# Groundwater Quality Evaluation in Kalar Town-Sulaimani/NE -Iraq

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## ABSTRACT

The Kalar town which is situated at the north east of Iraq was chosen for the investigations of the effect of rapid population increase on the quality of groundwater. The results showed that there are slight changes in ion concentrations due to dilution by rainfall. Pollutions with nitrate, phosphate and fluoride were detected in some water samples. The chemical relationships in expanded Durov, Chadha diagram, and Gibbs diagrams suggested that the groundwaters mainly belong to Ca-$HCO_3$ type, and are controlled by chemical weathering of rock-forming minerals. Areal contour maps for electrical conductivity and ion distributions have shown that water samples from the town center are relatively rich in these values compared with other places in the town. This is attributed to the anthropogenic activity. A comparison of the groundwater quality in relation to drinking water quality standards proves that most of the water samples are suitable for drinking. US Salinity Laboratory's diagrams, used for evaluating the water quality for irrigation and indicated that the majority of the groundwater samples are good for drinking, irrigation, and suitable for some industries like textile, chemical pulp but not paper industry.

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# تقييم نوعية المياه الجوفية لمدينة كلار شمال شرق العراق

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## الملخص

تم اختيار مدينة كلار لغرض دراسة تاثيرالازدياد السكاني المفاجىء على نوعية المياه الجوفية خصوصا ان المياه الجوفية هي المصدر الاساسي للشرب.أظهرت نتائج التحاليل الكيميائية بان هناك تغاير موسمي طفيف لتركيز الايونات نتيجة التخفيف بواسطة الامطار.هناك تلوث عدد من النماذج بايونات الفوسفات والنترات والفلورايد. وعند استخدام مرتسمات(Durov, Chadha, and Gibbs) ظهر بان نوع المياه هو كالسيوم-بايكاربونات و ان التجوية الكيمياوية هي العامل المسيطرفي نوعية المياه. اظهرت الخرائط الكونتورية بأن مركز المدينة يحتوي على قيم عالية من التوصيلية الكهربائية و الأيونات نتيجة

الفعاليات البشرية. ان معظم نماذج المياه هي صالحة للشرب عند مقارنتها مع المواصفات القياسية وجيدة للزراعة، كذلك صالحة لبعض الصناعات مثل الصناعات النسيجية والأقمشة ماعدا صناعة الورق.

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## INTRODUCTION

As a resource, groundwater is gaining increasing importance in the supply of water to sub districts in the drier regions of Kurdistan where surface waters are very scarce or absent or unsafe for drinking purpose. The combination of population growth, economic and agriculture development, and an arid climate results in overexploitation of the water resources in the region. The continuous high water demand leads to a rapid degradation of the quality of fresh-water resources .Understanding the groundwater characteristics is crucial for groundwater management in the studied area.

The result of chemical composition of groundwater is combined between the composition of water that enters the groundwater reservoir and reactions with minerals present in the rock. Apart from natural processes as controlling factors on the groundwater quality, in recent years the effect of pollution, such as nitrate from fertilizers and acid rain, also influences the groundwater chemistry. Due to the long residence time of groundwater in the invisible subsurface environment, the effects of pollution may first become apparent tens to hundreds of years afterwards. It is clear that a proper understanding of the processes occurring in aquifers is required in order to predict what the effects of present day human activities will be on such a time scale (Appelo and Postma, 1999)

The interest of Society in groundwater geochemistry is mainly to ensure good quality drinking water. .Although drinking water can be manufactured in a chemical plant, as for example in desalinization plants; this is a very costly affair. Preservation of good ground-water resources therefore has a high priority for environmental authorities. (Adams et al., 2001).

Water compositions change through reactions with the environment, and water quality may yield information about the environments through which the water has circulated.

**Location of studied area**

The Kalar district is located at the southern part of the Sulaymaniyah Governorate North east of Iraq between longitude ($44^{o}$ $15^{-}$ $00^{=}$, $45^{o}$ $23^{-}$ $31^{=}$) and latitude ($34^{o}$ $23^{-}$ $25^{=}$, $34^{o}$ $40^{-}$ $54^{=}$) fig. (1). It is (142) km far from governorate capital, Sulaymaniyah, and (70)km from Darbandikhan famous reservoir, along Sirwan (Diyala) River, being part of the Garmian area.

The Sirwan (Diyala) River, which is one of the major water sources in Sulaymaniyah, forms the eastern boundary of the district. The urban area of the municipality of Kalar is approximately 22 $km^2$, and its elevation ranges between 210 and 293 m asl, with major mountain ranges in the western part of the district, while the southern part is generally semi-flat.

**Climate:**

Kalar has extremely hot summers, with temperatures ranging from 39 to 48ºC. Winter is wet and cold with temperatures between 13º and 22ºC. The average annual precipitation in the district is 300 mm. In the winter the region is invaded by Mediterranean cyclones moving east to north-east over the region. Arabian Sea cyclones moving northward and passing over the Gulf usually carries great amount of moisture which causes a large amount of precipitation (Stevanovic and Markovic, 2004).

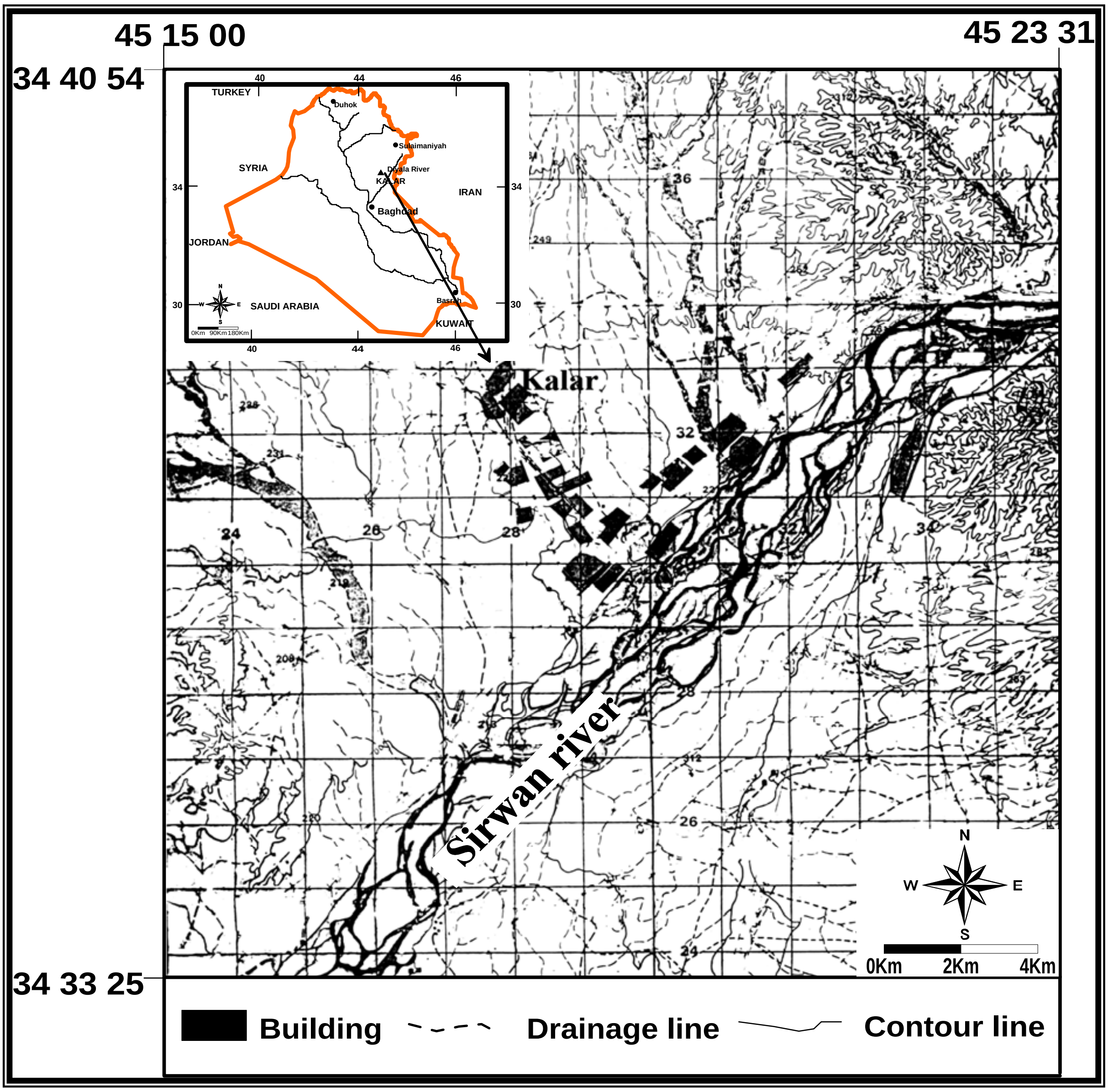



Fig 1: Location map of the studied area

**Water resources**

Kalar town has two sources of water for its system, these are the Sirwan (Diyala) River and deep wells. Raw water is diverted from the river to a collection pond. From this pond, water is extracted by means of shallow wells. The raw water is lift by submersible pumps from the shallow wells to the Kalar Water project and then chlorine gas is disinfected. It is reported during the field visits that the quality of the surface water is better during summer than it is during winter.

