Evaluation of Groundwater and Seawater Intrusion at Tajoura Area, Northwest Libya

Abdalraheem Huwaysh, Yasmin ElAhmar

***Abstract*—**Water quality is an important factor that determines its usage for domestic, agricultural and industrial uses. This study was carried out through the Tajoura Area, Jifarah Plain, Northwest Libya. Chemical and physical parameters were measured and analyzed for groundwater samples collected in 2021 from 26 wells distributed throughout the investigation area. Overexploitation of groundwater caused considerable deterioration in the water quality, especially at Tajoura Town (20 km east of Tripoli). The aquifer shows an increase in salinization, which has reached an alarming level in many places during the past 25 years as a result of the seawater intrusion. Based on the WHO and Libyan standards, groundwater from the targeted area was not suitable for direct drinking purposes. Sodium is the dominant cation, while the dominant anion is chloride. Based on the Piper trilinear diagram, most of the groundwater samples (90%) were identified as sodium chloride type. The best groundwater quality exists at the southern part of the study area. Serious degradation in the water quality, expressed in salinity increase, occurs as we go towards the coastline. The abundance of NaCl waters is strong evidence to attribute the successive deterioration of the water quality to the seawater intrusion. Considering the values of Cl- concentration and the ratio of Cl^-/HCO^{3-}, about 70% of the groundwater samples were strongly affected by the saline water. Car wash stations in the study area as well as the unlined disposal pond used for the collection of untreated wastewaters, contribute significantly to the deterioration of water quality. In the area of interest (Tajoura), treatment of the groundwater before drinking is essential, and its quality needs to be routinely checked.

***Keywords*—**Tajoura, groundwater, overexploitation, seawater intrusion.

I. Introduction

In recent decades, groundwater became one of the most important natural resources because of increasing water demand and decreasing surface water supplies particularly at the arid and semi-arid regions. It became very necessary to find large quantities of groundwater, reachable, and has a good quality to use it in multi-purposes. Libya is a country that suffers from water scarcity. The situation has become more problematic due to continued population growth, low rainfall and higher water demand for domestic, agricultural and industrial uses. Coastal aquifers are an important source of fresh water supply in many countries, particularly in the arid and semi-arid regions that characterized by their relatively dense population [1]. The intensive groundwater extraction from such aquifers reduces the freshwater outflow towards the sea and creates significant drawdown in the water table, causing what is known as seawater intrusion phenomenon [1], [2]. Consequently, a considerable deterioration in groundwater quality has taken place and it has become one of the serious issues that challenge the water resources management in Libya for the past few decades.

A. Location of the Study Area

Libya, the third largest country in Africa, is located in the north of the continent. It lies between latitudes 33°10' N and 18°45' N and longitude 9°58' E and 25°E. It possesses a Mediterranean coastline of approximately 1820 km in length [3].

The Jifarah Plain lies at the northwestern part of Libya, extending from the Mediterranean coast at the north to Jabel Naffusah at the south. The Jifarah Plain lies at the northwestern part of Libya, extending from the Mediterranean coast at the north to Jabel Naffusah at the south. About 50% of all agricultural products are produced in Jifarah Plain, which is populated with about 60% of the nation's people [4]. The targeted area lies in the Jifarah Plain and occupies about 156 km^2, extending for about 13 km from the coast line of the Mediterranean Sea southward (from 3630000 to 3643000 northing) with a width of about 12 km (from 338000 to 350000 easting), Zone 33 S, Fig. 1.

B. Objectives of Study

This study aims to evaluate the causes, impacts and mitigation measures of seawater intrusion. A combination of previous works review, field and laboratory investigations have been used to evaluate the extent of seawater intrusion and its impacts on water resources in this part of Libya.

The main objectives of this study can be summarized as follows:

1. Assessment of the hydrogeochemical characteristics of groundwater in the targeted area.
2. Determination of groundwater facies and classification.
3. Assessment of the risk due to intrusion of salty marine water (Sea water intrusion) at Tajoura Area.

II. Methodology

A flowchart diagram representing research design is made to illustrate research stages, and because this study aims to evaluate the water chemistry types and water quality in Tajoura Town; the research will be designed to achieve the objectives set out by the researchers, as shown in the flowchart, Fig. 2.

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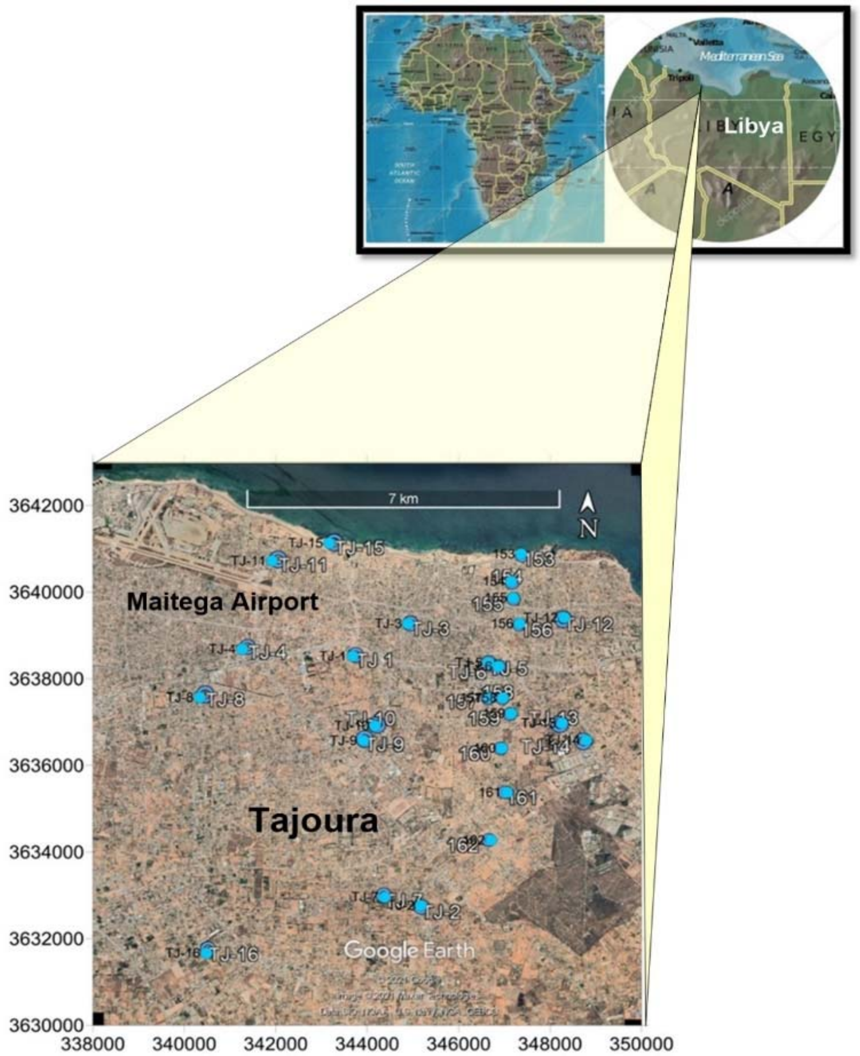

Fig. 1 Location map of the study area

III. Data Acquisition and Collection

The first step was the collecting of necessary available data related to geological, hydrogeological, hydrological, hydrochemical features in the targeted area documented in technical reports, papers, internet websites and journals. Some data were collected from study area during the fieldwork stage, while others, especially hydrological information (Rainfall, Evaporation and static water level) and wells location in Tajoura Area were obtained from the General Water Authority (GWA).

A. Field Work

Several field trips have carried out to collect 26 water samples from 26 water points (wells) through two weeks. The coordinates of each sampling point (well) were recorded at the field by using the GARMIN GPS. Additionally, other data such as depth to water and ground surface elevation were recorded for each well, Fig. 3.

B. Water Sampling and Rapid Field-Test

The 26 water samples were filled in plastic bottles of 1.5-liter size. Rapid field tests, including measurements of acidity (pH), total dissolved solids (TDS), temperature (T) and electrical conductivity (EC) have been also carried out for all the collected water samples by using portable water analysis device.

C. Laboratory and Office Work

The laboratory works included chemical analyses of water samples in order to determine the concentrations of the major elements have been carried out in the Laboratories of the *Advanced Laboratory for Chemical Analyses*, *Tajoura*. These analyses aimed to determine the concentration of cations such as Ca^{2+}, Mg^{2+}, Na^+, K^+ and the anions such as HCO^{3-}, SO_4^{2-}, Cl^-, NO_3^-, in addition to pH, TDS and EC.

