from groundwater wells were precisely analysed and compared with the regulatory standards set by the World Health Organisation.

3.1. Temperature

The temperature of the groundwater wells varied between 20.8 and 23.2, as presented in Table 2. The lowest temperature was found in the Al Marthi groundwater well (20.8 ± 2.2), whereas the highest temperature was recorded in the Salam Edaab groundwater well (23.3 ± 1.2). This finding is similar to that of a previous study by Mostafa et al. [19], who revealed that the variation in groundwater temperature may be due to dissimilarities in the collection time, which fluctuates from one period to another. Another study by Parmar [20] examined the groundwater quality in five villages of Chalisgaon in India and confirmed that the temperature of the groundwater wells varied within approximately 30 °C from August 2009 to April 2011, and the mean temperature was 27.40 °C in all seasons for both years. No statistically significant differences were found in the temperature of the groundwater wells (p-value = 0.965).

Table 2. Descriptive statistics and p-value of Temperature (°C).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	21.8	23.2	20.8	21.2	22.1	21.8	22.3	21.6	21	22.2	22.3
Std Dev	2.9	1.2	2.2	2.6	1.2	1.9	2.1	1.5	2.5	2	2.4
p-Value	0.965										
WHO's guideline	-										

The spatial distribution of temperature within the groundwater wells is shown in Figure 2. The groundwater temperature is usually equivalent to the mean air surface temperature, and it typically stays within a small area all year round. The fluctuation in the groundwater's temperature was linked to the well's temperature tendency, lithology profile and geological environment, as well as the depth of the aquifers [21]. Similar results in terms of groundwater temperature were found by Chacha et al. [22], who conducted research in Arusha in northern Tanzania and confirmed that the groundwater temperature ranged from 19.4 °C to 24.5 °C. The temperature in Figure 2 shows that the measured temperature often decreases with depth.

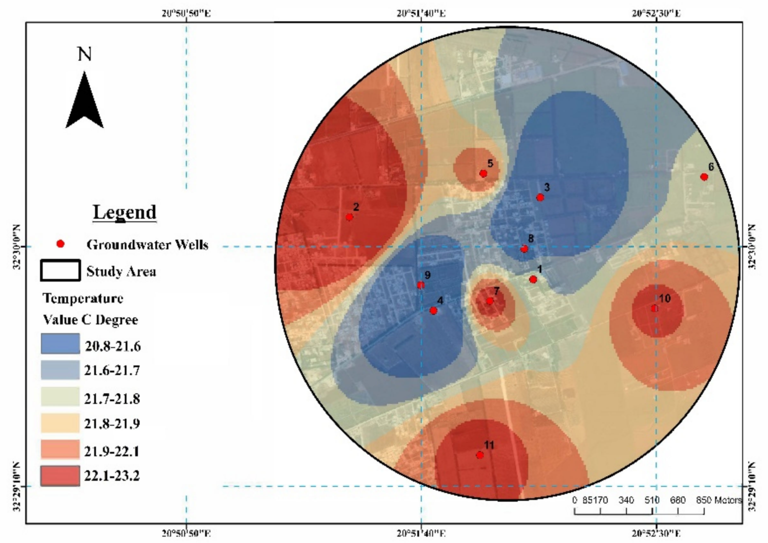

Figure 2. Spatial distribution map of Temperature.

3.2. pH

The water samples from the groundwater wells had a total pH between 6.6 and 7.3, as shown in Table 3. The lowest pH was found in the Sediq Al Rashed groundwater well (6.6 ± 1.2), whereas the highest value was recorded in the Abo Shuisha groundwater well (7.3 ± 1). A similar finding was observed by Suk-Ueng et al. [23], who stated that the pH range varied between 6.96 and 8.5 and indicated the alkaline nature of the groundwater. No significant differences were found amongst the pH of the groundwater wells (*p*-value = 0.099). Therefore, the pH of the groundwater wells is acceptable on the basis of the WHO's recommended limit for drinking water [24].

Table 3. Descriptive statistics and *p*-value of pH.

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	7.1	7.2	7	6.9	7.1	7.2	7.2	7.1	6.6	7	7.3
Std Dev	0.95	0.96	0.55	0.85	0.7	1.1	1.2	0.95	1.2	0.8	1
p-Value	0.99										
WHO's guideline	6.5–8.5										

The distribution of pH within the groundwater wells ranged between 6.5 and >7.3, as shown in Figure 3. A similar finding was discovered by Brhane [25], who studied the groundwater quality in Adiabat, Ethiopia and reported that the pH distribution was within 6.5–8.5. In [26], the pH of the groundwater wells in the city of Konya in Turkey was reported to be distributed within 7.0–8.6.

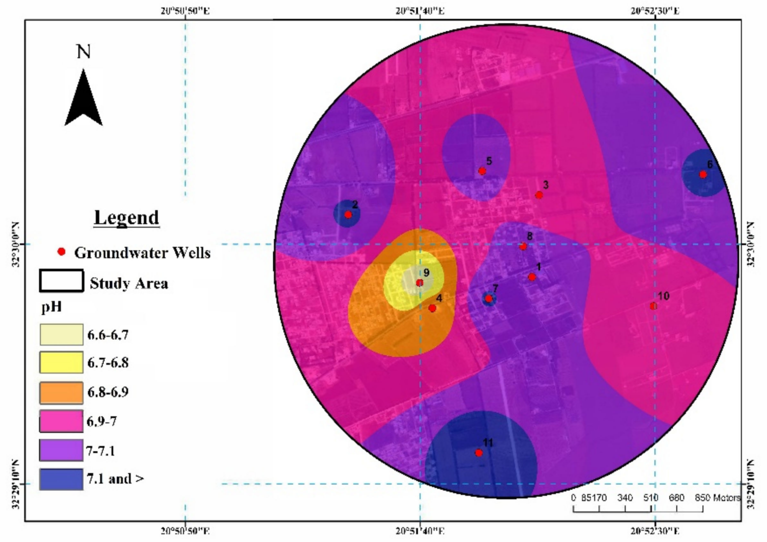

Figure 3. Spatial distribution map of pH.

3.3. Turbidity

The turbidity of the groundwater wells in the study area ranged from 0.2 to 1.2 nephelometric turbidity units (NTU), as shown in Table 4. The lowest level of turbidity (i.e., 0.2 NTU) was found in two groundwater wells (Salah Amtaual and Idris Moftah), and the highest quantity was recorded in the Al Marthi groundwater well (1.2 ± 0.8 NTU). The high value of turbidity was due to the discharge of the residential area's sewage that reached the groundwater well and the soil erosion caused by natural phenomena and human activities near the study area. Akinbile and Yusoff [27] conducted an analogous study of groundwater quality in the city of Akure in Nigeria and confirmed that the turbidity ranged between 1.6 and 6.6 NTU; some of the studied groundwater wells were above the recommended value for drinking water (i.e., <5 NTU). The turbidity quantum within the groundwater wells showed no statistically significant differences (*p*-value = 0.076). Therefore, the turbidity level of the groundwater wells was within the limit of the guidelines for drinking water. In the current research, the turbidity value did not cross the limit of the WHO guidelines for drinking water [24].

Table 4. Descriptive statistics and *p*-value of Turbidity (NTU).

Groundwater Wells	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Mean	0.2	0.3	1.2	0.4	0.5	0.6	0.7	0.8	0.6	0.2	0.3
Std Dev	0.08	0.1	0.8	0.2	0.2	0.4	0.2	0.4	0.09	0.2	0.2
p-Value	0.076										
WHO's guideline	5										

The concentration and distribution of turbidity within groundwater wells were distributed from 0.2 to <0.7 NTU, as shown in Figure 4. Turbidity refers to the cloudiness of water caused by suspended solids (e.g., clay and sediments), various chemical sources (e.g., manganese and iron), biological substances (e.g., agricultural debris), and microorganisms [28]. Thus, groundwater wells located near an inoperative wastewater treatment station exhibit high turbidity. Turbidity is assumed to be mainly for aesthetics in water sources, and evidence has been found to prove that managing turbidity is an effective defence against contaminants in drinking water [29].

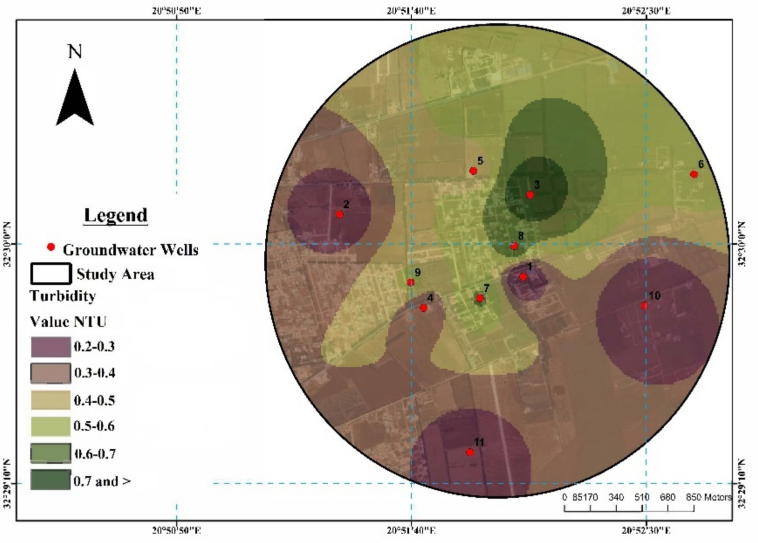

Figure 4. Spatial distribution map of Turbidity.

3.4. Electrical Conductivity

The EC of the tested groundwater wells varied between 826 and 1711 µS/cm, as shown in Table 5. The Abo Shuisha groundwater well had a low EC value (826 ± 11.5), and that of the Al Marthi groundwater well had a high EC value (1711 ± 10). The obtained values of EC of the studied groundwater wells were above the permissible limit of drinking water (i.e., 300 µS/cm); these results indicate the strong mineralisation of the groundwater wells. This phenomenon might be due to the discharge of sewage water from the residential area towards the groundwater wells in the city. Qaseem and Al-Barwary [30] evaluated the groundwater quality in Iraq and showed that the high EC value was due to the high level of dissolved chemical ions in the groundwater wells; the flow of water through calcite rocks resulted in high TDS. Significant differences were found amongst the EC of the studied groundwater wells (*p*-value = 0.00).

