# Deep groundwater quality and its suitability for drinking and agricultural purposes, Wadi Baye, Middle Region, Libya

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## Abstract

Assessment of suitability of deep artesian groundwater (Kiklah aquifer) for domestic and agricultural purposes was carried out in the Wadi Baye area; Middle Region, Libya, where, groundwater is the main source for domestic and agricultural activity. Eighteen groundwater samples were collected from different wells, distributed over the Wadi's area. Suitability of groundwater for irrigation purpose was evaluated based on US Salinity diagram, which shows that 89% of the samples falls in the zone of very high-salinity hazard (C4) and medium-sodium hazard (S2) type. The Wilcox diagram shows that most of the samples (89%) fall in the category of doubtful to unsuitable for irrigation purposes. The residual sodium carbonate (RSC) and the sodium adsorption ratio (SAR) in groundwater signified good quality. While soluble sodium percentage (Na%) indicates water is doubtful for irrigation, permeability index (PI) indicates water is injurious to unsatisfactory for irrigation and the magnesium adsorption ratio (MAR) indicative that 72.2% of groundwater samples are suitable for irrigation purposes. Overall, the groundwater can be classified with few exceptions as suitable for irrigation under certain conditions such as good management, good drainage system, deep ground to keep soil salt balance and highly salt tolerant plants. However, it is recommended that water drawn from such sources should be purified of excess elements well before being used for drinking and other purposes. Wells numbered as 1, 3, 4, 6 should also be excluded from domestic and drinking uses. Also it is recommended that the water should be not used directly after pumping.

*Keywords: water quality, Kiklah aquifer, physicochemical parameter, Libyan drinking water standards, salinity hazard.*

# 1   Introduction

Groundwater plays an important role in North African countries' agriculture, drinking and in shaping the countries' economy. A good quality of groundwater can help in the better yield of crops. Water used for irrigation purpose should have certain quality specifications. The suitability of water for irrigation mainly depends upon the tolerance of plants to certain chemical constituents, properties of soils and irrigation practices. Groundwater always contains some amount of constituents dissolved in it. Water containing high concentrations of soluble salts may be harmful for many crops because their presence affects the soil structure, permeability and aeration [1–3]. Hence it is essential to properly evaluate groundwater quality for irrigation purpose. Therefore, the requirement for the assessment of suitability of groundwater resources for drinking and irrigation purposes is becoming increasingly important and this is demonstrated by the relatively large number of recent studies in this field [4, 5]. Generally, the suitability of groundwater for agriculture and domestic purposes largely depends on the site specific quality of the water, with possible temporal variations caused by climatic conditions, as well as the residence time of water within the aquifer materials and anthropogenic activities [6]. In certain conditions, especially where there is accumulation of sodium ions and other ions in the soil structure due to extended use of certain irrigation water, could cause deterioration in the soil physical properties, and thereby results in the decrease of the crop yield. Hence, this work intends to assess the physical and chemical characteristics of the local groundwater resources around the Wadi Baye area in order to determine its suitability for a different purpose such as irrigation and drinking.

# 2   The study area

Wadi Baye area situated 70 Km at west of Sirte city (Northern Libya). It extends from the Hun graben at South Western up to Mediterranean sea at the North, between 15°00'–15°56' E longitude and 31°00'–31°53' N latitude, flows from southwest to northeast and covering an area of about 37.3 km$^2$ [7, 8], fig. 1. Depending on De Martonne classification, the study area has been classified as arid or semi-arid region, temperature ranges between (13.8°C) in January and (26.9°C) in August. The average annual precipitation decreases from 170 mm/yr in north to 50 mm/yr in south with the distance away from the coast, and the evaporation increases from 1701 mm/yr in north to 2607 mm/yr in south, during the last 20 years according to [9].