D. Data Interpretation

Different software packages were used in handling, drawing figures and diagrams, geochemistry modeling, graphical plots and data analysis, which are:

- Aquachem 2014.2
- Rochwork version 16.

- Surfer version 11.
- Google Earth pro 2014
- Microsoft office Excel 2010

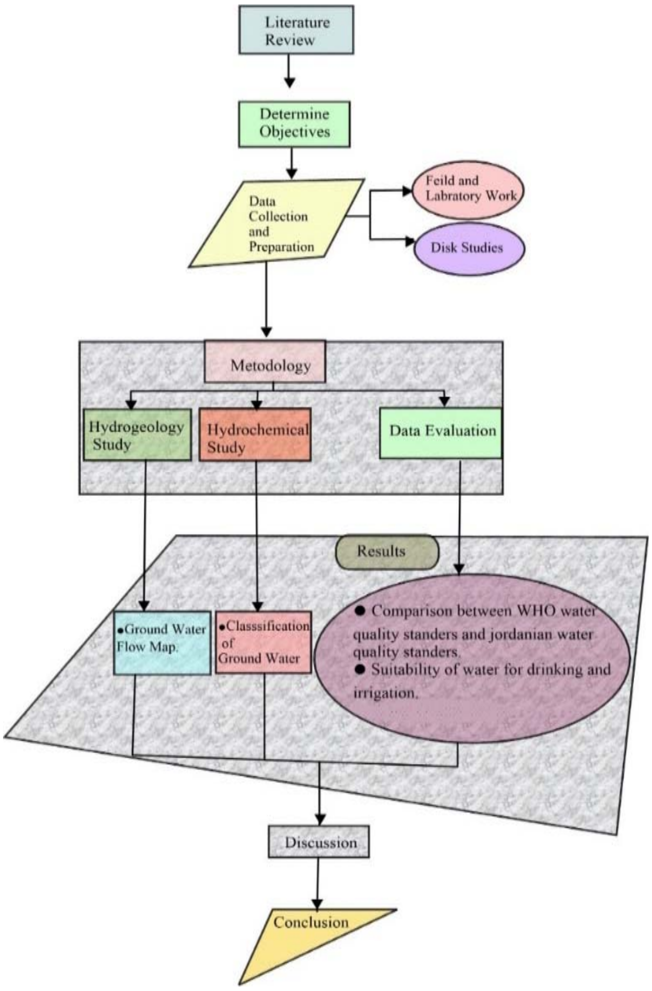

Fig. 2 Flowchart illustrating research stages

IV. Hydrogeology

In the past, the Jifarah Plain was the most important basin, providing water for domestic and agricultural uses in the populous Tripoli region. The aquifers of the Jifarah plain are estimated to be recharged by 200 Mm^3/yr. of water from rainfall, wadi runoff, and return flows from the irrigation and water supply systems [4]. Water extraction was 1000 Mm^3/yr. in 1993 (800 Mm^3/yr. for irrigation and 200 Mm^3/yr. for settlement water supply), thus producing an annual deficit of 800 Mm^3/yr. The water resources of the basin were in natural balance up to the year 1950. There after groundwater extraction surpassed the annual recharge. Due to the increasing rate of extraction, there has been an ever-increasing annual deficit in the water balance [4].

The average rainfall ranges between 221.7 mm/yr. in the Al-Ajilat region and increases gradually until it reaches about 301.2 mm/yr. in the Tripoli area and gradually decreases towards the east until it reaches about 241 mm/yr. in the Zliten region.

Fig. 3 Field work (Collection of samples and water level measurements)

Jifarah Plain is characterized by the presence of some seasonal valleys whose water collects as a result of rain fall on the mountain slopes in the southern regions. The most important of which are Wadi Al-Majnin, Wadi Gan, Wadi Labda and Wadi Kaam, and dams have been constructed on them to collect their water instead of losing it in the sea [4].

A. Main Aquifers

The aquifers which play an important role in the groundwater flow and storage in the Jifarah plain are as follows:

The Quaternary–Pliocene-Upper Miocene aquifer consisting of sand, calcalcarenites and clay, has approximately the same extension as the Miocene formation. The saturated thickness of the aquifer varies from 10 to 150 m.

A thick series of sandstones forms another important aquifer in the central and eastern part of the plain. The age of the sandstones is uncertain but is generally attributed to Kiklah Formation, whereas in some places the sandstone aquifer can be attributed to Abu Shaybah Formation [5].

Azizia dolomitic limestones (middle Triassic) form another aquifer which is well developed in the south–central part of the

Jifarah. This formation shows interesting hydraulic properties mostly in its out cropping area where Karstic channels and openings enable the groundwater to flow easily. In the western part of Al Jifarah, Azizia also seems to form a good aquifer (although with poor quality water) in the area where its depth does not exceed 300 to 400 m [5].

B. Hydraulic Behavior of the Aquifers

Recharge

The spreading zones of the wadis have been identified and indicated on the map in order to understand the recharge by infiltration of runoff water from the wadis, Fig. 4, assuming that 10 to 30% of the runoff infiltrates to the underlying aquifers [5].

Groundwater Flow

At the south-central part of the Jifarah Plain, the main aquifers consist of Triassic sandstones and dolomitic limestones and the direction of the groundwater flow is mainly northward, but this hypothesis still needs to be confirmed by some deep wells south of Gharyan because it is also possible that the flow, at least in Azizia limestone, comes from further south. To the north, most of the ground water flows into the Quaternary-Pliocene-Upper Miocene aquifers but part of the flow probably also recharges the Lower Miocene and Mesozoic sandstone aquifers confined by the clays of the Middle Miocene [4].

In the eastern part of the Jifarah Plain the groundwater flows mainly in the Mesozoic sandstone Kiklah Formation. This groundwater flow path is related to the regional south-north flow in the Souf Al Jeen basin. At the northern part, most of the groundwater aquifers are of Lower Miocene age. The shallow aquifer is independent and has its own direct surface recharge and mostly of Quaternary and Upper Miocene age [4]. In the central and eastern parts of the Jifarah Plain, the groundwater flow is directed towards the sea which is the natural outlet of the aquifers. In the southwestern part of the Jifarah the groundwater flows northwards through Jurassic aquifers of limited intake (the groundwater divide is located a few kilometers to the south) and of limited extension to the north (Middle and Lower Jurassic evaporites outcrop a few kilometers north of jabal escarpment). The groundwater flow is discharged in small springs or in diffuses outlets.

The Jifarah upper aquifer is overexploited, as evidenced by the excessive deterioration of the water quality, and decrease of the hydraulic head over a large area. In many locations, the drawdown in the water levels ranged between 25 to 35 meters below sea level, indicating the inversion of the hydraulic gradient and the influx of saltwater. This was mostly seen in southern Tripoli and the Sabratah regions [4].

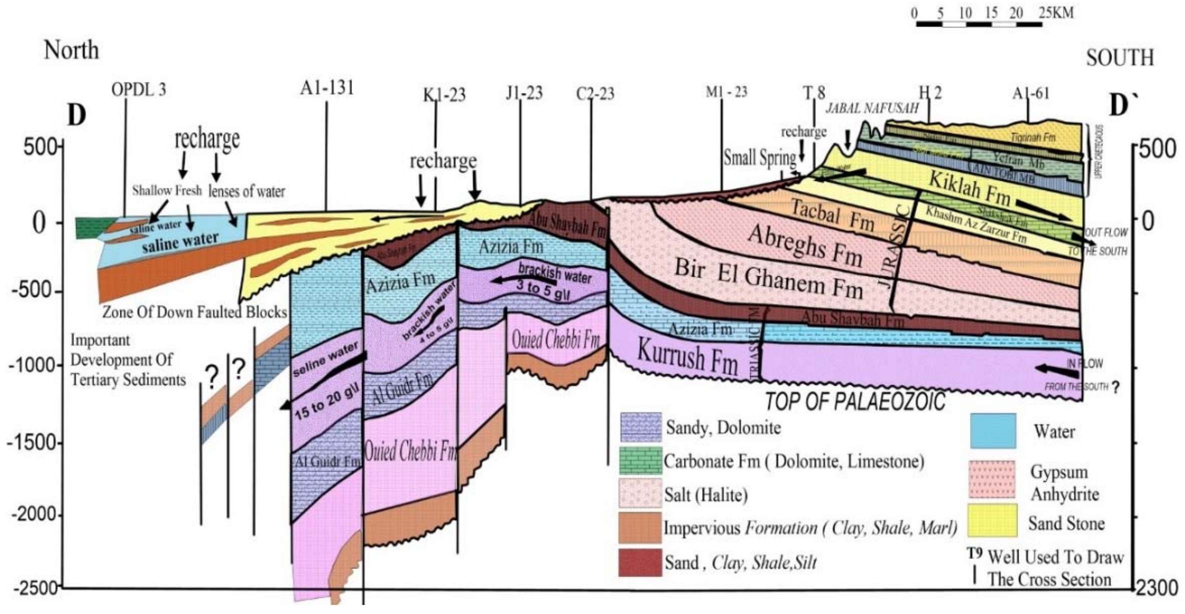

Fig. 4 Hydrogeological cross section of the Jifara Plain [5]

C. Groundwater Use

Despite the scarcity of water resources, consumption is on the rise as a result of improving economic conditions, urbanization, and improving standards of living.

