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Full Length Research Paper

Correlation-regression model for physico-chemical quality of groundwater in the South Indian city of Gulbarga

Abdul Saleem[1]*, Mallikarjun N. Dandigi[2] and K. Vijay Kumar[3]

[1]Department of Civil Engineering, PDA College of Engineering, Gulbarga, India.
[2]PDA College of Engineering, Gulbarga, India.
[3]Department of Zoology, Gulbarga University Gulbarga, India.

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Groundwater is a major source of municipal and private water supply in Gulbarga city. Water samples were collected from spatially referenced bore wells located in various wards of the city. 150 bore well water samples were analyzed for electrical conductivity (EC), pH, total dissolved solids (TDS), total hardness (TH), Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, CO_3^{2-} Cl^-, SO_4^{2-} ,NO_3^-, F and Fe. All tests were performed as per standard methods and water quality was compared for both Indian and WHO drinking water standards. Significantly positive correlation at 1 and 5% was found between many parameters. EC prediction with multiple R^2 value of 0.999 indicated that 99.9% variability in observed EC could be ascribed to Cl^- (76%), HCO_3^- (12.5%), NO_3^- (10.3%) and SO_4^{2-} (1.1%). Multiple regression models can predict EC at 5% level of significance. Nitrate, chlorides, TDS and fluoride concentration exceed permissible level of drinking water in 75, 41, 95 and 3.33% of the samples respectively. It is recommended to treat groundwater prior to domestic use.

Key words: Groundwater, water quality, bore well, water supply, correlation, regression.

INTRODUCTION

Groundwater is the prime source of drinking water supply for many of the Indian rural and urban habitats, like other parts of the world. Contamination of groundwater results in poor drinking water quality, high clean-up costs, high costs for alternative water supplies, and/or potential health problems. As worldwide extraction of groundwater is accelerated to meet increasing demand, the significance of chemical quality of groundwater also increases, relative to its economic value and usefulness (Adhikari et al., 2009). Optimal and sustainable usage of ground water is possible only when the quantity and quality is properly assessed. Rapid deterioration of groundwater quality is commonly observed in places which are densely populated, thickly industrialized and have shallow groundwater table (Patil et al., 2001).

Rasula and Rasula (2001) studied groundwater quality for Belgrade city, specifically for the zones of infrastructure facilities such as roads, railway, oil and gas pipelines, which may be considered as potential linear polluters. He concluded that with traffic development and economic growth, many potential groundwater sources would not be adequately exploited if hydro geological investigations are not undertaken in zones of infrastructure.

Urban groundwater in Seoul, South Korea, was monitored for trace metal and volatile organic compound and its relation to land use and spatial distribution. It is reported that some volatile organic compounds are significantly higher in the industrial, residential and traffic areas, suggesting that groundwater quality in urban areas is closely related with land use (Seong-Sook et al., 2005). Nitrate pollution increased dramatically between 1998 and 2001 in groundwater of Konya city in Turkey (Nas and Berktay, 2006).

Study on the impact of urbanization on the groundwater

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*Corresponding author. E-mail: abdussaleem@yahoo.com. Tel: +97455841130.

in Sholapur city in India (Pradeep et al., 2008) revealed a rise in groundwater level in the city area due to increased recharge associated with increased water supply; the water quality is reported to be deteriorating over the last 10 years. Subba Rao (2008) studied groundwater chemistry in parts of Guntur district in India, and reported higher concentration of total dissolved solids (TDS), Na^+, Mg^{2+}, Cl^-, $SO4^{2-}$, NO_3^-, F^- and SiO_2 ions in the groundwater during post-monsoon period. Groundwater regime of Varaha river basin study in Andhra Pradesh, India, showed that alkaline environment is the dominant controlling factor for leaching of fluoride from the source material in groundwater (Subba Rao, 2009). It is suggested that increasing effective infiltration through surface water management structures may reduce fluoride concentration in groundwater. Madhavi and Prasad (2003) observed that indiscriminate disposal of industrial effluent around Hyderabad has aggravated the acidity of electrical conductivity (EC), TDS, COD, Cl^-, SO_4^{2-}, PO_4^{2-}, NO_3^-, F^- and heavy metals in the groundwater.

Mohapatra et al. (2001) made a correlation study on the physico-chemical characteristics of groundwater in Paradip areas. Statistical calculations were made to interpret the quality of groundwater of seven villages around Udayarpalayam, Tamil Nadu (Sangeetha et al., 2000). The reliability between well water and bore well water was predicted from the values of co-efficient of variance in correlation co-efficient. Ground water quality of an industrial town, Bhilwara, in Rajasthan, showed (Sharma et al., 2001) a positive correlation among total hardness (TH) and EC with Mg^+ and TDS. Linear relation was obtained for rapid monitoring of groundwater alkalinity. The experimental values of Cl^- and TDS agreed with predicted values calculated as function of EC.