## 2.1  Geology and hydrogeology setting

The only water resource in Wadi Baye is groundwater with minimal rainfall during wet season, and the most groundwater production is from Kiklah (deep) and Eocene (shallow) aquifers. Kiklah sandstone aquifer is a confined aquifer with groundwater levels above ground surface. Kiklah aquifer is the main current source for domestic and agricultural water supply in many parts of Libyan Middle

Region and it provides water for the villagers living in the Wadi region. This aquifer is artesian but very deep (1,210 m–1,574 m). The water is slightly mineralized (1530 mg/L) and at high temperature (> 60°C). The aquifer thickness ranges from 30 m to 182 m. [10]. Part of this aquifer extends outside the Wadi catchment area where eighteen of productive wells are located within the valley region, fig. 2. The groundwater production has been from naturally overflowing wells. However, Because the groundwater levels have fallen since the mid of 1970s as a result of groundwater production, only four wells (3, 4, 5, 6) still playing a basic role as a water source in Wadi Baye project to provide water for irrigation and other purposes [10]. In addition, the groundwater level has dropped more than 60 meters since the 1970s in some surrounding wells which are located within the surrounding wadis such as Wadi Zamzam and Wadi Amrah. This decline makes some non-productive wells have been occurred [10].
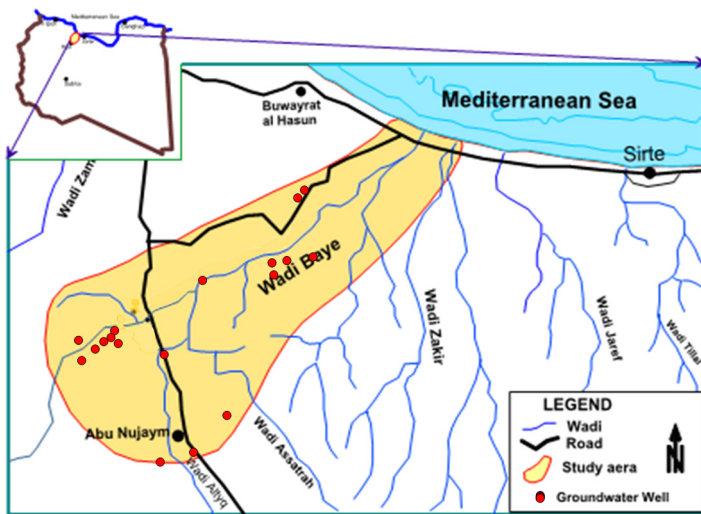


Figure 1:   Location map of Wadi Baye area, Northern Libya.

## 2.2  Field and laboratory methods

Ground water samples were collected from eighteen deep groundwater wells in the study area (figs. 1 and 2). Sampling was carried out in October 2010, pH, temperature and electrical conductivity were measured in the field using digital meters immediately after sampling, [10].

Total dissolved solid TDS determined in laboratory by evaporation the water to dryness and weighing the residue [10], total hardness TH was calculated using equation:

$$TH = (2.49\ Ca + 4.11\ Mg)\ [11] \tag{1}$$

The major ions (Cations and Anions) were carried out using standard method for water analyses as suggested by [11], table 1, the laboratory work was completed within a few weeks of water samples collections.

Each sample was checked for accuracy by calculating ion-balance (I.B) equal:

$$I.B\% = [(sum\ cation - sum\ anion)/\ (sum\ cation + sum\ anion)] * 100 \qquad (2)$$

It was found that the analytical errors of all samples were less than 5%, which ensured the reliability of the chemical data. All these analyzed were measured by the General Water Authority Laboratory, Tripoli [10].

Table 1: Methods used for major ion analysis of ground water samples.