D.Agricultural Use

Agriculture is and will continue to be the major water consumer. Even though rational irrigation methods are used in almost all agricultural regions, it still accounts for almost 85% of the world's water use, with application rates among the highest. This is mostly because of the improper soil and climate conditions. Two types of irrigated areas have been identified and correspond to [5]:

- *Permanently irrigated fields* with heavy groundwater extraction estimated to range from 5000 to 9000 m^3/ha/ year.
- *Partly irrigated fields* with moderate groundwater extraction estimated to range from 1500 to 3000 m^3/ha/ year. The groundwater extraction from the Jifarah Plain has been estimated by different authors and at different dates,

Table I [6].

E. Domestic Use

In Libya, 80% of the population live in urban centers, varying in size from 5000 to 1000000 inhabitants. Depending on the size of the city, its location, and the age of the supply network, the average daily water consumption per capita was found to range from 150 to 300 l/capita [6]. People in rural areas rely somewhat on their own sources of water supply (private wells), rainwater collection systems, and springs. Per capita consumption ranges from 100 to 150 liters per person per day on average. Domestic water consumption rates are generally increasing with time as a function of income. In Jifarah Plain, estimates of annual domestic water use found to be 228.59 million cubic meters [6].

V. Hydrochemistry

The geology and chemical properties of the aquifer determine the hydrogeochemistry of groundwater, which varies both spatially and temporally. The quality of groundwater is almost as important as its quantity [7].

A. Water Quality in Jifara Plain

Quaternary-Pliocene-Miocene aquifer: Water of this aquifer is generally of good quality with TDS of less than 1000 ppm. However, in the western part of the plain (mainly west of Sabratah), the water quality deteriorates rapidly and becomes saline with TDS higher than 5000 ppm. Along the coast and mostly between Sabratah and Az Zawiyah and in the immediate surroundings of Tripoli, higher salinity resulting from seawater intrusion can be observed .

Mesozoic sandstone aquifer: The water quality is generally good with TDS ranging from 1000 to 2000 ppm [1].

Azizia aquifer: Water is usually of medium to poor quality with TDS ranging from 2000 to 4000 ppm. This hydrochemical study of groundwater in the targeted area includes interpretation of the chemical properties and the concentration of the major cations Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} and the major anions CO_3^{2-}, HCO_3^{-}, SO_4^{-2}, Cl^{-} and NO_3^{-} as well as the total dissolved solids (TDS) [2].

TABLE I
THE WATER BALANCE OF JIFARA PLAIN AREA

Region	Available (Million cubic meters per year)						Total	Consumption (Million cubic meters per year)			Total	Water balance
	conventional		nonconventional									
	Renewable	Nonrenewable	Surface water	Desalination	Treated sewage	Transported		Agricultural	Domestic	Industrial		
Jifara Plain	300	50	25.5	19.70	11.10	215.6	621.94	995.2	228.59	12.3	1236.09	- 614.15

TABLE II
CALCULATIONS OF THE CHARGE-BALANCE ERROR IN PERCENT

No	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	HCO_3 (meq/L)	Cl (meq/l)	NO_3 (meq/l)	SO_4 (meq/l)	TDS	Total Cations +	Total Anions-	Ionic Balance
153	6.74	4.34	142.01	0.28	6.39	148.08	0.85	13.33	9840	153.37	168.65	-4.7%
154	2.58	2.47	63.16	0.81	8.80	50.07	1.70	8.33	4230	69.01	68.90	0.1%
155	3.32	11.51	138.10	1.36	8.00	127.18	0.10	14.57	7480	154.28	149.85	1.5%
156	2.52	4.52	42.36	0.15	13.19	20.03	1.42	11.45	3730	49.56	46.09	3.6%
157	3.07	1.64	25.49	0.05	4.39	20.03	1.35	4.37	1788	30.25	30.14	0.2%
158	4.40	0.00	45.67	0.10	4.00	40.05	0.74	8.54	3710	50.17	53.33	-3.1%
159	8.62	5.75	43.71	0.14	8.39	40.05	2.41	7.08	3530	58.23	57.93	0.3%
160	3.05	4.11	31.58	0.10	4.39	23.02	1.98	6.66	2210	38.84	36.06	3.7%
161	2.24	3.04	32.06	0.14	2.79	27.05	0.92	6.04	2220	37.47	36.80	0.9%
162	0.12	2.63	3.82	0.05	5.20	1.00	0.25	0.83	338	6.62	7.28	-4.7%
tj-2	0.06	2.47	3.20	0.03	3.11	2.20	0.40	0.62	329	5.75	6.34	-4.8%
j-16	0.75	0.49	3.49	0.03	0.51	1.00	1.28	1.87	486	4.77	4.66	1.2%
tj-7	3.03	5.75	32.45	0.11	1.20	31.06	0.57	4.79	2520	41.35	37.61	4.7%
tj-8	10.48	0.41	68.42	0.12	5.20	70.09	0.34	8.12	5500	79.43	83.75	-2.6%
tj-9	4.94	8.22	81.12	0.22	6.00	80.11	0.58	5.41	5750	94.50	92.10	1.3%
tj-10	8.32	1.64	27.84	0.07	7.59	28.04	1.35	2.71	2280	37.87	39.68	-2.3%
tj-11	7.24	0.82	78.29	0.12	7.60	66.43	1.49	18.11	5470	86.47	93.63	-4.0%
tj-12	1.02	6.08	6.32	0.04	6.39	2.93	2.19	3.33	1686	13.46	14.85	-4.9%
tj-13	2.61	2.88	13.27	0.03	1.97	10.30	1.28	3.96	2360	18.79	17.49	3.6%
tj-14	1.56	6.99	3.83	0.05	5.57	5.98	0.69	1.46	729	12.43	13.70	-4.9%
tj-15	4.64	2.71	261.84	1.20	12.39	213.97	0.34	17.70	11030	270.40	244.40	5.0%
TJ-1	4.28	4.11	18.70	0.04	1.79	20.05	1.35	2.08	1535	27.13	25.27	3.5%
TJ-3	1.74	2.05	23.18	0.16	10.33	10.01	2.41	7.08	3530	27.14	29.83	-4.7%
TJ-4	1.49	0.41	27.62	0.06	3.70	18.62	1.77	7.91	2040	29.59	32.00	-3.9%
TJ-5	1.38	1.64	14.16	0.09	1.79	9.59	0.03	5.83	9840	17.27	17.23	0.1%
TJ-6	2.09	0.41	30.36	0.09	4.00	23.78	0.85	3.75	1883	32.96	32.38	0.9%

B. Data Reliability –Error Balance Equation

Charge Balance Error (CBE) has been used to judge the reliability of water analyses according to:

$$CBE = \frac{\sum cations - \sum anions}{(\sum cations + \sum anions)} * 100 = Error\% \tag{1}$$

The error % for the 26 wells were calculated, and therefore the analyses results of these water samples are reliable and can be used in this study, Table II.

C. Physical Properties

Temperature (C°)

All groundwater samples taken from the wells measured to have temperature ranges from 25 to 27 °C, Fig. 5.

