J Environ. Science & Engg. Vol. 57, No. 2, p. 102-108, April 2015

Qualitative Assessment of Groundwater Quality in a Tank Irrigated Watershed, Tamil Nadu, India

SRINIVASAN K*+ AND POONGOTHAI S**

The groundwater plays a major role in hard rock terrains with limited source. The quality of the available source further determines the utility of the groundwater. Hence an attempt has been made in this study to determine the quality of water and to categorise them for the different purpose, like drinking, domestic and irrigation purposes. 37 groundwater samples were collected around the tank irrigated watershed of wellington reservoir and analysed for major cations and anions. The analysed samples were classified based on the drinking water standard, SAR, RSC, Na%, electrical conductivity, total hardness, permeability index, corrosivity ratio, chloride values etc. The study concludes that few of the samples fall in good category and many of them indicate low suitability and therefore groundwater from these areas have to be used judiciously for irrigation purpose.

Key words: *Groundwater quality, WATCLAST, watershed*

Introduction

Groundwater is a natural resource, which is being renewed by various processes. Within the groundwater, geochemical processes occurr and react with the dissolved minerals with a profound effect on water quality. Hydrogeochemical composition of groundwater can indicate its origin and history of passage through underground materials, of which water has been in contact. According to the Zaporozec (1972)[23], knowledge of hydrochemistry is necessary to establish the origin of chemical composition of groundwater. Water quality gets modified along the movement of water through the hydrological cycle and the different operations, like evaporation, transpiration, oxidation and reduction, cation exchange, dissolution of minerals, precipitation of secondary salts (Appelo and Postma 1999)[2]. Mixing of water leaching of fertilizers and manure, pollution and biological processes have also been reported to contribute to the chemical variation of groundwater. The quality of water is directly linked with individual welfare. Poor quality of water affects the plant growth and also human health (Todd 1980 and ISI 1983)[20,10]. The physical, chemical and bacteriological quality of water assesses its suitability for different purposes, such as drinking, domestic, agricultural and industrial purposes. A number of attempts were carried out for the studies of groundwater quality with respect to various aspects like drinking and irrigation purposes in different parts of India (Subba Rao 2006)[18]. The study area predominantly an agricultural zone with den agricultural activities and located near the Wellingt Reservoir. Predominant agricultural activities and oth anthropogenic activities with various landuse patte in the study area have a considerable influence on t groundwater. People are mainly dependent groundwater for drinking and domestic, but during t failure of monsoon the groundwater still forms essential component in irrigation too. Hence, t present study aims to characterize the groundwa quality to determine its utility and suitability agricultural and drinking purposes. It also aims to fi out the major geochemical processes and evolution the study area.

Study area

The study area considered is Wellingt reservoir watershed which is located in the Tittak taluk. It lies between the longitudes of 11°13' to 11° E and latitudes of 77°26' to 77°56'N (Fig 1). Tittak is a panchayat town and taluk headquarters Cuddalore district, Tamil Nadu, India. As of 2001 In Census, Tittakudi had a population of 20,734. In taluk, agriculture area is 823.74 km^2 and mean ann rainfall is 1110mm. Black soil is predominant type in this area and main occupation of the are agriculture. The groundwater level of the study a ranges from 2m to 8m bgl (below ground level).

*Assistant Professor, Department of Civil Engineering. Annamalai University, Annamalainagar 608 002 (Inc
** Professor, Department of Civil Engineering. Annamalai University, Annamalainagar 608 002 (India)
+ Corresponding author

