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Geochemical Evaluation of Groundwater Quality in Katedhan IDA and Surrounding Areas, Hyderabad, A.P., India

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ABSTRACT. The region comprising Miralam, Katedhan IDA and surrounding areas constitutes the southern part of the old city of Hyderabad and parts of Ranga Reddy district of the State of Andhra Pradesh, India. Marked urbanization and industrial concentration characterize this region. In this paper, the quality of groundwater is evaluated from geochemical analysis of fifty groundwater samples collected from the region. Ionic concentrations of K^+, Na^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-, and parameters such as pH, total hardness (TH), total dissolved solids (TDS), sodium absorption ratio (SAR), permeability index (PI), residual carbonate (RC), electrical conductance (EC) and groundwater quality index (GWQI) are determined. Groundwater in the Miralam and surrounding areas is found to be alkaline, with low CO_3^{2-}, high HCO_3^-, high dissolved oxygen and low level of nutrients. Anomalously high values of total hardness (TH) and total dissolved solids (TDS) at numerous places indicate the unsuitability of groundwater for drinking and irrigation. Excessive leaching of various chemical components into the groundwater leading to the enrichment of different anions and cations in the Sivarampally and Katedhan IDA areas indicates pollution from extraneous sources.

Keywords: geochemical analysis, groundwater quality, hyderabad

1. Introduction

In regions of arid to semi-arid type of climate (average annual rainfall < 100 cm), the dependence on groundwater is significant, so much so that in the rapidly expanding urban areas continued exploitation results in depletion of the resource. Furthermore, rapid urban sprawl and industrialization accompanied by inadequate waste management strategies lead to environmental degradation as well. Domestic, agricultural, industrial and other effluents released into streams pollute the water sources and, percolating into the ground, adversely affect the quality of groundwater (Back and Hanshaw, 1965; Rouabhia et al., 2009; Sunil Kumar Srivastava and Ramanathan, 2008; Todd, 1980). The city of Hyderabad is a case in example. Though there is tremendous growth in terms of population, extent and land-use profile, it is mostly unplanned or ill-planned. Domestic and industrial pollutants contaminate groundwater in large areas of the city.

Geochemical analysis of groundwater comprises determination of its physical, chemical and organic characteristics, from which its suitability for different purposes – domestic, agricultural or industrial – is evaluated. Here, the quality of groundwater in the southeastern part of Hyderabad city is evaluated from geochemical analyses of groundwater samples collected from a study area in the region.

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2. The Study Area

Hyderabad, the capital of Andhra Pradesh, is located between latitudes 17°15’ N ~ 17°35’ N and longitudes 78°20’ E to 78°37’ E. The study area consisting of Miralam, Katedhan IDA and surrounding areas (latitudes 17°18’ N ~ 17°22’ N and longitudes 78°25’12” E ~ 78°27’18” E, Survey of India Toposheet number 56K/7/SE) has an approximate extent of 24 sq km and lies in the southeast part of Hyderabad and Ranga Reddy districts (Figure 1). Surface relief in the region consists of a gradual decrease in elevation from the south to the north.

3. Geochemical Analyses

The quality of groundwater in the region is assessed from chemical analyses of fifty groundwater samples collected from bore wells in the study area (at depths of 0.5 ~ 3 m below the water table) during December 2007. The geographic coordinates of the locations of these samples are determined using a GARMIN 12-channel Global Positioning System (GPS) instrument. The samples are analyzed for different parameters pH, TDS, K^+, Na^+, Mg^{2+}, F^-, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, TH, HCO_3^- and EC by standard methods in the geochemical laboratory of the National Geophysical Research Institute (NGRI), Hyderabad, India, as per the standard procedure of the American Public Health Association (Brown et al., 1974; APHA 1985, 1998).