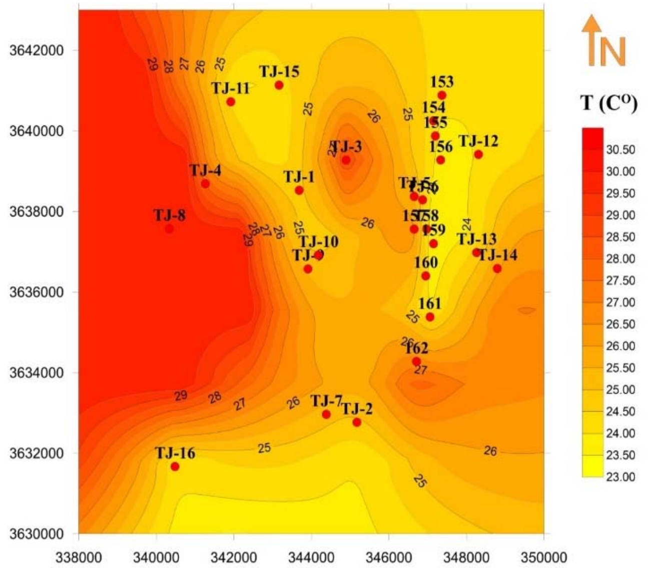

Fig. 5 Contour map of groundwater temperature (°C)

Hydrogen Number (pH Value)

The negative logarithm of a solution's hydrogen ion activity is called its pH [8]:

$$\text{pH} = -\log[\text{H}+] \tag{2}$$

One of the most crucial factors affecting the quality of water is pH, with a pH of 7.0 to 8.5 often being the ideal range. The maximum permissible limit for pH in drinking water as given by the WHO is 8.5 [8]. The values of pH in the groundwater samples in this study varied from 6.8 to 7.27 with an average value of 6.9, Fig. 6.

Electrical Conductivity

Electrical Conductivity (EC) is the ability of 1 cm³ of water to conduct electrical current, at temperature of 25 °C, when measured by micro Siemens per centimeter (μs/cm). It depends on the concentration of soluble salts and the temperature of the water [8]. The EC depends on water temperature, where an increase in water temperature of 1 °C causes an increase in electrical conductivity by 2% [9]. Also, the EC increases with the increase of the total dissolved salts [10]. The EC values of the groundwater samples in the study area are shown in Fig. 7.

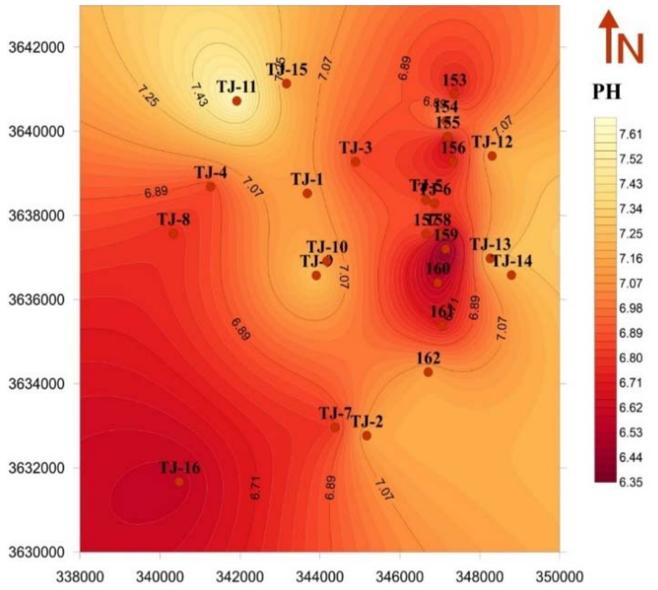

Fig. 6 Contour map of pH values

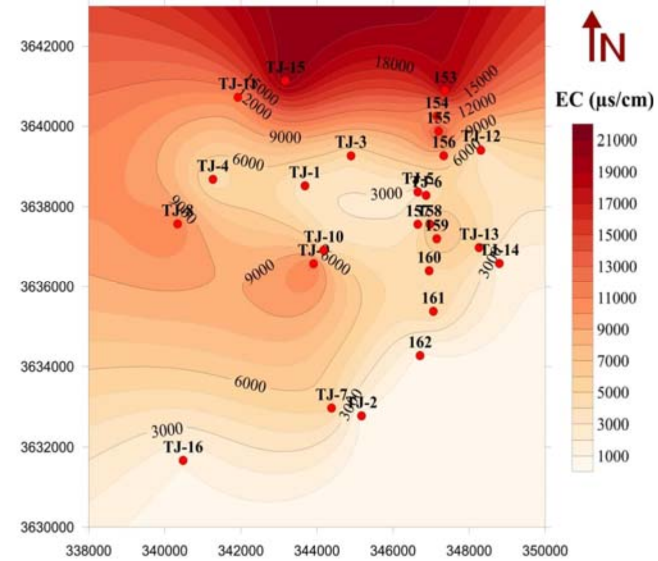

Fig. 7 Contour map of electrical conductivity (EC) values

Total Dissolved Solids

TDS comprise inorganic salts; principally calcium, magnesium, potassium, sodium, bicarbonate, chlorides, and sulphates and some small amount of organic matter that are dissolved in water [11]. TDS values of the collected groundwater samples measured as (ppm) or (mg/l) units are represented as a contour map, shown in Fig. 8. It is clear that the northern part of the study area has the highest TDS values (11030 ppm) compared to the southern part where the minimum value is recorded to be 329 ppm, with an average value of 3694 ppm, Fig. 8.

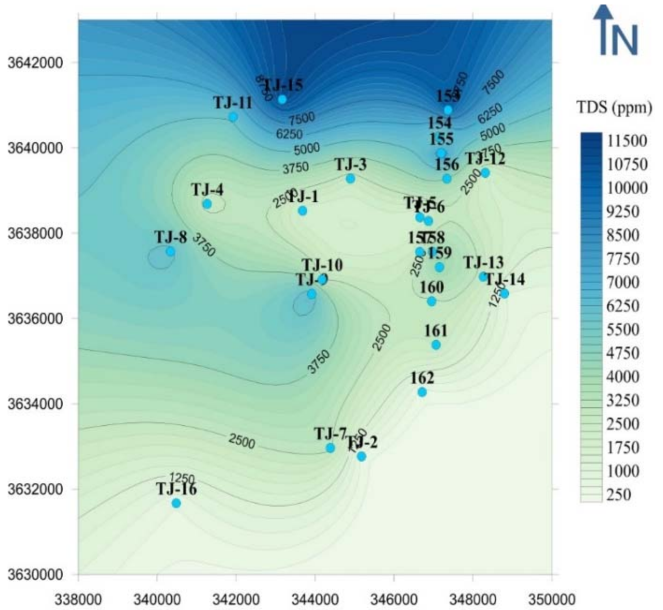

Fig. 8 Contour map showing the TDS concentration

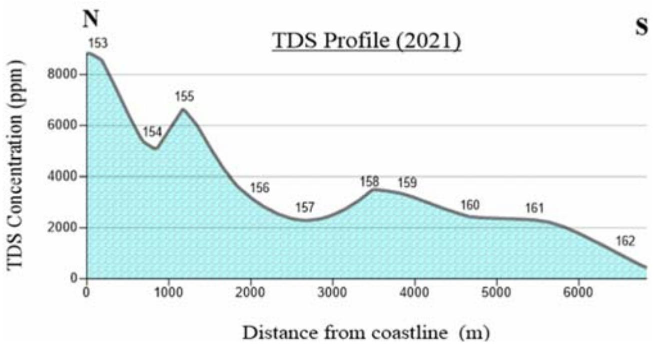

Fig. 9 North-south profile showing the spatial variation of TDS concentrations in the study area

North-south profile was selected to determine the spatial variation of the concentration of the TDS. It is very clear that this concentration is inversely proportional to the distance from the coastline, that is to say, it decreases as we go southward, Fig. 9.

Major Ions

Groundwater always contains variable amounts of dissolved salts. These are derived from the interaction between the water and various solids, liquids and gases as the groundwater makes its way from its recharge area to discharge area. More than 90% of the dissolved solids in groundwater can be attributed to eight ions: Na^+, Ca^{2+}, K^+, Mg^{2+}, $SO4^{2-}$, Cl^-, HCO_3^- and $CO3^{2-}$ [12].

Major Cations

Calcium (Ca^{2+})

Calcium ion concentration in the groundwater samples collected from the study area are shown in Table II. The limit of Ca^{2+} for drinking water is specified as maximum permissible limit about 75 mg/l [13]. In the study area, calcium reached a maximum value of 210 mg/l for the sample that taken from well No. TJ-8 whereas it reached only 1.3 mg/l for the sample collected from the well No. TJ-2. The average was calculated to be 71.1 mg/l, Fig. 10.