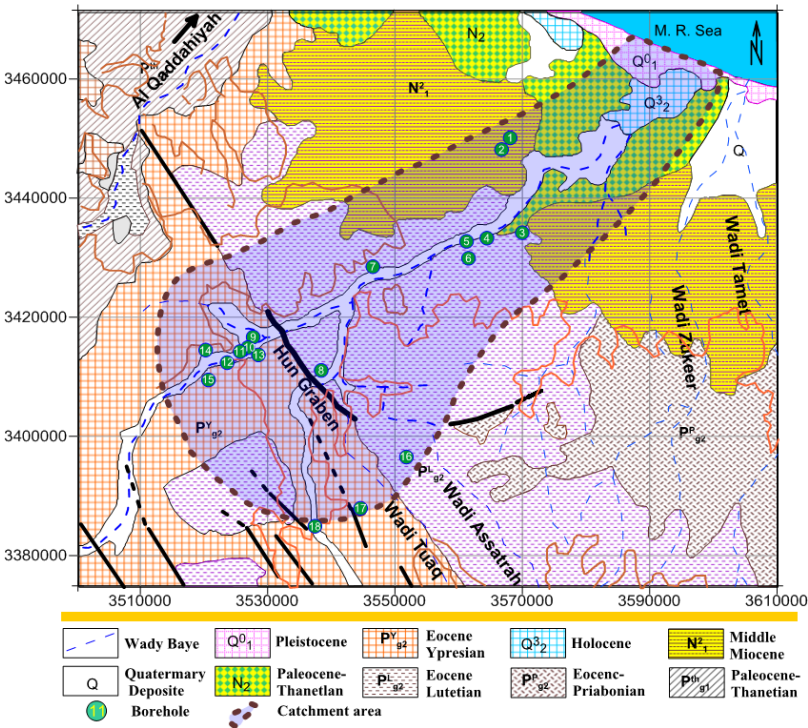| Soluble Ions | Ca and Mg | Na and K | HCO$_3$ | Cl | SO$_4$ |
|---|---|---|---|---|---|
| Methods | Titration using EDTA | Flame photometer | Titration H$_2$SO$_4$ | Titration using 0.05N AgNO$_3$ | Spectro-photometer |



Figure 2:    Geological map and wells location of the study area (after [7]).

# 3   Hydrogeochemistry

Ground water quality assessment; carried out to determine suitability of water samples in terms of domestic and agricultural purposes. The portability of drinking water from domestic well samples is mainly based on recommended permissible limits for certain parameters described in Libyan Standards [12], WHO [13] and US Public Health Service [14].

The data revealed that there were considerable variations in physico-chemical properties of examined samples from the different wells. Temperature of the water samples were ranging from 56–73°C. Temperature is important to assess the quality of water because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature. Groundwater, with higher temperatures can dissolve more minerals from the rocks it is in and will therefore have a higher electrical conductivity (EC) [15]. The pH of analyzed samples varies from 7.01 to 7.35; this indicates that ground water is neutral to alkaline range. In addition, EC of the water samples ranged from 2250 to 4033 µS/cm which revealed a variation in EC. High EC were found in water samples which located near the coast. It has been reported that EC is affected by the presence of TDS and Temperature, high value of EC is correlated with high TDS ($r^2 = 0.979$). EC is used as an indicator and classification of salinity. Therefore, high EC means high degree of salinity and an index of the amount of dissolved substances in water [16]. TDS of the water samples ranged from 1451.5 to 2700.9 mg/l gradually increasing towards the coastal areas as shown in fig. 3.
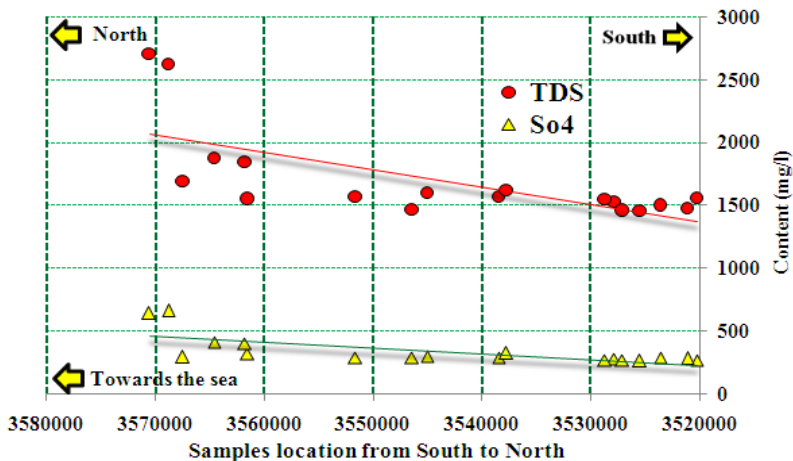


Figure 3:   Variation of TDS mg/l and SO4 with distance from South to North.