There are 25 deep wells throughout the city, ranging in depth between 50 and 120 m. Wells 1, 2 and 3 feed a separate network called the Bardasour area, while wells 4 through 7 supply the Casino network. Wells 8 through 17 pumps into the Kalar distribution network, it is reported that the wells are currently operated, on the average, 7 h/d, water service via the distribution network is limited to 1 h/d (Parsons, 2006).

A recent study of water supply to Kalar, prepared by the Water and Environmental Sanitation Department in 2003, provides additional well details, including locations, static and dynamic water depths, discharge, pump type and installation date. The study reports that the total capacity of the wells is approximately 500 $m^3$/h (12,000 $m^3$/d if operated 24 h/d). The municipal center of Kalar and the sub district center of Rzgary were combined for the purpose of creating a demand projection since they are being served by a common source. The estimated combined population in 2005 was about 119,665. Over the planning period through 2025, their population is projected to increase to approximately 216,128. The projected water demand for Kalar and Rzgary is proposed to increase from the year 2005 level of approximately 50,183 $m^3$/d to around 90,636 $m^3$/d, by the year 2025. There is currently a theoretical deficit of about 35,723 $m^3$/d in the Kalar-Rzgary area, and that will increase to approximately 70.082 by the year 2025. (Parsons, 2006).

**Geological setting**

the Geological setting of Kalar town is mainly based on the publications of (Buday 1980, Bellen et al., 1959 , Al-Rawi et al., 1992, Jassim and Goff, 2006).Kalar town composed of different geological rock units which are shown in Fig(2) and can be summarized as follows.

**Mukdadiya formation (Pliocene)**

The Mukdadiya (Lower Bakhtiari) Formation comprises up to 2000 m of fining upwards cycles of gravely sandstone, sandstone, and red mudstone (Jassim and Goff 2006). The sandstones are often strongly cross-bedded and associated with channel lags and clay balls. An interval about 600 m above the base of the formation consists of sandstones with rounded and rod-like calcite-cemented concretions. The Mukdadiya (Lower Bakhtiari) Formation was deposited in fluvial environment in a rapidly subsiding fore deep basin.

**Quaternary Deposits**

The age is Pleistocene; it covers a wide area of the Kalar town and composed of Alluvium, river, and flood plain deposits which consist of clay, loam, silt, sand and conglomerate. It is poorly sorted and it contains weathered products of Mukdadiya Formation and other formations which are far from the area and transported by Sirwan River. These sediments now constitute good and exploitable aquifer in the area both for drinking and local irrigation. The thickness is highly variable in the area (ranging from 10 to 150 m) fig (3),and increases toward the north and west of the town where it reaches its maximum thickness.

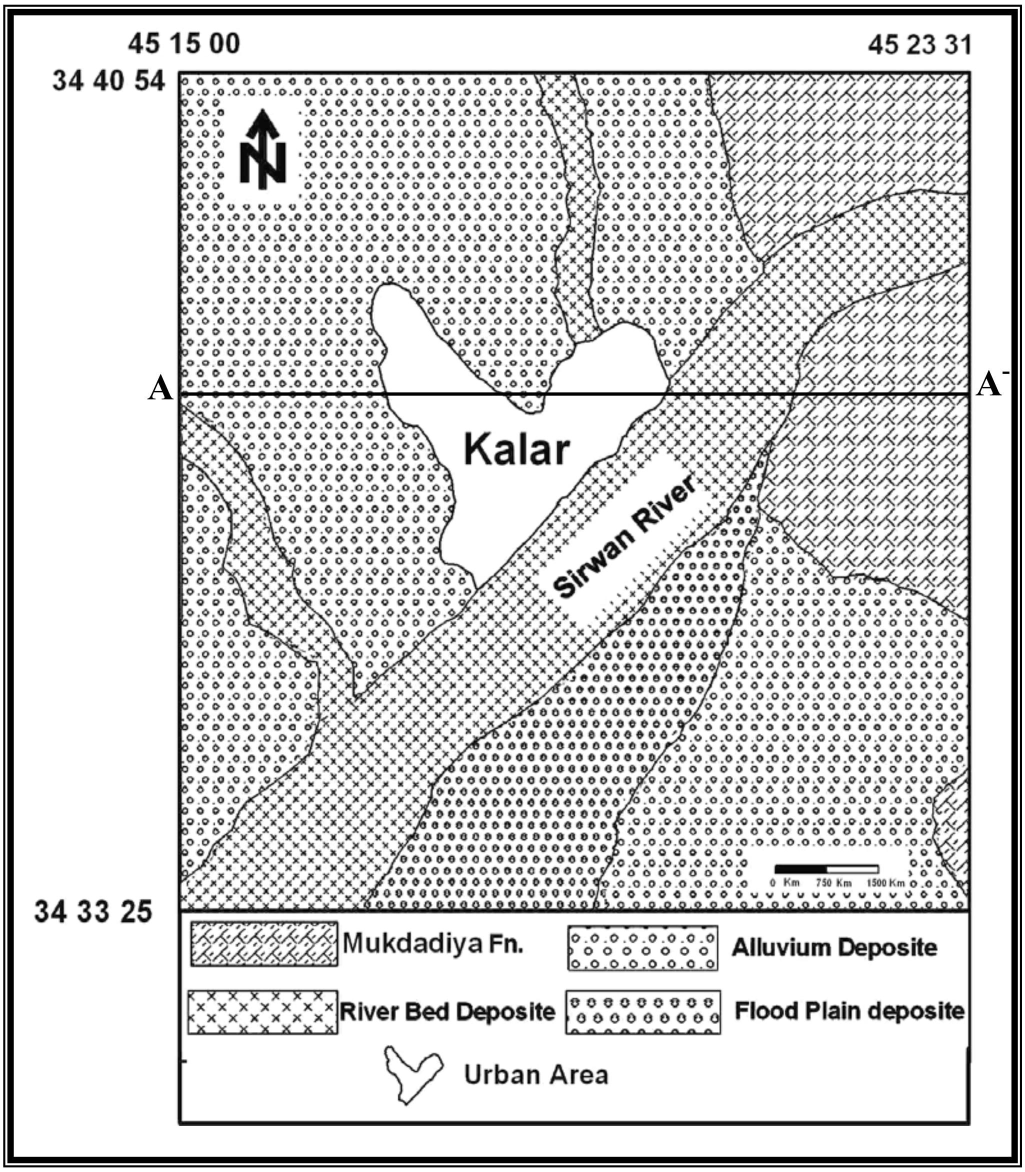



Fig 2: Geological map of the studied area (Modified after Sissakian, 2000)

## Hydrogeology

Hydrologically the studied area is located in Kalar-Qradagh basin.The intergranular aquifer which consists of combining Quaternary and Mukdadiya Formations comprises the main highly productive aquifer in this basin. Based on the results of previous investigations achieved by water well drilling company in Sualimaniyah, FAO activities during 2000-2003 and some geo-electrical surveys the thickness of the surfacial deposits within the town of Kalar is estimated to be at the range of 10-150 meters. From the surface down, the lithological column starts with alluvial or recent sediments (gravel, sand, silt, and clay). The lower layer consists of altered impermeable clays or semi-permeable clayey-sand and gravel. This impermeable clay layer brings a semi confined condition to the Mukdadiya aquifer in the area where the quaternary covers the Mukdadiya formation but in other places when the cover is absent the aquifer is unconfined. Variation in permeability from one site to another within the same aquifer horizon, is a characteristic of this aquifer (Stevanovic and Markovic, 2004).

Sirwan, river play a key role in groundwater circulation and define the direction of groundwater. This rich aquifer is tapped by many deep wells, which inturn provide large amounts of water for irrigation and water supply.