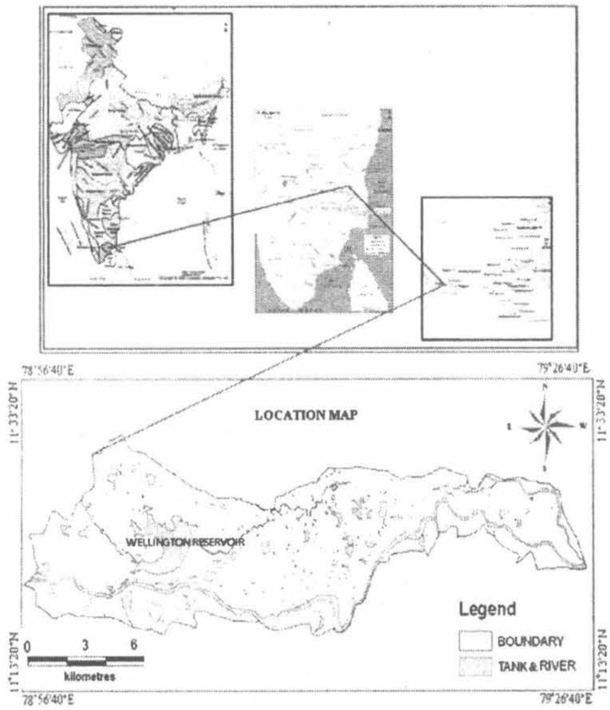

Fig 1. Location map of the study area

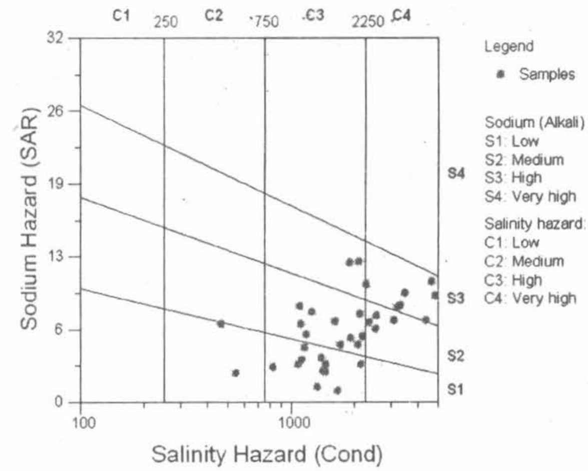

Fig 2: Sodium and salinity hazard plots for groundwater samples (Wilcox 1955)[22]

Methodology

37 groundwater samples were systematically collected using clear acid washed polythene bottles. Sampling was carried out during July 2012 and analysis was carried out using APHA (1995)[1] standard procedures. The parameters, such as temperature, pH, electrical conductivity and total dissolved solids, were measured in the field. Na^+ and K^+ were determined by using flame photometer. Ca^{2+}, Mg^{2+}, Cl^- and HCO_3^- were determined by volumetric titration methods, SO_4 and PO_4 using Spectrophotometer (SL 171 minispec). Fluoride concentration was determined by using Orion fluoride ion electrode model, whereas Nitrate was analyzed by Consort ion meter C933 using ion selective electrode. Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Sodium percentage (Na %) were determined by using WATCLAST (Chidambaram *et al.*, 2003)[4]. Different thematic layers were produced for SAR, RSC, Na%, and EC.

dissolution of minerals, dispersive of ions and agricultural practice (Fig. 3).

Results and discussion

In the study area groundwater is alkaline in nature with the pH ranging from 7.1 to 8.97 and an average of 8.4. Higher pH values contributed to the presence of considerable amount of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- ions (Table 1). Electrical Conductivity is an indirect determination of ionic strength and mineralization of water. In study area, it ranged from 465 to 5140 µs/cm with an average value of 2095.73 µs/cm. The results showed that EC of most of the samples was much above the permissible limit. Total Dissolved Solids (TDS), which are generally the sum of dissolved ionic concentration, varied between 320 and 3420mg/L with an average of 1372.10mg/L. The dominance of cations and anions were as follows: $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $HCO_3^- > Cl > SO_4^- > NO_3^- > F^- > PO_4^-$.

Table 1. Maximum, Minimum and Average values of the Chemical constituents in groundwater (All values in mgl^{-1} except EC in μscm^{-1} and pH)

Samples		pH	EC	TDS	Ca^+	Mg^+	Na^+	K^+	Cl^-	HCO_3	SO_4^-	No3-	PO_4^-	F^-
N=37	Max	8.9	5140	3420	152	98	563	161	903	524	106	9.9	3	2.3
	Min	7.1	465	320	20	5	50	1.5	70.9	244	12.5	0.9	0.01	0.04
	Avg	8.4	2095.7	1372.1	64.5	39.2	244.3	17.1	350.0	376.3	43.9	4.7	0.6	0.7

