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Assessment of Ground Water Quality in Metropolitan Town of Meerut

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Abstract : Urban settlements and growing industrial development, combined with rapid increasing demand for water, are causing more and more water quality problems during recent years. India is also facing increasing scarcity of water and water quality degradation. Rapid urbanization and changing demand patterns would extenuate the problem further. The challenge of urban water management is multifaceted, but includes a lack of freshwater sources within feasible proximity to sustain water demand in many cities, especially the growing number of 'metropolitan cities'. The population density and intensity of economic uses of urban water also lead to water quality degradation that is often most critical in urban settings. There are 35 metropolitan cities as per 2001 census with a population of one million or more each. These 35 cities account for roughly one tenth of country's total population. There are 6 mega cities with a population of 5 million or more each indicating clear shift from rural to urban areas. It is estimated that by year 2050 about 60 70% of population will migrate to cities. With increasing urbanization, the problems associated with it are more visible. In this paper, an attempt has been made to present the status of ground water quality in metropolitan city of Meerut as part of comprehensive assessment of ground water quality mapping, its relative vulnerability for pollution control and identification of degraded water quality zones for quality improvement.

INTRODUCTION

Ground water forms the major source of water supply for drinking purposes in most part of India. For proper utilization of water for various purposes, understanding of geo chemical controls and study of the extent of ground water contamination are of prime importance. The increasing rate of urbanization place cities squarely in the center of the global water management challenge. Cities today account for 60% of all water allocated for domestic human use. With political power and money concentrated in the larger metropolitan areas, governments face growing pressures to reallocate water from other sectors (most notably agriculture) to meet growing urban demands.

The migration from rural areas to cities is inevitable as economy is now more industrial and service based and not agro based as in past. Further rural infrastructure is not adequate to cater the increasing population. As a consequence slums are increasing resulting in random expansion of cities and towns keeping aside town planning obligation of development. There is large scale migration to cities and town. In India, during 1901 there were 1827 urban agglomerations with a population of 25.85 million which was 10.84% of the then total population, whereas as per 2001 census there are 3768 urban agglomerations/ towns covering a population of 285.4 million which works out to about 27.8% of the country's population. As per the same census the metropolitan cities (population of one million and above) account for 37.8% of the total urban population of the country.

Urban settlements and growing industrial development, combined with rapid increasing demand for water, are causing more and more water quality problems during recent years. More than ninety percent of water quality problems in India are due to indiscriminate discharge of municipal wastes. These wastes being biodegradable produce a series of directional but predictable changes in water quality. Industrial effluents are responsible for pollution to a lesser extent but the effects produced by them may be more serious as nature is often unable to assimilate them. Agriculture is also responsible for degrading the water quality by generating runoff from animal husbandry units, which contain predominantly organic compounds from the use of mineral fertilizers and chemical pesticides.

Solid waste is one of the main sources of potential contamination of ground water in urban areas and surroundings. Disposal of waste on land has been practiced for centuries, which is subjected to reaction with percolating rain water and reaches the ground water level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the ground water. The problem of ground water pollution in several parts of the country has become so acute that unless urgent steps for detailed identification and abatement are taken, extensive ground water resources may be damaged.

The contamination of ground water by heavy metals has also assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today.

Until recently, the contamination of ground water in urban areas by pesticides has not been regarded as a potential problem; in fact the vast majority of pesticide studies have ignored wells in urban areas and have focussed exclusively on agricultural sources of pesticide and impacts on rural well water. There is no clear world-wide picture of the true nature and extent of pesticide contamination in ground water. The vast majority of countries do not include the common pesticides in routine analyses of ground water. In addition, there is no consensus on the health hazards posed by pesticides and what constitutes a safe level in drinking water. It was once believed that the vast majority of pesticides released into the subsurface would become immobilised in the upper levels of the soil or degrade before reaching the water table. This is clearly not the case. Where detailed studies have been undertaken, notably in the United States, they often reveal widespread degradation of ground water, albeit at very low concentrations.

With rapid increase in population and growth of industrialization, ground water quality is being increasingly threatened by agricultural chemicals and disposal of urban and industrial wastes. It has been estimated that once pollution enter the subsurface environment, it may remain concealed for many years, becoming dispersed over wide areas of ground water aquifer and rendering ground water supplies unsuitable for consumption and other uses. The rate of depletion of ground water levels and deterioration of ground water quality is of immediate concern in major cities and towns of the country (Khurshid et al., 1997; Das et al., 1998; Garode et al., 1998; Kapley et al., 1998; Naidu et al., 1998; Jain et al., 2000a,b,c; Sohani et al., 2001; Jain, 2002; Jain et al., 2003a,b,c; Meenakumari and Hosmani, 2003; Dhindsa et al., 2004; Jain, 2004a,b,c; Jain et al., 2004; Ramasubramanian et al., 2004).