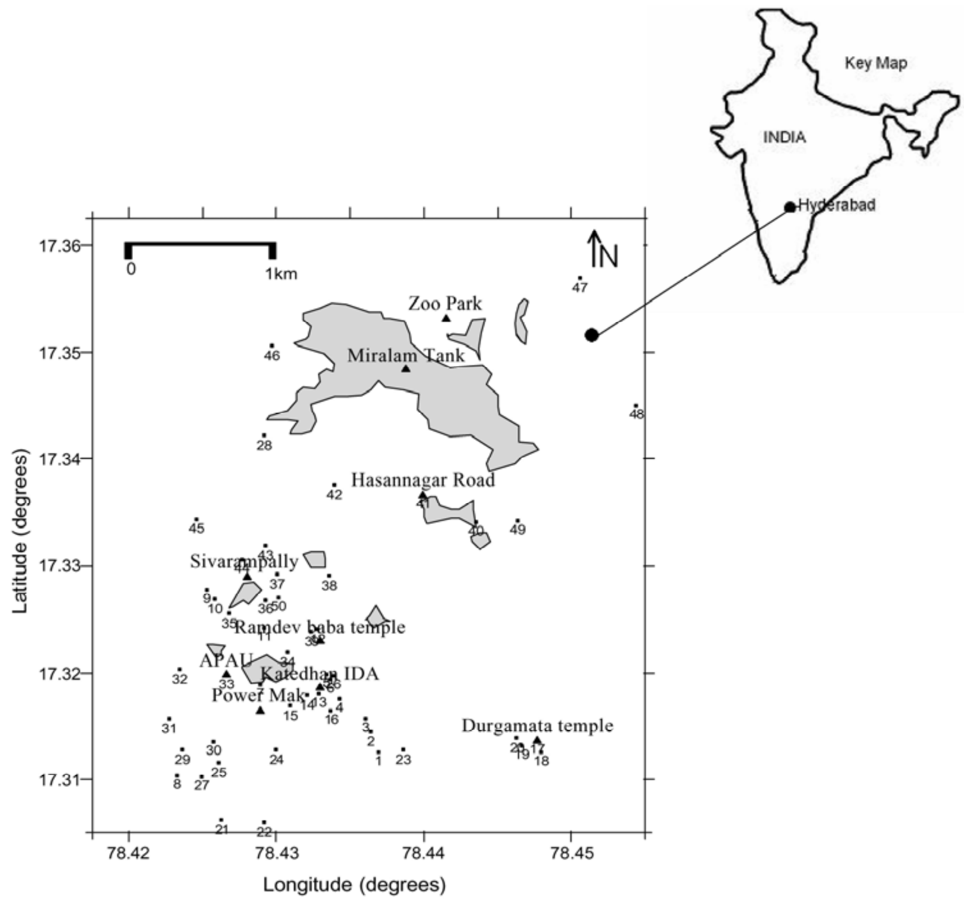


Figure 1. Location map of groundwater samples in the study area.

Table 1. Statistical Analysis of Groundwater Samples of the Study Area

No	Parameter	Min	Max	Mean	SD
1	pH	6.7	8.4	7.36	0.3537
2	EC(μS/cm)	694.0	6922.0	2568	1203
3	TDS(mg/l)	428	4419	1548.443	770.19
4	Na^+(mg/l)	16	507.1	156.83	99.78
5	K^+(mg/l)	0.7	29	6.23	4.38
6	Mg^{++}(mg/l)	19	408	116.98	77.247
7	Ca^{++}(mg/l)	16	800	222.77	126.58
8	Cl^-(mg/l)	60	1450	486.30	278.08
9	SO_4^{--}(mg/l)	30	1300	350.10	279.14
10	HCO_3^-(mg/l)	40	722.85	260.328	173.63
11	NO_3^-(mg/l)	0	901	140.3	146.84
12	F^-(mg/l)	0.0	2.37	0.9016	0.730
13	TH	159	3276	1003	573
14	SAR	0.20	5.75	2.23	1.32
15	RC (me/l)	-64.9	0.6	-15.8	12.2
16	PI	6.8	84.2	36	16.4
17	GWQI	73.59	579.98	183.38	84.40

Table 1 is a statistical summary of the measured chemical parameters of the groundwater samples.

Apart from the above, the sodium absorption ratio (SAR), permeability index (PI), residual carbonate (RC), alkalinity and the groundwater quality index (GWQI) are also determined. To delineate zones prone to excessive groundwater pollution, the distribution patterns (contour maps) and the correlation (if any) between the parameters are generated and examined:

(a) pH: The pH is an important parameter for determining geochemical conditions and equilibrium (Hem, 1991; Satish Kumar et al., 2007) as it influences many chemical and biological processes within a water body. The pH in the study area (Figure 2a) varies from 6.7 to 8.4 with an average of 7.36, against permissible limits of 6.5 to 8.5 (BIS, IS 10500, 1983). Values of over 7.8 are noticed near Miralam tank, east of Hasannagar and Durgamata temple. The increase in pH is a result of the soil-rainwater interaction (Subramanian and Saxena, 1983). Similarly, values less than 7 occur near Ramdev baba temple, APAU, Power Mak Generator Company and Katedhan.

(b) EC: Electrical Conductivity (EC) is a measure of ionic concentrations. Water-soluble salts increase the conductivity of water. The maximum permissible limit of EC in groundwater (BIS, IS 10500, 1983) is 1,500 μS/cm. In the study area (Figure 2b) it varies from about 694 to 6,922 μS/cm. Except for the region between east of Miralam and Durgamata temple, the entire study area has values of EC that exceed permissible limits.

