

# Evaluation of Groundwater and Seawater Intrusion at Tajoura Area – NW-Libya

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**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 twenty-six wells distributed throughout the investigation area. Overexploitation of groundwater caused a 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 sea water intrusion. The chemical composition of the water samples was compared with the drinking water standards of WHO and Libyan Standards. Groundwater from this area was not suitable to be source for direct drinking based on Total Dissolved Solids. The dominant cation is sodium while the dominant anion is chloride. Based on the Piper trilinear diagram, most of groundwater samples (90%) was 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 a strong evidence to attribute the successive deterioration of the water quality to the seawater intrusion. Considering the values of Cl<sup>-</sup> concentration and the ratio of Cl<sup>-</sup>/HCO<sub>3</sub><sup>-</sup>, 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 wastewater contribute significantly to the deterioration of water quality. The water quality in this area needs to be monitored regularly and it is crucial to treat the water before consumption.

**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 serve as major sources for freshwater supply in many countries around the world, especially in the Mediterranean [1]. The fact that coastal zones contain some of the most densely populated areas in the world makes the need for freshwater even more acute [1]. The intensive extraction of groundwater from coastal aquifers reduces freshwater outflow to the sea and creates local water

table depression, causing seawater to migrate inland and rising toward the wells [1]-[2], resulting in deterioration in groundwater quality. This phenomenon, called seawater intrusion, has become one of the major constraints imposed on groundwater utilization in coastal areas. It is a significant issue that affects water resources in Libya.

## 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 at the northwestern part of the country, located between the Mediterranean coast and the Jabel Naffusah Mountain in the south. It comprises more than 60% of the country's population and produces 50% of the total agricultural outputs [4]. The targeted area lies in the Jifarah Plain and occupies about 156 km<sup>2</sup>, 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.

## II. 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.

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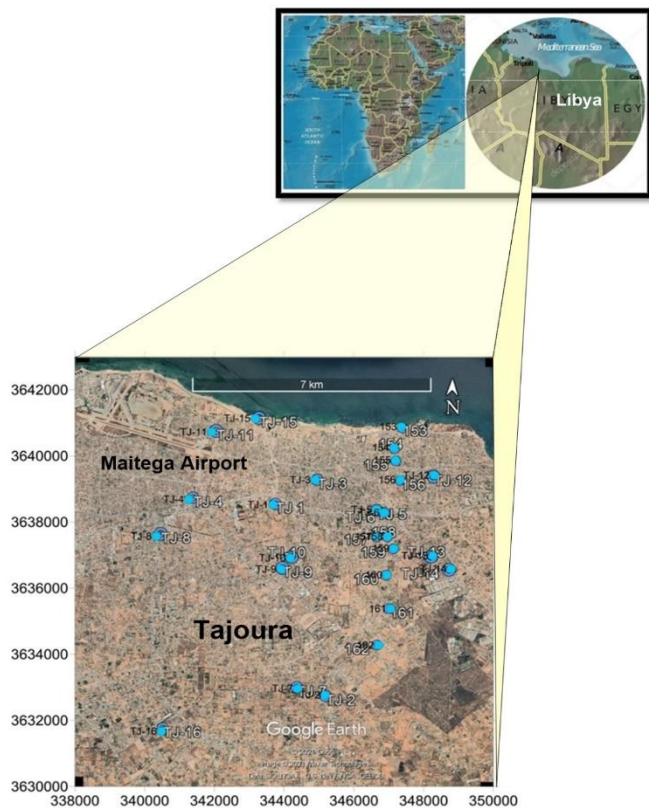


Fig. 1: Location map of the study area.

### III. 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 was designed to achieve the objectives set out by the researchers, as shown in the flowchart, Fig. 2.

