Hydrogeochemical Characterization and Groundwater Quality and its Suitability for Domestic and Irrigation in Coastal Parts of Kakinada District Andhra Pradesh India

B. Ramakrishna*, T. Vinoda Rao, G. Vijayakumar, E. N. Dhanamjaya Rao, and P.Sreedhar
Department of Geology, Andhra University, Visakhapatnam - 530003
E-mail: *ramakrishnabonela@gmail.com

Abstract

Evaluation of the hydrogeochemical characteristics and groundwater suitability for domestic use was conducted in the in Coastal Parts of Kakinada District Andhra Pradesh India. The aquifers in the coastal area is affected by salinization processes related to intense groundwater exploitation for different purposes during the last three decades. As a result, the dynamic balances among freshwater and seawater have been disturbed and the quality of groundwater has deteriorated. To understand the groundwater chemical distribution and evolution in the regional aquifers, hydrogeochemical studies have been conducted based on the water samples from 40 dug and bore wells. Groundwater levels and salinities in monitoring wells are measured to study the general groundwater flow and chemical patterns and seasonal variations. Chemical constituents such as Na^+ , K^+ , Ca^{2+}, Mg^{2+}, Cl^- , SO_4^{2-} , HCO_3^- , NO_3^- ,F^- , and TDS during the field period are analyzed to explore geochemical evolution, water-rock interactions and sources of salt concentrations. The decreased water levels without typical seasonal variation in the coastal tract of the study area confirm an over-exploitation of groundwater. The hydrogeochemical characteristics indicate fresh-saline pattern from inland to coast where evaporation is a vital factor to control the chemical evolution. The cation exchange processes are occurred at fresh-saline interfaces of mixtures along the hydraulic gradient. Groundwater suitability for drinking and agriculture purposes are further evaluated according to water quality standards. The saltwater intrusion is to be analyzed to be responsible for part of dissolution of minerals containing groundwater.Therefore, water treatment before drinking is needed in urgent to reduce the health expose risk.

Key Words: Hydrogeochemistry; ground water quality ; domestic and irrigation use; Kakinada

Introduction

Water demand has never ceased to increase due to demographic growth that has induced expanding agriculture, industry, and urbanization worldwide. Both population increase and economic development exert high pressure on water resources especially in arid and semi-arid areas of the world (Hamoda, 2004). About two-thirds of the world's population is maintained by groundwater (Adimalla et al.,2018), particularly in a densely populated country like India, There has been tremendous increase in demand for freshwater water shortage in arid and semi-arid regions due to population increase, intense agricultural activities in many parts of the world (Raju et al., 2011).The World Health Organization (WHO) has suggested desirable and permitted groundwater concentration limits for a variety of chemical characteristics (WHO, 1993). It has been found that groundwater quality analysis has received less attention than quantity analysis, particularly in emerging and under developed nations, owing to a lack of scientific expertise and enough funding (Mukate et al., 2019). Climate, drainage network, geology, geomorphology, hydrogeology, and most importantly, anthropogenic activities all influence the occurrence, storage, and flow of groundwater (Sabale and Thorat, 1991; Elango.2013). Natural factors like atmospheric salt deposition in wet and dry conditions, precipitation, evapotranspiration, soil matrix, rock-water interaction, resident time, and anthropogenic activities such as disposal of industrial and domestic wastes, recharge from agriculture, and resident time all influence the geochemical composition of groundwater (Todd 1999; Todd 2006, Barbieri et al., 2014; Devic et al., 2014, Mukate et al., 2019).

STUDY AREA

The study area is situated on the east coast of India between Tuni, a prominent taluk head quarters town and Annavaram, a pilgrim centre in Kakinadai district, Andhra Pradesh (Fig. 1). The area is bounded by the Eastern Ghats on the north, the Bay of Bengal on the east and rivers Tandava and Pampa forming the northern and southern limits. The geographical co-ordinates of the area Lat.17°13'00" to 17°22'30" N and Long. 82°24'15" to 82°37'00" E and is included in Survey of India toposheet Nos. 65 K/7, K/8, K11, and K/12. The weather in the study area in May is very warm with a gentle breeze, with average highs of 35°C and lows of 27°C.