Considering the huge groundwater consumption in Gulbarga city and lack of water quality monitoring, the present study is undertaken. The main objective of the study is to assess the quality of groundwater based on large number of spatially referenced sampling wells located in various wards of the city. An attempt is made to represent water quality through conventional physico-chemical parameters. Suitability of groundwater for drinking and irrigation purposes is explored. Statistical analysis and characterization of hydro geochemistry of the ground water, with correlation and regression model is also presented.

Study area

Gulbarga (Figure 1) is a major city in the south Indian state of Karnataka. It lies geographically between latitudes 17°17’ to 17°22’ and longitudes 76°47’ to 76°52’, at a mean sea level of 454 m. It covers an area of 54.13 km^2, with a population of 430,000 and over 50,000 properties as per census record of the year 2001. It is divided into 55 corporation wards based on population and municipal jurisdiction. Average annual rainfall observed is about 750 mm and the mean daily temperatures range from 19°C in winter to over 40°C in summer. The study area is identified as a chronically drought prone district of the Karnataka state, due to less and variable occurrence of annual rainfall. The district is underlain by the Deccan traps of upper Cretaceous to Eocene age. Groundwater occurs in the deeper weathered and fractured zones. It occurs in water table condition in weathered zone and in semi confined conditions in the fractured and joined formations. The depth of the wells ranges between 20 and 30 m (Majagi et al., 2008).

Gulbarga city is served by piped potable water supply derived from Bennithora and Bhima rivers and Bhosga reservoir located 10 to 25 km away from the city and through more than 1850 bore wells installed and maintained by City Corporation. Two million gallons per day of groundwater is supplied by the city corporation which constitute about 30% of daily water supply to the city (Gulbarga city, 2010). Apart from municipal bore wells, groundwater is also extracted from large number of private bore wells. There is no record of the number of private bore wells in the city. Based on physical observation, it may be safely quoted that almost every third house has one bore well and the total number of bore wells in the city may exceed 20,000. The municipality water supply extracted from the bore wells without any treatment and most of the private bore well users also consume groundwater without treatment (Saleem et al., 2011).

MATERIALS AND METHODS

Groundwater sampling and analysis

Groundwater samples were collected in clean plastic containers of 2 L capacity during March 2009 from 150 bore wells, spread in all 55 municipal wards of the city. The selected bore wells are both municipal and private owned and were fitted with either hand pump or electric motor and were being used to supply water for domestic demand. Water of the bore well was run for 2 to 3 min and the containers were rinsed with the sample water prior to collection of the sample.

The samples were immediately transferred to the laboratory and analyzed for various physico-chemical parameters, namely, EC, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-} ,NO_3^-, F and Fe, using standard methods (APHA, 1989). The analyzed test results were checked for electro-neutrality and the percentage difference of cation and anion was found to be within the acceptable range of 5%. Mean, standard deviation, correlation and regression were calculated using SPSS software.