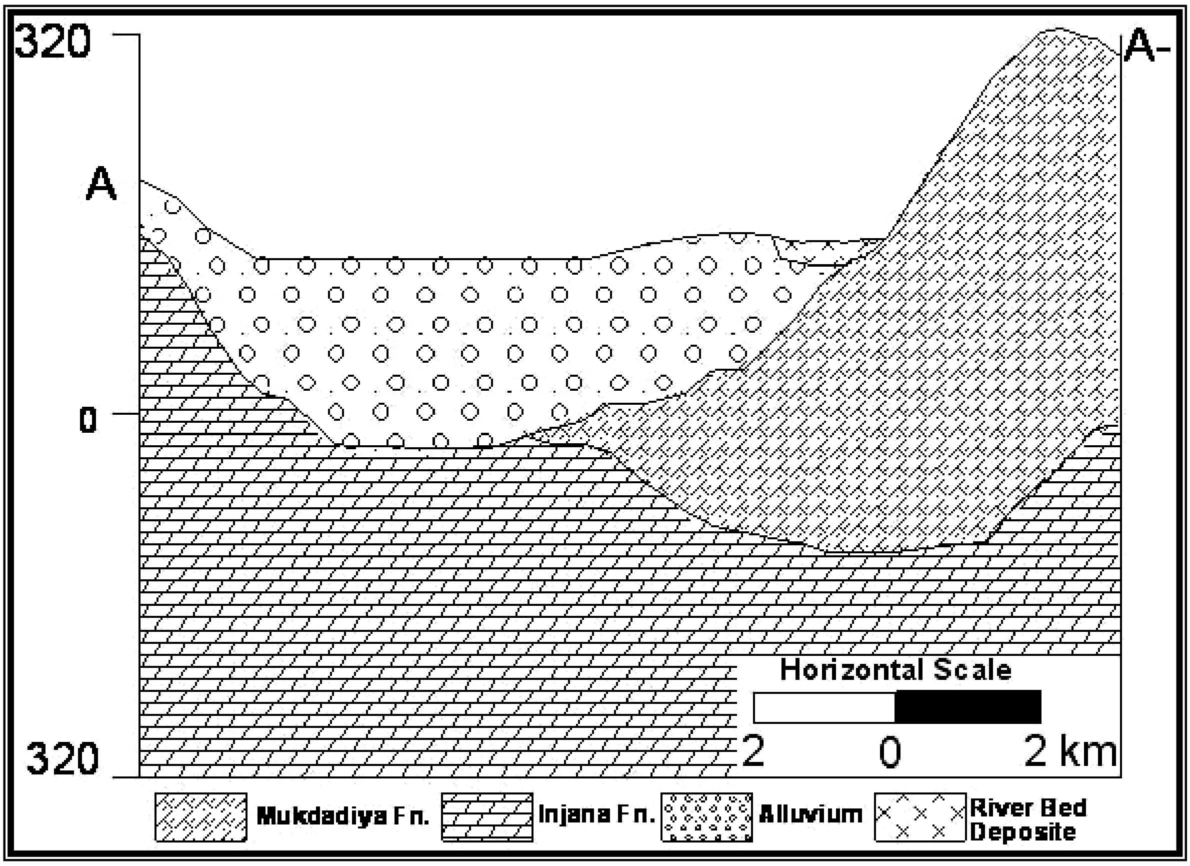



Fig 3: Geological cross section of the studied area (Modified after Sissakian, 2000)

**Methods of investigation**

Water samples from Seventeen deep wells were taken twice during May and October 2004 for assessing seasonal variations of groundwater quality fig (4). Samples from all wells were collected in acid-washed 250 and 500 ml polyethylene bottles, following the standard guidelines (Hem 1991; APHA 1998, Schoenleber, 2005). The samples were analyzed immediately for hydrogen ion concentration (pH), temperature ($T^oC$) and electrical conductivity (EC), turbidity using portable multiparameter analyzer model (TPS/90FL-T Field Lab Analyzer) plate (1). Other parameters were later analyzed in the laboratories of the Health and Environmental Protection Office, and Department of Geology, Sulaimany University. All water samples for cation and anion analyses were filtered through 0.45 µm Millipore filters upon return from the field (Kerr 1993, Mustafa 2007). Samples for cation analyses of $Na^+$, $K^+$ were acidified with 0.5 ml concentrated (16 M) $HNO_3$ per 100 ml sample within days of collection. Unacidified samples were analyzed for $Ca^{2+}$, $Mg^{2+}$, $SO4^{2-}$, $Cl^-$, $NO_3^-$ and $PO_4^{3-}$ . Total dissolved solids (TDS) were computed by multiplying the EC by a factor of (0.64). Calcium and magnesium ($Ca^{2+}$& $Mg^{2+}$) were analyzed titrimetrically, using standard EDTA using E.B.T indicator Sodium ($Na^+$) and potassium ($K^+$) were measured, using a flame photometer(Genway PFP7). Bicarbonate ($HCO_3^-$) analyzed by titrating with HCl using Methyl orange. Chloride ($Cl^-$)

was determined titrimetrically by standard $AgNO_3$ titration. Sulphate ($SO_4^{2-}$), nitrate ($NO_3^-$), phosphate ($PO_4^{3-}$) and fluoride ($F^-$) were analyzed, using spectrophotometer type (HATCH). All parameters are expressed in milligrams per liter (mg/l) and milliequivalents per liter (meq/l), except pH (units) and EC. The EC is expressed in micromhos per centimeter (µS/cm) at 25°C. The ion-balance-error computation, taking the relationship between the total cations ($Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$) and the total anions $HCO_3^-$, $Cl^-$ ,$SO_4^{2-}$, for each set of complete analyses of water sample.

## RESULTS AND DISCUSSION

### General evaluation of the water analysis

The results of chemical analysis of water samples for two seasons tabulated in table(1)&(2) ,$Ca^{2+}$ and $HCO_3^-$ are the dominant ions ,the second species in abundance are $Na^+$,$Mg^{2+}$ for cations $SO_4^{2-}$and $Cl^-$, for anions ,$Ca^{2+}$ concentration range from (25-70 mg/l )for wet season and ( 28-72 mg/l)for dry season ,also $Mg^{2+}$ from ( 12-30 mg/l) for wet season and(13-31 mg/l ) for dry season, $Na^+$ from (12-44 mg/l )and (15-50 mg/l),$K^+$ from (0.7-2.3 mg/l ) and (0.85-2.4 mg/l )$Cl^-$ from (16-28 mg/l)and(16-30 mg/l) $HCO_3^-$ from (150-288 mg/l)and (145-280mg/l)$SO_4^{2-}$ from(31-85 mg/l )and(35-90 mg/l). The highest values of (EC) and ion concentrations were observed in the central part of the city, because water wells in the urban area are generally near sewage system, and effluents are likely to contribute ions to groundwater, also the anthropogenic activities are higher in the center Fig(5).

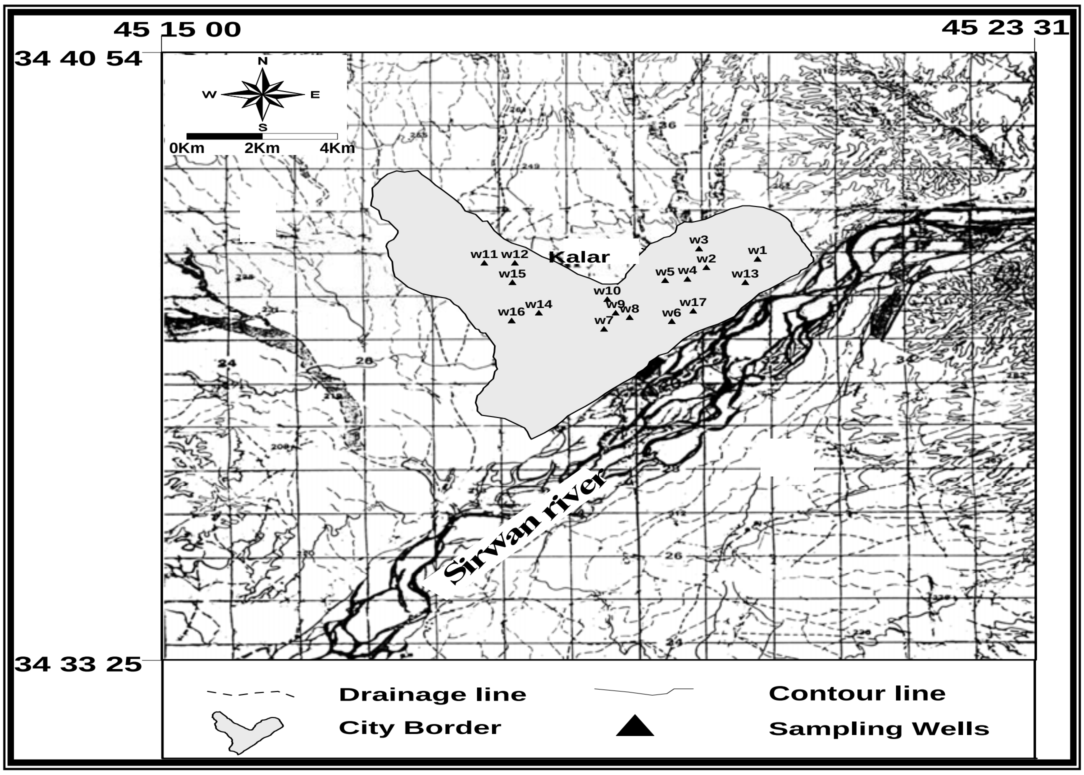



Fig 4: location of sampling wells

The concentration of major ions decreases slightly in the second season due to excess rainfall which normally dilutes dissolved elements. Soils and aquifer materials are the major sources of cations and anions (Eq.1), whereas the fertilizers, municipal wastewater and irrigation-return-flows are additional contributors of $Mg^{2+}$, $Na^{+}$, $K^{+}$, $Cl^{-}$), $SO_4^{2-}$) ions (Langmuir, 1997).

