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Water quality evaluation of the groundwater resources in Amran basin, Yemen

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ABSTRACT

This study investigates the hydrological, hydrogeological and environmental conditions in Amran basin that covers approximately 1590 km². The importance of this study is to identify the different environmental conditions associated with the socio-economic development, increase of population of Amran basin, depletion of groundwater, production of large quantity of industrial and domestic wastewater and the increase in using the fertilizer and pesticides for agriculture purposes. The socio-economic development affects badly the quality of the groundwater resources to be used directly for domestic purposes. The collected of water samples of groundwater resources analyzed for their physical, chemical and biological characteristics. According to the obtained results, some of groundwater wells are contaminated biologically by faecal coliform and chemically by high contents of salinity (calcium, bicarbonate, sulfate and nitrate). The groundwater resources in part of the study area unsuitable for irrigation purposes whereas, the water is classified as high salinity hazard with low sodium hazard (C3-S1). Also thermodynamic analyses were performed using Phreeqci software to state the capability of water resources to precipitate or to dissolve the aquifer matrix. Seventy seven percent of the water samples are free of the fecal and total coliform respectively; these percentages are mainly limited to the deep wells. Therefore about 23% of the samples are contaminated with coliform bacteria thus need treatment of disinfection and coagulation before being used for drinking.

Key words: Wells, Groundwater, Pollution, Amran basin.

INTRODUCTION

The water problem in Yemen reached a critical level in many water basins; in Amran basin, where (348297) inhabitants live[1], basically on agriculture (90% of the inhabitants), the annual amounts extracted annually are about 120 million cubic meter (MCM), 85-90% of it is used for agricultural purposes, and about 10-15% is used for other purposes, where the recharge didn't exceed 40m³, which led to a decrease in the level of groundwater. On the other hand, due to the inhabitant's dependence on the septic tanks till a recent date, and also the human activities, specially the agricultural and industrial ones, which are exercised in Amran area, might cause the pollution to reach ground layers to the groundwater basins. This study aims to achieve the following objectives, Evaluation of the suitability of groundwater resources for different purposes (drinking and irrigation), Specification of the different pollutants, their possible sources and their actual impact on the water resources, to study the water quality of the groundwater boreholes in the area for chemical, physical, and biological constituents This should be demonstrated on a map of the location (Its location is within the UTM coordinates 1728000 and 1726000 north, 375000 and 403000 east 15° 40' to 16° 00 north, 43° 50'to 44° 10' in the east) .It is 45km in the southwest to northeast, and 10 km wide west to east, (Fig. 1). The total area of the plain is 24800 hectares and the entire catchment area of

the Valley is 1280 km². The Amran Valley forms, via wadi Attaf, part of the catchment area of wadi Karid, which is in turn a major tributary of wadi Jauf in the east[2].

MATERIAL AND METHODS

Hydrology

The study area has a predominantly the Red sea and the Mediterranean Sea type climate. It is characterized by hot wet summers and cool dry winters[3], Temperatures exhibit large seasonal and diurnal variations. Absolute daily temperatures range from a maximum of 26.6°C to a minimum of 9.7°C. The humid wind in summer changes from north easterly and north direction. While in winter it is affected by dry wind from west and south westerly. Generally, the north easterly wind is dominant in summer and south westerly wind in winter.

The annual rainfall resulting largely from orographic effects, decreases diagonally from west south to north east; from about 321 mm at Shibam rainfall station to 255 mm at Raydah station. Cold and warm fronts steered from derision occurring over the Indian Ocean, the Red sea and the Mediterranean Sea in south westerly to north easterly direction, and by the or graphic effect, cause rainfall in Yemen. At the beginning of warm months, April May and sometimes October, thunderstorm precipitation might occur. The average annual temperature ranges from 9.7 °C and 26.6 °C reactively. The average annual relative humidity is 43.7 %. The sunshine hours are about 9.13 h/d. The average daily wind speed is 2.41 km/h while the wind direction is N.E. The main climatic parameters of Amran basin[4].

Geology and hydrogeology

The Amran valley floor is a graben or down-faulted trough. Quaternary volcanic in the four of dark gray to black basalts up to several of meter thick flank the valley to the East and South-East .Quaternary alluvium, up to 300m thick and consisting of clay, loess, silt, sand and boulder gravel, forms the valley floor. The volcanics are interbedded with the alluvial sediments in many areas. Amran limestone underlies the alluvial in the valley sector and from the high mountainous regions to the West and North of Amran town. Although essentially a yellow-white limestone, marls and calcareous shale's occur within the sequence classified as the Amran limestone[5].

