

## Temporal changes in groundwater quality in an industrial area of Andhra Pradesh, India

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**Temporal changes in groundwater quality in the industrialized area of Visakhapatnam, Andhra Pradesh have been studied. The results from 1982 to 2006 have been compared. The present study indicates that groundwater is mainly contaminated by  $\text{SO}_4^{2-}$  concentration, which is more than that observed in groundwater in 1982. This is attributed to prolonged persistent and perennial industrial activity rather than other sources on the aquifer chemistry. High concentration of  $\text{SO}_4^{2-}$  above the safe limit for drinking purposes causes health disorders. Remedial measures have been suggested to control pollution in the groundwater system.**

**Keywords:** Groundwater quality, industrial area, pollution activity, remedial measures, temporal changes.

GAJUWAKA is the most industrialized area in Visakhapatnam, Andhra Pradesh (Figure 1), where zinc smelter, heavy plates and vessels, fertilizer and oil refinery are the dominant industrial units in addition to other small-scale industries. These industries are located in a residential area. The population in the area has increased more than three-fold within a span of two decades, because of the rapid growth in industrial activity. Groundwater is the prime source of drinking water and its quality is getting degraded due to increasing industrialization<sup>1</sup>. The present communication is focused on the study of temporal changes in the groundwater quality to assess the intensity of pollution activity on it in the industrial area, where more than two decades ago major ion chemistry of groundwater was investigated<sup>2,3</sup>.

The study area experiences a semi-arid climate, with temperature in the range of 14–38°C. The annual average rainfall is 910 mm. The area is mainly underlain by khondalite suite of rocks of the Precambrian Eastern Ghats, over which the Recent red sediments occur. Charnockites, pegmatites and quartzites occur as intrusive bodies. The rocks show a foliation trend of NE–SW through EW to NW–SE with a dip 75°SE. The sub-surface geology indicates that the average weathered rock portion extends up

to 16 m and the fractured rock zone up to 30 m depth from the ground surface. The red sediments vary in depth from 1 to 3 m, with an average of about 2 m, from surface level, depending upon the topography.

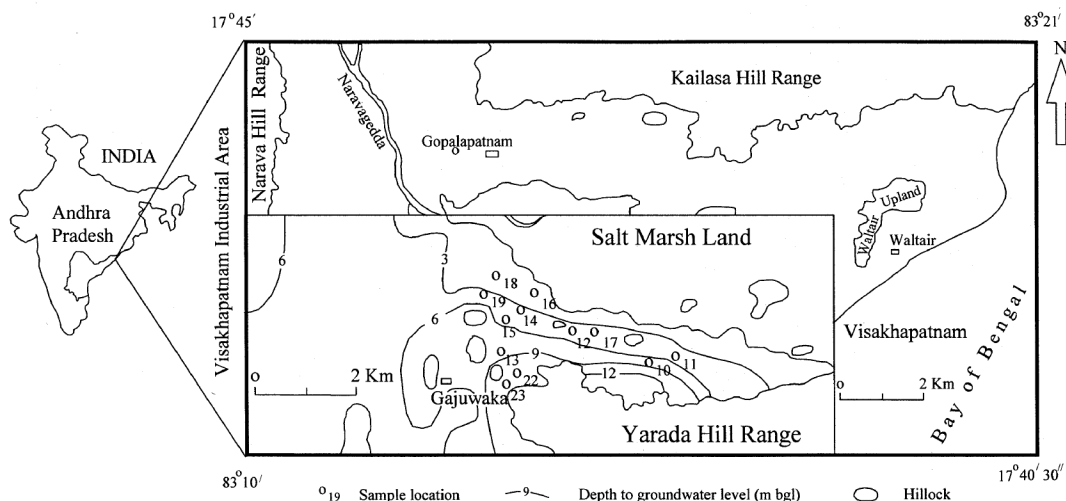
Rainfall is the main natural replenishable recharge source of groundwater. Groundwater occurs in the weathered and fractured rock portions. The depth to groundwater level ranges from 2 to 11 m below ground level (bgl). Shallow groundwater level less than 3 m bgl was observed at topographic-lows (downstream), while deep groundwater level more than 9 m bgl was found at elevated ground (upstream; Figure 1). The general slope of the area was towards the salt marsh land from all the directions. Hence, the direction of the groundwater flow followed the topography of the area.