Total hardness (TH) as $CaCO_3$ mg/L of the water samples were ranged between 500.2 to 760.8 mg/l. The TH values of all samples exceeds (WHO) allowable limit. These values of hardness could be occurring as a result of the dissolution of limestone deposit.

Also, the result show that chloride varied from 399–685 mg/l, the permissible limit for chloride in drinking water is up to 250 mg/l. The result shows that the highest values of Cl were observed at wells that nearer to the coast. Therefore, increasing in the values of both chlorides and TH near the coast indicated that high values may be caused by water-rock interaction or ancient saline conditions (fig. 4). Therefore, the results are plotted in the Piper [17] Trilinear Diagram (fig. 5). This diagram provides a convenient method to classify and compare groundwater types, based on the ionic composition of different water samples. This diagram reveals that there are two different groundwater types have been identified in the study area. The first is rich in sodium chloride – sulphate (Cl·SO4-Na) water type. The second is rich in calcium sodium sulphate – chloride (Cl·SO4-Na·Ca) water type, fig. 6. However, the water type for this aquifer is more complex and can be divided to more than four types.
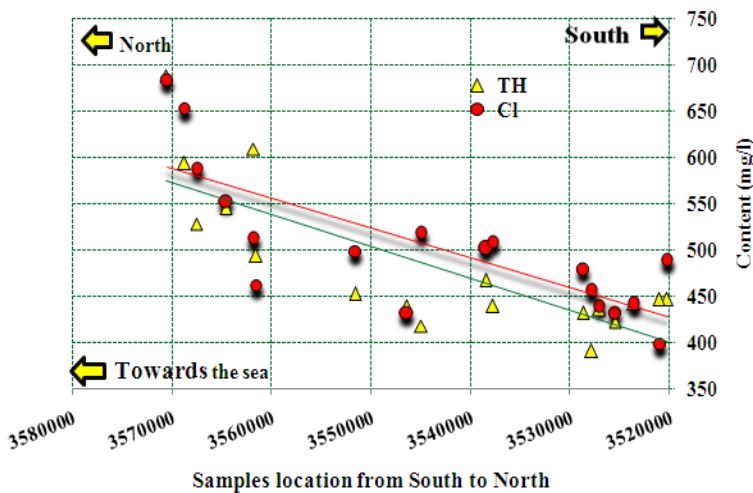


Figure 4:    Variation of Cl mg/l and TH with distance from South to North.

Table 2:    The summary of the hydrochemical analyses result of ground water samples, after [10].

| Parameter | TDS mg/l | $CaCO_3^-$ mg/l | $Na^+$ mg/l | $K^+$ mg/l | $Mg^{2+}$ mg/l |
|---|---|---|---|---|---|
| Maximum | 2700.86 | 840.29 | 508.0 | 120.0 | 86.44 |
| Minimum | 1451.5 | 500.18 | 236.0 | 48.0 | 28.81 |
| Average | 1700.86 | 598.75 | 288.44 | 65.78 | 66.04 |

