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# Effects of urbanization on changes in groundwater quantity and quality in Delhi State, India

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**Abstract** Urbanization in India results in a population increase and other infrastructure developments leading to a large demand for water. For Delhi, the demands for water and population growth have increased exponentially, whereas water availability (surface and groundwater) has decreased resulting in an increase in tube well-irrigated areas. Thus, during the last 25 years, over exploitation of groundwater for industrial, domestic and irrigation purposes has occurred. The annual rainfall and associated groundwater recharge has been below normal during this period. Composite groundwater samples from 250 cased wells in villages adjacent to Delhi were collected during 1998 and compared to earlier published data. The spatial variations in anions, cations and micronutrients indicate that water quality has deteriorated in the west and northwestern parts of the city.

**Key words** anion; cation; contamination; GIS Themes; groundwater quality; urbanization

## INTRODUCTION

Urbanization in India was relatively constant until about 1900 AD. Prior to 1900, urban populations varied from 5% to 12% of the total population. Since 1900, however, urbanization has been progressively increasing. By 1981, India's urban population of 159 million was about 24% of total population. In the past few years, three million rural people have migrated to the cities annually, and the migration is steadily increasing (Ramachandran, 1989). The increased urbanization is in response to the migration of people from the surrounding rural areas. The main cause for the migration is the lack of jobs in rural areas and higher job availability in the urban areas (Singh & Jagmohan, 2000).

Delhi, the capital of India, has been developed with the urban and metropolitan processes. During the pre-Independence period (prior to 1947) urbanization was limited to the Walled City and the area spread to nearby States during the next 50 years. Although the total geographical area of the city remained more or less constant, the population within the city has been increasing exponentially since 1900 (Fig. 1). Thus the rural population growth is only marginal when compared to that of urban and total rates. Consequently, the demand for freshwater has increased, which mainly consists of groundwater, for potable, domestic, irrigation, and industrial uses. The increased demand and related supply has caused the water table to decline and groundwater quality to deteriorate. Although water availability and water demand have increased since 1980, the demand has increased at a much faster rate than the availability, mainly due to urbanization (Datta, 1999). The results of analyses of hydrochemical data from 250 groundwater samples from select locations in the vicinity of the Delhi urban areas have been evaluated to determine the spatial and temporal changes in water quality. To aid in evaluating the hydrochemical changes associated with land-use change, the data were overlaid using ARC-INFO and ARCVIEW GIS applications.

