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Full Length Research Paper

Hydrogeochemistry of subsurface water around waste disposal sites in Hyderabad city, India: Geogenic and anthropogenic consequence

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Geochemical study of groundwater around major dumpsites in Hyderabad city India, this study was carried out to evaluate the groundwater quality. Approximately 4,000 tons of solid wastes are dumped in low-lying areas as landfills on daily basis affecting groundwater quality. The samples were collected from sixty location points in/around dumpsites and were precisely analysed for physicochemical characters by standard methods recommended by American Public Health Association (APHA), double junction ion analyzer, turbidimetric method and Inductively Coupled Plasma Mass Spectrometer. The type of water that predominated in the study area was assessed based on hydro-chemical facies whereas the suitability of groundwater for irrigation was evaluated based on sodium adsorption ratio, percent sodium, residual sodium carbonate and the US salinity diagram. High concentrations of major ions (Ca^{++}, Mg^{++} and F^-) observed in bore wells were attributed to differential weathering of minerals such as pyroxenes, plagioclase, feldspars, and apatite together with dissolution/precipitation reactions along fractures and joints in the granites. The high NO_3^- level (>50 mg/l) in groundwater is ascribed to consequence of the oxidation of ammonia and similar sources from leachates emanating from waste. Although the water is not suitable for domestic purposes, it is however, found to be suitable for irrigation purposes with little risk in the development of detrimental level of exchangeable sodium.

Key words: Groundwater quality, solid waste, physicochemical character, major ions, Hyderabad.

INTRODUCTION

The urban and suburban population in and around Hyderabad city greatly depend on groundwater from weathered and fractured Precambrian bedrock for various purposes other than drinking. These bedrock aquifers are extremely heterogeneous and their characteristics are complex to generalize (Knutsson, 2000). Presence of any component such as major ions in excess concentration compared to values prescribed by World Health Organisation (WHO) (2004) will result in water unsuitable for irrigation, domestic or industrial uses. The dissolved physicochemical parameters in groundwater play a significant role in classifying and assessing water quality. Residual sodium carbonate (RSC) can be used as a decisive factor for finding the suitability of irrigation water. It was observed that the criteria used in the classification of water for a particular purpose may not satisfy find the suitability standards for other purposes, but better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters (Handa, 1964; Handa, 1965; Hem, 1985). Chemical categorization also throws light on the concentration of various predominant cations, anions and their interrelationships. The present study was taken up to establish the levels of dissolved major ions in and around solid waste disposal sites

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Abbreviations: APHA, American public health association; **RSC,** residual sodium carbonate; **ICPMS,** inductively coupled plasma mass spectrometer; **NIST,** national institute of standards and technology; **TDS,** total dissolved solids; **EC,** electrical conductivity; **USEPA,** US environmental protection agency; **MCL,** maximum contaminant level.

