# *ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF GROUNDWATER IN EN NUHUD BASIN-SUDAN*

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## *1. ABSTRACT*

Physico-chemical characteristics of groundwater are measured in situ in water samples from existing wells and water samples were collected for subsequent chemical analysis. Generally the water in En Nuhud Basin is characterized by low mineralization with respect to the WHO and Sudanese regulation limits for drinking water; anomalous values were observed at Abu Dagal in the western part which interpreted as related to high clay content within the saturated zones. The concentrations of the different chemical constituents usually decrease inwards in a manner indicates recharge potentials from the boundaries and from surface drainage within the basin area. The dominant types of water quality in the study area are: [Ca (Mg) $Hco_3$], [Ca (Mg) Cl($No_3$, $So_4$)] and [Na HCO3] type. In view of the quality tolerances for industrial process, some water samples not suit many of these processes; due to relatively high alkalinity, EC and acidity (low PH). On the other hand groundwater of En Nuhud Basin is quite satisfactory for irrigation use; limit exceptional case concerns Gabreddar- Abu Dagal Area; where high to very high salinity occur.

***Key words:*** *En Nuhud Basin, groundwater, Physico-chemical, regulation limits, quality tolerances.*

## *2. INTRODUCTION*

Chemical composition and physical characteristics of groundwater depends on many factors; time of circulation in the rocks, composition of these rocks and physical conditions surround the environment extended from the atmosphere to the point of abstraction. Groundwater contains a lot of dissolved minerals; some of these minerals are essential for good health; others if too abundant may cause a taste or odor or healthy problems (Driscoll, 1987).

The study area is situated in west-central Sudan, within Kordofan Region, covering an area of about 20,466 km. It is bounded by longitudes $28^o\ 15^'$ and $30^o\ 00^'$, and latitudes $12^o\ 22^'$ and $13^o\ 28^'$ (Fig. 1). The land surface is a gently undulated plain, mostly covered by sand sheets and low dune complex, and it is punctuated by some elevated rock outcrops. The altitude of the surface generally ranges between (538) and (660) meters above the mean sea level. Coarse dendritic drainage system dominates over the area, and there is a lack of standing water. Groundwater is the only source of water supply in the study area. The economy of the province mainly based on pasture and dry farming. Many studies were conducted in the area such as Rodis et al (1964), Karkanis, (1966), Ginaya, (2001) and Ginaya, (2011). Most of these studies include a statement on the subject of water quality.

## *3. OBJECTIVES*

Despite that the previous studies approved the groundwater quality in En Nuhud basin, and whereas the water quality may change with time, this study aimed to update the groundwater characteristics, and to reveal the impact of the hydrogeological conditions in groundwater quality.

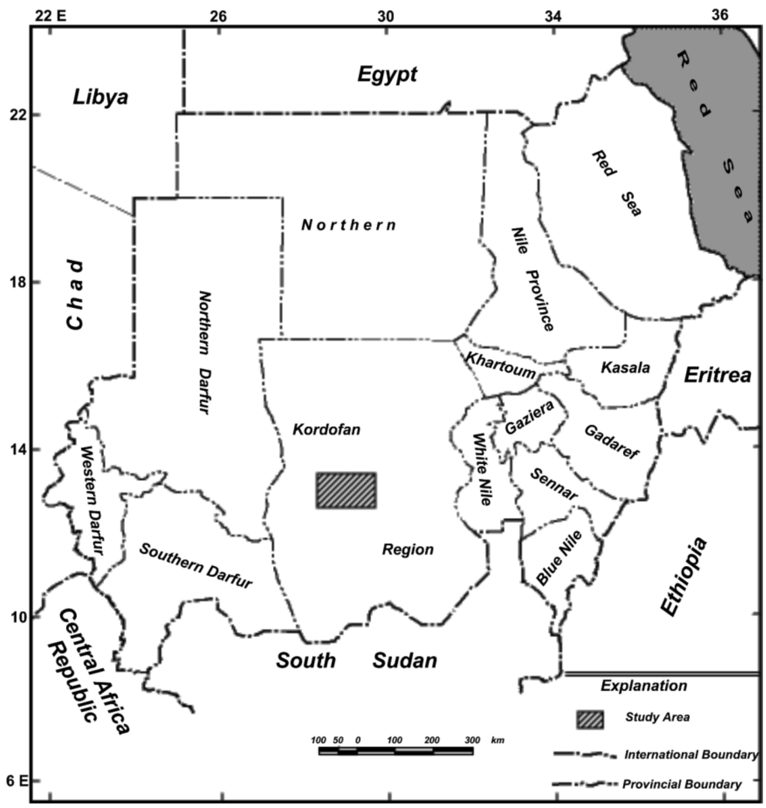


***Fig. (1): Location map of the study area.***

## *4. METHODOLOGY*

Some physico-chemical characteristics of groundwater in the study area were measured in situ in fresh water samples from existing wells. These characteristics include temperature "T", hydrogen ion concentration "PH", electrical conductivity "EC" and total dissolved solids "TDS". Measuring these characteristics in situ aims to prevent the effects of the atmosphere and other elements on them.

Water samples were collected under the above conditions for later chemical analysis. Standard sampling techniques were used to collect the water samples; a volume of (500 ml) is collected for each well, in cleaned polythene bottles, tightly sealed and labeled. A number of 26 water samples were used in chemical analysis considering the spatial distribution of these samples. Analysis includes the concentrations of major cations and anions, and hardness and alkalinity are then calculated. The concentrations of the dissolved materials are defined under the SI system as milligrams per liter (mg/l), EC in µs/cm and temperature in centigrade. The physico-chemical characteristics of water samples were assessed according to the WHO and Sudanese standards for drinking water. Also the chemical characteristics are assessed according to the quality tolerances for industrial and agricultural process. The analysis was performed in the laboratory of Groundwater Research Administration-Khartoum.

## 5. GEOLOGY

Four geological units underlie the area, those are: Basement Complex, Mesozoic Formations, and Pleistocene and recent deposits (Strojexport, 1976).

### *5.1 Basement Complex*

Basement complex is the oldest rock unit, most of which is of Precambrian age, and includes metamorphosed and folded schists and gneisses of sedimentary and volcanic origin as well as syn-orogenic or late orogenic granitic emplacements and basic and ultrabasic bodies (Vail, 1978). Gneisses and migmatites form the dominant rocks around the study area and crop out at many places; schists and slates are shown at the western and southwestern parts; quartzites are wide spread an crop sometimes as sharp ridges and cliffs; granites and syenites intrusions have been evidenced by drilling west of En Nuhud town (Strojexport, 1976).

### *5.2 Mesozoic Formations*

The Mesozoic Formations in Kordofan region is represented by the Nubian Sandstone Formation (Rodis et al, 1964), which is believe to be laid down in subaqueous environment "marine or continental" (Whiteman, 1971). For the age, Early cretaceous (Whiteman, 1971) and Upper Jurassic/ Cretaceous Harms et al (1990) are the common.

The common lithology is poorly sorted, coarse to medium grained sandstones and conglomerates containing quartz pebbles and mud flakes. Mudstones and clays may form thick lenses, but they are usually thinly bedded (Vail, 1978). Cement is clayish to silty in sandstones and clayish to sandy in conglomerates. Borehole data show thickness more than 410 m for the Nubian Sandstone Formation, (Strojexport, 1972).