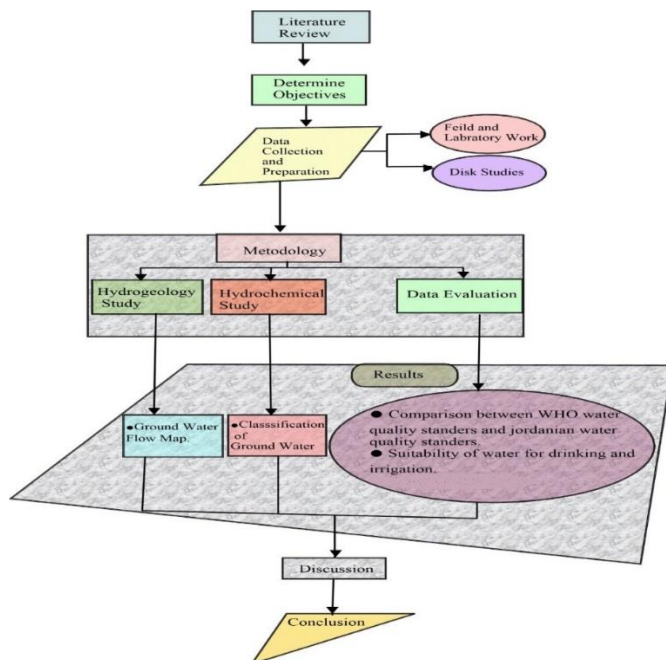


Fig. 2: Flowchart illustrating research stages

### IV. 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).

#### Field work

Several field visits to collect 26 water samples from 26 boreholes, all of them are private wells have been carried out 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.

#### Water Sampling and rapid field-test

The 26 water samples were filled in plastic bottles of 1.5-liter size. Rapid field tests, including PH, TDS, T & EC have been also carried out for all the collected water samples by using portable water analysis device.

#### 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.

#### 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

### V. 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].



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

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.

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].

#### **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, calcarenites 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 lower

Cretaceous-upper Jurassic (Kiklah Formation). In some places, the sandstones probably belong to the upper Triassic (Abu Shaybah Formation).

**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 outcropping 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].

#### **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 all the infiltrated water will contribute to the recharge of the aquifers (which is not completely true between Bi'r al Ghanam and Qasr al Haj where the Jurassic evaporites subcrop) and assuming that 10 to 30% of the runoff infiltrates [5].

##### **Groundwater flow**

In the south-central part of the Jifarah Plain the ground water flows mainly in the Triassic sandstones and dolomitic limestones. The flow is likely to originate a few kilometers south of the jabal escarpment 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 (mostly Kiklah Fm.). This groundwater flow is in continuity with the general south-north flow in the eastern Suf Ajjln basin. To the north, most of the groundwater flow remains in the Mesozoic sandstone (associated with the Lower Miocene aquifer). The shallow aquifer (mostly Quaternary and Upper Miocene) becomes independent and has its own direct recharge [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 overexploitation of the Jifarah upper aquifer is characterized by the falling of piezometric head over a wide region, reducing the outflow rate to the sea, and the continuous degradation of the chemical quality of water. Depression cones in various places have dropped from 25 to 35 m below sea level, which testifies the inversion of the hydraulic gradient and the intrusion of seawater. This was mainly observed in Sabratah region and southern Tripoli [4].