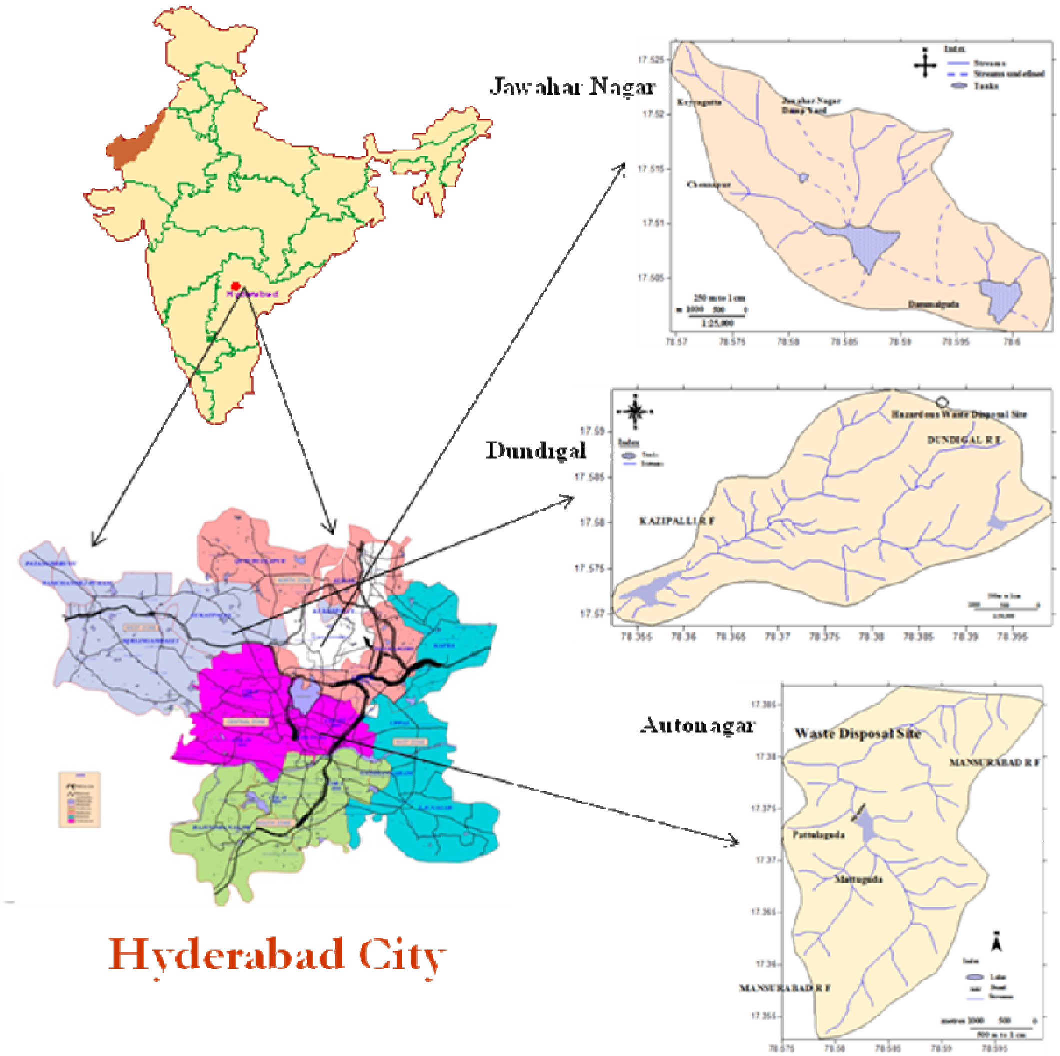

Figure 1. Key map of study area showing watershed of Jawahar Nagar, Dundigal and Autonagar.

located on structurally deformed terrain to classify the groundwater and to examine the water quality and suitability for drinking and irrigation purposes. In this case, various methods have been used to study critically the geochemical characteristics of the groundwater in Hyderabad city.

Study area

Solid waste disposal sites in and around Hyderabad are a fraction of the peninsular gneissic complex (Figure 1). The study area are covered by granite, which is a part of large granitic batholiths having exposures covering an areal extent of over 5000 km^2 belonging to the Archaean age (Janardhan Rao, 1965; Sitaramayya, 1971; Kanungo et al., 1975). The granites are medium to coarse grained and are mainly of two varieties-grey and pink granite-depending upon the colour of the feldspars. However, the grey granites are usually fine to coarse grained, with the medium grained variety being the dominant, whereas the pink granites are fine grained, aplitic types through coarse grained to often porphyritic varieties and are devoid of foliation. Mineralogically, these rocks consists of quartz (21 to 42%), potash feldspar (34 to 60%) and plagioclase (2 to 30%) with biotite (1 to 22%) forming the chief accessory. Epidote and pyroxene are frequently observed in such terrain (Gnaneshwar and Sitaramayya, 1998).

The groundwater occurs in the weathered and fractured zones under the water table in semi-confined conditions. The depth of weathering and fractured zones dominantly controls the occurrence and the movement of groundwater in these rocks. These rocks possess negligible primary porosity but secondary porosity and permeability occurred as a result of deep fracturing and

Table 1. Analytical results of physicochemical parameters of groundwater in Jawahar Nagar.

Samples	pH	EC (µS/cm)	TDS (mg/l)	F^- (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Total alkaline (mg/l)	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
W 1	7.4	1180	690.1	2.6	161.5	130.2	176.4	474.16	108.86	82.85	69.71	32.1
W 2	7.8	883	522.6	2.1	210.2	174.3	109.2	373.26	105.63	651.65	63.62	6.44
W 3	5.1	779.9	455.2	2.4	256.5	172.0	106.2	553.21	108.87	50.98	119.1	5.58
W 4	7.5	1086	634.4	2.8	271.8	10.6	137.7	151.46	80.48	70.25	50.6	6.33
W 5	7.5	1335	782.3	2.7	69.40	3.7	52.3	544.36	88.64	89.84	65.85	6.65
W 6	7.5	923	540.5	1.6	194.5	36.0	44.8	144.86	66.35	70.96	42.48	4.85
W 7	7.5	1355	794.4	1.9	49.30	13.2	27.9	532.11	90.18	79.9	55.3	6.08
W 8	7.8	1498	879.1	2.2	150.9	38.1	37.2	370.61	97.53	62.7	49.8	5.14
W 9	8.1	432.4	252.6	1.6	177.7	15.51	46.1	587.16	27.12	66.66	50.08	5.59
W 10	7.6	1277	753.3	1.5	107.0	15.9	63.4	378.91	51.83	51.17	66.42	5.93
W 11	7.6	957	562.8	2.0	164.6	27.41	41.4	133.26	61.43	42.34	79.8	3.97
W 12	7.3	1871	1097	2.4	58.52	31.81	39.7	474.31	71.53	54.99	51.5	5.95
W 13	7.5	1486	873.6	1.3	259.6	12.91	50.3	151.51	54.65	59.23	98.7	6.18
W 14	7.6	1005	590.2	1.9	274.9	6.01	49.0	526.31	70.7	59.18	50.75	4.72
W 15	7.5	1178	691.6	3.1	205.6	38.3	56.5	154.51	84.86	42.04	64.75	5.23
W 16	7.4	1810	1062	3.0	197.6	53.0	141.9	270.36	107.6	79.37	43.5	10.05
W 17	6.9	434.2	246.4	2.2	155.2	40.41	110.4	282.56	38.92	66.91	31.27	4.37
W 18	7.2	350.7	200.0	2.5	154.0	55.3	180.6	431.16	32.54	17.69	29.26	4.25
W 19	7.4	914	515.8	1.9	80.8	18.21	70.5	367.76	82.13	29.12	64.75	4.13
W 20	7.8	619	350.8	1.8	110.1	25.1	67.6	264.11	50.06	32.97	43.5	4.35
W 21	7.1	1492	841.1	1.0	79.90	18.3	35.5	221.41	93.09	16.77	55.4	4.38
W 22	7.8	1488	875.1	1.7	150.1	29.5	32.1	145.61	80.47	19.63	49.6	5.71