### 5.3 Cenozoic Formations

Laterite deposits are developed extensively on the Nubian Sandstone rocks as a product of weathering of the host rocks under tropical climatic conditions in the Early to Middle Tertiary time Rodis etal (1964). They occur at the western part of the study area (Whiteman, 1971). The laterite consists of hematitic and limonitic ironstones and ranges from a few meters to as much as 15 m thick.

Pleistocene and Recent Formations which Known as Superficial Deposits include Qoz sands, clay plains, hill wash deposits and alluvial deposits.

Qoz sands form gently-rolling sheets and fixed dunes and consist of well rounded quartz grains (Whiteman, 1971) with thickness as much as 45 m thick (Rodis et al, 1964). Grabham (1935) derived these deposits from the weathering of the Basement granites; Edmond (1942) ascribed them to the weathering of the Nubian Sandstone.

Clay plain deposits (cotton soil) are uniform, with clay content from 50 to 60 per cent and very little coarse material (Strojexport, 1976). Wash deposits occur along foot slopes of elevated rocky areas and built dominantly by unsorted coarse-grained clastic material, (Strojexport, 1976). Alluvial Deposits as unconsolidated sands, clays and gravels are found along water courses.

## 6. RESULTS

### *6.1 Presentation and interpretation*

Appendix (1) shows the results of the physical measurements and chemical analysis of the collected water samples; table (1) summarizes these physico-chemical properties. The results show normal values for the physical properties, with some exceptions in the EC. Temperature (range 22.9 - 34.61) has no regular distribution over the area except that the relatively high

***Table (1): Summary for the physico-chemical properties*** *(mg/l)*

| # | *Property* | *Range* | *Mean* | *Anomalous values* |
|---|---|---|---|---|
| 1 | **T** $C^o$ | 22.9- 34.6 | 28.50 | - |
| 2 | **EC** *µs/cm* | 124- 582 | 311.10 | 1155- 2540 |
| 3 | **PH** | 6.7- 8.5 | 7.45 | - |
| 4 | **TDS** *mg/l* | 68- 494 | 202.21 | 808.5- 1524 |
| 5 | **T.H** *mg/l* | 60- 310 | 172.64 | 624- 826 |
| 6 | **T.Alk** *mg/l* | 65- 390 | 179.81 | - |
| 7 | **Ex.Alk** *mg/l* | 0- 191 | 38.87 | - |
| 8 | $HCO_3^-$ *mg/l* | 0- 756 | 166.45 | - |
| 9 | $CO_3^{--}$ *mg/l* | 0- 18 | 2.08 | - |
| 10 | $SO_4^{--}$ *mg/l* | 0- 21 | 6.85 | 51- 385 |
| 11 | $Cl^-$ *mg/l* | 0.41- 71 | 17.55 | 276.9- 320 |
| 12 | $NO_3^-$ *mg/l* | 0- 62 | 15.9 | - |
| 13 | $NO_2^-$ *mg/l* | 0- 0.39 | 0.044 | - |
| 14 | $F^-$ *mg/l* | 0- 1.70 | 0.472 | - |
| 15 | $NH_3^+$ *mg/l* | 0 -0.04 | 0.0056 | - |
| 16 | $Na^+$ *mg/l* | 1.1- 64.9 | 12.14 | 213 |
| 17 | $Ca^{++}$ *mg/l* | 14- 78.4 | 36.39 | 120- 160 |
| 18 | $Mg^{++}$ *mg/l* | 5.8- 46.2 | 20.58 | 104- 150 |

values (31.5- 34.6 $C^o$) are compared to the southern half of the basin which can be due to relatively deep saturated zones. Regard to PH (6.7- 8.5) it is found that about 80.5% of the samples indicate alkaline solutions, 11.5% are acidic and 8% are neutral, the only note about the PH is that the acidic solutions are compared to the western and northwestern boundary of the basin. Concerning TDS (68- 407.4) it shows anomalous values in Gabreddar (808.5) and Abu Dagal (1210- 1524) in the western part.

Generally the distribution of the chemical constituents over the area show good resemblance. The contours of equal concentrations usually stretch in the east-west direction and graded in inwards or outwards along north-south axis, closed areas of high or low concentrations often exist within the area.

Relatively high saline water is marked in the northern half of the study area (Fig. 2). Bicarbonates usually decrease inwards (Fig. 3) with agreement to general flow directions (Fig. 4); as indictor to fresh water or recharge areas. On the other hand sulphates, chloride and nitrate usually agree with the bicarbonates (decrease inwards) (Figs. 5, 6 and 7); this situation disagrees with the general rule of the chemical evolution of groundwater. The un-normal distribution of these anions may be due to recharge potentials. The very low concentrations of sulphates (0.4- 1.4 mg/l) in the west and the southwest can be justified in the same manner.

Cations concentrations also show the same distribution as anions in that they generally decrease inwards, and in that the relatively high mineralized water is in the north (Figs. 8, 9 and 10). In general the groundwater mineralization is clearly affected by the recharge potentials from the surface water in the center of the area (Fig. 11).