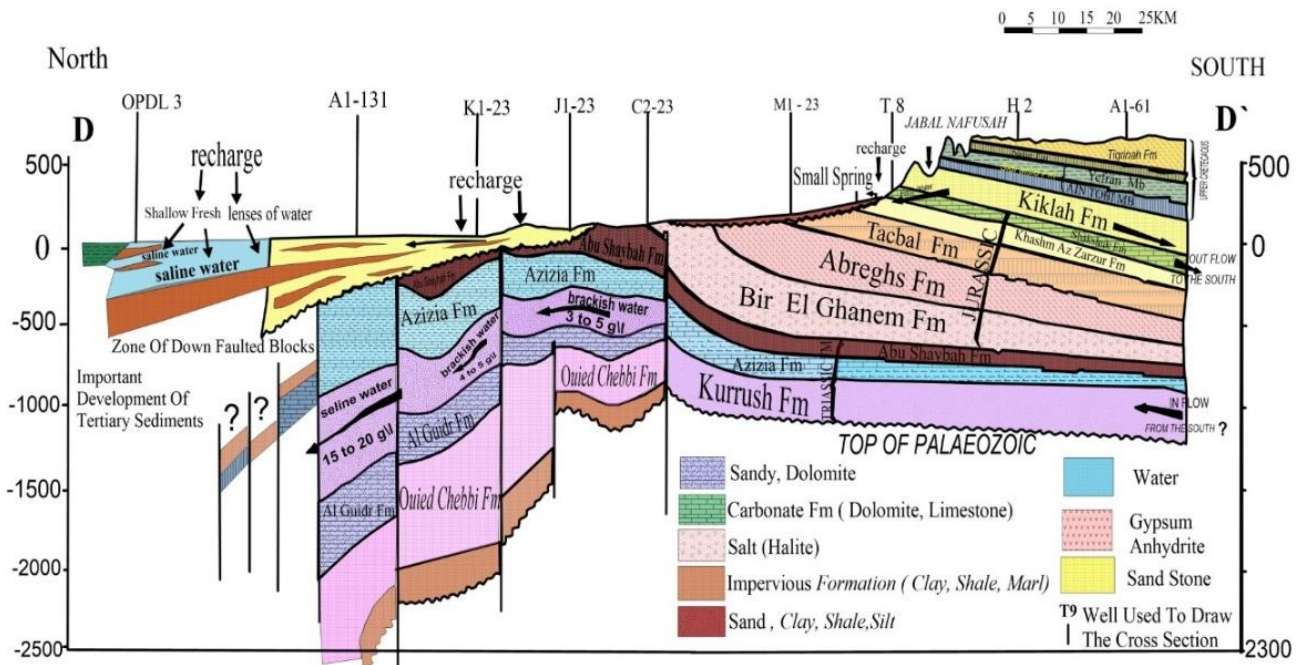


Fig. 4: Hydrogeological cross section of the Jifara Plain (after Pallas, 1980)

### 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.

### Agricultural use

Agriculture is and will continue to be the major water consumer. It represents about 85% of the current water demand and despite the use of pressurized irrigation techniques in practically all farming areas, application rates are still among the highest in the world. This is mainly due to the unsuitable climatic and soil 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<sup>3</sup>/ha/year.

**Partly irrigated fields** with moderate groundwater extraction estimated to range from 1500 to 3000 m<sup>3</sup>/ha/year. The groundwater extraction from the Jifarah Plain has been estimated by different authors and at different dates, Table I [6].

### Domestic use

In Libya, 80% of the population live in urban centers, varying in size from 5000 to 1000000 inhabitants, The average water consumption per capita was found to range from 150 to 300 l/capita/day, depending on the size of the city, location, and age of the supply network [6]. In rural areas, people depend to a certain extent on private water supply sources, usually wells, rainwater reservoirs and springs. The average per capita consumption falls between 100 and 150 l/capita/day. 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].

## VI. HYDROCHEMISTRY

The hydrogeochemistry of groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer and the groundwater quality is nearly of equal importance to the quantity [7].

### 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<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> and the major anions CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup> and NO<sub>3</sub><sup>-</sup> as well as the total dissolved solids (TDS) [2].

### Data Reliability –Error balance equation

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

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

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

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				Agricultural	Domestic	Industrial		
	Renewable	Nonrenewable	Surface water	Desalination	Treated sewage	Transported						
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 (CBE) in percent

No	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	HCO <sub>3</sub> (meq/L)	Cl (meq/l)	NO <sub>3</sub> (meq/l)	SO <sub>4</sub> (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%
tj-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%