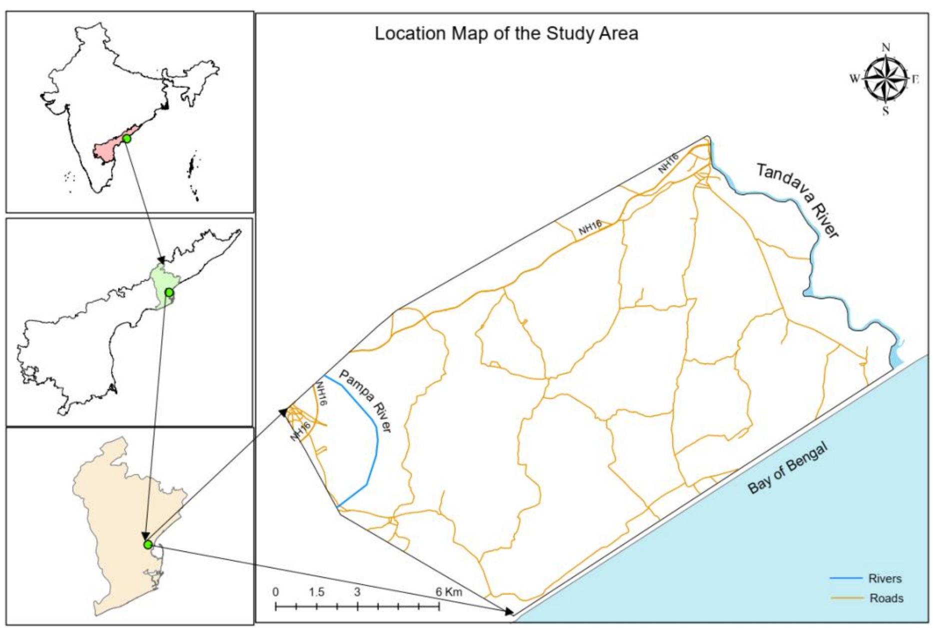

Fig 1: Study area

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Geology

The study area forms a part of the Eastern Ghats tectonic complex and the coastal plain. The prominent geological formations in the area belong to Archaen metamorphics, Upper Gondwanas of Upper Jurassic and Quaternary. Quaternary sediments consist of lateritic kankar and surficial deposits (Fig.2). Laterites are not significant as they are of very limited extent. The surficial deposits are colluvium, valley sediments, alluvium, coastal sediments and dune sands.Laterites are found as thin tappings, varying in thickness between a fraction of a metre and 3 m. along the foot-hills of the Eastern Ghats and around Hamsavaram at 50 m.