Minerals (Silicate) + $H_2CO_3$ = $H_2SiO_4$ + $HCO_3^-$ + Cations + Clays ……… (1)(Rao, 2006)

Plate 1: Portable Multiparameter Analyzer Model (TPS/90FL-T Field Lab Analyzer)

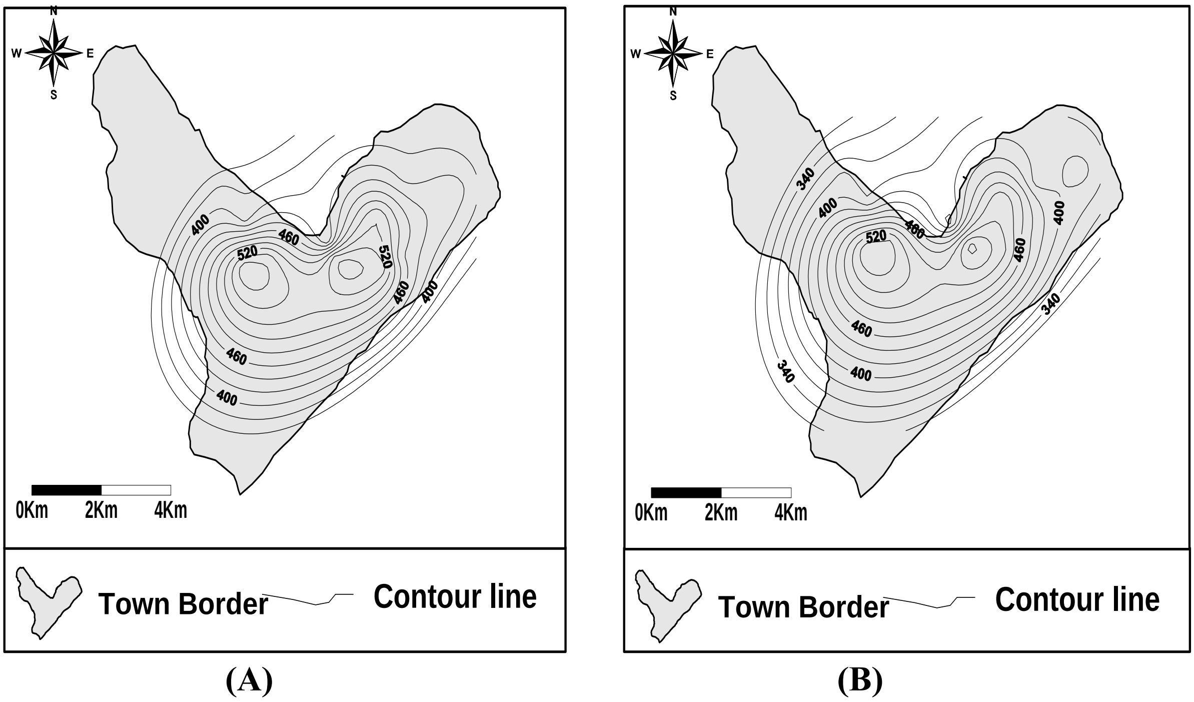



Fig 5 : Areal distribution of Electrical Conductivity:(A) Dry season(B) Wet season

**Minor ions**

The concentrations of $PO_4^{3-}$, $NO_3^-$ and $F^-$are given in table (3). It is clear that the concentration of $NO_3^-$ is high in samples (8,9,10,)for both seasons and sample(7)in wet season because it exceeds (WHO 2006)and (Iraqi) standard 1998 which is (50mg/l), so it is considered to be polluted. The most probable source of pollution is supposed to be from infiltrated municipal wastewater in to the groundwater because the sewage system of Kalar town is still open and not developed yet, plate(2) , so agricultural activities, principally irrigation and fertilizer applications add to the pollution problem. However, the main occupation in the district is farming, and main crops are wheat, barley, chickpeas and vegetables, leading to higher concentration of nitrate during wet season.

The consumption of water with high nitrate concentration causes a number of health disorders, such as, gastric cancer, goitre, birth malformations, hypertension and decreasing oxygen bearing capacity of the blood(methemoglobinemia), which is particularly important in the health of young infants (Hudak, 2000; Majumdar and Gupta, 2000; McKenzie, 2001; Esteller, 2005). $PO_4^{3-}$ is relatively high, in groundwater in the urban area associated with municipal wastewater. In Canadian standard the concentration limit of 0.2mg/l has been defined as the acceptable limit for drinking water, therefore the water samples (7,8,9,10,12,13)for both seasons and samples(5,11,19,17)for wet season are polluted with $PO_4^{3-}$.Too much phosphate can cause health problems, such as kidney damage and osteoporosis, Phosphate shortages can also occur. Fluoride is an essential element for maintaining normal development of healthy teeth and bones. Deficiency of $\mathbf{F^-}$ in drinking water below 0.6 mg/l contributes to tooth caries. An excess of over 1.5 mg/l causes fluorosis (WHO2006). Groundwater samples have less than the limits of 0.6 mg/l are deficient in $F^-$, and if concentration is more than 1.5mg/l the waters are considered to be not acceptable for drinking.

Plate 2 : Open Sewage System in Kalar Town

Table 3:Minor Ions Concentrations, $SAR_{adj}$, TU and TH of Water Samples

| No. | Dry Season(October) | $PO_4^{3-}$ | $NO_3^-$ | $F^-$ | $SAR_{adj}$ | TU | TH | Wet season(May) | $PO_4^{3-}$ | $NO_3^-$ | $F^-$ | $SAR_{adj}$ | TU | TH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W1 | | 0.08 | 23 | 1.65 | 1.21 | 2.1 | 183 | | 0.12 | 27 | 1.4 | 1.02 | 2.18 | 173 |
| W2 | | 0.02 | 28 | 0.69 | 1.50 | 0.6 | 249 | | 0.08 | 29 | 0.69 | 1.31 | 0.65 | 229 |
| W3 | | 0.09 | 23 | 0.91 | 1.05 | 1.4 | 185 | | 0.11 | 20 | 0.43 | 0.99 | 1.42 | 153 |
| W4 | | 0.05 | 18 | 0.57 | 1.21 | 1.21 | 240 | | 0.1 | 21 | 0.33 | 1.09 | 2.12 | 224 |
| W5 | | 0.11 | 18 | 0.55 | 1.67 | 0.56 | 264 | | 0.3 | 19 | 0.4 | 1.51 | 0.6 | 242 |
| W6 | | 0.09 | 38 | 0.45 | 2.51 | 0.92 | 293 | | 0.15 | 41 | 0.3 | 2.30 | 0.98 | 273 |
| W7 | | 0.73 | 47 | 0.94 | 3.03 | 1.5 | 181 | | 0.9 | 51 | 0.65 | 2.84 | 1.5 | 176 |
| W8 | | 1.19 | 53 | 0.78 | 3.02 | 2.31 | 245 | | 1.42 | 54 | 0.7 | 2.33 | 2.5 | 236 |
| W9 | | 0.36 | 51 | 0.92 | 2.75 | 2.51 | 203 | | 0.5 | 53 | 0.9 | 2.68 | 2.8 | 183 |
| W10 | | 0.53 | 55 | 0.85 | 2.07 | 1.98 | 160 | | 0.95 | 58 | 0.8 | 1.97 | 2.2 | 139 |
| W11 | | 0.18 | 30 | 1.6 | 1.86 | 1.3 | 123 | | 0.35 | 31 | 1.3 | 1.85 | 1.8 | 113 |
| W12 | | 0.24 | 42 | 1.11 | 1.08 | 0.82 | 159 | | 0.35 | 42.5 | 1 | 1.07 | 0.82 | 135 |
| W13 | | 0.27 | 46 | 0.96 | 0.87 | 1.8 | 240 | | 0.27 | 47.5 | 0.81 | 0.87 | 1.91 | 204 |
| W14 | | 0.12 | 36 | 0.6 | 1.08 | 0.8 | 220 | | 0.17 | 37 | 0.4 | 0.91 | 0.82 | 190 |
| W15 | | 0.09 | 21 | 0.2 | 0.93 | 1.2 | 185 | | 0.12 | 22 | 0.2 | 0.77 | 1.1 | 170 |
| W16 | | 0.21 | 37 | 0.35 | 1.39 | 2 | 295 | | 0.47 | 39 | 0.33 | 1.21 | 2.1 | 269 |
| W17 | | 0.18 | 33 | 0.15 | 1.40 | 0.6 | 182 | | 0.28 | 36 | 0.12 | 1.33 | 0.6 | 163 |
| Mean | | 0.3 | 35.2 | 0.8 | 1.7 | 1.4 | 212 | | 0.39 | 36.9 | 0.63 | 1.53 | 1.53 | 192 |
| Max. | | 1.19 | 55 | 1.65 | 3.03 | 2.51 | 295 | | 1.42 | 58 | 1.4 | 2.84 | 2.8 | 273 |
| Min. | | 0.02 | 18 | 0.15 | 0.87 | 0.56 | 123 | | 0.08 | 19 | 0.12 | 0.77 | 0.6 | 113 |

*Note: $PO_4^{3-}$, $NO_3^-$,$F^-$ in mg/l TU: Turbidity in( NTU)units TH: Total hardness

**Seasonal changes in groundwater quality**

Several features of the aquifer and some environmental conditions can cause seasonal changes in groundwater quality. These aspects include variations in the input concentration of pollutant; changes in meteorological and hydrological conditions. In the studied area, generally slightly low ionic concentrations occur in wet season, and high concentrations in dry season. The greatest pollution, especially of $NO_3^-$, $PO_4^{3-}$ was measured in wet season, Groundwater recharge is greater in wet months; thus, fresh-water input to the aquifer via precipitation is greater this is clear from the value of pH which is greater in the wet period, and in these months fertilizer application to the agricultural land is applied.

