Water Quality Evaluation of Bura'a Natural Protected Area, Hodeidah, Yemen

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Abstract. Water quality study carried out in Bura'a natural protected area for fifteen water samples collected from differen springs and surface water resources distributed within the study area. This study aims to evaluate the suitability of water resources for drinking purpose and also to find its suitability for agricultural uses. Physical, chemical and bacteriological parameters of water resources such as temperatue (T), Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Na^{+}, K^{+}, Ca^{+2}, Mg^{+2}, Cl^{-}, HCO_3^{-2}, SO_4^{-2},NO_3^{-1}, Fe^{+2}, F^{-1}, PO_4^{-2}, total coliform and fecal coliform were determined. The results shows that the abundance of the major ions is as follows: Ca^{+2}> Na^{+} > Mg^{+2} >> K^{+} and HCO_3^{-} > Cl^{-} > SO_4^{-2} >NO_3^{-}. Water classification of the study area indicate the the role of simple dissolution and weathering in the chemistry of water resources. Water resources in the study area is generally hard to very hard and considered as fresh water type with TDS less than 600 mg/l. The analytical results of physical and chemical studied samples identify a suitability of water for drinking except few samples that shows a relatively high concentration level of nitrate. Water resources in the study area have a considerable amounts from fecal coliform above the maximum permissible limits that determined from WHO and Yemeni standards fron drinking purposes. Therfore, the bacteriological parameters of water samples indicate unsuitability of studied samples for drinking. Sewage and agricultural activities are generally leading to water resources pollution in the study area which is alarming considering the use of this water for drinking. All water samples have low sodium hazard (SAR) (S1) and high salinity hazard (C3), Na% less than 40% that indicate the suitability of water resources for all types of irrigation purposes.

Keywords: Bura'a natural protected area, water quality, water pollution, Yemen.

1 INTRODUCTION

Bura’a natural protected area is considered one of the last remaining Arabian forests, hides between the sea and the desert in the shelter of the magnificent granite Jabal Bura’a mountain overlooking the Tehama plain onto the Red Sea. In 2011 UNESCO added the protected to its list of World Network of Biosphere Reserves. It is the second Yemeni protectorate to be included in the World Heritage registration after the island of Soqotra. The protected covers about 4,200 hectares and is named by UNSECO as one of 57 locations that are maximum importance to birds. It includes about 12 percent of Yemen’s rare flora, including 209 highly significant plants (Environment Protection Authority (EPA) open file).

An accurate description of the biodiversity of Bura’a Protected is hard to provide, as detailed studies are few and infrequent. Surveys and studies have reported about 315 types of plants divided among 83 species, of which 63 are rare at the local and regional levels. Bird studies have listed about 93 different species, of which 32 are sedentary and 17 are of African origin. . According to studies conducted by EPA, the woodland has at least nine species of mammal, including such rarities as the striped hyena, the white-tailed mongoose and the African lynx. There are numerous hard-to-classify reptiles with at least 13 known reptile genera represented. These include the large Yemeni monitor lizard (also called the snake hunter). The cobra snake also inhabits the protected, along with many fresh water reptiles. Amphibians and fresh water fish species have been recognized also in the protected. Recently, The forest has already suffered much by the introduction of a tarmac road through its heart, and the pollution and logging that followed it. The road construction has destroyed up to 30 percent of the forest, disrupted the local water supplies and damaged the unique local fauna and flora. Hydrologically, the protected is considered as a part of the lower part of Wadi Siham basin (Fig. 1).

The evaluation of Bura'a protected is important due to the following reasons: it's locally and international importance, agricultural activities in the area and it's touristic importance in the near future where the protected area become one of the major touristic areas in Yemen.

The main objectives of this study are to:

- Study the water quality characteristics in the protected area.
- Assess the suitability of water resources in the protected area for drinking and irrigation purposes.
- Study the spatial distribution of major ions in the protected area.

2 DESCRIPTION OF THE STUDY AREA

Bura'a protected area lies about 50km north-north-east of the coastal city of Hodeida. The highest elevation of Jabal Bura of reached to 2040 m in the Rokab village, and the lowest elevation is 300 m in the Al-Kaba village (Figs. 1 and 2). The geology of study area, surface drainage system have been greatly influenced by the orogenic processes, which completely controlled by the tectonic environmental history of the Red Sea Rift System. The tertiary volcanics of Yemen are related to the Afar mantle plume which impacted the Arabia-Africa area during the Oligocene (Geoffroy *et al.*,1998). The Tertiary volcanics consist of both lava flows and intrusions which mainly of granites. Tertiary granites intrusions outcrop mainly along the western border of the Yemen plateau (uplifted Mesozoic sediments and tertiary lavas) which separates from the subsiding Tihama plain. The main granites outcrops occur in Jabal Hufash, Jabal Bura and Jabal Sabir. The chemistry granitic bodies of Yemen are generally alkaline or peralkaline granites and are produced by fractional crystallization from basic magmas (Capaldi *et al.* 1987, Chazot and Bertrand, 1995).

The Jabal Bura granite is located in the western border of the plateau, about 50 km eastern side of Hodeidah city. Jabal Bura Granite is bounded by faults which can be recognized along most of their borders (Fig. 3). The border faults are EN-WS to E-W trending normal faults at the southern borders in the Bura natural protected area. This protected area is located in the southwestern side of Jabal Bura. The intrusion granites at Jabal Bura are a porphyritic alkali feldspar granite with minor quantities of altered biotite and arfvedsonite (Davison *et al*., 1994). The alkaline granitic rocks consist of perthite, microcline sodic amphibole and quartz (El-Anbaawy, 1985). Some silicic granite intrusions (holocrystalline) enclose crystals of amphibole, and show more affected by weathering.