Table 5. Descriptive statistics and *p*-value of Electrical Conductivity (µs/cm).

Groundwater Wells	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Mean	1479	1513	1711	1514	1564	1497	1648	1522	1530	905	826
Std Dev	16.5	4.6	10	16	3.6	15.5	8.5	9	95.6	13.1	11.5
p-Value	0.00										
WHO's guidelines	300										

The spatial variation of EC in the groundwater wells is shown in Figure 5. The distribution of EC in the measured groundwater wells may be due to the effectiveness of the depth amongst the groundwater wells. However, a broad range of high EC values was found in the groundwater wells due to the sewage discharge in the area. Alfaifi et al. [28] assessed the groundwater quality in the city of Najran in the southern part of Saudi and found that the distribution range of EC was from 1791 S/cm to 2622 S/cm.

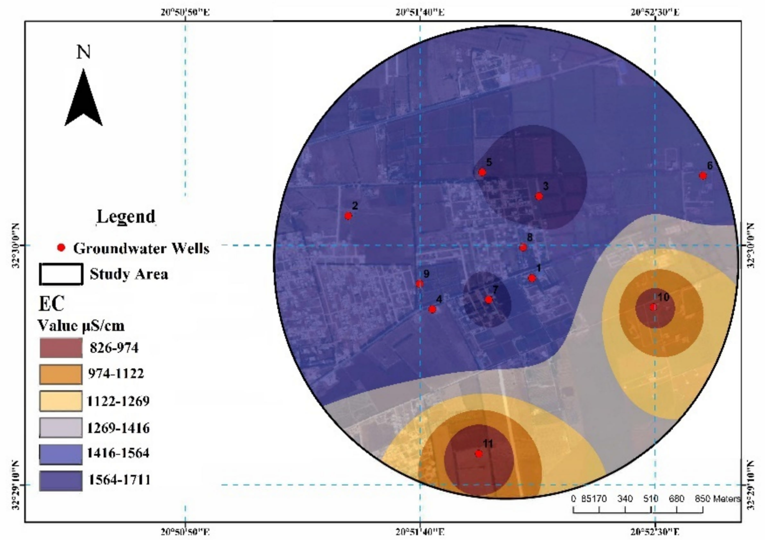

Figure 5. Spatial distribution map of Electrical Conductivity.

3.5. Total Dissolved Solids

The TDS value varied between 412 and 854 mg/L in the tested groundwater wells, as listed in Table 6. The lowest TDS was recorded in the Abo Shuisha groundwater well (412 ± 4.6), whereas the highest level was observed in the Al Marthi groundwater well (854 ± 4.5). The palatability of water with a TDS below 600 mg/L is generally considered to be satisfactory; drinking water becomes unpalatable in higher TDS levels (i.e., >1000 mg/L) [15]. Similar findings were reported by Mahmood et al. [31], who conducted a study in the city of Kirkuk in Iraq and showed that TDS ranged from 401 mg/L to 759 mg/L. Except for that of the Abo Shuisha groundwater well, the TDS value of the studied groundwater wells exceeded the allowable limit for drinking water (i.e., 500 mg/L) recommended by the WHO [24]. Results of the one-way ANOVA showed significant differences amongst the TDS of the examined groundwater wells (p-value = 0.00).

Table 6. Descriptive statistics and p-value of Total Dissolved Solids (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	739	757	854	756	782	748	824	761	765	452	412
Std Dev	12	12.3	4.5	13.5	3.6	11	8.2	8.5	6	18	4.6
p-Value	0.00										
WHO's guidelines	500										

Figure 6 illustrates the spatial distribution of TDS on the groundwater wells. Accordingly, TDS may enter the groundwater by recharging water that has been polluted by human use via wastewater or returning agricultural drainage to groundwater wells. The quality of groundwater for drinking can be expressed in terms of TDS concentration [32]. Groundwater with a low TDS value of 300 mg/L can be considered suitable for drinking [24]. A high value of TDS indicates the presence of numerous cations and anions in the water [33].

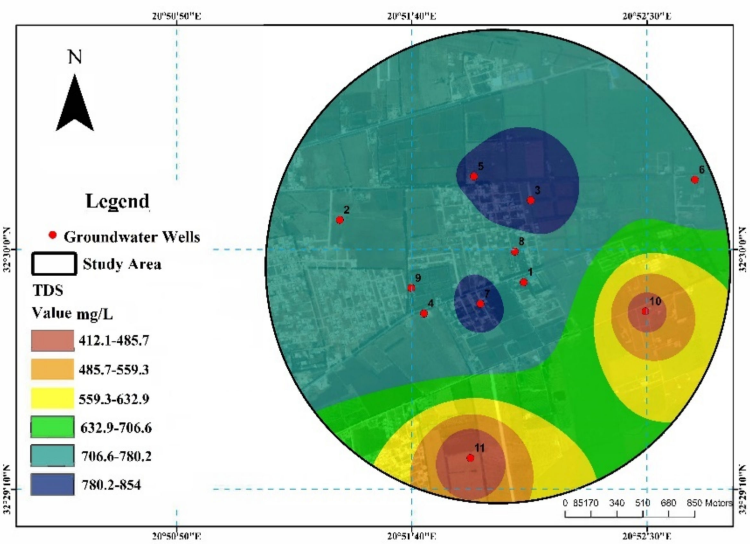

Figure 6. Spatial distribution map of Total Dissolved Solids.

3.6. Chloride

The chloride concentration within the groundwater wells ranged between 134.3 mg/L and 353.1 mg/L, as shown in Table 7. The lowest value was found in the Abo Shuisha groundwater well (134.3 ± 5.7), and the highest level was recognised in the Al Marthi groundwater well (353.1 ± 6.5). Only two groundwater wells had a chloride concentration lower than the WHO-recommended allowable limit for drinking water (i.e., 250 mg/L) [24]. The exponential rise in Cl^- concentration may be linked to the geographical location of the groundwater wells, i.e., near a deactivated wastewater treatment station. High chloride concentration in groundwater originates from natural sources, sewage and industrial effluents, and urban runoff containing de-icing salt and saline intrusion. Wei et al. [34] examined the quality of groundwater in Taiwan and observed that the concentration of Cl^- ranged from 550 mg/L to 6190 mg/L. Significant differences were found amongst the chloride concentration of the evaluated groundwater wells (*p*-value = 0.00).

Table 7. Descriptive statistics and *p*-value of Chloride (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	288	283.4	353.1	285	281.3	284.4	319	282	282.6	147.6	134.3
Std Dev	11	3	6.5	14.7	7	9	6.2	4.6	7	10.1	5.7
p-Value	0.00										
WHO's guideline	250										

Figure 7 elucidates the spatial distribution of Cl^- on the groundwater wells in the study area. The distribution of Cl^- in the studied groundwater wells was analysed. High concentrations of Cl^- were found in most of the groundwater wells, except for two wells; the nine groundwater wells exceeded the allowable limit of chloride in groundwater [24]. Based on the spatial distribution of Cl^-, high concentrations were found in most groundwater wells; the high chloride level could be due to industrial and domestic wastes, leaching in dry climates from the upper soil layers and natural geophysical activities in the region [35].

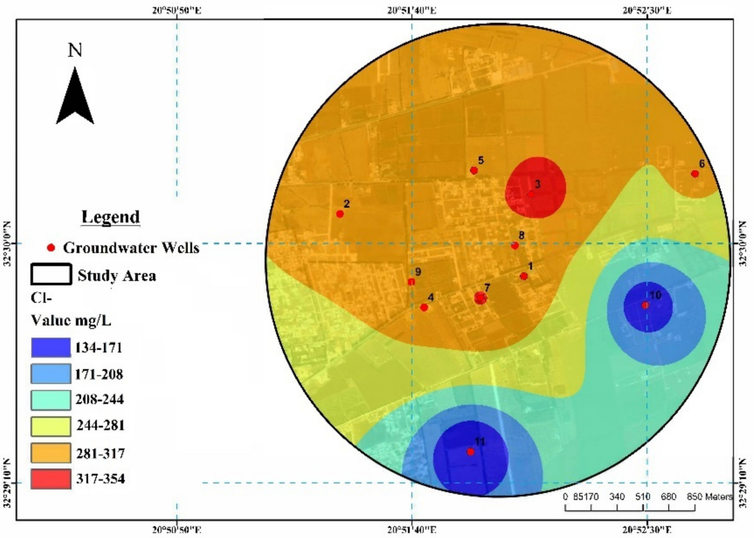

Figure 7. Spatial distribution map of Chloride.

3.7. Sulphate

The concentration of SO_4^{2-} in the measured groundwater wells was within 20–69 mg/L, as shown in Table 8. The lowest level of SO_4^{2-} concentration was observed in the Abo Shuisha groundwater well (20 ± 4), whereas the highest concentration was found in the Ali Ibrahim groundwater well (69 ± 8.2). The concentration of SO_4^{2-} in the groundwater wells was below the prescribed level of 250 mg/L. A high concentration of SO_4^{2-} is expected in groundwater wells near disrupted wastewater treatment stations adjacent to the same area of groundwater wells or intensively irrigated areas. It can also come from the degradation of organic materials; dissolved wastes, such as building waste or ash; synthetic detergents; and inert wastes, such as dredging. SO_4^{2-} typically occurs naturally in numerous minerals and is predominantly used in the chemical industry [15]. Therefore, elevated SO_4^{2-} concentrations may be derived from seawater or generated by pyrite oxidation [36]. A groundwater quality assessment conducted by Nas and Berktay [26] in the city of Konya in Turkey revealed that the mean concentration of SO_4^{2-} was 50 mg/L. The one-way ANOVA findings showed significant variations in sulphate concentration amongst the groundwater wells (p-value = 0.00).