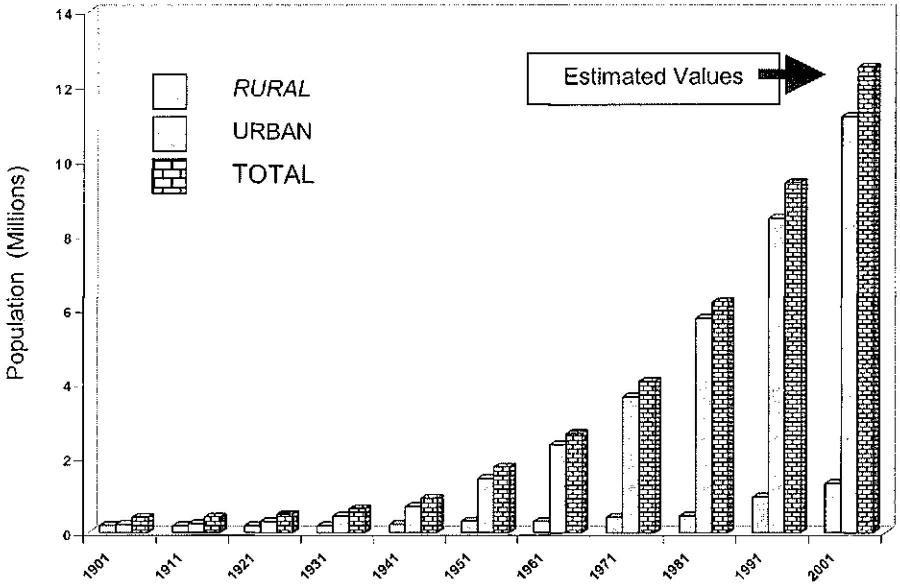


**Fig. 1** Population growth in Delhi State (1901–2001) (from Bhatt, 1998).

## The study area

Delhi State is a part of the Indo-Gangetic plains and situated between the Himalayas and Aravali mountain ranges of the Indian sub-continent. The State has a geographical area of 1485 km$^2$, of which the rural villages occupy about 795 km$^2$, and it is in the fourth agro-ecological region having the hot semiarid climate of the northern plain and central highlands. In the 65 years since 1930, mean monthly evapotranspiration exceeded precipitation each month except during August and September (Trivedi, 2000). The area contains four physiographic units, including the Aravali (Delhi) ridge, flood plains of the Yamuna basin, piedmont plains, and undulating to flat plains of the Aravali alluvium. The area also is composed of five drainage basins including the Najafgargh, Alipur, Shahdara, Kushak-Barapulla, and Mehrauli. The underlying bedrock geology ranges from Algonkian to Quaternary in age and consists primarily of Alwar quartzite, whereas the surficial geology consists of alluvium and sand dunes (aeolian). The area primarily contains alluvium-derived soils. During the past 53 years, urban developments in terms of both population and developed area have increased by a factor of 12 resulting in a reduction in agricultural lands and rural areas. Water collected in the main drains, link drains, and small streams is discharged into the River Yamuna.

## MATERIALS AND METHOD

More than 250 groundwater samples were collected in screw-capped plastic bottles from pumped bore wells at 125 villages adjacent to Delhi (Fig. 2). Related information on water table depth, vegetation, cropping system and location of nearby surface water sources, is available (Trivedi, 2000). For each groundwater sample, electrical conductivity (EC) and the concentrations of the major anions, cations, and several minor and trace elements (Fe, Cu, Mn and Zn) were measured by conventional laboratory methods. Data on the hydrochemical composition of the groundwater in 1976 were extracted from the literature (Paliwal & Yadav, 1976). The map of Delhi was digitized using ARC/INFO (ESRI, 1993), and maps were generated in ARCVIEW, details of which are available elsewhere (Kaushalya, 1999).

## RESULTS AND DISCUSSION

### Urbanization effects on groundwater quantity

The urban areas of Delhi in 1976, 1991 and 1998, and the location of wells from which groundwater samples were collected for the present study, are shown in Fig. 2. The urbanized area increased by about 80 $km^2$ from 1976 to 1998 and groundwater was indiscriminately exploited (Table 1). The approximate net quantity of groundwater, i.e. the withdrawal in excess of recharge, has been evaluated at some urbanized locations near Delhi. The total water use in the area was estimated to be $1044 \times S_y \times 10^6$ $m^3$. ($S_y$ is the specific yield of the aquifer.)

**Table 1** Urbanization effects on groundwater in the suburbs of Delhi.

| S. no. | Name of the village | Urbanized area ($10^6$ $m^2$) | Water table decline during 1976—1998 (m) | Withdrawal in excess of recharge during 1976—1998 ($10^6$ $m^3$) |
|---|---|---|---|---|
| 1 | Kurani (north Delhi) | 13.77 | 13.33 | $183.55 \times S_y$ |
| 2 | Sultanpur Majra (northwest Delhi) | 5.49 | 16.77 | $92.07 \times S_y$ |
| 3 | Budhanpur East (north Delhi) | 1.62 | 15.78 | $25.56 \times S_y$ |
| 4 | Gumanhera (west-south Delhi) | 1.35 | 16.77 | $22.64 \times S_y$ |
| 5 | Chhatarpur (south Delhi) | 5.85 | 12.50 | $73.13 \times S_y$ |
| 6 | Mehrauli (south Delhi) | 46.89 | 13.80 | $647.08 \times S_y$ |

($S_y$ is the specific yield of the aquifer.)