RESULTS AND DISCUSSION

The minimum, maximum, mean and standard deviation

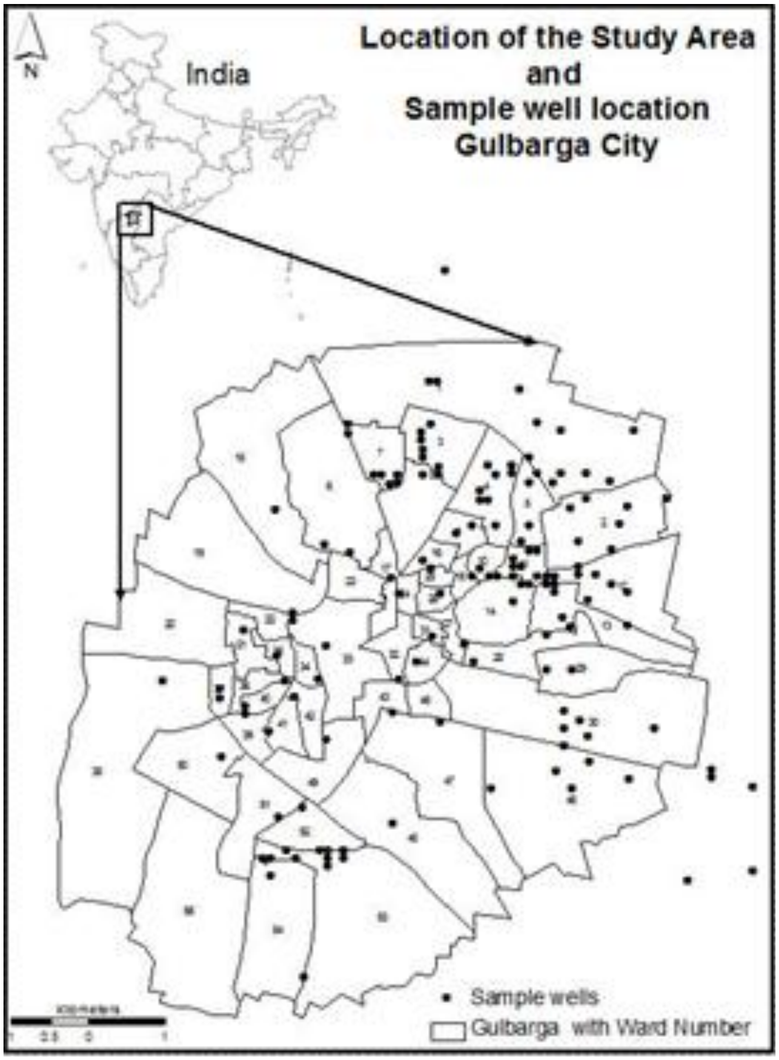

Figure 1. Spatial position of sampling bore wells.

values generated from the analysis of the 150 samples are presented in Table 1. The data was compared with drinking water guidelines of India (ISI, 1991) and WHO (1993), and tabulated in Table 2. It was observed that pH of ground water is between 6.8 and 8.40 and meets drinking water criteria. Among the cations, calcium dominates, ranging between 16 and 429 mg/L, and mean of 112.42 mg/L. About 67.5% of samples observed with Ca^{2+} value are more than the desirable limit of 75 mg/L; however, excess Ca^{2+} is not a hazard as 90% of the samples showed value below 200 mg/L, the maximum permissible limit. Magnesium varies between 3 and 193 mg/L with 95% samples within maximum permissible value of 100 mg/L. Potassium values ranged between 1 and 20 ppm mg/L, with 97% samples conforming to UK (max) limit of 12 mg/L.

In terms of salinity hazard (Table 6), 98% water samples indicated high /very high salinity values. The maximum contaminant level (MCL) for chloride in drinking water is 250 mg/L as per WHO and Indian standards. In the present study, chloride concentration varied from 64 to784 mg/L, with mean value of 249.4 mg/L, and standard deviation of 112.5 mg/L. About 58.7% of samples fall within the maximum chloride limit of 250 mg/L. Shanthi et al. (2002) reported that higher concentration of chloride is an indicator of pollution due to higher animal waste. Sivakumar et al. (2000) and Haran (2002) reported that chloride concentration up to 250 mg/L are not harmful but is an indication of organic pollution resulting from sewage mixing and increased temperature and evapo-transpiration of water.

Maximum permissible limit for nitrate in drinking water is 50 mg/L as per WHO and 45 mg/L as per Indian standards. In the present study, nitrate varied from 9 to 680 mg/L with mean and SD of 102.2, and 99.18, respectively. About 75.3% of the samples exceed nitrate concentration permissible level of 45 mg/L. Majagi et al. (2008) also reported excess nitrate level of 342 mg/L in

Table 1. Groundwater physic chemical quality descriptive statistics.

Parameter	Minimum	Maximum	Mean	Std. Deviation
pH	6.80	8.40	7.83	0.39
EC	575.00	3220.00	1571.47	510.04
TDS	82.00	1910.00	926.43	313.41
TH	52.00	1184.00	459.04	229.73
Ca^{2+}	16.00	429.00	112.83	67.25
Mg^{2+}	3.00	193.00	44.26	32.48
Na^{+}	26.00	360.00	145.84	64.94
K^{+}	1.00	20.00	5.15	3.81
HCO_3^-	98.00	652.00	275.15	96.25
CO_3^{2-}	0	0	0	0
Cl^-	64.00	784.00	249.44	112.47
SO_4^{2-}	29.00	220.00	122.53	38.68
NO_3^-	9.00	680.00	102.22	99.18
%Na	8.12	89.23	42.50	17.23
F	0.05	1.9	0.253	0.372
Fe	0.1	0.15	0.1037	0.013
SAR	0.35	8.87	2.63	1.57
$Ca^{2+} + Mg^{2+}$	19.00	457.00	156.82	79.41
$Na^{+} + K^{+}$	28.00	370.00	150.68	67.64
$Ca^{2+} + Mg^{2+} / Na^{+} + K^{+}$	0.09	8.00	1.38	1.24

N=150. All the values are in mg / L except EC, in µS / cm.

Gulbarga city during 2001 to 2002, and attributed this to poor sewerage and solid waste disposal system, leaky sewers, large number of septic tanks and soak pits, and practice of sewage discharge through open surface drains. High incidence of water related diseases such as cholera, jaundice, typhoid and diarrhoea were reported for Gulbarga city due to non wholesome water supply, poor sanitation and inefficient solid waste collection and disposal system (Degaonkar and Chaya, 2003). The problem of groundwater contamination by nitrates has been thoroughly studied all over the world and has been found that water in shallow wells containing more than 45 mg/L excess nitrate content causes methemoglobinemia/blue baby syndrome in humans (Durfor and Baker, 1964). Several studies document adverse effects of higher nitrate levels, most notably methemoglobinemia (Hudak, 2000; Levallois et al., 1998; WHO, 1985).