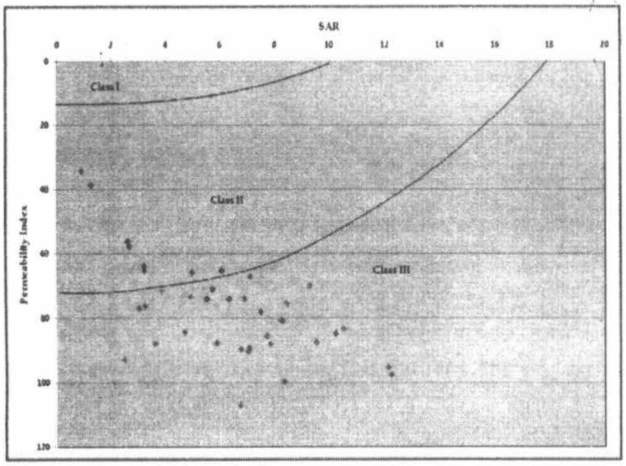

Fig 3: Modified Doneen plot for groundwater samples

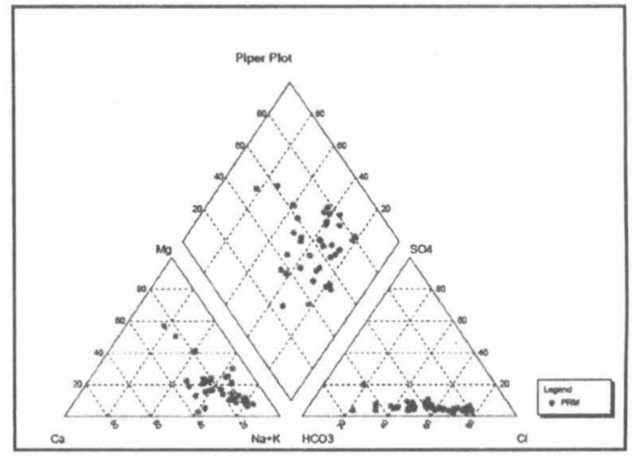

Fig 4: Facies plot for groundwater samples (Piper 1944)[12]

Comparison with drinking water standard

Table 2 exhibits the percentage of water samples exceeded the permissible limit of pH, EC, TDS and ionic concentration with the range of ionic concentration in groundwater of the study area with respect to specifications of WHO (2004)[24] and BIS (1991)[3]. 32.4% of samples exceeded the pH standard value of WHO and 64.8% of samples exceeded the BIS standards in respect of ionic concentration of EC. 94.5% samples exceeded the permissible limit of TDS. 24.32%, 56.7%, 64.8% and 27% of samples exceeded the permissible limit of Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-} respectively. SO_4^{2-} and NO_3^- were within the permissible limit of WHO (2004) and BIS (1991). HCO_3^- was also within the permissible limit. Thus most of the groundwater samples in the study area were found unfit for domestic and drinking purposes.

Domestic water quality

Total dissolved solids

The results of TDS showed that 27% of the samples were within 1500-3000mg/L and 62% of the samples were in range 500- 1500mg/L. About 5.4% o samples were within the range 200-500mg/L. Tota Dissolved Solids (TDS) are generally the sum o dissolved ionic concentration.

Corrosivity ratio

Corrosion is an electrolytic process that take place on the surface of the metal, which severel attacks and corrodes away the metal surfaces Groundwater extracted from the study area for variou purposes is transported by metallic pipes that may o may not be suitable for transport. This fact is highlighte using Corrosivity Ratio (CR) proposed by Ryzne (1944)[15]. The formula for calculating CR is:

$$CR = \{(Cl/35.5) + (SO_4/96)\}/2(HCO_3) \times 100 \quad ...(1)$$

Corrosivity ratio was <1 in 57% of the samples fall i safe zone (Table 2). Corrosivity ratio was > 1 in 43 of samples fall in unsafe zone.

Hardness

Hardness is the sum of concentration of ion expressed in mg/L of $CaCO_3$. Hardness increases fro

Table 2: Maximum permeable limit of Cations and Anions along with pH, EC and TDS
(EC=Electrical Conductivity, TDS=Total Dissolved Solids)

	pH	EC ms/cm	TDS mg/l	Ca^{2+} mg/l	Mg2+ mg/l	Na+ mg/l	Cl- mg/l	F- mg/l
% of Samples exceeding permissible limit	32.43	64.86	94.59	24.32	56.76	64.86	70.27	27.03
WHO (2004)	6.5-8.5	1400.00	500	75.00	<30	200.00	200.00	1.50
BIS (1991)	6.5-8.5	1400.00	500	75.00	30.00	200.00	200.00	1.00

metallic ions dissolved in water. According to Handa (1964)[8] USGS hardness shows four categories of hardness: soft, slightly hard, moderately hard and very hard. Total hardness of more than 180 mg $CaCO_3$/L can be treated as very hard water and can lead to scaling problems in air-conditioning plants (Hem 1970)[9]. More than 92% of samples represent moderately hard to very hard water. About 8% of samples represent slightly hard water.