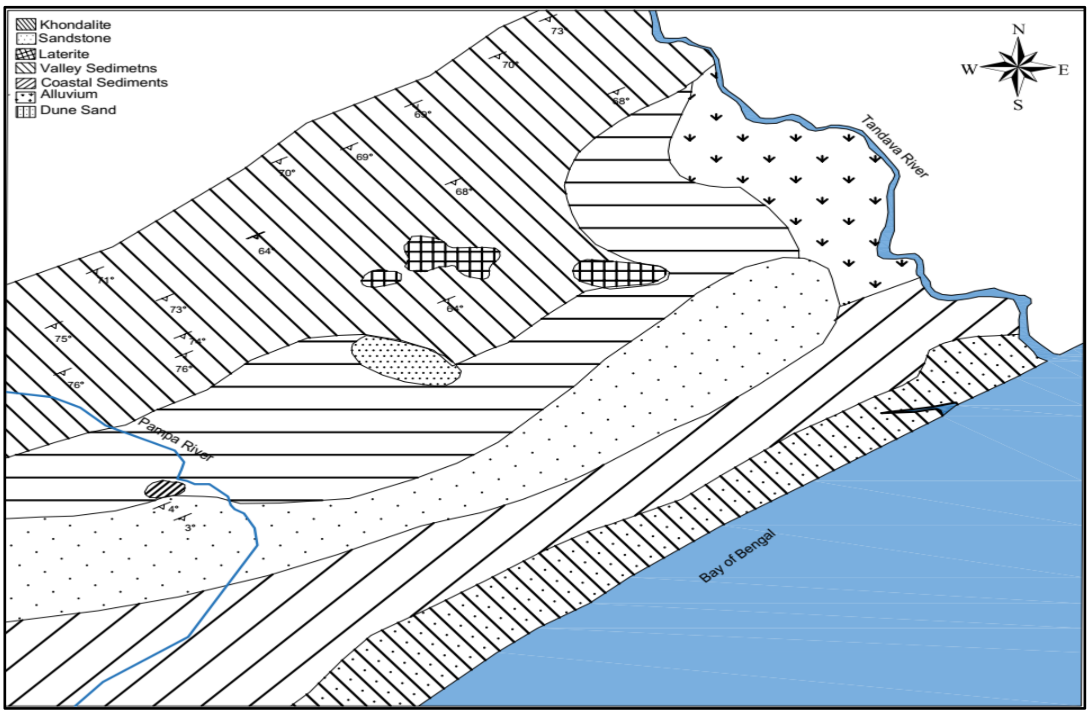

Fig 2: Geological Map

Hydrogeological Setting

Ground water is developed in the study area through dug wells, bore wells and tube wells to meet the domestic and irrigation requirements. The aquifers are apparently taped at different by these wells structures. The nature of porosity in these aquifers is described below to understand the occurrence of ground water in them. Water table generally is a subdued expression of the land surface. The elevation of the water table tends to parallel the land elevation because precipitation, the source of ground water recharge, falls fairly uniformly over the land surface.

Material and Methods

Sampling and analysis

For the groundwater quality assessment of study area, the sampling procedure was carried out systematically as per Bureau of Indian Standards (BIS), 1987. Forty groundwater samples were collected during pre-monsoon and post-monsoon from the study area. Before collecting the samples, the bottle were also rinsed with groundwater at each location.

Analysis of groundwater samples for evaluation of water quality parameters were done as per Standard Methods (APHA, 1998). All reagents used were of analytical grade. pH, TDS and EC were measured in the field with the help of portable devices. For various hydro chemical parameters the groundwater samples were analyzed, such as potential of hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS) total hardness (TH); cations like Ca^{2+}, Mg^{2+}, sodium (Na^{+}) and potassium (K^{+}); anions bicarbonate (HCO_3^{-}), Chloride (Cl^{-}), sulphate (SO_4^{2-}), and nitrate (NO_3^{-}). Titration method was used for determining calcium and magnesium, using standard EDTA solution. Sodium and potassium contents were calculated using flame photometer.

The obtained data from the analysis was plotted in piper diagram for identification of water types, and various indices were calculated for determining the agriculture water quality for parameters such as Residual Sodium Carbonate (RSC), Sodium Percentage (%Na), Sodium Adsorption Ratio (SAR), Magnesium Hazard Ratio (MH), Kelly's Ratio (KR), and Permeability Index (PI). The analyzed water quality indices has been computed with Bureau of Indian Standards (BIS) and world Health Organization (WHO).

Results and Discussions

Pipers Trilinear Diagram

Piper trilinear diagram (Piper, 1953) is useful to classify the groundwater based on basic geochemical characters of the constituent ionic concentrations, and to determine geochemical relationship with water. In the study area the groundwater classified as(I) Ca^{2+} - HCO_3^{-}(II) Mixed Ca^{2+}-Na^{+}-HCO_3^{-} and (III) mixed Ca^{2+}- Mg^{2+}-Cl^{-}, (IV) Ca^{2+}-Cl^{-}. The groundwaters in the khondalites are rich in alkaline earths (Fig. 3). The ground waters in sandstone and coastal sediments contain alkalies and alkaline earths, almost equally while

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in the valley sediments and alluvial they are predominant in alkalies with respect to anions, strong acids exceed weak acids in a majority of the samples in all the geological formations. This type of water is designated as mixed water. The bore well waters in khondalite formation contain alkaline earths as predominant cations. In the other formations they are alkali predominant samples in all the geological formations. In about 34 to 58% of the samples in all the formations, no one cation-anion pair exceeds 50%. This type of water is designated as mixed type water (Hem, 1975). In about 25 to 64% water samples in different aquifers (maximum in valley sediments) non—carbonate alkali. (primary salinity) exceeds 50% i.e. chemical properties are dominated by alkalies and-strong acids. Where carbonate hardness exceeds 50%, chemical properties of ground waters are dominated by alkaline earths and weak acids. About 3 to 13% of the water samples possess this property and is conspicuously absent in the valley sediments.