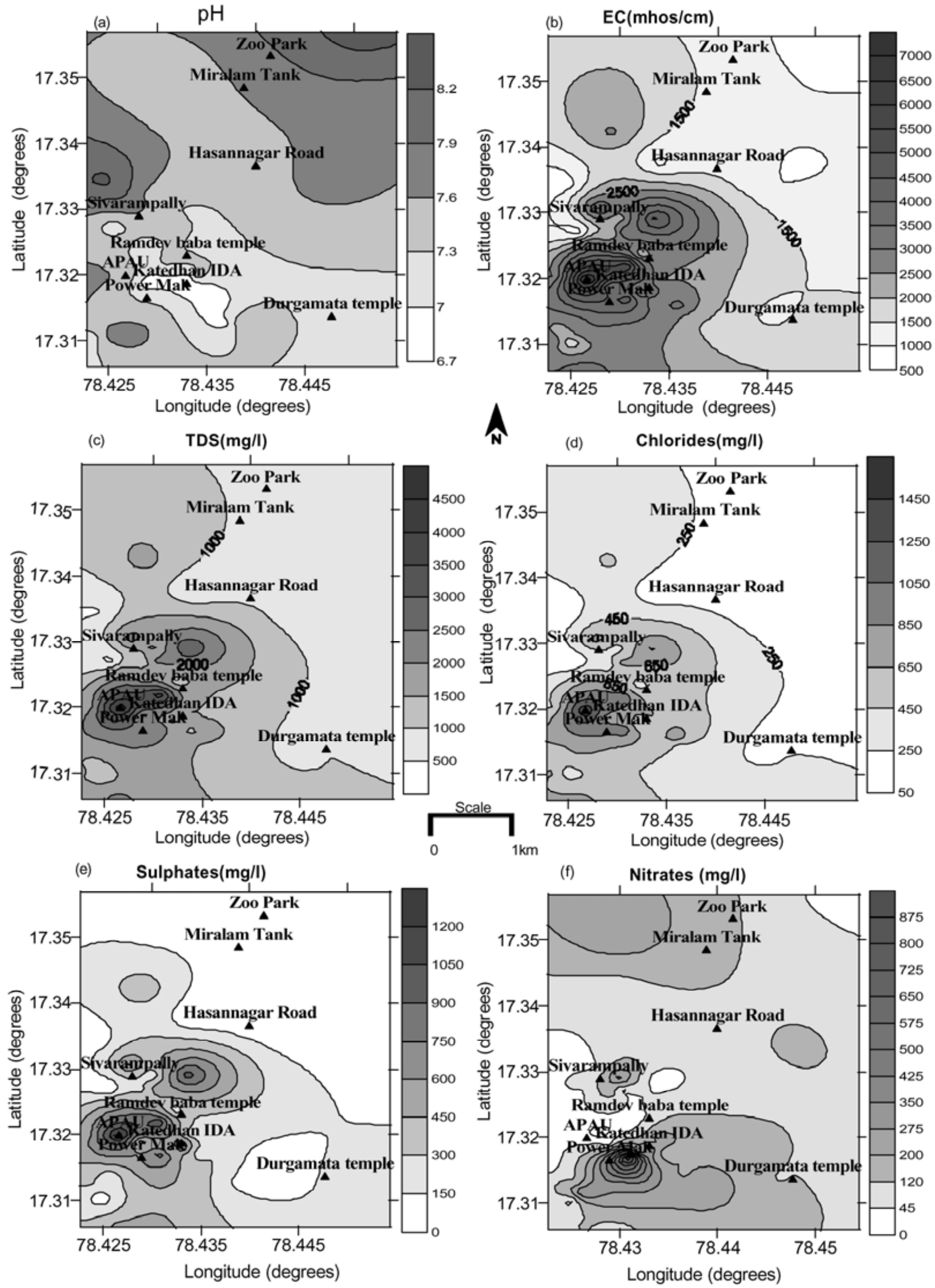


Figure 2-1. Contour maps of (a) pH, (b) electrical conductivity (EC), (c) total dissolved solids (TDS), (d) chlorides, (e) sulphates, and (f) nitrates in the study area.

(c) Total dissolved solids (TDS): TDS gives the extent of contamination (Annon, 1946; Robinnove et al., 1958; Davis and De Weist, 1966; AWWA, 1971; Chauhan et al., 2009) and is a measure of groundwater quality. The permissible limit (BIS, IS 10500, 1983) for TDS is about 500 mg/l. In general, TDS values of < 1,000 mg/l are characteristic of fresh water, while values > 1,000 mg/l are associated with brackish water. Figure 2c is a contour map (contour interval of 200 mg/l) of the mea-