Hydrologically, There are wadis and streams cutting the study area, these wadis extend EN-WS or WS -EN. BNP represent the Wadi Regaf drainage basin (Fig. 1). The wadi Regaf drainage basin is the part in the catchment area of Wadi Siham, and extending E-W. The morphometric measurements of the Wadi Regaf basin show the main channel is 4^{th} order according to the methods of Strahler (1952, and 1957) and Horton (1945). The stream length reflects the importance of the basin towards the runoff quantities. Also, it can help in locating dam site to break the flow passage and thus minimizing losses due to evaporation and seepage. The total length of Wadi Regaf basin is 59.6 km. The drainage density of the wadi basin is 3.5 km/km^2. The major faults trends represent the main factor affecting of the drainage density at Wadi Regaf.

3 MATERIALS AND METHODS

Water samples were collected from fifteen representative springs and surface water resources during February, 2012 from different fields in the protected (Fig. 1). Temperature, electrical conductivity (EC) and pH were measured using digital meters immediately after sampling in the field. Water samples collected in the field were analyzed for chemical constituents such as sodium, potassium, calcium, magnesium, chloride, bicarbonate, sulphate, nitrate, phosphate, iron and fluoride, and bacteriological analysis for total coliform and fecal coliform using recommended methods of analysis as suggested by the American Public Health Association (APHA, 1995) at the laboratories of faculty of marine science and environment, Hodeidah University and Hodeidah local water and sanitation corporation (HLWSC). The accuracy of the chemical analysis was verified by calculating ionic balance error which is generally with 5%.

Graphical methodologies were used to classify the water samples into homogeneous groups by using aqua hem version 3.6.2 for windows. The SI were calculated using The particular GIS software tool used in this study is (ESRI) ArcGIS 9 software package to mapping the spatial distribution of salinity and major ions and all other maps of geology and DEM of the study area.

Evaluation of the water for drinking uses was carried out based on a comparison of the physical, chemical and biological parameters in the water of wells and springs with the drinking water guidelines of World Health Organization WHO (1997) and the Yemeni Quality Standards (2000). Evaluation of water quality also for agricultural uses was carried out based on EC, Sodium Adsorption Ratio (SAR) and Sodium content (Na%).

4 RESULTS AND DISCUSSION

4.1 Water chemistry

The results of the physico-chemical and bacteriological characteristics of the studied water samples are presented in Table (1). The pH values range from 7.13 to 7.4 with an average value is 7.26. pH values indicate the alkaline water nature in the study area. while the field temperature range varies between 23.1 ^{o}C and 27.4 ^{o}C . electrical conductivities indicates the amount of ions dissolved in water and its values of the studied samples range from 780 µS/cm to 1028 µS/cm and TDS range from 424 mg/l to 599 mg/l. Water resources in the study area is fresh water type. Fresh water has TDS less than 1000 mg/l (Freeze and Cherry, 1979). Approximately all studied samples have TDS less than 1000 mg/l. Among the cations, the concentrations of Na, K, Ca and Mg ions ranged from 44 to 72, 0.66 to 1.8, 90 to 119 and 11 to 30 mg/l with a mean of 58, 0.93, 98.6 and 18.4 mg/l, respectively. The order of abundance is Ca>Na> Mg >>K. Among the anions, the concentrations of Cl, HCO3, SO4 and NO3 lie between 71 to 113, 115 to 210, 80 to 190 and 24 to 69 mg/l with a mean of about 84.4, 163, 121.8 and 43.5 mg/l in respective order. The order of abundance of major anions is HCO3 > Cl> SO4 > NO3. The cation and anion concentrations are defined the hydrogeological setting where the HCO3 , SO4 dominant anion species of water indicate the recharge characteristics of the study area (Stuyfzand 1999; Toth 1999, Wen etal., 2005, Nasher etal., 2011). Generally, water in the discharge zones tend to have higher salinity compared to that of the recharge areas due to the longer residence time and prolonged contact with the aquifer matrix (Freeze and Cherry, 1979; Suhuh et al., 1997). The spatial distribution of TDS within the study area shows that the low TDS concentration with maximum value less than 600 mg/l is attributed to the hydrogeological setting of the study area which is considered as a recharge area to the lower part of Wadi Siham basin. The increases in the water salinity are in agreement with groundwater flow within the study area and it's topographical where high TDS values is coincide with low relief area along foot hills as shown in figure (4).The distribution of the major ions especially chloride, sulfate and sodium show approximately the same increase trends coincide with the concentration map of the TDS (Fig. 5). It is also noted that the nitrate concentration shows a different trend of increases. Its maximum concentration reaches 69 mg/l in the eastern part of the study area (Fig.5). Here parts of the study area are comparatively more densely populated and has larger agricultural activities. Therefore, the source of nitrate is attributed to the infiltration of house waste water and fertilizer application into the water resources bodies.