Twelve groundwater samples collected from the study area (Figure 1) they were measured for pH and TDS, and analysed for  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{F}^-$ , following standard water quality procedures<sup>4,5</sup>. The results are shown in Table 1. The concentration of pH varies from 6.7 to 8.3 (units), TDS from 736 to 4275 mg/l,  $\text{Ca}^{2+}$  from 110 to 570 mg/l,  $\text{Mg}^{2+}$  from 15 to 113 mg/l,  $\text{Na}^+$  from 14 to 533 mg/l,  $\text{K}^+$  from 4 to 80 mg/l,  $\text{HCO}_3^- + \text{CO}_3^{2-}$  from 26 to 315 mg/l,  $\text{Cl}^-$  from 65 to 400 mg/l,  $\text{SO}_4^{2-}$  from 113 to 2100 mg/l,  $\text{NO}_3^-$  from 1 to 38 mg/l and  $\text{F}^-$  from 0.3 to 0.9 mg/l. Based on the concentration of TDS, samples 10, 11, 22 and 23 belonged to freshwater (TDS < 1000 mg/l), samples 12, 13 and 17–19 came under slightly brackish water (TDS 1000–2000 mg/l), samples 14 and 16 were classified as moderately brackish water (TDS 2000–3000 mg/l) and sample 15 was considered as highly brackish water (TDS > 3000 mg/l)<sup>6</sup>. Groundwater was characterized by  $\text{HCO}_3^-$ -type (sample 23) at topographic-highs and by  $\text{SO}_4^{2-}$  type (sample 15) at topographic-lows (Table 1, Figure 1). This suggests that the groundwater quality changed from potable (freshwater) to non-potable (brackish water) category, following the topography.

The groundwater showed low concentration of TDS (845 mg/l; sample 22; Table 1), where the depth to groundwater level was more than 9 m bgl at elevated ground (Figure 2). The groundwater sample 13 had low concentration of TDS (1056 mg/l), with water level between 9 and 6 m depth from the ground surface at less elevated ground compared with the location of the groundwater sample 22. The groundwater observed between 6 and 3 m depth from ground level suddenly showed high concentration of TDS (4275 mg/l; sample 15), where the industrial waste is disposed onto the ground, at medium-topography. The groundwater, occurring below 3 m depth from surface level showed high concentration of TDS (2899 and 2720 mg/l in samples 14 and 16 respectively) at topographic-lows. This indicates that the pollutants have moved in the direction of groundwater flow.

The movement of pollutants in the unsaturated zone is controlled by moisture content of soils and permeability

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**Figure 1.** Location of the industrial area in Visakhapatnam, Andhra Pradesh.

**Table 1.** Results of chemical composition of groundwater in 2006 in the industrial area of Visakhapatnam, Andhra Pradesh

Sample no. as shown in Figure 1	pH (units)	TDS	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>
		mg/l										
10	6.7	883	190	34	44	5	—	26	65	540	1	0.8
11	8.0	736	155	21	50	7	—	136	65	310	1	0.3
12	8.0	1696	370	34	130	8	—	128	190	730	38	0.3
13	7.7	1056	235	23	90	4	—	213	110	440	1	0.5
14	7.9	2899	250	113	14	80	—	298	250	1370	30	0.4
15	7.8	4275	570	69	533	55	—	315	400	2100	10	0.3
16	7.7	2720	480	55	210	23	—	187	200	1330	20	0.3
17	7.6	1792	240	91	200	30	—	170	150	930	20	0.7
18	8.0	1677	340	15	180	33	—	306	240	600	3	0.4
19	7.7	1504	320	58	74	13	—	196	180	660	13	0.4
22	8.1	845	110	26	135	20	—	255	180	115	7	0.8
23	8.3	760	120	18	95	17	68	213	110	113	8	0.9