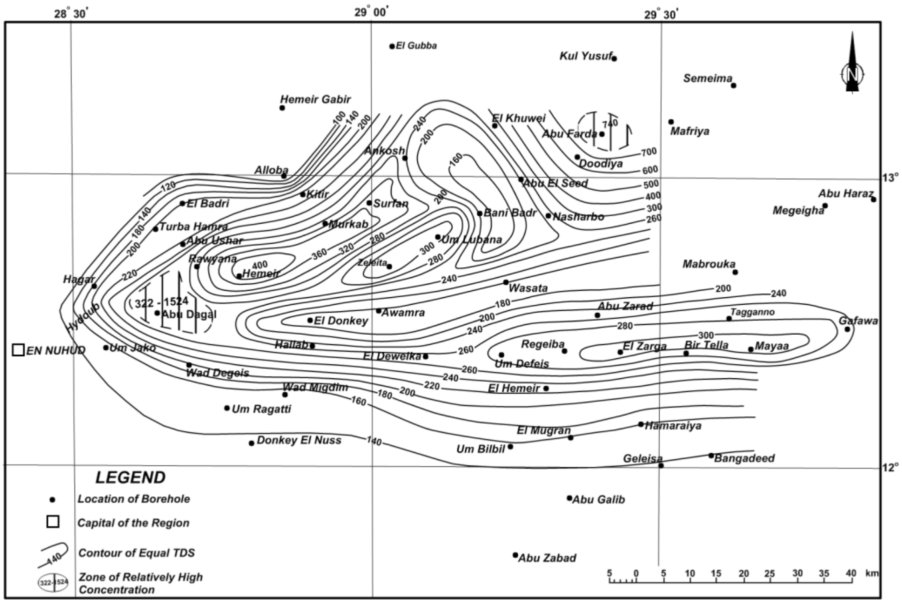


*Fig. (2): Total Dissolved Solids in Groundwater*

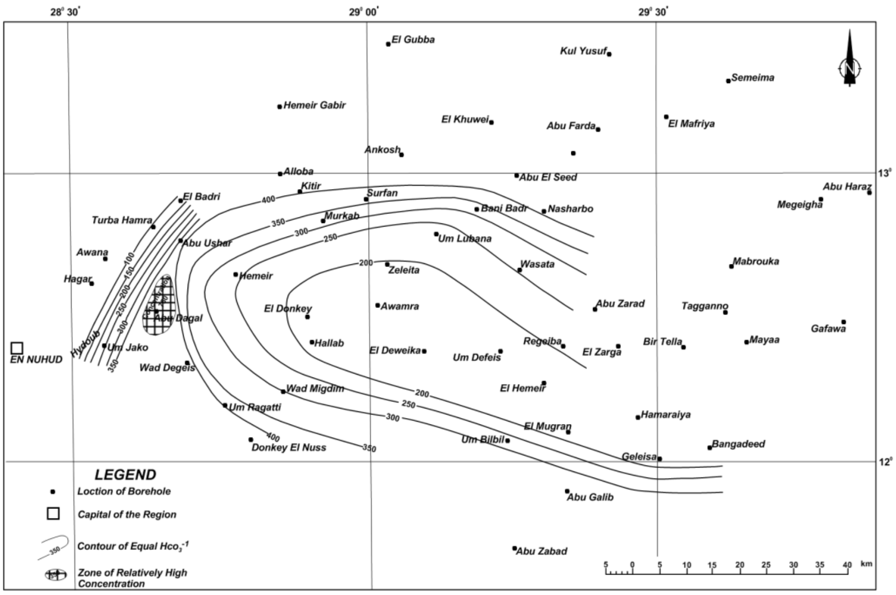


*Fig. (3): Bicarbonate Concentrations in Groundwater*

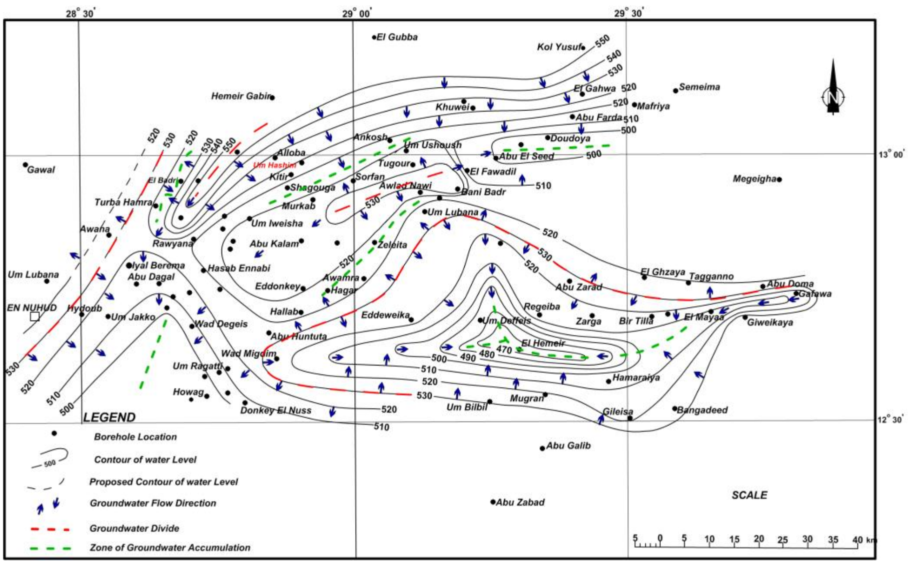


*Fig. (4): Water Table Contours and Groundwater Fluxes*

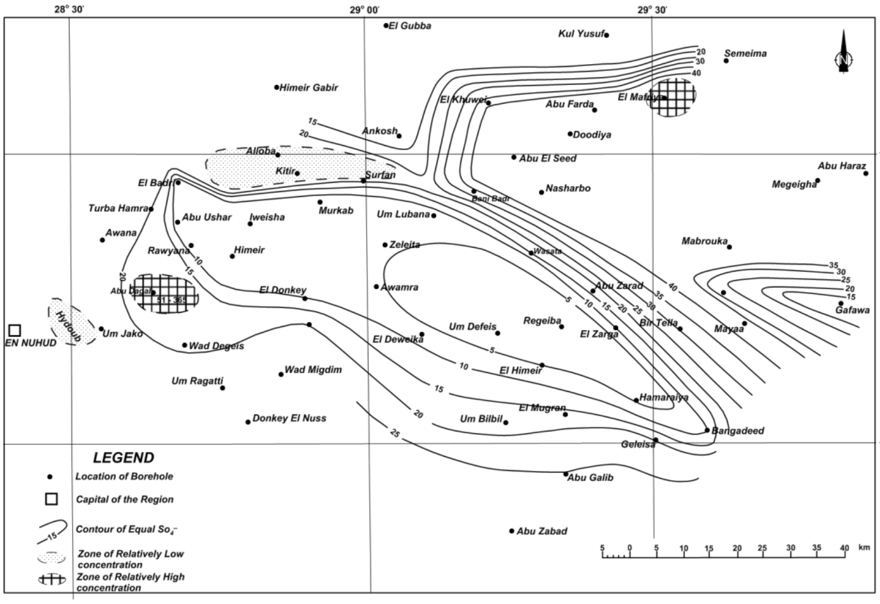


*Fig. (5): Sulphate Concentrations in Groundwater*

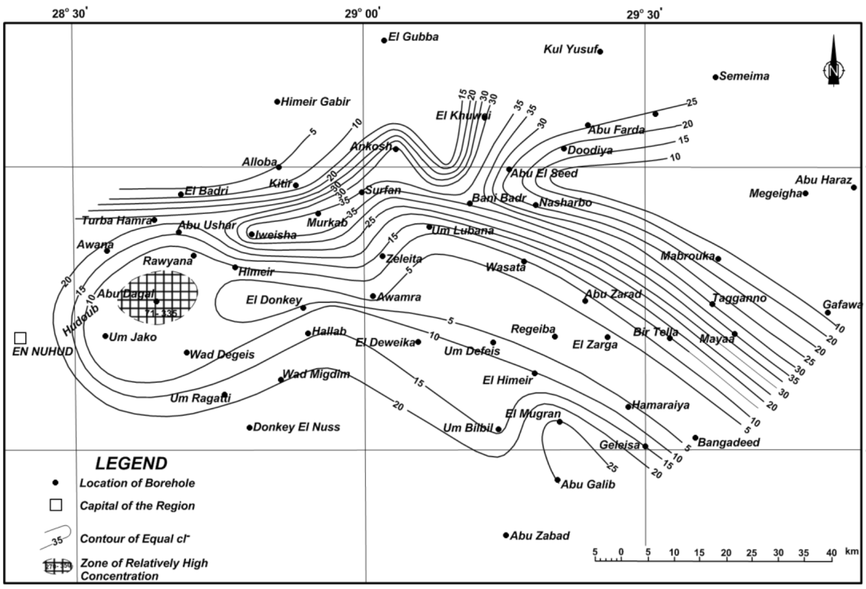


*Fig. (6): Chloride Concentrations in Groundwater*

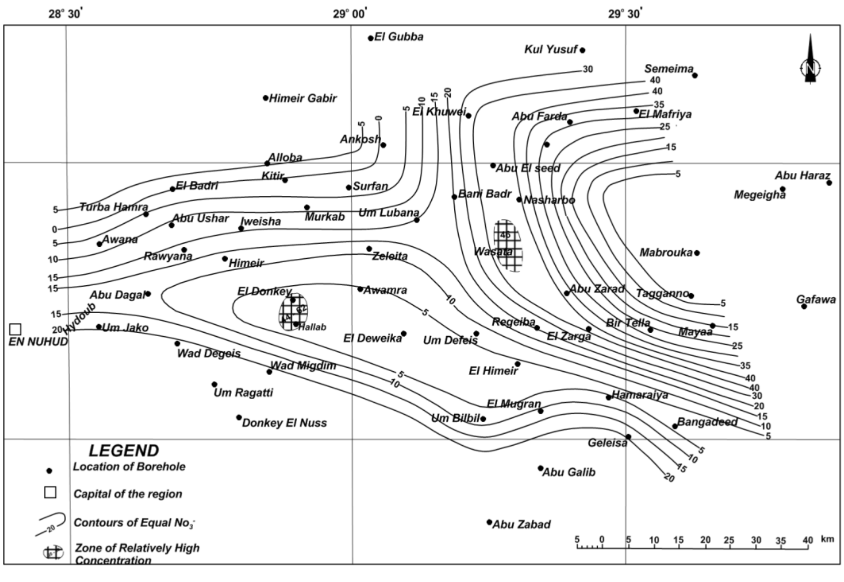


*Fig. (7): Nitrate Concentrations in Groundwater*

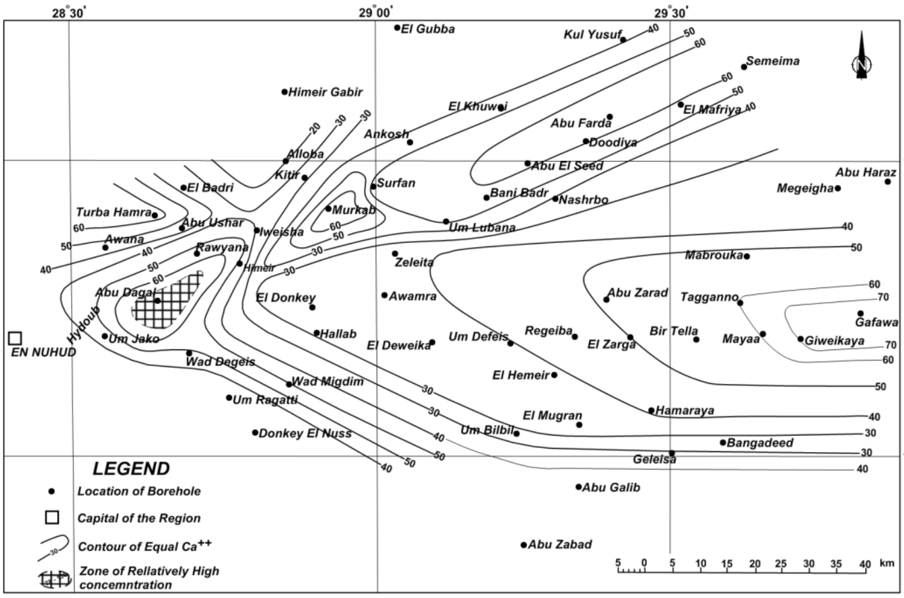


*Fig. (8): Calcium Concentrations in Groundwater*

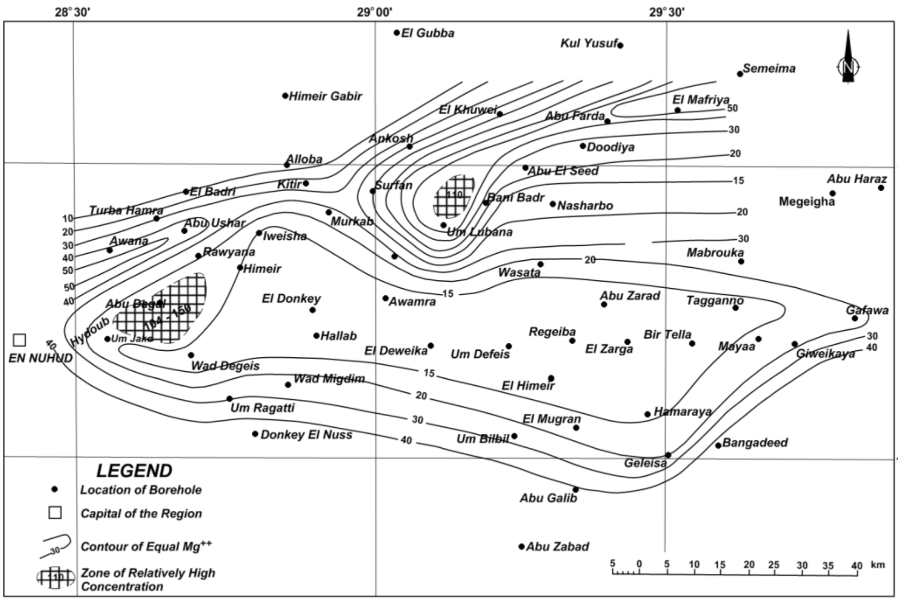


*Fig. (9): Magnesium Concentration in Groundwater*

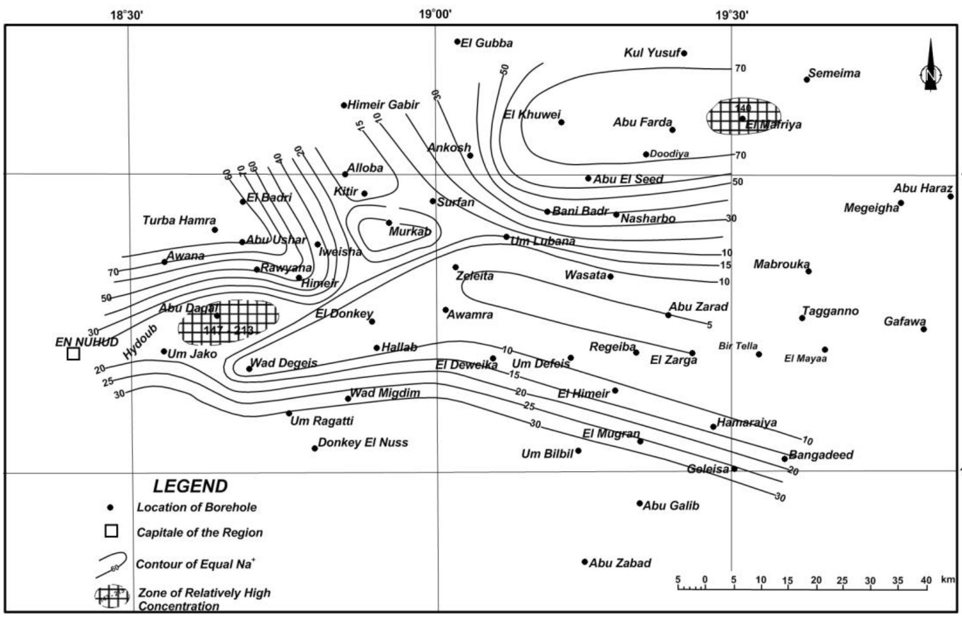


*Fig. (10): Sodium Concentrations in Groundwater*

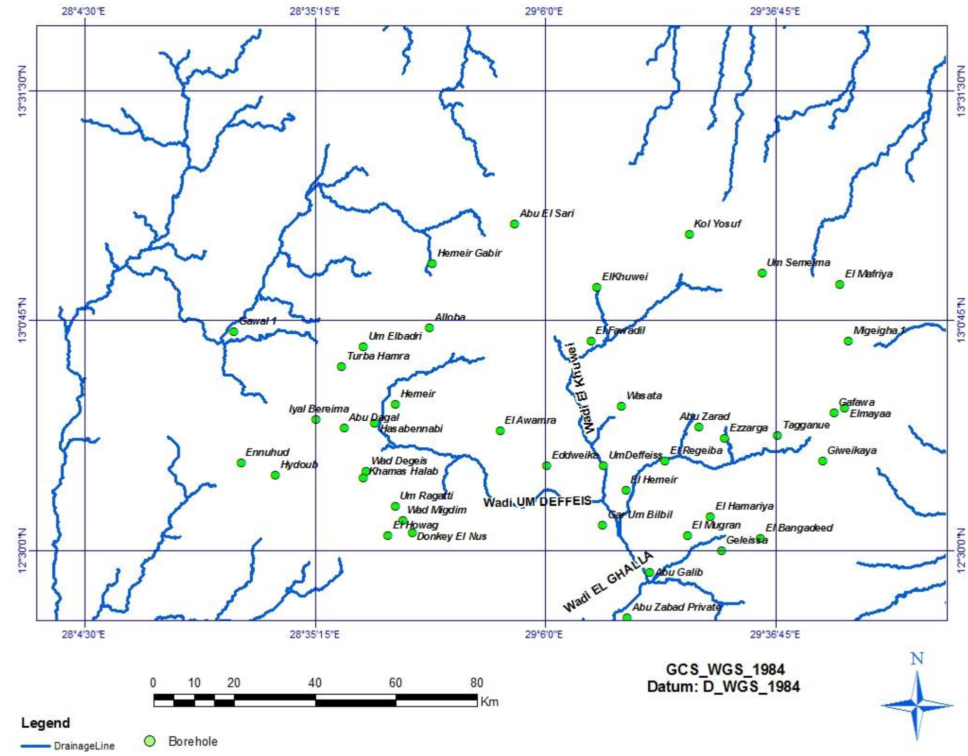


***Fig. (11): Drainage in the Study Area** (based on landsat image of the study area)*

Low mineralization in water of En Nuhud basin can be justified as due to insoluble components of aquifer materials, where the main aquifers in the area are conglomerates and sandstones which consist of the durable quartzitic grains. On the other hand anomalous high mineralization is shown in the western part (TDS: 808.5- 1524 mg/l) and in the northeast (TDS: 740 mg/l). These anomalous concentrations are clearly related to presence of high clay content on the saturated zones or due to contacting Basement rocks; a test on 10 boreholes in these areas show that about 60% of the aquiferous zones with clay content and/ or contact the weathered Basement. Presence of durable aquifer material and/ or high recharge potentiality may justify the case of very low mineralization at the northwestern boundary of the basin (TDS: 68.2 mg/l).