4.2 Hydrochemical facies

The hydrochemical facies classification is based on the three anions (HCO_3, Cl and SO_4) and the cations (Na, K, Ca and Mg) calculated in meq/l, which occur in water as major chemical elements. These classification bases include the diagrams of Piper and Durov. The major ions concentrations of the analyzed samples were plotted on Piper diagram using “Aquachem” software as shown in Figure (6). It can be seen that the majority of data form a distinct group of HCO3 – SO4 water type. This water type explain the recharge setting of the study area (Wen etal., 2005). The major ion concentrations of water samples are also plotted on Durov diagram using “Aquachem” software (Fig.7). This diagram has advantages over Piper diagram because it reveals some geochemical processes that could affect water genesis. From Figure (7) reveals that most samples plot in the dissolution or mixing line based on the classification of Lloyd and Heathcoat (1985). This type suggest the simple dissolution and weathering in the area where the area is characterized by relatively high rainfall amount and the main Raggaf wadi in the protected is permanent wadi and is the main source recharge to groundwater. This hydrogeological setting with geological setting of the area increase the weathering and dissolution processes.

4.3 Dissolution and deposition

The saturation indices are useful in predicting the extent of water chemical equilibrium with the minerals composing the rock and the dissolution and/or deposition processes during rock-water interactions. The SI of a particular mineral can be defined based on the following equation (Lloyd and Heathcode 1985):

$$SI = \log (K_{IAP} / K_{SP})$$

Where K_{IAP} is the ionic activity product and K_{SP} is the solubility product of the mineral.
When the SI value equals zero then the water is in equilibrium with respect to a particular mineral. But if the SI is over zero (positive value) then the water is oversaturated with respect to the concerned mineral and that mineral tends towards precipitation, while if the SI is less than zero (negative value) then the water is undersaturated and that mineral tends towards dissolution from the rock matrix. The SI for halite, anhydrite, gypsum, calcite, dolomite, aragonite and fluorite were calculated using PhreeqC program for windows (Parkhurt and Appelo, 2003) and are listed in Table (1). From Table it can be seen that all studied samples are undersaturated with respect to all considered minerals with different undersaturation degrees. This undersaturation state of all studied minerals can be attributed to the hydrogeological and geological setting. The functional sources of dissolved ions can be broadly assessed by plotting Na/ (Na+Ca) and Cl/ (Cl+HCO_3) as a function of TDS (Gibbs, 1970) which indicate the chemical weathering of the rock forming minerals in the study area as shown in figure (8).

4.4 Water Quality

Drinking water suitability

To foresee the suitability of water for drinking purpose, each sample was compared with the WHO guidelines (1997) and Yemeni standards (2000) for drinking water. To ascertain the suitability of water for any purposes, it is essential to classify the water depending upon their hydrochemical properties based on their TDS values (Freeze and Cherry 1979; Subramani et al, 2005). TDS concentration is a secondary drinking water criteria because of its esthetic effect rather than a health hazard. Elevated TDS value indicates that the dissolved ions may cause the water to be corrosive, have salty or brackish taste and it may also indicate that the water contains elevated concentrations of ions that are above primary or secondary drinking water standards such as, nitrate, lead, zinc, etc. The water resource of the study area is fresh water according to the classification of Freeze and Cherry (1979). All of the studied samples are within the maximum permissible level of WHO (1997) and Yemeni standards for drinking purposes.

Water hardness measures the amount of divalent cations present in the water especially calcium and magnesium that react with soap to form precipitates. Therefore, hard water requires considerably more soap to produce lather. The total hardness (TH) is usually expressed as the equivalent milligrams of calcium carbonate equivalent per liter. In the studied samples the TH values range from 282 mg/l to 379 mg/l with an average value 321 mg/l. The classification of studied samples based on TH shows that they fall in hard to very hard category (Sawyer and McCartly, 1967). All of the studied samples have TH within the maximum permissible level of WHO (1997) and Yemeni standards for drinking purposes.

At present there are no documented health impacts for pH, temp., major cations and anions except nitrate. But they are used as indication for the immediate environment of the well and spring sites. In the studied samples the concentrations of these parameters are within the maximum allowable limits for drinking water. From Table (1). The results of selected minor constituents (Fe, F, and PO_4^{-2}) show that all the studied water samples contain very low concentrations that are far below the WHO (1997) and Yemeni standards.

Nitrate is a very important compound to be controlled in the drinking water due to its negative effects on human health especially infants less than two years in age. The high concentration of nitrate in drinking water is toxic and causes blue-baby disease/ methemoglobinemia in children and is responsible for an increased risk to develop stomach and intestinal cancer if consumed for a long periods (Gilly etal., 1984; WHO, 1993). two samples have nitrate concentration exceeding the desirable limit of 50 mg/l based on the WHO (1997) and Yemeni standards and the majority of the studied samples have nitrate concentration exceed 40 mg/l which indicates the role of using fertilizers in agricultural activities in the deterioration of water quality in the study area.

Microbiological water quality

According to WHO (1993), the examination for total and fecal coliform indicator organisms is the most sensitive and specific way for assessing the hygienic quality of water, therefore this test was used in this study. Fecal coliform bacteria are a group of bacteria which are present in sewage material. The presence of fecal coliform bacteria indicates that a fecal source such as animal feedlot run-off, septic tank or cesspool leakage, etc. is in the vicinity. Their presence also indicates that the water may be contaminated with organisms that can cause disease which represents a serious and even deathly health concern.

It is recommended by the WHO (1997) and the Yemeni standards (2001)for drinking water that the count of the total and fecal coliform bacteria must be zero in 100 ml. From the results of this study it was found that studied samples showed low counts, 1-100, of both TC and FC per 100 ml. indicating that the local environment of the well or the springs is the key factor in its biological contamination. From the above result it could be concluded that water resources in the study area are contaminated with coliform bacteria, therefore they are not suitable for drinking unless being treated. Boiling, sun disinfection, or chlorination of the water are possible treatment techniques.

