

## **The impact of urban industrial growth on groundwater quality in Visakhapatnam, India**

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**Abstract** The process of urbanization and industrial expansion has been phenomenal in the port city of Visakhapatnam since 1940. In addition to the port, major industries such as shipyards, petroleum refineries, zinc smelter plants, fertilizer units, ceramics and polymers have started in the city heartland. Forty percent of the one million population lives in the industrial belt within which the quality of groundwater has become seriously polluted. Fifteen percent of the industrial well waters have recorded more than 3000  $\mu\text{s}$  level of conductivity and major ions have crossed the "safe" limits at many places. Toxic elements including lead, chromium, arsenic, zinc, cobalt have been traced in large amounts in the groundwaters of the industrial zones, with a zinc plant being identified as the worst offender followed by the port and polymer facilities. The extent of effluent contamination has been delineated using geo-electrical techniques.

### **INTRODUCTION**

The 270 km<sup>2</sup> area of Visakhapatnam, a port city on the east coast of India abutting the Bay of Bengal, is located between 17°38'30"–17°47'10"N and 83°7'30"–83°21'15"E. A small town, with a modest population of 30 000 in the year 1900, it has experienced a tremendous growth rate since 1941, due to rapid industrialization, and the population crossed the one-million mark in 1991. The industrial expansion of the port started with shipyards in 1952 and continued unabated following the introduction and growth of various heavy industries, as identified in Table 1, along with a proliferation of minor accessory industries. Most of the industries are located in the central valley of the city, separated by distances ranging between 2–4 km. The industrial zone is highly focussed within a 4 km core area and about 40% of the population lives in this industrial area in slum like conditions with improper sewage lines. The water demand of the town rose to  $510 \times 10^5$  gallons day<sup>-1</sup> and the municipal water supply from reservoirs was about  $284 \times 10^5$  gallons day<sup>-1</sup> in 1993. The deficit is to be met from groundwater resources. With a 5.64% growth rate of population, the city is likely to touch the 1.5 million mark by the year 2001, an explosion of 15 times within fifty years. The impact of industrialization, thus makes out a typical case history for quality studies.

### **HYDROGEOLOGY**

The main urban aquifers are made up of Khondalites, highly metamorphosed sediments of Archaean age, which are composed of quartz, garnet and sillimanite. Industrial waste and domestic sewage release large amounts of chloride and sulphate

**Table 1** Urban growth pattern of Visakhapatnam city since 1941.

Year	Population	Major industry started	Product	Water demand of the city (10 <sup>5</sup> gall day <sup>-1</sup> )	Supplied from reservoirs (10 <sup>5</sup> gall day <sup>-1</sup> )	Ground-water demand (10 <sup>5</sup> gall day <sup>-1</sup> )
1941	70 243	Port (existing)	Exports and imports of coal, sulphur, iron etc.	No records		
1951	108 042	Hindusthan Shipyard (1952)	Ship building	0133		
		HPCL (1957)	Oil refinery	0235		
1961	211 190	Coromandel	Nitrogen, phosphates		68	65
1971	363 367	Fertilizers(1967)	Pressure vessels & boilers		140	95
		BHPV (1971)	Ethyl alcohol & polysterene			
		H. Polymers (1973)	Zinc, lead, cadmium	0500		
1981	603 822	H. Zinc Plant (1977)	Shrimp processing			
1991	1 006 000	Union Carbide (1979)	Slag cement	0570	240	260
2001	1 500 000	Cement factory (1982)	Steel	1000		
		Steel plant (1989)	Processed fish		284	216
		Aqua marine products	Acetylene		?	?
		Oxygen plant				

Data: Courtesy Visakhapatnam Municipal Corporation.

whilst coastal spray adds to the background ionic content to some extent. The weathered Khondalite is the main water bearing layer below a red loamy soil cover of 1–2 m thickness. The weathered zone extends up to 10–15 m below the soil cover. The fractured Khondalite occurs below the weathered zone. The porosities have a range of 10–15% for the weathered section and 15–25 % for the fractured zone. The average transmissivity of the Khondalitic aquifer is 50 m<sup>2</sup> day<sup>-1</sup>. Groundwater is present in the unconfined conditions at depths ranging 0.4–8.0 m from the surface. Thousands of open wells (diameter 3–6 m) and hundreds of bore wells (diameter 6–12 cm) exist in city aquifers. The present study deals with waters from open wells.