Variations in groundwater quality (represented by EC) during 1976 and 1998 showed that, with the exception of a few wells, the water quality has deteriorated in the west and northwestern parts of the city (Fig. 3). The pattern is similar for areas that were urbanized between 1976 and 1998. To better understand the effect of urbanization on groundwater quality, changes in selected hydrochemical parameters of three rural areas that were urbanized from 1976 to 1998 were evaluated (Fig. 4). These areas are shown as B, D and F (urbanized villages) and A, C and E (adjoining villages) in Fig. 2.

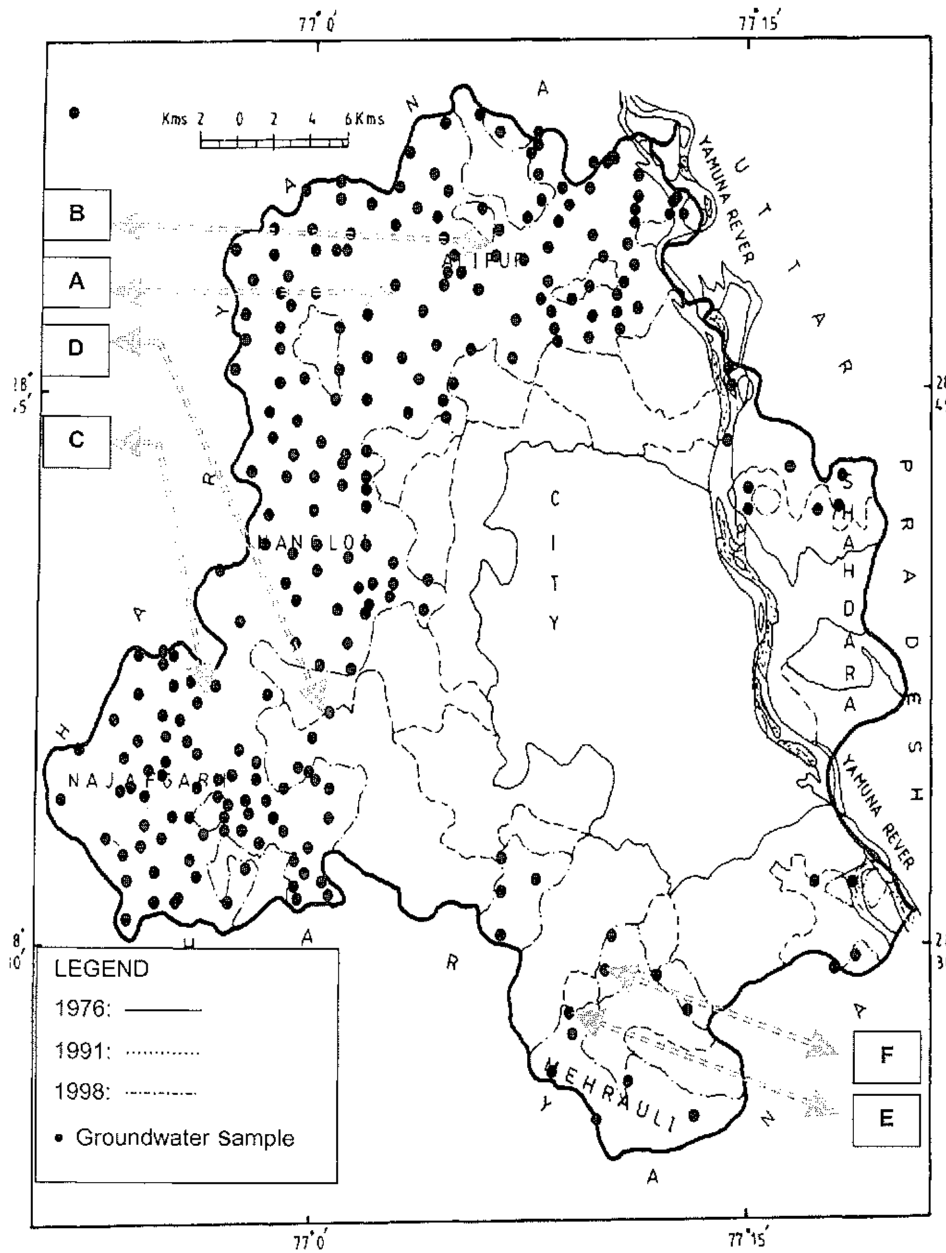


**Fig. 2** Map of Delhi State showing urban boundaries in 1976, 1991, and 1998 and groundwater sampling locations. B, D and F represent urban villages and A, C and E represent adjoining rural areas.