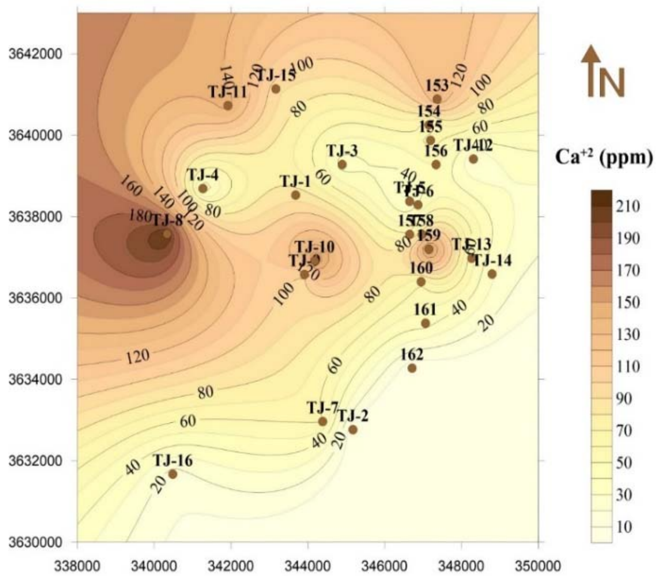

Fig. 10 Contour map showing the spatial variation of calcium concentration (mg/l)

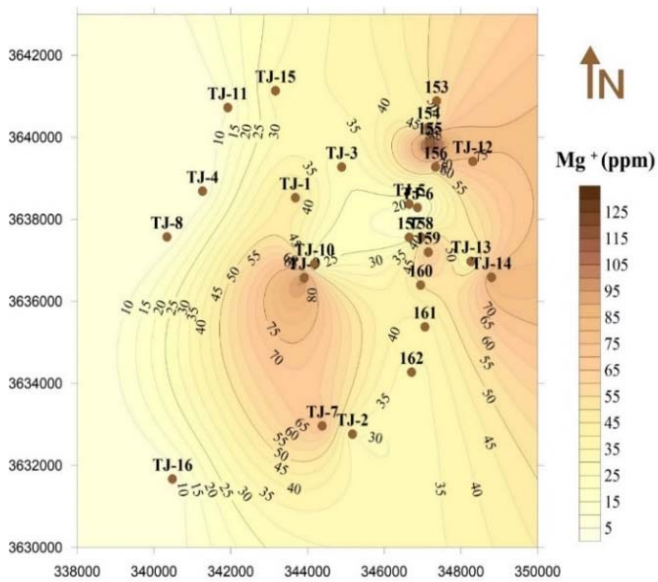

Fig. 11 Contour map showing the spatial variation of magnesium concentration (mg/l)

Magnesium (Mg^{2+})

This cation is mainly less abundant than calcium in the groundwater, a fact that can be explained by the low abundance of dolomitic rocks spread of Mg^{+2} ions in the water. The maximum acceptable limit of Mg^{2+} for drinking water is 50 mg/l [13]. In the study area, the minimum Mg^{2+} concentration observed in Well No.TJ-8 (5 mg/l) at the western part, and reached the maximum value in the well No. 155 (140 mg/l) with an average value of 42.8 mg/l, Fig. 11.

Sodium (Na^+)

Sodium is the most abundant member of the alkali-metal group in nature. This cation is found in brines and hard water and percolated easily into the groundwater through the municipal dumping of industries wastes and effluent plants infiltration, so it spreads very fast and well dissolved in groundwater and generally increases with the increasing of TDS.

The limit of Na^+ for drinking water is specified as 200 mg/l as desirable limit [13]. In the study area the sodium concentration reached its maximum value of 6020 mg/l; exceeding permissible limit, at the well No. TJ-15 and minimum value of 73.5 mg/l at well No. TJ-2 with an average value of 1116 mg/l, Fig. 12.

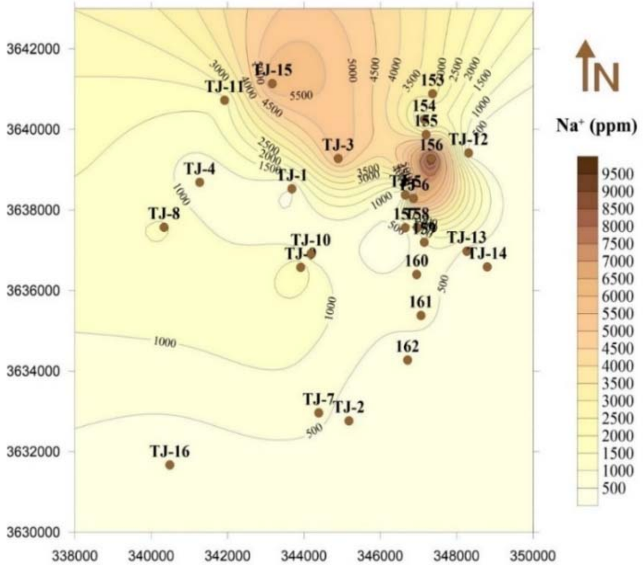

Fig. 12 Contour map showing the spatial variation of sodium concentration (mg/l)

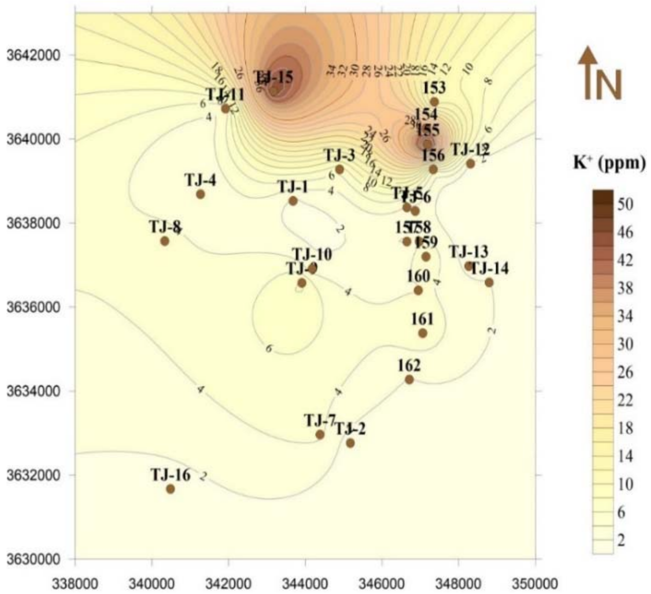

Fig. 13 Contour map showing the spatial variation of potassium concentration (mg/l)

Potassium (K^+)

The potassium content in natural waters is usually less than that of sodium, magnesium and calcium. Potassium infiltrated into the groundwater through leaching of some salty rocks from industry and municipal sewage treatment plants, as well as from potassium salts that used as fertilizers. The potassium is substantially larger than sodium ion and it would normally be expected to be adsorbed less strongly than sodium in ion-exchange reactions [9]. The potassium ion (K^+) concentrations of groundwater samples are given in Table II. In the study area the highest Potassium concentration found to be of 53 mg/l at well No.155 whereas the lowest value found to be 1 mg/l at well No.TJ-2 with an average value of 8.49 mg/l, Fig. 13.

Major Anions

Bicarbonates (HCO^{3-})

Carbonates and bicarbonates are considered to be the most important anions in natural water. They are considered as a source of alkalinity (Carbonate Alkalinity), while total alkalinity is a measure of carbonates, bicarbonates and hydroxyl dissolved in groundwater, and responsible of PH. The results of bicarbonate analyses of groundwater samples are shown in Table II.

The maximum acceptable limit of bicarbonates for drinking water is 500 mg/l [13]. In the study area, the minimum bicarbonate concentration was observed to be of 31 mg/l at well No.TJ-16 and maximum of 805 mg/l at well No. 157 with an average of 339.5 mg/l, Fig. 14.

Sulfates ($SO4^{2-}$)

Sulfates are abundant in most groundwater species, their occurrence can be attributed to the chemical weathering of some of the sedimentary rocks such as gypsum and anhydrite, oxidation of barite minerals. Human activities (agricultural and industrial activities) can be also considered as significant sources for sulfates [14]. The sulfate concentrations of groundwater samples are shown in Table II.

High levels of sulphate in drinking water can cause diarrhea [13]. It is generally considered that sulphates can be tasted in levels between 250-1000 mg/l [16]. Maximum sulphate concentration was observed to be 870 mg/l; exceeding permissible limit at well No.TJ-11 whereas the minimum value was 30 mg/l at well No.TJ-2 in the study area with an average value of 325 mg/l, Fig. 15.