weathering forming potential aquifers. The general pattern of groundwater flow in the area is from south-west to north-east. The transmissivity of granite aquifer ranges from 30 to 200 m^2/day (Ahmed et al., 2002). Major part of the study area is covered with pedi-plain having shallow weathering. The soil cover is well-developed residue of weathered granite consisting of clay loam, red loam and sandy loam with variable width. The area is semi-arid with subtropical climatic conditions. The temperature varies between 25 to 45°C. It receives more than 80% precipitation from SW monsoon with an average rainfall of 812 mm.

MATERIALS AND METHODS

Groundwater samples were collected from sixty continually used bore wells (depth 150′ to 250′; diameter 8″ to 10″) located around dumpsites at the target interval of 200 to 400 m in a network formation. The samples were collected during April and May (summer) when the water levels are low and the mineral contents in water are likely to reach the maximum. Samples were collected in pre-cleaned high-density polyethylene bottles from representative bore wells distributed throughout the area. The collected samples were filtered using whatmann filter paper no. 42, and acidified with nitric acid (AR grade) to pH < 2 (0.2% v/v). The number of samples varies from one site to the other depending upon the availability of bore wells or pumps within a particular watershed. Seventeen groundwater samples were collected from the area around industrial waste disposal site at Dundigal, twenty-one groundwater samples were collected from the watershed of Autonagar (municipal waste disposal area) and twenty two groundwater samples were collected from the watershed of Jawahar Nagar (municipal dumpsite). On-site observations like location, source and depth of the bore wells were recorded. Water pH, total dissolved solids and temperature were measured instantly with corresponding pH/EC/TDS/°C portable meter. Total alkalinity was determined in non acidified samples by titration against 0.1 M hydrochloric acid using methyl orange and phenolphthalein as indicators (APHA, 1998). Anions (nitrate, fluoride, chloride) were analysed by double junction electrode at 25°C. Sulphate ion was determined by turbidimetric method. Inductively Coupled Plasma Mass Spectrometer (ICPMS) model ELAN DRC II, Perkin-Elmer Sciex instrument, USA, was used to determine calcium, magnesium, sodium and potassium ions in groundwater. Calibration of the instrument was performed using certified reference material NIST 1640 (National Institute of Standards and Technology, USA), to minimize the matrix and other associated interference effects. Blanks were analyzed along with the samples and rectifications were carried out accordingly.

RESULTS AND DISCUSSION

Chemistry of major ions

The analytical results of physicochemical parameters are shown in (Tables 1, 2 and 3). The pH of groundwater

Table 2. Analytical results of physicochemical parameters of groundwater in Dundigal.

Samples	pH	EC (µS/cm)	TDS (mg/l)	F^- (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Total alkaline (mg/l)	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
W 1	7.1	395.3	210.3	1.9	173.3	43.2	180.1	132.65	65.84	70.65	68.26	30.25
W 2	7.8	441.2	263.5	2.3	67.22	66.7	109.9	181.35	50.32	68.23	59.45	2.89
W 3	7.2	1272	750.9	1.2	268.3	185.7	145.6	217.95	76.25	49.25	50.28	2.54
W 4	7.3	944	550.4	3.0	283.6	54.11	141.4	157.0	91.56	66.50	46.79	3.33
W 5	7.1	930	545.2	2.9	81.20	52.0	56.0	138.95	101.36	90.16	70.25	3.65
W 6	7.2	974	565.7	3.3	206.3	51.8	48.5	440.5	100.27	71.39	45.54	1.98
W 7	7.5	1491	874.1	3.2	255.3	49.7	31.6	546.9	102.44	77.01	39.58	3.78
W 8	7.6	1278	751.3	2.1	162.7	24.3	67.1	245.4	101.29	50.23	0	2.12
W 9	8.1	778.9	453.2	2.4	89.50	29.6	45.1	513.3	60.32	72.01	0	2.95
W 10	8.0	1171	682.6	1.8	118.8	38.8	43.4	99.4	88.90	45.66	68.99	2.99
W 11	7.5	775	452	2.2	176.4	41.11	54.0	470.7	90.53	34.25	30.25	0.89
W 12	7.0	613	347.3	2.6	70.34	45.51	40.9	175.4	60.58	50.18	60.48	2.94
W 13	7.1	919	513.8	1.5	271.4	26.61	39.2	148.2	88.26	55.98	40.59	3.55
W 14	7.5	778.9	459.2	2.1	286.7	19.71	49.8	291.0	74.80	58.65	0	1.67
W 15	7.5	1709	838.0	2.4	84.35	26.9	60.2	415.6	45.69	43.56	70.31	3.59
W 16	6.8	1254	769.4	1.8	209.4	29.21	52.7	315.45	23.85	11.36	40.30	8.45
W 17	6.8	1015	623.2	1.7	60.30	17.4	35.8	407.26	30.33	15.54	31.98	2.88

Table 3. Analytical results of physicochemical parameters of groundwater in Autonagar.