METROPOLITAN CITIES

There are 35 metropolitan cities as per 2001 census with a population of one million or more each (Table 1). These 35 cities account for roughly one tenth of country's total population. It is estimated that by year 2050 about 60 70% of population will migrate to cities. With increasing urbanization, the problems associated with it will be more critical in terms of environmental degradation including ground water quality. In earlier reports, we have

Table 1. Metropolitan Cities

S.No.	Metropolitan City	Dsitrict	State	Civic Status	Population
1.	Greater Mumbai	Mumbai	Maharashtra	UA	16368084
2.	Kolkata	Kolkata	West Bengal	UA	13216546
3.	Delhi	Delhi	Delhi	UA	12791458
4.	Chennai	Chennai	Tamil Nadu	UA	6424624
5.	Banglore	Banglore	Karnataka	UA	5686844
6.	Hyderabad	Ranga Reddi	Andhra Pradesh	UA	5533640
7.	Ahmedabad	Ahmedabad	Gujarat	UA	4519278
8.	Pune	Pune	Maharashtra	UA	3755525
9.	Surat	Surat	Gujarat	UA	2811466
10.	Kanpur	Kanpur	Uttar Pradesh	UA	2690486
11.	Jaipur	Jaipur	Rajasthan	MC	2324319
12.	Lucknow	Lucknow	Uttar Pradesh	UA	2266933
13.	Nagpur	Nagpur	Maharashtra	UA	2122965
14.	Patna	Patna	Bihar	UA	1707429
15.	Indore	Indore	Madhya Pradesh	UA	1639044
16.	Vadodara	Vadodara	Gujarat	UA	1492398
17.	Bhopal	Bhopal	Madhya Pradesh	UA	1454830
18.	Coimbatore	Coimbatore	Tamil Nadu	UA	1446034
19.	Ludhiana	Ludhiana	Punjab	MC	1395053
20.	Kochi	Ernakulam	Kerala	UA	1355406
21.	Visakhapatnam	Visakhapatnam	Andhra Pradesh	UA	1329472
22.	Agra	Agra	Uttar Pradesh	UA	1321410
23.	Varanasi	Varanasi	Uttar Pradesh	UA	1211749
24.	Madurai	Madurai	Tamil Nadu	UA	1194665
25.	Meerut	Meerut	Uttar Pradesh	UA	1167399
26.	Nasik	Nasik	Maharashtra	UA	1152048
27.	Jabalpur	Jabalpur	Madhya Pradesh	UA	1117200
28.	Jamshedpur	Singhbhum	Jharkhand	UA	1101804
29.	Asansol	Barddhaman	West Bengal	UA	1090171
30.	Dhanbad	Dhanbad	Jharkhand	UA	1064357
31.	Faridabad	Faridabad	Haryana	MC	1054981
32.	Allahabad	Allahabad	Uttar Pradesh	UA	1049579
33.	Amritsar	Amritsar	Punjab	UA	1011327
34.	Vijayawada	Krishna	Andhra Pradesh	UA	1011152
35.	Rajkot	Rajkot	Gujarat	UA	1002160
UA - Urban Agglomeration/City (10,00,000 + population)					
MC - Municipal Corporation					

reported the ground water quality in several metropolitan cities of the country (Jain, 2003a,b, 2004a,b,c,d, 2005).

METROPOLITAN CITY MEERUT

The metropolitan city of Meerut is one of the important industrial towns of the western Uttar Pradesh. The city occupies an area of about 142 km^2 and lies between 28°57' to 29°02' N latitude and 77°40' to 77°45' E longitude (Fig. 1). It is the 25th largest town in India (population wise), and the 5th largest town in Uttar Pradesh after Kanpur, Lucknow, Agra and Varanasi. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of Meerut (including cantonment area) is 11,67,399.

The two important rivers of the area are Yamuna and Hindon, which flow from north to south. The river Ganga and the river Yamuna forms the eastern and the western boundaries of the area. The other important rivers flowing in the area are Kali and Krishni. These rivers are effluent in nature, i.e., ground water is discharged into the rivers. These rivers carry base flow from ground water storage during the non-monsoon season. Apart from these rivers, the Upper Ganga Canal also drains the area.

Water requirement for Meerut city is mainly met from ground water. There are 20 over head tanks having a total capacity of 20,000 KL and 3 under ground water tanks having a total capacity of 16,000 KL. The total water supply to the city is about 154 mld through Nagar Nigam and covers most of the localities within the municipal area. The municipal area has been divided in to 70 wards for water supply distribution.

The total municipal waste water generation in the city is about 35 mld. Only 30% area is covered through sewerage system. In other parts of the city, people are using septic tanks and soak pits. In most of the places sewage is discharged into six major drains (Abu Nala, Suraj Kund Nala, Odian Road Nala, Clock Tower Nala, Bachcha Park Nala and Kishanpur Nala) without any treatment. These drains discharge both domestic and industrial waste water from densely populated city areas and ultimately join river Kali. The city has no sewage treatment plant.