## RESIDENTIAL AND INDUSTRIAL ZONES

The industry-free colonies are called residential (R) areas to segregate them from industrial zones (I) which are also thickly populated. The division helps to identify the pollution levels more clearly. Murthy & Rao (1981) observed that the elements of the industrial air zone are washed out during the rainy period and mix with groundwaters derived from residential aquifers. To verify the phenomenon, 375 well waters (R-161, I-214) were collected during the pre-monsoon period of May–June 1993 and analysed for conductivity, chloride, bicarbonate, sulphate, calcium, magnesium, sodium and potassium (Table 2). Out of the total number, 82% of the waters are above the 1000 µs level of conductivity and 250 mg l<sup>-1</sup> limit (WHO) of chloride. Among the R-type wells, 67% cross the “safe” limits, compared to 91.5% of I-type wells (Table 2). The hydrogen ion concentration or pH of R-wells varies between 7 and 8 whilst I-well waters are slightly acidic with pH varying between 6 and 7. The hydrochemical facies of R-wells belong to Ca-Mg-HCO<sub>3</sub> (with <1500 µs of cond.) type and those of I-wells belong to Na-Mg-Cl-SO<sub>4</sub> type (with >2500 µs). Facies analysis suggests that chloride and sulphate are industrially derived.

**Table 2** Percentage of wells crossing the limits of tolerance from Residential and Industrial areas

Element	Range (mg l <sup>-1</sup> )	Residential (%)	Industrial (%)
Conductivity ( $\mu$ s)	>1000	67.0	91.0
Chloride	>250	12.5	30.7
Bicarbonate	>400	54.8	54.0
Sulphate	>400	19.7	43.8
Calcium	>75	5.0	28.0
Magnesium	>50	1.4	13.9
Sodium	>150	54.1	81.0
Potassium	>100	1.8	4.6
Total no. of samples	375	161	214

## INDUSTRIAL ZONES: PRIORITIZATION OF POLLUTION

To observe the quality levels of groundwater associated with different industries, a few wells close and downstream of each industry were selected and average salinity levels estimated. Eight industries and two residential colonies are studied in this manner. The resultant data is given in Table 3 which shows that the zinc plant is the worst polluter, followed by the port, polymer and oil refinery (HPCL) in that order. These four segments have a high range of conductivity (2000–3500  $\mu$ s) with only the steel and cement facilities recording a safe range of less than 1000  $\mu$ s. The industry-free residential zones (H. B. Colony and M. V. P. Colony) recorded between 1000–1500  $\mu$ s.

The average depths to groundwater in the zinc plant (1.4 m), port (3.87 m) and polymer (1.99 m) areas are shallow and liable to contamination by surface industrial wastes. It is also observed that, whilst the port has no particular piped effluent discharge, other industries discharge their effluents via pipes to the sea. Zinc effluent, though conveyed by a cement pipe, has developed accidental leakage resulting in solid wastes which make the zone the highest polluter in the area.

## HEAVY METAL CONCENTRATIONS

To understand the contamination process, an analysis of heavy metal concentrations in groundwaters and effluents of the zinc and polymer plants was conducted. Heavy metal traces within a residential colony were also included as a comparison (Table 4).

**Table 3** Comparative concentrations (average) of major ions in Industrial and Residential segments.

Zone (No. of samples)	Depth to GW (m)	Conduct -ivity ( $\mu$ s)	Cl (mg l <sup>-1</sup> )	HCO <sub>3</sub> (mg l <sup>-1</sup> )	SO <sub>4</sub> (mg l <sup>-1</sup> )	Ca (mg l <sup>-1</sup> )	Mg (mg l <sup>-1</sup> )	Na (mg l <sup>-1</sup> )	K (mg l <sup>-1</sup> )
Zinc plant (15)	1.40	3393	174	540	1226	246	173	259	41
Port (10)	3.87	3042	676	403	297	126	75	380	59
Polymers (10)	1.99	2556	340	720	314	59	57	434	36
HPCL (15)	8.99	2365	379	554	127	102	89	220	13
Coromandel (11)	2.34	1635	185	512	117	77	79	106	27
BHPV (10)	2.20	1317	138	519	62	66	53	90	05
Steel plant (10)	3.12	1220	180	369	40	63	35	126	09
Cement factory (10)	8.20	482	45	233	07	20	23	40	03
Res. Colony (MVP)	3.20	1297	155	462	53	32	48	148	10
Res. Colony (HB)	6.09	828	75	453	30	36	48	102	05

**Table 4** Average concentrations ( $\mu\text{g l}^{-1}$ ) of heavy metals at Zinc and Polymer Plants and at a Residential colony.