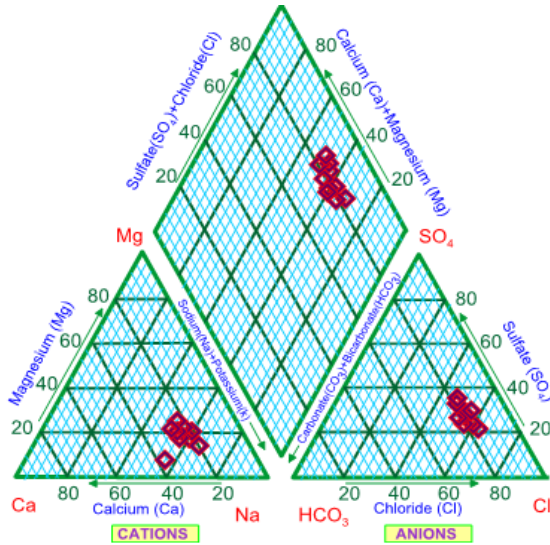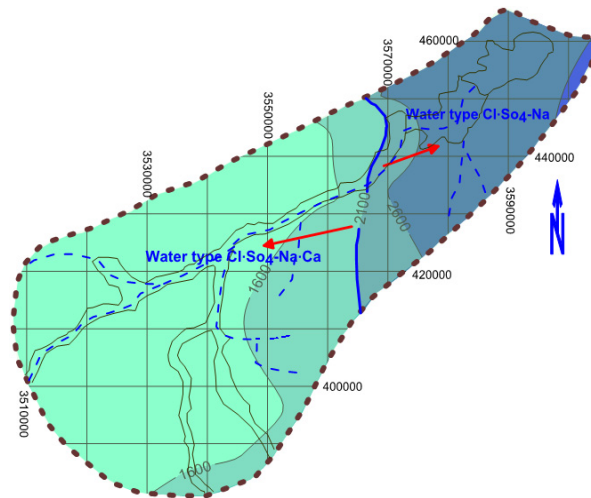| Parameter | $Ca^{2+}$ mg/l | $HCO_3^-$ mg/l | $Cl^-$ mg/l | $SO_4^{2-}$ mg/l | pH | T.Cº. |
|---|---|---|---|---|---|---|
| Maximum | 216.05 | 468.63 | 684.61 | 658.52 | 7.35 | 73 |
| Minimum | 96.02 | 253.84 | 399.88 | 260.12 | 7.01 | 56 |
| Average | 129.43 | 304.59 | 503.77 | 339.38 | 7.21 | 64.3 |

Figure 5:   Groundwater sample plotted in Piper diagram.



Figure 6:   EC (µS/cm) contour map which represents the distribution of the groundwater types for the deep aquifer.

## 3.1 Drinking water quality

Groundwater quality assessment was carried to determine its suitability in terms of drinking purposes, the hydro chemical analysis of groundwater samples is presented in, table 3. The physical and chemical parameters of the analytical results of groundwater were compared with [12–14].

The concentration of total dissolved solids exceeds the desirable limit of 1000 mg/L in all samples. $Na^+$ values exceed the desirable limit of 200 mg/L in all samples. $Cl^-$ values exceed the desirable limit of 250 mg/L in all samples. And also $So_4$ desirable limit of 400 mg/L in all samples. However, the concentration of Ca, and K were found few values exceed the desirable limit. While the $Mg^{2+}$, $HCO_3^-$ and pH values were indicative of suitable groundwater for drinking and domestic applications. It is recommended that water drawn from such sources should be purified of excess elements well before being used for drinking and other. It also should be excluded wells numbered as 1, 3, 4, and 6 from the domestic and drinking use.

Table 3:    GW minimum specifications of Wadi Baye compared with maximum permissible limits prescribed by [12–14].

| Parameter | **Wadi Bayi** GW samples | Maximum permissible limits | | | No of sample. over limit |
|---|---|---|---|---|---|
| | | LDWS [12] | WHO [13] | U.SEPA [14] | |
| | Min–Max | Maximum | Maximum | Maximum | |
| TDS mg/l | 1452–2701 | Up to 1000 | 1000 | 500 | All |
| pH | 7.01–7.35 | 6.5–8.5 | 6.5–9.5 | - | Nil |
| $K^+$    mg/l | 48–53.0 | 40 | - | 20 | All |
| $Na^+$   mg/l | 236- 508 | 200 | 200 | 200 | All |
| $Mg^{2+}$  mg/l | 29–115.3 | 150 | 50 | 125 | Nil |
| $Ca^{2+}$  mg/l | 96–216.1 | 200 | 200 | 200 | 1 (6) |
| $Cl^-$  mg/l | 394–823.4 | 250 | 250 | 250 | All |
| $So_4^{2-}$   mg/l | 260–658 | 400 | 250 | 250 | 3 (1, 3, 4) |
| $HCO_3^-$ mg/l | 254–468 | - | - | 500 | Nil |
| TH mg/l | 500.2–760.8 | 500 | 500 | - | All |

(1, 3, …) = well number.