The approximate solid waste generation in Meerut city is around 600 MT/day. The solid waste disposal in Meerut is not thoroughly systematic and the solid waste is dumped at low-lying areas. The solid waste from house holds and industries is dumped near the roads, parks or in municipal dalaos, from where it ultimately reaches to sanitary land fill at Kamela (opposite Karim Nagar), a place outside the Meerut municipal area on Hapur road. There is no proper system of monitoring the dumping activities.

It is estimated that there are approximately 14,000 registered industrial units in the metropolitan city of Meerut, out of which only about 9,000 units are functional at present. Most industries are located in Mukampur, Udyog Puram, Sports Complex and Partapur Industrial Estate. Distillery and small scale industries like sports goods, chemicals, food processing, surgical goods, engineering works, petrochemicals, rubber, plastic, leather goods, flour mills and readymade garments predominate in the area.

There are three petroleum storages (IOCL, HPCL and BPCL) existing in Partapur Industrial Estate and Maqbara Diggi (Kesar Ganj). The total number of petrol pump of different agencies in the metropolitan city is 38.

WATER QUALITY PROTOCOL

The Ministry of Environment and Forests vide its Notification S.O. 2151 dated 17th June 2005 issued Uniform Protocol on Water Quality Monitoring in order to maintain uniformity in the procedure for water quality monitoring mechanism by all monitoring agencies, departments, Pollution Control Boards and such other agencies so that