Samples	pH	EC (µS/cm)	TDS (mg/l)	F^- (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Total alkaline (mg/l)	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
W 1	6.6	1177	687.1	2.1	164.2	57.2	27.8	132.75	64.53	60.66	24.26	2.71
W 2	6.7	880	519.6	3.4	68.10	176.2	171.2	434.3	47.65	60.92	58.62	29.11
W 3	7.1	776.9	452.2	4.3	259.2	173.9	36.7	540.7	44.83	44.97	64.71	2.58
W 4	6.7	1083	631.4	2.2	274.5	54.9	128.3	239.2	73.48	64.25	45.59	3.33
W 5	6.8	1332	779.3	4.0	115.1	27.0	167	507.1	81.63	83.84	60.85	3.65
W 6	7.2	920	537.5	2.9	197.2	31.4	42.9	93.2	59.34	64.96	37.47	1.85
W 7	7.2	1352	791.4	3.1	56.24	12.5	35.4	464.5	83.18	73.91	0	3.08
W 8	7.5	1495	876.1	3.5	153.6	37.9	18.5	169.2	90.53	56.69	0	2.14
W 9	7.8	429.4	249.6	2.9	210.1	15.1	99.8	142.0	20.12	10.77	45.08	2.59
W 10	7.3	1274	750.3	2.8	109.7	40.0	96.8	284.8	100.59	45.17	61.42	2.92
W 11	7.3	954	559.8	3.3	167.3	17.8	54.0	409.4	54.42	36.33	0	0.96
W 12	7.0	1868	1094	3.7	245.6	29.31	32.0	309.25	101.86	48.99	0	2.95
W 13	7.2	1483	870.6	3.1	262.3	33.71	30.3	401.06	98.63	53.23	0	3.18
W 14	7.3	1002	587.2	3.9	277.6	14.81	40.9	361.05	63.7	53.18	45.75	1.72
W 15	7.2	1175	688.6	2.3	210.9	7.91	132.5	333.65	77.85	36.04	0	2.23
W 16	7.1	1807	1059	3.2	200.3	40.2	47.1	190.5	101.87	73.36	0	7.05
W 17	7.1	431.2	243.4	3.5	50.22	17.41	39.6	105.4	31.92	13.62	26.27	1.37
W 18	7.5	347.7	197.0	3.8	156.7	42.31	22.7	202.7	25.53	11.69	46.49	1.25
W 19	7.3	911	512.8	2.3	83.50	20.2	101	257.3	75.12	23.12	59.74	1.12
W 20	7.2	616	347.8	2.6	112.8	20.11	58.2	446.05	43.06	26.97	38.5	1.35
W 21	7.2	1489	838.1	2.5	82.60	5.6	26.1	315.45	86.09	76.85	0	1.38

varies from 5.1 to 8.1 in Jawahar Nagar, 6.8 to 8.1 in Dundigal and 6.6 and 7.8 in Autonagar. The average concentrations of total dissolved solids (TDS) in the groundwater varies from 500 to 1500 mg/l except in few

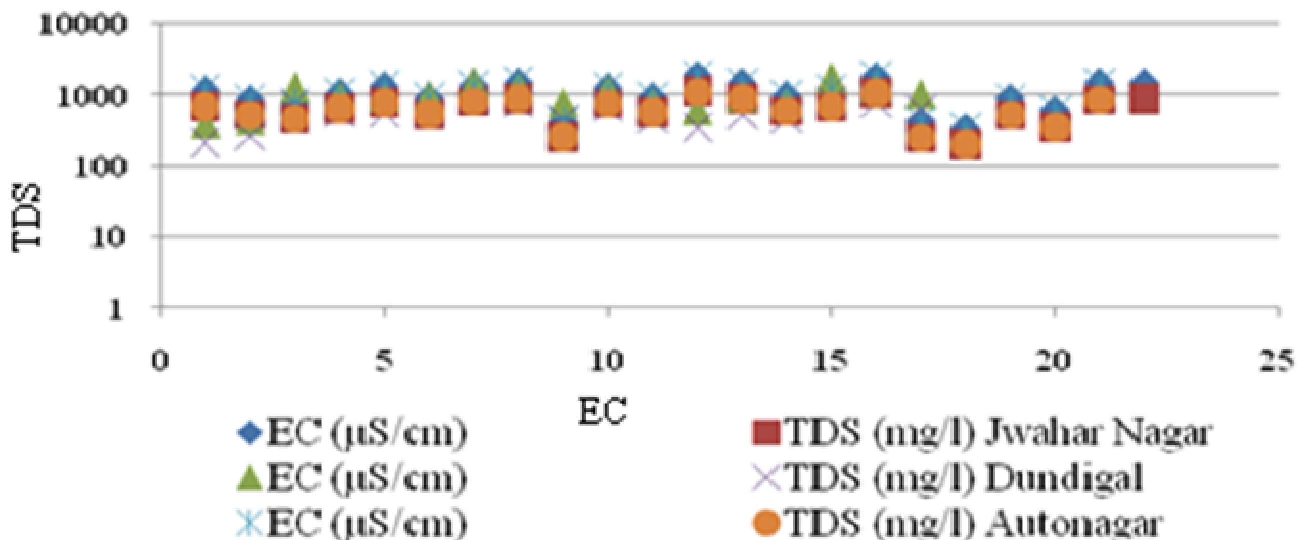

Figure 2. Scatter plot of EC-TDS in groundwater.