Table 8. Descriptive statistics and p-value of Sulfate (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	38	30	51	30	40.7	69	47	34	31.7	21.3	20
Std Dev	5.5	6	7.5	5.5	9.6	8.2	9.6	6.2	2.5	3.5	4
p-Value	0.00										
WHO's guideline	250										

Figure 8 shows the spatial variation of SO_4^{2-} concentration in the investigated groundwater wells. The high level of sulphate in the groundwater wells could be due to the discharge of different polluting substances in the area. Lorite-Herrera and Jiménez-Espinosa [37] experimentally analysed the groundwater quality in Jae'n, Spain and found that the other sources of sulphate in groundwater may be agricultural practices; they also reported that groundwater is mainly saturated or slightly supersaturated for calcite in the aquifer.

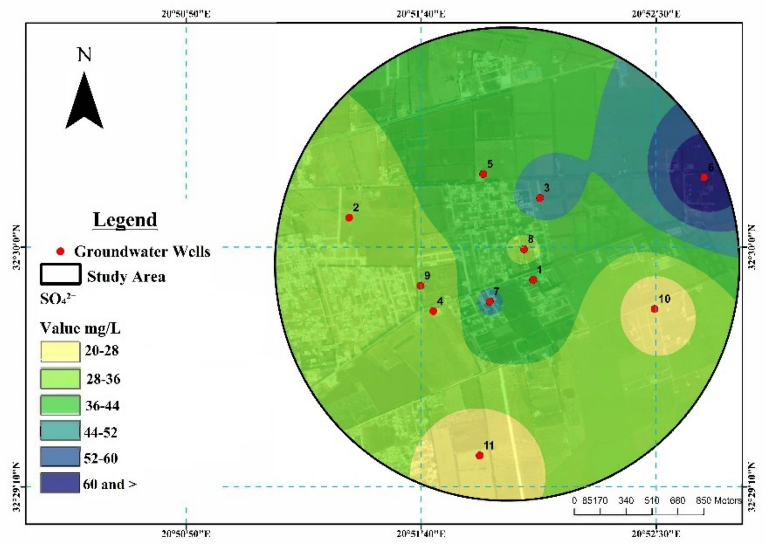

Figure 8. Spatial distribution map of Sulfate.

3.8. Bicarbonate

The bicarbonate concentration in the groundwater wells ranged from 101 mg/L to 161 mg/L, as shown in Table 9. The Idris Moftah groundwater well had a low level of HCO_3^- (101 ± 4.6), whereas the Al Marthi groundwater well had the highest concentration (161 ± 8.5). The HCO_3^- concentration in the groundwater wells was lower than the WHO-recommended limit for drinking water (i.e., <300 mg/L) [24]. In a recent study conducted by Adimalla and Venkatayogi [35], the groundwater quality in India's Medak community was assessed; results revealed that the content of HCO_3^- in the groundwater wells varied from 18 mg/L to 527 mg/L, with a mean value of 306.5 mg/L. Biglari et al. [38] examined the groundwater quality parameters in Iran and reported that the average value of HCO_3^- was 549 mg/L, suggesting that the groundwater wells were contaminated with a high concentration of bicarbonate. Results of the one-way ANOVA indicated significant variations in the bicarbonate concentration of the groundwater wells (p-value = 0.00).

Table 9. Descriptive statistics and p-value of Bicarbonate (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	111	125	161	128	110	131	135	151	151.3	101	101.7
Std Dev	3.6	8.7	8.5	7	7.5	6.5	6	8	3.8	4.6	3.5
p-Value	0.00										
WHO's guideline	300										

The high level of bicarbonate in the groundwater wells may be due to the influence of harmful pollutants emitted from the city to the groundwater wells via sewage flow (See Figure 9). The distribution of HCO_3^- is supported by a study by Brhane [25], who assessed the quality of groundwater in Tigray, Ethiopia; a considerably high amount of HCO_3^- was detected in the central region and some points in the northern part of the country due to untreated wastewater that reached the groundwater from old dumpsites and small factories.

3.9. Total Hardness

The accumulation of TH in the groundwater wells ranged from 149 mg/L to 271 mg/L, as summarised in Table 10. The lowest concentration was found in the Abo Shuisha groundwater well (149 ± 3.6), and the highest value was recorded in the Ali Ibrahim groundwater well (271 ± 8). The TH concentration in groundwater was affected by fluctuations in the amount of heavy rain and leachate drainage from farming or agricultural fields and by the usage of well water for gardening and farming. On the basis of TH, the water samples can be categorised as soft (greater than 1–70 mg/L), moderately hard (75–150 mg/L), hard (150–300 mg/L), and extremely hard (above 300 mg/L) [39]. The analysed groundwater wells were below the acceptable limit of drinking water (i.e., 500 mg/L). The water samples were considered suitable for consumption and domestic use and classified as moderately-hard to hard. Significant differences were found amongst the TH of the studied groundwater wells (*p*-value = 0.00).

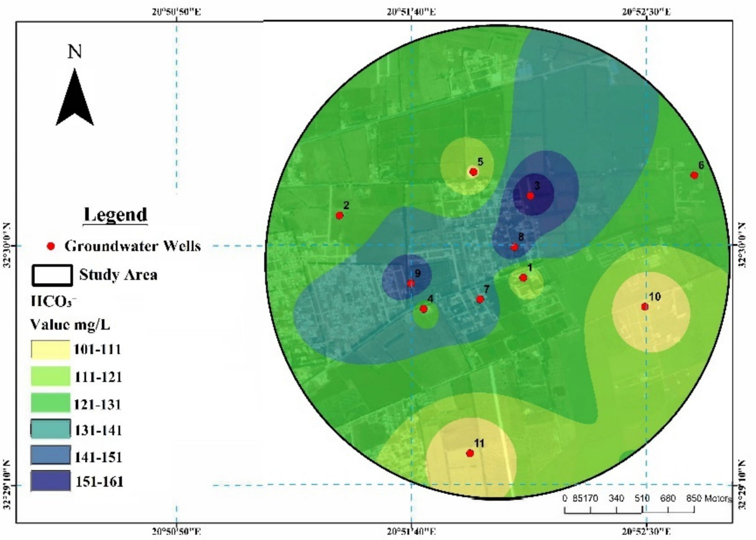

Figure 9. Spatial distribution map of Bicarbonate.

Table 10. Descriptive statistics and *p*-value of Total Hardness (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	228	222	250.7	216	271	176	231	219	211.7	161	149
Std Dev	7	6.2	2.5	3.6	3.6	8	3	7.5	6.5	9.1	3.6
p-Value	0.00										
WHO's guideline	500										

The spatial distribution of TH in the groundwater wells increased from 0 mg/L to 300 mg/L, as shown in Figure 10. A previous study by James [40] determined the water quality of groundwater wells in the city of Paynesville in Liberia; results showed that the distribution of TH was within 25–425 mg/L. Talat et al. [41] evaluated the quality of groundwater in the city of Mosul city in Iraq and confirmed that the distribution of TH ranged from 460 mg/L to 2230 mg/L.

3.10. Calcium

In comparison with the WHO-recommended limit for drinking water (i.e., 75 mg/L) [24], high levels of Ca were recorded in all the groundwater wells, except for the Abo Shuisha groundwater well as shown in Table 11. The abundance of Ca in water is mostly due to its usual presence in Earth's crust. Deshpande et al. [42] examined groundwater quality in the Aurangabad district of India and reported an average Ca value of 112.22–168.33 mg/L. Significant differences were found amongst the Ca concentration of the examined groundwater wells (*p*-value = 0.00).

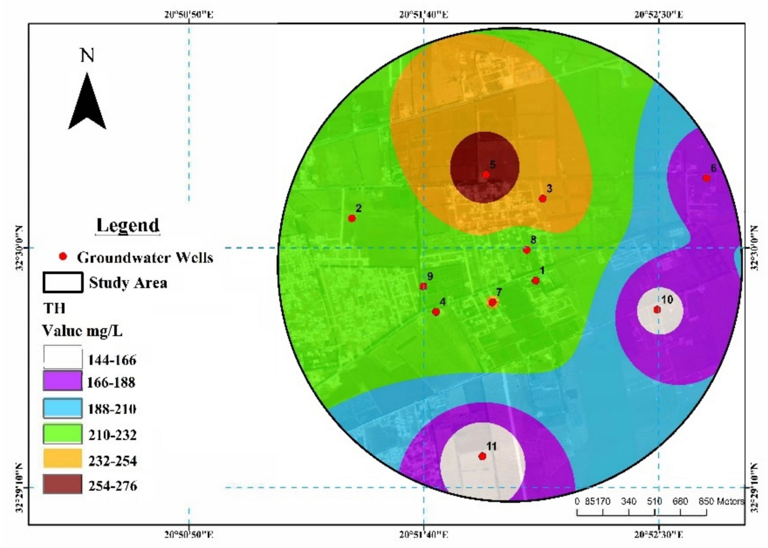

Figure 10. Spatial distribution map of Total Hardness.

Table 11. Descriptive statistics and p-value of Calcium (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	124	116	140	127.7	167	94	122	110	123.7	81	74
Std Dev	3.6	8.1	4	6.5	5.3	4.6	3.6	6.2	3.5	2.1	6.6
p-Value	0.00										
WHO's guideline	75										

As shown in the data presented in Figure 11, most of the groundwater wells had a high distribution of Ca, exceeding the WHO-recommended limit for drinking water [24]. The main water chemistry of the groundwater wells may reflect the geology of the area. The total concentration of Ca is the main factor that increases the hardness of water [43].