Total dissolved solids values indicate that 95% of the water samples (142 bore wells) were above the desirable limit of 500 mg/L and TDS ranged between 82 and 1910 mg/L with mean and SD of 926 and 313, respectively. Groundwater classification based on TDS values is presented in Tables 3 and 4. The results indicated fresh water type for 62.7% of the sample locations and the rest represent brackish water based on Freeze and Cherry (1979). As per Davis and Dewiest (1966) classification method, only 5.3% of the samples (8 bore wells) have TDS below 500 mg/L. Almost all the samples need to be treated before supply. TDS concentration was high due to the presence of bicarbonates, carbonates, sulphates and chlorides of calcium (Subba Rao et al., 1998; Deepali et al., 2001) and TDS value of 500 mg/L is the desirable limit and water containing more than 500 mg/L TDS causes gastrointestinal irritation (Jain et al., 2003). High value of TDS influences the taste, hardness, and corrosive property of the water (Joseph and Jaiprakash, 2000; Haran, 2002; Subhadra Devi et al., 2003).

Groundwater classification based on hardness value is given in Table 5. Hardness values ranged from 52 to 1184 mg/L with mean and SD of 459 and 229, respectively. The maximum allowable limit of TH for drinking purpose is 600 mg/L and the desirable limit is 300 mg/L (ISI, 1991). Groundwater exceeding the limit of 300 mg/L is considered to be very hard (Sawyer and McCarty, 1967). TDS in 71.3% of groundwater samples (107 bore wells) exceed the maximum allowable limit of 500 mg/L. All the groundwater samples were rated as hard to very hard and require softening prior to domestic uses.

Fluoride varies from 0.05 to 1.9 mg/L, with mean value 0.253 mg/L and SD of 0.372 mg/L. Five samples exceed permissible limit of 1.5 mg/L. Excess fluoride are also reported in the outskirts of the city (The Hindu, 2011) and in some villages 30 km from the city (Shivashankara et al., 2000). Iron content in the groundwater was observed within the permissible limit of drinking water and ranged between 0.05 and 0.10 mg/L, with a mean of 0.1037 mg/L

Table 2. Comparison of the samples bore well water with drinking water standards.

Substance or characteristic	IS 10500 : 1991		WHO (1993) recommendation	Undesirable effect outside the desirable limit	% Sample exceeding recommended value
	Desirable limit	Permissible limit			
Essential characteristics					
pH value	6.5 to 8.5	No relaxation	<8.0	Beyond this range the water will affect the mucous membrane and/or water supply system	100% within range of 6.5-8.5
Total hardness (as $CaCO_3$) mg/L	300	600		Encrustation in water supply structure and adverse effects on domestic use	71.3% above 300, and 23.3% above 600 mg/L
Cl^- mg/lL	250	1000	250	Beyond this limit, taste, corrosion and palatability are affected	58.7% below and 41.3% exceeds 250 mg/L
Desirable characteristics					
Dissolved solids (TDS) mg/L	500	2000	1000	Beyond this palatability decreases and may cause gastro intestinal irritation	5.3% below 500. 58.7 between 500-1000, 36% above 1000 mg/L
Ca^{2+} mg/L	75	200	250 (UK 1989 max)	Encrustation in water supply structure and adverse effects on domestic use	32% below 75, 58.7% between 75-200, 9.3% above 200 mg/L
Mg^{2+} mg/L	30	100	50 (UK 1989 max)	Encrustation in water supply structure and adverse effects on domestic use	39.3% <30, 60.6% <50, 94.6% <100, 5.4% <100 mg/
Na^+ mg/L			200		78.7% below, 21.3% above 200 mg/L
K^+ mg/L			12 (UK 1989 max)		93.3% <12, 6.7% >12 mg/L
SO_4^{2}-mg/L	200	400	250	causes gastro intestinal irritation when Mg or Na are present	96% below 200 and 4% between 200-400 mg/L
NO_3^- mg/L	45	100	50	Methemoglobinemia takes place	24.7% <45, 30% <50, 43% between 45-100, 32.7% above 100 mg/L
HCO_3^- (mg/L)	200	600		Beyond this limit taste becomes unpleasant	74.7% above 200 mg/L
F (mg/L)	1	1.5	1.5	High fluoride may causes fluorosis	10% exceed 1.5 mg/L, max value is 1.9 mg/L
Fe (mg/l)	0.3	1	0.3	Taste/appearance are affected, has adverse effect on domestic uses and water supply structures	All samples show Fe within the limit

Table 3. Classification of water based on TDS by Davis and DeWiest (1966).