## 3.2  Quality criteria for irrigation purpose

Sodium and EC play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure [18]. The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth. Sodium adsorption ratio (SAR), ratio of dissolved sodium as %Na, or residual sodium carbonate (RSC) might equally be used for calculating a value which can be utilized as an index of ground water suitability for irrigation purposes [19].

### 3.2.1  Total Dissolved Solids (TDS)
Salts of calcium, magnesium, sodium, potassium present in the irrigation water may prove to be injurious to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration. The TDS values of the study area ranged from 1452 to 2701 mg/L. They are generally

very high values and according to Robinove *et al*. [20], it can be classified (88.8%) of the water samples as good to injurious for irrigation and 11.2% as unsatisfactory for irrigation, table 4.

### 3.2.2  Sodium Absorption Ratio (SAR)

SAR is the most commonly used for evaluating groundwater suitability for irrigation purposes [20]. It is normally expressed as Na content or alkali hazard which is normally expressed in SAR [21]. SAR is expressed as follows, [22]:

$$SAR= Na^+/\sqrt{(Ca^{+2} +Mg^{+2})/2} \tag{3}$$

where the ion concentrations are expressed in meq/l, as shown above, SAR values in irrigation waters have a close relationship with the extent to which Na is absorbed by soils. If water used for irrigation is high in Na and low in Ca, the ion exchange complex may become saturated with Na, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. The total concentrations of soluble salts in irrigation water can be classified as low (S1: < 10), medium (S2: 10-–8), high (S3: 18–26) and very high (S4: > 26) [22]. The zones (S1–S4) have the value of EC less than 250 µS/cm, 250-750 µS/cm, 750-2250 µS/cm and more than 2250 µS/cm respectively. The US salinity lab's diagram [1] is used widely for rating irrigation waters, where SAR is plotted against EC. The analytical data plot is shown in fig. 7.
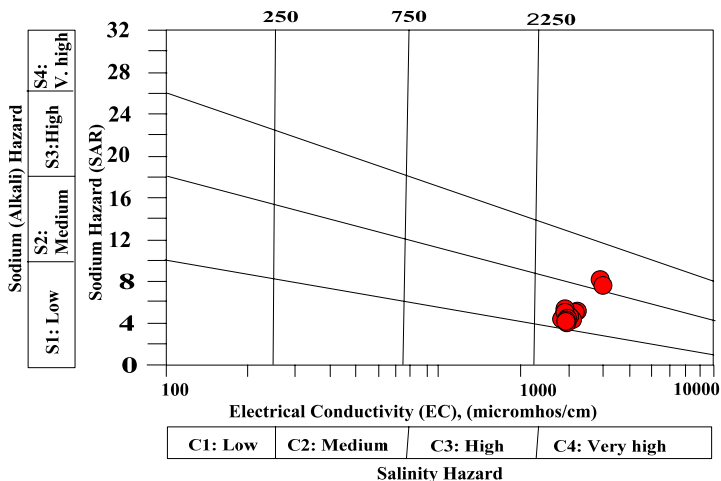


Figure 7:    Salinity diagram of groundwater samples from the study area.

The SAR values range between 4.15 and 8.23 in the study area, where 11% of samples fall in C4-S3 classes and 89% of samples fall in C4-S2 classes of USDA. The diagram in fig. 7 indicates very high salinity/ high sodium, and very high salinity/medium sodium type, respectively.

