

## Geochemical evaluation of groundwater quality in selected areas of Hyderabad, A.P., India

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### Abstract

This paper examines the quality of groundwater in a 40 sq km region comprising Osmania University and surrounding areas in the north eastern part of Hyderabad city in India. 171 groundwater samples from bore wells in the region have been analyzed for ionic concentrations of  $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $F^-$ ,  $Cl^-$ ,  $SO_4^{2-}$ ,  $HCO_3^-$  and  $NO_3^{2-}$ . 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) have been evaluated, contoured and analyzed to determine the areas of contaminated groundwater. It is inferred from Wilcox plot and Piper trilinear diagram, the samples in the study area falls under C3S1 class and characterized by alkaline. It was found the groundwater in the entire region is too hard for drinking. Groundwater contamination in the study area is attributable to different sources; in the southern part of the study area, it is due to proximity to the river Musi that acts as a carrier of domestic and industrial effluents. In and around Nacharam and Mallapur, the effluents discharged from the several industries are responsible for polluting the groundwater in the region. Regions such as Jamai Osmania, Lallaguda and Lalapet are very densely populated and it is the domestic sewage in this area that is the primary cause of groundwater contamination.

**Keywords:** Geochemical analysis, groundwater quality index (GWQI), Hyderabad.

### Introduction

As the distribution of surface sources of water is so uneven as to be inadequate, in many parts of the country the dependence on groundwater is almost total. This is especially true in regions of arid to semi-arid type of climate where average annual rainfall is less than 100 cm and the scope of aquifer recharge is limited. Thus, groundwater continues to be exploited at ever increasing rates, especially in the rapidly expanding urban areas of the country. But rapid urban sprawl and industrialization have the unfortunate fallout of environmental pollution. In the absence of appropriate waste management strategies, many human activities and their by-products have the potential to pollute surface and subsurface water. Industrial effluents, and wastes from urban infrastructure, agriculture, horticulture, transport and discharges from abandoned mines and deliberate or accidental pollution, all eventually affect the water quality. The pollutants from the stream may move slowly in to the ground, thus affecting the quality of groundwater. Depending on various natural and cultural factors, the quality of groundwater in terms of its physical, chemical and organic characteristics is variable, determining its suitability for different purposes- domestic, agricultural or industrial. This paper studies the extent and degree of groundwater contamination in a part of the city of Hyderabad from geochemical analysis of groundwater samples.

#### Study area

Hyderabad, the capital of Andhra Pradesh, is located between latitude  $17^{\circ} 15'N$  to  $17^{\circ}35'N$  and longitude  $78^{\circ}20'E$  to  $78^{\circ}37'E$ . It is the sixth largest city of India (2001). It is one of the fastest growing metropolises in

terms of population, area and land use, and with its heterogeneous demographic profile, is cosmopolitan in its truest sense. The study area has an approximate extent of 40 sq kms and lies in Ranga Reddy district between latitudes  $17.3750$  ( $17^{\circ}22'30"N$ ) and  $17.50$  ( $17^{\circ}30'N$ ) and longitudes  $78.50$  ( $78^{\circ}30'E$ ) to  $78.60$  ( $78^{\circ} 37'E$ ) in degrees (Survey of India toposheet number 56K/11/NW). Fig.1 is a location map of the study area. Physiographically, the area represents flat topography with gentle slope. The drainage pattern; it varies from dendritic to sub-parallel/rectangular trellis.

#### Geochemical analyses

In the present study 171 ground water samples were collected from bore wells located in parts of the city in Dec 2007. The geographic coordinates of the locations of these samples were determined using a GPS and are shown in Fig.1. These samples were analyzed for constituents like pH, TDS,  $K^+$ ,  $Na^+$ ,  $Mg^{2+}$ ,  $F^-$ ,  $Cl^-$ ,  $SO_4^{2-}$ ,  $NO_3^{2-}$ ,  $Ca^{2+}$ , TH,  $HCO_3^-$  and E.C by standard methods in the geochemical laboratory of the National Geophysical Research Institute (NGRI), as per the standard procedure for American Public Health Association (Brown *et al.*, 1974; APHA, 1985; 1998). Apart from the above, the sodium absorption ratio (SAR), permeability index (PI), residual carbonate (RC), alkalinity and the groundwater quality index (GWQI), were also determined. Table 1 summarized the evaluated statistical parameters namely minimum (min), maximum (max), mean and standard deviation (S.D) values for each of the measured constituents of the groundwater samples from study area.

**pH:** The pH an aqueous solution is measure of the number of hydrogen ions or protons present and measured with a pH meter (Hem, 1985). It is expressed

as the negative logarithm the hydrogen-ion concentration in water. The pH of the analyzed samples in the study area (Fig. 2a) varies from 6.2 to 8.65 against permissible limits of 6.5 to 8.5 (BIS, 1983). The measure of pH is on a scale of 0-14 wherein pH less than 7 is acidic and greater than 7 is alkaline (basic) and exact 7 is neutral. Thus the groundwater samples are, at places slightly more basic than acceptable limits. Values of over 8 are noticed near Uppal, Tarnaka, Pedda cheruvu and Nadimi cheruvu. Similarly, values less than 7 occur near Jamai Osmania, northeast of Safilguda and around Mallapur.