The Quaternary alluvium forms the principal aquifer of the region. The groundwater in the aquifer is being replenished from the surrounding hills via numerous Wadis. Lack of krast-type solution cavities the Amran limestone means it is a relatively poor aquifer regionally, although fractured zone do occur, particularly along the flanks of the valley, renders the formation more productive in some places[6]. The Quaternary alluvium is relatively good aquifer. The highest permeabilities in which are in the gravel layers, aquifer tests were performed given the following ranges of aquifer parameters, transmissivity 860 m²/day, storage coefficient 0.0001 and hydraulic resistant 400days[7].

Aquifer would be exhausted in year 2041 and 30 percent of the valley would have gone dry by 2011. The worse-case scenario presented by[7] was that 60 percent of the wells existing in 1991 would be dry by year 2004, if the increase in depletion of aquifer storage observed between 1977 and 1999 continued at the same rate[7].

Hydrochemistry

The quality of groundwater is a function of its chemical, physical and biological constituents. This study focues on the chemical properties of the different wells located in the study area. The work in the study consists of field and laboratory works as follows:

Field work

The Fieldwork was restricted to the collection of samples from the water sources for chemical and physical analyses in the field by using portable equipment. Measurements included are temperature, electrical conductivity (EC), and pH.

Laboratory work

Chemical and physical analyses were performed on the collected samples to determine concentrations of: (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, NO_3^{-}, $HCO_3^{-}$and Fe^{+2}). The data were be interpreted and reported by using many programs for thermodynamic calculations and statistical and hydrochemical analyses calculations. All analyses

were carried out at the Ministry of Water and Environmental (Yemen). The samples were analyzed according to the standard methods for the examination of water and wastewater[8].

RESULTS AND DISCUSSION

Most of wells in the study area, the cations , anions,, total coliform and fecal coliform, The concentration is within the permissible limits for drinking water recommended by[9,10,11], While concentrations of some elements were higher the maximum limits of drinking water recommended by WHO and standard Yemen, Table 1. Of concentration above limits in some wells according to WHO standard.

Bicarbonate concentration was higher than the maximum limits of drinking water recommended by the World Meteorological Organization (WHO) but it is still within the limits of drinking water recommended by the Yemen standard.

Sulfate concentration was higher than the maximum limits of drinking water by WHO and the Yemen standard. The nitrate concentration in well 3 and 14 is 50 and 45.3 mg/L respectively, the wells lie close to a wastewater treatment plant and a agricultural activities. It is recommended by all the standards that the long-term count of the total and faecal coliform must be zero. According to this it was found the 77% of the samples are free of the fecal and total coliform, is percentage and mainly limited to the deep wells. Therefore, about 23% of the samples are contaminated with coliform bacteria; thus, need disinfection and coagulation before being used for drinking purposes.

The water quality of the water resources depends on the intended uses, domestic, irrigation or industry. Classification of water samples according to their total hardness:

Most of the groundwater in the study area can be used for domestic purpose, the water is

$SO_4^{2-} > HCO_3^- > Cl^-$

Fig. 1: The location map of the study region

classified as moderate (35%) to hard (55%), according to [12], (Tables 2). The evaluation of the sodium adsorption ratio and total dissolved solids/ electrical conductivity plays a major role in the evaluation of irrigation water. The SAR calculated according to the following equation:

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

Most of water samples had very low EC or were non-saline. Water quality analysis showed that water can be used for use in arid region, such as the Amran Valley, where it might have a high salinity hazard, however be used occasionally on a supplemental basis with little danger to all but the most sensitive crop, [13] Only two of the sampled wells (Table 3 and Figure, 2) showed water with a high salinity hazard; whereas all of analyses indicate a low sodium hazard.

Based on the four main cations calcium, magnesium, sodium and potassium, and the four anions, bicarbonate, sulfate, chloride and nitrate[14] proposed a Trilinear diagram that permits the classification of the water according to[15], into six types. All the groundwater samples were plotted on piper's Trilinear Diagram. Fig.3, these water types are:

Type one

This type characterized by normal earth alkaline water with prevailing bicarbonate. This type represents around 65 % of the total samples. The majority of the samples of this water type are located around Amran town, Aljannat, Karef, Raydah and North Amran valley (Thebeen).