Irrigation water quality

The primary use of water resources in the study area is for irrigation purposes. The suitability of water resources for irrigation is contingent on the effect of the mineral constituents of the water on both plant and soil. Salts may harm plant growth physically by limiting the uptake of water through modification of osmotic processes, or chemically by metabolic reaction such as those caused by toxic constituents (Todd, 1980). Numerous parameters are used to define irrigation water quality. Two criteria were used in this study for evaluating irrigation water quality; total soluble salt content (salinity hazard) and the relative proportion of sodium cations (Na^+) to other cations (sodium hazard).

The electrical conductivity is a good measure of salinity hazard to crop as it reflects the TDS of the water. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soils (Saleh et al., 1999). The water resource in the study area is good for irrigation purposes for all types of agricultural activities where all studied samples have low EC values less than 1500 µS/cm (Agha, 1986). While a high salt concentration (EC) leads to formation a saline soil, a high sodium concentration leads to development of alkaline soil. The sodium or alkali hazard in the use of water for irrigation is expressed in term of sodium adsorption ratio (SAR) which is very important parameter for determining the suitability of water for irrigation because it is a measure of alkali hazard to crops. It can be calculated using the formula:

$$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}}$$

Where the concentrations are in meq/l. All studied samples have SAR values less than 5 indicate that there is no alkali hazard anticipated to the crops (Saleh et al., 1999). The SAR was plotted on the USA salinity laboratory diagram in which the SAR appears as an index for sodium hazard (S) and EC as an index of salinity hazard (C) (Fig.9). The waters were found mostly confined in one class of water types C3-S1 which means high salinity hazards and low sodium alkalinity hazards that indicates the water resources in the study area are useful for irrigation purposes.

Sodium percentage (Na%) is also an estimation of the sodium hazard in the use of water for irrigation like SAR, but it expresses the percentage of sodium out of the total cations not as SAR that correlate sodium with calcium and magnesium only. The Na% is calculated using the formula:

$$Na\% = \frac{\mathrm{Na} + \mathrm{K}}{\mathrm{Na} + \mathrm{K} + \mathrm{Ca} + \mathrm{Mg}} \times 100$$

Where all concentrations are in meq/l. The Na% in the study is less than 40 indicates that the water in the study area is good for irrigation based on Todd (1980) classification.

5. Conclusions

The results of this study provide information that can be useful for the management of the water resources in Bura'a protected especially with respect to water pollution. Interpretation of hydrogeochemical analyses reveals that the water resources in Bura'a protected is fresh water type and is fall into one class HCO3 – SO4 water type. Simple dissolution and weathering process controls the water chemistry with major ions abundance is as follows: Ca>Na> $Mg^2 \geq$ K and HCO_3>Cl> SO_4> NO_3. Although, the physical and chemical parameters except nitrate of water resources fall within acceptable limits for drinking purposes with TDS less than 600 mg/l, the study showed that water resources are unacceptable microbiological quality due to fecal coliform and total coliform type of pollutants in water. The study also highlighted the fact that abnormal nitrate concentration as compared with TDS. Deterioration in water quality from anthropogenic activities has resulted from extensive use of fertilizers and sewage water. All studied water samples have low sodium hazard (SAR), salinity hazard, Na% less than 40% indicate the suitability of water resources for all types of irrigation purposes. It is recommend not to use the water resources especially those located in the vicinity of houses for drinking purposes unless it is treated properly.

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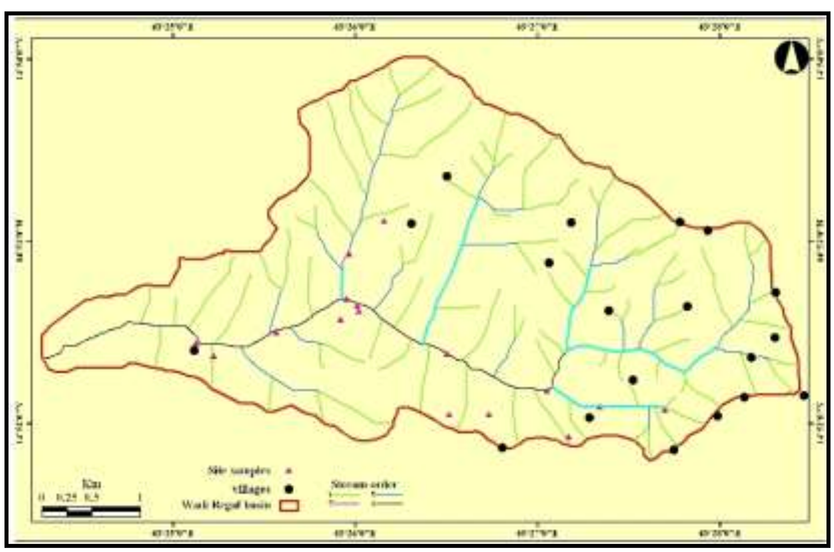


Fig. 1. Location map of the Bura natural protected and Wadi Regaf drainage basin.

