CHAPTER III

FINDINGS: METRO-CITIES OF INDIA

3.1 Metropolitan Cities of India:

Metro-cities are those cities having population more than one million & above. As per 2001 census there are 35 metro cities in India. The metropolitan cities along with area and population are presented in Table 6.

Table 6: PROFILE OF METROPOLITAN CITIES OF INDIA

CITIES	AREA (sq.km)	POPULATION IN THOUSAND
Greater Mumbai	437.71	16,368,084
Kolkata	187	13,216,546
Delhi	862.18	12,791,458
Chennai*	170	6,424,624
Bangalore	125.9	5,686,844
Hyderabad	172.68	5,533,640
Ahemadabad	190.94	4,519,278
Pune	198.00	3,755,525
Surat	111.16	2,811,466
Kanpur	NA	2,690,486
Jaipur	200.4	2,324,319
Lucknow*	310.1	2,266,933
Nagpur	217.17	2,122,965
Patna	99.45	1,707,429
Indore	130.17	1,639,044
Vadodara	108.26	1,492,398
Bhopal	284.9	1,454,830
Coimbatore*	314.84	1,446,034
Ludhiana*	134.67	1,395,053
Kochi	39.58	1,355,406
Vishakhapatnam	78.33	1,329,472
Agra*	NA	1,321,410
Varanasi	83.6	1,211,749
Madurai*	115.48	1,194,665
Meerut*	NA	1,167,399
Nashik	NA	1,152,048
Jabalpur	NA	1,117,200
Jamshedpur	NA	1,101,804
Asansol	NA	1,090,171
Dhanbad	NA	1,064,357
Faridabad	NA	1,054,981
Allahabad	NA	1,049,579
Amritsar	NA	1,011,327
Vijayawada*	NA	1,011,152
Rajkot	NA	1,002,160

Area: 1991and Population figures 2001 Census, The cities marked as starred taken for the study in this report.

In this report study results with respect to eight Metropolitan cities have been presented. The results are summarised below:

3.2 Agra Metropolitan city

3.2.1 Environmental Profile of Agra:

Topography/Location: The metropolitan city of Agra is one of the important industrial towns of north central India. It is situated about 200 km southeast of Delhi. The metropolitan city of Agra occupies an area of about 140 km^2 and lies between $27^o8'$ to $27^o14'$ N latitude and $77^o57'$ to $78^o04'$ E longitude. It is the 22^{nd} largest town in India (population wise), and the 3^{rd} largest town in Uttar Pradesh after Kanpur and Lucknow The urban area of Agra is divided into Nagar Mahapalika (renamed as Municipal Corporation in 1994), Agra Cantonment Area and the Dayalbagh and Swamibagh Panchayat. The municipal area is further divided into three parts, viz., the main city, the Trans Yamuna and the Tajganj. The city map is shown in figure 2.

Population: The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Agra (including cantonment area) is 13,21,410.

Climate: The study area is a characterized by semi-arid area bounded by Thar Desert on its southwest, west and northwest peripheries. The maximum temperature is attained upto 47°C in summer months (May to June) and minimum temperature as low as 3°C in winter. The average rainfall in the region is 685 mm. The city experiences extreme hot summers and extreme cold winter. The climate of the city experiences a typical extreme climate as of the plains of Uttar Pradesh. All seasonal climatic changes e.g. temperature; rainfall, wind-pattern etc. are observed throughout the year, particularly high temperature during the summer, cold weather during winters and sufficient rains in the monsoon.

Water Supply: Most of the water supply of the Agra city is met from river Yamuna. The water is taken directly from the river Yamuna by diverting its flow and pumping from the three intake wells at the Agra Water Works located on the right bank of the river Yamuna. There are two water works i.e. Jiwani Mandi & Sikandara. Treatment of the raw water includes sedimentation, filtration and chlorination. Total 225 mld of treated water is being served through 11 zonal pumping stations in which 200 mld goes to the city residents and 25 mld goes to MES, Railways, Air Force and Cantonment. The water supply covers most of the localities within the municipal area. However, most parts of the wards of Sikandra II, Bodla II & III, Shahganj III, Tajganj II & III, Trans Yamuna II and Ghawasan II are not covered by piped water supply. Out of the total water of 225 mld, 40% is lost in transmission and distribution. Hence the actual water available is about 120 mld, which comes out to be 100 lpcd whereas the requirement is 150 lpcd. There is a shortage of about 60 mld. The demand for water supply will grow by additional 20 mld by 2011. The local residents through bore wells and hand pumps currently augment water supply with groundwater. For administrative purposes, the water supply is divided into three major zones, viz., Surya Nagar - Zone I, Loha Mandi - Zone II and Taj Ganj - Zone III. The three major zones are further divided into 26 minor zones including cantonment. Out of the 26 zones, 15 zones are developed and rests of them are undeveloped.

Wastewater Management: The total sewage generated in the city is 128.6 mld. The city has three sewage treatment plants. The total area available for sewage farming is 800 Ha of which only 300 Ha is being irrigated by sewage. The Agra city has a severe sewage problem. Most of the city does not have sewerage system. The sewage is found flowing along the roads into the open drains and the total wastewater of the Agra city flows into river Yamuna through local drains. Some of the areas are even not drained and hence leading to stagnation of sewage. In the absence of sewerage system, people are using septic tanks and soak pits. In most of the places sewage is discharged into open drains without any treatment, which ultimately discharge to river Yamuna. River Yamuna in its course of 10 km in the city of Agra receives wastewater discharge through 28 points. The major contributor to the water pollution for BOD load is Mantola drain followed by Bhairon and Water Works Nala. These drains discharge both domestic and industrial wastewater from densely populated old city areas. In Trans Yamuna, the Etmadullah and the Narich drains are the major contributors and mainly carry discharges from industrial areas.