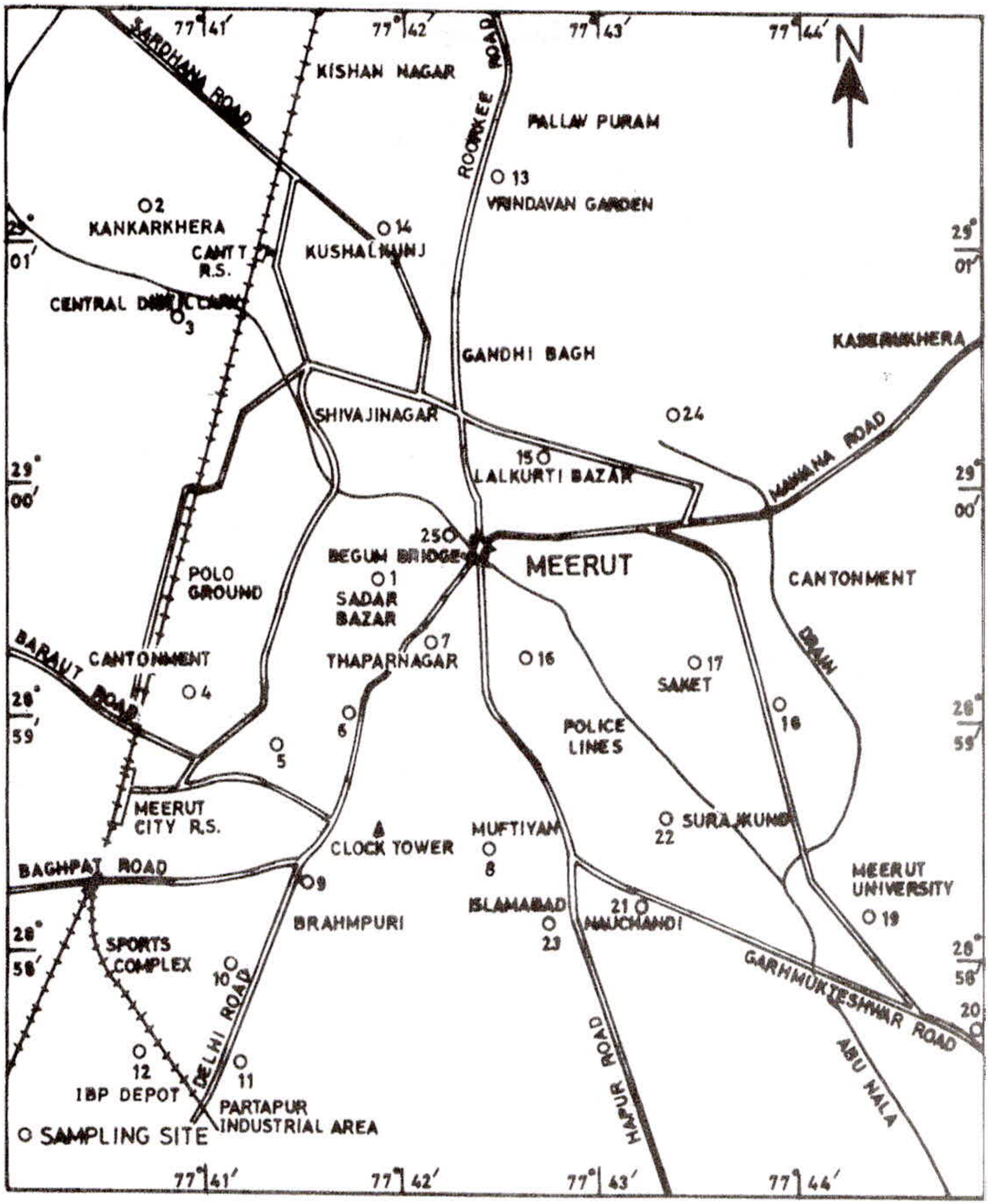

Fig. 1. Metropolitan City Meerut

water related action plans may be drawn up on the basis of reliable data. It applies to all organizations, agencies and any other body monitoring surface and ground water quality for observance of uniform protocol on water quality monitoring.

The frequency of sampling and parameters for analysis in respect of ground water samples are given in Table 2. All ground water stations are classified as Baseline Stations and 20-25% of Baseline Stations shall be classified as Trend Stations where there is a perceived problem. As per the Water Quality Protocol, all agencies are required to follow the sampling frequency and parameters for analysis of ground water as mentioned in Table 2.

METHODOLOGY

The ground water quality of the Metropolitan Cities has been assessed to see the suitability of ground water for domestic and irrigation applications. Ground water samples were collected during pre- and post-monsoon seasons and analysed for various physico-chemical and bacteriological parameters, heavy metals,

Table 2. Frequencies and parameters for analysis of ground water samples

Type of Station	Frequency	Parameters
Baseline	Twice a year (Pre and post-monsoon)	A. Pre and post-monsoon season: Analyse 20 parameters as listed below: a. General: Colour, Odour, Temp., pH, EC, TDS b. Nutrients: $NO_2 + NO_3$, Orthophosphate c. Demand Parameter: COD d. Major Ions: Na^+, K^+, Ca^{++}, Mg^{++}, CO_3^{--}, HCO_3^-, Cl^-, SO_4^{--}, %Na & SAR e. Other inorganics: F, B and other location specific parameters, if any.
Trend	Twice a year (Pre and post-monsoon)	A. April-May: Analyse 20 parameters as listed for Baseline monitoring B. Other times: Analyse 14 parameters as below: a) General: Colour, Odour, Temperature, EC, pH, TDS, %Na & SAR b) Nutrients: NO2 + NO3, orthophosphate c) Demand parameter: COD d) Major ions: Cl e) Other inorganics: F,B f) Microbiological: Total coliform and Faecal coliform C. Micropollutant (parameters may be selected based on local need): a) Pesticides- Alpha BHC, Beta BHC, Gama BHC (Lindane), OP-DDT, PP-DDT, Alpha Endosulphan, Beta Endosulpham, Aldrin, Dieldrin, 2, 4-D, Carbaryl (Carbamate), Malathian, Methyl, Parathian, Anilphos, Chloropyriphos. b) Toxic Metals – As, Cd, Hg, Zn, Cr, Pb, Ni, Fe *(Pesticides and toxic metals may be analysed once a year in pre-monsoon season on selected locations)*

Source: Census of India, 2001

pesticides and polynuclear aromatic hydrocarbons (APHA, 1992). The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content. An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram and U.S. Salinity Laboratory Classification.

RESULTS AND DISCUSSION

The pH values in the ground water of metropolitan city of Meerut are mostly confined within the range 6.65 to 7.40 during pre- as well as post-monsoon season and lies well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water. The conductivity values vary from 389 to 1447 mS/cm during pre-monsoon season and 360 to 1350 mS/cm during post-monsoon season with about 20% samples having conductivity value above 1000 mS/cm during both pre- and post-monsoon seasons. The TDS values in the ground water varies from 249 to 926 mg/L during pre-monsoon season and 230 to 864 mg/L during post-monsoon season indicating low mineralization in the area. Sixty percent of the samples analysed were found within the desirable limit of 500 mg/L while 40% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L. The TDS content at deeper levels (>40 m depth) is comparatively low and lies well within desirable limit of 500 mg/L. The TDS distribution map for the pre-monsoon season is shown in Fig. 2. Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991). No sample of the metropolitan city crosses the maximum permissible limit of 2000 mg/L.