## Physical properties

### Temperature (C°)

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

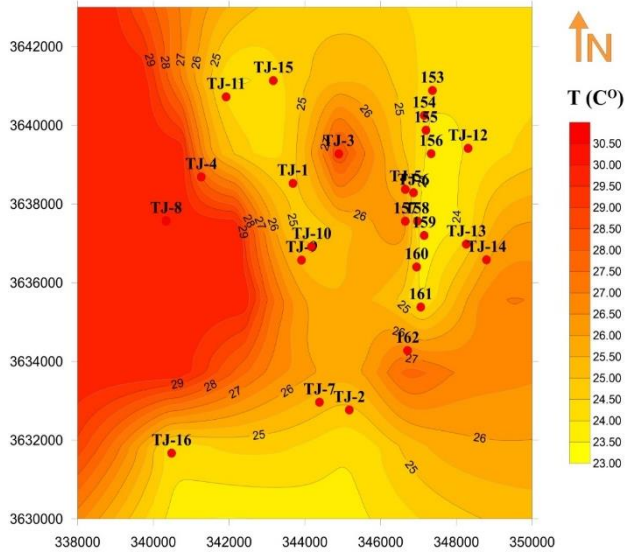


Fig. 5: Contour map of groundwater temperature (C°)

### Hydrogen number (pH value)

The pH of a solution is defined as the negative logarithm of its hydrogen ion activity [8].

$$\text{pH} = -\log [\text{H}^+] \quad (2)$$

PH is one of the most important operational water quality parameters with the optimum pH required often being in the range of 7.0–8.5. 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.

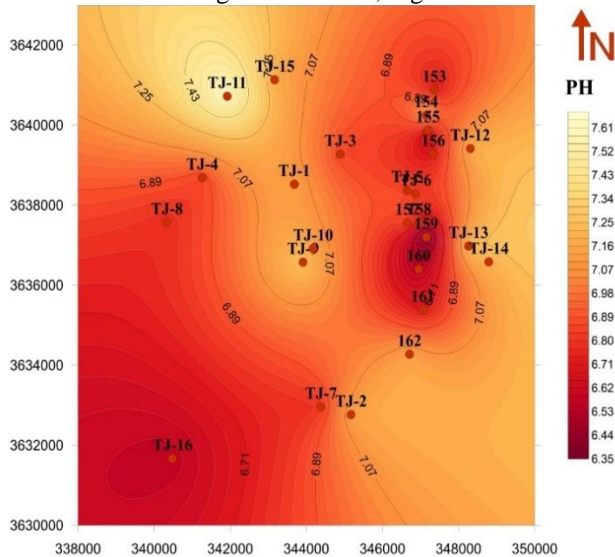


Fig. 6: Contour map of PH values.

### Electrical Conductivity (EC)

Electrical Conductivity (EC) is the ability of (1cm<sup>3</sup>) of water to conduct electrical current, at temperature of 25C°, 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 one degree Celsius 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

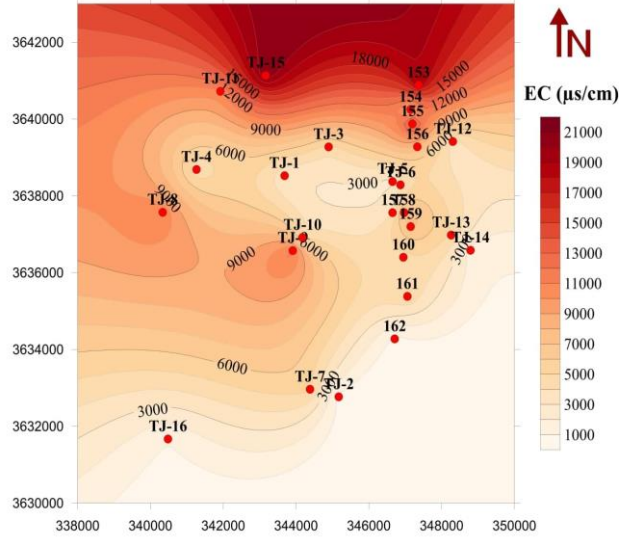


Fig. 7: Contour map of electrical conductivity (EC) values

### Total Dissolved Solids (TDS)

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.