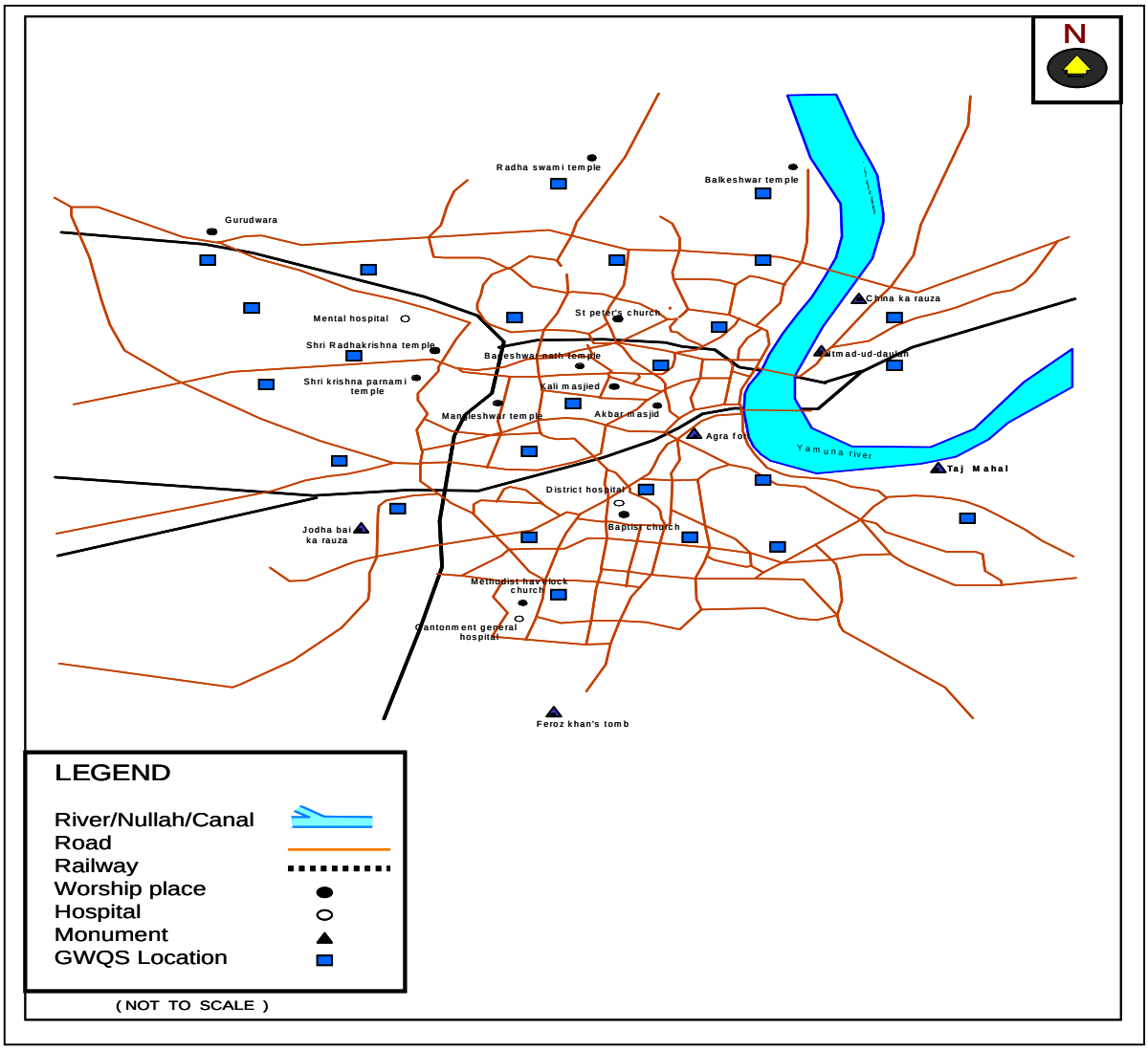


Figure 2: Map of Agra City

Municipal Solid Waste: The municipal solid waste generated is about 644 t/day. The Agra Nagar Nigam is facing serious shortage of waste transportation vehicles and facilities such as garages and workshops needed to maintain and repair the vehicle. The Nagar Nigam has only 47 vehicles including tractors, tippers, loaders and refuse collectors of which only 29 are in working condition. As a result, only 50% of the city waste is being transported and disposed by the Nagar Nigam daily. Due to the shortage of vehicles, many wards are not attended for days together, leading to the accumulation of the solid waste. In fact, it appeared that in many wards 60 to 80% wastes are never collected. The solid waste is also being dumped irregularly in many areas, even in residential colonies, along the highways or even in parks. The metropolitan city of Agra has only one disposal site at Shahdara near Jharna nallah, a place outside the Agra Municipal area on Agra-Firozabad road. There is no system of monitoring the dumping activities. Sweepers are also resorting to open burning due to shortage of handcarts and inadequate capacity of the bins. The landfill site at Shahdara is already filled up. According to Nagar Swastha Adikari, no area has been identified for development of any sanitary landfill in future.

Industries: There are 73 industries and 2 industrial clusters, which discharges their effluent into the river. Of these industries, only 64 industries have effluent treatment plants. The metropolitan city of Agra has the status of an important place in India in production of various handicraft items like Zari work, leather craft, and marble craft and carpet craft. Today the Agra district has 6,463 small-scale units, out of which a majority is located in Agra city. The small-scale units are mushroomed in the older city area. The estimated quantity of hazardous waste from the city is about 100 t/year from electroplating, chemical industries and the foundry units. Industrial sector of the metropolitan city comprises of textiles, hosiery items, woolen, jute, footwear, leather, metal processing, machinery parts, marble, food processing and handicrafts. There are two petroleum storages existing in Idgah Colony area, one of Bharat Petroleum Corporation Ltd. (BPCL) and the other one of Indian Oil Corporation Ltd. (IOCL). The total number of petrol pump of different agencies in the metropolitan city is 46.

Geology & Soil: The soil of Agra is loose, sandy and calcareous. The river Yamuna is the only river flowing through the metropolitan city of Agra. The river enters the city on its northern boundary and takes U-shape while crossing through the heart of the city. The area is characterized by alluvium, which is an admixture of gravel, sand, silt and clay in various proportions, deposited during the Quaternary period. The study area is a part of Indo-Gangetic alluvium of quaternary age and is made up of recent unconsolidated fluviatile formations comprising sand, silt, clay and kankar with occasional beds of gravel. There are some underground rocks of quartzite and sand stone of Vindhyan-series, in the west and south west of Agra. The topsoil is coarse and angular sand with small clay fraction. The sub-soil is sandy throughout. The stabilized topsoil is reddish brown with sand and clay mixed. The minimum depth of topsoil layer is 60 cm. Sand and silts are slightly alkaline to saline. The topography of the area is flat. Saline soils are generally brown. Alkaline soils are grey and get sticky on wetting and hard on drying, acquiring a clotted structure.

Groundwater: The groundwater in the study area occurs in unconfined state in the shallow zone. The groundwater in unconfined conditions rests at 1 m below ground level to a maximum of 29.4 m below ground level. In general deeper water level remains within 19.20 m below ground level. Groundwater in boreholes occurs at depths of 4.57 to 27.60 m below ground level.

In pre-monsoon the water level ranges from 4.89 to 12.3 m below ground level. While in the post-monsoon depth of water level varied between 2.24 m to 17.82 m below ground levels. Most of the wells in Agra have saline water except immediately after the monsoons. According to the Agra Jal Sansthan, 4298 hand pumps are in operation in the town. As per the studies carried out by the University of Roorkee under the Agra Heritage Project, the Agra Heritage area has large groundwater potential.

3.2.2 Groundwater Quality Survey

Total twenty five groundwater samples from the metropolitan city of Agra were collected each during pre-monsoon (June 2002) and post-monsoon (October 2002) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation. The details of sampling locations and source and depth wise distribution are given in Table 7.

Table 7: Description of groundwater sampling locations in Metropolitan City – Agra

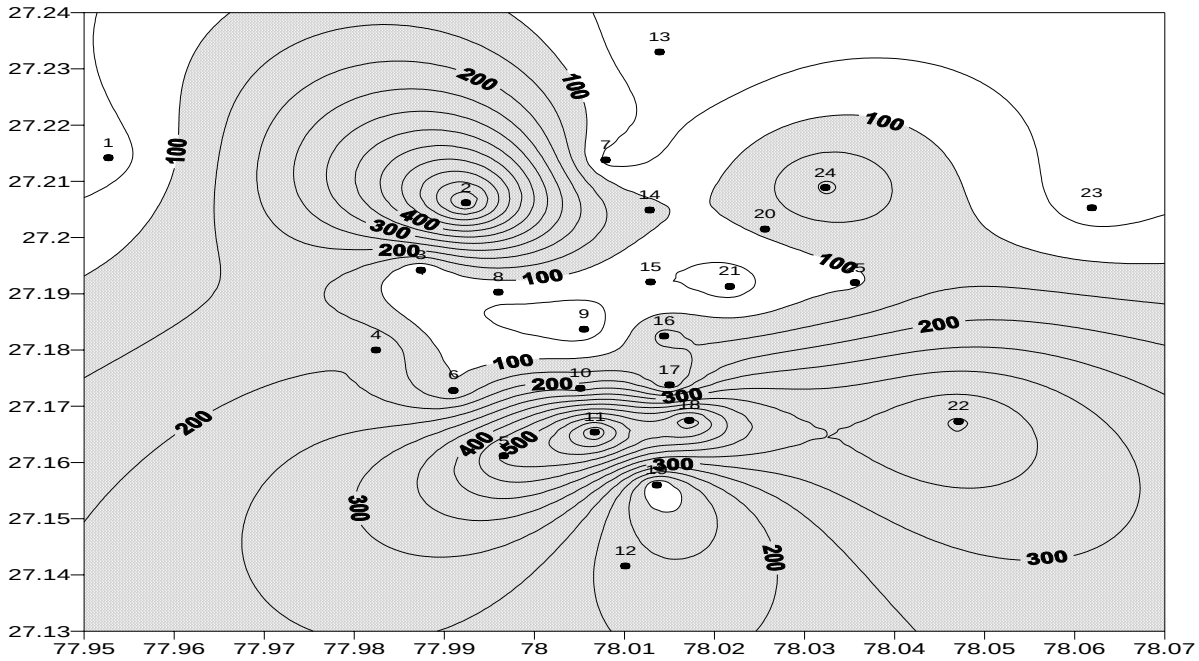
Sl. No.	Location	Identification	Source	Depth, m	Water Use	Land Use/ Specific Activity
1	Sikandra	Opp. Getwell Hospital	HP	18	Drinking	Residential
2	Khandari	Police Chowki Compound	HP	24	Cloth washing	Residential
3	Lohamandi	Saiyad Para Ground	HP	30	Drinking	Residential/ Slaughtering
4	Shahganj	Rui ki mandi Chauraha	HP	27	Drinking	Residential
5	Sultanpura	Jiva Ram Temple	HP	27	Drinking	Residential
6	Idgah Colony	Opp. IOCL Depot	HP	19	Drinking	Residential/ Petro. Storage
7	New Agra Colony	Basic Primary School	HP	21	Drinking	Residential
8	Rajamandi	Opp.Rama Swing Work	HP	38	Drinking	Residential
9	Nai ki mandi	Meera Husaini Chauraha	HP	21	Drinking	Residential
10	Rakabganj	Opp. Over Head Tank	HP	15	Drinking	Residential
11	Namner	Durga Mandir Compound	HP	21	Drinking	Residential
12	Bundu Katra	Opp. Over Head Tank	HP	24	Drinking	Residential
13	Dayalbagh	DEC Gate	HP	30	Drinking	Residential