The chemistry of this water originates from dissolution of almost pure carbonate. This type of water is characterized by low salinity and with the following ionic order:

$Ca^{2+} > Mg^{2+} > (Na^{+} + K^{+})$

$HCO_3^{-} > Cl > > SO_4^{2-}$

Table 1: The descriptive statistics for different calculated parameters for Sample

Parameter	Minimum	Maximum	Mean	Standard Devitation	N
Temp °C	20.10	28.20	25.23	25.23	20
pH-value	7.00	8.50	7.66	7.66	20
EC ìs/cm	330	1598	616.10	616.10	20
Ca^{2+}(mg/l)	9	167	58.73	41.30	20
Mg^{2+}((mg/l)	2.15	73	20.69	18.19	20
Na^{+} (mg/l)	1.90	319	55.19	65.78	20
K^{+} (mg/l)	0.80	5.50	2.73	1.22	20
HCO_3^{-} (mg/l)	69.80	314	198.55	55.11	20
SO_4^{2-}((mg/l)	8.70	664	117.84	198.60	20
Cl> (mg/l)	3.60	151	42.53	30.58	20
NO_3^{-} (mg/l)	4.80	50	24.76	14.72	20
Fe^{+2}(mg/l)	0.01	0.40	0.12	0.10	20
Total Coliform (Col/100ml)	0.0	560	43.69	155.14	13
Fecal Coliform (Col/100ml)	0.0	2	0.23	0.60	13
SI anhydrite	-30.40	-9.96	-2.30	0.64	20
SI Aragonite	-1.12	0.44	0.00	0.35	20
SI Calcite	-0.97	0.58	0.14	0.34	20
SI Dolomite	-1.19	1.13	0.17	0.63	20
SI Gypsum	-3.18	-0.73	-2.08	0.64	20
SI Halite	-9.71	-5.95	-7.47	0.67	20
SI Hematite	15.48	18.45	16.94	0.85	20