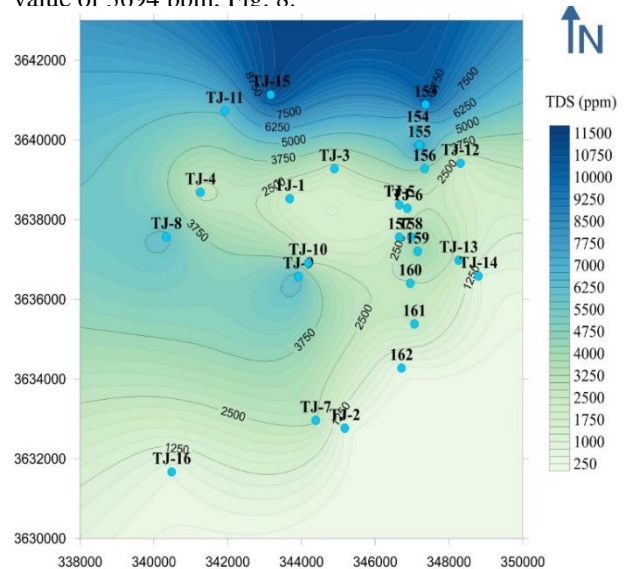


Fig. 8: Contour map showing the TDS concentration





## Potassium (K<sup>+</sup>)

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<sup>+</sup>) concentrations of groundwater samples are given in Table 2. 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.

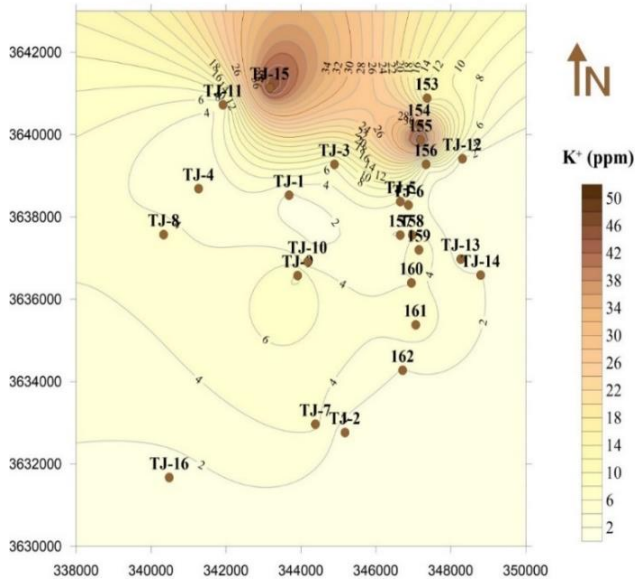


Fig. 13: Contour map showing the spatial variation of potassium concentration (mg/l).

## Major Anions

### Bicarbonates (HCO<sub>3</sub><sup>-</sup>)

Carbonates and bicarbonates are considered to be the most important anions in natural water. They 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 HCO<sub>3</sub><sup>-</sup> concentrations of groundwater samples are shown in Table 2. The maximum acceptable limit of HCO<sub>3</sub><sup>-</sup> 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 (SO<sub>4</sub><sup>2-</sup>)

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. The human activities (agricultural and industrial activities) can be also considered as a significant sources for sulfates [14]. The sulfate concentrations of groundwater samples are shown in Table II.

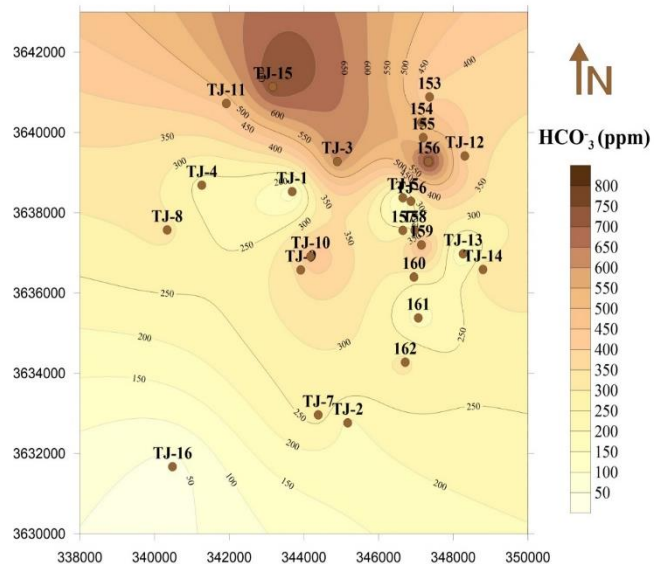


Fig.14: Contour map showing the spatial variation of bicarbonates concentration (mg/l).