In Fig. 4, the villages that remained rural are A, C and E and those in the same areas that became urban are B, D and F. The change in groundwater solute concentrations of rural areas A and C is small from 1976 to 1998, except for potassium. Both these villages are located north and southwest of Delhi, wherein urban development occurs

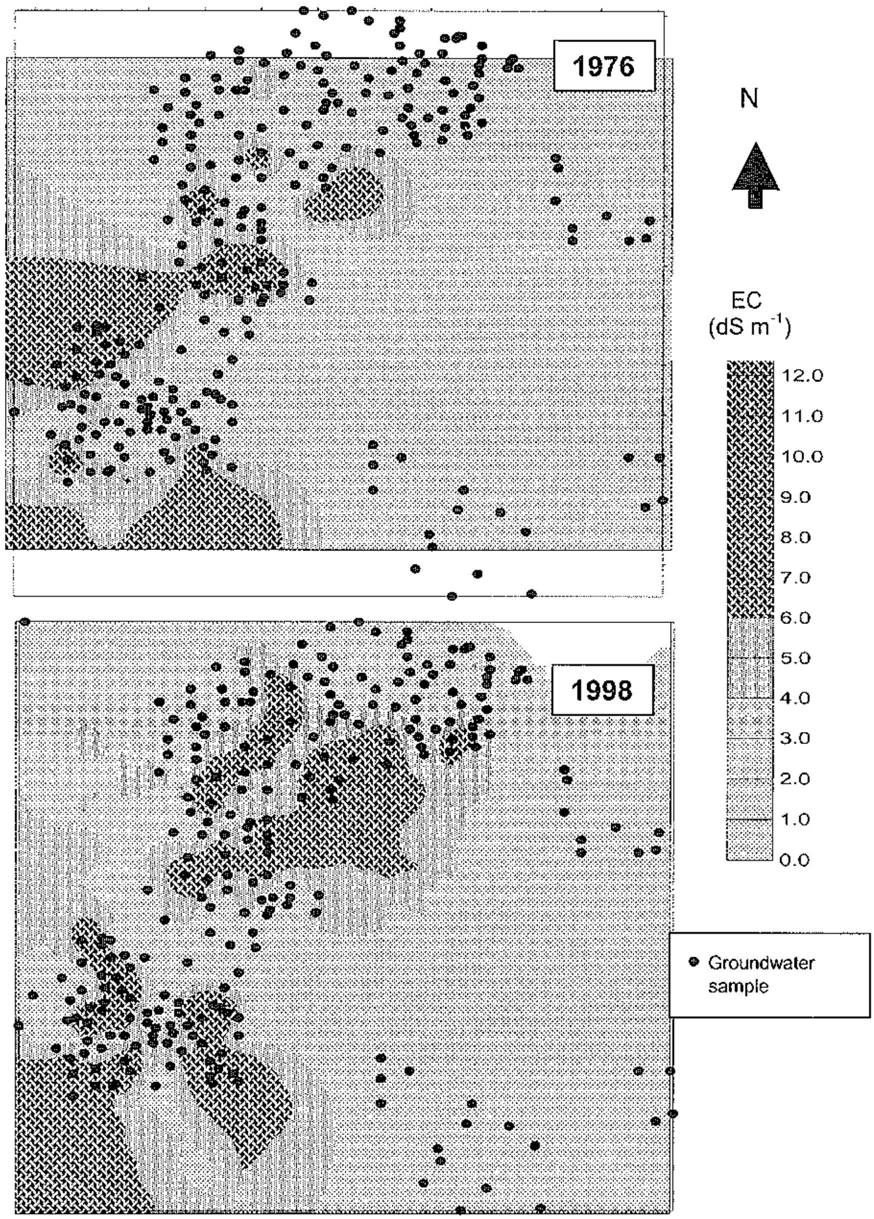


**Fig. 3** Variations of electrical conductivity of groundwater samples during 1976 and 1998 in Delhi State.

in small areas. In contrast, the change in groundwater solute concentrations of rural area E, located south of Delhi, is similar to that of an adjacent urbanized village (F).