Table 4. Summary of physicochemical parameters of groundwater.

Parameter	Groundwater Jawahar Nagar	Mean value	Groundwater Dundigal	Mean value	Groundwater Autonagar	Mean value	BIS (1991)	WHO Guidelines (2004)
pH (pH units)	5.1-8.1	7.5	6.8-8.1	7.3	6.6-7.8	7.1	6.5-8.5	6.5-8.5
EC (µS/cm)	350.7-1871	1107	395.3-1709	984.66	347.7-1868	1085.8	…	…
TDS (mg/l)	200-1097	645.9	210.3-874.1	567.65	197-1094	632	500	500
Ca^{++} (mg/l)	27.12-108.87	75.15	23.85-102.44	73.68	20.12-101.87	67.901	75	75
Mg^{++} (mg/l)	16.77-651.65	81.69	11.36-90.16	54.74	10.77-83.84	48.54	30	< 30
Na^{+} (mg/l)	29.26-119.1	58.89	30.25-70.31	51.646	24.26-64.71	47.288	...	< 200
K^{+} (mg/l)	3.97-32.1	6.72	0.89-30.25	4.732	0.96-29.11	3.739	…	…
T. alkaline (mg/l)	133.2-587.1	342.4	99.4-546.9	288.0	93.2-540.7	301.8	200	…
F^{-} (mg/l)	1.0-3.1	2.1	1.2-3.3	2.2	2.1-4.3	3.1	1.0	1.5
Cl^{-} (mg/l)	49.3-274.9	160.89	60.3-286.7	168.53	50.22-277.6	164.655	250	200
NO_3^{-}(mg/l)	3.7-174.3	43.89	17.4-185.7	47.198	5.6-176.2	41.69	45	50
SO_4^{2-} (mg/l)	27.9-180.6	76.21	31.6-180.1	70.66	18.5-171.2	67.085	200	200

samples, as shown in correlation scatter diagram between electrical conductivity (EC) and TDS (Figure 2).

These indicate that 80% of samples are beyond the permissible limit of 500 mg/l of TDS prescribed by WHO guidelines, 2004 (Table 4). The large dissimilarity in the values of TDS is as a result of the alteration in water level, leaching of minerals in subsurface water and weathering processes. High TDS can be attributed to addition of ions by weathering and leaching of minerals from rocks and leachates emanating from waste disposal sites.

Among major ions, the concentrations of Ca^{++}, Mg^{++}, Cl^{-}, F^{-} and total alkalinity in the groundwater are greater than the acceptable limit for drinking purpose as per WHO, 2004 and Bureau of Indian Standard (BIS), 1991 (Table 4). Calcium varies from 27.12 to 108.87 mg/l in Jawahar Nagar, 23.85 to 102.44 mg/l in Dundigal and 20.12 to 101.87 mg/l in Autonagar. Its concentration exceeds the permissible limit of 75 mg/l in about 50% of groundwater samples. Calcium is derived mainly from weathering of silicate minerals like feldspars, amphiboles and pyroxenes (Karanth, 1987). Therefore the concentration of calcium in the groundwater is attributed to the weathering of pyroxenes, plagioclase, feldspars and apatite present in the granites. Magnesium levels vary from 16.77 to 651.65 mg/l, 11.36 to 90.16 mg/l and 10.77 to 83.84 mg/l in Jawahar Nagar, Dundigal and Autonagar respectively, which are many folds greater than the desirable limit of 30 mg/l (BIS, 1991) due to mineral weathering.

The average concentration of total alkalinity exceeds the desirable limit of 200 mg/l (BIS, 1991, Table 4).

Chloride ranges from 49.3 to 274.9 mg/l in Jawahar Nagar, 60.3 to 286.7 mg/l in Dundigal and 50.22 to 277.6 mg/l in Autonagar and exceeds the acceptable level of 250 mg/l prescribed by (WHO, 2004) in about 35% of the samples. The average concentration of fluoride in groundwater is 2.1, 2.2 and 3.1 mg/l in Jawahar Nagar, Dundigal and Autonagar, respectively (Table 4). It signify that about 71% of groundwater samples indicate fluoride values larger than the permissible limit of 1.5 mg/l in drinking water approved by WHO (2004) and 1.0 mg/l prescribed by BIS (1991). High fluoride is attributed to geogenic consequence of fractured hard rock zones consisting minerals like biotite, fluorapatite, fluorite, cryolite and fluoride-replaceable hydroxyl ions such as ferro-magnesium silicates; fluoride ions from these minerals leach into the groundwater contributing to elevated fluoride levels. The leaching of these ions is governed by climatic factors, the composition of the host rock and the chemical parameters such as pH of the draining solutions. Nitrate concentration in groundwater varies from 3.7 to 174.3 mg/l in Jawahar Nagar, 17.4 to 185.7 mg/l in Dundigal and 5.6 to 176.2 mg/l in Autonagar watershed and its average level exceeds the permissible limit of 45 and 50 mg/l set by BIS, 1991 and WHO, 2004, respectively.