Chloride (Cl^-)

Chloride concentrations of groundwater samples are shown in Table II. The maximum acceptable limit of chloride for drinking water is 250 mg/l [13]. The maximum chloride concentration was observed to be of 7586 mg/l; exceeding the potable limit at well No.TJ-15 and the minimum value was found to be of 35.5 mg/l at well No.162 in the study area, with an average value of 1487mg/l, Fig. 16.

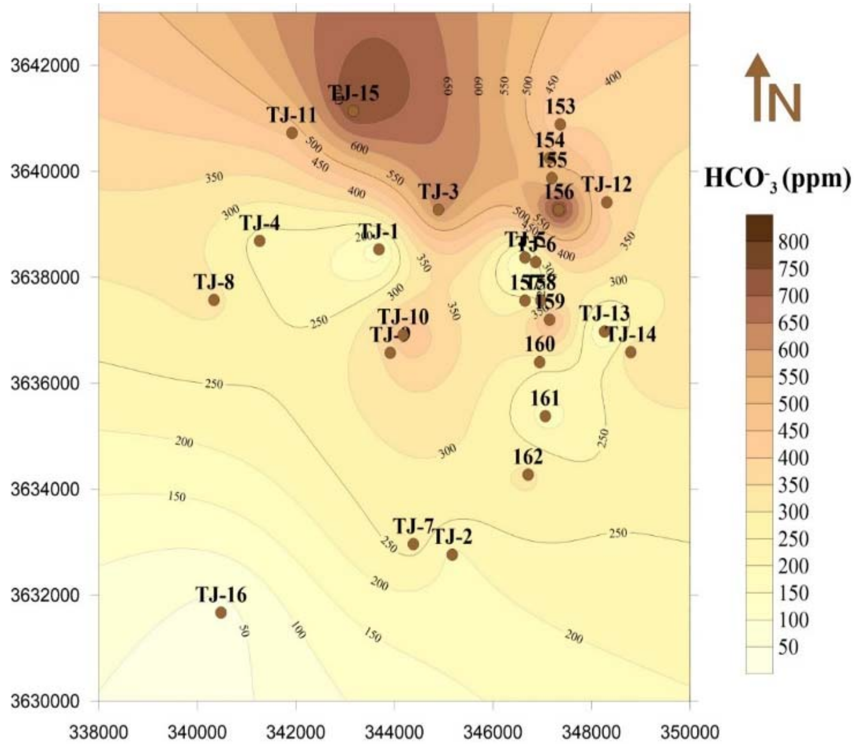

Fig. 14 Contour map showing the spatial variation of bicarbonates concentration (mg/l)

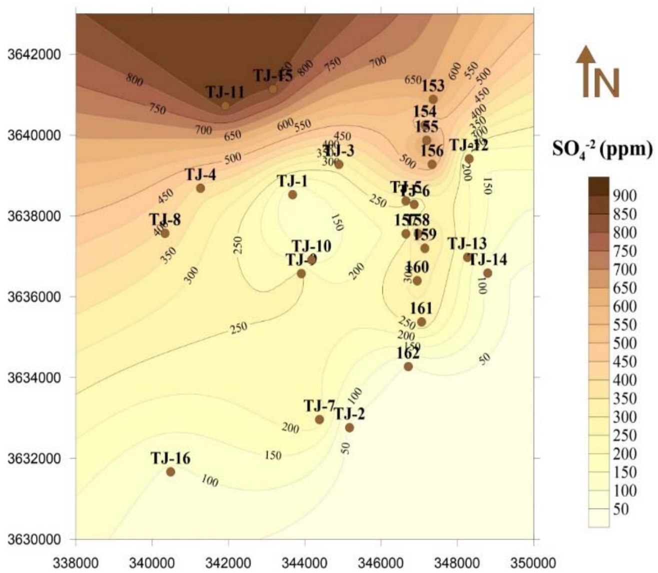

Fig. 15 Contour map showing the spatial variation of sulphates concentration (mg/l)

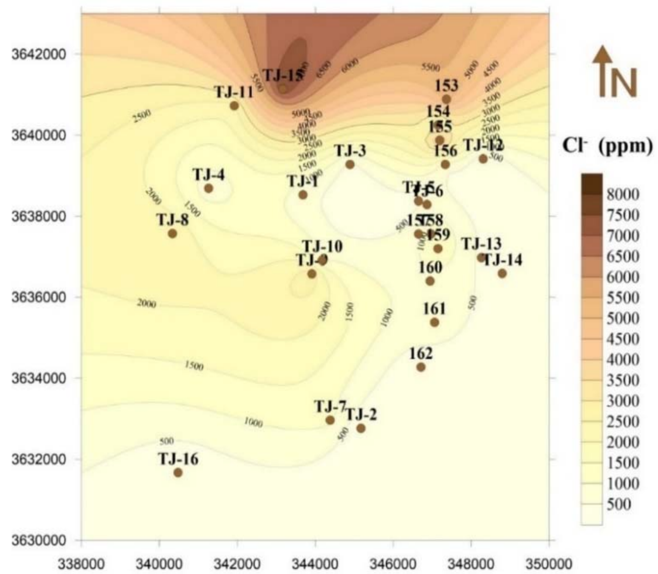

Fig. 16 Contour map showing the spatial variation of chloride concentrations (mg/l)

Nitrate (NO^{3-})

Nitrate is the most available indicator for pollution and it is well-dissolved in groundwater and easily leached from soils. Nitrogen occurs in water as nitrate or nitrite anions. Nitrate concentrations in the study area are given in Table II. They range from 1.8 mg/l at the well No. TJ-5 to 150 mg/l at the well No. 159, with an average value of 68.8 mg/l, Fig. 17. This high concentration of nitrates might be attributed to the disposal of untreated sewage water either from septic tanks or from the sewage water treatment station.

VI. Results and Discussion

Field measurements of water levels and the results of chemical analyses of samples collected from 26 water points (wells) distributed throughout the targeted area have been plotted and interpreted in order to evaluate the changes in the groundwater levels and quality during a period of 25 years.

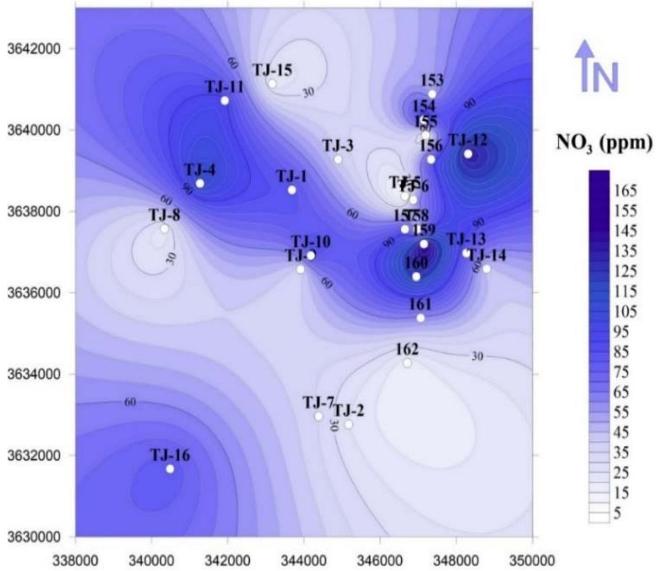

Fig. 17 Contour map showing the spatial variation of nitrates concentrations (mg/l)

A. Groundwater Levels (Hydraulic Head)

A contour map of the hydraulic head was constructed to represent the configuration of the potentiometric surface and flow direction within the targeted area in July 2021. It was noticed that there is a significant cone of depression at the southern part of the study area with a maximum head value of about 10 m below the sea water level, Fig. 18. It has been also noticed that there is a buildup (or Upconing) in the hydraulic head at two locations; one of them located at *cars washing station* and the other one is very close to the disposal pond of the sewage water station. This confirms that there is a possible recharge of the shallow aquifer by this contaminated water.

B. Groundwater Classification

The interpretation of analytical results was performed mainly based on the water-type classification according to the Aquachem version 3.7 program and the graphical illustration method Piper diagram.

C. Piper Classification

The well-known piper diagram is extensively used by plotting the concentrations of major cations and anions in the Piper trilinear diagram [15]. Based on the chemical analyses, groundwater is divided into three distinct fields; two triangular fields and one diamond-shaped field.