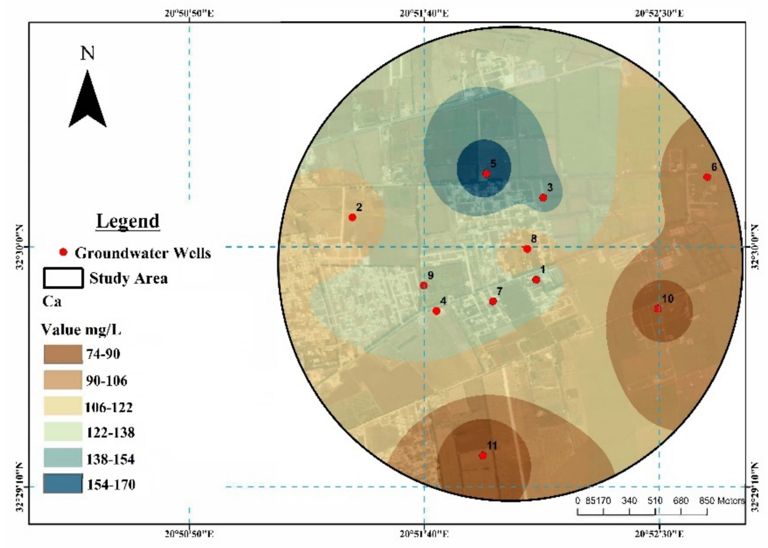

Figure 11. Spatial distribution map of Calcium.

3.11. Potassium

The potassium content in the assessed groundwater wells ranged between 2.3 and 12 mg/L, as presented in Table 12. The minimum concentration was found in the Abo Shuisha groundwater well (2.3 ± 1.1), whereas the maximum concentration was determined in the Salam Edaab groundwater well (12 ± 3). The K content in the studied underground wells was within the WHO-recommended limit for drinking water (i.e., 12 mg/L) [24]. Potassium may primarily come from rock weathering in addition to solid and liquid wastes [44]. Belkhiri and Narany [45] assessed the quality of subterranean water in Ain Azel, Algeria and discovered that the potassium value ranged from 3.13 mg/L to 10.03 mg/L. Significant differences were found amongst the potassium level of the studied groundwater wells (p-value = 0.00).

Table 12. Descriptive statistics and p-value of Potassium (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	9.8	12	9.5	11.3	6.2	6.9	8.1	10.7	11.2	2.4	2.3
Std Dev	1.3	3	1.8	2.9	0.8	0.9	1.2	1.9	1.2	0.7	1.1
p-Value	0.00										
WHO's guideline	12										

The results shown in Figure 12 depict that the allocation of potassium in the groundwater wells ranged between 0 and 12 mg/L. The collapsed sewage pipe system in the study area could be the primary source of the increasing amount of pollutants, including potassium, in the groundwater wells. Kringel et al. [46] assessed the aquifer quality of water in the city of Yaounde in Cameroon and revealed that the potassium distribution amongst the groundwater wells varied from 1.1 mg/L to 26.2 mg/L; the high concentration of potassium in the groundwater could be related to nearby anthropogenic discharges.

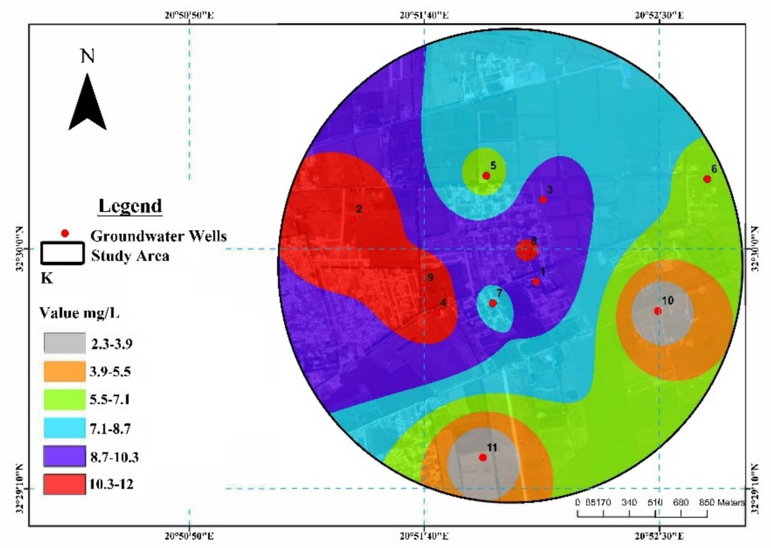

Figure 12. Spatial distribution map of Potassium.

3.12. Magnesium

The magnesium concentration in the studied groundwater wells varied from 75 mg/L to 123.7 mg/L, as shown in Table 13. The lowest content of magnesium was observed in the Abo Shuisha groundwater well (75 ± 10), whereas the highest level was found in the Sediq Al Rashed groundwater well (123.7 ± 3.5). The abundance of Mg in the groundwater wells referred to the dissolution of all solids and rocks but mostly from limestone, dolomite and gypsum, which are found in large quantities in some brines [47,48]. The obtained Mg concentration in the studied groundwater wells was within the WHO-recommended limit for drinking water (i.e., 150 mg/L) [24]. Significant differences were found amongst the Mg concentration of the groundwater wells (p-value = 0.00).

Table 13. Descriptive statistics and p-value of Magnesium (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	104	106	110	88.3	104	82	108	109	123.7	80	75
Std Dev	3.6	4.4	2.6	3.1	2.6	3.6	6.6	13.1	3.5	4.6	10
p-Value	0.00										
WHO's guideline	150										

Figure 13 shows the spatial distribution of magnesium in the groundwater wells in the study area. The distribution of Mg fluctuated in different concentrations on the basis of the geographical location of the groundwater wells. The high distribution of Mg in the groundwater wells was due to the discharge in the adjacent area of the studied wells. Kouras et al. [49] investigated the quality of underground water in the city of Chalkidiki in Greece and confirmed that the accumulation of Mg ranged from 21 mg/L to 278 mg/L; Mg was found to be the dominant cation in groundwater probably due to seawater intrusion.

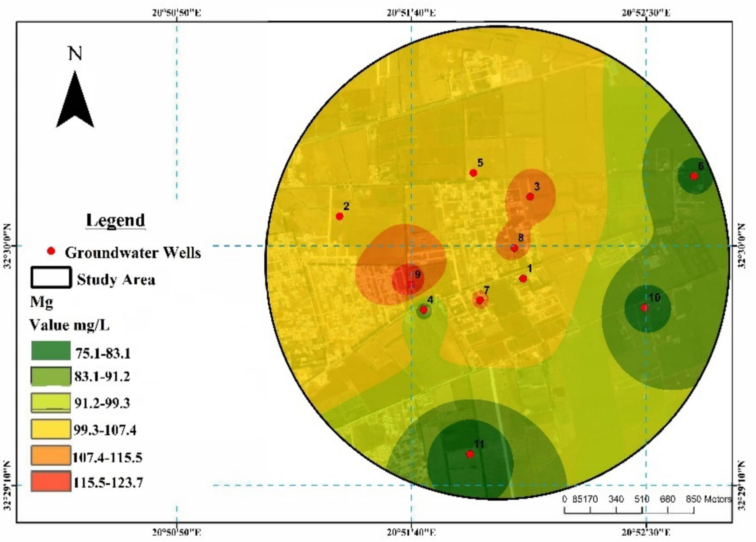

Figure 13. Spatial distribution map of Magnesium.

3.13. *Ammonia*

The ammonia concentration in the groundwater wells was within 0.02–7 mg/L, as shown in Table 14. The lowest value was detected in the Abo Shuisha groundwater well (0.02 ± 0.02), whereas the highest content was measured in the Saad Mokhtar groundwater well (7 ± 1). The NH_3 abundance in the studied groundwater wells was principally due to agricultural activities and the residential utilisation of NH_3 contained in cleaning products that enter the groundwater wells through an improper wastewater network system. Eight groundwater wells were considered polluted with NH_3 as they exceeded the WHO-recommended limit for drinking water (i.e., 1.5 mg/L) [24]. The presence of NH_3 is generally an indicator of domestic wastewater contamination that would be consistent with the strong influence of runoff or other discharges from urban settlements [50]. Significant differences were found amongst the NH_3 level of the groundwater wells (p-value = 0.00).

Table 14. Descriptive statistics and p-value of Ammonia (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	4.4	5.1	3	7	0.7	1.6	2.7	4.2	4.7	0.04	0.02
Std Dev	1.5	1.1	0.6	1	0.2	0.5	0.7	0.5	0.2	0.04	0.02
p-Value	0.00										
WHO's guideline	1.5										

The spatial distribution of ammonia in the groundwater wells fluctuated from 0 mg/L to 7 mg/L, as depicted in Figure 14. The high distribution of NH_3 in the groundwater wells was due to the discharge from the city to the affected wells. Fu et al. [51] found a similar finding in their study of subterranean water quality in China and reported that the NH_3 distribution ranged from 0.01 to 7.6. Harms-ringdahl [52] analysed the quality of aquifers of water in the city of Hanoi in Vietnam and identified that the ammonia content in uncontaminated groundwater was lower than 0.2 mg/L but might be higher in cultivated areas and regions with dense animal production. The presence of NH_3 in groundwater is not an immediate health concern, and a high value of this ion indicates water contamination from animal waste or sewage sludge.

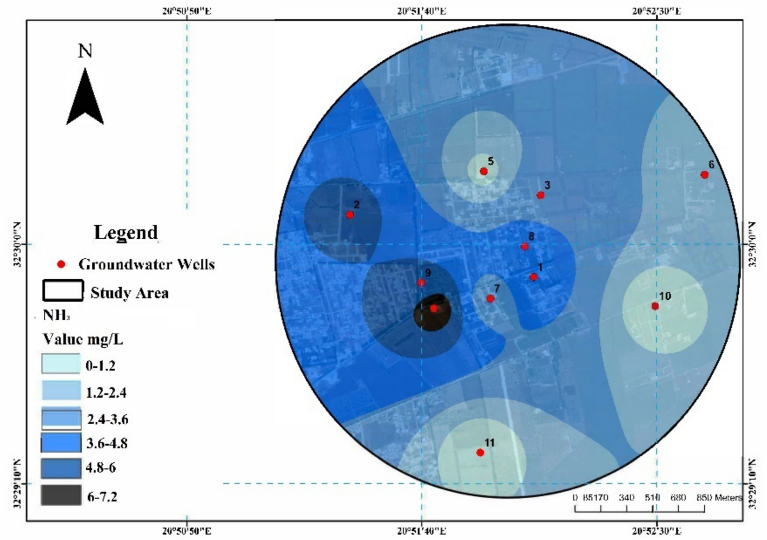

Figure 14. Spatial distribution map of Ammonia.