14	Gandhi Nagar	Main Chowk	HP	18	Drinking	Residential
15	Maithan	Near City Railway Station	HP	24	Drinking	Residential
16	Mantola	Opp. Jama Masjid	HP	24	Drinking	Residential
17	Chilgarh	Opp. Agra Machhua Sahkari Samiti	HP	24	Drinking	Residential/ Slaughtering
18	Baluganj	Near Agra Montessori School	HP	24	Drinking	Residential
19	Naulakha	Near Girja Building Materials	HP	24	Drinking	Residential
20	Ratanpura	Near BSP Office	HP	12	Drinking	Residential
21	Belanganj	Main Chowk	HP	12	Drinking	Residential
22	Tajganj	Nanda Bazar Chowk	HP	30	Drinking	Residential/ Slaughtering
23	Industrial Estate	Trans Yamuna Colony	HP	10	Drinking	Industrial Area
24	Balkeshwar	Opp. S. K. Mittal Agency	HP	21	Drinking	Residential
25	Itma-Ud-Daulla	Opp. Itma-Ud-Daulla Building	HP	12	Drinking	Residential

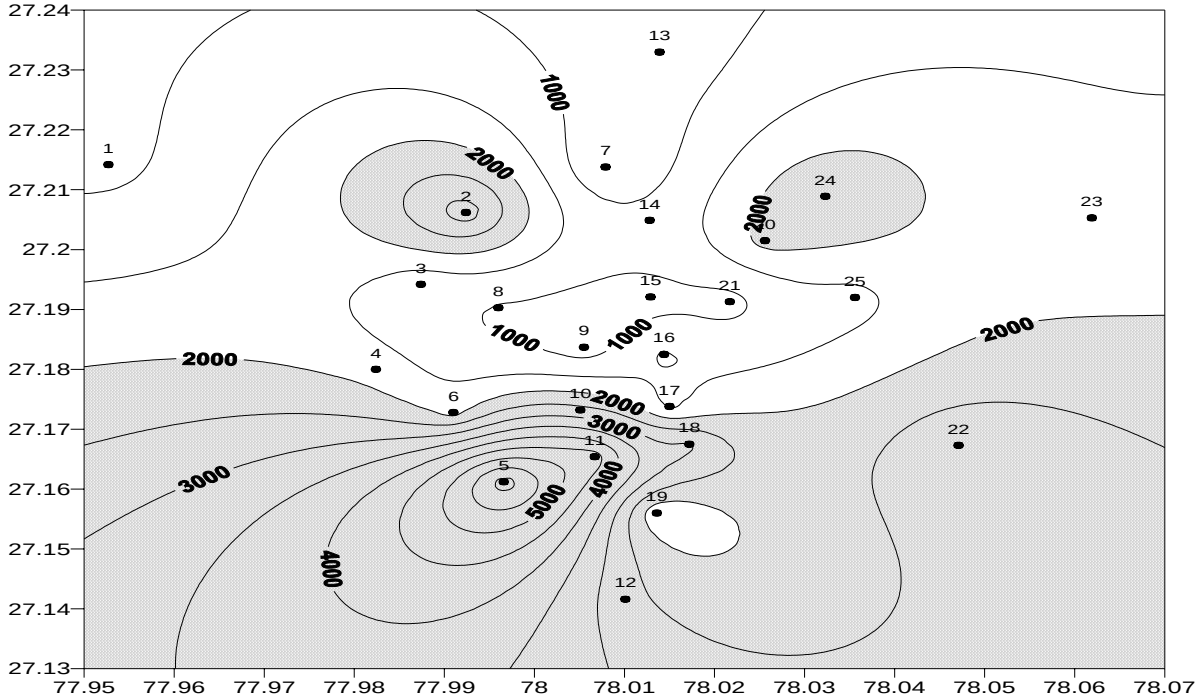
Note: HP-Hand Pump, BW - Bore Well; OW - Open Well, TW-Tube Well

3.2.3 Observations on status of Groundwater Quality in Agra City

The groundwater quality of Agra has been assessed to see the suitability of groundwater for drinking applications. The samples were analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards and hydro-chemical facies were determined. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of electrical conductivity, total dissolved solids, hardness, calcium, magnesium, chloride, sulphate, nitrate, fluoride, iron, manganese, nickel, lead and cadmium vis-à-vis drinking water quality standards. The ranges of each parameter and their percent violation along with observations on groundwater quality are presented in Table 1 of Annexure I. The distribution of critical groundwater parameters such as TDS and Nitrates of pre and post monsoon seasons has been presented in Figure 3 & 4. No poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city.

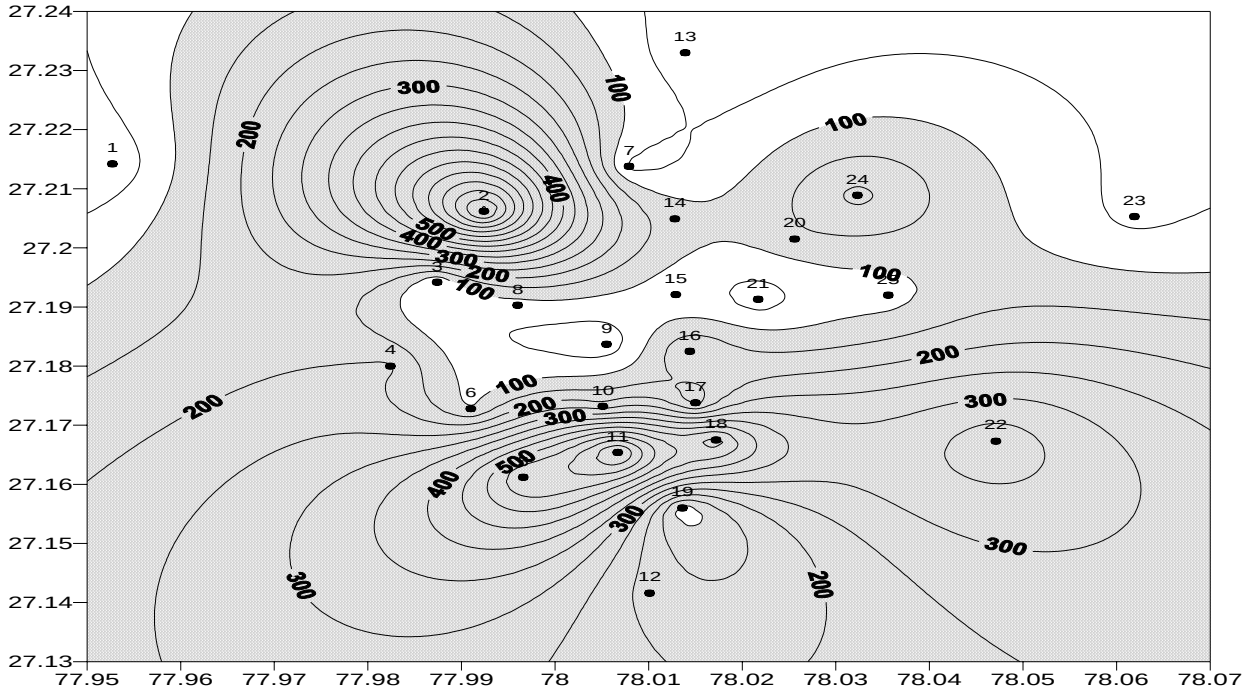


Nitrate distribution in ground water of Metropolitan City - Agra (Pre-monsoon 2002)