*Table 1. Statistics of groundwater quality analysis in OU and surrounding areas of Hyderabad, Dec 2007 (all values in mg/l except pH & E.C).*

Parameter	Min	Max	Mean	S D
pH	6.2	8.65	7.54	0.440
EC ( $\mu\text{S/cm}$ )	222.9	5086.9	1898.4	868.02
TDS (mg/l)	29.9	2330	1044.53	421.55
$\text{Na}^+$ (mg/l)	2.5	455	122.8	80.3
$\text{K}^+$ (mg/l)	0.2	28.4	6.8	4.39
$\text{Mg}^{++}$ (mg/l)	10	525	93.5	98.8
$\text{Ca}^{++}$ (mg/l)	16	860	192.9	149.78
$\text{Cl}^-$ (mg/l)	30	1020.0	287.8	192.5
$\text{SO}_4^{--}$ (mg/l)	14	361.2	111.6	68.97
$\text{HCO}_3^-$ (mg/l)	30	622.2	275.5	144.6
$\text{NO}_3^-$ (mg/l)	0.1	326.0	77.5	69.86
F (mg/l)	0.0	7.0	1.7	1.11
TH	117.9	3712.3	862.5	723.7
SAR	0.0	8.5	2.2	1.55
RC (me/l)	-71.0	1.8	-12.6	14.3

*E.C:* Electrical Conductivity (EC) depends upon temperature, ionic concentration and types of ions present in the water (Hem, 1985). Thus the EC gives a qualitative picture of the quality of groundwater. The maximum permissible limit of EC in groundwater (BIS, 1983) is 1500  $\mu\text{S/cm}$ . It varies from about 222 to 5086  $\mu\text{S/cm}$  with the mean value of 1898  $\mu\text{S/cm}$  in the study area (Fig. 2b). Except for the region between Pedda cheruvu and Uppal, and small regions off Moulali and Mallapur, the entire study area has values of EC that exceed permissible limits. Anomalous peaks (>3000

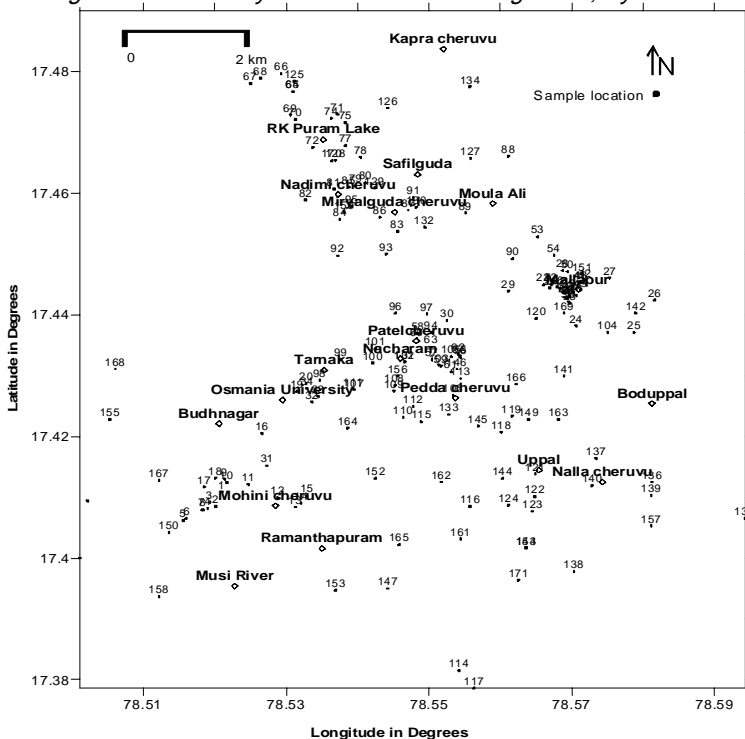
$\mu\text{S/cm}$ ) are observed over Jamai Osmania, north of Nacharam and around Mallapur. Such anomalous values arise from various anthropogenic activities and geochemical processes prevailing in the region (Sujatha & Reddy, 2004).

*Total dissolved solids (TDS):* The weight of the residue consisting of pollutants (dissolved ions) left behind after all the water from a water sample is evaporated is a measure of the TDS and gives the general nature of groundwater quality and extent of contamination (Annon, 1946;

Robinnove, 1958; Davis & de Wiest, 1966; AWWA, 1971). The permissible limit (BIS, 1983) for TDS is about 500 mg/l. In general, TDS values of <1000 mg/l are considered as fresh water and values >1000 mg/l are considered brackish. The TDS values vary between 29.9 to 2330 mg/l with mean value of 1044 mg/l. The measured TDS values in the study area contoured with an interval of 100 mg/l are shown in Fig. 2c. Except for the region to the northwest of Moulali where TDS values of <500 are observed, in the industrial zones (Nacharam & Mallapur) and several residential zones high concentrations ranging between 1500-2300 mg/l are observed. The higher concentrations were due to leaching of solid wastes from ground surface as well as enhanced seepage from lakes during monsoon. In general, the TDS concentration were found to increase downstream, possibly due to topography gradient, deposition of silt due to erosion and floods along drainage channels and tanks, as also due to industrial and municipal waste disposal (Freeze & Cherry, 1979).