### 3.2.3  Soluble Sodium Percentage

Sodium Percentage (Na%) is the ratio of Na in epm in water to total cations epm multiplied by 100. Irrigation water with Na% > 60 may result in accumulation and possibly a deterioration of soil structure, infiltration, and aeration [23]. The values of collected water samples ranged from 60.1 to 72.2% with an average 63.9. The Na% and EC is important to categorize groundwater samples with respect to suitability as irrigation water. Wilcox [24] used percentage sodium and electrical conductance in evaluating the suitability of groundwater for irrigation. Wilcox diagram showing the position of the water samples is represented by fig. 8. The diagram illustrates that 11%, of the samples fall in the field of unsuitable and 89% fall in the field of doubtful to unsuitable for irrigation, table 4.
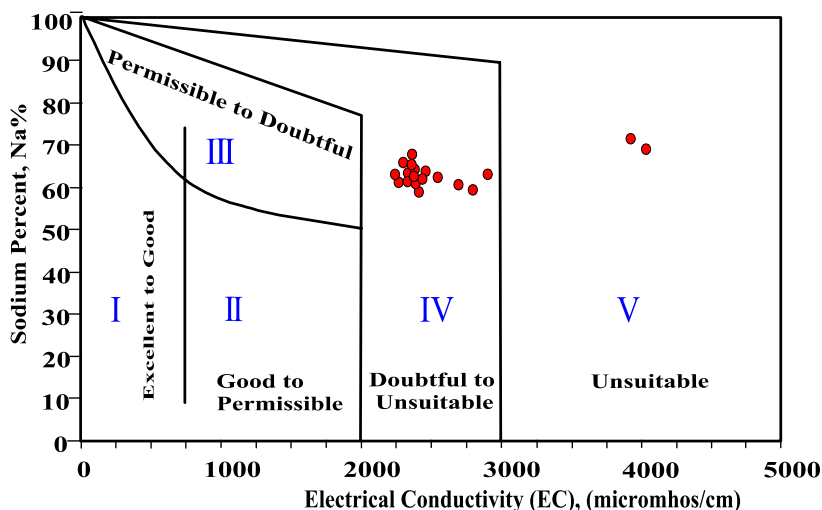


Figure 8:    Position of water samples on the Wilcox plots.

### 3.2.4  Residual Sodium Carbonate (RSC)

Residue Sodium Carbonate (RSC) is a valuable parameter that has a great influence on the suitability of irrigation water [25]. The RSC significantly influence the pH, EC and SAR of irrigation water. The samples of the study area have RSC ranged from -9.31 to -5.13. With respect to RSC values, all the groundwater samples of the study area can be classified as "Good" for irrigation since all the values are less than 1.25 (table 4).

### 3.2.5  Permeability Index (PI)

The soil permeability is affected by long term use of irrigation water. It is influenced by sodium, calcium, magnesium and bicarbonate contents of soil. Doneen [26] has evolved a criterion for assessing the suitability of water for irrigation based on Permeability Index (PI):

$$PI = [(Na^+ + \sqrt{HCO_3^-}) / (Na^+ + Ca^{+2} + Mg^{+2})] \times 100 \qquad (4)$$

where all, ionic concentrations are expressed in (epm) [26]. The samples of the study area have PI ranged from 54.6 to 67.7%. With respect to PI values, all the groundwater samples in the study area can be designated as class III (40–80%) implying that the water is injurious quality for irrigation purposes with 75% or more of maximum permeability (table 4).

Table 4: Table Classification of irrigation water in Kiklah aquifer.