**Quality criteria for drinking purpose**

The water analyses were classified with regard to the hardness using Todd (1980) and Detay(1997) classification. Water samples are considered to be hard (Table 3).According to Iraqi Drinking Water Standards (IDWS, 1998) in which the recommended limit for hardness is 500mg/l.Hard water leads to incidence of urolithiosis (WHO ,2006), anencephaly, parental mortality, some types of cancer. Such waters can also develop scales in water heaters, distribution pipes and well pumps, boilers and cooking utensils, and require more soap for washing clothes. The pH (7.1–7.7) in groundwater samples in dry and wet season during 2004 (Table 1,2) is within the safe limits (6.5–8.5) prescribed for drinking water by Iraqi Drinking Water Standards (IDWS,1998) and (WHO, 2006). The concentration of TDS (mg/l) is also safe with respect to recommended limit of 500 mg/l allowed in all groundwater samples in both seasons. All samples for both seasons are suitable with respect to cations and anions except samples (16,14,6,4) which exceed the recommended limit for calcium ion for IDWS which is 50 mg/l.

**Quality criteria for irrigation purpose**

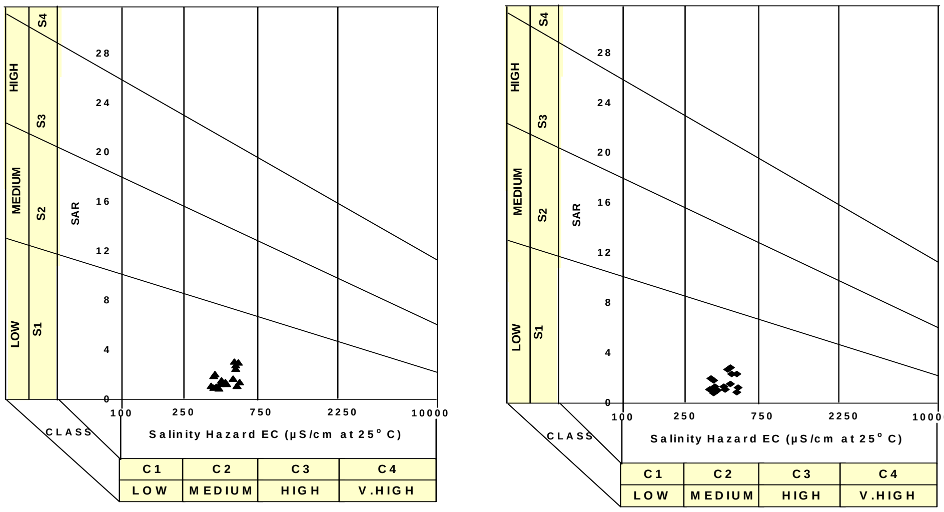
EC and $Na^+$ play a vital role in suitability of water for irrigation. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Ayers and Westcot, 1994). Since plant, roots extract water by osmosis, the water uptake of plants decreases. The osmotic pressure is proportional to the salt content or salinity hazard. The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability, and aeration, which indirectly affect the plant growth. Another important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed in adjusted sodium adsorption ratio ($SAR_{adj}$). The $SAR_{adj}$ is computed, where the ion concentrations are expressed in meq/l, as shown below:

$$SAR_{adj} = \frac{Na}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}[1 + (8.4 - pH_c)] \cdots\cdots\cdots\cdots\cdots \text{(1) (Ayers and Westcot 1994)}$$

There is a close relationship between SAR values in irrigation water and the extent to which $Na^+$ is absorbed by soils. If water used for irrigation is high in $Na^+$ and low in $Ca^{2+}$, the ion-exchange complex may become saturated with $Na^+$, which destroys soil structure, because of dispersion of clay particles. As a result, the soils tend to become deflocculated and relatively impermeable. Such soils can be very difficult to cultivate. The values of $SAR_{adj}$ in the study area range from about (0.87-3.03) in dry season and (0.77-2.84) in wet season of groundwater samples (Table 3). The US Salinity Laboratory diagram (US Salinity Laboratory Staff 1954) is used widely for rating the irrigation waters. $SAR_{adj}$ is plotted against EC. The plot of chemical data of the groundwater samples of the area on the US Salinity Laboratory diagram is illustrated in Fig.(6).A computer program prepared by the auther of this article (Al-Manmi 2007) used for plotting the data on the diagram. The groundwater sample points, as shown as a cluster, fall in ($C_2S_1$). These waters are relatively good for irrigation sources. These rates indicate low salinity and low sodium hazards. The good waters can be used for irrigation with little danger of harmful levels of exchangeable $Na^+$.

**Quality criteria for Industrial purpose**

The quality requirements of waters used in different industrial processes range widely and almost every industrial application have its own standards (Hem, 1991). Salinity, hardness, and dissolved silica are three parameters that usually are important for industrial water (Todd, 1980). The standards represent maximum values permitted in the water at the point of use. Comparison of the water quality data with the standards (Hem, 1991) (Table 4) reveals that the water samples of Kalar town are suitable for all industries except Chemical pulp and paper, because ($Ca^{2+}$,$Mg^{2+}$) concentrations exceed maximum permitted values(20,12 mg/l)respectively.




(A) (B)

Fig. 6: Classification of irrigation waters (After U.S. Salinity Laboratory Staff 1954): (A) Dry Season (B) Wet Season

**Mechanisms controlling groundwater chemistry**

Gibbs's diagrams, representing the ratios of $Na^+$: ($Na^+$+ $Ca^{2+}$) and $Cl^-$: (($Cl^-$)+ $HCO_3^-$ )) as a function of TDS, are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation-dominance, rock-dominance and evaporation-crystallization- dominance or by combination of these influences (Gibbs 1970,Langmuir 1997).The reason of using the ratios parameters above is the composition of world rainfall(unpolluted) is chiefly determined by the (NaCl) of sea salt, also weathering of chemical rocks increases their (TDS) and concentrations of ($Ca^{2+}$) and ($HCO_3^-$) relative to ($Na^+$) and ($Cl^-$), evapotranspiration further increase the ($Na^+$)and (TDS) content of water The chemical data of groundwater sample points of the area are plotted in Gibbs's diagrams Fig. (7). The distribution of sample points, as shown as a cluster, suggests that the chemical weathering of rock-forming minerals is influencing the groundwater quality.

Table 4 : Water Quality Standards for Industrial Uses (after Hem, 1991)

| Parameters | Textile | Chemical pulp and paper | | Wood chemicals | Synthetic rubber | Petroleum products | Canned, dried, and frozen fruits and vegetables | Soft-drinks bottling | leather tanning | Hydraulic cement manufacture |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Unbleached | Bleached | | | | | | | |
| Ca | 0 | 20 | 20 | 100 | 80 | 75 | -- | 100 | -- | -- |
| Mg | 0 | 12 | 12 | 50 | 36 | 30 | -- | -- | -- | -- |
| Cl | 0 | 200 | 200 | 500 | -- | 300 | 250 | 500 | 250 | 250 |
| $HCO_3^-$ | 0 | -- | -- | 250 | -- | -- | -- | -- | -- | -- |
| $SO_4^{2-}$ | 0 | -- | -- | 100 | -- | -- | 250 | 500 | 250 | 250 |
| $NO_3^-$ | 0 | -- | -- | 5 | -- | -- | 10 | -- | -- | -- |
| Cu | 0.01 | -- | -- | -- | -- | -- | -- | 500 | -- | -- |
| Zn | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| TH | 25 | 100 | 100 | 900 | 350* | 350 | 250 | -- | Soft | -- |
| TDS | 100 | -- | -- | 1000 | -- | 1000 | 500 | -- | -- | 600 |
| pH | 2.5 – 10.5 | 6 – 10 | 6 – 10 | 6.5 – 8 | 6.5 – 8.3 | 6 – 9 | 6.5 - 8.5 | -- | 6 - 8 | 6.5 - 8.5 |
| T (°F) | -- | -- | 95 | -- | -- | -- | -- | -- | -- | -- |
| TSS | 5 | 10 | 10 | 30 | 5 | 10 | 10 | -- | -- | 500 |

## Groundwater quality classification

To assess the geochemical evaluation and classification of groundwater, a graphical representation of expanded Durov diagram (1958), and Chadha diagram (1999) are used. As little attention is paid by Iraqi researchers and lack of articles in the Iraqi libraries on these diagrams it is necessary to discuss the two diagrams in details. The chemical data of the groundwater samples collected from the studied area are plotted in the expanded Durov diagram (Fig.8). The chemical data of the sample points, appeared as a cluster, and fall in the subdivisions of (2) fig(8) while samples(14,16) located in the field(1)and no(13)located in the field(5) for dry season and samples (14,16,5,4)located in the field no.(1)for wet season. When the data plotted in the Chadha diagram all samples fall in the field(5)except sample (13) which is located in the field no.(1) for dry season ,this means that the type of all water is $Ca^{2+}$-$Mg^{2+}$-$HCO_3^-$ fig (10).