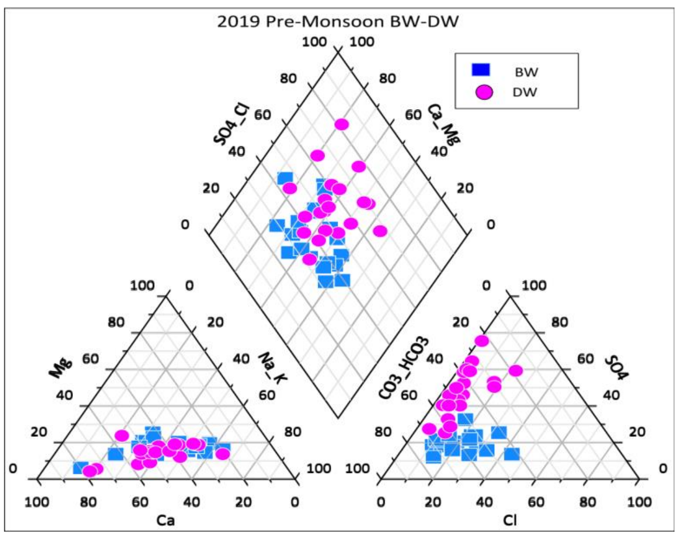

Fig 3: Piper Classification for water types

Evolution of Groundwater Chemistry and Mechanisms

Groundwater Chemistry is widely used to establish the relationship of water composition and aquifer lithological characteristics(Gibbs, 1970). Three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas are shown in the Gibbs diagram (Gibbs, 1970).The present investigations show that the groundwater consist mainly calcium-magnesium-bicarbonate type. Calcium and magnesium dominance are mainly due to weathering and mineral dissolution of basalts. Bicarbonate majorly dominates the ionic concentrations in the groundwater due to weathering of carbonates and dissolution of silicate minerals.

Table 1. Groundwater analysis

Parameters	Desirable Limits	Permissible Limit	Pre-Monsoon Min-Max
pH	7-8.5	9.2	7.26- 8.2
EC	250	2500	1171- 4644
TDS	500	1500	749- 2972
TH	100	500	300- 1049
Ca	75	200	34- 157
Mg	50	150	29 -172
Na	-	200	75-681
K	-	30	8- 201
HCO3	300	-	220- 850
Cl	200	600	161- 1045
SO4	200	400	41- 465
NO3	45	-	4 -77
F	1	1.5	0.15-1.05

Comparison with WHO standards (1993)

Suitability of Groundwater for Irrigation

There is an increasing requirement to check the quality of irrigation water on a regular basis. Agriculture will become nearly impossible if irrigation is not available. It boosts crop productivity and aids in the cultivation of superior crops that require a lot of water. Depending on rainwater for agriculture is problematic in today's changing environment. As a result, the quality of water for irrigation purposes is the subject of this research. Important irrigation water quality characteristics include various specific features of water that are related to agricultural output and quality, soil productivity, and environmental protection.Sodium Adsorption Ratio (SAR), Permeability Index (PI), Kellys Ratio (KR), Sodium Percentage, Residual Sodium Carbonate (RSC), Magnesium Hazard (MH) are the parameters used to determine the suitability of groundwater for irrigation.

Sodium Adsorption Ratio (SAR)

In groundwater, sodium hazard is determined by the absolute and relative concentration of cations and is termed as Sodium Adsorption Ratio (SAR) equation (1)

$$\text{SAR} = \frac{Na}{\sqrt{(Ca+Mg)/2}} \quad \text{-----} \ (1)$$

SAR values play an important role in irrigation purposes due to the amount of sodium content that is present in soil after absorption. High sodium concentration has a tendency of decreasing the soil permeability and the structure of the soil. Hence, SAR measures the amount of sodium hazard which is in association with the concentration of calcium and magnesium present. SAR value is used to calculate the degree to which irrigation water tends to enter cation exchange reaction in the soil. Groundwater samples

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consisting of high Na^+ content and relatively low Ca^{2+} content often results in the ion exchange of Na^+ with Ca^{2+} and Mg^{2+}. Thus, the ion exchange leads to the destruction of soil due to clay particles dispersion. Na^+ amount in water leads to salinization and degradation of crops. From the values observed that a further provision can be made to avoid future destruction of soil content which will lead to good crop production.

The calculated SAR values are ranging from 1.70 to 11.15, where average value observed are 5.56. These values for most of the samples are classified as excellent. About 56% samples (Fig. 4) were found to be excellent, 44% samples were good according to sodium hazard. Accordingly, it is inferred that the few samples have salinity issue and it cannot be used for agricultural purposes.