3.14. *Ammoniacal Nitrogen*

The ammonia nitrogen content varied between 0.01 and 5.8 mg/L in the studied groundwater wells, as illustrated in Table 15. The highest concentration of NH_3-N (5.8 ± 0.6) was found in the Saad Mokhtar groundwater well, whereas the lowest level was discovered in the Abo Shuisha groundwater well (0.01 ± 0.02). Most of the groundwater wells were considered polluted due to the discharge of city sewage, which run into the wells. Moreover, the wells are located in agricultural areas and might have been affected by fertiliser usage. Jafari and Khayamian [53] evaluated water quality in the city of Isfahan in Iran and reported that the high concentration of NH_3-N in Zayanderood water could be due to sewage discharged from houses. Shakya et al. [54] tested the quality of groundwater in the city of Kathmandu in Nepal and identified that the average concentration of NH_3-N was 0.6 mg/L. Significant differences were found amongst the ammonia nitrogen content of the examined groundwater wells (p-value = 0.00).

Table 15. Descriptive statistics and p-value of Ammoniacal Nitrogen (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	3.7	4.3	2.5	5.8	0.6	1.3	2.2	3.5	3.7	0.03	0.01
Std Dev	1.5	1.2	0.7	0.6	0.1	0.5	0.8	0.5	0.2	0.03	0.02
p-Value	0.00										
WHO's guideline	0.1										

The spatial distribution map shows that NH_3-N contaminated several groundwater wells due to human farm activities and sewage discharge to the groundwater wells (See Figure 15). Wu and Ye [55] conducted a study on groundwater quality in 30 provinces in China and stated that the high distribution of NH_3-N in most groundwater samples could be due to discharge from agricultural, industrial and residential sources. Wakida and Lerner [56] assessed groundwater quality in the city of Nottingham in England and indicated that the primary sources of NH_3-N were correlated with wastewater disposal and solid waste disposal through the system and leaky sewers.

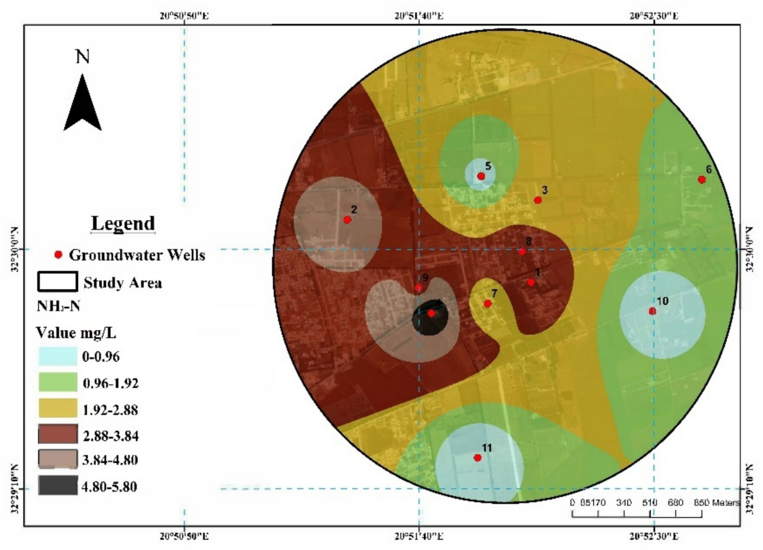

Figure 15. Spatial distribution map of Ammoniacal Nitrogen.

3.15. Nitrate

The nitrate concentration in the groundwater wells ranged from 0 mg/L to 11 mg/L, as shown in Table 16. NO_3^- was not detected in the Salam Edaab groundwater well. The highest value was found in the Al Sahly well (11 ± 1.1). The concentration of NO_3^- in the examined groundwater wells was lower than the WHO-recommended limit for drinking water (i.e., 50 mg/L) [24]. Sources of NO_3^- pollution are septic tanks, animal and human waste, and commercial fertilisers [57]. Wagh et al. [58] determined the quality of water in the Maharashtra district of India and observed that the concentration of NO_3^- in the groundwater wells varied between 19.31 and 68.62 mg/L. Significant differences were found amongst the nitrate level of the groundwater wells (p-value = 0.00).

Table 16. Descriptive statistics and p-value of Nitrate (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	2.7	0.0	4.1	0.6	11	5	2.2	0.4	2.3	5.4	4.5
Std Dev	0.5	0.0	0.8	0.1	1.1	0.8	0.2	0.3	0.9	0.4	0.3
p-Value	0.00										
WHO's guideline	50										

Figure 16 shows the spatial distribution of nitrate in the groundwater wells. The level of nitrate was low in some groundwater wells but increased in other wells due to the hydrogeologic features of the well's locations and the cumulative loading of NO_3^- into the groundwater well reserves via the application of fertilisers. El Hamidi et al. [59] evaluated the spatial distribution of underground wells in a town in Morocco and assessed the quality of water in the Rmel aquifers by detecting nitrate; the result showed that the nitrate level was satisfactory, with a concentration of less than 35 mg/L. Odoma and Ocheri [60] conducted a study in the town of Lokoja in Nigeria and estimated the spatial distribution of nitrate levels in groundwater wells; they observed that the levels in the studied aquifers were below the maximum limit of 50 mg/L.

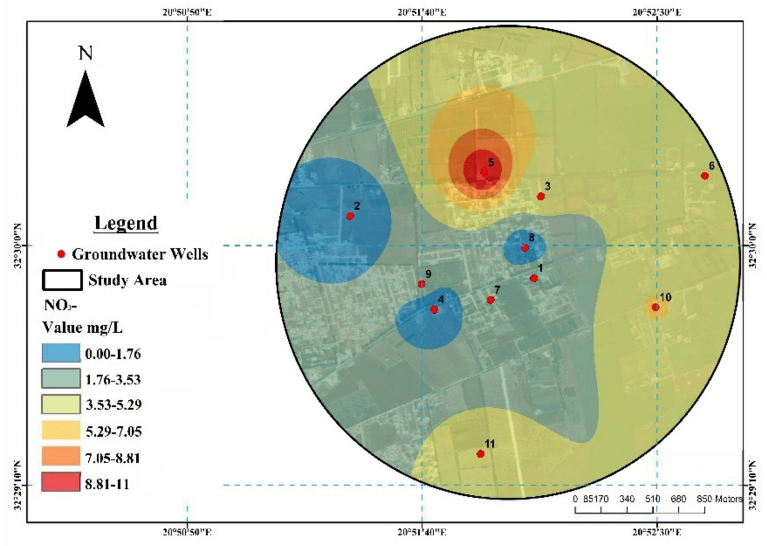

Figure 16. Spatial distribution map of Nitrate.

3.16. Sodium

The content of Na in the groundwater wells ranged between 60.8 and 160 mg/L, as shown in Table 17. The lowest concentration was observed in the Abo Shuisha groundwater well (60.8 ± 6.9), whereas the highest concentration was found in the Military groundwater well (160 ± 8.1). A high concentration of Na in the groundwater wells could indicate sturdy water–aquifer interaction due to the interchange of cations and anthropogenic activities, such as wastewater disposal. Sodium ions naturally occur in water due to some phenomena, such as vaporisation, farming and human activities, and clay weathering [61]. The Na concentration in the groundwater wells was below the WHO's recommended limit for drinking water (i.e., 200 mg/L) [24]. Rezaei et al. [62] evaluated the quality of underground water for irrigation and drinking purposes in the village of Dalgan in Iran and proved that the concentration of Na varied between 22.20 and 124.3 mg/L. Significant differences were found amongst the Na content of the examined groundwater wells (*p*-value = 0.00).

Table 17. Descriptive statistics and *p*-value of Sodium (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	153	149	160	63.8	136.3	150	155.3	144	145.7	65.7	60.8
Std Dev	14	8.5	8.1	4.3	9.5	8.7	6	8	5	12	6.9
p-Value	0.00										
WHO's guideline	200										

Figure 17 shows the spatial distribution of sodium in the groundwater wells. The higher distribution of Na was observed in the middle and eastern portions of the study area. The highest distribution was observed in several groundwater wells due to sewage discharges from the domestic area. Sodium has a large distribution and has a significant proportion in groundwater, indicating that sodium ions can be formed from a wide range of sources [63].

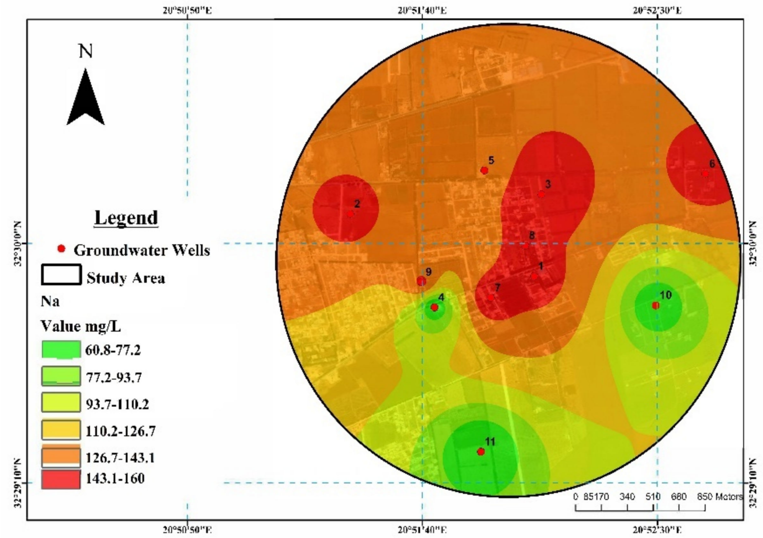

Figure 17. Spatial distribution map of Sodium.