Index of base exchange

Index of Base Exchange (IBE) is proposed by Scholler (1965)[16] to describe the geochemical reactions taking place in groundwater. All ionic concentration is expressed in equivalent parts per million. The IBE indicates that there is a significant exchange of Na + K in groundwater to the Ca+Mg in rock matrix, whereas the reverse is more prominent and the exchange Na+K from the rock to the Ca+Mg in groundwater is less notable (Chidambaram, 2000)[4]. More than 67 % of samples were found in (Na+K) in rock to Ca+Mg in groundwater and 32% of the samples were in (Na+K) groundwater to Ca+Mg in rock category.

Chloride classification

The Stuyfzand chloride classification (1989)[17] of groundwater exhibited 54% brackish categories, 32.4% of samples represented the fresh brackish categories and 13.5% of samples fresh categories. The higher concentration of Chloride in groundwater may be due to the pollution from different sources or longer residence time of groundwater in host rock (Freeze and Cherry, 1979)[7].

Irrigation water quality

The cultivation and productivity of the crops depend on the quality of water. In this regard, the SAR, RSC, Na% and permeability index were studied to determine their utility.

Sodium absorption ratio

The suitability of the water was evaluated by determining SAR values and categorized under different irrigation on the basis of salinity and alkalinity hazards. Salinity is due to weathering of rocks and leaching from the apex soil and anthropogenic sources It is mainly due to the effect of sodium exchangeable on the physical condition of the soil. The SAR values were computed from the following equation (Richards, 1954 and Todd, 1980)[14,20]:

Table 3: Results of computer program WATCLAST (Chidambaram 2003)

Category	Grade	PRM n=37	Category	Grade	PRM n=37	Category	PRM n=37
Na% Wilcox (1955)	**Na% Wilcox (1955)**		**USGS Hardness**			**TDS Classification(USSL,1954)**	
Excellent	0-20	1	Soft	<75	0	<200	0
Good	20-40	2	Slightly Hard	75-150	3	200-500	2
Permissible	40-60	12	Moderately Hard	150-300	14	500-1500	23
Doubtful	60-80	19	Very Hard	>300	20	1500-3000	10
Unsuitable	>80	3	**IBE Schoeller (1965)**			**CationFacies**	
Na% Eaton (1950)	**Na% Eaton (1950)**		(Na+k)rock->(Ca+Mg) g.w.		25	Ca-Mg Facies	1
Safe	<60	15	(Na+k)g.w.->(Ca+Mg) rock		12	Ca-Na Facies	36
Unsafe	>60	22	**Schoeller Classification (1967)**			Na-CaFacies	0
S.A.R. Richards (1954)	**S.A.R. Richards (1954)**		Type I		37	Na Facies	0
Excellent	0-10	33	Type II		0	**Anion facies**	
Good	18-Oct	4	Type III		0	HCO_3 Facies	0
Fair	18-26	0	Type IV		0	HCO_3-Cl-SO_4 Facies	0
Poor	>26	0	**Corrosivity Ratio (1990)**			Cl-SO_4-HCO_3 Facies	35
R.S.C. Richards(1954)	**R.S.C. Richards(1954)**		Safe	<1	21	Cl- Facies	2
Good	<1.25	26	Unsafe	>1	16	**Hardness Classification (Handa,1964)**	
Medium	1.25-2.5	4	**Chloride Classification (Stuyfzand,1989)**			**Permanent Hardness (NCH)**	
Bad	>2.5	7	Extremely fresh	<0.14	0	A1	0
EC Wilcox (1955)	**EC Wilcox (1955)**		Very fresh	0.14-0.84	0	A2	6
Excellent	<250	0	Fresh	0.84-4.23	5	A3	13
Good	250-750	2	Fresh Brackish	4.23-8.46	12	**Temporary Hardness (CH)**	
Permissible	750-2250	23	Brackish	8.46-28.21	20	B1	0
Doubtful	2250-5000	11	Brackish-salt	28.21-282.1	0	B2	7
Unsuitable	>5000	1	Salt	282.1-564.1	0	B3	11
			Hyperhaline	>564.3	0		

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} \quad \text{——— (2)}$$

Tijani (1994)[19] showed that the levels of Na^+ and HCO_3^- in groundwater affect the soil permeability and drainage. About 89% of samples were found under the excellent category and the rest of samples were under the good category.