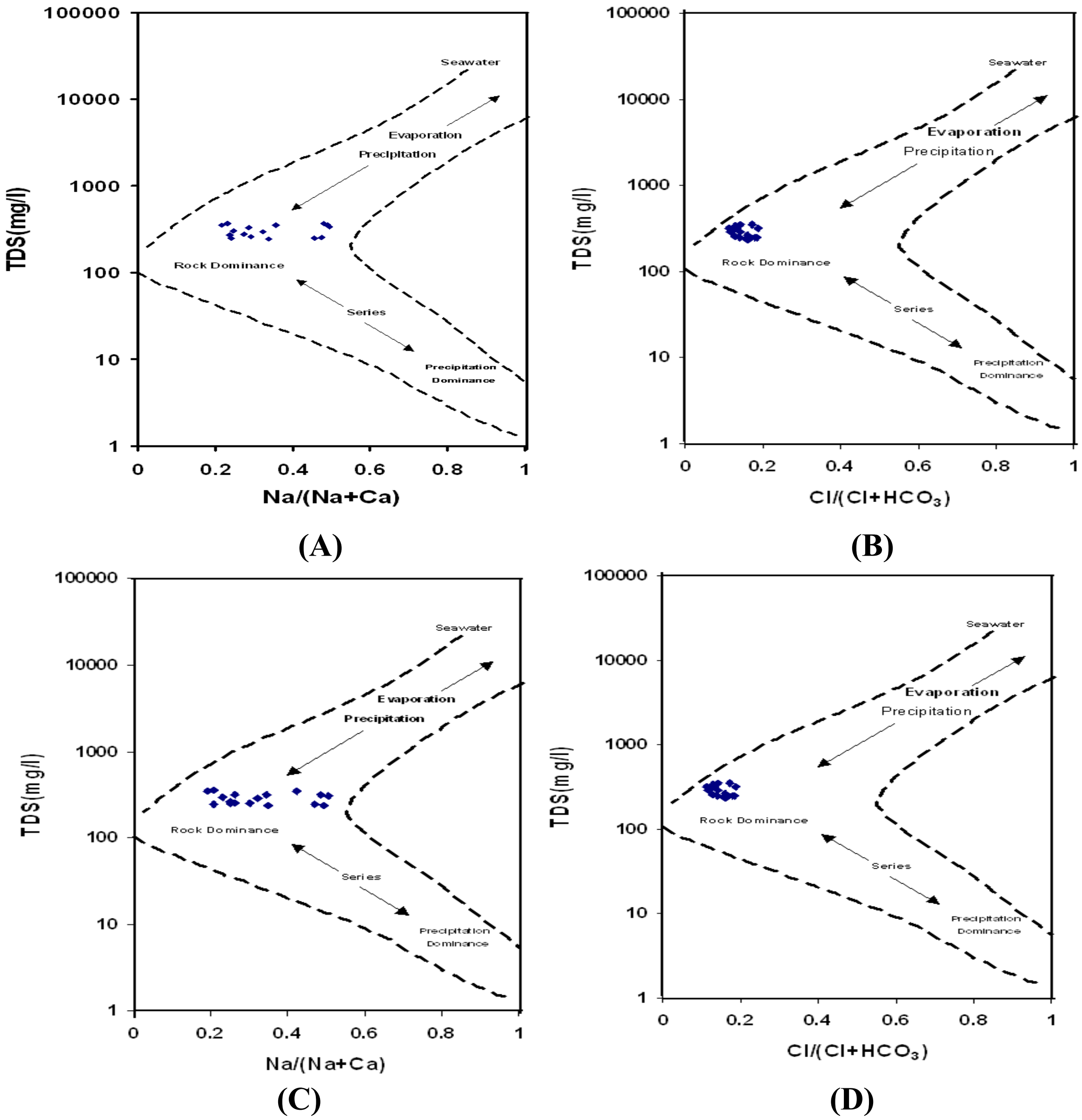



Fig. 7: Mechanisms Controlling Groundwater Quality (After Gibbs 1970): (A, B) Dry Season (C, D) Wet Season

## REVIEW

### Durov Diagram

The diagram normally based upon percentage major ion millequivalent values, but in this case the cations and anions together total 100 per cent. The cation and anion values are plotted in the appropriate triangle and projected into the square main field. An expanded version of the Durov diagram developed by Burdon and Mazlounr (1958) and Lloyd (1965) fig (7), tile cation and anion triangles are recognized and are separated along the 25 per cent axes so that the main field is conveniently divided. The expanded Durov diagram has the distinct advantage over the Piper diagram in that it provides a better display of hydrochemical types and some processes, and in practical terms has less line work in the main field. Although as shown in Fig. (8), waters with a 25 percent concentration of a certain ion can theoretically plot ambiguously,and in practice the ambiguity has little relevance and can be solved by the association of the problem water with neighboring waters The significance of nine fields on the expanded Durov diagram can be discussed with respect to Fig. (9) As follows:

1. $HCO_3^-$ and $Ca^{2+}$ dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers.
2. $HCO_3^-$ dominant and eight $Mg^{2+}$ dominant or cations indiscriminant, with $Mg^{2+}$ dominant or $Ca^{2+}$ and $Mg^{2+}$ important, indicates waters often associated with dolomites, where $Ca^{2+}$ and $Na^+$ with important partial ion exchange may be indicated.
3. $HCO_3^-$ and $Na^+$ dominant, normally indicates ion-exchanged waters although the generation of $CO_2$ at depth can produce $HCO_3^-$ where Na+ is dominant under certain circumstances.
4. $SO_4^{2-}$ dominant or anions indiscriminant and $Ca^{2+}$ dominant, $Ca^{2+}$and $SO_4^{2-}$ dominant frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or a water exhibiting simple dissolution may he indicated

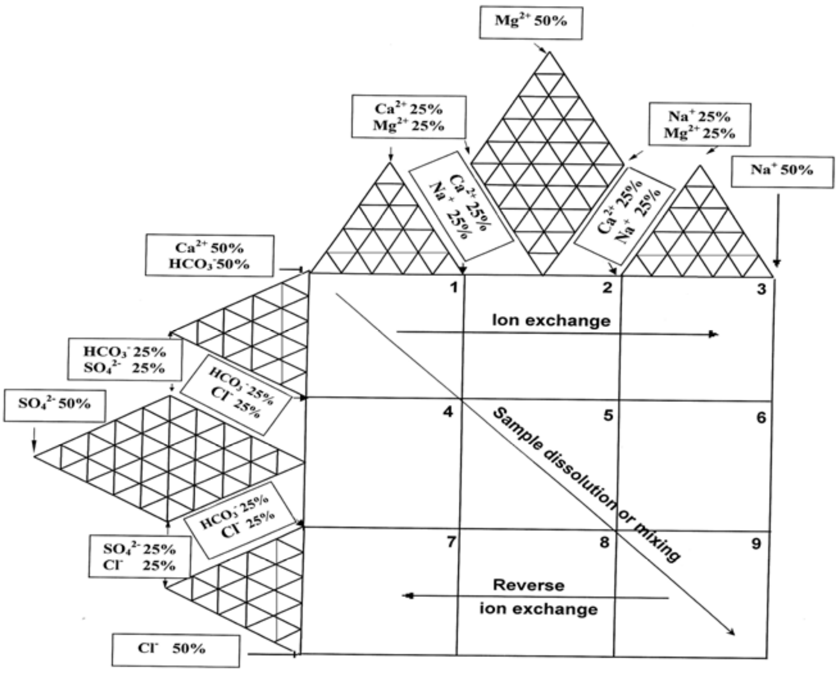



Fig. 8: Expanded Durov Diagram (After Burdon and Mazlounr (1958) and Lloyd (1965))

5- No dominant anion or cation, indicates waters exhibiting simple dissolution or mixing.