Nitrogen (N) is an essential input for the sustainability of agriculture (Delgado, 2002; Shrestha and Ladha, 2002; Lake et al., 2003; Schroder et al., 2004). However, nitrate contamination of groundwater is a worldwide problem (Goodchild, 1998; Joosten et al., 1998; Birkinshaw and Ewen, 2000; Saadi and Maslouhi, 2003; Kyllmar et al., 2004; Liu et al., 2005). Nitrate is soluble and negatively charged and thus has a high mobility and potential for loss from the unsaturated zone by leaching (DeSimone and Howes, 1998; Chowdary et al., 2005). Many studies showed high correlation and association between agriculture and nitrate concentration in groundwater (Ling and El-Kadi, 1998; Joosten et al., 1998; Harter et al., 2002; Shrestha and Ladha, 2002; Jordan and Smith, 2005; Dunn et al., 2005; Liu et al., 2005). Elevated nitrate concentrations in drinking water can cause methemoglobinemia (blue-baby syndrome) in infants and stomach cancer in adults (Wolfe and Patz, 2002). As such, the US Environmental Protection Agency (USEPA) has established a maximum contaminant level (MCL) of 10 mg/l NO_3-N (USEPA, 2000). High nitrate in the study area can be attributed to consequence of the oxidation of ammonia and similar sources within leachates originating from waste disposal facilities (anthropogenic). This observation is made based on the fact that sample points in the vicinity of dumpsites (2 to 3 km radius) show higher nitrate levels.

Chemical characteristics for irrigation

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Sodium content is usually expressed in terms of percent sodium (%Na) and is computed from following equation:

$$\% \, Na = (Na + K)\, 100/Ca + Mg + Na + K$$

Where the quantities of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} are expressed in milliequivalents per litre (epm). Indian condition allow a maximum %Na for irrigation water to be 60%, and entire samples from study area show %Na below this level representing their suitability for irrigation (Table 5). In waters having high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate. RSC is calculated using the following equation.

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Where all ionic concentrations are expressed in epm. According to the US Department of Agriculture, water having more than 2.5 epm of RSC is not suitable for irrigation purposes. Groundwater was classified on the basis of RSC and the results are presented in Table 5. Based on RSC values, over 20 (Jawahar Nagar), 15 (Dundigal) and 19 (Autonagar) samples, had values less than 1.25 and are safe for irrigation. Only 10% of the samples exceeded the RSC value of 2.5 in study areas, rendering the groundwater unsuitable for irrigation. Negative values stipulate that sodium build-up is unlikely since adequate calcium and magnesium are in excess of what can be precipitated as carbonates. For the purpose of diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. A better measure of the sodium hazard for irrigation is the sodium adsorption ratio (SAR), which is used to express reactions with the soil. SAR is computed as:

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

Where all ionic concentrations are expressed in epm. The classification of groundwater samples with respect to SAR is represented in Table 5. The SAR values of samples collected from study area were found to be less than 10, and were classified as 'excellent' for irrigation purposes. When the SAR and specific conductance of water are identified, the classification of the water for irrigation can be determined by graphically plotting these values on the USSL diagrams (US salinity laboratory, 1954). Waters have been divided into C1, C2, C3 and C4 types on the basis of salinity hazard and S1, S2, S3, S4 types on the basis of the sodium hazard. The significance and interpretations of quality ratings on the USSL diagram can be summarized as follows: (a) Low salinity

Table 5. Chemical characteristics of groundwater for irrigation purpose.

Samples	SAR			Na (%)			RSC		
	Jawahar Nagar	Dundigal	Autonagar	Jawahar Nagar	Dundigal	Autonagar	Jawahar Nagar	Dundigal	Autonagar
W 1	1.0	1.3	0.5	18.8	23.1	11.3	-4.5	-6.9	-6.0
W 2	0.2	1.3	1.4	4.5	24.0	23.9	-52.8	-5.2	-0.3
W 3	2.2	1.1	1.9	34.7	21.6	31.9	-0.6	-4.3	2.9
W 4	0.9	0.8	0.9	18.1	16.7	18.0	-7.3	-7.5	-5.0
W 5	1.0	1.0	1.0	19.3	19.6	19.3	-2.9	-10.2	-2.7
W 6	0.8	0.7	0.8	16.6	15.3	16.3	-6.8	-3.7	-6.8
W 7	0.9	0.6	0.0	17.6	13.0	0.0	-2.4	-2.5	-2.6
W 8	0.9	0.0	0.0	17.6	0.0	0.0	-4.0	-5.2	-6.4
W 9	1.3	0.0	4.1	23.8	0.0	50.1	2.8	-0.5	0.4
W 10	1.7	1.5	1.2	29.4	26.6	23.3	-0.6	-6.6	-4.1
W 11	2.1	0.7	0.0	34.3	15.2	0.0	-4.4	0.4	1.0
W 12	1.1	1.5	0.0	21.4	26.7	0.0	-0.3	-4.3	-4.0
W 13	2.3	0.8	0.0	35.6	16.2	0.0	-5.1	-6.6	-2.7
W 14	1.1	0.0	1.1	20.6	0.0	20.8	0.2	-3.8	-1.6
W 15	1.5	2.1	0.0	26.5	33.9	0.0	-5.2	0.9	-1.4
W 16	0.6	3.3	0.0	13.5	42.8	0.0	-7.5	3.0	-8.0
W 17	0.7	2.0	1.7	15.2	32.7	29.4	-2.8	3.9	-1.0
W 18	1.7	---	3.6	28.5	---	47.1	4.0	---	1.1
W 19	1.7	---	1.8	29.9	---	31.4	-0.5	---	-1.4
W 20	1.5	---	1.5	26.2	---	27.6	-0.9	---	2.9
W 21	1.6	---	0.0	28.2	---	0.0	-2.4	---	-5.4
W 22	1.5	---	---	27.2	---	---	-3.2	---	---