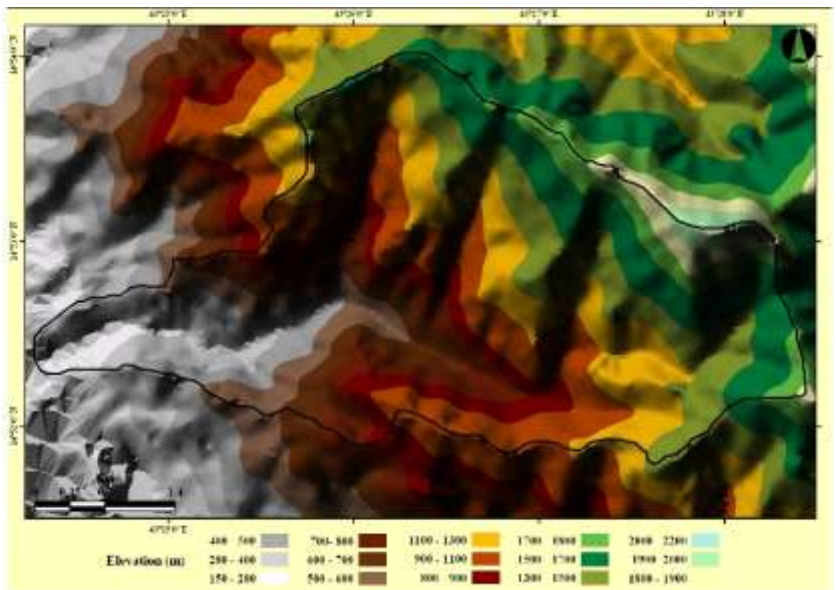


Fig. 2. A DEM map of the Bura natural protected area.

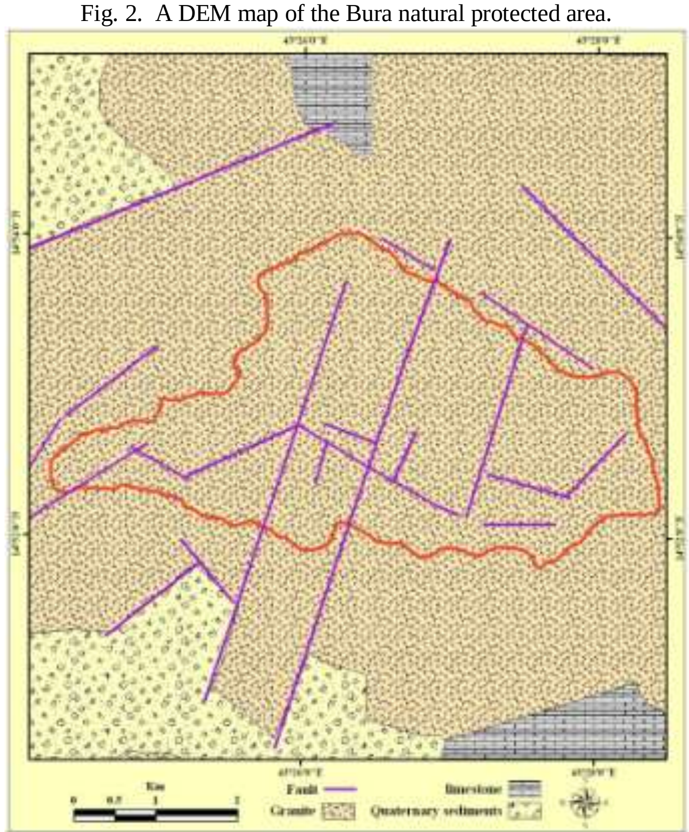


Fig. 3. Geological map of the study area.

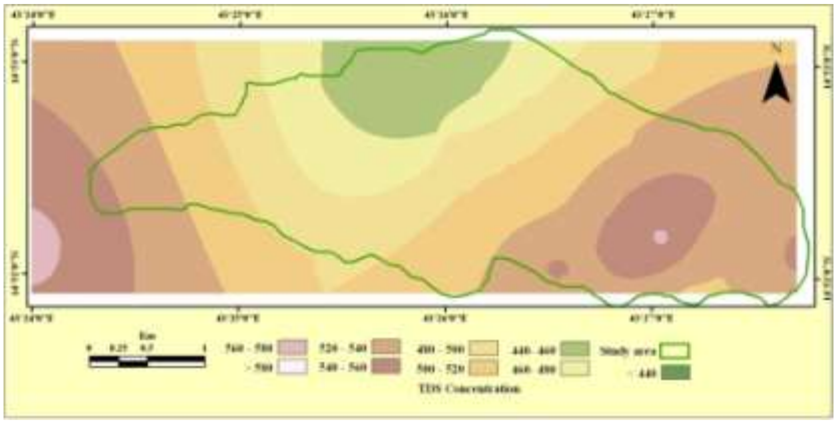
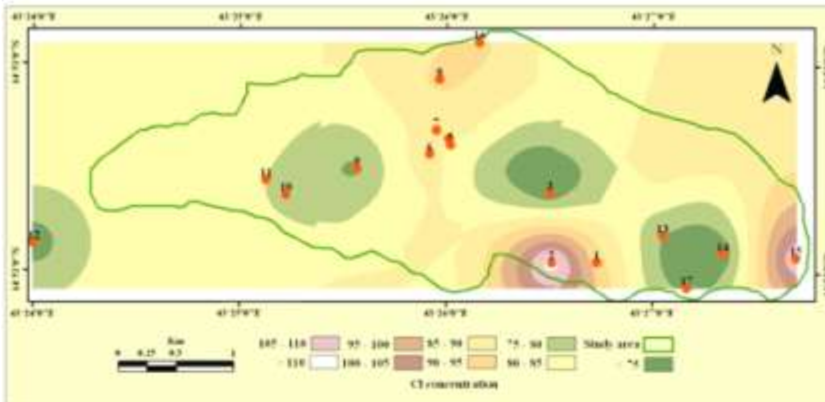
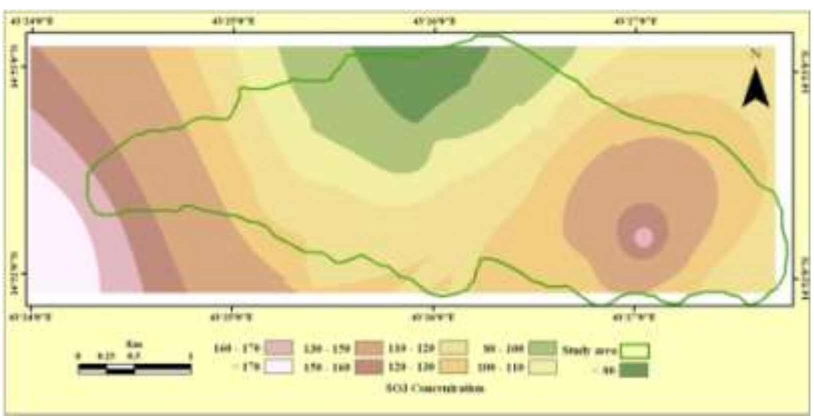