of rock-materials through which the pollutants can move. Downward movement of the solute through the unsaturated zone, with infiltrating recharge water, may take considerable time to reach the saturated zone. On reaching the saturated body, the pollutants spread out laterally moving in the direction of groundwater flow (Figure 3). Then, pollution plumes can form, which are likely to move further along the groundwater flow-path, with dilution of pollutants, so that there is a lot of variation in the concentration of TDS in the groundwater from the source point to the non-source point of the pollutant along the movement of groundwater flow (Figure 2). Therefore, the main cause of groundwater pollution in the study area is attributed to disposal of industrial wastes onto the ground without any pre-treatment, which get infiltrated down into the aquifer system. Abnormal concentration of SO<sub>4</sub><sup>2-</sup> (average 769.83 mg/l), among the ions observed in the groundwater in 2006 (Table 2), is indicative of man-made

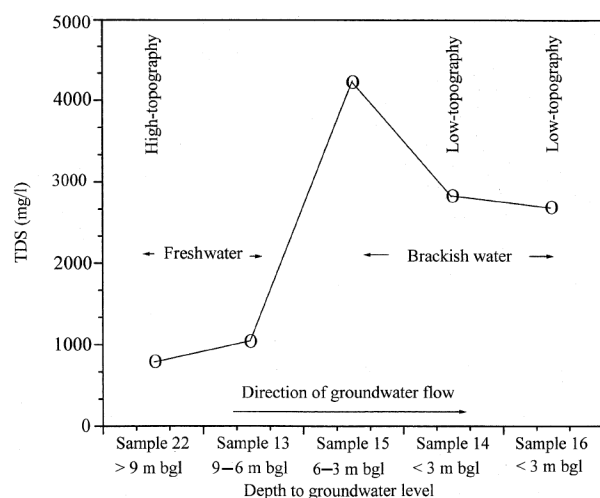
pollution, since there are no known sulphide-bearing minerals in the litho-units of the study area. Thus, the high SO<sub>4</sub><sup>2-</sup> concentration is due to industrial effluents.

The chemical quality of groundwater was earlier studied<sup>3</sup> in 1982. The groundwater was mainly contaminated by SO<sub>4</sub><sup>2-</sup> (average 583.33 mg/l) and Cl<sup>-</sup> (average 196.67 mg/l), which together contributed 71.59% to the total anions (Table 2). The observed average concentrations of SO<sub>4</sub><sup>2-</sup> and Cl<sup>-</sup> in the groundwater of the present study were 769.83 and 198.33 mg/l respectively, which together contributed 85.52% to the total anions. Decreasing concentration of HCO<sub>3</sub><sup>-</sup> + CO<sub>3</sub><sup>2-</sup> from 1982 (average 426.67 mg/l; 28.31%) to 2006 (average 209.25 mg/l; 13.57%) and increasing concentration of SO<sub>4</sub><sup>2-</sup> from 1982 (average 583.33 mg/l; 49.21%) to 2006 (average 769.83 mg/l; 63.41%) suggests the change of environment from active groundwater flushing to less active groundwater circulation in a major ion evolution sequence in the groundwater

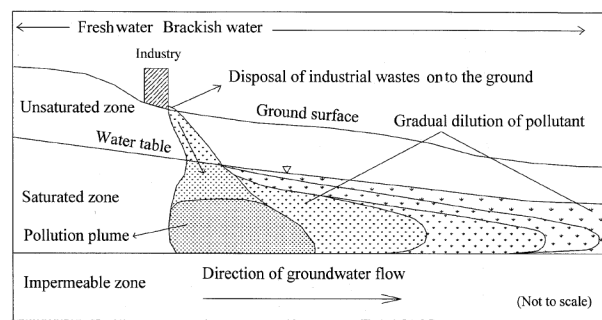
**Table 2.** Average chemical composition of groundwater in 1982 and 2006 in the industrial area of Visakhapatnam