SAR sodium adsorption ratio, RSC residual sodium carbonate.

water (C1) can be used for irrigation with most crops on most soils. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability. (b) Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices of salinity control. (c) Medium to high salinity water (C3) is satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching. (d) High salinity water (C4) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected. (e) Very high salinity water (C5) is not suitable for irrigation under ordinary conditions, but may be used occasionally, under extraordinary conditions.

The soil must be permeable, drainage must be adequate, irrigation water must be in excess to provide considerable leaching and salt tolerant crops should be selected. The classification of irrigation waters with respect to SAR is based chiefly on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, undergo injury as a result of sodium accumulation in the plant tissue when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil. Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium sodium water (S2) in fine-textured soils of high cation exchange capacity, particularly under low leaching conditions, presents appreciable sodium hazard, but may be used on coarse textured or organic soils which have good permeability. Very high sodium water (S4) is generally unsatisfactory for irrigation purposes, except at low and possibly medium salinity. The plots of groundwater chemistry in the USSL diagram are shown in Figure 3. About 20% of the groundwater samples fall under C2S1 class indicating medium salinity low sodium waters whereas 80% of the groundwater samples fall under C3S1 class indicating high salinity and low sodium waters. EC affects the total salt concentration and soil salinity and thereby affecting the yield of the crop and its tolerance accordingly. Since most of Jawahar Nagar, Dundigal and Autonagar area fall in high salinity group, these waters require adequate drainage, special management for salinity control, and plants having good

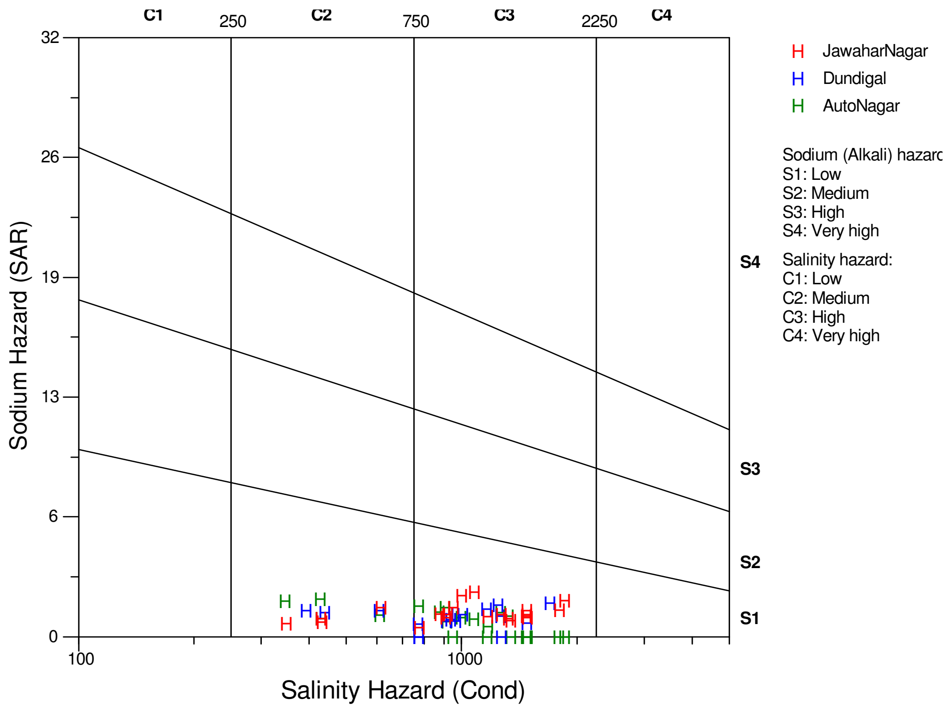

Figure 3. USSL Classification of groundwater.

salt tolerance for cultivation.