Some substances are not included in the analysis of this study are extracted from previous analysis conducted in the period 2007- 2008, which are copper, iron, Potassium and phosphate (table, 2).

***Table (2): Concentrations of Some Substances from Previous analysis (2007- 2008)***

| # | Substance | Range of concentration *mg/l* |
|---|---|---|
| 1 | Potassium (**$K^+$**) | 1.00- 6.38 |
| 2 | Copper (**$Cu^{++}$**) | 0.00- 0.70 |
| 3 | Iron (**$Fe^{++}$**) | 0.00- 0.59 |
| 4 | Phosphate (**$Po_4$**) | 0.00- 0.02 |

***Classification of Groundwater Quality:***

Piper plot is used to visualize the chemistry of groundwater samples. It is used for representing and comparing water quality and reveals the similarities and difference among water samples. Water samples are grouped as confined and unconfined aquifer samples before they represented in piper plot (Fig. 12) to correlate water quality to the hydrogeological conditions.

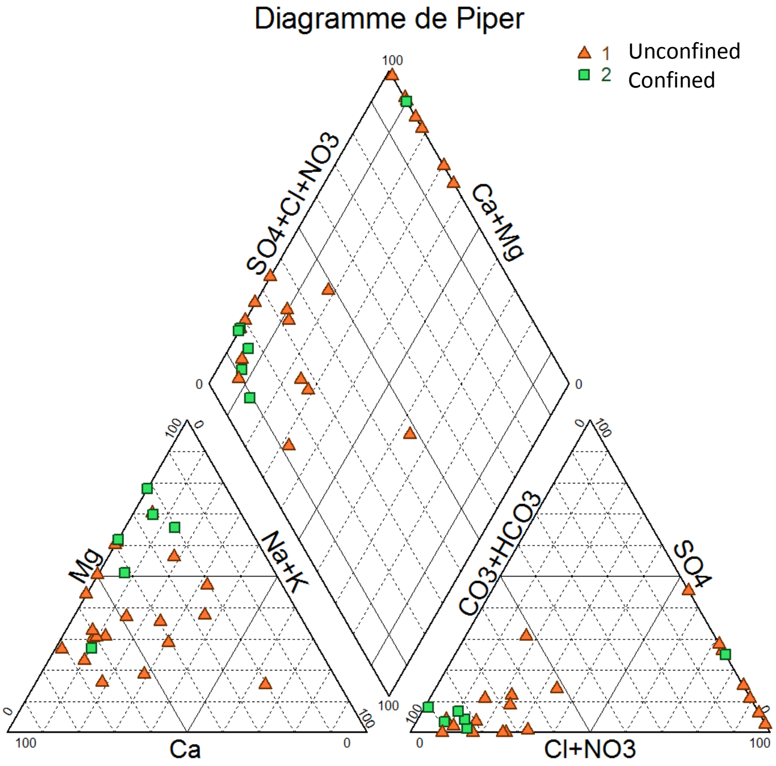


***Fig. (12): The representation of Groundwater Samples in Piper Diagram***

Accordingly groundwater quality is determined and classified; three types are obtained:

1- Na HCO3
2- Ca (Mg) $Hco_3$
3- Ca (Mg) Cl($No_{3,}$ $So_4$)

The dominant type of water quality in the study area is the [Ca (Mg) $Hco_3$] where (19) samples of the total (26) belong to this class. In the second order is the [Ca (Mg) Cl($No_{3,}$ $So_4$)] which represented by (7) samples. The [Na HCO3] class is represented by only one sample.
The dominance of bicarbonate water type manifests existence of fresh groundwater. When appreciable number of the samples is from the center of the basin, then the previously mentioned deduction about the recharge from the surface water bodies within the basin can be supported.