*Chloride (Cl):* Chloride concentration of the groundwater samples in the study area is varying from 30 to 1020 mg/l, with average value of 287 mg/l. The WHO limit for chloride in groundwater is < 250 mg/l. Surprisingly, concentration values exceeding this figure are observed over the entire study area (Fig. 2d), except Moulali and a small pocket near Boduppall. Chloride concentrations in the groundwater samples were found to vary from <50 to 250 mg/l near Moulali and south of Pedda cheruvu to 250 to 500 mg/l south of Jamai Osmania, south of Boduppall and off Nadimi cheruvu. Chloride concentrations appear to be elevated in the downstream side of the lakes in the area; peak values of 500-1000 mg/l were observed in the southern part of the study area, and north of Pedda cheruvu. So, it is concluded that a large part of the investigated area,

*Fig. 1. Location map of groundwater samples for geochemical analysis in OU & Surrounding areas, Hyderabad*



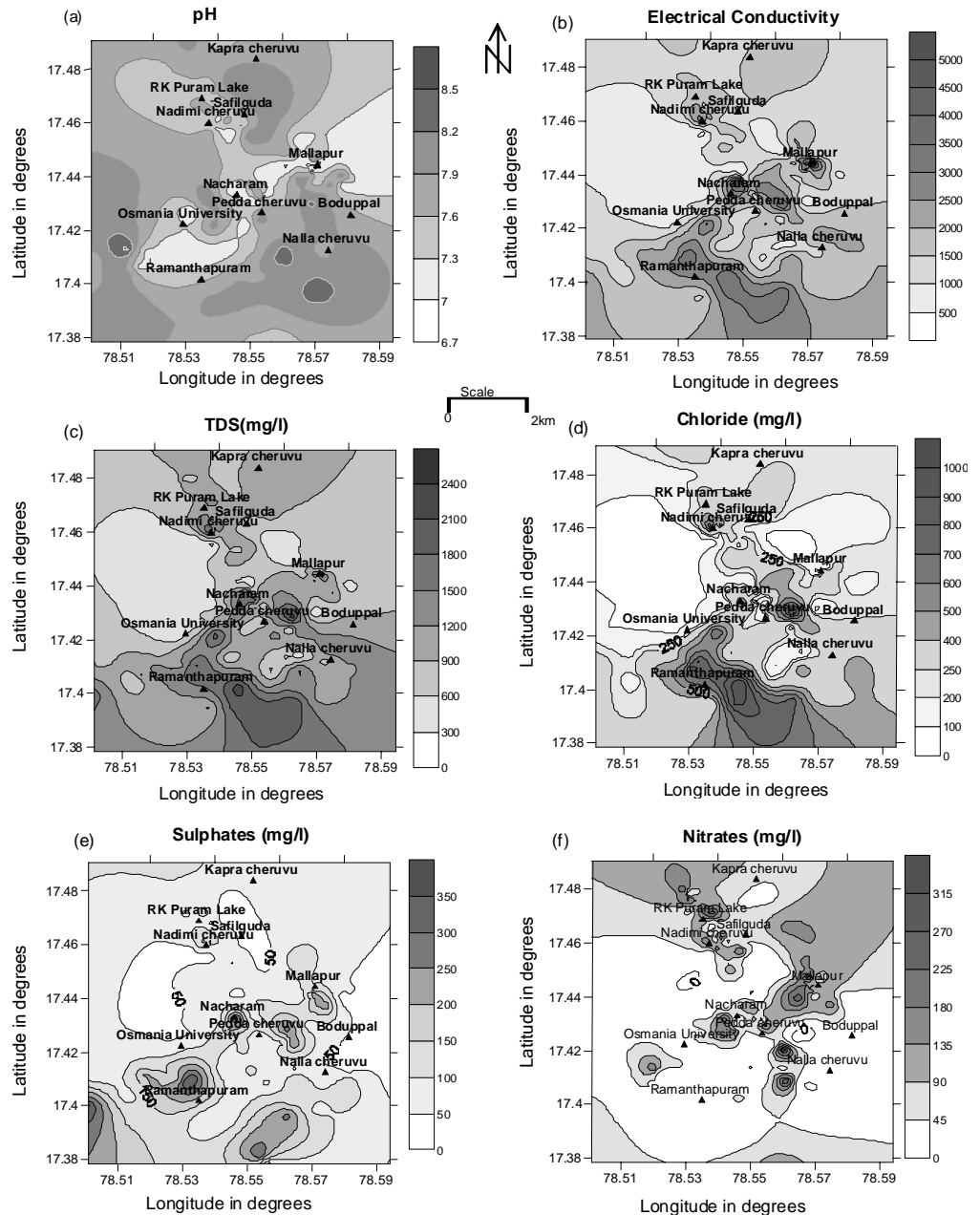
especially so in the southern part, is polluted, whereas in the northern part the extent of chloride contamination is relatively irregular (Sunitha *et al.*, 2002; Satish Kumar *et al.*, 2007).

**Sulphate ( $SO_4^{2-}$ ):** Sulphates in groundwater in excess of the WHO limit of 150 mg/l are seen at several places in the study area. High sulphate concentration causes GI irritation. Concentrations exceeding 500 - 600 mg/l impart a bitter taste and may cause laxative effects in some individuals (Ragunath, 1987). The sulphate concentration in the groundwater samples in the study area was found to vary from 14 mg/l to 361.2 mg/l, with mean value of 111 mg/l (Fig. 2e). Peak concentrations of over 250 mg/l occur near Jamai Osmania, and in the southwest corner of the study area and are attributable to domestic sewage. Slightly lower concentrations of 190-230 mg/l (attributable to industrial effluents) are evident near Nacharam, Mallapur and Pedda cheruvu.