Sodium percentage

The sodium percentage was determined from the equation mentioned below (Kacmaz and Nakoman, 2010)[11]:

$$\%Na = \frac{(Na^{+} + K^{+}) \times 100}{Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}} \quad \text{——— (3)}$$

Concentration of Na % was distributed based on the classification of Richards (1954)[14] as excellent, good, permissible, doubtful and unsuitable categories. Wilcox (1955)[22] showed that the Na% can be used to assess the suitability for agriculture purpose. About 3% of the samples were in excellent category in the study area. The permissible category was indicated by 32% of the samples. About 51% of the samples were doubtful and 8% in unsuitable category.

Wilcox (1955)[22] demonstrated that the Na% and EC values are significant for classifying irrigation water quality. In Wilcox diagram sodium hazard was plotted against the EC values, used to assess the quality of groundwater. This plot was used to assess the quality of groundwater samples of study area. The plot showed that 16%, 8%, 14%, 27%, 30% and 5% of samples fall in high sodic and very high salinity hazard category, high sodic and high salinity hazard category, medium sodic hazard and very high salinity category, medium sodic and high salinity hazard category, low sodic hazard and high salinity hazard category and low sodic and low salinity hazard category respectively. Low and medium sodium and high salinity hazard are due to dissolution of minerals, dispersive of ions and agriculture practice (Fig. 2).

Residual sodium carbonate

The excess of Carbonate and Bicarbonate water having the alkaline earth mostly consists of $Ca^{2+}$and Mg^{2+} in excess of allowable limits affects agriculture unfavourably (Richards 1954)[14]. RSC = $(CO_3 + HCO_3^-) - (Ca^{2+} + Mg^{2+})$: the tendency of alkaline earth influence the suitability of water for irrigation purpose, with al values in epm (equivalent parts per million). Th water gets more precipitated with Ca^{2+} and Mg^{2+} an as a result Na^+ in water gets increased in the form o sodium carbonate. The variation of RSC was draw using (Richards 1954)[14] as good, medium and ba categories. About 70% of the groundwater samples o the study area were in good category, 11% in mediun category and 19% in bad category.

Doneen plot

The Permeability Index (PI) of the water wa derived by Doneen, (1948)[6] using major cations an HCO_3 concentration adopting the following expression

$$PI = [\{Na^{+} + \sqrt{(HCO_3^{-})}\} / \sqrt{(Ca^{2+} + Mg^{2+} + Na^{+})}] \times 10 \quad ....(4$$

Permeability index (PI) is a factor whic influences quality of irrigation water, in relation t soil for development in agriculture. Permeability indice of the water samples in each of the water classes i the study area were calculated as part of the assessmen of the irrigation quality of groundwater. PI was plotte together with the SAR content of the groundwate samples. Three water types are clearly distinguishabl similar to Doneen's chart: Class I water is 'Excellen suitable for irrigation and are characterized by lo PIs; Class II water is generally 'Good' which i acceptable type, Class III water is 'Poor ' which is Nc Suitable' for irrigation. Based on permeability inde and SAR, a new plot has been designed and sample falling in Class I, Class II and Class III determine th suitability of groundwater for irrigation purpose (Fi 3). The majority of the samples in all the season were in Class III and few samples in Class II. Most c the samples observed in Class III which is poorl suitable for irrigation and few in Class II were suitabl for irrigation purpose.

Geochemical nature (Piper Facies)

Ion concentration facies interpretation is a toc for determining the flow pattern and origin c groundwater. Hydrogeochemical facies using trilinea diagram is classified by Piper (1944)[12]. The plc shows that most of the groundwater samples analyze fall in the field of Na-Cl, indicating the discharg region with saline nature in the groundwater (Prasann et al 2010)[13].

There are two basic types of water observe from the Piper classification that:

Ca-Cl ⟶ Ca-Mg-Cl ⟶ Na-Cl ...(5

Ca-Na-HCO_3 Na-HCO_3 Na-Cl ...(6)

Na-Cl type indicated the predominance of alkaline and strong acid. The few samples were in the mixed Ca-Na-HCO_3 indicating that Ca^{2+}ion is dominant in the cation in this type. The inter play with the HCO_3 and Cl ion in anion was mostly from the weathering of rocks related with recharge areas and that for Cl was from the anthropogenic activities. There was a minor representation of mixed Ca-Mg-Cl type, where Cl is the major anion and Ca+Mg is major cation. From the plot, it was observed that alkalinity (Na and K) exceeded alkaline earth (Ca and Mg) and strong acids exceeded weak acids. In general, water chemistry of the study area was dominated by alkali and strong acids.