TDS distribution in ground water of Metropolitan City - Agra (Pre-monsoon 2002)

Figure 3: TDS and Nitrate distribution (Pre Monsoon) in Groundwater of Agra Metropolitan City



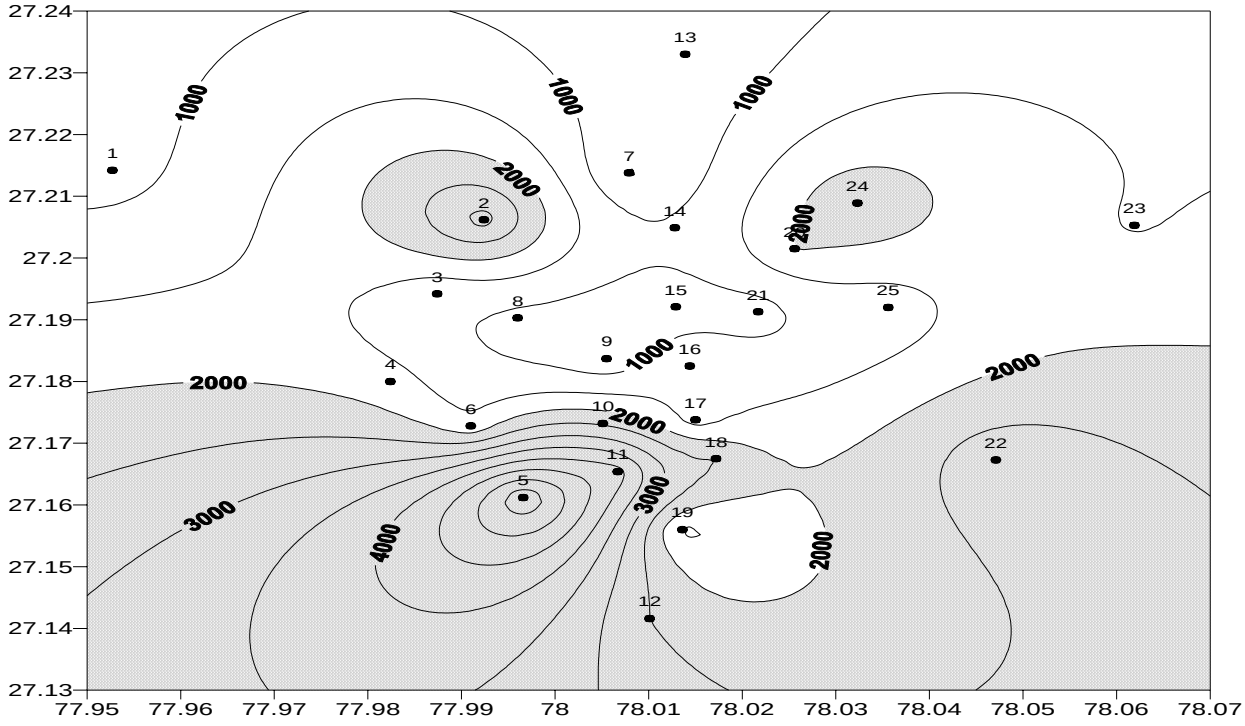


Figure 4: Nitrate and TDS distribution (Post Monsoon) in Groundwater of Agra Metropolitan City

3.3 Meerut Metropolitan city

3.3.1 Environmental profile of Meerut

Topography: The metropolitan city of Meerut is one of the important industrial towns of the western Uttar Pradesh. It is situated about 85 km from Delhi. The metropolitan city occupies an area of about 142 km^2 and lies between $28^o57'$ to $29^o02'$ N latitude and $77^o40'$ to $77^o45'$ E longitude. The metropolitan city of Meerut is a part of Indo-Gangetic plains. The city map has been shown in Figure 5.

Population: The population pressure on the city is ever growing. As per the 2001 census, the population of Meerut (including cantonment area) is 11,67,399. It is the 25th largest town in India (population wise), and the 5th largest town in Uttar Pradesh after +Kanpur, Lucknow, Agra and Varanasi.

Climate: The metropolitan city has a moderate type of climate. Extreme dryness with an intensely hot summer and cold winter is the characteristics of the climate. It has a cool dry winter season from October to March, a hot dry summer season from April to June and a warm rainy season from July to September. The average annual rainfall is about 1000 mm, major part of which is received during the monsoon period (June to September). Significant diurnal variations in hydro-meteorological parameters like precipitation, temperature and relative humidity also exist. The daily maximum temperature varies from 10 to 43^OC and minimum temperature varies from 4.6 to 29.2^OC. The daily relative humidity varies from 30 to 100%.

Geology and soil type: The area is almost devoid of any significant relief features and is composed of unconsolidated alluvial deposits. The land surface lies at an elevation of 220 m from mean sea level. The city is a part of Indo-Gangetic plains, which is mainly composed of pleistocene and sub-recent alluvial sediments transported and deposited by river action from the Himalayan region. Lithologically, sediments consist of clay, silt and fine to coarse sand. The deposits of sandy horizons of varying thickness are the main source of groundwater in the area. The soils are very fertile for growing wheat, sugar cane and vegetables. However, along the sandy river course, fruit orchards are also common. In spite of enormous surface and groundwater resources, the western Uttar Pradesh faces problem scarcity of water for irrigation in dry months, when groundwater is extensively used for irrigation. Varying lithology of the geological formations considerably influences the groundwater conditions in all alluvial parts. The main sources of water, which sustains groundwater body in fine to coarse grained sands, is rainfall, the other sources of groundwater replenishment are infiltration from river, return seepage from irrigation and inflow from neighboring areas.

Water Resources: The two important rivers of the area are Yamuna and Hindon, which flow from north to south. The river Ganga and the river Yamuna form the eastern and the western boundaries of the area. However, The other two rivers flowing in the area are Kali and Krishni. Apart from these rivers, the Upper Ganga Canal also drains the area. Certainly of the above mentioned recharge sources, rainfall is probably the most important. The rate and amount of infiltration of rainwater depends on several factors. The most common groundwater structures in the area are shallow and deep tube wells. Dug wells have become almost rare in the region, the

surface water in the region are fully utilized. Regarding the occurrence of groundwater, the principal groundwater reservoir in the region is unconsolidated alluvial deposits. The recent studies in the region indicated that the top aquifers are unconfined in nature and deeper aquifers are confined to semi-confined in nature.

Water Requirement: Water requirement for Meerut city is mainly met from groundwater. There are 20 overhead tanks having a total capacity of 20,000 KL and 3 under groundwater 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.