Element	Zinc plant		Polymers		Res. colony (MVP)
	Groundwater	Effluent	Groundwater	Effluent	
Conductivity ( $\mu\text{S}$ )	3400.0	3900.0	2556.0	4500.0	1550.0
Cadmium	20.8	4562.0	0.0	0.0	0.0
Chromium	0.2	18.9	0.1	0.0	0.2
Copper	4.7	11.6	52.7	170.0	1.4
Iron	11.4	259.0	0.2	300.0	2.4
Lead	164.0	317.0	0.0	10.0	3.7
Manganese	26.1	575.0	0.5	12.0	6.7
Zinc	2172.0	17560.0	61.0	2270.0	14.0
Cobalt	5.7	11.8	0.1	5.0	0.4
Nickel	5.4	39.1	0.0	20.0	2.9
Arsenic	1.1	85.5	1.6	2.4	0.0
Silver	0.8	1.2	0.2	0.2	0.0
Molybdenum	5.2	9.5	0.7	1.6	0.0
Selenium	35.0	48.8	2.6	13.8	0.0

Whilst there is no surprise at the presence of heavy metals such as cadmium, chromium, arsenic, iron and lead in effluents, their presence in groundwaters suggests contamination.

Significantly, cadmium ( $4562 \mu\text{g l}^{-1}$ ), lead ( $317 \mu\text{g l}^{-1}$ ), and zinc ( $17\ 560 \mu\text{g l}^{-1}$ ), from the zinc plant effluent seem to be joining the groundwater and both arsenic and nickel occur at higher concentrations in the groundwater.

## EXTENT OF CONTAMINATION AT THE ZINC AND POLYMER PLANTS

Geoelectrical techniques offer a practical method which has been used successfully in detecting groundwater contamination by industrial effluents, leachates and sewage liners (Urish, 1980; Stollar & Roux, 1975). Zohdy *et al.* (1974) suggested the use of Vertical Electrical Sounding (VES) surveys with a Schlumberger array to obtain electrical resistivity values of layers up to required depths. A series of single depth resistivity measurements and VES survey have been used to draw the iso-resistivity maps. With enough contrast between contaminated and natural waters, the extent of contamination can be delineated by this technique. Stollar & Roux (1975) suggest the following resistivity range to identify contamination by the VES technique:

Resistivity of the layer ( $\Omega\ \text{m}$ )	Contamination level
0–5	Maximum
5–10	Medium
10–15	Low

Figure 1(a) shows the location of open wells downstream of the zinc plants, along with resistivity points surveyed by VES. Iso-conductivity lines have been drawn from conductivity values of well waters and are given in Fig. 1(b). An iso-resistivity map, prepared from VES results is shown in Fig. 1(c), which shows the areal extent of contamination and VES curves for the three zones of contamination are shown in Fig. 1(d). The depths of contaminant influence are given as “h” and contamination ends with the second layer thickness which is 2.1 m for the zinc plant.