From piper plot it is shown that calcium and magnesium dominate over the sodium, and chlorides and nitrates dominate over the sulphates. Also it is noticed that all samples from confined aquifers are belong to the [Ca (Mg) $Hco_3$] water type except one sample (Awamra sample). For water from unconfined aquifer (13 samples) belong to [Ca (Mg) $Hco_3$] type, six samples belong to [Ca (Mg) Cl($No_{3,}$ $So_4$)] type and only one is of [Na HCO3] type.

**Water Quality for Drinking Purposes:**

Water quality and its suitability for drinking water is determined based on the maximum contaminant levels, at which no adverse health effects are known to exist. The contaminant levels permitted under the primary regulations usually based on the individual consumption of water per day, because the potential effects of contaminants in drinking water vary according to the amount of water ingested, which differ from regime to another.

On the whole the physico-chemical properties of groundwater in En Nuhud basin satisfy the WHO and Sudanese regulations for drinking water (Appendix 2). Exception is found in Abu Dagal in the western part of the area. Concentrations of individual elements in groundwater samples are mostly within the stated limits. Regarding Abu Dagal area anomalous values exceeding the permissible limits are shown on EC (2420 and 2540 *μs/cm*), TDS (1524 mg/l), T.H (624 mg/l), $So_4$ (365 mg/l), $Cl^-$ (276.9-320 mg/l) and $Na^+$ (213 mg/l).

Special attention is paid to nitrate and fluoride due to their healthy effects when exceeding the permissible limits. The relatively High concentrations of nitrate are found at Khamas in the western part of the basin (43- 62.4 mg/l) which slightly exceed the limits. Relatively high concentrations are found the central (Wasata: 48 mg/l) and eastern (Saata Abdelrazig: 37 mg/l) parts, but all are within the permissible limits.