Classification of groundwater

The Piper Hill diagram (Piper, 1953) is used to infer hydrogeochemical facies. These plots include two triangles, one for plotting cations and the other for plotting anions. The cation and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydrogeochemical facies concept. These Tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other potential plotting methods. Chemical data are presented by plotting them on a Piper tri-linear diagram (Figure 4). These diagrams reveal the analogies, dissimilarities and different types of waters in the study area, which are identified and listed in Table 6. Facies are recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are distinct zones that possess cation and anion concentration categories. The interpretation of distinct facies from the 0 to 10 and 90 to 100% domains on the diamond-shaped cation to anion graph is more helpful than using equal 25% increments. It clearly explains the variations or domination of cation and anion concentrations in groundwater. The groundwater is classified into different types according to the percentage of chemical constituents (Table 6). Based on Piper diagram, the groundwater from bore wells can be classified as Ca-HCO_3 type, Ca-Cl type, Mg-HCO_3 type and Mg-Cl type. The carbonate hardness exceeds 50% of the total ionic composition, which signifies that the chemical properties are dominated by alkaline earth (Ca^{2+} + Mg^{2+}) and weak acids (CO_3^{2-} + HCO_3^-). The diamond shaped field indicates that no cation-anion pair exceeds 50% of the total ions.

Conclusion

Groundwater in granitic aquifer shows a vast variability in its major ions concentration likely due to the interaction of various processes involving groundwater mineralization and hydraulic conductivity through fractures and joints. The transmissivity of granite aquifer varies from 30 to 200 m^2/day indicating dynamic hydraulic conditions of groundwater in this area making it suitable for weathering and leaching, which is the possible means for groundwater quality. The chief factors governing groundwater chemistry in this region are attributed to chemical weathering and dissolution/precipitation processes taking place along the weak zones. High nitrate levels in the groundwater can be attributed to leachates originating from municipal solid wastes as a consequence of the oxidation of ammonia. Though the suitability of water for irrigation is determined based on SAR, RSC, %Na and USSL diagram, it is only an experimental conclusion. In addition to water quality,

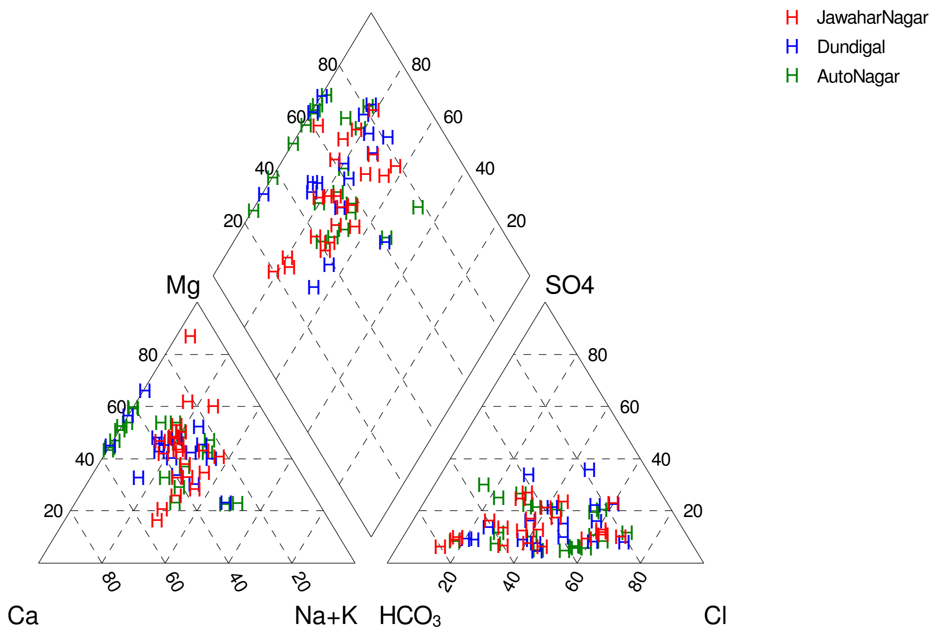

Figure 4. Piper tri-linear diagram of groundwater: major ions are plotted as cations and anions % of meq/l in two *base triangles*. Total cations and anions in meq/l are set to equal 100%. The *data points* in two triangles are then projected into the square grid to show the clustering of samples.

Table 6. Classification of groundwater based on Piper tri-linear diagram.

Sub division number of the diamond shaped field	Characteristics of corresponding sub division of diamond shaped field	% of samples in this category
1	Alkaline earths (Ca^{2+} + Mg^{2+}) exceeds alkalis (Na^{+} + K^{+})	95
2	Alkalis exceeds alkaline earths	5
3	Weak acids (CO_3^{2-} + HCO_3^{-}) exceeds strong acids (SO_4^{2-} + Cl^{-} + F^{-})	33
4	Strong acids exceed weak acids	58
5	Carbonate hardness (secondary alkalinity) exceeds 50% that is, chemical properties of the groundwater are dominated by alkaline earths and weak acids	47
6	Non carbonate hardness (secondary salinity) exceeds 50%, that is, chemical properties of the groundwater are dominated by alkalis and strong acids	32
7	Non carbonate alkali (primary salinity) exceeds 50%, that is, chemical properties of the groundwater are dominated by alkalis and weak acids	5
8	Carbonate alkali (primary alkalinity) exceeds 50%, that is, chemical properties are dominated by alkalis and weak acids	None
9	No one cation - anion exceeds 50%	37

other factors such as soil type, crop pattern, frequency and recharge (precipitation), climatic conditions, have a vital role in determining the suitability of water. Hence water that is not suitable based on the above classification may be suitable in well-drained soils.

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