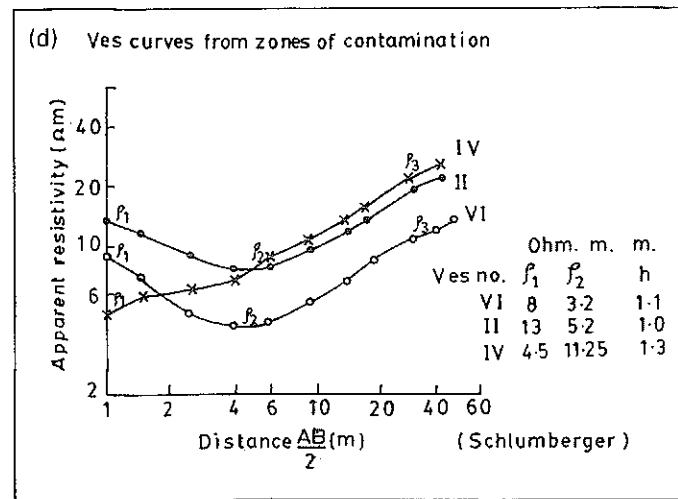
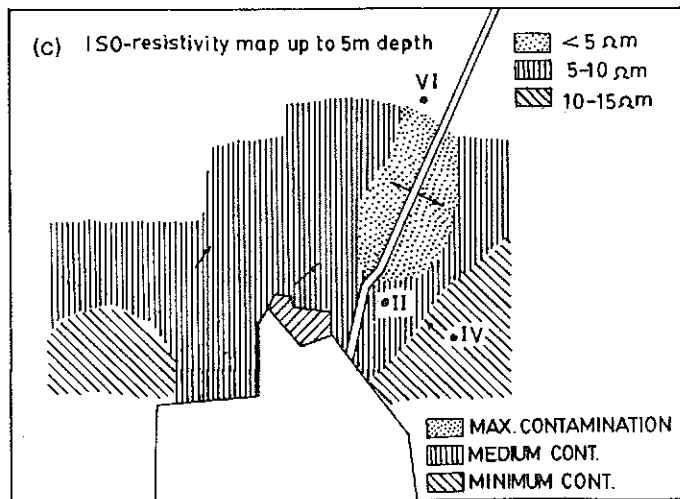
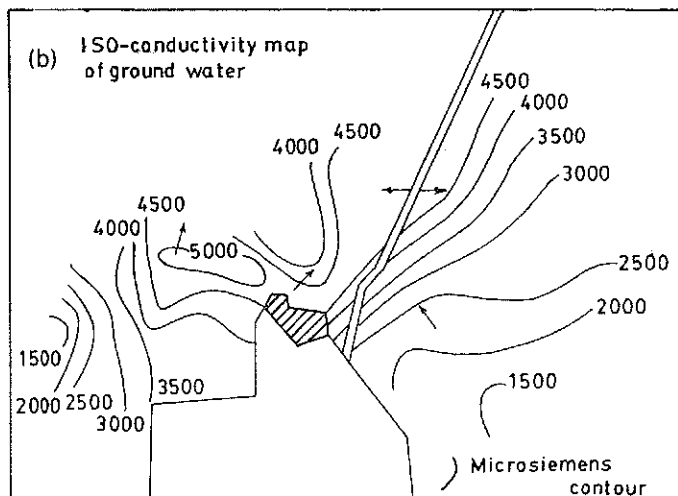
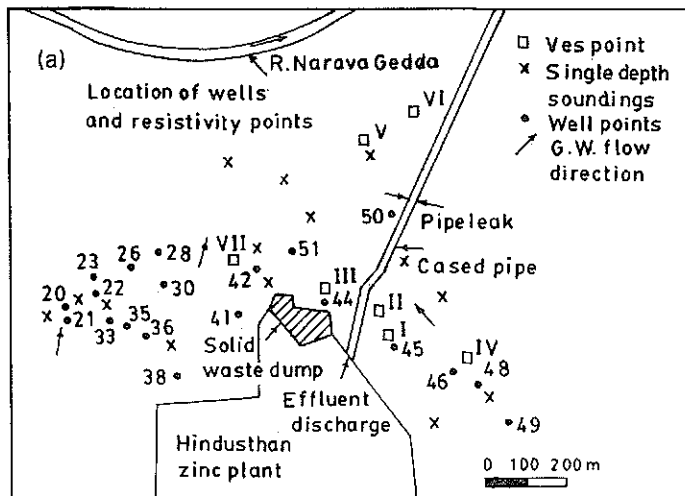


Fig. 1 Delineation of contamination levels by VES technique for the zinc plant.