Fig. 4. Isosalinity contour map for the study area (mg/l).





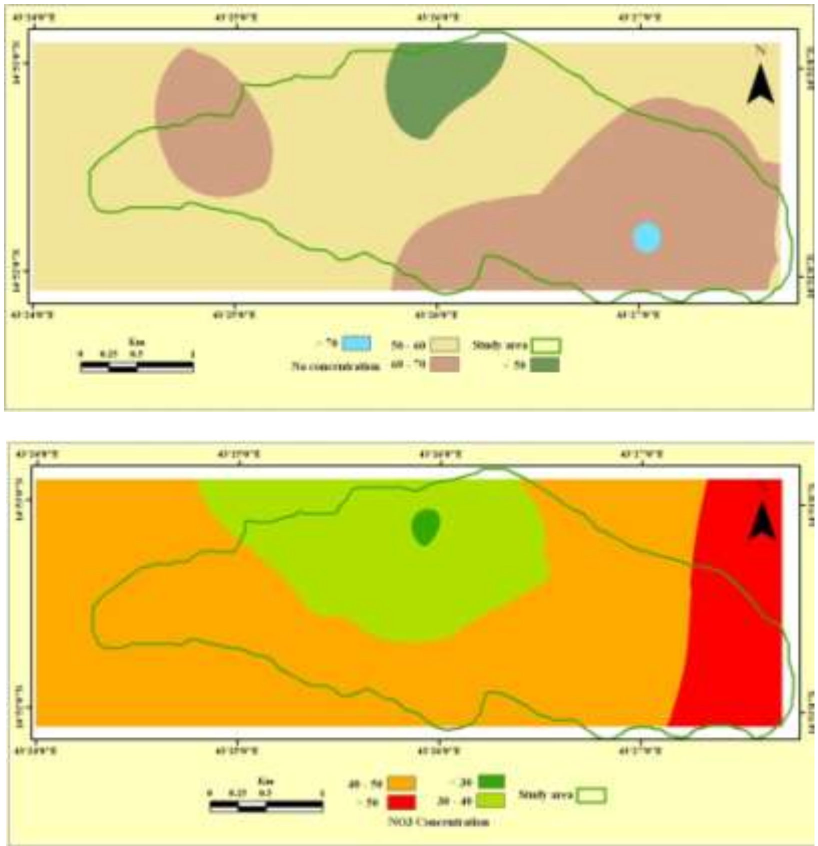


Fig. 5. Distribution map of major anions chloride, sulfate, sodium and nitrate.

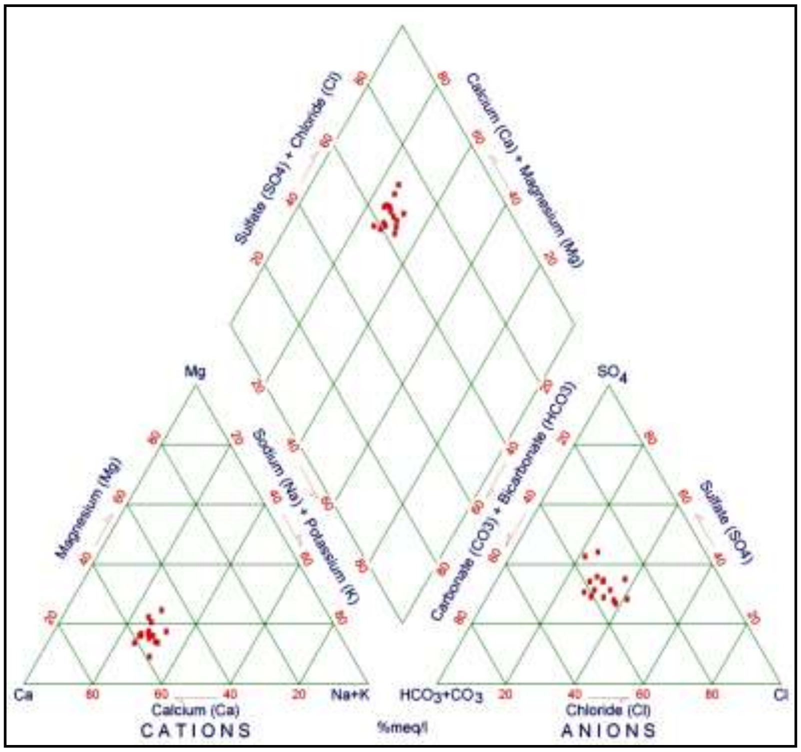


Fig. 6. Piper diagram of the studied samples in the study area.