6- $SO_4^{2-}$ dominant or anions indiscriminant and $Na^+$ dominant, is a water type not frequently encountered and indicates probable mixing influences.

7-$Cl^-$ and $Ca^{2+}$dominant, is infrequently encountered unless cement pollution is present in a well; otherwise the waters may result from reverse ion exchange of $Na^+$- $Cl^-$ waters.

8-$Cl^-$ dominant and no dominant cation indicate that the groundwater may be related to reverse ion exchange of $Na^+$- $Cl^-$ waters.

9- $Cl^-$ and $Na^+$ dominant frequently indicate end-point waters. The Durov diagram does not permit much distinction between $Na^+$- $Cl^-$ waters.

The arrows indicate possible process paths such as ion exchange or dissolution.

**Chadha Diagram**

The diagram, shown in Figure (10), is a somewhat modified version of the Piper diagram and the expanded Durov diagram. The difference is that the two equilateral triangles are omitted, and the shape of the main study-field is different. In the Piper diagram, the milliequivalent percentages of the major cations and anions (percentage reacting values) are plotted in each triangle and the type of water is determined on the basis of position of the data plot in the respective cationic and anionic triangular fields. The plotting from triangular fields is extended further into the central diamond field, which provides the overall character of the water.

In contrast, in this diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis, and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle, depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earths and alkali metals, and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub-fields of the proposed diagram. The main advantage of the proposed diagram is that it can be made simply on most spreadsheet software packages (Chadha, 1999).

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end-product water), and other related hydroehemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows(Chadha, 1999);

1. Alkaline earths exceed alkali metals.
2. Alkali metals exceed alkaline earths.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. Such water has temporary hardness. The positions of data points in the diagram represent $Ca^{2+}$-$Mg^{2+}$-$HCO_3^-$type ,$Ca^{2+}$-$Mg^{2+}$-dominant $HCO_3^-$-type, or $HCO_3^-$dominant $Ca^{2+}$-$Mg^{2+}$ -type waters.

6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The positions of data points in the diagram represent $Ca^{2+}$-$Mg^{2+}$-$Cl^-$ type, $Ca^{2+}$-$Mg^{2+}$-dominant $Cl^-$type, or $Cl^-$-dominant $Ca^{2+}$-$Mg^{2+}$-type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in the proposed diagram represent $Na^+$-$Cl^-$-type, $Na_2SO_4^{2-}$type, $Na^+$-dominant $Cl^-$type, or $Cl^-$dominant $Na^+$-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the proposed diagram represent $Na^+$-$HCO_3^-$-type, $Na^+$-dominant $HCO_3^-$-type, or $HCO_3^-$-dominant $Na^+$-type waters.

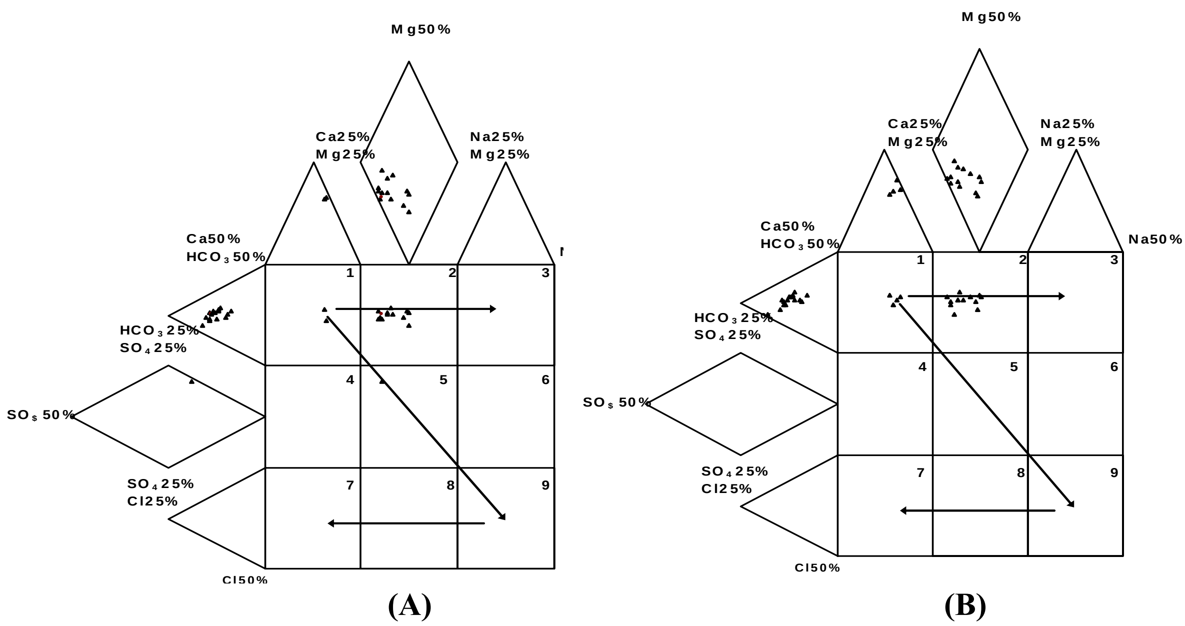



Fig 9: Expanded durov diagram for water samples:
(A) Dry season, (B) Wet season

## CONCLUSION

The main conclusions of this study are:

1- There is a slightly seasonal variation of groundwater quality due to excess rainfall in the wet period.
2- Soils and aquifer materials are the major sources of cations and anions, whereas the fertilizers, municipal wastewater and irrigation-return-flows are additional contributors of $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$, $NO_3^-$, and $PO_4^{3-}$).
3- Some wells are polluted with nitrate and phosphate due to impact of urbanization.
4- The hydrochemical study showed that the water type is $Ca$-$HCO_3$ type.
5- The areal distribution of electrical conductivity (EC) showed that the center of Kalar town has high value of ions.

6- Some of the water samples are not suitable for drinking because they exceeds permissible limit, proposed by (IDWS).
7- According to US Salinity Laboratory diagram, the water samples are relatively good for irrigation and the water samples located in the field ($C_2S_1$).
8- Water samples are suitable for all industrials except for textile, chemical pulp and paper industry.
9- The chemical weathering of rock-forming minerals is the major mechanism that influence the groundwater quality.

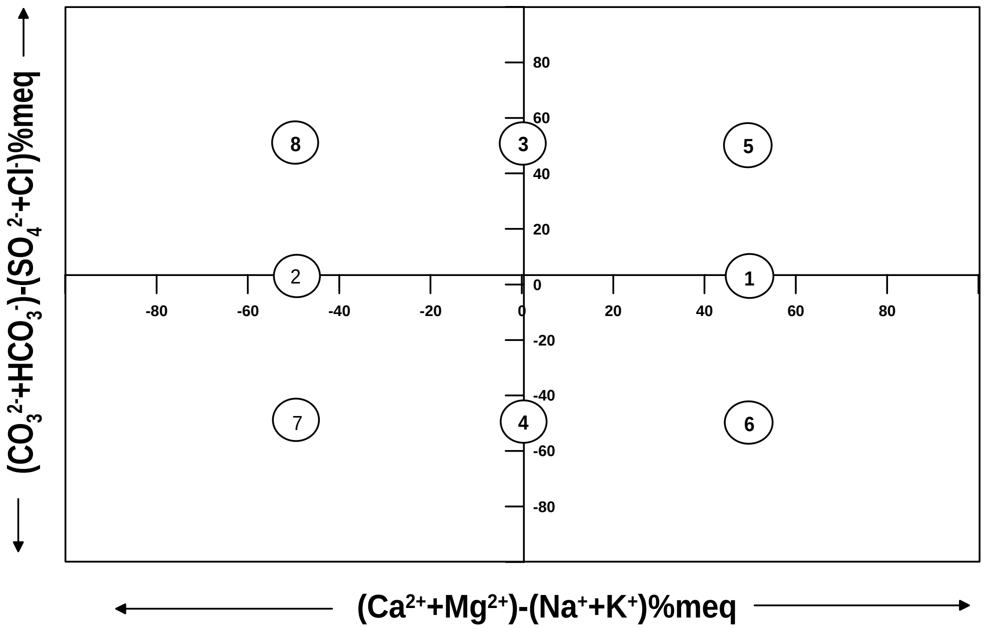



Fig 10 : Chadha Diagram(1999)