| Param. | Min | Max | Mean | Category | No of Sample | Water Class |
|---|---|---|---|---|---|---|
| **Na%** | 60.1 | 72.2 | 63.9 | < 20 | Nil | Excellent |
| | | | | 20–40 | Nil | Good |
| | | | | 40–60 | Nil | Permissible |
| | | | | 60–80 | **18** | Doubtful |
| | | | | > 80 | Nil | Unsuitable |
| **EC μS/cm** | 2250 | 4033 | 2628 | < 250 | Nil | Excellent |
| | | | | 250–750 | Nil | Good |
| | | | | 750–2000 | Nil | Permissible |
| | | | | 2000–3000 | **16** | Doubtful |
| | | | | > 3000 | **2** (1, 3) | Unsuitable |
| **SAR** | 4.15 | 8.23 | 5.13 | < 10 | **18** | Excellent |
| | | | | 10–18 | Nil | Good |
| | | | | 18–26 | Nil | Fair |
| | | | | > 26 | Nil | Poor |
| **RSC** | -9.3 | -5.1 | -6.9 | < 1.25 | **18** | Good |
| | | | | 1.25–2.50 | Nil | Medium |
| | | | | > 2.50 | Nil | Bad |
| **PI%** | 54.6 | 67.7 | 59.9 | < 20 | Nil | Excellent |
| | | | | 20–40 | Nil | Good |
| | | | | 40-80 | **18** | Injurious |
| | | | | > 80 | Nil | Unsatisfactory |
| **TDS (mg/l)** | 1452 | 2701 | 1700 | < 1000 | Nil | Excellent |
| | | | | 1000–2000 | **16** | Good |
| | | | | > 2000 | **2** (1, 3) | Injurious |
| **MAR%** | 18.03 | 52.7 | 46.1 | < 50 | **13** | Suitable |
| | | | | > 50 | **5** (2,9,11,14,15) | Unsuitable |

### 3.2.6 Magnesium Adsorption Ratio (MAR)

Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more saline [28]. The values of the magnesium adsorption ratio of deep groundwater in the study area varies from 18.03% to 52.7% indicating that five wells are above the acceptable limit of 50% [29]. The waters are therefore, 27.8% of the samples considered unsuitable. This is because high magnesium adsorption ratio causes a harmful effect to soil when it exceeds 50%. However, 72.2% of the samples were found suitable for irrigation.

## 4  Conclusions

Groundwater quality of deep artesian groundwater (Kiklah aquifer) in Wadi Baye area, Middle Region, Libya, was analyzed to classify the groundwater into different categories for the drinking and irrigation purposes. The hydrochemistry of major-ions ($K^+$, $Na^+$, $Mg2+$, $Ca^{2+}$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$ was used to constrain the hydrochemical characteristics of the groundwater. The results show that the values of total dissolved solids (< 1452 mg/L), electrical conductivity (< 2250 μS/cm), soluble sodium percentage (60.1 to 72.2%), permeability index (59.6 to 67.7%), residual sodium bicarbonate (< 1.25), sodium adsorption ratio (< 10) and magnesium adsorption ratio varies from (18.03% to 52.7%). The results of hydrochemical analyses also indicate show that the most of water parameters are higher than the maximum standard limits, according to Libyan Standards (1993), WHO (1983) and US Public Health Service (1975). The hydrochemical composition reflects the Cl·SO4-Na·Ca water type is recorded within the Wadi upstream area and another major water type is Cl·SO4-Na. According  to the important constituents' parameters affecting the water quality for irrigation such as the sodium adsorption ratio, sodium percentage ratio, residue sodium carbonate, permeability index  and the magnesium hazard, most of the ground waters are classified as good, doubtful, good, injurious and 72.2% stable for irrigation respectively. In addition, the US Salinity Laboratory diagram illustrates that, most of the ground waters are located in the high salinity and medium sodium hazard zone(C4-S2), while the Wilcox diagram illustrates that 11%, of the groundwater samples fall in the field of unsuitable and 89% fall in the field of doubtful to unsuitable for irrigation.

 In conclusion, overall, the groundwater can be classified with few exceptions as suitable for irrigation under certain conditions such as good management, good drainage system, deep ground to keep soil salt balance and highly salt tolerant plants. However, it is recommended that water drawn from such sources should be purified of excess elements well before being used for drinking and other domestic uses. It also should be excluded wells numbered as 1, 3, 4, and 6 from the domestic and drinking use. Also it is recommended that the water should be not used directly after pumping.

## Acknowledgements

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