3.17. Copper

The concentration of copper in the tested groundwater wells ranged from 0.0009 mg/L to 0.054 mg/L, as presented in Table 18. The lowest value was recorded in the Abo Shuisha groundwater well (0.0009 ± 0.0007), whereas the highest concentration was found in the Salah Amtaual groundwater well (0.054 ± 0.01). The Cu concentration in the groundwater wells was less than the WHO's recommended limit for drinking water (2 mg/L). The presence of Cu metals could be due to corrosion from the plumbing system or from the rocks related to groundwater wells based on the geographical location of each well; corrosive water could also contribute to the increasing concentrations of Cu in water. The movement of copper relies on the characteristics of solid constitutes and the solution [64]. Santos et al. [65] conducted a study on groundwater in the city of Seville in Spain to determine the quality of water. They detected that the mean value of Cu was 0.021 mg/L and reported that the highest proportion of the metal was linked with dissolved organic materials and suspended matter. Significant differences were found amongst the Cu content of the studied groundwater wells (*p*-value = 0.00).

Table 18. Descriptive statistics and *p*-value of Copper (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	0.054	0.0035	0.0123	0.0021	0.0086	0.0083	0.0096	0.012	0.0096	0.001	0.0009
Std Dev	0.01	0.003	0.02	0.002	0.0017	0.014	0.0007	0.006	0.003	0.001	0.0007
p-Value	0.00										
WHO's guideline	2										

The spatial distribution of copper in the measured groundwater wells is shown in Figure 18. In general, the obtained Cu proportion in the groundwater well was within the WHO's recommended limit for drinking water [24]. The distribution of Cu could be due to the locations of the groundwater wells near the city; these locations are affected by the mixed solid waste discharged from the town or due to leaky sewage. Emenike et al. [66] determined the quality of groundwater in southwestern Nigeria and revealed the absence of Cu in the studied groundwater wells. Yessuf et al. [66] investigated groundwater in the Visakhapatnam district of India and found that the concentration and distribution of Cu ranged from 0.0001 mg/L to 0.0286 mg/L; the distribution of Cu differed from one place to another on the basis of the geographical location and environmental conditions of the well.

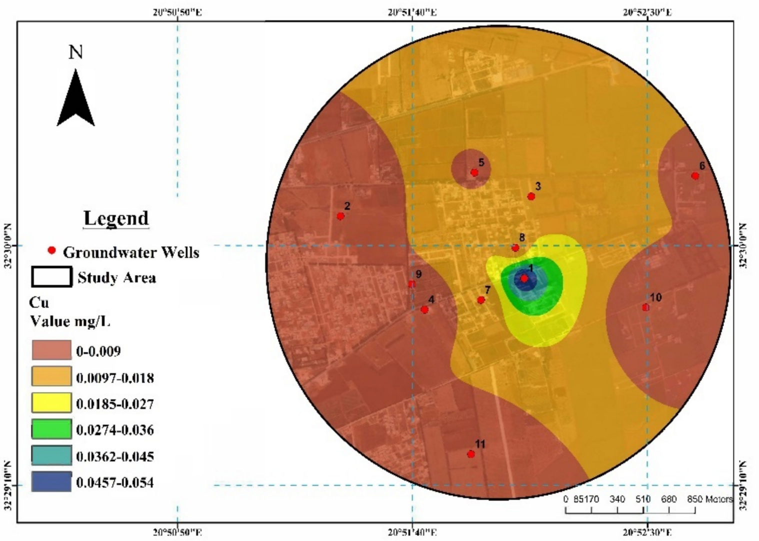

Figure 18. Spatial distribution map of Copper.

3.18. Iron

The concentration of iron in the groundwater wells was within 0.007–0.83 mg/L, as shown in Table 19. The lowest value was found in the Idris Moftah groundwater well (0.007 ± 0.006), whereas the highest amount was detected in the Al Marthi groundwater well (0.83 ± 0.12). The Fe level in the groundwater wells was within the WHO's recommended limit for drinking water [24], except for the Al Marthi groundwater well where the iron content exceeded the allowable value of 0.3 mg/L. The high amount of Fe in groundwater could be due to its natural presence because of the weathering of iron, minerals and rocks. In addition, industrial streaming, sewage and landfill leachate could contribute Fe to domestic groundwater. Rajappa et al. [67] investigated the heavy metal concentration in the groundwater in the Karnataka state of India and reported that the content of Fe ranged from 0.175 mg/L to 1.0 mg/L in the studied groundwater well. Kanoo and Jawed [68] identified the Fe concentration in the groundwater wells in Amingaon around the city of Guwahati in India and stated that the level of Fe varied between 0 and 11.03 mg/L, which exceeded the allowable limit of 0.3 mg/L for drinking water. Significant differences were found amongst the iron content of the groundwater wells (p-value = 0.00).

Table 19. Descriptive statistics and p-value of Iron (mg/L).

Groundwater Wells	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Mean	0.22	0.26	0.83	0.07	0.05	0.04	0.02	0.04	0.07	0.06	0.007
Std Dev	0.1	0.12	0.12	0.07	0.03	0.04	0.17	0.03	0.08	0.06	0.006
p-Value	0.00										
WHO's guideline	0.3										

Figure 19 illustrates the spatial distribution of iron in the groundwater wells in the study area. The highest allocation of Fe was found at three groundwater wells (3, 2, 1), as shown in the figure below. The high distribution of Fe could be an indication of tillage activities, and it might be freed to water from natural deposits, industrial waste, refining of iron ore, and corrosion of Fe-containing metals. A similar study was conducted by Qiao et al. [69] in the Guanzhong region of China to evaluate the quality of groundwater and found that the concentration and distribution of Fe were lower than the limit for safe drinking water (i.e., 0.3 mg/L).

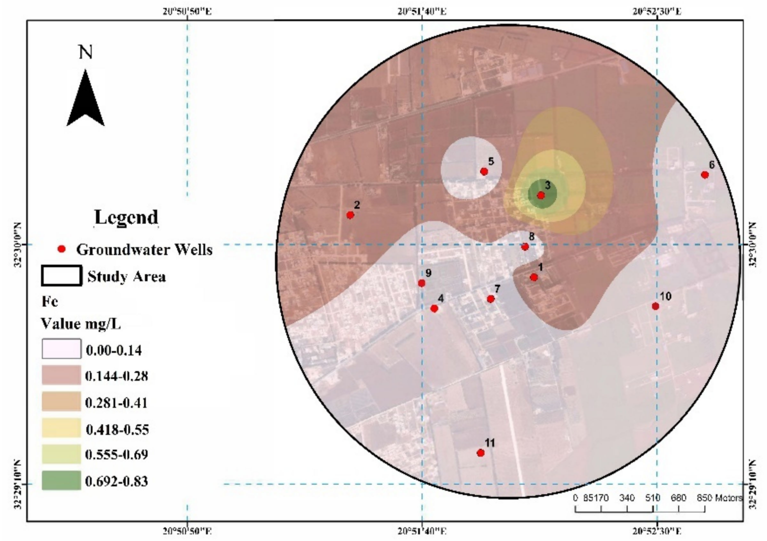

Figure 19. Spatial distribution map of Iron.

3.19. Dissolved Oxygen

The DO value in the groundwater wells was within 5.1–7 mg/L, as illustrated in Table 20. The minimum value was determined in the Al Marthi groundwater well (5.1 ± 0.56), whereas the maximum level was reported in the Abo Shuisha groundwater well (7 ± 0.9). The richness of DO in the groundwater wells was higher than the WHO-recommended limit for drinking water [24]. The variation in the concentration of DO in the groundwater wells was due to the well's depth and groundwater temperatures. Cold water has a higher level of DO, whereas warm water has a lower level [70]. DO in underground water relies on the depth to the aquifers from which the water is coming from; shallow groundwater aquifers have a higher value than those in deeper areas [71]. Owamah [72] assisted a study on water quality and hand-dug wells in the Niger delta community in Nigeria and stated that the mean value of DO ranged from 8.00 mg/L to 12.00 mg/L. No statistically significant variations were found in the DO amongst the groundwater wells (*p*-value = 0.09).

Table 20. Descriptive statistics and *p*-value of Dissolved Oxygen (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	6.7	6.9	5.1	5.2	5.9	5.2	6.4	5.4	6.4	5.2	7
Std Dev	1.2	1.3	0.56	0.46	0.82	0.53	0.81	1.25	1.41	0.4	0.9
p-Value	0.09										
WHO's guideline	4										

The spatial distribution of DO in the groundwater wells is demonstrated in Figure 20. The high distribution of DO in several groundwater wells was due to organisms' activities and inversely related to water temperature, that is, cold water might result in more DO than warm water. Thus, DO considerably contributes to the quality of water concerning the stabilisation of numerous organic and inorganic contaminants in subterraneous water [73]. Distinctions in DO could occur seasonally or during the day in relevance to temperature and biological effectiveness (i.e., photosynthesis, respiration and organic breathing could lead to dissolution, thereby reducing the concentration of DO) [74].