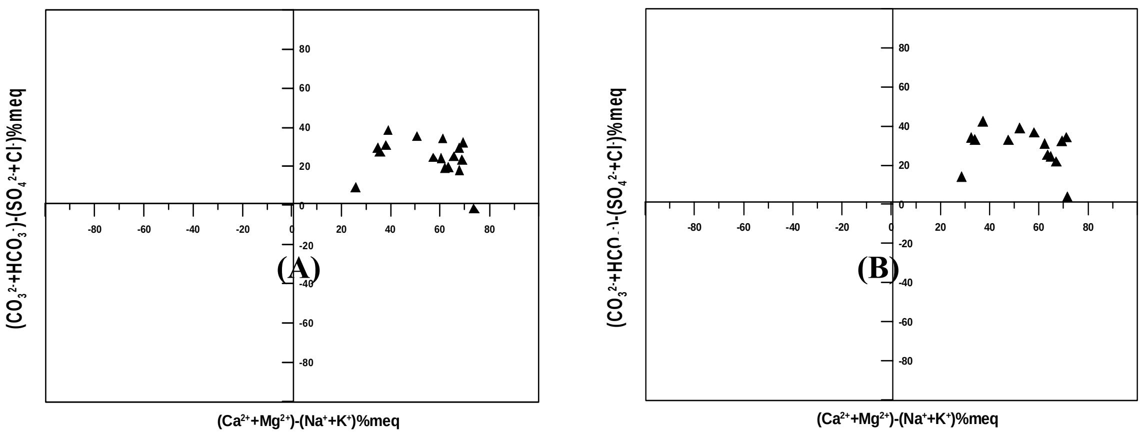



Fig 11 : Chadha Diagram for Water Samples:(A) Dry Season,(B) Wet Season

**Recommendations**

Inferior quality of groundwater may cause water-borne diseases and crop damage. About 80% of water-borne diseases in the world (WHO 2006) and over one-third of the total deaths in the developing countries are caused by consumption of polluted water and lack of knowledge of water quality assessment .Pollution of water severely damages eco-system, which, in turn, reduces agricultural production. Since quality of groundwaters in the studied area has been deteriorated, the following management plan is suggested for sustainable development:

1- Proper treatment of groundwaters, such as water softening, ion exchange, and demineralization and defluoridation of water, should be used to reduce concentrations of $SO_4{}^{2-}$, $NO_3^-$ ,$PO_4^{3-}$ and $F^-$ .
2- Excess use of fertilizers for higher crop yields should be avoided to reduce $Na^+$, $Cl^-$ ,$SO_4^{2-}$, $NO_3^-$, $PO_4^{3-}$ and $F^-$) from infiltrating recharge waters.
3- Environmental education is needed to create awareness regarding damage on irrigation and health due to inferior quality of groundwater.
4- Construction of new sewerage system in the city to reduce infiltration of municipal water to the groundwater.
5- Heavy metals analysis of groundwater in order to ensure that it is clear from such elements.

## REFERENCES

Adams, S., R., Pietersen, K., Tredoux, G., Harris, C.2001. Hydrochemical Characteristics of Aquifers near Sutherland in the Western Karoo, South Africa Journal of Hydrology 241 91-103 pp.

Al-Manmi.D.A.M.2007. Excel Program to Calculate Adjusted Sodium Adsorption Ratio (SAR) and Suitability of Groundwater for Irrigation.

Al-Rawi,Y.T, Al-Sayyab, A.S., Al-Jassim, J.A.,Tamer-Agha, M.Y, 1992.New Names for Some of the Middle Miocene-Pliocene Formation of Iraq.Geol.J.V.25.No.1. 1-17 pp.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. 20th Ed., Washington D.C., American Public Health Association.

Appelo, C.A.J. and Postma, D. 1999. Geochemistry, Groundwater and Pollution. Rotterdam: A.A. Balkama, 536 P.

Ayers, R.S. and Westcot, D.W. 1994. Water Quality for Agriculture. Irrigation and Drainage Paper 29, Rev. 1, FAO, Rome, Italy, 174 P.

Bellen, R.C., Van Dunnington, H.V., Wezel, R. and Morton, D.M. 1959. Lexique Stratigraphique International. Vol. III, Asie, Fasc. 10a, Iraq,Paris, 336 P.

Buday, T. 1980. The Regional Geology of Iraq, Vol. I: Statigraphy an Paleogeography. I.I.M. Kassab and S.Z.Jassim (Eds).SOM, Baghdad, Dar El Kutib Publ. House, University of Mosul., 445 P.

Buday, T. and Jassim, S.Z. 1987. The Regional Geology of Iraq, Vol. II Tectonism, Magmatism, and Metamorphism. 352P.

Burdon, d.j., Mazloum, S.1958.Some Chemical Types of Groundwater from Syria.UNESCO Symp.Teheran, UNESCO, Paris.73-90 pp.

Chadha,D.K. 1999.A Proposed New Diagram for Geochemical Classification of Natural Waters and Interpretation of Chemical Data. Hydrogeology journal: 7:431-439pp

Detay, M. 1997. Water Wells – Implementation, Maintenance and Restoration. John Wiley and Sons, London, 379 P.

Domenico, P.A. and Schwartz, F.W. 1998. Physical and Chemical Hydrogeology. John Wiley and Sons Inc., New York, 506 P

Durov, S.A.1948.Natural Waters and Graphic Representation of their Composition.Dokl. Akad.Nauk SSSR 59, 87-90 pp.

Esteller, M.V. and Andreu,J.M. 2005.Anthropic Effects on Hydrochemical Characteristics of the Valle de Toluca Aquifer(central Mexico).Hydrogeology J.13:378-390 pp.

Gibbs, R.J.1970.Mechanisms Controlling World Water Chemistry, Science 170: 1088-90 pp.

Hem, J.D. 1991. Study and Interpretation of the Chemical Characteristics of Natural water**.** USGS Water Supp. Paper no. 2254, 263 P.

Hudak, P.F. 2000. Regional Trends in Nitrate Content of Texas Groundwater. J. Hydrology 228: 37-47pp.

IGS, 1998.Iraqi guideline standard for drinking water, in Arabic.

Jassim,S.Z.Goff.J.C(eds.).2006.Geology of Iraq .Dolin ,Prague and Moravian Musium, Brno.341P.

Kerr, R., S.1993. Ground Water Sampling -A Workshop Summary, Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency, 158 P.

Langmuir, P., 1997**.** Aqueous Environmental Geochemistry**.** Prentice-Hall, 600 P.

Lioyd,J.W.(1965).The Hydrochemistry of the Aquifers of North-Eastern Jordan.J. hydrology.3,319-330pp.

Majumdar D, Gupta N 2000. Nitrate Pollution of Groundwater and Associated Human Health Disorders. Indian J Environ Health 42(1):28–39pp.

McKenzie, J.M., Sigel, D.I., Patterson, W. and McKenzie, D.J. 2001. A Geochemical Survey of Spring Water from the Main Ethiopian Rift Valley, Southern Ethiopia: Implications for well-head Protection**.** Hydrogeology J. 9: 256-272pp.

Mustafa O. M.2007. Impact of Sewage Wastewater on the Environment of Tanjero River and Its Basin within Sulaimani City/NE-Iraq.Msc thesis, unpublished, College of Science University of Baghdad, 142 p.

Omelon C. R., Pollard W. H., Andersen D. T. 2006. A Geochemical Evaluation of Perennial Spring Activity and Associated Mineral Precipitates at Expedition Fjord, Axel Heiberg Island, Canadian High Arctic**,** Applied Geochemistry: 21: 1–15pp.

Parsons,C. 2006. Mini Master Plan for the Public Water Supplies for the Governorate of Sulaymaniyah Iraq Public Works/Water Sector, Project and Contracting Office United States Mission to Iraq Baghdad, Iraq Contract No. W914NS-04-C 0003, 358 P.

Rao N. S.2006. Seasonal Variation of Groundwater Quality in a part of Guntur District, Andhra Pradesh, India. Environmental geology 49: 413–429pp.

Schoenleber, J. R., 2005. Field Sampling Procedures Manual, Department of environmental protection, New Jersey, 574P.

Sissakian,V.K.2000. Geological Map of Iraq. State Company of Geological Survey and Minning,Baghdad,Iraq.

Stevanovic, Z. and Markovic, M., 2004a. Hydrogeology of Northern Iraq.vol.1, Climate, Hydrology, Geomorphology and Geology. Food and Agriculture Organization of the United Nations, Rome.190 P

Stevanovic,Z. and Markovic,M.,2004b. Hydrogeology of Northern Iraq.vol.2, General Hydrogeology and Aquifer Systems. Food and Agriculture Organization of the United Nations, Rome 264P.

Todd , D.K. 1980.Groundwater Hydrology(2nd edition).John Wiley and Sons, New York,USA,535p.

US Salinity Laboratory Staff 1954.Diagnosis and Improvement of Saline and Alkali soils. US Department of Agricultural Hand Book 60, Washington.

USA, Lioyd, J.W.1965.The Hydrochemistry of the Aquifers of North-Eastern Jordan.J.Hydrology.3, 319-330pp.

World Health Organization (WHO), 2006. Guidelines for Drinking-Water Quality. 3rd ed., Vol.1, Recommendations, Geneva, 595 P.