**Nitrate ( $NO_3^{2-}$ ):** Nitrate in natural water is due to organic sources or from industrial and agricultural chemicals (Feth, 1966). While nitrogen is an essential constituent of protein in all living organisms, nitrate concentrations of greater than 45 mg/l (WHO limit) can cause cyanosis or blue baby syndrome among infants (Young *et al.*, 1976; Vigil *et al.*, 1965) and development of cancer in adults (Gass, 1978; WHO, 1984). The concentration of nitrate values in the study area varying from 0.1 to 326 mg/l, with a mean value of 77.5 mg/l. The limit of nitrate concentration for drinking water is specified as 45 mg/l (BIS, 1983). It is observed that nearly 90% of groundwater from the study area is exceeding the permissible limit. While highs of >200 mg/l are observed over Peddacheruvu, Uppal, Nacharam and south of Ramakrishnapuram, relatively lower values (< 200 mg/l) are seen near Jamai Osmania

IDA Mallapur, Nadimi Cheruvu and Lallaguda (Fig. 2f). High nitrate values noticed in the vicinity of water bodies indicates lake water seepage into the groundwater regime. Similarly, in the urbanized and industrial zones,

Fig. 2. Contour maps of (a) pH (b) Electrical conductivity (E.C.) (c) Total dissolved solids (TDS) (d) Chloride (e) Sulphates (f) Nitrates in OU & surrounding areas of Hyderabad.



high nitrate concentrations result due to solid wastes from sewage and septic tanks and industrial effluents.

**Fluoride (F):** The concentration of fluoride in the study area (Fig. 2g) varies from 0 mg/l to about 7 mg/l (Table 1). The permissible limit of fluoride in drinking water is 0.6 to 1.2 mg/l (BIS, 1983). While it is <0.6 mg/l near Jamai Osmania, Institute of Public Enterprise (IPE) and Lalaguda, it is >4 mg/l north of Uppal, near Mallapur,

Lalapet and Nacharam. High fluoride concentration is seen in the region between Pedda cheruvu and Patel cheruvu, and adjacent to the Nacharam area. The effluents from the several industries in the region contribute to the high levels of pollution. Elevated fluoride concentrations are also observed in the lakes in the downstream side. 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 lead to flourosis that can result in skeletal damage.

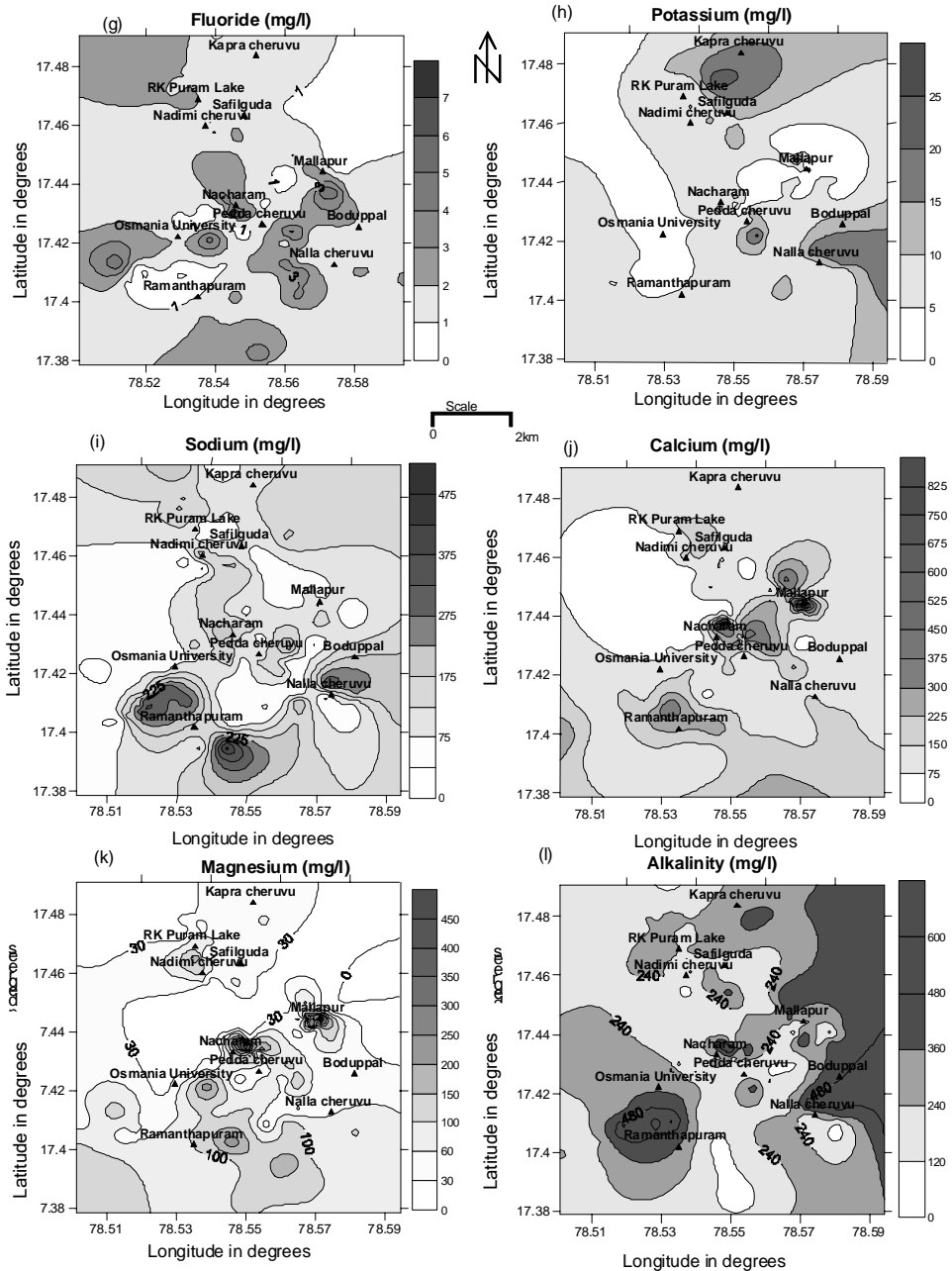
**Potassium ( $K^+$ ):** Ionic potassium occurs at fairly low concentrations in groundwater (Sravanthi & Sudarshan, 1998) and is derived from weathering of the mostly stable orthoclase, microcline feldspars and biotite minerals present in the granites of the area (Satish Kumar *et al.*, 2007). However, excessive fertilizer usage can increase its concentration in surface as well as groundwater. The potassium concentrations of the area are varying from 0.2 to 28.4 mg/l (Fig. 2h). While lows are noticed over Jamai Osmania, significant highs are seen off Mallapur, Nadimi cheruvu and R.K Puram lake. The source of this contamination is likely to be effluents discharged by industries and also domestic sewage. However, high potassium concentrations are indicative of sewage contamination.