TDS (mg/L)	Class	No. of samples	% of samples
<500	Desirable for drinking	8	5.3
500-1000	Permissible for drinking	88	58.7
1000-3000	Useful for irrigation	54	36
>3000	Unfit for drinking and irrigation	0	0
Total		150	100

Table 4. Classification of water based on TDS by Freeze and Cherry (1979).

TDS (mg/L)	Class	No. of samples	% of samples
<1000	Fresh water type	94	62.7
1000-10000	Brackish water type	56	37.3
10000-100000	Saline water type	0	0
>100000	Brine water type	0	0
Total		150	100

Table 5. Classification of water based on hardness (Sawyer and McCarty, 1967).

TH (mg/L)	Water type	No. of samples	% of samples
0-75	Soft	1	0.7
75-150	Moderately hard	5	3.3
150-300	Hard	37	24.7
>300	Very hard	107	71.3
Total		150	100

Table 6. Classification of water samples after US salinity laboratory staff (1954).

Salinity hazard	EC (micromohs/cm) at 25°C	No. of samples	% of samples
Low	<250	0	0
Medium	250-750	3	2
High	750-2250	133	88.7
Very high	>2250	14	9.3
Total		150	100

and SD of 0.013 mg/L, respectively. EC values varied between 575 and 3220 µS/cm, with mean and SD of 1571 and 510, respectively, and showed a salinity hazard from high to very high as shown in Table 6.

Sodium concentration is one of the important parameters in the classification of irrigation water. Soils containing a large proportion of sodium with carbonate as predominant anion are termed alkali soils and those with chloride or sulphate as predominant anion are termed as saline soils and these affects plant growth (Todd, 2007). Sodium content is usually expressed in terms of percent sodium defined by:

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

where all ionic concentrations are expressed in milli equivalents per litre. Percent sodium classification is presented in Table 7, which indicates that most of the water is suitable for irrigation purposes. The salinity laboratory of USDA recommends sodium adsorption ratio (SAR) due to its direct relation to adsorption of sodium by soil and is defined by:

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

where all ionic concentrations are expressed in milli equivalents per litre. Classification of the analyzed water for irrigation, based on SAR and EC indicated a low sodium alkali hazard and high to very high salinity hazard

Table 7. Groundwater classification according to %Na (Wilcox, 1955).

Na (%)	Class	No. of sample	% of samples
0-20	Excellent	14	9.3
20-40	Good	60	40
40-60	Permissible	49	32.7
60-80	Doubtful	25	16.7
>80	Unsuitable	2	1.3
Total		150	100

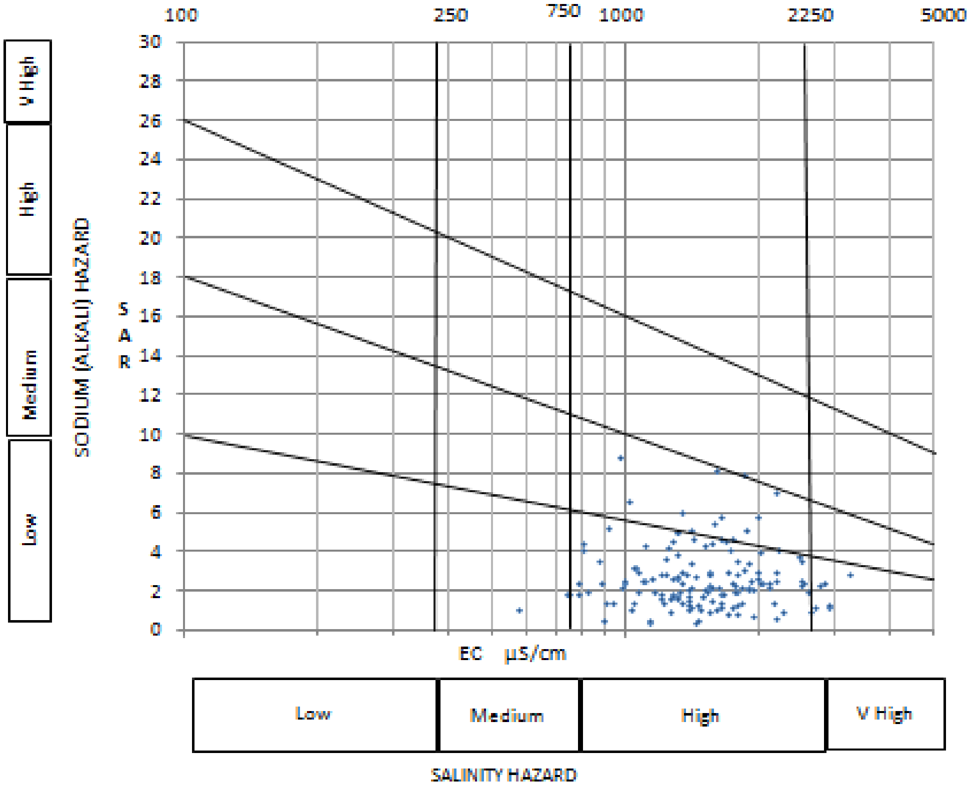

Figure 2. Classification of groundwater for irrigation (after Richard's).

in the collected groundwater samples (Figure 2).