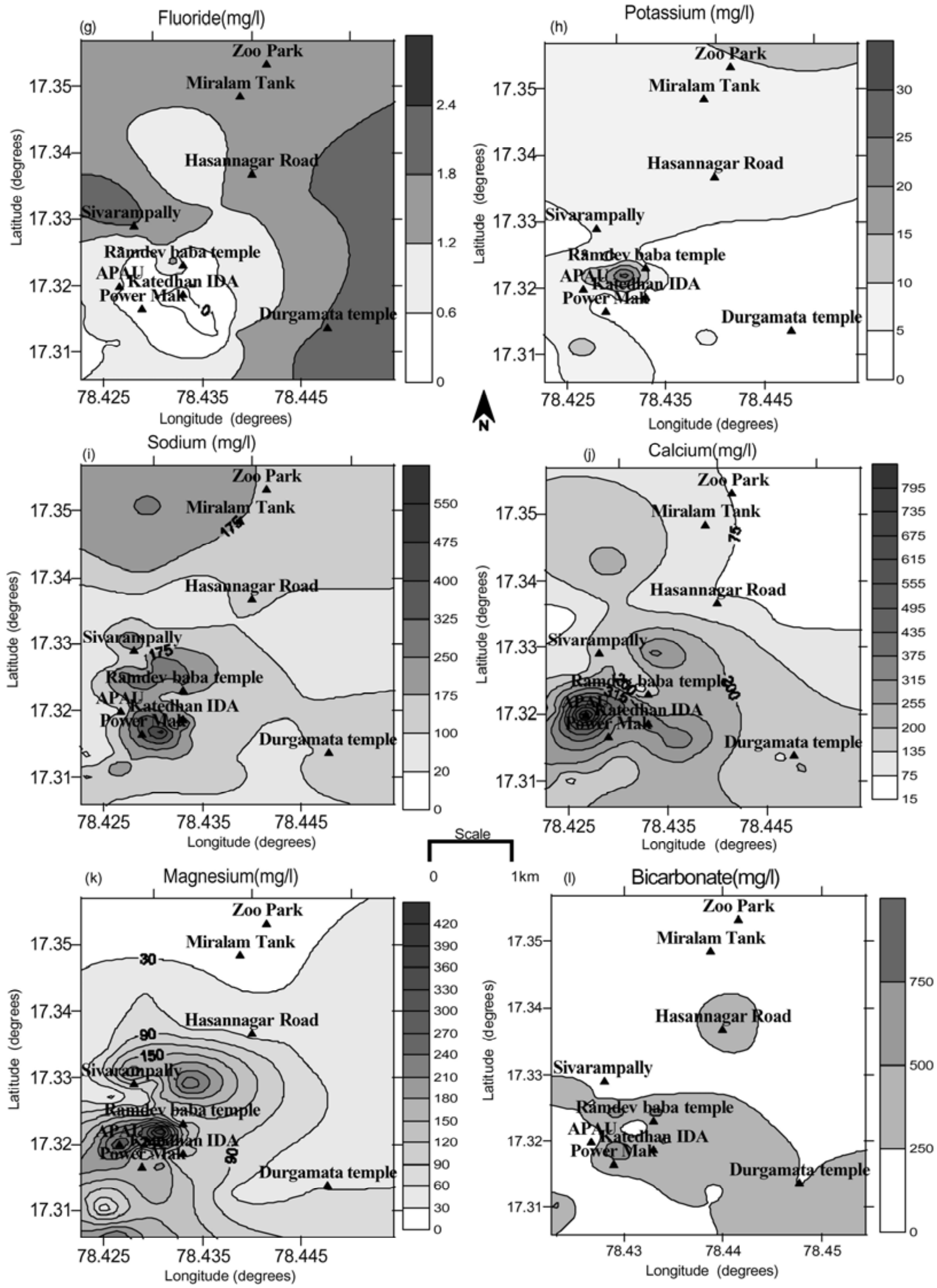


Figure 2-2. Contour maps of (g) fluoride, (h) potassium, (i) sodium, (j) calcium, (k) magnesium, and (l) bicarbonate in the study area.

sured TDS values in the study area. Two anomalous trends are evident - elevated TDS values (428 ~ 4,419 mg/l, with an average of 1,548.4 mg/l) are noticed between Katedhan IDA and Miralam Tank. This is attributable to industrial pollution from Katedhan IDA entering the groundwater regime in the upstream part of the region. Also, the concentration of TDS is found to increase downstream, possibly due to the topographic gradient, deposition of silt due to erosion and floods along the drainage and tanks, as also due to industrial and municipal waste disposal.