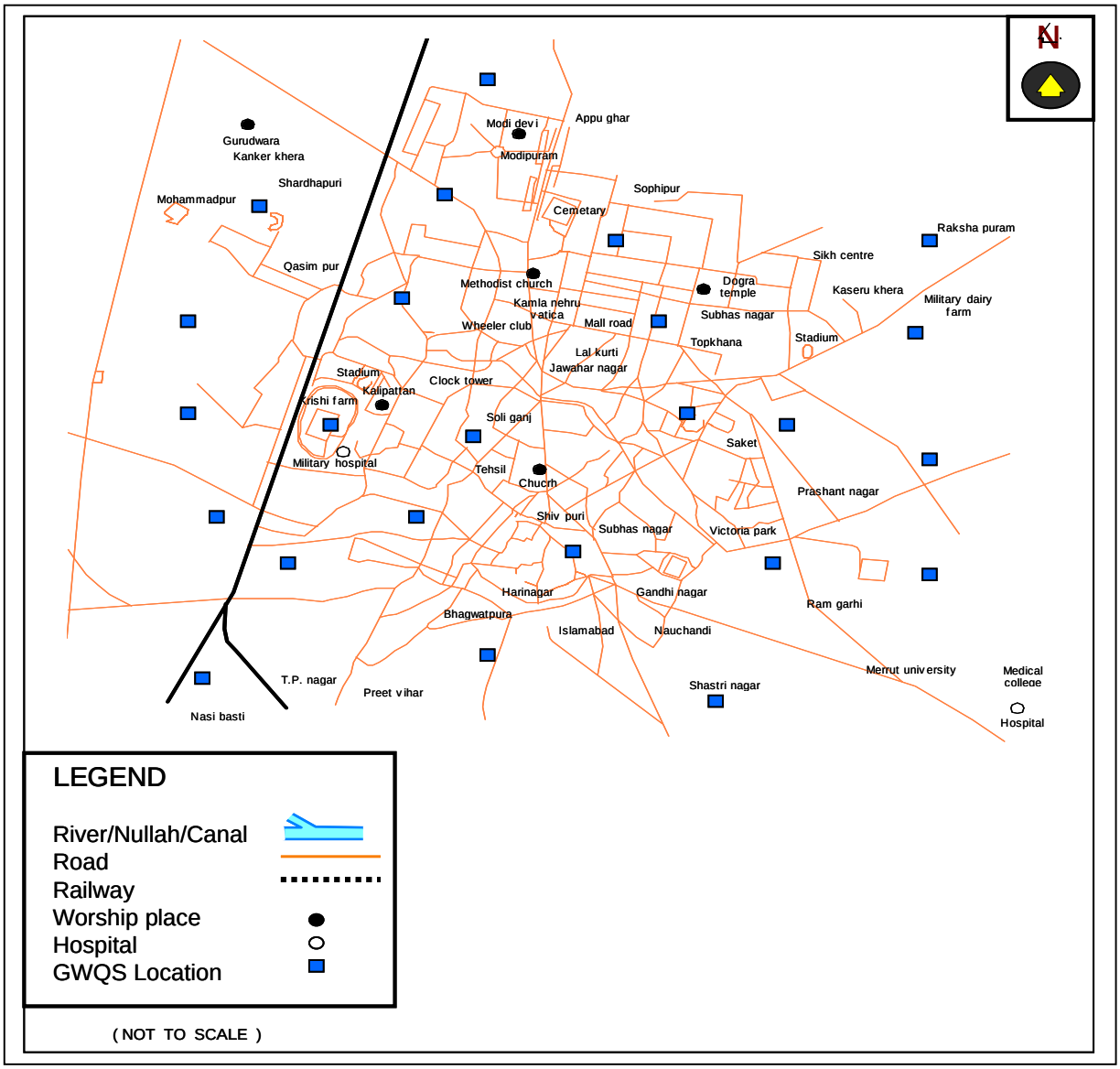


Figure 5: Map of Meerut City

Wastewater generation and Sanitation: The total municipal wastewater 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.

Municipal solid waste generation: The approximate solid waste generation is around 600 MT/day. The solid waste disposal is not thoroughly systematic and the solid waste is dumped at low-lying areas. The solid waste from households and industries is dumped near the roads, parks or in municipal dalaos, from where it ultimately reaches to sanitary landfill 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.

Industries: 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.

3.3.2 Groundwater Quality Survey

Groundwater samples from the metropolitan city of Meerut were collected each during pre-monsoon (June 2002) and post-monsoon (October 2002) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation. Location and other details for sampling points are described in Table 8.

Table 8: Description of groundwater sampling locations in Metropolitan City – Meerut

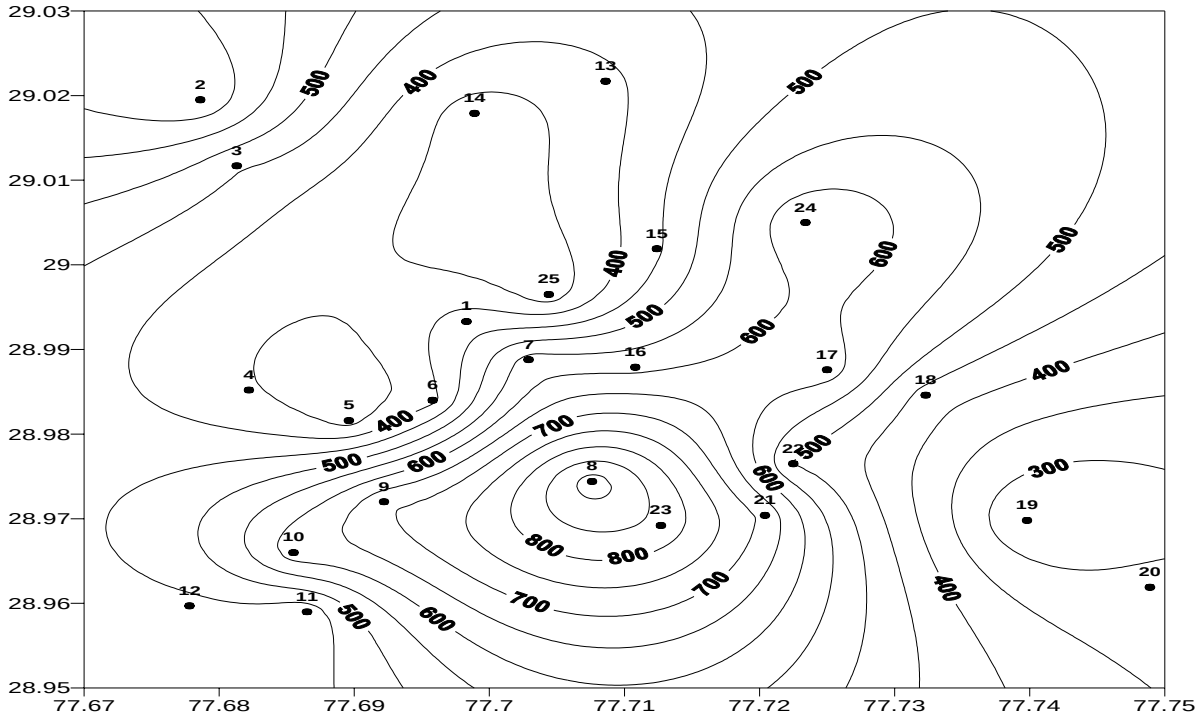
Sl. No.	Location	Identification	Source	Depth, M	Water Use	Land Use/ Specific Activity
1	Sadar Bazar	Opp. Gulathi Opticals	HP	33	Drinking	Residential
2	Kankar Khera	Opp. Saru Engineering Corp.	HP	30	Drinking	Residential
3	Central Distillery	Opp. Lal Quarters	HP	24	Drinking	Residential Area/Distillery
4	Gurudwara (Cantt Area)	Opp. Central School	HP	6	Drinking	Residential
5	Prempuri (Devpuri)	Opp. Vardhman Academy	HP	36	Drinking	Residential
6	Kesar Ganj	Opp. Kesar Ganj Mandi	HP	24	Drinking	Residential