**Sodium ( $Na^+$ ):** The primary source of sodium in natural water is from the release of the soluble products during the weathering of plagioclase feldspars. The sodium concentration of the area in groundwater (Fig. 2i) was found to vary from 2.5 to 455 mg/l with a mean value of 122.8 mg/l during the post monsoon period, which is well below the WHO limit of 200 mg/l for domestic use. The contour map of Na concentration depicts anomalous zones near Osmania University, Ramanthapur, Boduppall and Nalla cheruvu.

**Calcium ( $Ca^{2+}$ ):** The calcium concentration of the area is varying from 16 to 860 mg/l with the mean value of 192.9 mg/l. While the permissible limit of calcium concentration is about 75 mg/l (BIS, 1983), concentrations

of over 200 mg/l are considered excessive. Except for small pockets southwest of Mallapur, northeast of Osmania University and south of Nadimi cheruvu, over the rest of the study area, calcium concentration is >150 mg/l (Fig. 2j). The mean value of calcium concentration is 192.9 mg/l. Peak concentrations of >300 mg/l are seen near Osmania University, Lalaguda and north of Moulali. Near Mallapur, extremely high calcium concentration (>600 mg/l) is noticed. The heavy civil constructions and rapid industrialization and urbanization in the area contribute to the high concentration of Ca in the groundwater of the region (Somasundaram *et al.*, 1993).

Fig. 2. Contour maps of (g) Fluoride (F) (h) Potassium (K) (i) Sodium (Na) (j) Calcium (Ca) (k) Magnesium (Mg) (l) Alkalinity in OU & surrounding areas of Hyderabad.



**Magnesium ( $Mg^{2+}$ ):** Magnesium also is one of the abundant elements in rocks. It causes hardness in water. High concentration of  $Mg^{2+}$  leads to encephalitis. Magnesium concentration is varying between 10 to 525 mg/l with the mean value of 93.5 mg/l. The permissible limits of Magnesium are <30 mg/l (BIS, 1983). It is observed that a 90% groundwater samples exceeds the limit. Anomalously high concentrations of magnesium (>350 mg/l) are seen near Lalaguda and near Mallapur (Fig. 2k). Slightly lower concentrations of 100-200 mg/l are seen near Lalapet, Osmania University, south of Uppal and south of R K Puram lake.

**Alkalinity ( $CO_3^{2-}+HCO_3^-$ ):** In the area the value of alkalinity varies from 30 mg/l to 622.2 mg/l with a mean value of 275.5 mg/l (Table 1). The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural water is caused by hydroxides, carbonates and bicarbonates, which may be ranked in order of their association with high pH values. The WHO limit for alkalinity in water is 120-250 mg/l. In the study area alkalinity varies from <120 mg/l south of Uppal, south of Boduppal, north of Pedda cheruvu, north of Nacharam, south of Nadimi cheruvu, and near Mallapur. Over Boduppal and off Mallapur, it varies from 250 to 500 mg/l and near Osmania University and Lalaguda it is >600 mg/l (Fig. 2l). The source of alkalinity in the water is from sewage and various human activities. Water with high concentration of alkalinity when use for irrigation may responsible to cause for white deposits on the various fruits and leaves and thus result to health hazard.

**Total hardness (TH):** Total hardness, an important property indicating the quality of groundwater is mainly caused by calcium and magnesium cations and is defined as the sum of their concentrations expressed in mg/l. Basically, it is the soap-consuming property of water (Fletcher, 1986). The desirable limit for TH is up to 300 mg/l, and up to 600 mg/l is acceptable (BIS, 1983), actual values observed in the study area were found to vary from 117.9 to 3712.3 mg/l (Fig. 2m). Less than 10% of the total study area has groundwater with TH values within