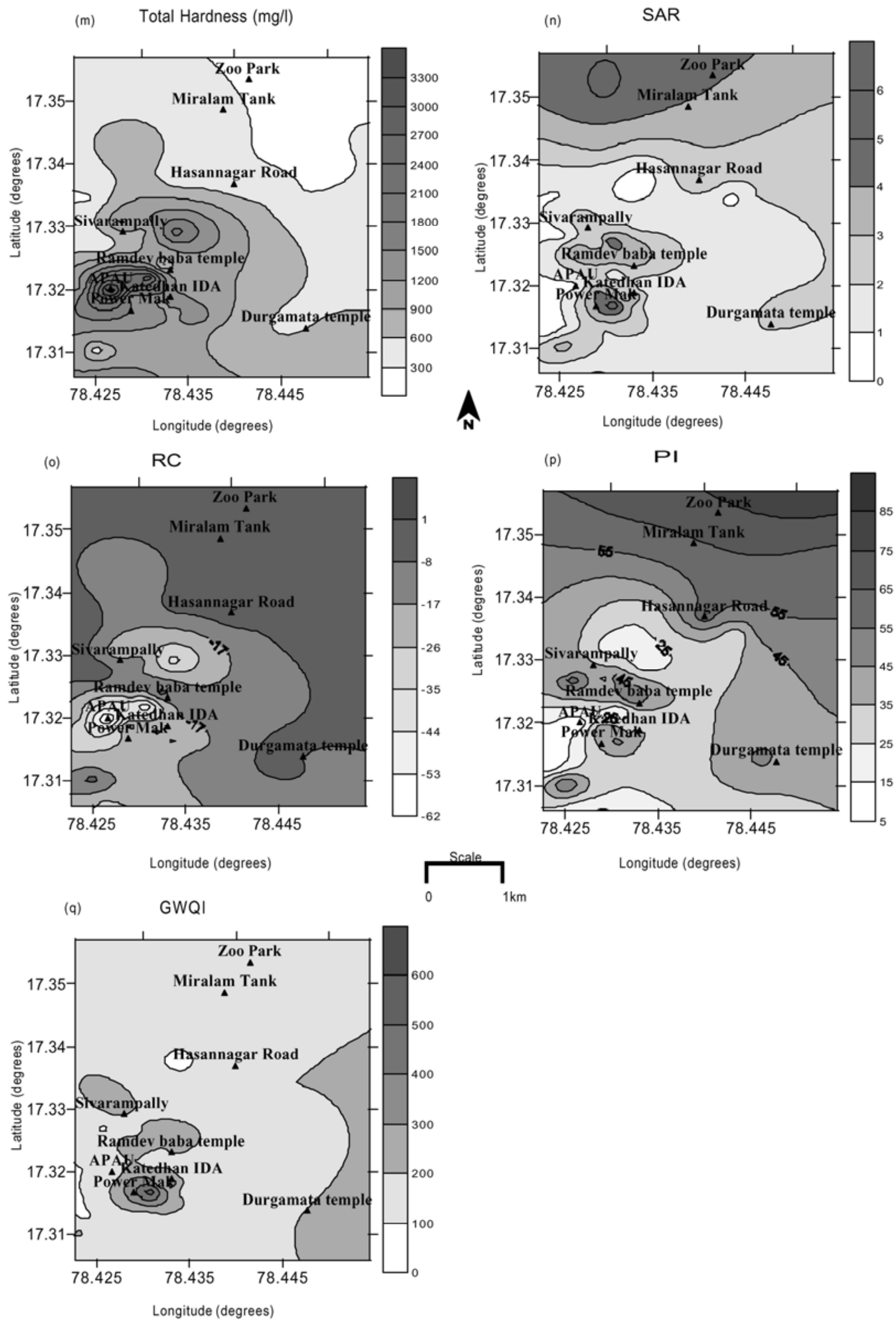


Figure 2-3. Contour maps of (m) Total Hardness (TH), (n) Sodium Absorption Ratio (SAR), (o) Residual Sodium Carbonate (RC), (p) Permeability Index (PI), and (q) Groundwater Quality Index (GWQI) in the study area.

(d) Chloride: Chloride is a minor constituent in the earth's crust, but a major dissolved constituent in natural water. The source of chloride in groundwater is traced to the weathering of crystalline rocks (Sunitha et al., 2002; Satish Kumar et al., 2007; Sujatha and Reddy, 2004) and domestic sewage or industrial effluents (Karanth, 1987). High chloride content has a deleterious effect on metallic pipes and structures. The WHO limit for chloride in groundwater is lower than 250mg/l. Surprisingly, concentration values exceeding this figure are observed over the entire study area (Figure 2d), except to the east of Miralam tank and Hasannagar. Chloride concentrations in the groundwater samples vary from 60 ~ 1,450 mg/l with an average of 486.3 mg/l and show good positive correlation with TH. Concentrations lower than 150 mg/l are noticeable betweenn Sivarampally and Katedhan IDA.

(e) Sulphate: Sulphates occur naturally in water as a consequence of leaching from surrounding rocks. Domestic waste and industrial effluents too result in enhanced values of the concentration of the ion. Concentrations exceeding 500 ~ 600 mg/l impart a bitter taste and may cause laxative effects in some individuals (Raghunath, 1987).

In the study area sulphate concentration varies from 30 to 1,300 mg/l with an average of 350.10 mg/l (Figure 2e). Concentrations in excess of the WHO limit of 150 mg/l are seen at several places with peak values of over 550 mg/l occurring north of Ramdev baba temple, and in the southwest corner of the Katedhan IDA area and are attributable to domestic sewage. Lower concentrations of 30 ~ 150 mg/l are evident east of Hasannagar.

(f) Nitrate: Nitrogen is an essential constituent of protein in all living organisms. Nitrates in natural water originate from organic sources or industrial and agricultural chemicals (Feth, 1966; Sunil Kumar Srivastava and Ramanathan, 2008). However, nitrate concentrations of greater than 45 mg/l (the WHO limit) can cause cyanosis (Young et al., 1976; and Vigil et al., 1965) and some kinds of cancer in adults (WHO, 1984; Gass, 1978).

The concentration of nitrates in groundwater over the entire study area is greater than 45 mg/l (Figure 2f). Anomalous highs of > 200 mg/l are observed over Sivarampally and Katedhan IDA. Relatively lower values (< 200 mg/l) are seen near Miralam tank. The increase in nitrate concentration in the vicinity of water bodies indicates lake water seepage into the groundwater regime. While solid wastes and industrial effluents from the urbanized and industrial zones result in an increase in nitrate concentration (Sunil Kumar Srivastava and Ramanathan, 2008), groundwater pumping from the deeper fracture zones results in a decrease in the concentrations of the ion.