The groundwater contamination map for Delhi State (Fig. 5) was constructed by overlaying the groundwater Fe, Cu and Mn concentrations and the associated toxicity levels of 5.0 mg $l^{-1}$ for Fe; 0.2 mg $l^{-1}$ for Cu and 0.2 mg $l^{-1}$ for Mn (FAO, 1985). Contaminated areas have been demarcated as: desirable, permissible and toxic.

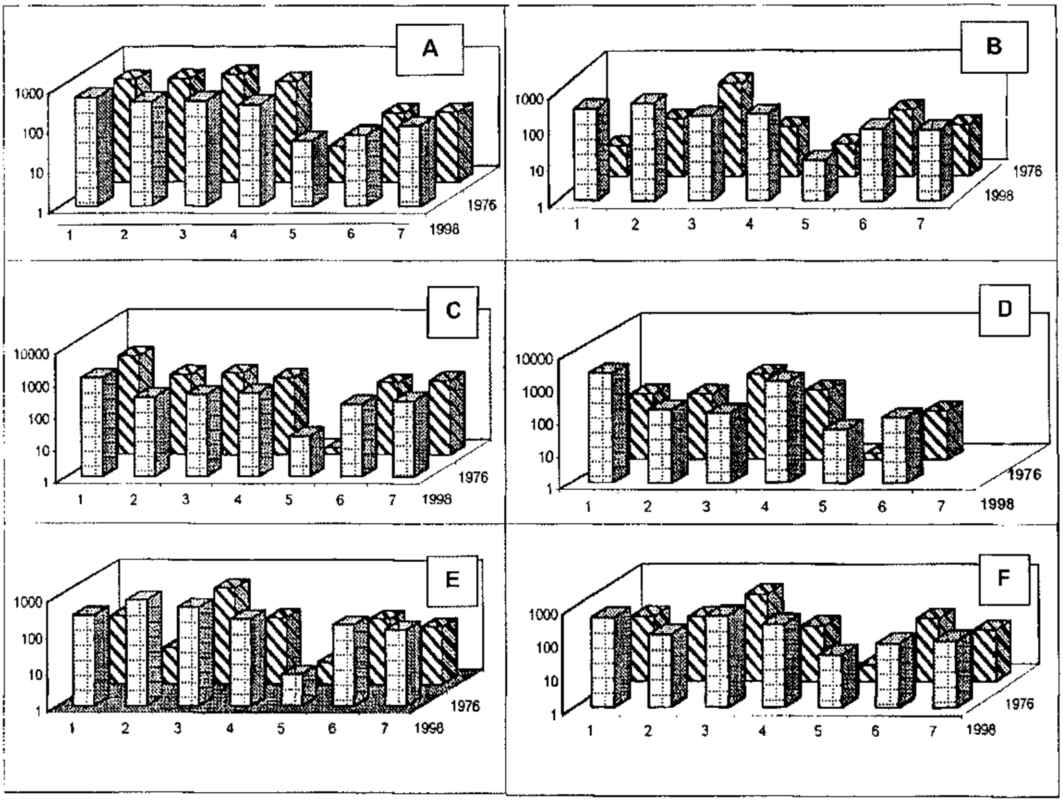


**Fig. 4** Variations of select hydrochemical parameters of rural (A, C and E) and urbanized (B, D and F) areas in Delhi State. *X*-axis: 1: chloride; 2: sulphate; 3: bicarbonate; 4: sodium; 5: potassium; 6: calcium; 7: magnesium. *Y*-axis: concentrations (mg $l^{-1}$) of ions (presented using log scale).

All possible combinations of the three constituents in groundwater are indicated on the map (Fig. 5). The results of this analysis indicate that the groundwater in the urbanized areas in the west and northwest of Delhi are toxic.