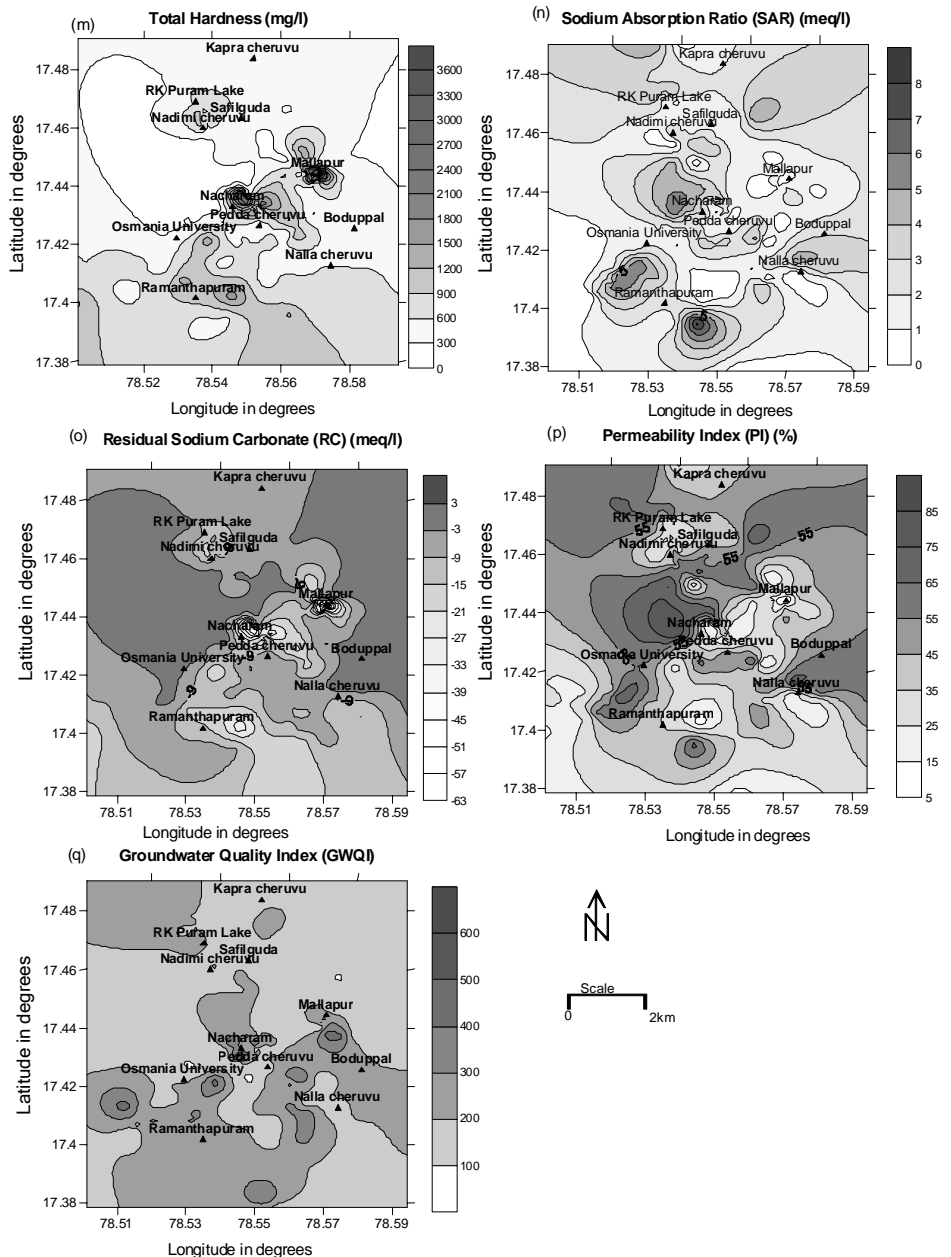
desirable limits. Values over the lakes in the region have TH values within acceptable limits (300-600 mg/l). Anomalously high values of >3000 mg/l are observed over Mallapur and off Lalaguda. Thus by and large, the groundwater in the city is hard.

**Sodium absorption ratio (SAR):** The US salinity laboratory (1954) gives the following expression:

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

This gives the amount of sodium relative to calcium

Fig. 2. Contour maps of (m) Total hardness (TH) (n) Sodium absorption ratio (SAR) (o) Groundwater quality index (GWQI) (p) Residual sodium carbonate (RC) (q) Permeability index (PI) in OU & surrounding areas of Hyderabad.



and magnesium increase and is a measure of possible sodium hazard. The SAR values were found to vary (Table 1) from 0.0-8.5 with an average value of 2.2 (Fig. 2n) during the study period. In general, relatively higher values of SAR (> 5) are observed over Jamai Osmania, southwest of Uppal and northwest of Nacharam. For the rest of the area, the SAR values range between 3-4, indicating low sodium hazard for groundwater.

**Residual sodium carbonate (RC):** Eaton (1950) indicated that if waters which are used for irrigation contain excess of  $\text{CO}_3 + \text{HCO}_3$  than its equivalent  $\text{Ca} + \text{Mg}$ , there will be a residue of  $\text{Na} + \text{HCO}_3$  when evaporation takes place and the pH of the soil increase up to 3. RC is obtained by the following formula.

$$RC = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+});$$

Where, all the ionic concentrations are expressed in milliequivalents per liter.

In the study area, the RC values range from -78 to 1.8 me/l with an average value of -12.6 me/l (Fig. 2o) during the post monsoon period. Over Lalaguda and Mallapur, very low RC values of < -60 me/l are seen. Relatively higher values from -30 to -10 me/l are seen south of R.K Puram lake, Tarnaka, south of IPE and south of Boduppal. However, over Osmania University, anomalously high values of >-1 are noticed.

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

$$PI = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \times 100$$

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 would facilitate widespread contamination of groundwater. In the study area the PI values range from 7.8 to 84.2% with a mean post monsoon value of 40.2 (Fig. 2p). In and around Mallapur, near Nacharam near Nadimi cheruvu and south of Nalla cheruvu, low PI values of less than 20% are noticed. Off Mohini cheruvu, in and around Osmani University, south of Ramanthapuram, south of Boduppal and Tarnaka, high PI values varying from 60-80% are apparent.