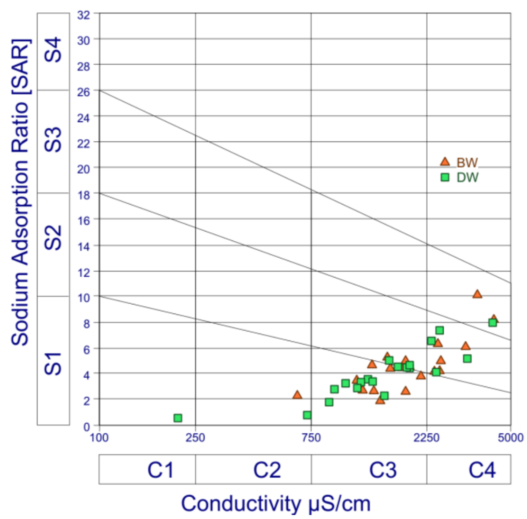

Fig. 4 Salinity and Sodium Adsorption Ratio (after USSL 1954)

Permeability index (PI)

The suitability of groundwater for purpose of irrigation can also be determined by considering the permeability index parameter. The soil permeability is an important factor as it allows the infiltration of groundwater. PI values (equation (2)) are greatly shaped by the concentration of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- parameters.

$$PI = \frac{Na+\sqrt{HCO3}}{Ca+Mg+Na} X100 \text{ --- (2)}$$

The PI values are categorized as excellent, good and unsuitable indicating the quality of groundwater that used for the agricultural purposes. Doneen (1964) and Ragunath (1987) have proposed a classification scheme of groundwater for irrigation purposes using PI into three classes namely class 1, class 2 and class 3. WHO(1993) evaluates the quality of groundwater considering the PI as: Class I and II of groundwater are categorized as good for irrigation with 75% or more of maximum permeability and Class III of groundwater is unsuitable with 25% of maximum permeability. PI ranges from 14 to 67% with average values being 40% in the study area. About 80% of calculated PI values for all the groundwater samples were categorized in the class 2 and 20% fall under class 3.

Kelly's Ratio (KR)

Kelly's Ratio is another important parameter that is practiced in order to avail details about the quality of groundwater by considering sodium concentration. However, SAR is a more advanced method for the detection of sodium content. A Kelly index is used to derive the samples as suitable or unsuitable. A Kelly index with values exceeding 1 are termed as unsuitable, while those of less than 1 are considered as suitable for irrigation purposes. Higher values indicate high concentration of sodium present. Kelly ratio is calculated by

$$KR=Na^{+}/Ca^{2+} +Mg^{2+} \text{ ------- } (3)$$

Kelly index for the analyzed samples are ranging from 0.44 to 2.10 (Table 2) and out of the 40 samples collected about 21 were calculated as suitable and 19 samples were unsuitable for irrigation.

Magnesium Hazard (MH)

Magnesium and calcium concentration in groundwater also play vital roles in determining the quality of groundwater. Magnesium concentration has more adverse effects on groundwater as compared to calcium. Hence it is extremely important to detect the amount of magnesium which is done with the help of magnesium hazard (MH). MH calculates magnesium with respect to calcium concentration.

$$MH= Mg^{2+}/ (Ca^{2+} + Mg^{2+})/100 \quad \text{ ---------- } (4)$$

Raghunath (1987) has developed a ratio, namely Magnesium Hazard Ratio. Based on this, the values obtained by calculation were termed into two classes, suitable and unsuitable. Values less than 50 were considered to suitable and values exceeding 50 were considered as unsuitable for irrigation purposes. Calculated MH values are ranging from 35 to 79 (Table 2). In which about 20 samples were suitable, and 20 samples were unsuitable for irrigation purposes.

Sodium (Na %)

Sodium hazard in irrigation is calculated with the help of sodium percentage, thus being a very useful parameter. Sodium content has extremely adverse effects on soil. Percentage of sodium is calculated using the formula.

$$Na\ (\%) = Na^{+}/(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})\times 100 \text{ ------ } (5)$$

Wilcox's (1955) method is used to understand the Na% where it is observed that values ranging from 27.26 to 66.68 are obtained. From the values calculated about 3 samples were considered as excellent, 12 as good,