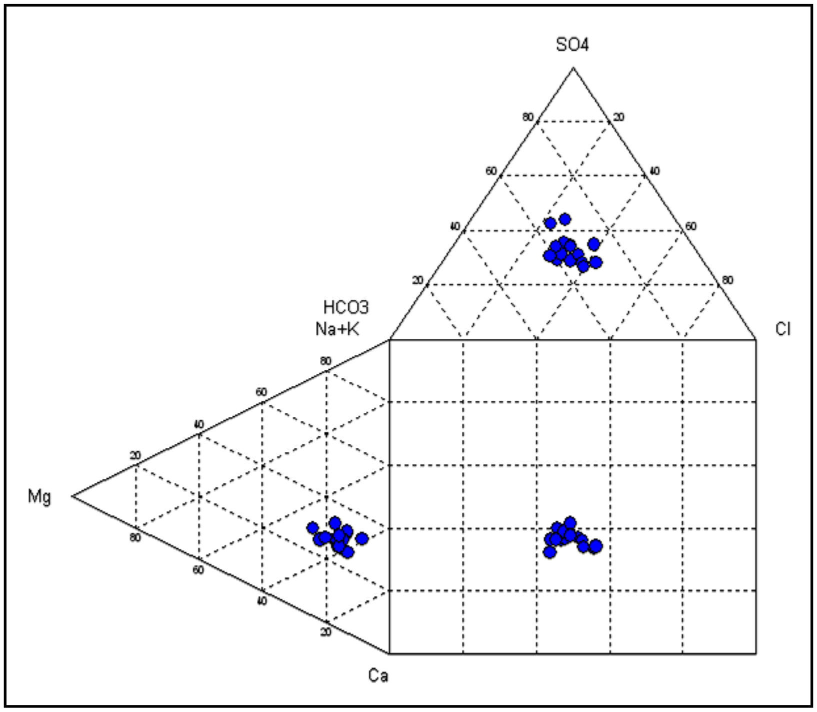


Fig. 7. Durov diagram of studied samples in the study area.

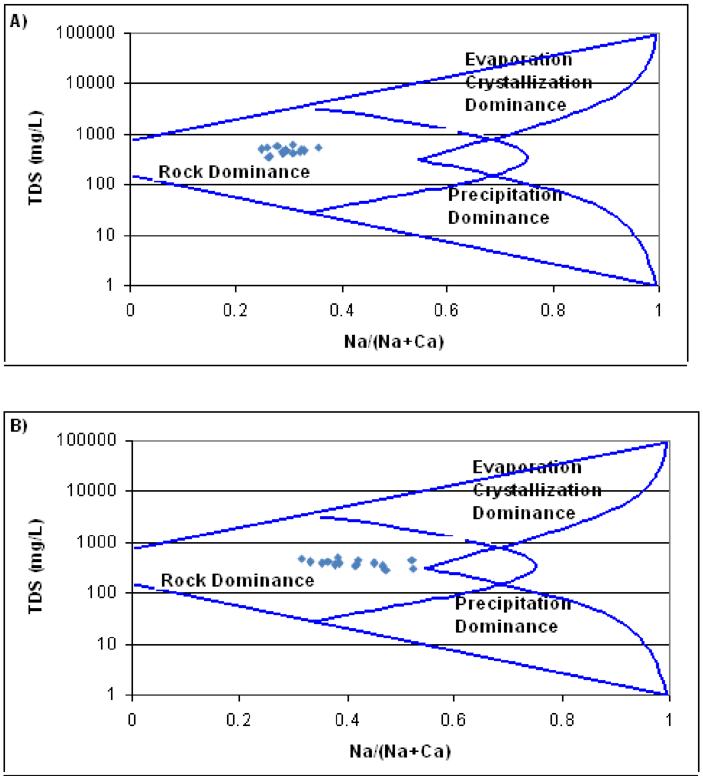


Fig. 8. Mechanisms governing water chemistry (After Gibbs, 1970).