Groundwater type is also shown through piper diagram as in Figure 3. It indicates that the sampled groundwater is characterized by prevalence of calicum, magnesium and sodium cations and sulfate and chlorides anions.

Normal statistics for variables

Correlation analysis

Correlation and regression analysis is useful for interpreting groundwater quality data and relating them to specific hydro geological processes. These tools are quite useful in characterizing and obtaining first hand information of the groundwater system than actually going through complex methods and procedures. Table 1 presents the range, arithmetic mean and standard deviation for the cations and anions considered, and transformations used in the multiple regression analysis. The range, mean and standard deviation values revealed considerable variations in the water samples with respect to their chemical composition.

The degree of linear association between any two of the water quality parameters is measured by the simple correlation coefficient (r). Correlation matrix for different water quality parameters along with the significance level (2 tailed) is shown in Table 8. It is observed that the significant correlation between EC and other hydro geochemical parameters is significantly positive.

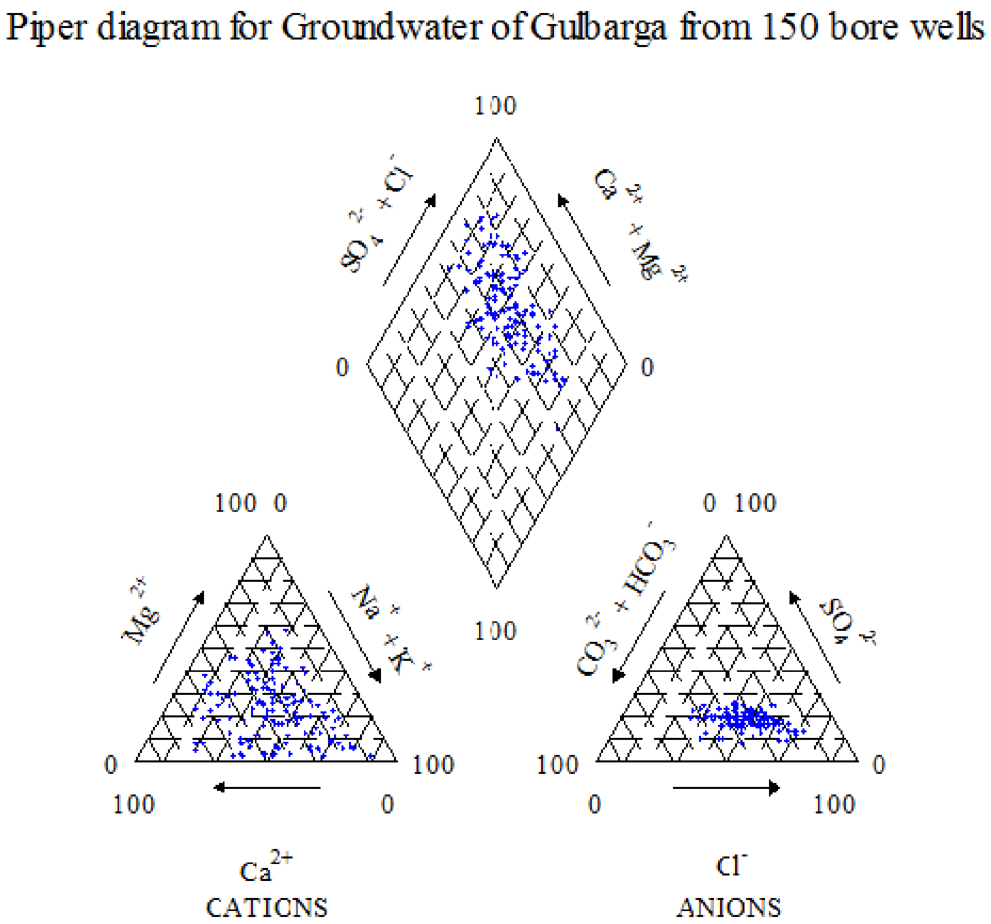

Figure 3. Piper diagram reflecting groundwater type.

The r value between EC and Ca^{2+} and Mg^{2+} was 0.814 and for $Na^+ + K^+$, it was 0.434 and the relative coefficient of determined value shows that the 66.2 and 19% of the variability with EC could be respectively ascribed to the variable $Ca^{2+} + Mg^{2+}$ and $Na^+ + K^+$ concentration in the water. The correlation between EC and Cl^- is significant (r = 0.872) and coefficient of determination value indicated that 76% of the variability in EC could be ascribed to the Cl^- concentration in water. Ca^{2+} (r = 0.689), Mg^{2+} (r = 0.569), K^+ (r = 0.568), HCO_3^- (r = 0.594), and SO_4^{2-} (r = 0.783) are other significant variables with determined values for EC prediction.