Conclusion

Interpretation of geochemical characteristics of groundwater samples is alkaline in nature. The sequence of the abundance of the ion for cation and anion is $Na^{+} > Ca^{2+} > K+ > Mg^{2+}$ and $HCO_3^- > Cl > SO_4^-$ $. > NO_3^- > F^- > PO_4^-$. The SAR classifications for majority of the samples grouped as excellent to good category. In electrical conductivity classification, the samples showed the permissible representations. Na% classification in most of the samples was in unsafe zone. The dominant cation facies was Ca-Na facies and the anion was Cl-SO_4-HCO_3 facies. The study area was fresh brackish to brackish category according to chloride classification used for agriculture activity. Permeablity index of Doneen plots revealed that most of the samples were under Class III which indicates poor suitability of groundwater for irrigation purpose. The chemical composition of ground water in the basin showed that the dominant facies in the entire litho unit was Na–Cl type, indicating saline nature of the groundwater. Hence, it was observed that only few percent of the samples in the study had good water quality.

References

1. APHA (1995) Standard methods for the examination of water and waste water, 19th edition, APHA, Washington DC, USASS.
2. Appelo CA and Postma D, Geochemistry, groundwater and pollution. *Balkema, Rotterdam* (1999).
3. Bureau of Indian Standards, Analyses of water and wastewater, *BIS, Institution,* New Delhi (1991).
4. Chidambaram S, Hydrogeochemical studies of groundwater in Periyar district, Tamil Nadu, India, unpublished Ph D thesis, *Department of Geology, AnnamalaiUniversity* (2000).
5. Chidambaram S, Ramanathan AL and Srinivasamoorthy K, Lithological influence on the groundwater chemistry - Periyar districts a case study. *Conference on Coastal and Freshwater Issues,* 173 (2003).
6. Doneen LD, The quality of irrigation water. *California Agriculture Dept,* 4 (11), 6 – 14 (1948).
7. Freeze AR and Cherry JA, Groundwater, *Prentice – Hall,* Inc Englewood Cliffs, New Jersey, 604 (1979).
8. Handa BK, Modified classification procedure for rating irrigation waters, *Soil Sciences,* **98(2),** 264-269 (1964).
9. Hem JD, Study and interpretation of the chemical characteristics of natural water. *USGS Water Supply* 1473, 363 (1970).
10. ISI Indian standard specification for drinking water. IS: 10500. *Indian Standard Institute,* India (1983).
11. Kacmaz H and Nakoman ME, Evalution of shallow groundwater quality for irrigation purpose in the Koprubasi Uranium Area (Manisa,Trkey).*BALWOIS,* **25,** 1-9 (2010).
12. Piper AM, A graphic procedure in the geochemical interpretation of water analysis. Trans Amer Geophys union, 25, 914 – 923 (1944).
13. Prasanna MV,Chidambaram S, Shahul Hameed A and Srinivasamoorthy K, Study of evaluation of groundwater in Gadilam basin using hydrogeochemical and isotope data. *Environ Monit Assess,* **168,** 63–90 (2010).
14. Richards LA, Diagnosis and improvement of saline and alkali soils Agriculture, *Handbook 60 U.S Dept Agri* Washington DC, 160p (1954).
15. Ryzner JW, A new index for determining amount of calcium carbonate scale formed by water.*Jr.Am Wat Wor Assn,* 36, 472- 486 (1944)
16. Scholler H, Hydrodynamic dams lekar collogue doboronik 1, 3 – 20 (1965).

17. Stuyfzand PJ, Nonpoint sources of trace elements in potable groundwaters in the Netherlands. Proceedings 18th TWSA Water Workings. Testing and Research Institute KIWA (1989).

18. Subba Rao N, Seasonal variation of groundwater quality in a part of Guntur district, Andhra Pradesh, India. *Environ Geol*, **49**, 413–429 (2006).

19. Tijani J, Hydrochemical assessment of groundwater in Moro area, Kwara state, Nigeria, *Environ. Geol.*, **24**, 194-202 (1994).

20. Todd DK, Groundwater Hydrology-*John Wiley and Sons* New York, 535 (1980).

21. WHO (World Health Organization) Guidelines for drinking water quality recommendations, *WHO*, Geneva, 515 (2004).

22. Wilcox LV, Classification and use of irrigation water. *U.S. Geological Department Agri Circ*, .969, 19p, (1955).

23. Zaporozec A, Graphical interpretation of water quality data. Groundwater, **10(2)**, 32–43 (1972).

24. Eaton, E.M., Significance of carbonate in irrigation water, *Soil Science*, 69, 123-133 (1950)