7	Thapar Nagar	Opp. Devta Park	HP	24	Drinking	Residential
8	Mufttiyan	Back Side of Kotwali	HP	39	Drinking	Residential
9	Bharampuri	Near Shiv Temple	HP	24	Drinking	Residential
10	Sports Complex	Sports Complex	HP	15	Drinking	Industrial Area
11	Partapur Ind. Area	Opp. Sub Station	HP	30	Drinking	Industrial Area
12	IBP Depot	IBP Depot	HP	30	Drinking	Petroleum Storage
13	Vrindavan Garden	Roorkee Road	TW	42	Drinking	Residential
14	Koshal Kunj (Cantt Area)	Pump House No. 17	TW	60	Drinking	Residential
15	Lal Kurti	Bada Bazar	HP	24	Drinking	Residential
16	Vijay Nagar	Near R. G. College	HP	18	Drinking	Residential
17	Saket	Opp. Nandan Apartment	HP	15	Drinking	Residential
18	Prabhat Nagar	73 Prabhat Nagar	HP	27	Drinking	Residential
19	Meerut University	University Campus	TW	87	Drinking	Residential
20	Medical College	Medical College Campus	TW	88	Drinking	Residential
21	Kalyan Nagar	Shiv Temple	HP	14	Drinking	Residential
22	Suraj Kund	Sports Market	HP	15	Drinking	Residential
23	Islamabad	Market Area	HP	24	Drinking	Residential/ Slaughtering
24	Subhash Nagar	Near Samart Cement Agency	HP	18	Drinking	Residential
25	Begum Bridge	Opp. Dream Hotel	HP	36	Drinking	Residential

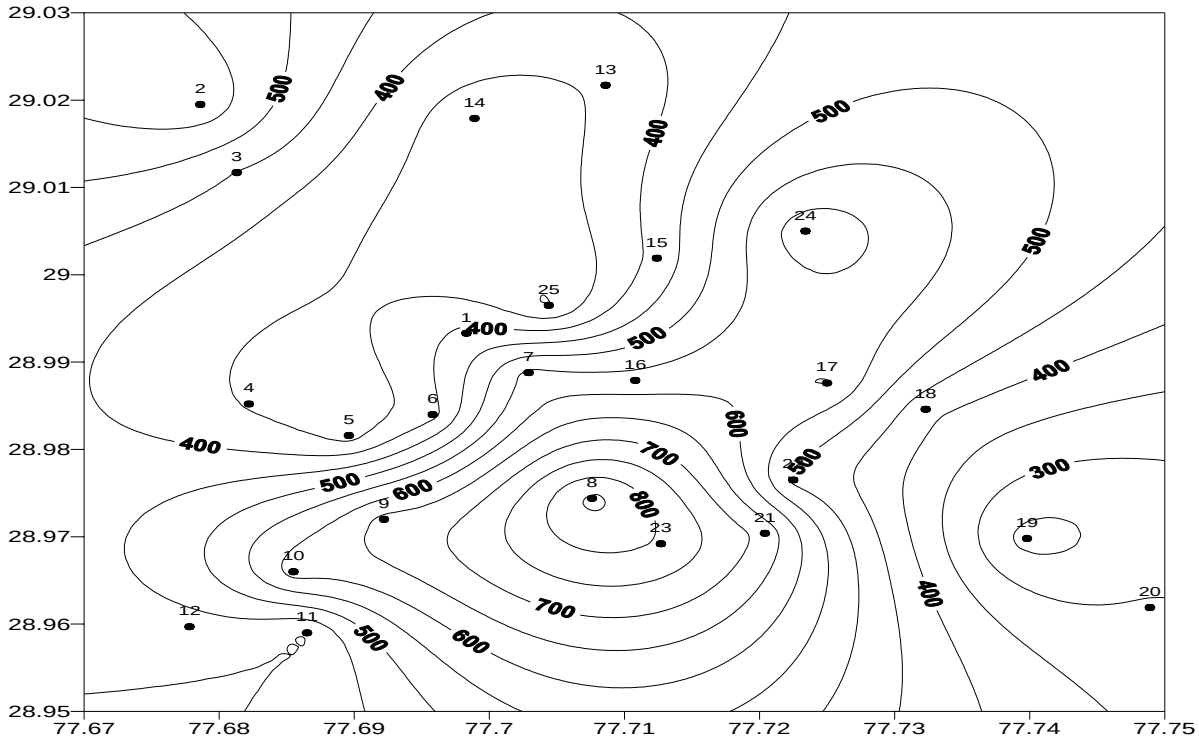
Note: HP-Hand pump, BW - Bore Well; OW - Open Well, TW-Tube Well

3.3.3 Observations on status of Groundwater Quality in Meerut City

The groundwater quality of the Metropolitan City of Meerut has been assessed to see the suitability of groundwater for domestic applications. Groundwater samples from hand pumps and tube wells were collected during pre- and post-monsoon seasons respectively and analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards, hydro-chemical facies were determined. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of nitrate, fluoride, iron, manganese and lead at few locations. The ranges of each parameter and percent violation of samples along with observations/comments on groundwater quality are presented in Table 2 of Annexure I. No poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city. An attempt has also been made to show TDS and Nitrate distribution in Meerut Metropolitan city during pre and post Monsoon seasons (Figure 6 & 7).

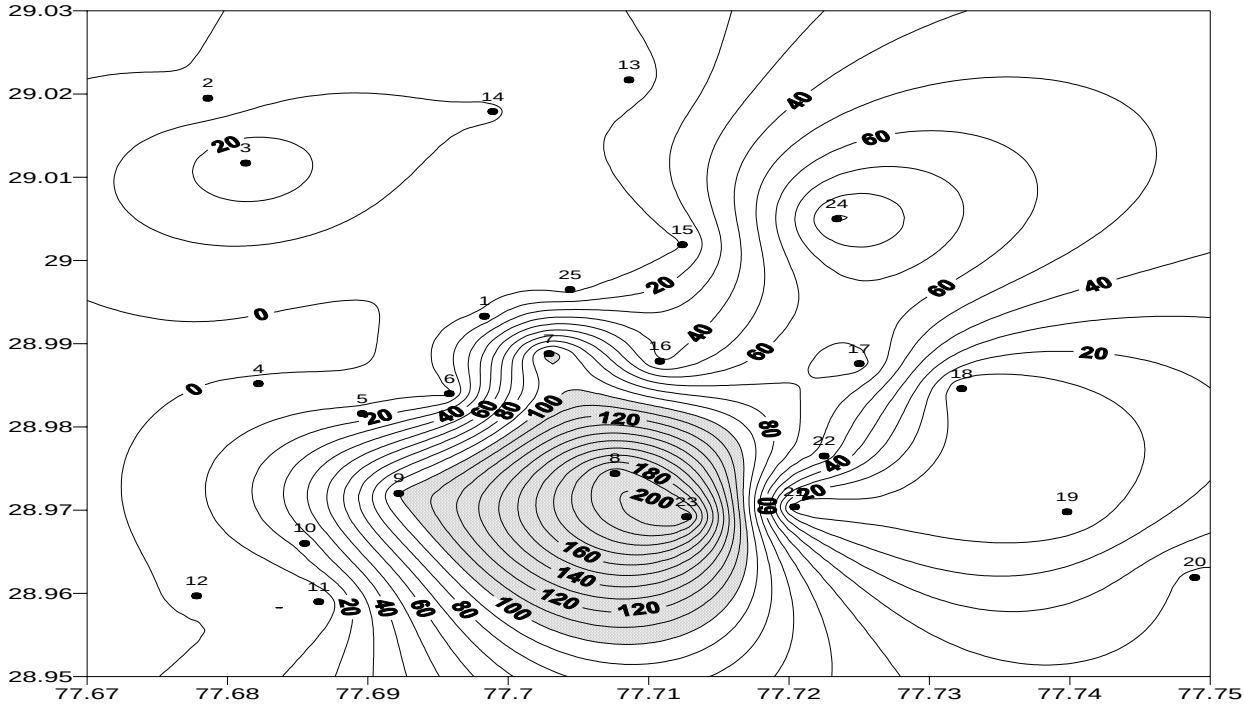


TDS distribution in ground water of Metropolitan City - Meerut (Pre-monsoon 2002)