Chemical parameter	Average concentration of ions			
	1982 (Subba Rao <i>et al.</i> <sup>3</sup> )	Contribution of individual ions (%) to the total cations/anions*	2006	Contribution of individual ions (%) to the total cations/anions*
pH (units)	7.50	–	7.79	–
TDS (mg/l)	1646.67	–	1.736.92	–
Ca <sup>2+</sup> (mg/l)	43.34	8.92	281.17	56.48
Mg <sup>2+</sup> (mg/l)	62.67	21.27	46.42	15.38
Na <sup>+</sup> (mg/l)	358.00	64.31	146.25	25.60
K <sup>+</sup> (mg/l)	51.83	5.50	24.58	2.54
HCO <sub>3</sub> <sup>-</sup> + CO <sub>3</sub> <sup>2-</sup> (mg/l)	426.67	28.31	209.25	13.57
Cl <sup>-</sup> (mg/l)	196.67	22.48	198.33	22.11
SO <sub>4</sub> <sup>2-</sup> (mg/l)	583.33	49.21	769.83	63.41
NO <sub>3</sub> <sup>-</sup> (mg/l)	–	–	12.67	0.79
F <sup>-</sup> (mg/l)	–	–	0.51	0.06
Geochemical ratios*				
Na <sup>+</sup> : Cl <sup>-</sup>		2.81		1.14
HCO <sub>3</sub> <sup>-</sup> : Cl <sup>-</sup>		1.26		0.61
Ca <sup>2+</sup> : Cl <sup>-</sup>		0.40		2.51

\*Computed on the basis of ions expressed in milliequivalents per litre.



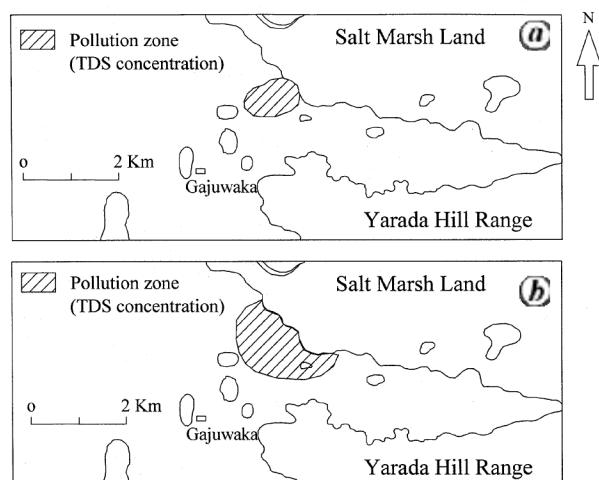
**Figure 2.** Relation between depth to groundwater level and TDS along the direction of the groundwater flow.



**Figure 3.** Schematic diagram showing the formation of pollution plume and movement of pollutant with its dilution along the direction of groundwater flow.

system<sup>7</sup>. Further, the average concentration of NO<sub>3</sub><sup>-</sup> (12.87 mg/l) was more than its natural occurrence (10 mg/l)<sup>8</sup>, which suggests lack of sufficient sanitary facilities due to uncontrolled urbanization. Moreover, the average concentration of Ca<sup>2+</sup> was 43.34 mg/l (8.92%) in 1982 and 281.17 mg/l (56.48%) in 2006, while the average concentration of Na<sup>+</sup> was 358 mg/l (64.31%) in 1982 and 146.25 mg/l (25.60%) in 2006. This may be expected due to the reverse effect, which is the exchange of Na<sup>+</sup> for Ca<sup>2+</sup> by the advancing salt water<sup>9</sup>, because of the over-exploitation of groundwater, as the study area is located nearby the salt marsh land (Figure 1). The lower ratios of Na<sup>+</sup>:Cl<sup>-</sup> and HCO<sub>3</sub><sup>-</sup>:Cl<sup>-</sup> in 2006 (1.14 and 0.61 respectively) than in 1982 (2.81 and 1.26 respectively) and the higher ratio of Ca<sup>2+</sup>:Cl<sup>-</sup> in 2006 (2.51) than in 1982 (0.40), further support the hypothesis of salt water entry into the aquifer system. However, further detailed research is required to confirm the influence of salt water on the groundwater chemistry.