D. Groundwater Facies in the Study Area

The Rockware software version 17.2 has been used for plotting the Piper Diagram to display the relative concentrations of different ions in 26 samples collected from the targeted area. Classification of hydrochemical facies for groundwater according to Piper diagram is shown in Fig. 19.

Generally, the predominant anions and cations are chloride and sodium respectively. Based on the contents of major cations and anions, most of the samples fall within sodium chloride type.

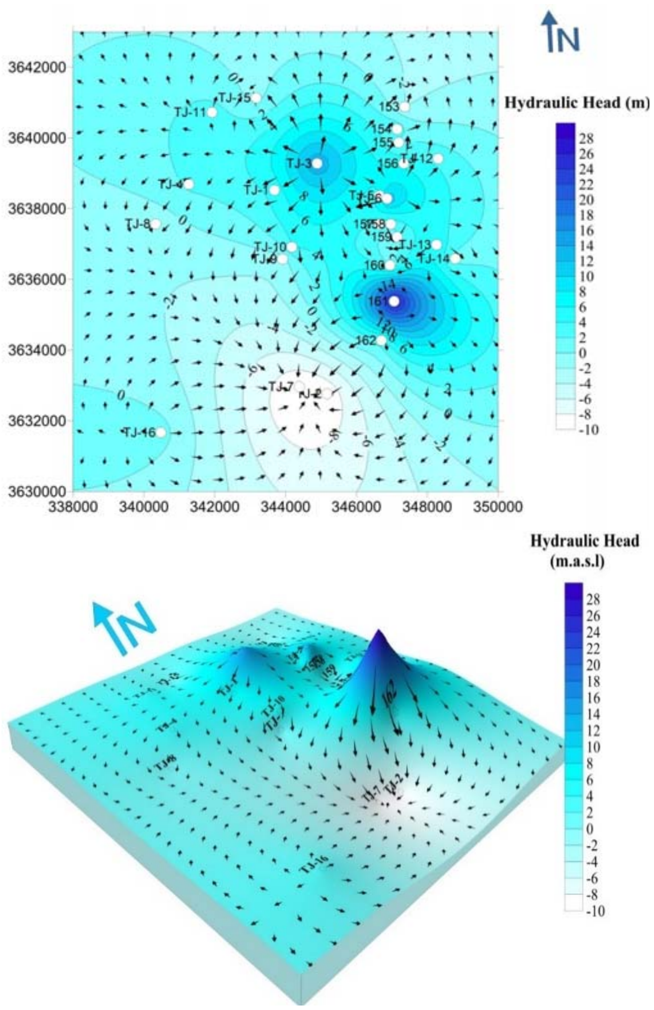

Fig. 18 Contour map of hydraulic head in the study area in 2021

E. Simpson Ratio (Ionic Ratio)

The Simpson Ratio, first described by Todd [7] is the ratio of $Cl^-/(HCO_3^{--})$. Five classes were created to evaluate the level of contamination;

- Good quality (< 0.5),
- Slightly contaminated (0.5-1.3),
- Moderately contaminated (1.3-2.8),
- Injuriously contaminated (2.8-6.6), and
- Highly contaminated (6.6-15.5).

Based on the Simpson Ratio of the water samples, the evaluation of the quality of such samples are shown in Table III:

- 2 samples are of good quality,
- 3 samples are slightly contaminated,
- 2 samples are moderately contaminated,
- 8 samples are injuriously contaminated, and
- 10 samples are highly contaminated

F. Comparison of Water Quality with the Libyan and WHO Standards

During this study, the average values of chemical analyses for the collected water samples were matched with the Libyan specifications as well as the specifications of the World Health

Organization for drinking water, Table IV.

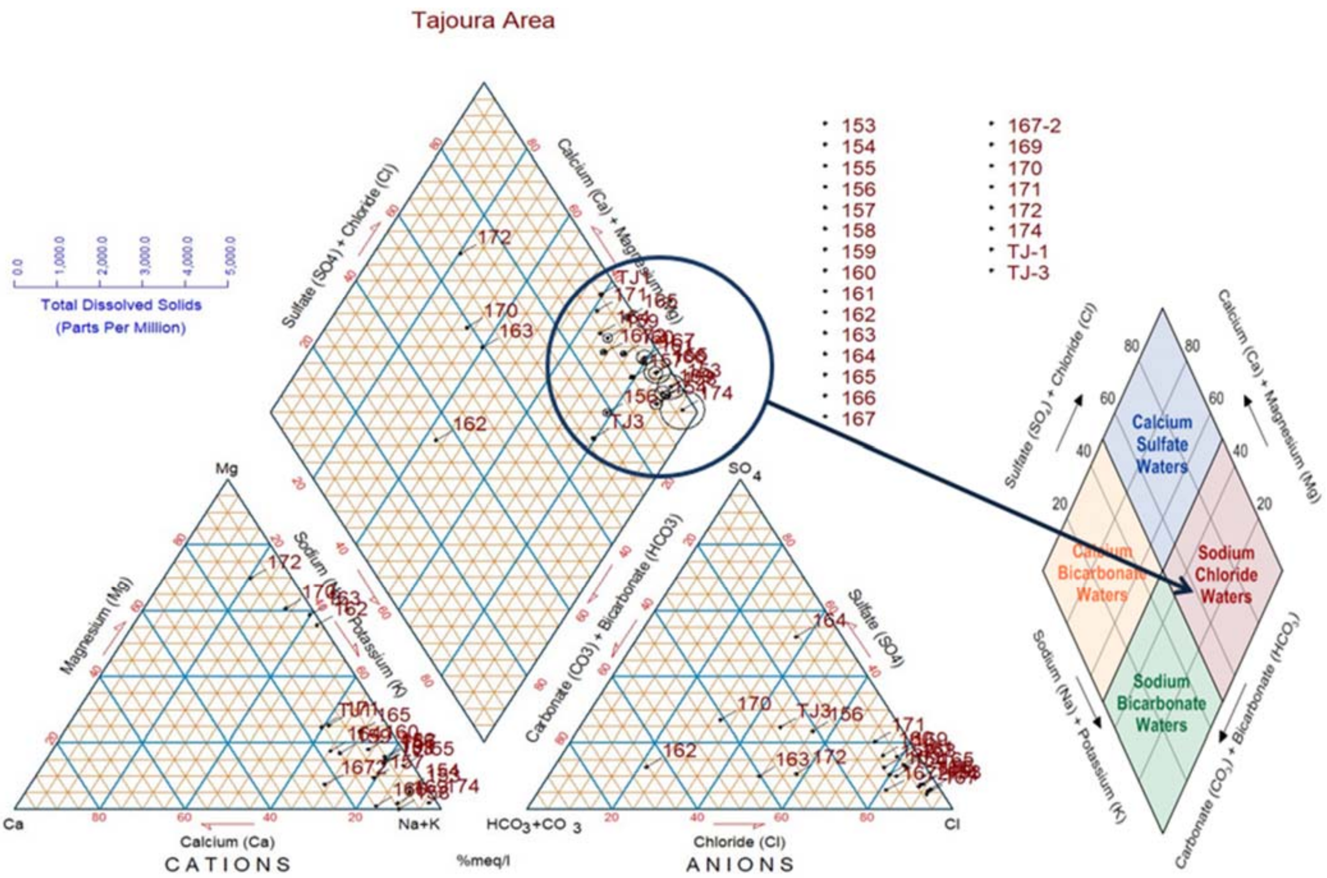

Fig. 19 Piper classification diagram illustrating the chemical composition of groundwater in the study area

Only calcium, magnesium, potassium and PH fall within the permissible limits, whereas the rest of the parameters fall outside the acceptable range.

G. Temporal Changes in TDS Concentration (1994 –2021)

The results of chemical analyses of samples from 10 water wells obtained from the historical data by the GWA in 1994 have been compared with the results of water samples collected from the same locations in 2021, in order to evaluate the temporal changes in the groundwater quality during a period of 25 years, Fig. 20.

It is clear that the overexploitation of groundwater caused a considerable increase in salinization, which has reached an alarming level in many places during the past 25 years. This deterioration in groundwater quality can be attributed to the sea water intrusion.

In contrast with all water samples, it has been noticed that two locations (wells No 159 & 160) displayed anomalies, in which the TDS concentration in 2021 is lower than that in 1994. This decrease in the TDS concentration with time can be attributed to the presence of these two wells very close to the unlined disposal pond of a sewage treatment plant.