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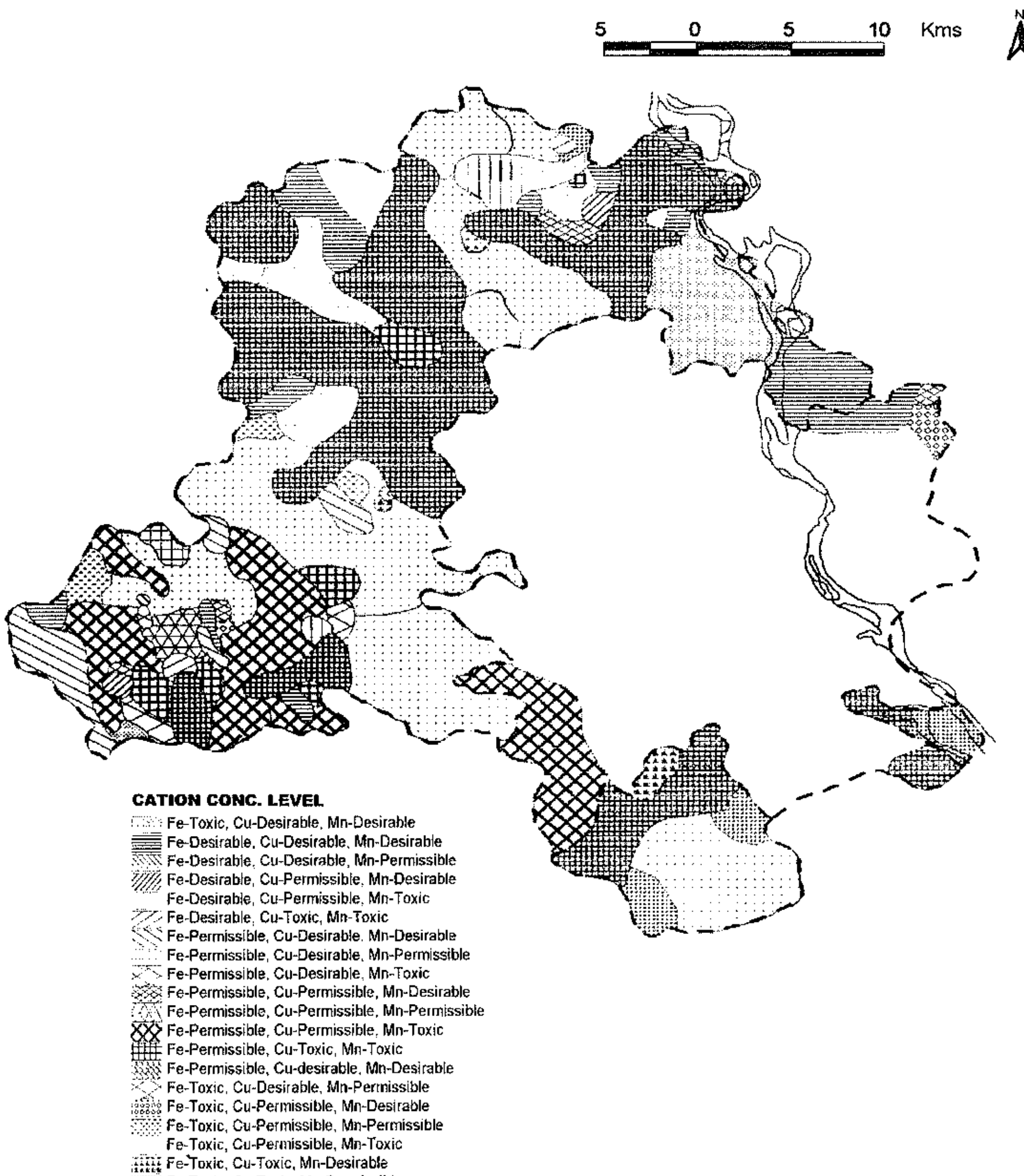


**Fig. 5** GIS map of heavy metals contamination based on variations in Fe, Cu and Mn ions in groundwater in Delhi State.

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