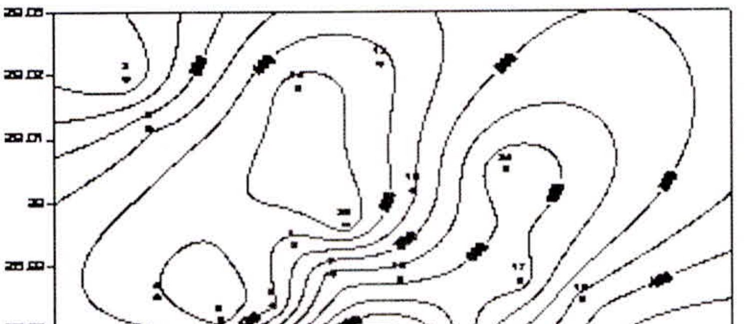

Fig. 2. TDS Distribution Map

The alkalinity value in the ground water varies from 124 to 282 mg/L during pre-monsoon season and 121 to 279 mg/L during post-monsoon season. More than 50% of the sample of the study area falls within the desirable limit of 200 mg/L both during pre- and post-monsoon season. About 40 to 50% of the samples crosses the desirable limit but are within the maximum permissible limit of 600 mg/L. No sample of the study area crosses the maximum permissible limit of 600 mg/L. The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. The total hardness values in the study area range from 98 to 239 mg/L during pre-monsoon season and 86 to 236 mg/L during post-monsoon season. All the samples of the metropolitan city were found well within the desirable limits for domestic applications during both pre- and post-monsoon seasons. The values of calcium and magnesium range from 23 to 58 and 8.3 to 25 mg/L respectively during pre-monsoon season. Slight lower values of calcium and magnesium were observed during the post-monsoon season due to dilution effect of rain water. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons.

The concentration of sodium in the study area varies from 22 to 128 mg/L during pre-monsoon season and 21 to 130 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values at certain locations may be attributed to base-exchange phenomena. Ground water with high sodium is not suitable for irrigation due to sodium sensitivity of crops/plants. The concentration of potassium in ground water of the metropolitan city of Meerut varies from 5.1 to 128 mg/L during pre-monsoon season and 4.8 to 170 mg/L during post-monsoon season. The maximum concentration of potassium was observed at Muftiyan. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, 28% samples crosses the guideline level of 10 mg/L in the metropolitan city. Though potassium is extensively found in some of igneous and sedimentary rocks, its concentration in natural waters is usually quite low. This is due to the fact that potassium minerals offer resistance to weathering and dissolution. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 3.7 to 59 mg/L during pre-monsoon season. Almost similar trend was observed during the post-monsoon season. The chloride content in ground water of the metropolitan city is quite low. No sample in the study area crosses the desirable limit of 250 mg/L. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit for drinking water supplies (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride.

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 10 to 150 mg/L during pre-monsoon season and 9.0 to 140 mg/L during post-monsoon season. It is clearly evident from the results that all the samples of the metropolitan city fall within the desirable limit of 200 mg/L for drinking water supplies.

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Meerut varies from 0.44 to 209 mg/L during pre-monsoon season and 0.2 to 168 mg/L during post-monsoon season. Out of the total 25 samples analysed, 18 samples (72%) shows nitrate content less than the desirable limit of 45 mg/L, while 28% samples crosses the desirable limit of 45 mg/L. About 15% sample even crosses the maximum permissible limit of 100 mg/L. The nitrate distribution map for the pre-monsoon season is shown in Fig. 3. The higher level of nitrate at certain locations (Thapar Magar, Muftiyan, Bharampuri and Islamabad) may be attributed to the surface disposal of domestic sewage in the region.

The concentration of phosphate in the metropolitan city of Meerut is generally low at all the locations except at Mufttiyan, where concentration exceeds 1.0 mg/L. The higher