Adhikari et al. (2009) studied statistical approaches for hydro geochemical characterization of groundwater in west Delhi, India. The study showed good correlation between EC and other water quality parameters and also showed that multiple regression model can predict EC at 5% level of significance.

Regression analysis

Multiple linear regression model was performed by using SPSS software. Most multiple linear regression model in predicting EC, TDS, TH, Ca^{2+}+ Mg^{2+}, $Na^+ + K^+$, HCO_3^-, Cl^-, NO_3^- and SO_4^{2-} are presented in Table 9.

All the independent variables were noticed to have a significant effect ('t' test for the partial regression coefficients at 5% level of probability) on the corresponding dependent variable. The prediction of EC from selected ionic compositions was fairly good. The independent variables such as Cl^-, HCO_3^-, NO_3^- and SO_4^{-} were significant in predicting EC value. The multiple R^2 value (0.999) indicates that 99.9% of the variability in EC could be ascribed to the combined effect of Cl^-, HCO_3^-, NO_3^- and SO_4^{-}.

Out of 99.9% of the variability in EC due to the combined effect of Cl^-, HCO_3^-, NO_3^- and SO_4^{2-}, 76% was due to Cl^- alone and 12.5, 10.3 and 1.1% were due to HCO_3^-, NO_3^- and SO_4^{2-} respectively (Table 10). 71.7% of the variability of HCO_3^- could be ascribed to the combined effect of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} whereas in Cl^-, 89.6% of the variability of the observed Cl^- could be ascribed to the combined effect of Na^+, K^+, Ca^{++}, Mg^{2+}, HCO_3^-, SO_4^{2-} and NO_3^-. In predicting NO_3^-, 73.3% of the variability could be ascribed to the combined effect

Table 8. Correlation matrix of water quality parameters with Sig level 2 – tailed.

Parameter	**EC**	**TDS**	**TH**	**Na^+**	**K^+**	**Ca^{++}**	**Mg^{++}**	**HCO_3^{--}**	**Cl^-**	**SO_4^{--}**	**NO_3^-**	**$Na^+ + K^+$**	**$Ca^{++} + Mg^{++}$**	**$Ca^{++} + Mg^{++}/Na^+ + K^+$**
EC	1													
TDS	0.958** 0.000	1												
TH	0.827** 0.000	0.761** 0.000	1											
Na^+	0.419** 0.000	0.454** 0.000	-0.163* 0.047	1										
K^+	0.568** 0.000	0.567** 0.000	0.156 0.056	0.726** 0.000	1									
Ca^{++}	0.689** 0.000	0.684** 0.000	0.830** 0.000	-0.119 0.147	0.079 0.335	1								
Mg^{++}	0.569** 0.000	0.460** 0.000	0.693** 0.000	-0.134 0.102	0.173* 0.034	0.174* 0.033	1							
HCO_3	0.594** 0.000	0.547** 0.000	0.464** 0.000	0.287** 0.000	0.527** 0.000	0.305** 0.000	0.426** 0.000	1						
Cl^-	0.872** 0.000	0.811** 0.000	0.707** 0.000	0.387** 0.000	0.481** 0.000	0.490** 0.000	0.616** 0.000	0.294** 0.000	1					
SO_4^{2-}	0.783** 0.000	0.752** 0.000	0.585** 0.000	0.429** 0.000	0.500** 0.000	0.491** 0.000	0.399** 0.000	0.573** 0.000	0.631** 0.000	1				
NO_3^-	0.470** 0.000	0.521** 0.000	0.474** 0.000	0.070 0.392	0.080 0.333	0.671** 0.000	-0.030 0.714	0.041 0.620	0.182* 0.026	0.174* 0.033	1			
$Na^+ + K^+$	0.434** 0.000	0.467** 0.000	-0.147 0.072	0.999** 0.000	0.752** 0.000	-0.110 0.181	-0.119 0.148	0.305** 0.000	0.398** 0.000	0.439** 0.000	0.072 0.382	1		

Table 8. Contd.

Ca^{2+}+ Mg^{2+}	0.814**	0.766**	0.984**	-0.155	0.138	0.916**	0.555**	0.431**	0.665**	0.578**	0.554**	-0.141	1	
	0.000	0.000	0.000	0.058	0.093	0.000	0.000	0.000	0.000	0.000	0.000	0.085		
Ca^{2+} + Mg^{2+} / Na^+ + K^+	0.178*	0.139	0.587**	-0.633**	-0.302**	0.549**	0.327**	0.041	0.132	0.060	0.233**	-0.623**	0.597**	1
	0.030	0.090	0.000	0.000	0.000	0.000	0.000	0.621	0.107	0.468	0.004	0.000	0.000	

N=150. **, Significant at 0.01 level; *, significant at 0.05 level.