Nitrogen compounds in water in the study area may be derived from two main sources:

- Legume plants that fix atmospheric nitrogen and transfer it to the soil, where it may be partially removed in solutions by downward percolating soil water.
- Soil nitrogen derived from decomposing plant debris and animal wastes.

These proposed sources can be acceptable in view of wide spread cultivated peanuts and the dense livestock population in the study area.

According to United States Environmental protection Agency "EPA", (1975) the usual recommended content of fluoride is 1.4- 2.4 mg/l depending on the local temperature regime (Appendix, 3) that related to accumulation within the daily water consumption (Driscoll, 1987). Based on the EPA temperature regime and the average temperature in the study area, the fluoride content at Gar Um Bilbil (1.7) may cause some problems, at least seasonally; excessive fluoride causes mottling of tooth enamel or teeth brittleness, especially in children.

**Water Quality for Industrial Purposes:**

In spite of the above facts some quality problems may be exist in groundwater of En Nuhud Basin in respect to industrial tolerances. Driscoll (1987) stated that water with hardness less than 50 mg/l is considered to be soft, and water with hardness above this limit especially when it exceeds 100 mg/l may cause many problems such as scaling or staining in steam boilers, well screens, pipes, plumbing fixtures, and many other industrial and municipal uses.

According to the statement of Driscoll (1987), all sampled water can be considered as hard water. Also in view of the quality tolerances for industrial process, the alkalinity property of the sampled water not suit many of these processes where many of them require water with alkalinity less than 150 mg/l. As the same some water samples can be considered as corrosive; those have relatively high EC and/ or low PH "acidic" (Driscoll 1987). These cautions are stated in the case when industrial activities are to be planned in the area, where accurate assessment for water quality is needed.

***Water Quality for Irrigation Purposes:***

Water quality as well as soil types and cropping practices play an important role in successful irrigation. The tolerance for certain elements must be determined before specific crops can be selected. Appendix (4) list some substances and qualities that are important when evaluating a particular water for irrigation purposes.

The suitability of groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. Irrigated water influenced by sodium, calcium, magnesium and bicarbonate contents; affects the permeability of soil after a long-term use (Nagaraju et al., 2006). High salinities might pose problems in poorly drained soils due to the prospects of salt accumulations over long periods of application, Umar (2001); affects soil structure permeability and aeration, which indirectly affects plant growth, Mohan et al. 2000). Excess salinity reduces the osmotic potential of plants and thus interferes with the absorption of water and nutrients from the soil, Umar (2001). A high value of sodium may also damage sensitive crops because of sodium phytotoxicity (Goel 1997). Appendix (5) gives some recommended concentrations for trace elements in irrigation waters.

In this study the physico-chemical quality of groundwater for irrigation purposes is highlighted by salinity and sodium (alkali) hazards. The excess sodium or limited calcium and magnesium are evaluated by SAR; the salinity content is measured in terms of specific electrical conductance (Fig. 13).

With regard to salinity most groundwater samples (88.5%) fall in class 1 (low) and class 2 (medium); only one sample (Gabreddar) in class 3 (high) and two (Abu Dagal) in class 4 (very high). From the SAR index all samples values fall in class 1(low) and are in excellent category having the SAR values as high as 4.5meq/L; thus no alkali hazards expected.

Generally it can be stated that the groundwater of En Nuhud Basin is quite satisfactory where it meets the standard guideline value and the water is suitable for irrigation use, (Appendix 6). Limit exceptional case concerns Gabreddar- Abu Dagal Area; where high to very high salinity occur, it is recommended that the use of these wells be avoided.

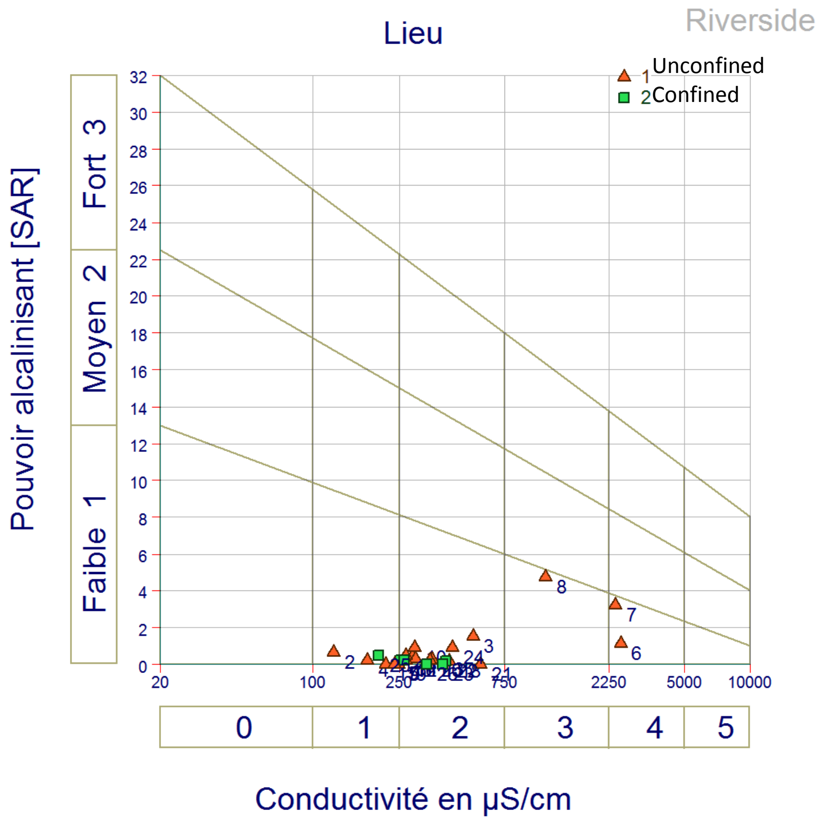


*Fig. (13): Classification of Groundwater for Irrigation Purposes*

**DISCUSSION**

What can be noted is that the water quality is clearly affected by the geological conditions, where we find the physico-chemical properties show contrasts that can be correlated to specific geological zones. For example, the acidic solutions are compared to the western and northwestern boundary of the basin; the relatively high values of temperature are compared to the southern half of the basin which characterized by deep saturated zones; five of six samples from the confined aquifers belong to [Ca (Mg) $Hco_3$] water type; and relatively high concentrations of TDS are marked in the northern half of the study area which dominated by the unconfined aquifer. On the other hand the groundwater of En Nuhud basin on the whole is suitable for most uses which may motivate the investments opportunities.

**CONCLUSION**

Generally it can be stated that the groundwater of En Nuhud Basin is quite satisfactory where it meets the standard guideline for most uses. Re-assessment for the mineralization standards in drinking water may be needed depending on the local temperature regime that related to accumulation within the daily water consumption for individuals. Attention must be paid to chemical analysis for the assessment of drinking water quality to include heavy metals that can affect human health when high concentrations exist. Accurate assessment for water quality is needed in the case when industrial activities are to be planned in the area, since different industrial activity need water quality.