TDS distribtion in ground water of Metropolitan City - Meerut (Post-monsoon 2002)

Figure 6: TDS distribution in Meerut Metropolitan City



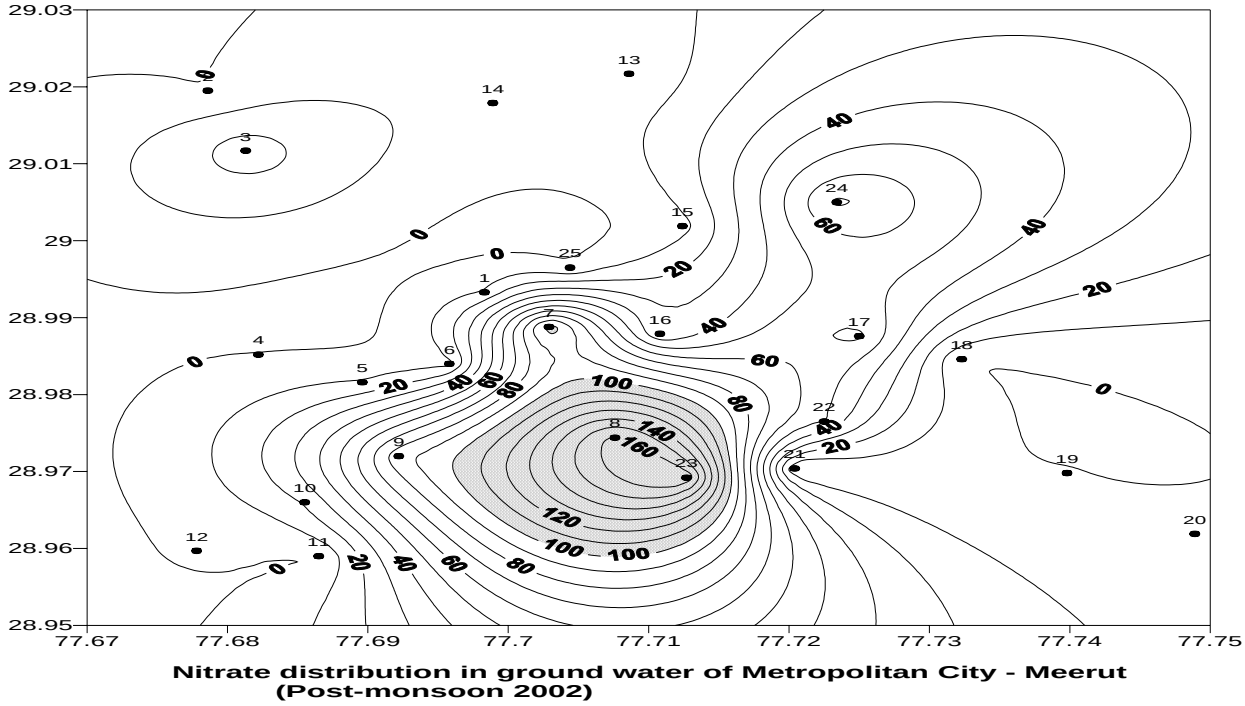


Figure 7: Nitrate distribution in Meerut Metropolitan City

3.4 Lucknow Metropolitan City

3.4.1 Environmental Profile of Lucknow

General features and Topography: Lucknow is a centrally placed district of Uttar Pradesh spread over an area of 2528 sq.kms. It lies between the parallel 26" 30' and 27" 10' north latitude and 80" 34' and 81" 12' east longitude. This elegant capital city of the state of Uttar Pradesh lies on the banks of the river Gomti that divides the city into two unequal halves, the southern half being larger than the northern part. Lucknow urban area has been divided into 40 municipal wards excluding cantonment. City map of Lucknow Metropolitan has shown in Figure 8.

Population: Lucknow has the population of about 25 lacs as per census 2001 with % decadal increase of about 49.80 %. The estimated present population density is 8065.1person/sq. km.

Climate: The climate of the city remains generally dry except during Southwest monsoon period. The hottest month is May with the mean daily maximum temperature at 41 deg C. January is the coldest with the mean daily minimum temperature being 22 deg C. Lucknow city has three main seasons namely summer, rainy and winter. The average normal maximum temperature has been observed as 44.9 deg C during May/June and minimum 4.8 deg C during January. The average wind speed ranges from 0.16 to 0.28 km/hr and from 4.0 to 4.16 km/hr during winter and summer respectively. The relative humidity of air varies from 19% in dry season to 86% during the rainy season. The average normal rainfall of the city is approximately 1100 mm.

Geology and Soil Type: Lucknow city, falls in the central Ganga alluvial plain chiefly forms a part of sai-Gomti sub basin, Hydro-geologically the city as a whole is represented by unconsolidated alluvial sediments, comprising sand of varying grades with kanker and clay and their admixtures, wherein fine grained sand mostly constitutes the aquifers, i.e. groundwater bearing strata. Jal Sansthan provides the existing water supply in the city. The city falls in the central Ganga Plain and lies in the interfuvial belt of Gomti and Sai basins. It has conspicuous natural depression in northeastern part around Janki Puram and Bakshi Ka talab. The general slope of the area is from north and northwest to south and southeast. The highest elevation is 123.5 above mean sea level in the northwest and the lowest 110 msl in the east in flood plain of river Gomti. The whole area of Lucknow may be divided into two geologic units, namely, younger and older alluvium of quaternary age. The younger alluvial plain lies all along the river Gomti and forms a wide flood plain. The older alluvial plain occupies higher elevation than the younger alluvial plain. The alluvium consists of sand, clay and kanker of different proportions.

Water supply: The drinking water supply is drawn from surface and groundwater. The source of surface water is only Gomti River, which is highly polluted mainly due to discharge of about 28 drains of the city. Deep tube wells, hand pumps and private bore wells are the main sources for extraction of groundwater in the city to cater the water demand of the population. There are about 300 tube wells and Jal Sansthan has provided 450 hand pumps. Besides this private boring is also very common. There are two sources of domestic water supply available at Lucknow use Groundwater & Surface Water (River). These water sources are also been use for Industrial purposes, Irrigation purpose and other domestic usage of the city. U.P. Jal Nigam provided about

5435 hand pumps and 345 Tube wells. The surface water drawn from river Gomti is 280 mld and the groundwater withdrawl is 170 mld for domestic uses. The total water supply is 450 mld.