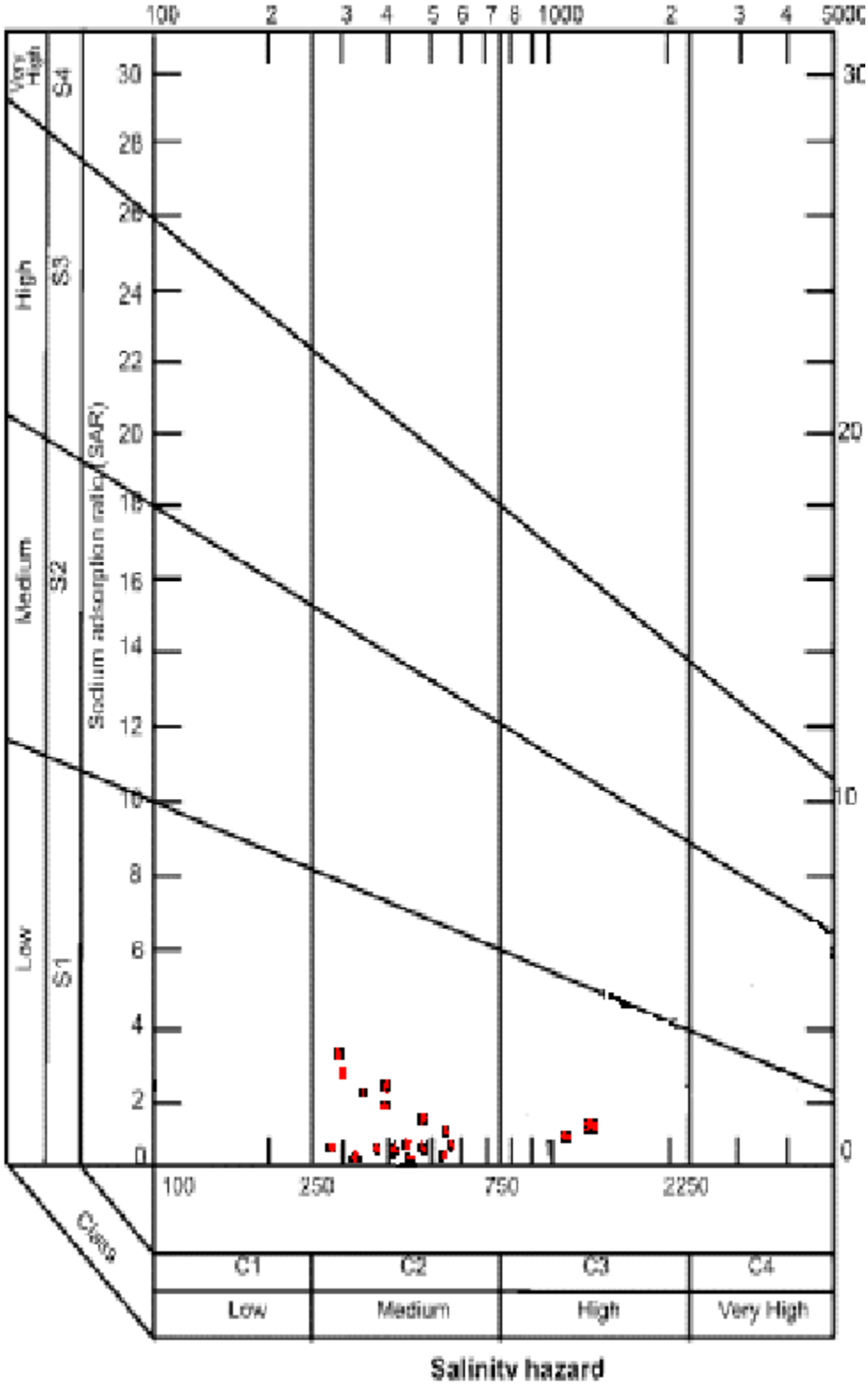

Fig. 2: Classification of the water samples for irrigation purposes Based on SAR and EC (µs/cm)

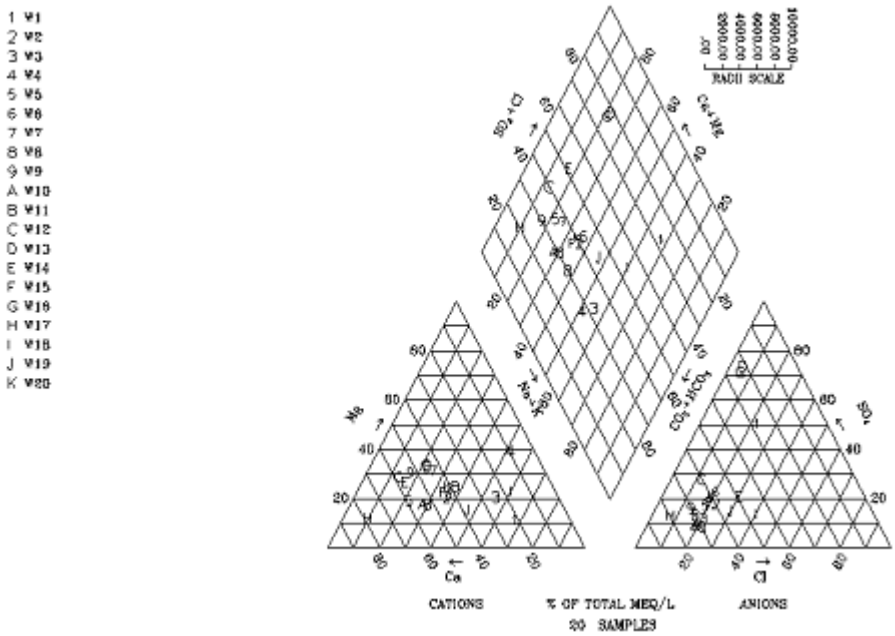

Fig. 3: Piper's Trilinear diagram of the major ions of the water samples

Table 2: Classification of Hardness for Water Group, Based on Sawyer and McCarty (1976)

Well	Hardness as $CaCO_3$	Water Class
W1	336	Very hard
W2	168	Hard
W3	90	Moderately hard
W4	32	Soft
W5	240	Hard
W6	148	Moderately hard
W7	158	Hard
W8	127	Moderately hard
W9	272	Hard
W10	208	Hard
W11	168	Hard
W12	169	Hard
W13	147	Moderately
W14	156	Hard
W15	148	Moderately hard
W16	274	Hard
W17	182	Hard
W18	85	Moderately hard
W19	86	Moderately hard
W20	192	Hard

Table 3: Classification of Groundwater use for Irrigation based EC

Well	EC (µs/cm)	Class
W2	541	Good
W3	330	Good
W4	422	Good
W5	596	Good
W6	450	Good
W7	441	Good
W8	405	Good
W9	542	Good
W10	531	Good
W12	663	Good
W13	1598	Permissible
W14	676	Good
W15	361	Good
W16	1465	Permissible
W17	478	Good
W18	336	Good
W19	476	Good
W20	577	Good

Type two

This type characterized by normal earth alkaline water with prevailing bicarbonate. It is classified as $NaHCO_3$ water. Only the water samples collected from Joop and Almonjedah belons to in this type of water (20%). It is characterized by the highest salinity among the other three types, and by the following ionic order:

$$Na^+ > Ca^{2+} > Mg^{2+}$$
$$HCO_3^- > Cl^- > SO_4^{2-}$$

Type three

This type characterized by earth alkaline water with increased portion of alkalis and prevailing sulfate. Around 15% of the analyzed water samples especially those collected from the vicinity of the Amran cement plant.

This water type is characterized by low salinity and with the following ionic order:

$$Ca^{2+} > Mg^{2+} > (Na^+ + K^+)$$

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