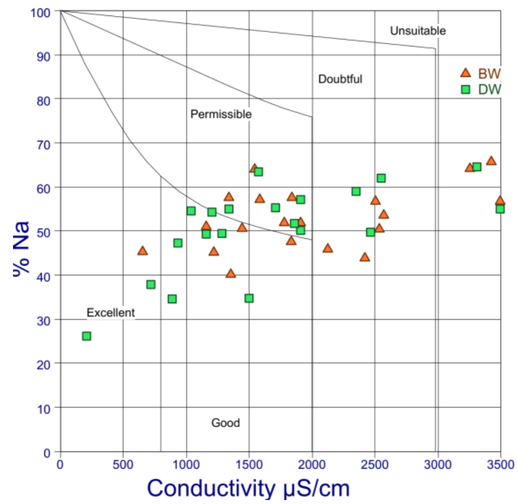

Fig. 5 Wilcox Diagram (Na %)

12 in permissible limits, 8 of the samples were classified as doubtful, and 4 samples were fallen in unsuitable (Figure 5). Wilcox's (1955) diagram shows plot of EC values against Na%. According to the diagram few samples fall in excellent class, while most of the samples fall in good-permissible class. There were a few samples which were doubtful and needs some treatment before using for irrigation purposes.

Table. 2 Groundwater Suitability for irrigation

Parameter	Range	Water Type/ Classification	SampleNo	%
SAR (Richards, 1954)	< 10	Excellent	35	87.5
	10 – 18	Good	5	12.5
	18 – 26	Doubtful	0	0
	>26	Unsuitable	0	0
PI (Doneen, 1964)	>75	Excellent	0	0
	75-25	Good	40	100
	<25	Unsuitable	0	0
KR (Kelly, 1946)	<1	Suitable	22	55
	>1	Unsuitable	18	45
MHR (Raghunaht, 1987)	<50	Suitable	38	95
	>50	Unsuitable	2	5
Na % (Wilcox, 1955)	<20	Excellent	0	0
	20 – 40	Good	0	0
	40 – 60	Permissible	35	87.5
	60 – 80	Doubtful	5	12.5
	>80	Unsuitable	0	0
Na % (Eaton, 1950)	<60	Safe	35	87.5
	>60	Unsafe	5	12.5
RSC (Eaton, 1950)	<1.25	Good	37	92.5
	1.25-2.5	Doubtful	3	7.5
	>2.5	Unsuitable	0	0

Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate RSC is one of the most important and widely used method in order to calculatethe suitability of groundwater for irrigation purposes. The hazardous effect of carbonates and bicarbonates were calculated with the help of RSC detecting the attributes of groundwater for irrigation purposes. Particularly, the high amount of feeble acids such as the total concentration of the carbonates and bicarbonates in groundwater over the alkaline earths such as the total of calcium and magnesium alter the suitability of groundwater for irrigation (Eaton, 1950; Raghunath, 1987).

$$RSC = (HCO_3^- + CO_3^{2-}) – (Ca^{2+} + Mg^{2+}) \text{-------- (6)}$$

Higher concentration of cations such as calcium and magnesium in the groundwater generally show negative values of RSC. Hence, the concentration of calcium and magnesium play a vital role in determining the quality of groundwater. Eaton (1950) has concluded that increasing amount of RSC values in groundwater leads to increase in the SAR values, thus resulting in the soil becoming infertile due to such increasing concentration levels. The RSC values calculated, only 1(BW-16) sample indicated high concentrations of calcium and magnesium in the groundwater.

CONCLUSIONS

The area comprises of varied geology form Archean basement complex, sandstone and alluvium. The groundwater quality of the study area has been evaluated by using physicochemical parameters, and the drinking suitability of groundwater was examined through hydrochemical facies. The dominate groundwater type in this basin is alkaline water with existing bicarbonate as well as sulfate and chloride, and this might be due to the geology of the area and water-rich ionic exchange, and the groundwater samples were in the class of hard to very hard for most of the groundwater samples. Major ion concentrations were compared with WHO standards to confirm the suitability with help of graphical methods and indices techniques.The hydrogeochemical characteristics indicate fresh-saline pattern from inland to coast where evaporation is a vital factor to control the chemical evolution. The cation exchange processes are occurred at fresh saline interfaces of mixtures along the hydraulic gradient. Groundwater suitability for drinking and agriculture purposes are further evaluated according to water quality standards. The saltwater intrusion is to be analyzed to be responsible for part of dissolution of minerals containing groundwater. Therefore, water treatment before drinking is needed in urgent to reduce the health expose risk.

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