(g) Fluoride (F^-): Fluoride is a common element in the earth's crust and concentrations of 0.6 to 1.2 mg/l are considered permissible, while concentrations > 1.5 mg/l are considered excessive. According to UNESCO specifications, water containing more than 1.5 mg/l of fluoride can cause mottled tooth enamel in children. Excess fluoride may also result in flourosis, a condition that eventually leads to skeletal damage.

The concentration of fluoride in the study area (Figure 2g) varies from 0 to 2.37 mg/l (Table 1) and is in excess of 1.5 mg/l in about 75% of the samples. High fluoride (>1.5 mg/l) concentration is evident around Sivarampally and is attributable to industrial pollution. Elevated fluoride concentrations are also observed in the downstream side of lakes.

(h) Potassium (K^+): The concentration of potassium in the study area varies from 0.7 to 29 mg/l with a mean value of 6.23 mg/l (Figure 2h). Significant highs (> 7 mg/l) are noticed in the region extending from Sivarampally to Power Mak, and off Miralam tank. The source of this contamination is the effluents discharged by industries, and more importantly, domestic sewage.

(i) Sodium (Na^+): Sodium is one of the important constituents in the determination of suitability of water for irrigation purposes. Excess sodium can cause cardiovascular diseases. The concentration of sodium in groundwater (Figure 2i) varies from 16 to 507.1 mg/l during the post monsoon period. High concentrations (> 250 mg/l) are observed near Sivarampally and Power Mak.

The WHO limit for sodium in water for domestic use is 200 mg/l. The relatively low concentration of the ion for the study area as a whole (mean value of 156.83 mg/l) is attributed to groundwater recharge during the monsoon season.

(j) Calcium (Ca^{2+}): Calcium concentration in groundwater (Figure 2j) varies from 16 to 800 mg/l with a mean value of 222.77 mg/l. While the permissible limit of calcium concentration is about 75 mg/l, concentrations of over 200 mg/l are considered excessive. High concentration of calcium is not desirable for washing and other domestic uses. In the study area anomalously high concentrations of > 300 mg/l are seen near Sivarampally and Katedhan IDA. These are attributable to heavy civil construction, industrial concentration and rapid urbanizetion (Somasundaram et al., 1993).

(k) Magnesium (Mg^{2+}): Magnesium also is one of the abundant elements in rocks. It causes hardness in water. High concentration of Mg leads to encephalitis. The concentration of magnesium in the groundwater of the study area varies from 19 to 408 mg/l with a mean value of 116.98 mg/l (Figure 2k). About 90% of the samples have concentrations exceeding the permissible limit of < 30 mg/l. Anomalously high concentrations of magnesium (> 160 mg/l) are seen near Sivarampally and Katedhan IDA.

(l) Bicarbonate (HCO_3^-): The presence of carbonic acid is Indicated when the pH is less than 4.5, bicarbonate if the pH is between 4.5 and 8.2, and possible carbonate if the pH exceeds 8.2. The source of bicarbonate in the water is from sewage and various other human activities. The WHO limit for bicarbonate in water for domestic use is 500 ~ 1,000 mg/l. High concentration of bicarbonates when used for irrigation may cause white deposits on fruits and leaves and thereby pose a health hazard. In the study area bicarbonate concentrations vary from 40 mg/l to 722.85 mg/l, with a mean value of 260.32 mg/l (Figure 2l).

(m)Total Hardness (TH): Total hardness, an important property indicating the quality of groundwater (Rouabhia et al., 2009) is mainly caused by calcium and magnesium cations and is defined as the sum of their concentrations expressed in mg/l. According to the BIS, IS: 10500 (1983), while the desirable limit for TH is up to 300 mg/l, and up to 600 mg/l is acceptable, actual values observed in the study area vary from 159 to 3,276 mg/l with a mean value of 1,003 mg/l (Figure 2m). Only the region around Miralam tank has TH values within acceptable limits (300 ~ 600 mg/l). By and large, the groundwater in the study area is hard and unfit for drinking as less than 10% of the total study area has groundwater with TH values within desirable limits. Anomalously high values of > 1,200 mg/l are observed near Katedhan IDA and Durgamata temple.

(n) Sodium Absorption Ratio (SAR): The US Salinity Laboratory (1954) gives the following expression for SAR:

$$SAR = \frac{(Na^{+})}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}} \tag{1}$$

Thus SAR is the amount of sodium relative to calcium and magnesium increase and is a measure of possible sodium hazard. The SAR values (Table 1) vary from 0.20 ~ 5.75 with an average value of 2.23 (Figure 2n) during the study period. In general, relatively higher values of SAR (> 3) are observed over Power Mak and Sivarampally. For the rest of the area, the SAR values range between 1 and 4.2, indicating low sodium hazard for groundwater in the study area. As per the classifycation of irrigation waters based upon SAR (Sunitha et al., 2002) by the US Salinity Laboratory (1954), the groundwater of the area falls within the 'excellent' class, fit for all types of irrigation.