High levels of sulphate in drinking water can cause Diarrhea [13]. The WHO standards for sulphate in 2011 for drinking water is 400 mg/l. 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.

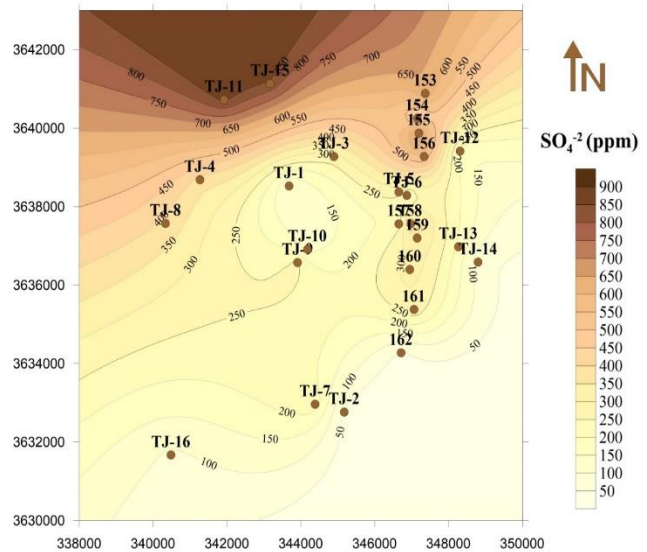


Fig. 15: Contour map showing the spatial variation of sulphates concentration (mg/l).

### Chloride (Cl<sup>-</sup>)

Chloride concentrations of groundwater samples are shown in Table 2. 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.



## VII. RESULTS AND DISCUSSION

Field measurements of water levels and the results of chemical analyses of samples collected from twenty-six 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.

### 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.

### Groundwater Classification

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

### 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.

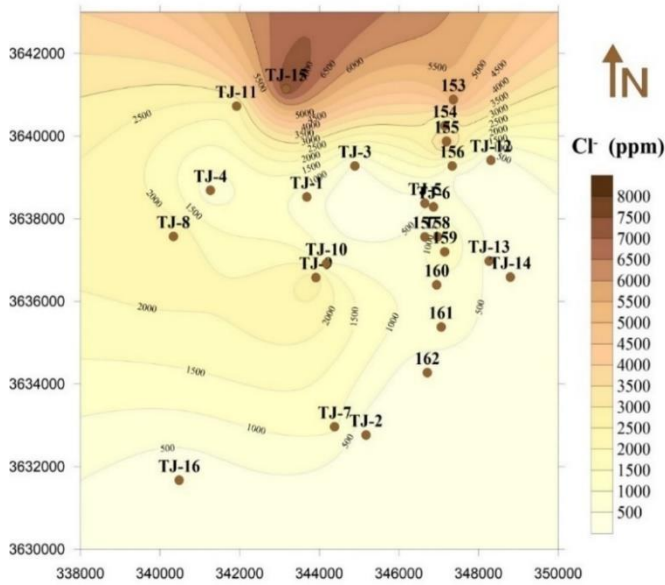


Fig.16: Contour map showing the spatial variation of chloride concentrations (mg/l).

### Nitrate (NO<sub>3</sub>-)

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.