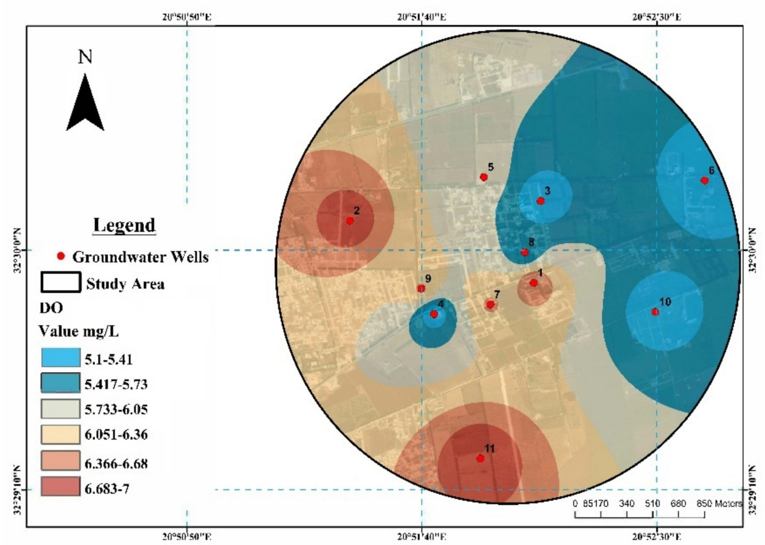

Figure 20. Spatial distribution map of Dissolved Oxygen.

3.20. Biological Oxygen Demand

The value of biochemical oxygen demand fluctuated from 1.03 mg/L to 6.25 mg/L in the studied groundwater wells, as shown in Table 21. The lowest level was recorded in the Agdora Al Abidi groundwater well (1.03 ± 0.58), whereas the highest amount was found in the Saad Mokhtar groundwater well (6.25 ± 0.13). In accordance with the WHO-recommended limit for drinking water [24], several groundwater wells were considered to have a high concentration of BOD5 (i.e., exceeding 3 mg/L). The present findings indicate that the highest concentration of BOD5 in several groundwater wells could be due to the percolation of biodegradable organic matter and the leaching of inorganic matter into the aquifers. Contaminated water from sewage treatment stations carries natural substances that are decomposed by microorganisms, which utilise oxygen in the process. The amount of oxygen consumed by these organisms in breaking down wastes is known as biochemical oxygen demand [75]. The biochemical oxygen demand is also used as an indicator of the impact of groundwater from leachate. In cases where leachate is discharged directly into a watercourse, it will absorb oxygen from the water to complete its decomposition [76]. Significant differences were found amongst the BOD5 of the measured groundwater wells (*p*-value = 0.00).

Table 21. Descriptive statistics and *p*-value of Biological Oxygen Demand (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	1.97	3.86	6.16	6.25	1.16	3.95	1.03	1.32	2.06	3.2	2.24
Std Dev	0	0.11	0.14	0.13	0.07	0.32	0.58	0.2	0.44	0.26	0.34
p-Value	0.00										
WHO's guideline	3										

Figure 21 displays the distribution of biochemical oxygen demand in the studied groundwater wells. The high distribution of BOD_5 in some groundwater wells indicated the level of contamination. Increasing the concentration of turbidity with a lower value of dissolved oxygen could negatively affect the level of BOD which increasing the BOD level in the waterbody. The values and distribution obtained were similar to the outcomes reported by Agbalagba et al. [77], who confirmed that BOD_5 varied between 1.34 and 9.55 mg/L and exceeded the WHO-recommended limit for drinking water [24]. This finding indicates the light pollution of groundwater due to solid organic waste. González et al. [78] reported that the increased value of BOD_5 is an indication of the occurrence of biological activities in the water environment; however, the amount of organic matter decreases rapidly as a consequence of a substantial oxygen transfer rate due to high water turbulence.

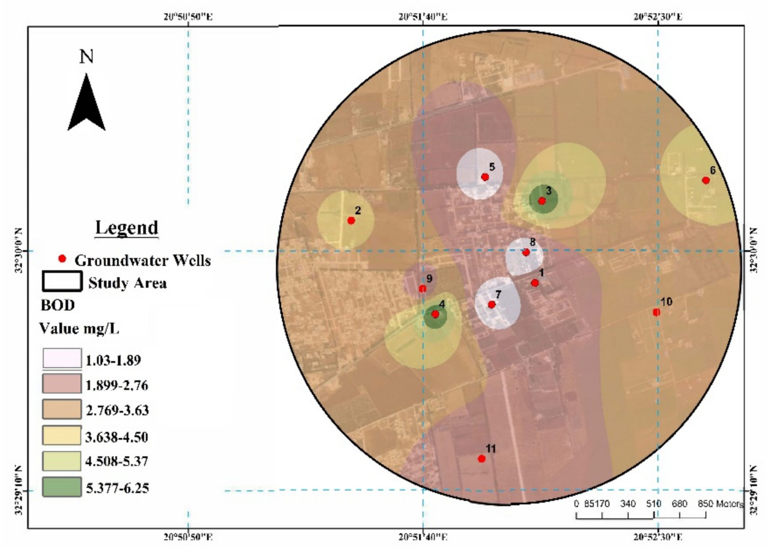

Figure 21. Spatial distribution map of Biological Oxygen Demand.

3.21. Chemical Oxygen Demand

The concentration of chemical oxygen demand (COD) in the measured groundwater wells ranged from 2.13 mg/L to 10.1 mg/L, as shown in Table 22. The lowest value was reported in the Al Sahly groundwater well (2.13 ± 0.1), whereas the maximum level was found in the Ali Ibrahim groundwater well (10.1 ± 0.1, which exceeded the limit for drinking water [i.e., 10 mg/L]). The sources of COD in groundwater varied; however, soluble organic compounds were most likely to contribute to the increase in the value of COD and residual food waste from the residential area. COD is a measure of organic pollution from human and animal wastes and is used to assess the effects of humans and animals on water [79]. Similar findings were found by Zhang et al. [80], who determined the water quality in the city of Shanghai in China and proved that the value of COD ranged from 0.3 mg/L to 10 mg/L. Significant variations were found in the COD of the groundwater wells (*p*-value = 0.00).

Table 22. Descriptive statistics and *p*-value of Chemical Oxygen Demand (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	4.41	8.25	9.26	9.34	2.13	10.1	2.25	3.7	3.07	5.62	3.61
Std Dev	0	0.2	0.7	0.3	0.1	0.1	0.1	0.1	0.4	0.3	0.2
p-Value	0.00										
WHO's guideline	10										

Figure 22 shows the variation in the COD in the groundwater wells. The high COD distribution within the groundwater wells was due to wastewater and agricultural activities. Sajil Kumar et al. [81] conducted a study in the city of Ghaziabad in India and emphasised the distribution and concentration of COD in groundwater; they proved that the variation ranged from 4.50 ppm to 20 ppm, indicating the presence of a different chemical combination reaching the areas of groundwater. The high concentrations of COD could be due to a large amount of oxidisable organic material in the water sample, thus decreasing the level of DO [76,82].

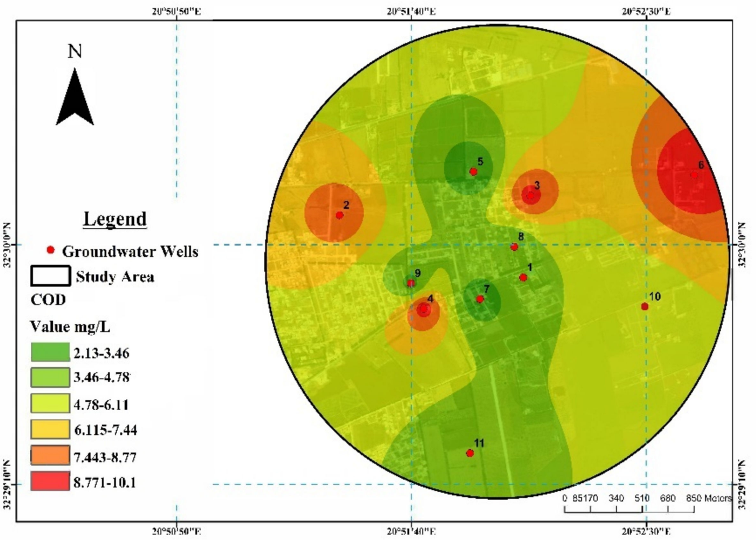

Figure 22. Spatial distribution map of Chemical Oxygen Demand.

3.22. *Total Suspended Solids*

The concentration of TSS ranged from 0.02 mg/L to 2.7 mg/L, as demonstrated in Table 23. The lowest amount was detected in two groundwater wells, namely, Salam Edaab and Abo Shuisha (0.02 mg/L). The highest content was observed in the Ali Ibrahim groundwater well (2.7 ± 0.65). The low detection of TSS in the studied groundwater wells could be due to the nature of the soil composition of the water filtration process. No limit has been stipulated for TSS [83]. Hassan and Nawaz [84] assessed the groundwater quality in the Punjab Province of Pakistan and reported that TSS did not accumulate in the tested groundwater wells. Significant differences were found amongst the TSS values of the examined groundwater wells (p-value = 0.00).

Table 23. Descriptive statistics and p-value of Total Suspended Solids (mg/L).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	0.41	0.02	0.65	0.21	0.25	2.7	0.21	0.77	0.19	0.11	0.02
Std Dev	0	0.02	0.14	0.11	0.13	0.65	0.21	0.13	0.12	0.11	0.03
p-Value	0.00										
WHO's guideline	NA										

The spatial distribution of TSS in the groundwater wells is shown in Figure 23. The spatial pattern map of TSS indicated a clear water body and a lack of dry-weight suspended particles in the wells. The low concentration of TSS could be due to the lack of heavy rain even in the winter season in the region, which is geographically considered semidry to relatively dry; this finding did not support the movement of the suspended particles into the investigated groundwater wells. A similar pattern of the result was found by Kumari et al. [85] in their study in the city of Ghaziabad in India. The results were also consistent with those reported by Bisiriyu et al. [86], who examined the water quality of groundwater in Tudun Fulani, Niger State, Nigeria; they found that the concentration of TSS varied from 0.5 mg/L in November to 39.0 mg/L in January. This finding indicated that temporal differences in TSS represented a remarkable seasonal pattern during the rainy season.