The spatial extent of groundwater pollution zone demarcated on the basis of TDS in 2006 was greater than that of the zone demarcated in 1982 (Figure 4)<sup>3</sup>. Since SO<sub>4</sub><sup>2-</sup> is the main contributor (49.21% in 1982 and 63.41% in 2006) to the concentration of TDS in groundwater (Table 2), it clearly indicates that there is prolonged, persistent and perennial industrial activity in the study area (Table 2), as explained by the operating mechanism of movement of industrial pollutant along the direction of groundwater flow (Figure 3), rather than other sources like salt water and urban wastes on the groundwater system. Otherwise, such high concentration of SO<sub>4</sub><sup>2-</sup> (average: 583.33 mg/l in 1982 and 769.83 mg/l in 2006) in the groundwater could not be possible under normal conditions.



**Figure 4.** Spatial extent of groundwater pollution zones (TDS) in (a) 1982 and (b) 2006.

The concentration of  $\text{SO}_4^{2-}$  (310–2100 mg/l) in some groundwater samples (10–19; Table 1) is two to fourteen times greater than the safe limit of 150 mg/l allowed for drinking purpose<sup>10,11</sup>. Excess  $\text{SO}_4^{2-}$  concentration (average 583.33 mg/l; Table 2) higher than the recommended limit for drinking water was reported in 1982, which was caused to health disorders related to the respiratory system<sup>2</sup>. These health conditions are till dominant and severe due to more concentration of  $\text{SO}_4^{2-}$  (average 769.83 mg/l; 63.41%) in 2006 than that in 1982 (average 583.33 mg/l; 49.21%) in the groundwater. Moreover, the concentrations of  $\text{Ca}^{2+}$  (samples 10–19, 22 and 23),  $\text{Mg}^{2+}$  (samples 10, 12, 14–17 and 19),  $\text{Na}^+$  (samples 15 and 16) and  $\text{Cl}^-$  (sample 15) were also higher than the desirable limits of 75, 30, 200 and 250 mg/l respectively, prescribed for drinking purpose<sup>10,11</sup> in the groundwater (Table 1). These cause health problems, which are associated with the digestive, urinary and circulatory systems<sup>10,11</sup>. Whereas the concentration of  $\text{F}^-$  in some groundwater samples (11–16, 18 and 19) was less than the safe limit (0.6 mg/l), which causes dental caries<sup>10</sup>. The reports of WHO<sup>11</sup> and the Earth Summit<sup>12</sup> mention that about 80% of the diseases on the world population and more than one-third of the deaths in the developing countries were due to consumption of inferior water quality.

This study emphasizes the need for regular groundwater quality monitoring to assess pollution activity from time to time for taking appropriate management measures in time to mitigate the intensity of pollution activity. The remedial measures include (a) strict implementation of environmental laws, (b) treatment of industrial wastes before their safe disposal, (c) development of greenery in and around industrial zones, (d) limited withdrawal of groundwater, (e) arrangement of proper drainage system,

and (f) supply of protected water. Moreover, the disposal sites for industrial and urban wastes should be away from residential areas. There is an urgent need to generate public awareness on the sources, causes, extent and prevention of groundwater pollution, and also the consequences of impact of pollution on human health, which would be a key factor for sustainable development of the area.

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