(o) Residual Sodium Carbonate (RC): Eaton (1950) indicated that if waters that are used for irrigation contain excess of $CO_3^{2+} + HCO_3^{-}$ than its equivalent $Ca^{2+} + Mg^{2+}$, there will be a residue of $Na^{2+} + HCO_3^{-}$ when evaporation takes place and the pH of the soil increases up to 3. RC is obtained by the following formula:

$$RC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \tag{2}$$

where all the ionic concentrations are expressed in milliequivalents per liter (meq/l).

In the study area, the RC values range from -64.9 to 0.6 me/l with an average value of -12.2 me/l (Figure 2o) during the post monsoon period.

Over Sivarampally and Katedhan IDA, very low RC values of less than -60 me/l are seen. Relatively higher values varying from -20 to -10 me/l are seen around Miralam tank.

According to classification of groundwater for irrigation based on the RC values, the study area falls under the 'excellent' class.

(p) Permeability Index (PI): Permeability Index (PI) is a parameter computed to evaluate irrigation water quality (Doneen, 1962) and is given by:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \tag{3}$$

where all the ions are expressed in meq/l.

From the environmental point of view, a high permeability index, in association with subsurface structural features contributing to secondary porosity would facilitate widespread contamination of groundwater. In the study area, PI values range from 6.8 to 84.2 % with a mean post-monsoon value of 36% (Figure 2p). Low PI values of < 20% are noticed near Sivarampally and Katedhan IDA. According to Doneen's (1962) classification of irrigation water based on PI values, the majority of the samples in the study area fall under 'Class II' category (PI range of 25 ~ 75%).

(q) Ground Water Quality Index (GWQI): While chemical analysis yields the physical and chemical composition of water, the water quality index gives an estimate of the quality of drinking water. The GWQI is calculated using the weighted arithmetic index method. The quality rating / sub index (Q_i) corresponding to the ith parameter P_i is a number reflecting the relative value of this parameter. Q_i is calculated by using the following expression:

$$Q_i = \frac{(M_i - l_i)}{(S_i - l_i)} \times 100 \tag{4}$$

Unit weight of the parameter is $W_i = K/S_i$, where:

$$K = \frac{1}{(1/S_1) + (1/S_2) + (1/S_3) + \cdots\cdots\cdots + (1/S_i)} \tag{5}$$

where $S_1, S_2, S_3, \ldots, S_i$ are standard values of various parameters from $1, 2, 3, \ldots, i$;

M_i = Estimated value of the ith parameter in the laboratory

l_i = Ideal value of the ith parameter

l_i = 0 for all the parameters except pH, which is equal to 7.0.

The overall GWQI is calculated by aggregating the quality rating (Q_i) with unit weight (W_i) linearly. Thus:

$$GWQI = \frac{(\sum_{i=1}^{n} Q_i W_i)}{(\sum_{i=1}^{n} W_i)} \tag{6}$$

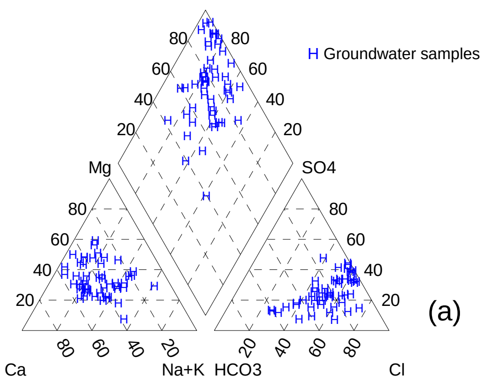
It is to be noted that parameter selection in calculating GWQI has great importance and consideration of too many parameters might widen the quality index.

In this study, the GWQI is considered for drinking purposes and the permissible value for the index is 100, i.e., any value above 100 indicates groundwater contamination. In the study area GWQI values range from 73.59 ~ 579.98 with a mean value of 183.38 (Figure 2q). While the areas around Katedan IDA and Ramdev baba temple have GWQI values varying from

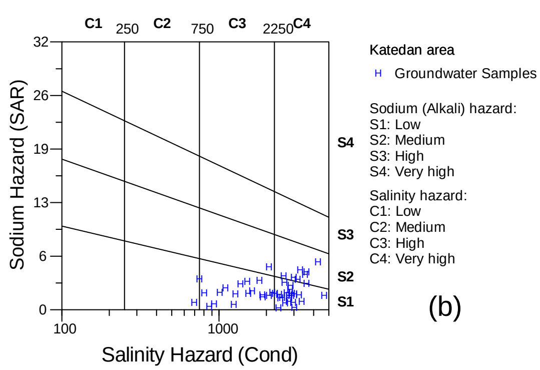
Table 2. Correlation Matrix of Geochemical Parameters in Study Area