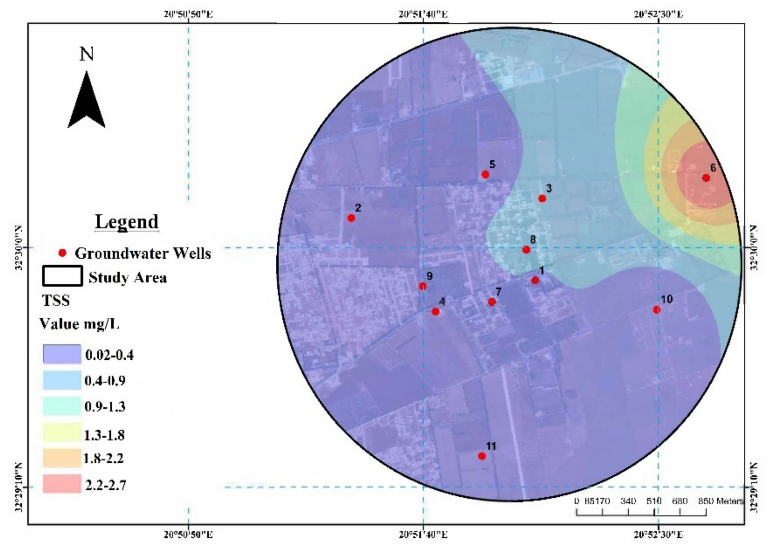

Figure 23. Spatial distribution map of Total Suspended Solids.

3.23. E. Coli

The prevalence of *E. Coli* in the measured groundwater wells was 0.00–8.00 CFU/100 mL, as given in Table 24. The lowest positive result was observed in the Al Sahly groundwater well (3.00 CFU). The highest occurrence of *E. coli* was recorded in the Ali Ibrahim and Al Marthi groundwater wells (8.00 CFU). Five groundwater wells were affected by *E. coli*. The presence of *E. coli* in groundwater wells is a crucial public health concern. This microorganism affects groundwater wells because the sewage systems in the city are not working correctly to prevent the discharge of faecal contamination from infected humans or animals from reaching the groundwater wells. *E. coli* is the most commonly applied indicator of faecal contamination [87]. Najafi Saleh et al. [3] examined the groundwater quality in the Kwale Province of Kenya and reported that the prevalence of *E. Coli* in the groundwater wells ranged from intermediate to high risk. Significant differences were found amongst the amount of *E. coli* in the studied groundwater wells ($p < 0.00$).

Table 24. Descriptive statistics and *p*-value of *E. Coli* (CFU).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	0.0	0.0	8.0	0.0	3.0	8.0	0.0	4.0	7.0	0.0	0.0
Std Dev	0	0	0	0	0	0	0	0	0	0	0
p-Value	*										
WHO's guideline	0										

* Zero Value of Std Dev between the analysis data of *E. coli*.

The spatial distribution of *E. coli* in the groundwater wells is depicted in Figure 24. The substantiation of *E. Coli* in the groundwater wells indicated that faecal contamination reached several wells due to the deterioration of the sewage network, causing the bacteria to reach the aquifers. The prevalence of *E. Coli* in some groundwater wells exceeded the WHO's recommended limit for drinking water [24]. It can be observed that there is a relationship of concentrations of some components in the groundwater wells, which was found to have a high concentration of BOD and decreased the value of DO and a high number of bacteria within the groundwater wells. The destroyed wastewater system network considerably contributed to the ejection of faecal content to the studied groundwater wells, resulting in a high concentration of *E. coli* in several wells. The presence of *E. coli* in groundwater indicated the increase in population density and faecal waste generation [88]. Daffi et al. [89] assessed the groundwater quality in the city of Jos in Nigeria and reported that *E. coli* prevalence was within 30–50 CFU; the high number could be attributed to the location of sewage contamination areas in relation to the groundwater wells.

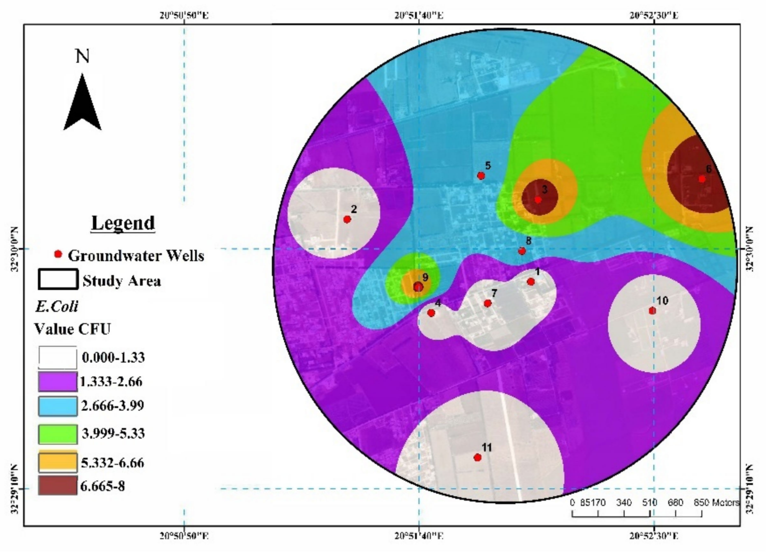

Figure 24. Spatial distribution map of *E. coli.*

3.24. Total Coliforms

The presence of TC in the groundwater wells was within 0.00–460 CFU/100 mL, as shown in Table 25. TC was detected in six groundwater wells in different numbers of propagations on the basis of their location in the study area and did not meet WHO's recommended safe limit for drinking water [24]. The highest MPN of TC (460 CFU) was found in the Ali Ibrahim groundwater well, which is adjacent to the city that is affected by sewage contamination caused by a poor sewage network. Therefore, neglect of the city's infrastructure and lack of regular maintenance in the sewage network considerably contributed to the pollution of the city and some groundwater wells in the study area. The current findings are consistent with those discussed by Mkandawire [90], who examined TC in the groundwater in the Blantyre district of Malawi; the mean values of TC were 181 CFU/100 mL in the dry season and 717 CFU/100 mL in the wet season. Invik et al. [91] presented similar findings and proved that high contamination occurs during the rainy season due to the waterborne nature of bacteria. Significant differences were found amongst the TC of the examined groundwater wells (p-value = 0.00).

Table 25. Descriptive statistics and p-value of Total Coliforms (CFU).

Groundwater Wells	1	2	3	4	5	6	7	8	9	10	11
Mean	0.0	0.0	240	0.0	39	460	0	39	210	7.0	0.0
Std Dev	0	0	0	0	0	0	0	0	0	0	0
p-Value	*										
WHO's guideline	0										

* Zero Value of Std Dev between the analysis data of Total Coliforms.

The enumeration and distribution of TC in the groundwater wells are demonstrated in Figure 25. The high distribution of TC was visible in three groundwater wells affected by the deteriorated sewage system network, which is located next to the sewage collection's lakelet. TC must not be found in the water used by humans in accordance with the drinking water quality standards by the WHO [24]. Stokdyk et al. [92] conducted a study on the groundwater quality of Minnesota, USA and confirmed the distribution and concentration of TC in 53 of 925 samples. Kausch et al. [93] evaluated the TC in the groundwater in Eastern Long Island in New York and found that 40% of the groundwater had a mean value of 1.3 CFU/100 mL. In conclusion, TC in some of the groundwater wells exceeded the WHO's recommended limit for drinking water [24].

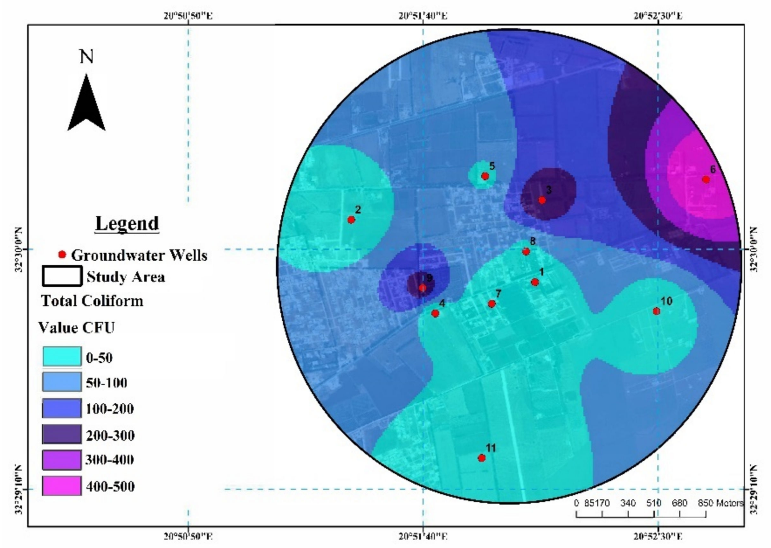

Figure 25. Spatial distribution map of Total Coliforms.

4. Conclusions

The city of Al-Marj in Libya has no available public water supply system due to the neglect of infrastructure. As a result, the population relies on groundwater for their needs. In this study, the eastern groundwater wells in the study area were investigated to estimate the suitability of its water for drinking, in comparison with the international standard recommended by the WHO [24]. EC was significantly high amongst the measured groundwater wells. Nine groundwater wells presented high concentrations of TDS and chloride. Calcium content was also remarkably high in the groundwater wells, except for the Abo Shuisha groundwater well. Moreover, most of the groundwater wells were contaminated by ammonia and ammoniacal nitrogen. High concentrations of DO were also reported in all the examined groundwater wells. The level of biological oxygen demand in five groundwater wells exceeded the safety limit, and only the Ali Ibrahim groundwater well presented a high concentration of COD. Several groundwater wells were notably polluted with *E. Coli* and TC. Furthermore, the groundwater was loaded with unacceptable quantities of some parameters; such quantities might have been obtained from a combination of sources, such as mineralisation, chemical weathering of rocks, industrial waste, sewage contamination, and intensive agricultural practices. The spatial distribution map of the physicochemical and biological parameters provided in the obtained data in the GIS environment can be used to determine a preferable groundwater location in the study area.

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