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***Appendix (1): Results of Chemical analysis*** *(concentrations in mg/l, EC in µs/cm and temperature in centigrade*

| S.N | Location | Coordinates | | T C° | PH | EC | TDS | T.H | T. ALK | EX.ALK | $Hco_3^-$ | $Co_3^{--}$ | $So_4^{--}$ | $Cl^-$ | $No_3^-$ | $No_2^-$ | $F^-$ | $NH_3^+$ | $Na^+$ | $Ca^{++}$ | $Mg^{++}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Long. | Lat. | | | | | | | | | | | | | | | | | | |
| 1 | Abu Dagal | 29.889 | 12.963 | 33 | 7.9 | 2540 | 1524 | 624 | 756.4 | 140.3 | 756.4 | 0.0 | 160 | 276.9 | 15.84 | 0.036 | 0.85 | 0.0 | 64.9 | 78.4 | 104.0 |
| 2 | El Donkey | 28.684 | 12.881 | 31.5 | 7.8 | 292 | 171.6 | 130 | 207.4 | 82.04 | 207.4 | 0.0 | 0.0 | 8.52 | 62.04 | 0.040 | 0.37 | 0.01342 | 23.9 | 38.4 | 8.262 |
| 3 | Hallab | 28.902 | 12..699 | 32.7 | 7.73 | 295 | 162.8 | 126 | 195.2 | 73.35 | 195.2 | 0.0 | 20 | 14.2 | 43.56 | 0.076 | 0.30 | 0.0122 | 7.9 | 32.8 | 10.69 |
| 4 | Abu Ushar | 28.683 | 12.881 | - | 7.8 | 540 | 220.4 | 274 | 390.4 | 123.4 | 390.4 | 0.0 | 14 | 14.2 | 11.44 | 0.040 | 0.66 | 0.0 | 59.2 | 33.6 | 46.17 |
| 5 | El Zeleita | 28.039 | 12.836 | 28.7 | 8.5 | 252 | 176.4 | 170 | 203.7 | 35.72 | 195.2 | 18 | 7.0 | 12.07 | 0.0 | 0.0 | 0.0 | 0.0 | 7.31 | 37.6 | 27.70 |
| 6 | Gabr El Dar | 28.705 | 12.742 | 33 | 8.3 | 1155 | 808.5 | 288 | 380 | 97.52 | 366 | 12 | 180 | 71.0 | 5.72 | 0.0 | 0.53 | 0.0244 | 147.2 | 41.6 | 18.47 |
| 7 | Bangadeed | 29.580 | 12.526 | 32.6 | 7.2 | 199 | 139.5 | 114 | 140.1 | 15.26 | 128.1 | 12 | 10.65 | 0.41 | 1.32 | 0.0 | 0.41 | 0.0 | 18.01 | 23.2 | 44.71 |
| 8 | Wasata | 29.270 | 12.821 | - | 7.5 | 344 | 240.8 | 200 | 207.4 | 7.632 | 195.2 | 12 | 0.0 | 9.23 | 5.71 | 0.0 | 0.30 | 0.0 | 7.31 | 51.0 | 17.01 |
| 9 | Um Lubana | 29.129 | 12.892 | 33 | 7.7 | 419 | 293.3 | 240 | 195.2 | 0.0 | 231.8 | 0.0 | 4.0 | 9.23 | 14.08 | 0.023 | 0.39 | 0.0366 | 6.27 | 24.8 | 43.25 |
| 10 | El Regeiba | 29.346 | 12.711 | 33.5 | 7.6 | 405 | 283.5 | 230 | 219.6 | 0.0 | 219.6 | 0.0 | 3.0 | 7.10 | 28.16 | 0.056 | 0.15 | 0.0 | 6.27 | 24.0 | 41.31 |
| 11 | Hydoub | 28.507 | 12.709 | - | 7.2 | 177 | 123.6 | 94.0 | 85.4 | 0.0 | 85.4 | 0.0 | 1.0 | 11.2 | 22.44 | 0.027 | 0.09 | 0.0 | 4.69 | 28.0 | 5.832 |
| 12 | Geleisa | 29.507 | 12.537 | 34.6 | 7.7 | 434 | 303.8 | 182 | 183 | 1.06 | 183 | 0.0 | 21 | 10.65 | 20.24 | 0.026 | 0.63 | 0.0 | 27.84 | 38.4 | 20.90 |
| 13 | Awamra | 29.015 | 12.769 | 25.7 | 7.2 | 263 | 144.7 | 120 | 110 | 0.0 | - | - | 5.50 | 8.0 | 7.48 | 0.055 | 0.42 | 0.0 | 6.11 | 33.6 | 8.64 |
| 14 | Gabr El dar | 28.705 | 12.742 | 25.0 | 8.0 | 247 | 494 | 310 | - | 50 | 360 | - | 51 | 71 | 0.0 | 0.001 | 1.3 | - | - | 160 | 150 |
| 15 | Agab El dor | 29.149 | 12.919 | 26.6 | 7.8 | 215 | 426 | 230 | - | 40 | 265 | - | 0.0 | 53.3 | 0.0 | 0.003 | 0.5 | - | - | 120 | 110 |
| 16 | Kitir | 28.884 | 12.963 | 28.3 | 6.9 | 285 | 171 | 156.4 | 165 | 0.0 | - | - | 0.7 | 6.0 | 3.08 | 0.015 | 0.11 | - | 12.5 | 35.2 | 16.42 |
| 17 | Hydoub | 28.507 | 12.709 | 23.5 | 6.7 | 242 | 157.3 | 132 | 135 | 0.0 | - | - | 0.4 | 8.0 | 4.4 | 0.017 | 0.12 | - | 1.11 | 38.4 | 8.64 |
| 18 | S.A. El Razig | 29.430 | 12.703 | 29.3 | 7.1 | 390 | 194 | 161.6 | 143.4 | 2.33 | 305 | - | 12 | 7.1 | 37.4 | - | 0.0 | 0.04 | - | 16.5 | 35.3 |
| 19 | Kh. Ingmena | 28.854 | 12.752 | 25.4 | 7.3 | 264 | 132.1 | 132 | 125 | 0.0 | - | - | 9.1 | 14 | 8.36 | 0.03 | 0.43 | - | 5.71 | 35.2 | 10.56 |
| 20 | Kh.Um Irig | 28.877 | 12.723 | 29.o | 7.3 | 353 | 176 | 163.6 | 165 | 0.0 | - | - | 4.5 | 10 | 15.4 | 0.389 | 0.64 | - | 8.07 | 43.2 | 13.34 |
| 21 | Kh.Hagar | 28.952 | 12.747 | 23.1 | 7.3 | 266 | 132.7 | 120 | 130 | 0.0 | - | - | 8.4 | 12 | 6.6 | 0.014 | 0.4 | - | 12.29 | 38.4 | 5.76 |
| 22 | Abu Dagal | 29.889 | 12.963 | 23.8 | 7.0 | 2420 | 1210 | 826 | 710 | - | - | - | 365 | 320 | 7.92 | 0.392 | 1.03 | - | 213.2 | 136 | 116.6 |
| 23 | El Fawadil | 29.201 | 12.967 | 22.9 | 7.2 | 235 | 135 | 236 | - | 191 | 427 | - | 0.0 | 34.8 | 30.8 | 0.231 | - | - | - | 63 | 30.1 |
| 24 | Wasata | 29.270 | 12.821 | 29.3 | 7.2 | 582 | 140 | 154.6 | 150.4 | 1.87 | 305 | - | 11 | 9.23 | 48.4 | - | 0.1 | 0.02 | - | 43.76 | 26.9 |
| 25 | Alloba | 28.844 | 12.998 | 24.3 | 6.9 | 124 | 68.2 | 60 | 65 | 0.0 | - | - | 1.4 | 5.0 | 6.0 | 0.012 | 0.84 | - | 12.0 | 14 | 6.0 |
| 26 | Gar Um Bilbil | 29.250 | 12.530 | 26.8 | 7.0 | 332 | 164 | 119.2 | - | 149.2 | 268.4 | 0.0 | 17 | 14.9 | 7.04 | 0.02 | 1.7 | - | - | 28 | 27.4 |