	EC	TDS	pH	HCO_3^-	Cl^-	TH	Mg^{2+}	Ca^{2+}	NO_3^-	SO_4^{2-}	Na^+	K^+
EC	1											
TDS	0.98	1										
pH	-0.24	-0.09	1									
HCO_3^-	-0.13	-0.29	-0.63	1								
Cl^-	0.97	0.93	-0.24	-0.08	1							
TH	0.96	0.94	-0.26	-0.15	0.93	1						
Mg^{2+}	0.88	0.91	-0.06	-0.32	0.84	0.9	1					
Ca^{2+}	0.85	0.79	-0.42	0.05	0.84	0.9	0.63	1				
NO_3^-	0.13	0.04	-0.24	0.16	0.13	0.05	-0.03	0.11	1			
SO_4^{2-}	0.93	0.92	-0.14	-0.21	0.85	0.9	0.88	0.76	0.11	1		
Na^+	0.42	0.33	-0.27	0.38	0.41	0.18	0.17	0.16	0.47	0.4	1	
K^+	0.36	0.49	0.47	-0.53	0.27	0.34	0.51	0.09	-0.14	0.37	0.05	1

200 to 400, an anomalously high value of > 500 is seen south of Power Mak. It is seen that approximately, 95% of the samples fall under 'unsuitable' category and the remaining 5% fall under 'permissible' to 'doubtful' category for the postmonsoon season.



Note: the units of variables are percentages of milli-equivalents.



Note: the units of SAR are percentage and salinity hazard (mhos/cm).

Figure 3. Groundwater samples in the study area in 2007: a) Piper trilinear diagram and b) Wilcox diagram.

3.1. Piper Trilinear Diagram

The piper diagram (Figure 3a), which aids geochemical evaluation of groundwater shows that in the majority of the samples, no single ionic pair exceeds fifty percent. Based on the Piper's trilinear classification, the groundwater of the area under investigation is classified as chemically alkaline-earth/strongly-acidic.

3.2. Wilcox Method

The Wilcox diagram (Figure 3b) shows that the lake waters fall under the C3S2 to C3S1 classes, signifying high salinity hazard and low to medium sodium hazard. This suggests that the HUDA's efforts to control contamination of lakes with sewage have helped in some improvement of lake water quality.

4. Correlation Matrix

Correlation analysis is a bivariate statistical method, which simply exhibits how well one variable predicts the other. In this study, the relationship between various elements is studied using the Spearman rank coefficient which is based on the ranking of the data and not their absolute values (Kurumbein and Graybill 1965; Kumar et al., 2006 a, b). Correlation analysis is thus merely a tool of ascertaining the degree of linear dependence or degree of association between the parameters. It does not establish the presence or absence of a cause-effect relationship between the parameters. The correlation coefficient (r) is determined using the following equation:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})((y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{7}$$

where x_i and y_i are the parameters, $\bar{x}$ and $\bar{y}$ are the respective mean values of the parameters given by

$$\bar{x} = (\frac{1}{N})\sum_{i=1}^{n} x_i \tag{8a}$$

$$\bar{y} = (\frac{1}{N})\sum_{i=1}^{n} y_i \tag{8b}$$

where *N* is the total number of samples.

Table 2 gives the correlation matrix between the different components affecting the quality of groundwater. A very high positive correlation is observed between TDS and EC, and TDS and Cl^-. Likewise, a strong correlation is also observed between TH and EC, between Mg^{2+} and EC, between Ca^{2+} and EC, between Ca^{2+} and TH, between Mg^{2+} and TH, and between Ca^{2+} and Mg^{2+}. However, the correlations of TDS with Ca^{2+}, Mg^{2+} and TH are only moderate.

A marginal negative correlation is seen between the pH and all other parameters, except potassium. Similarly a small negative correlation is observed between NO_3^- and Alkalinity and Cl^- as also between Na^+ and TH and Mg^{2+}.

5. Conclusions

Water is a limited resource and it needs to be properly managed. The study emphasizes the necessity for regular monitoring of groundwater quality as it constitutes one of the important parameters for environmental impact assessment, especially in urban and industrial areas.

From geochemical analysis of the fifty samples collected from a study area comprising Miralam, Katedhan IDA, Sivaramapally and the surrounding regions in the southern-southwestern part of Hyderabad city, it is seen that the entire region is severely affected by groundwater pollution. In more than 90% of the region, the values of EC, TDS, TH, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+} exceed permissible limits. The Sivaramapally and Katedhan areas appear to be particularly prone to groundwater pollution where anomalously high values of EC, TDS, NO_3^-, F^-, Ca^{2+}, Mg^{2+}, and Na^+, and relatively lower values of K^+ and Cl^- are observed. These areas are also characterized by high TH and SAR values and low RC and PI values.

The low sodium hazard coupled with high salinity over the study area indicates its utility, at best, for agricultural rather than domestic purposes. A variety of factors – regional topography, domestic sewage discharge, industrial effluents, seepage from lakes, monsoon recharge, pumping of groundwater from deeper horizons etc., all contribute to the widespread and variable pattern of pollution of the resource as revealed by the high values of GWQI (200 ~ 400, and over 500 in some places).

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