**Groundwater 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 (Brown *et al.*, 1970) was calculated using weighted arithmetic index method and the quality rating/sub index (Qi) corresponding to the ith parameter Pi is a number reflecting the relative value of this parameter. Qi is calculated by using the following expression.

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

Unit weight of the parameter  $W_i = \frac{K}{S_i}$ ;

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

$S_1, S_2, S_3, \dots, S_i$  are standard values of various parameters from 1, 2, 3, ---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 are 7.0.

The overall GWQI was calculated by aggregating the quality rating ( $Q_i$ ) with unit weight ( $W_i$ ) linearly.

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

It is to be noted that parameter selection in calculating WQI 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 72.7-986.9 with a mean value of 275.9 (Fig. 2q). While areas southwest of Budhnagar, southeast of Osmania University, south of Nalla cheruvu and south of Mallapur have GWQI values varying from 300-500, an anomalously high value of >600 is seen centered south of Nacharam. It is seen that approximately, 98 percent of the samples fall under unsuitable category and the remaining 2% (near Osmania University & south of Pedda cheruvu) fall under permissible to doubtful category for the post monsoon season.

**Piper trilinear method:** The Piper trilinear diagrams (Piper, 1953) is one of the most useful graphical representation in groundwater quality studies and help in understanding the geochemistry of shallow groundwater by bringing out the chemical relationships in large sample groups in more definite terms than with the other plotting methods (Walton, 1970).

Fig. 3a is the Piper trilinear diagram for the data obtained from chemical analysis of groundwater samples from the study area for post monsoon. This diagram consists of two lower triangles that show the percentage distribution, on the milliequivalent basis, of the major cations ( $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Na}^+$  &  $\text{K}^+$ ) and the major anions ( $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{CO}_3^{2-} + \text{HCO}_3^-$ ) and a diamond shaped part above that summarizes the dominant cations and anions to indicate the final water type. This classification system shows the anion and cation facies in terms of major-ion percentage. This diagram shows that most of the groundwater samples fall in the field of mixed  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ -

Cl<sup>-</sup> type of water. It is also observed from the Piper plot that groundwater in the region is alkaline earths (Ca<sup>++</sup> & Mg<sup>++</sup>) significantly exceed the alkalis (Na<sup>+</sup> & K<sup>+</sup>) and the strong acids (SO<sub>4</sub><sup>-</sup> & Cl<sup>-</sup>) exceed the weak acids (HCO<sub>3</sub><sup>-</sup>).

**Wilcox method:** Classify the groundwater suitability for irrigation Wilcox (1955) gave a diagram using sodium content as percentage sodium and electrical conductivity. A Wilcox plot can be used to quickly determine the viability of water for irrigation purposes. The Wilcox plot is a simple scatter plot of sodium hazard (SAR) on the Y-axis Vs salinity hazard (conductivity) on the X-axis. The conductivity is plotted by default in a log scale.

The groundwater quality from the Wilcox diagram indicates that about 80% of the samples in the study area were falling under low sodium and high salinity hazard C3S1 class (Fig. 3b), which can be used for irrigation on almost all type of soils with little danger of developing harmful levels of exchangeable sodium. The average sodium absorption ratio (SAR) of groundwater in the study area was 2.2. As per the classification of irrigation waters based upon SAR (Sunitha *et al.*, 2002) the groundwater of the area falls within the 'excellent' class.

**Correlation matrix:** To examine the degree of correlation (if any) between the different chemical parameters affecting the quality of groundwater, the correlation matrix between the different components was computed (Table 2). Statistics of groundwater show poor correlation with each other ions, but few ion pairs like EC with TDS, Cl, TH, Mg, Ca; TDS with Cl, TH, Mg, Ca, SO<sub>4</sub>, Na; HCO<sub>3</sub><sup>-</sup> - Na, Cl-SO<sub>4</sub>, Cl-Na, TH with Mg, Ca; SO<sub>4</sub> - Na show moderate to good correlation. Good correlation indicates chemical weathering and leaching of secondary salts contribution followed by multiple source inputs like industrial and agricultural effluents, which exhibit poor correlation in groundwater. Other anthropogenic sources also play a major role in controlling shallow groundwater chemistry. A very high positive correlation is observed between TDS and EC because conductivity increases as the concentration of all dissolved constituents/ions increases. Likewise, a strong correlation is also observed between EC with TH, Mg and Ca indicating most of the ions are involved in various physiochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system. A good relation to TH with Ca<sup>2+</sup>, Mg<sup>2+</sup> and Cl<sup>-</sup> indicates that hardness in groundwater is mainly due to CaCl<sub>2</sub> and MgCl<sub>2</sub>. A marginal negative correlation is seen between the pH and all other parameters, except potassium. The presence of certain cations appears to preclude to an extent the occurrence of other cations; a small negative correlation is observed between NO<sub>3</sub> and HCO<sub>3</sub> and NO<sub>3</sub> and Cl, as also between Na and TH and

Fig. 3a. Piper trilinear diagram for water samples of the study area  
Piper Plot - 2007