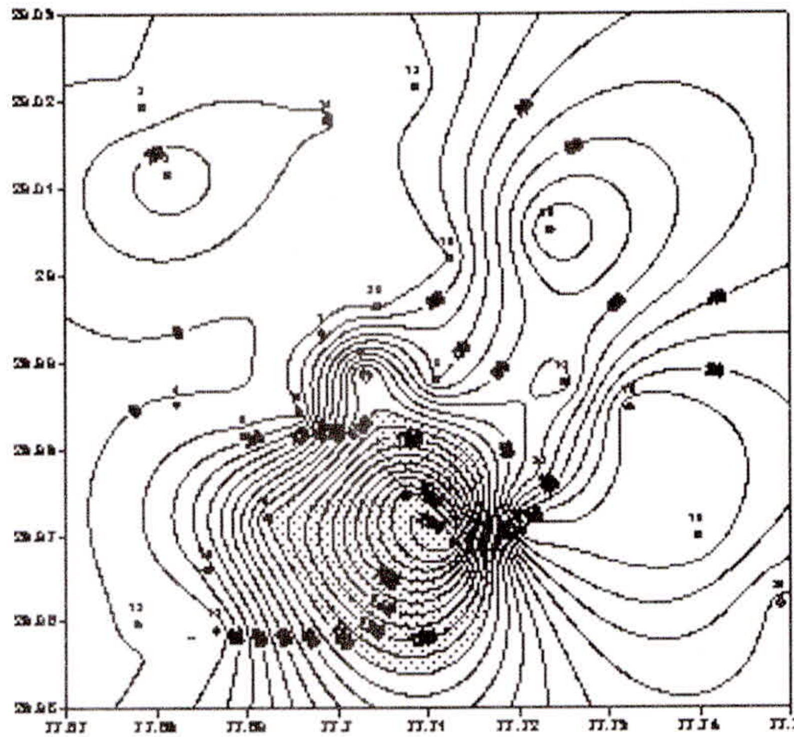

Fig. 3. Nitrate Distribution Map

concentration of phosphate at Mufttiyan may be attributed to physico-chemical processes undergoing in soil-strata due to influence of extraneous influence from surface discharges. Inadequate maintenance of hand pump, improper sanitation and unhygienic conditions in the area may also be responsible for higher concentration of phosphate in this particular sample. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.20 to 1.20 mg/L during pre-monsoon season and 0.20 to 1.30 mg/L during post-monsoon season and lies well below the permissible limit of 1.0 mg/L except in one hand pump sample located in the Sports Complex. The fluoride distribution map for the pre-monsoon season is shown in Fig. 4. The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities.

The study has clearly indicated that the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 40% of the samples analyzed but the values are well within the maximum permissible limit of 2000 mg/L in all the samples. The alkalinity values exceeds the desirable limit of 200 mg/L in about 45% of the

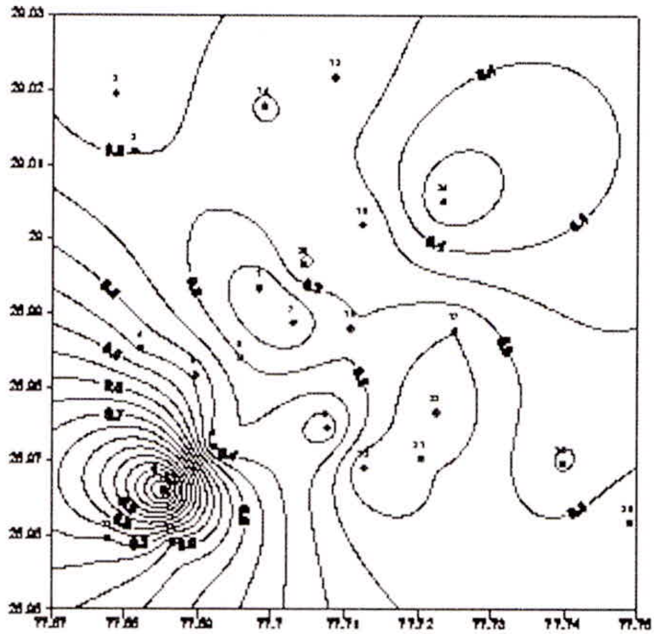

Fig. 4. Fluoride Distribution Map

samples but the values are well within the maximum permissible limit of 600 mg/L. The total hardness values for all the samples are well within the desirable limit of 300 mg/L. The nitrate content even exceeds the maximum permissible limit of 100 mg/L in about 15% of the samples analyzed. The fluoride content exceeds the desirable limit of 1.0 mg/L in one sample at Sports Complex. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit of sodium and potassium has been prescribed in BIS drinking water specifications.

Bacteriological Examination

The coliform group of bacteria is the principal indicator of suitability of water for domestic, industrial or other uses. The density of coliform group is the criteria for the degree of contamination and has been the basis for bacteriological water quality standard. In ideal situation all the samples taken from the distribution system should be free from coliform organisms but in practice, it is not attainable always and therefore, following standard for water has been recommended (BIS, 1991):

- 95% of water samples should not contain any coliform organisms in 100 ml throughout the year.
- No water sample should contain E.Coli in 100 ml water.
- No water sample should contain more than 10 coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

However, from bacteriological considerations, the objectives should be to reduce the coliform count to less than 10 per 100 ml and more importantly the absence of faecal coliform should be ensured. The presence of coliforms in water is an indicator of contamination by human or from animal excrement. The presence of faecal colifirms in ground water indicates a potential public health problem, because faecal matter is a source of pathogenic bacteria and viruses. The ground water contamination from faecal coliform bacteria is generally caused by percolation from contamination sources (domestic sewage and septic tank) into the aquifers and also because of poor sanitation. Shallow wells are particularly susceptible for such contamination. The indiscriminate land disposal of domestic waste on surface, improper disposal of solid waste, leaching of waste water from landfill areas, further aggravate the chances of bacterial contamination in ground water.

The bacteriological examination of the samples collected from the metropolitan city of Meerut does not indicate any sign of bacterial contamination except in one hand pump sample of Islamabad locality. Inadequate maintenance of hand pump, improper sanitation and unhygienic conditions around the structure may be responsible for bacterial contamination in this particular sample. Aquifer may be free from coliform organisms.

Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The distribution of different metals is shown graphically in Fig. 5.

Iron (Fe): The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5. The Bureau of Indian Standards has recommended 300 ìg/L as the desirable limit and 1000 ìg/L as the maximum permissible limit for drinking water (BIS, 1991). The increase of iron concentrations during post-monsoon season may be due to mixing phenomena of recharge water, which is having more oxygen to react with iron ore, which may be available in clay lenses in the aquifer. Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous (Fe^{2+}) and Ferric (Fe^{3+}) forms.

Manganese (Mn): The concentration of manganese recorded a maximum level of 523 ìg/L during pre-monsoon season and 362 ìg/L during post-monsoon season. The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 ìg/L has been recommended as a desirable limit and 300 ìg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures. It is evident from the results that only about 40% of the samples of the metropolitan city fall within the desirable limit of 100 ìg/L and 52% samples crosses the desirable limit but are well within permissible limits. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

Copper (Cu): The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5. The Bureau of Indian Standards has recommended 50 ìg/L as the desirable limit and 1500 ìg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 ìg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 ìg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city, 88% of the samples fall below the desirable limit of 50 ìg/L and remaining 12% samples crosses the desirable limit but are within the maximum permissible limit. As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High

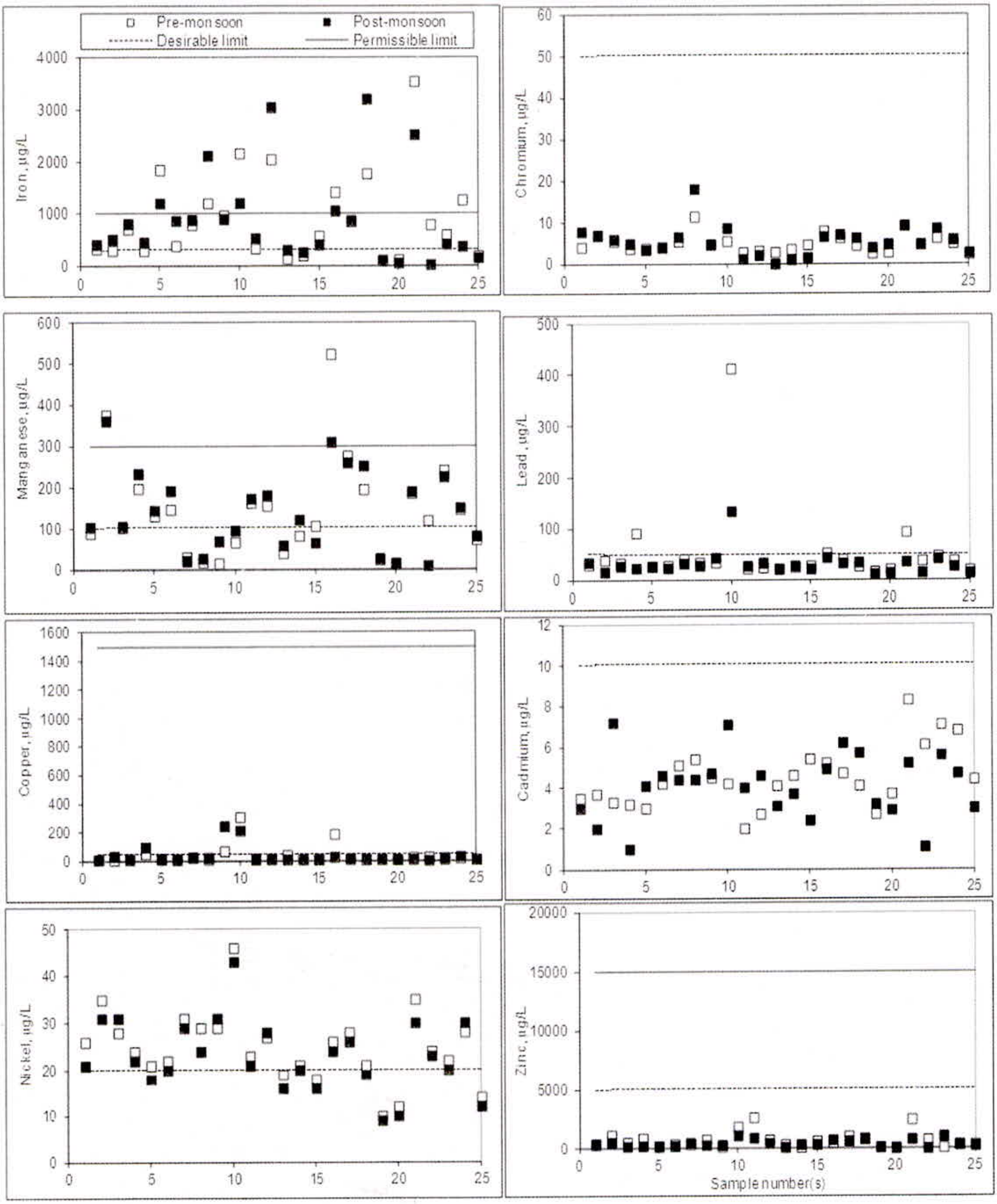

Fig. 5. Distribution of Metal Ions at Different Sites

intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

Nickel (Ni): The distribution of nickel at different sites during pre- and post-monsoon season is shown in Fig. 5. World Health Organization has recommended 20 ìg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Meerut, 80% samples crosses the WHO limit of 20 ìg/L during pre-monsson season and 60% samples during post-monsoon season. The violation of BIS limit could not be ascertained as no permissible limit of nickel has been prescribed in BIS drinking water specifications. Nickel at trace level is essential to human nutrition and no systemic poisoning from nickel is known in this range. The level of nickel usually found in food and water is not considered a serious health hazard. Some of the important nickel minerals include Garnierite, nickeliferous limonite and pentiandite. Certain nickel compounds have carcinogenic effects on animals, however, soluble compounds are not currently regarded as human or animal carcinogens.

Chromium (Cr): The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5. A concentration of 50 ìg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 ìg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Meerut, all the samples fall well within the desirable limit for drinking water. The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

Lead (Pb): The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5. The Bureau of Indian Standards has prescribed 50 ìg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Meerut, 84% of the samples fall within the permissible limit for drinking water during pre-monsoon season and 96% of the samples during post-monsoon season and therefore the ground water of city can be safely used as a source of drinking water supplies. Four samples during the pre-monsoon season and one sample during the post-monsoon season recorded higher concentration of lead than the permissible limit. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

Cadmium (Cd): Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5. The Bureau of Indian Standards has prescribed 10 ìg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed

3 ìg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Meerut, all the samples were found within the desirable limit of 10 ìg/L as prescribed by BIS. It is obvious, therefore, that the ground water of the metropolitan city does not present any cadmium hazards to humans. The levels of cadmium in public water supplies are normally very low since generally only small amounts exist in raw water and many conventional water treatment processes remove much of the cadmium.

Zinc (Zn): The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5. The Bureau of Indian Standards has prescribed 5000 ìg/L zinc as the desirable limit and 15000 ìg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 ìg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Meerut, all the samples analysed were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

The heavy metals in ground water except iron and nickel, which are present in appreciable concentration in ground water, have been below the prescribed maximum permissible limits in most of the samples (>80%). The concentration of iron varies from 112 to 3543 ìg/L during pre-monsoon season and 22 to 4638 ìg/L during post-monsoon season as against the maximum permissible limit of 1000 ìg/L while that of nickel vary from 10 to 46 ìg/L during pre-monsoon and 9 to 43 ìg/L during post-monsoon season as against the 20 ìg/L. The concentration of copper, chromium, cadmium and zinc were found well within the permissible limits in all the samples of the metropolitan city.

Recommendations

1. All the ground water extraction structures should be registered and regulated to avoid over exploitation and deterioration of ground water quality.

2. The water obtained from the ground water structures should be tested and analysed to ensure the suitability of ground water for human consumption.

3. The ground water abstraction sources and their surroundings should be properly maintained to ensure hygienic conditions and no sewage or polluted water should be allowed to percolate directly to ground water aquifer.

4. Proper cement platforms should be constructed surrounding the ground water abstraction sources to avoid direct well head pollution.

5. The surrounding surface area of the ground water abstraction structures should be frequently chlorinated by use of bleaching power.

6. Possibilities of construction of artificial recharge structures should be explored to augment the ground water recharge.

7. The hand pumps, which have been identified as having suspected water quality should be painted red to indicate and warn the public that the water drawn from the source is not fit for human consumption.

8. In the absence of alternate safe source of water, the water with excessive undesirable constituents must be treated with specific treatment process before its usé for human consumption.

9. The defluoridation treatment option (activated alumin or Nalgonda technique, domestic level) should be undertaken in ground water drawn from sources exceeding the permissible limit of 1.5 mg/L.

10. Treatment option for nitrate should be undertaken in ground water drawn from sources exceeding the permissible limit of 100 mg/L.

11. The ground water drawn from hand pumps

should be properly chlorinated to eradicate the presence of bacterial contamination.

12. The untreated sewage and sewerage flowing in various open drains are one of the causes of ground water quality deterioration. Proper under ground sewage system must be laid in all inhabited areas and the untreated sewage and industrial wastes should not be allowed to flow in open drains.
13. A proper system of collection and transportation of domestic waste should be developed. Land fill site(s) should be identified and it must be scientifically designed. Ground water quality near land fill sites should be regularly monitored.
14. The mass awareness should be created about quality of water, its effect on human health and responsibilities of public to safeguard water resources.

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