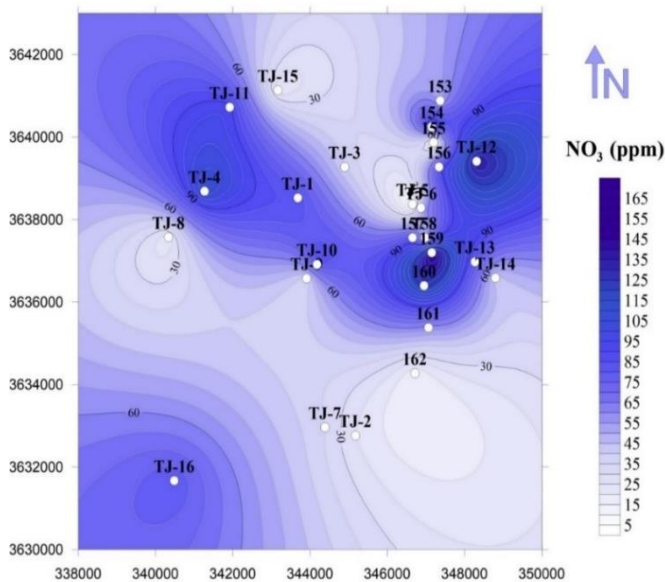


Fig.17: Contour map showing the spatial variation of nitrates concentrations (mg/l).

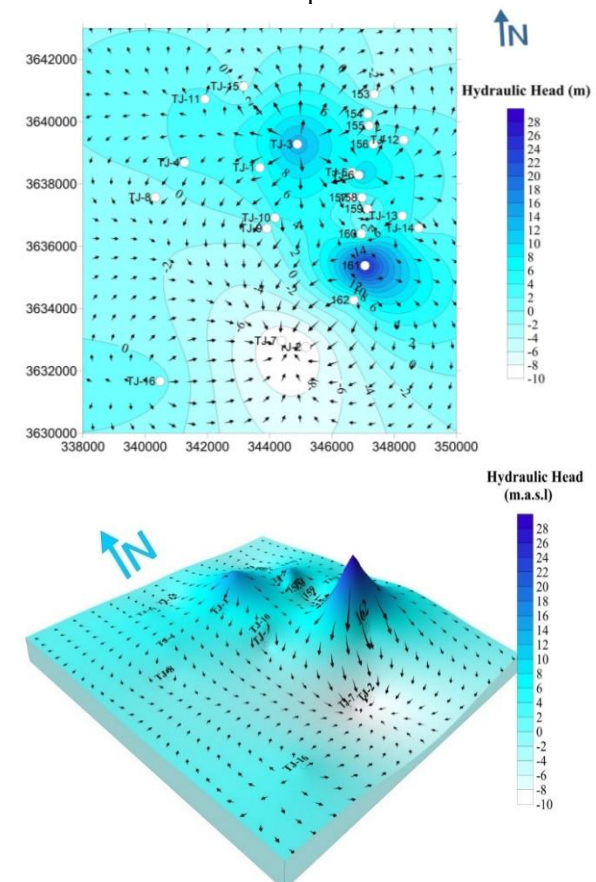


Fig. 18: Contour map of hydraulic head in the study area in 2021.

### 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 twenty six 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.

### 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

### 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.

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

### 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 General Water Authority (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.

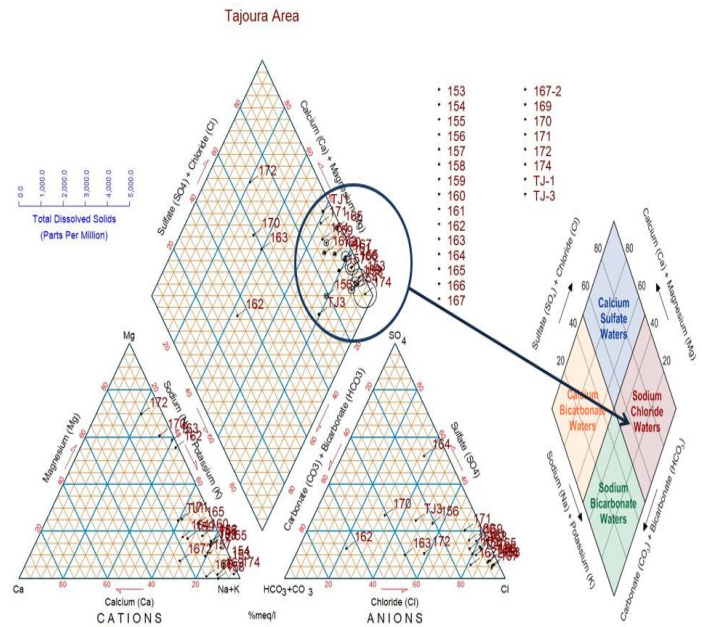


Fig. 19: Piper classification diagram illustrating the chemical composition of groundwater in the study area.