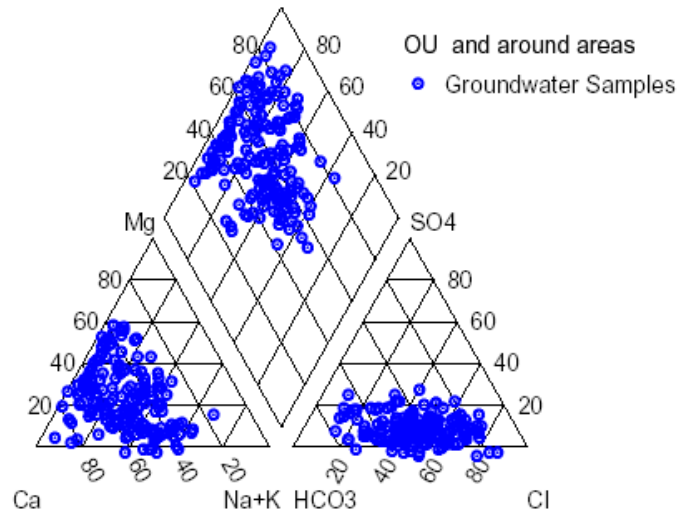
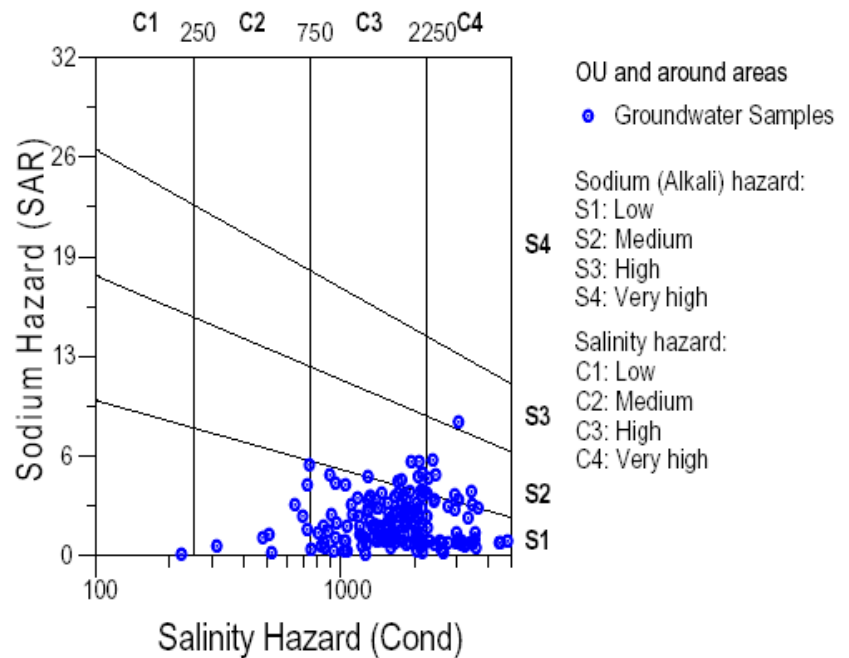


Fig. 3b. Wilcox plots for groundwater samples for the study area  
Wilcox Diagram - 2007



Na and Mg. The wide variation in the correlation coefficients suggests an irregular pattern and degree of groundwater pollution and helps in demarcating zones polluted to varying levels. Thus groundwater quality analysis assumes significance.

Apart from preventing groundwater contamination and water treatment, a multi-prong approach including rainwater harvesting and groundwater recharge has recently been suggested for educational institutions (Sayana, 2010) to meet their share of water needs in intensely urbanized cities/townships.

Table 2. Correlation matrix of geochemical parameters

	EC	TDS	PH	Alkalinity	Cl	TH	Mg	Ca	NO3	SO4	Na	K
EC	1.00											
TDS	0.84	1.00										
PH	-0.41	-0.17	1.00									
Alkalinity	0.29	0.18	-0.28	1.00								
Cl	0.53	0.83	-0.04	0.04	1.00							
TH	0.86	0.51	-0.44	0.14	0.10	1.00						
Mg	0.79	0.49	-0.29	0.11	0.10	0.93	1.00					
Ca	0.80	0.45	-0.53	0.16	0.09	0.92	0.72	1.00				
NO3	0.23	0.16	-0.26	-0.09	-0.05	0.22	0.16	0.26	1.00			
SO4	0.50	0.57	-0.25	0.26	0.54	0.22	0.16	0.25	0.08	1.00		
Na	0.39	0.53	-0.19	0.47	0.54	-0.02	-0.06	0.01	0.07	0.45	1.00	
K	0.03	0.25	0.35	0.06	0.17	-0.13	-0.05	-0.19	-0.04	-0.12	0.19	1.00

### Conclusions

Results of geochemical analysis of 171 groundwater samples from bore wells in Osmania University and surrounding areas of Hyderabad indicate that due to unplanned industrialization and rising urban sprawl, this natural resource is under considerable stress. It is found that the groundwater in the entire region is too hard for drinking.

- Areas especially prone to geochemical contamination are the southern part of the study area (on account of its proximity to the river Musi), the Nacharam and Mallapur regions (on account of the industries present in the area) and the Jamai Osmania, Lallaguda and Lalapet regions because of domestic sewage.
- A southward migration of pollutants in the study area along surface topography as also underground channels and other subsurface structural features is evident.
- In terms of extent of contamination with various geochemical parameters, the groundwater of the city is suitable for irrigation but not for drinking or other domestic purposes.
- The Piper trilinear classification for groundwater samples fall in the field of mixed  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ - $\text{Cl}^-$  type of water. The Wilcox classification, the groundwater in the study area is ranging between good to permissible for irrigation uses.

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