VII. Conclusion and Recommendations

Numerous natural and human factors have an impact on Libya's water supplies and their quality. Geological, hydrogeological and climatic factors are the most significant natural factors and they usually have the highest impact when there is a shortage of water, and more effort must be taken to utilize such scarce resource.

A. Conclusion

The area targeted by this research is a part of the Jifarah Plain basin and represented by different relevant rock formations, from the Cretaceous to the Quaternary deposits. Overexploitation of groundwater caused a considerable deterioration in the water quality especially at Tjura Town. As a result of the seawater intrusion, the aquifers are exhibiting successive increase in salinization, which has in several locations reached an alarming level over the last 25 years.

It can be concluded that:

- Dropping of water table has been recorded throughout the targeted area as a result of aquifer overexploitation.
- Based on the contents of major cations and anions, all (most of the) samples fall within NaCl type.
- The best groundwater quality exists at the southern part of the study area. Degradation in the water quality expressed in salinity increase, occurs as we go towards the coastline.
- The aquifer is becoming more salinized with time, and in many areas this salinization has reached dangerous levels.

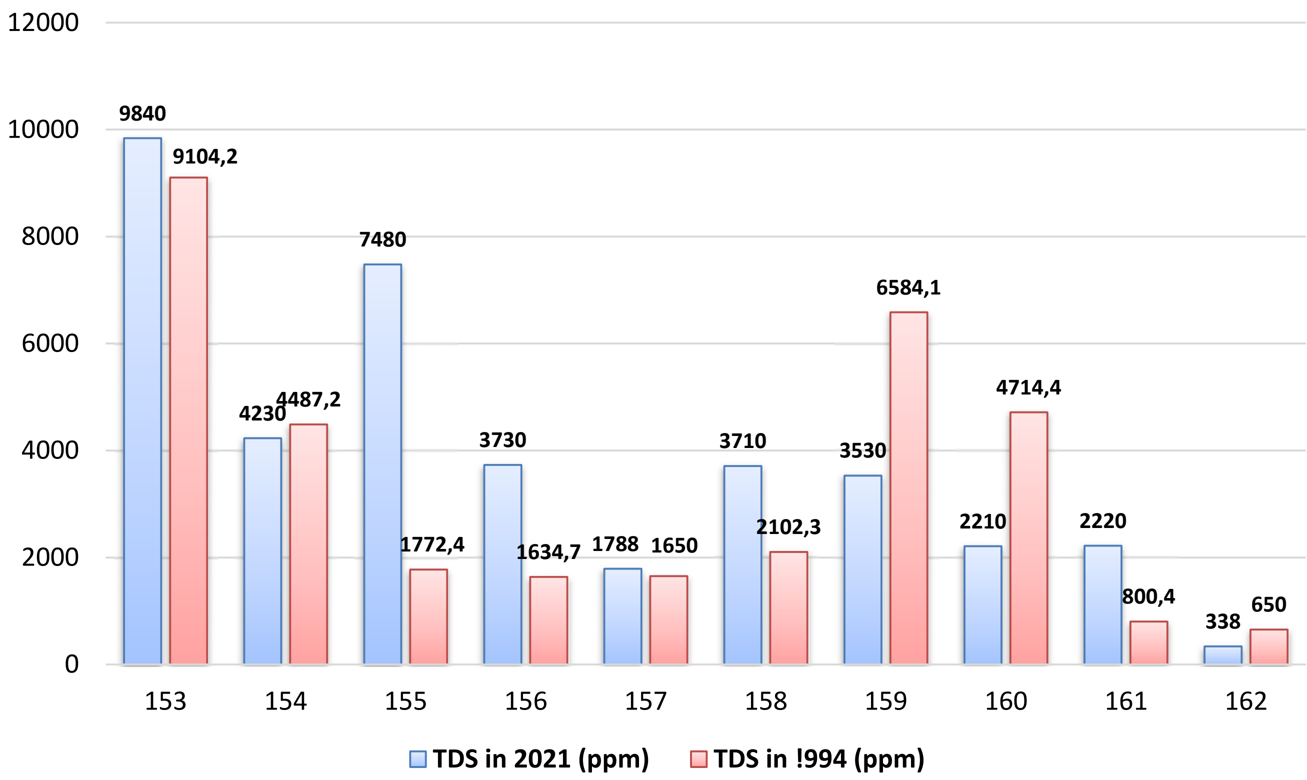

Fig. 20 Temporal changes in TDS concentration in the study area during the period 1994-2021

TABLE III
CONTAMINATION LEVEL BASED ON THE SIMPSON RATIO ($Cl^-/(HCO_3^-)$)

Sample No	HCO^{3-} (mg/l)	HCO^{3-} (meq/l)	Cl^- (mg/l)	Cl- (meq/l)	Simpson Ratio	Contamination Level
153	390	6.39	5250	148.08	23.17	highly contaminated
154	537	8.80	1775	50.07	5.69	injuriously contaminated
155	488	8.00	4509	127.18	15.90	highly contaminated
156	805	13.19	710	20.03	1.52	moderately contaminated
157	268	4.39	710	20.03	4.56	injuriously contaminated
158	244	4.00	1420	40.05	10.02	highly contaminated
159	512	8.39	1420	40.05	4.77	injuriously contaminated
160	268	4.39	816	23.02	5.24	injuriously contaminated
161	170	2.79	959	27.05	9.71	highly contaminated
162	317	5.20	35.5	1.00	0.19	good quality
TJ-1	109	1.79	711	20.05	11.23	highly contaminated
TJ-10	463	7.59	994	28.04	3.69	injuriously contaminated
TJ-11	464	7.60	2355	66.43	8.73	highly contaminated
TJ-12	390	6.39	104	2.93	0.46	good quality
TJ-13	120	1.97	365	10.30	5.23	injuriously contaminated
TJ-14	340	5.57	212	5.98	1.07	slightly contaminated
TJ-15	756	12.39	7586	213.97	17.27	highly contaminated
TJ-16	31	0.51	35.5	1.00	1.97	moderately contaminated
TJ-2	190	3.11	78	2.20	0.71	slightly contaminated
TJ-3	630	10.33	355	10.01	0.97	slightly contaminated
TJ-4	226	3.70	660	18.62	5.03	injuriously contaminated
TJ-5	109	1.79	340	9.59	5.37	injuriously contaminated
TJ-6	244	4.00	843	23.78	5.95	injuriously contaminated
TJ-7	73	1.20	1101	31.06	25.96	highly contaminated
TJ-8	317	5.20	2485	70.09	13.49	highly contaminated
TJ-9	366	6.00	2840	80.11	13.35	highly contaminated

TABLE IV
COMPARISON OF WATER QUALITY WITH THE LIBYAN AND WHO STANDARDS

Parameters	Minimum	Maximum	Average	WHO Standards (2011)	Libyan Standards
PH	6.8	7.27	6.9	6.5-8.5	6.5-8.5
EC (uS)	727	20880	6647.9	1500	1200
TDS (ppm)	329	11030	3694	500	500-1000
HCO_3^- (mg/l)	31	805	339.5	500	500
CL^- (mg/l)	35.5	7586	1487	250	250
So_4^- (mg/l)	30	870	325	250	400
Ca^{+2} (mg/l)	1.3	211	71.1	75	200
Mg^{+2} (mg/l)	5	140	42.8	50	150
Na^+ (mg/l)	73.5	6020	1116	200	200
K^+ (mg/l)	1	53	8.49	12	40
NO_3^- (mg/l)	1.8	150	68.8	45	45

The salinization process at the study area (Tajoura) can be attributed to the seawater intrusion, which mixes with the freshwater in the aquifer and lowers its quality. The NaCl waters show a significant association with seawater. Based on the chloride concentration values and the calculated chloride/ bicarbonate ratio, the saline water had a significant impact on around 70% of the groundwater samples.

There is a possible contamination of the shallow aquifer by the infiltrated surface water (from sewage water ponds and cars washing stations) as well.

B. Recommendations

In order to mitigate the serious deterioration in the water quality at Tajoura area, the following points are recommended:

- Periodic monitoring of the groundwater quality and water levels should be carried out.
- Conducting an urgent biological and detailed hydrochemical studies in the targeted area in order to determine the bacteriologic and heavy metals pollution.
- To improve the quality of water, the Government and non-government organizations should provide the support to design the rain water harvesting infrastructures and artificial recharge methods for young generation especially hydrogeologists and budding civil engineers.
- More attention should be paid for the nonconventional water resources such seawater desalination and treatment of sewage water.

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