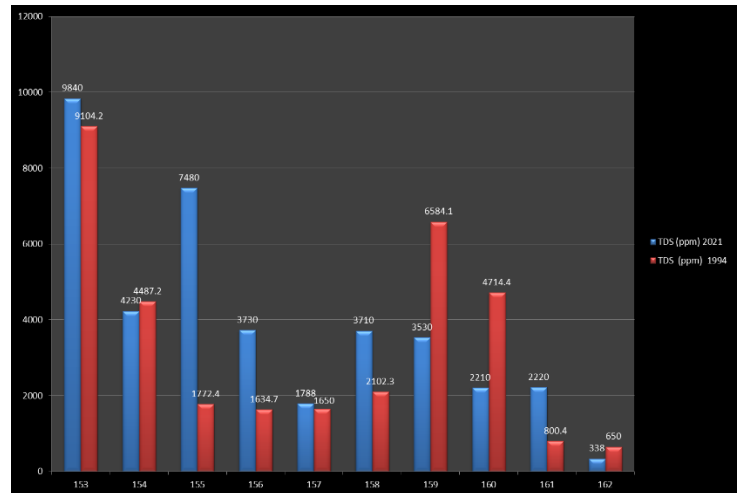


Fig. 20: Temporal changes in TDS concentration in the study area during the period 1994-2021

Table III: Contamination level based on the Simpson Ratio ( $\text{Cl}^-/(\text{HCO}_3^-)$ )

Sample No	$\text{HCO}_3^-$ (mg/l)	$\text{HCO}_3^-$ (meq/l)	$\text{Cl}^-$ (mg/l)	$\text{Cl}^-$ (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	injuriouly 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	injuriouly contaminated
158	244	4.00	1420	40.05	10.02	highly contaminated
159	512	8.39	1420	40.05	4.77	injuriouly contaminated
160	268	4.39	816	23.02	5.24	injuriouly 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	injuriouly 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	injuriouly 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	injuriouly contaminated
TJ-5	109	1.79	340	9.59	5.37	injuriouly contaminated
TJ-6	244	4.00	843	23.78	5.95	injuriouly 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
<b>PH</b>	6.8	7.27	6.9	6.5-8.5	6.5-8.5
<b>EC (uS)</b>	727	20880	6647.9	1500	1200
<b>TDS (ppm)</b>	329	11030	3694	500	500-1000
<b><math>\text{HCO}_3^-</math> (mg/l)</b>	31	805	339.5	500	500
<b><math>\text{CL}^-</math> (mg/l)</b>	35.5	7586	1487	250	250
<b><math>\text{So}_4^-</math> (mg/l)</b>	30	870	325	250	400
<b><math>\text{Ca}^{+2}</math> (mg/l)</b>	1.3	211	71.1	75	200
<b><math>\text{Mg}^{+2}</math> (mg/l)</b>	5	140	42.8	50	150
<b><math>\text{Na}^+</math> (mg/l)</b>	73.5	6020	1116	200	200
<b><math>\text{K}^+</math> (mg/l)</b>	1	53	8.49	12	40
<b><math>\text{NO}_3^-</math> (mg/l)</b>	1.8	150	68.8	45	45



## VIII. CONCLUSION AND RECOMMENDATIONS

Water resources in Libya and their quality are affected by a wide range of natural and human influences. Most important of the natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of available water. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource.

### 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. The aquifers are showing an increase in salinization, which has reached an alarming level in many places during the past 25 years as a result of the sea water intrusion.

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 showing an increase in salinization, which has reached an alarming level in many places.

The NaCl waters indicate a strong relationship with seawater, and the salinization process in the Tajoura coast is primarily due to seawater intrusion, which is mixed with the freshwater in the aquifer and reduces its quality.

Considering the values of  $\text{Cl}^-$  concentration and the ratio of  $\text{Cl}^-/\text{HCO}_3^-$ , about 70% of the groundwaters were strongly affected by the saline water.

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

### 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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