Table 9. Multiple linear regression models for selected groundwater quality parameters.

Dependent variable [R^2]	Constant for model	Significant 5% level regression coefficients for independent variables [std. error of regression coefficients]							Std. error for regression model
EC [0.999]	[-4.12]	2.83Cl^-	1.63HCO_3^-	1.625NO_3^-	2.085 SO_4^{2-}				87.149
	[5.359]	[0.017]	[0.019]	[0.015]	[0.058]				
HCO_3^- [0.717]	55.029	0.988 Ca^{2+}	2.968Mg^{2+}	1.012 Na^+	7.406 K^+	-0.973 Cl^-	-0.982 NO_3^-	0.281 SO_4^{2-}	52.253
	[17.486]	[0.113]	[0.266]	[0.158]	[1.836]	[0.087]	[0.009]	[0.184]	
Cl^- [0.892]	-14.490	2.737Mg^{2+}	1.193 Na^+	0.955 Ca^{2+}	-0.461 HCO_3^-	-0.099 SO_4^{2-}			36.913
	[11.253]	[0.118]	[0.064]	[0.059]	[0.041]	[0.131]			
NO_3^- [0.709]	-35.120	0.204 Ca^{2+}	1.354 Na^+	1.814 Ca^{2+}+ Mg^{2+}	-0.723 Cl^-	-1.531 SO_4^{2-}			54.402
	[16.545]	[0.212]	[0.131]	[0.263]	[0.089]	[0.192]			
SO_4^{2-} [0.692]	16.924	0.40 Ca^{2+}	0.363 Mg^{2+}	0.328Na^+	0.035 HCO_3^-	-0.127 NO_3^-			21.833
	[6.518]	[0.042]	[0.064]	[0.032]	[0.024]	[0.026]			
C a^{2+} + Mg^{2+} [0.977]	2.529	0.235 HCO_3^-	0.42 Cl^-	0.352 NO_3^-	0.448 SO_4^{2-}	-0.724Na^+			12.217.
	[3.727]	[0.013]	[0.012]	[0.010]	[0.040]	[0.017]			
Na^+ + K^+ [0.942]	2.824	0.328 HCO_3^-	0.571 Cl^-	0.465 NO_3^-	0.618 SO_4^{2-}	-1.321 Ca^{2+} +Mg^{2+}			16.631
	[5.046]	[0.018]	[0.019]	[0.018]	[0.054]	[0.031]			

N=150.

Table 10. Individual contributions of various independent chemical variables to predict chemical water quality parameters.

Dependent variable	**Independent variables**									**Total variability (R^2)**
	Na^+	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**	**NO_3^{2-}**	**$Ca^{2+} + Mg^{2+}$**	
EC					0.125	0.76	0.011	0.103		0.999
HCO_3^-	0.081	0.077	0.07	0.5		0.11	0.328			0.717
Cl^-	0.088		0.159	0.158	0.093		0.398			0.896
SO_4^{2-}	0.13		0.11	0.074	0.328			0.05		0.692
NO_3^-	0.093		0.45			0.038	0.032		0.096	0.709
$Na^+ + K^+$					0.128	0.192	0.193	0.196	0.234	0.942
$Ca^{2+} + Mg^{2+}$	0.2				0.121	0.442	0.02	0.194		0.977

N = 150. All the values are in mg/L, except EC. Units of EC are do/m.

of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-}, and in case of SO_4^{-} , 81.7% of the variability could be ascribed to the combined effect of Na^+, Ca^{2+}, Mg^{2+} CO_3^-, and SO_4^{2-}. The regression model of nitrate indicated that a maximum of 70.93% of the observed variability in nitrate is accounted for by this model. Similarly, Ca^{2+} + Mg^{2+} and Na^+ + K^+ regression model can predict up to 97.7 and 94.2% variability, respectively.

Conclusion

Variations noticed in specific water quality substance among the water samples drawn from various bore wells may be attributed to various land use and land cover factors. However, a significant correlation is noticed among many of the tested water quality parameters. The correlation between EC and other water quality parameters is significantly positive. 99.9% of the variability in EC could be ascribed to the comb ined effect of Cl- HCO3-, NO3- and SO42-. The multiple regression model can predict groundwater quality parameters with 5% level of significance.

The groundwater was classified as very hard and saline. Presence of high chlorides and nitrates concentration indicated potential influence of sewage pollution owing to poor drainage and solid waste disposal system in the city. Fluoride values were high in few samples. Many samples were not fit for drinking purpose. It is suggested to treat groundwater before drinking and potable uses. Suitable strategies to groundwater recharge, controlled groundwater usage, measures to reduce ground water pollution and awareness of the importance of water quality for private bore well users are recommended.

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