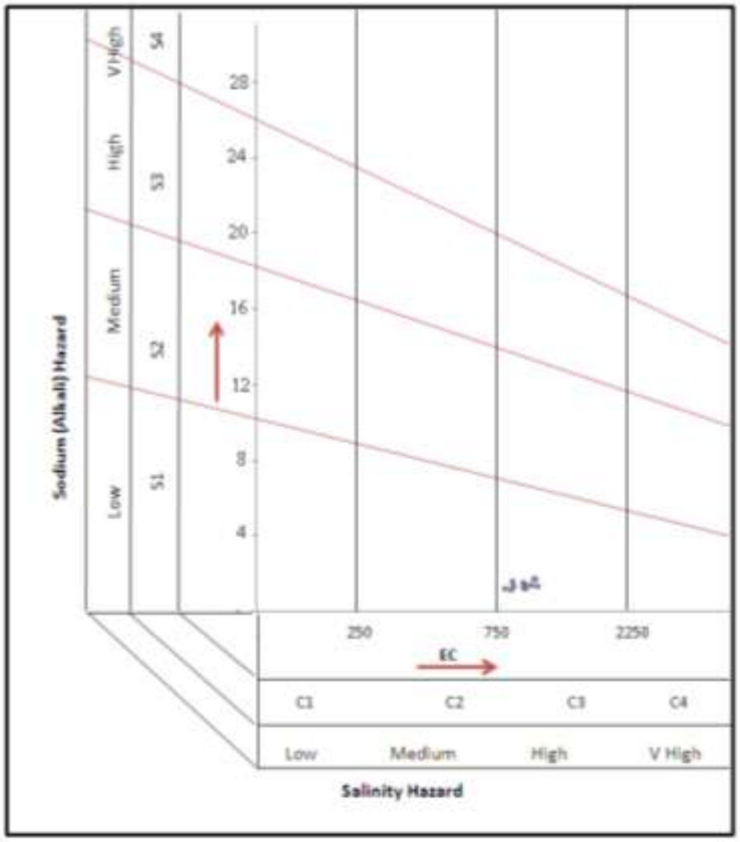


Fig. 9. US salinity diagram for the classification of irrigation waters (after Richards, 1954)

Table 1. Physical, Chemical and biological characteristics of studied samples

Sample	T	pH	EC	NO_3	SO_4	HCO_3	Cl	Mg	Ca	K	Na	Fe	F
BPA 1	23.4	7.16	931	25	120	210	92	30	95	1.8	63	Nil	0.88
BPA 2	23.2	7.13	1005	24	130	210	113	20	93	0.95	70	Nil	1.1
BPA 3	23.1	7.19	970	43	120	170	71	17	102	0.8	60	0.02	0.66
BPA 4	24.5	7.16	919	49	110	150	90	23	96	0.83	56	0.02	0.75
BPA 5	24.1	7.22	925	38	122	210	81	15	109	0.75	52	0.01	0.77
BPA 6	24.6	7.15	840	45	90	140	89	18	96	1.27	55	Nil	0.35
BPA 7	24.9	7.4	825	41	80	130	85	16	90	0.77	46	0.01	0.42
BPA 8	24.5	7.2	780	42	85	115	91	16	93	0.79	48	0.01	0.4
BPA 9	23.4	7.3	922	44	110	140	74	17	93	0.68	58	0.01	0.41
BPA 10	25.4	7.36	916	47	110	170	78	18	92	0.9	53	Nil	0.35
BPA 11	27.4	7.35	906	49	120	150	80	15	95	0.88	62	Nil	0.63
BPA 12	27.3	7.35	906	34	190	200	72	26	100	0.66	55	Nil	0.36
BPA 13	23.4	7.26	995	64	180	160	75	11	116	1.3	72	0.01	0.68
BPA 14	23.2	7.35	830	69	120	150	71	14	90	0.88	61	0.12	0.67
BPA 15	23.5	7.32	1028	25	140	140	110	20	119	0.76	60	0.01	0.41

Table 1. continued. Units mg l/1 except pH, SI, T (^{o}C), EC (µS/ cm), Na (%), SAR and RSC (meq/l)

Sample	TH	TDS	Total Coliform	Fecal Coliform	Na%	SAR	SI hal.	SI gyp.	SI flor.	SI dolo.	SI calc.	SI arag.	SI anhy.
BPA 1	360	533	95	6	27.88	1.44	-6.8	-1.5	-1.1	-0.22	-0.02	-0.17	-1.7
BPA 2	314	556	75	2	32.81	1.72	-6.7	-1.4	-0.88	-0.47	-0.07	-0.21	-1.6
BPA 3	324	499	Nil	Nil	28.85	1.45	-6.96	-1.45	-1.27	-0.56	-0.05	-0.2	-1.68
BPA 4	334	500	120	5	26.88	1.33	-6.89	-1.52	-1.2	-0.56	-0.14	-0.28	-1.74
BPA 5	334	523	Nil	Nil	25.47	1.24	-6.97	-1.4	-1.12	-0.39	-0.07	-0.08	-1.65
BPA 6	313	464	135	6	27.88	1.35	-6.9	-1.6	-1.85	-0.72	-0.17	-0.31	-1.8
BPA 7	290	424	236	3	25.81	1.17	-7	-1.65	-1.7	-0.33	-0.04	-0.11	-1.87
BPA 8	297	434	85	3	26.14	1.21	-6.96	-1.6	-1.73	-0.24	-0.04	-0.05	-1.83
BPA 9	301	467	100	4	29.61	1.45	-6.96	-1.5	-1.7	-0.5	-0.05	-0.2	-1.74
BPA 10	303	483	198	4	27.72	1.32	-6.98	-1.53	-1.8	-0.14	-0.11	-0.03	-1.7
BPA 11	298	497	162	1	31.28	1.56	-6.9	-1.48	-1.39	-0.26	-0.04	-0.08	-1.6
BPA 12	356	578	91	8	25.26	1.27	-7	-1.3	-1.8	-0.18	-0.05	-0.08	-1.5
BPA 13	334	599	170	4	32.11	1.71	-6.87	-1.25	-1.2	-0.67	-0.02	-0.13	-1.48
BPA 14	282	501	220	7	32.17	1.58	-6.96	-1.49	-1.3	-0.48	-0.01	-0.14	-1.72
BPA 15	379	558	200	7	25.75	1.34	-6.78	-1.34	-1.46	-0.34	-0.05	-0.09	-1.57