***Appendix (2):*** **Primary Drinking Water Regulations (Based WHO (2003), WHO (2004), WHO (2011) and Sudanese Local Guidelines (1999).**

| Parameter | units | Sudanese G.L | WHO G.L |
|---|---|---|---|
| **(A) : Pysical** | | | |
| Turbidity | NTU | 5 | 5 |
| Color | Cu | 15 | 15 |
| Taste | - | accept | accept |
| Odour | - | accept | accept |
| PH | - | 6.5-8.5 | 6.5-8.5 |
| EC | µs/cm | - | 1500 |
| T. hardness (as $CaCO_3$) | mg/l | - | 300 |
| Alkalinity | " | - | 200 |
| TDS | " | 1000 | 1000 |
| **(B)Inorganic** | | | |
| Free $Co_2$ | mg/l | - | - |
| Chloride | " | 250 | 250 |
| Residual, free Chlorine | " | - | 0.2 |
| Sulphate | " | 250 | 250 |
| Nitrate $No_3$ | " | 50 | 50 |
| Nitrite $No_2$ | " | 2 | 3 |
| Hydrogen sulphate $H_2S$ | " | 0.5 | 0.5 |
| Phosphorus P | " | - | - |
| Flouride F | " | 1.5 | 1.5 |
| Amonnia $NH_3$ | " | 0.5 | 0.5 |
| Sodium Na | " | 200 | 200 |
| Potassium K | " | - | - |
| Calcium Ca | " | 240 | - |
| Magnesium Mg | " | 125 | - |
| Aluminium Al | " | - | 0.2 |
| Iron Fe | " | 0.3 | 0.3 |
| Manganese Mn | " | 0.5 | 0.1 |
| Zinc Zn | " | - | 3 |
| Copper Cu | " | - | 1.2 |
| Lead Pb | " | 0.007 | 0.01 |
| Chromium Cr | " | 0.05 | 0.05 |
| Cyanide | " | - | 0.05 |
| Barium Ba | " | 0.7 | 0.7 |
| Boron B | " | 0.3 | 0.3 |
| Arsenic As | " | 0.007 | 0.001 |
| Cadmium Cd | " | 0.03 | 0.003 |
| Selenium Se | " | 0.007 | 0.01 |
| Mercury He | " | 0.007 | 0.001 |
| Antimony Sb | " | - | 0.005 |
| Molybdenum Mo | " | - | 0.07 |
| Radioactive materials:<br>(a) Alpha emitters | Bq/l | - | 0.01 |

| | | | |
|---|---|---|---|
| (b) Beta emitters | Pci/l | - | 1.00 |

***Continue Appendix (2):***

| | | | |
|---|---|---|---|
| **(C) : Organic** | | | |
| Benzene | " | 10 | 10 |
| Carbon Tetrachloride | " | 1.3 | 2 |
| Phenols Tetrachlorethene | " | 0.02 | 4 |
| Iodine | " | - | - |
| DDT | " | 1.5 | 2 |
| 2-4-D | " | 2 | 3 |
| Landene | " | 1.5 | 2 |
| Monochlomine | " | 2 | 3 |
| Chlorine | " | - | 5 |
| Chloroform | " | 200 | 200 |
| Mineral oil | " | - | 0.03 |
| **(D) : Biological** | | | |
| Coliforms , total | Organisms/ 100ml | 0 | 0 |
| Coliforms , E.coli | Organisms/ 100ml | 0 | 0 |

***Appendix (3): Fluoride Limits Based on Annual Average Maximum Daily Air Temperature***

| Degrees F | Degrees C | Maximum Fluoride Limit (mg/l) |
|---|---|---|
| 53.7 and bellow | 12 and bellow | 2.4 |
| 53.8 to 58.3 | 12.1 to 14.6 | 2.2 |
| 58.4 to 63.8 | 14.7 to 17.6 | 2.0 |
| 63.8 to70.6 | 17.7 to 21.4 | 1.8 |
| 70.7 to 79.2 | 21.5 to 26.2 | 1.6 |
| 79.3 to 90.5 | 26.3 to 32.5 | 1.4 |

According to U.S. Environmental Protection Agency, 1975a, in Driscoll (1987).

***Appendix (4): Laboratory Determination Needed to Evaluate Water Used for Irrigation***

| | |
|---|---|
| Acidity- Alkalinity | Iron[2] |
| Adjusted sodium adsorption ratio | Lithium[2] |
| Ammonium- Nitrogen[1.2] | Magnesium |
| Bicarbonate | Nitrate- Nitrogen[1] |
| Boron | Phosphate Phosphorous[2] |
| Calcium | Potassium[2] |
| Carbonate | Sodium |
| Chloride | Sulphate |
| Electrical conductivity | |

- [1] Nitrate- nitrogen ($No_3$- N) is nitrogen in the form of nitrate ($No_3$) and ammonium- nitrogen ($NH_4$- N) is nitrogen in the form of ($NH_4$), reported as nitrogen(N) in mg/l
- [2] Special situations only

According to Ayers Wescot (1976), in Driscoll (1987)

***Appendix (5): Recommended Maximum concentrations of Trace Elements in Irrigation Water[1]***

| ***Element (Symbol)*** | ***For Water Used Continuously on soils (mg/l)*** | ***For Use up to 20 years on Fine-Textured Soils of pH 6.0 to 8.5 (mg/l)*** |
|---|---|---|
| Aluminum (Al) | 5.00 | 20.00 |
| Arsenic (As) | 0.10 | 2.00 |
| Beryllium (Be) | 0.10 | 0.50 |
| Boron (B) | [2] | 2.00 |
| Cadmium (Cd) | 0.01 | 0.05 |
| Chromium (Cr) | 0.10 | 1.00 |
| Cobalt (Co) | 0.05 | 0.01 |
| Copper (Cu) | 0.20 | 5.00 |
| Fluoride (F) | 1.00 | 5.00 |
| Iron (Fe) | 5.00 | 15.00 |
| Lead (Pb) | 5.00 | 20.00 |
| Lithium (Li)[3] | 2.50 | 10.00 |
| Manganese (Mn) | 0.20 | 2.50 |
| Molybdenum (Mo) | 0.01 | 0.05[4] |
| Nickel (Ni) | 0.20 | 2.0 |
| Selenium (Se) | 0.02 | 0.02 |
| Vanadium (V) | 0.10 | 1.00 |
| Zinc (Zn) | 2.00 | 10.00 |
| | | |

- [1] These levels normally do not adversely affect pants and soils. No data are available for mercury (Hg), silver (Ag), tin (Sn), titanium (Ti) or tungsten (W).
- [2] No problem when less than 0.75 mg/l; increasing problem when between 0.75 and 2.0 mg/l; severe problem when greater than 2.0 mg/l.
- [4] For only acid fine- textured soils and acid soils with relatively high iron oxides content

According to National Academy of Science and National Academy of Engineering, 1972, in Driscoll, 1987

***Appendix (6): Water Quality for irrigation Purposes (after USSL 1954)***

| **Water Quality** | **EC** (µs/cm) | **SAR** (epm) |
|---|---|---|
| Excellent | 250 | Up to 10 |
| Good | 250- 750 | 10- 18 |
| Fair | 750- 2250 | 18- 26 |
| Poor | >2250 | >26 |