## STEADY DETERIORATION

The overall salinity distribution in the urban aquifers can be understood from the conductivity contour map (Fig. 2). While the R-localities have closures of  $<1000 \mu\text{s}$ ,  $1000\text{--}1500 \mu\text{s}$ , I-zones have closures of  $2000\text{--}2500 \mu\text{s}$ ,  $2500\text{--}3000 \mu\text{s}$  and  $>3000 \mu\text{s}$ . To study the temporal variation of groundwater quality, the salinity levels estimated by previous workers (Sarma & Swamy, 1981; Rao & Rao, 1990) have been noted and compared with the present study of 1993. Table 5(a) shows how the major ions have increased from 1975 to 1993 and Table 5(b) shows the percentage of wells of low conductivity waters declining, and higher orders rising. Within a span of 18 years, well waters of conductivity range ( $>3000 \mu\text{s}$ ) rose from 1% to 15 % and the middle order ( $1000\text{--}3000 \mu\text{s}$ ) from 43% to 57 %, which mean a steady deteriorating trend in groundwater quality.

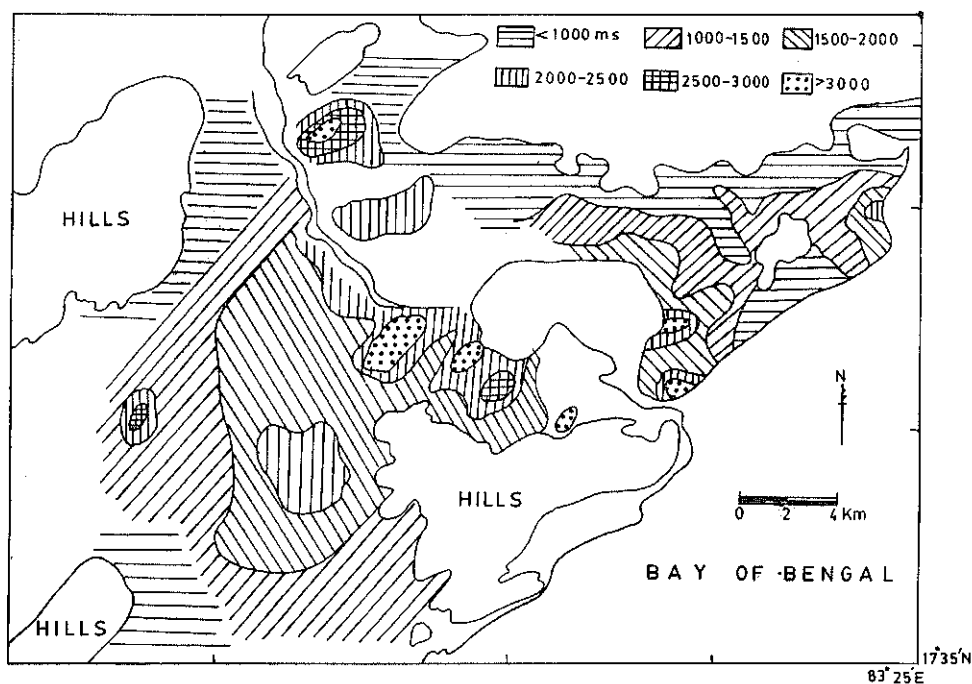


Fig. 2 Iso-conductivity map of the urban aquifer.

Table 5(a) Time variation of chemical composition of common ions in groundwater.

Ion ( $\text{mg l}^{-1}$ )	Sarma & Swamy (1975)			Rao & Rao (1981)			Present study		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Ca	176	2	35	550	5	35	552	15	97
Mg	158	7	53	185	6	52	338	13	75
Na + K	894	11	160	1060	38	211	1599	20	224
$\text{HCO}_3$	975	91	400	1200	40	321	907	183	513
Cl	1600	17	202	2020	50	258	2793	29	291
$\text{SO}_4$	980	5	43	1343	1	77	2564	5	276

**Table 5(b)** Time variation of conductivity ranges: Percentage of water samples.

Classification	Conductivity (μS )	Sarma & Swamy (1975)	Rao & Rao (1981)	Present study (1993)
Low conductive	<500	28.20	16.76	7.96
Lower medium	500–1000	46.60	32.90	20.35
Upper medium	1000–3000	24.40	42.50	56.60
High conductive	>3000	0.76	6.89	15.10

**Acknowledgements** The authors thank the University Grants Commission, New Delhi for research funds and our colleagues, Prof. C. Visweswara Rao, Prof. P. Rajendra Prasad and Mr E. Rajendra Prasad for their cooperation.

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