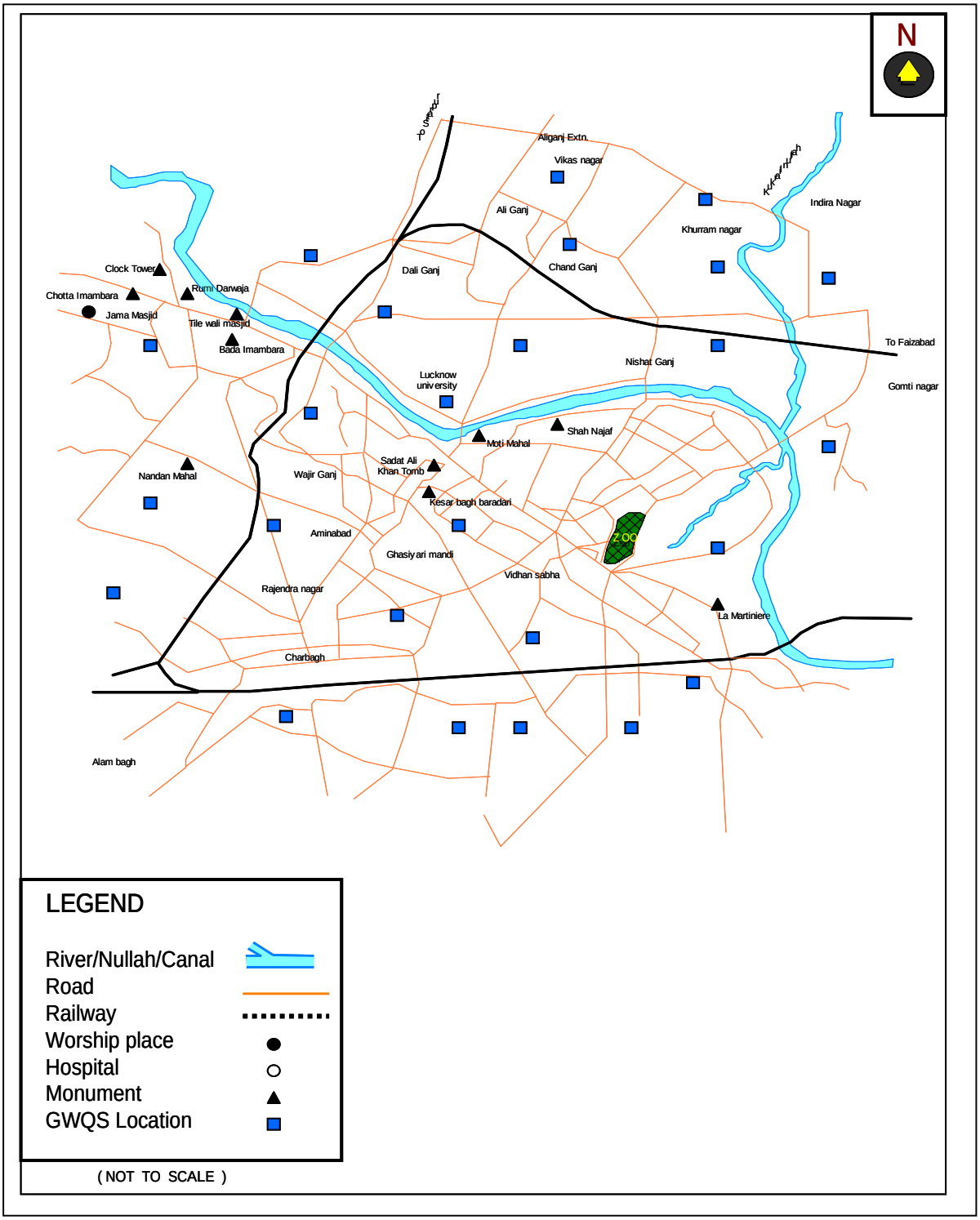


Figure 8: Map of Lucknow metropolitan city

Wastewater generation: The total wastewater generation is estimated as 360 mld. Wastewater treatment facilities are being developed under Gomti Action Plan of Govt of India. Presently the wastewater is flowing in open drains and joining Gomti river through 28 drains from the city. Since a large population is not covered under sewerage facilities the wastewater is flowing in unlined drains or stagnating in many areas, percolating in the ground and polluting the groundwater. Many areas have only septic tanks, pit latrines and even open defecation. All these led to contamination of groundwater. The river Gomti, which flows from North West to southeast, controls the drainage system in the Lucknow city. Kukrail nala is the only prominent tributary, which joins on the northern bank of river Gomti. Major part of the wastewater flows in these two water bodies.

3.4.2 Groundwater Quality Survey

Lucknow city is not dominated by industries. Only few industries are operating in the city in areas of Talkatora and Aishbagh. Most of the industries have been shifted to the outskirt of the city Chinhut. There are two sites for disposal of municipal solid waste namely Motijheel and Aishbagh. The rest comes under residential zone out of which some places are highly congested. The surveys was made more in residential areas, because of intensity of groundwater pumping and close variations in groundwater withdrawal from place to place. The quality of groundwater is widely variable in different areas of varying in quality of recharging source water. The first round of sampling during pre monsoon season for Lucknow city was carried in May 2002. The second round of sampling was done in post monsoon season in November 2002. The overall sampling includes various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation. Location and other details for sampling points are described in Table 9.

Table 9: Description of groundwater sampling locations in Metropolitan City Lucknow

INDUSTRIAL AREA	SANITARY LANDFILL	RESIDENTIAL AREA	PETROL PUMPS	SURFACE WATER
Chinhut (Hand Pump)	Motijheel (Hand Pump, Tube Well)	Indira Nagar (Tube Well, Hand Pump)	Gomti nagar (Hand pump)	Gomti river (Intake Point of Water Supply & Hand Pump along the bank)
Dalliganj (Hand Pump, Tube Well)	Ash bagh (Hand Pump)	Ashrafabagh (Hand Pump)		
Talkatora (Tube Well,Hand Pump)		Sahadatganj (Indana Kuan)		
		Alambagh (Hand Pump, Tube Well)		
		Ameenabad (Hand Pump, Tube Well)		
		Shahganj (Hand Pump)		
		Imambara (Hand Pump)		
		D/S Gomti (Bhainsa kund) (Hand Pump)		
		Gomti nagar (Tube Well, Hand Pump)		
		Charbagh (Tube Well)		

Note: BW - Bore Well; OW - Open Well, TW- Tube Well, HP-Hand Pump

3.4.3 Observations on Status of groundwater quality (GWQ) in Lucknow City

The groundwater quality of the Metropolitan City of Lucknow has been assessed to see the suitability of groundwater for domestic applications. The groundwater samples from hand pumps and tube wells were collected during pre- and post-monsoon seasons and analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of hardness, TC and FC, iron, manganese and lead at few locations. The ranges of each parameter and percent violation of samples along with observations/comments on groundwater quality are presented in Table 3 of Annexure I. No poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city.

3.5 Ludhiana Metropolitan City

3.5.1 Environmental Profile of Ludhiana

Topography: Ludhiana city, the district headquarter of Ludhiana district is one of the biggest city in Punjab. It lies between north latitude 30-34' and 30"01' and east longitude 75-18' and 76-20'. It is a central place in Punjab and is connected to all the major cities of the State through rail and roads. The general slope of the city is from East to West. The Municipal Corporation limit of Ludhiana city is 159.37 Sq. Kms. There are a large number of industries within the municipal limits of Ludhiana. It has developed into a main industrial and commercial town of the state. Ludhiana city map has shown in Figure 9.

Population: The population of the city within the Municipal Corporation area has grown at a fast pace since 1911 and has crossed one million. The population of Ludhiana city is around 13.93 lacs with 70 numbers of wards, and it also has a floating population.

Climate: The climate of Ludhiana generally ranges from semi humid in the North and North East to semi arid to arid in the South. The climate can be divided into three distinct seasons, the summer, the winter and the rainy season. There is large seasonal fluctuation of both temperature and rainfall. About 70% of the rainfall occurs from June to September. The average normal rainfall of the city is approximately 670 mm and the annual average rainfall in the district has been 437 mm.

The humidity is frequently high during the monsoon period (July-September) but is moderate to low during the rest of the year. The mean relative humidity varies from 43% in dry season to 81% during the rainy season. There is considerable variation between the normal mean maximum (June) and normal mean minimum (January) temperature. The mean maximum temperature is as high as 42.8°C and the mean minimum temperature is as below as 11.8°C. At all places the highest monthly temperature is obtained in June, followed by May and the lowest invariably in January, followed by December. The average wind speed ranges from 5.0 to 5.4 Km/hr during winter and 6.0 to 12.1 Km/hr during summer.

Geology and soil type: The geological succession found around Ludhiana is alluvium. The river Sutlej and its tributaries due to its changing courses deposit the alluvium in this part. The Sutlej River enters the Ludhiana district at Samrala tehsil, after flowing westwards along the border of Rupnagar and Hoshiarpur districts, for about 30 kms, it then flows west for about 90 kms, forming the boundary between Ludhiana and Jalandhar districts. The alluvium consists of sandy clay, gravel, pebbles and kankar. The lithology of the area is heterogeneous. Ludhiana is entirely occupied by alluvial deposits consisting of silt, clay, sand and kankar. Associated with the unconsolidated alluvium, occasionally beds of gravels and cemented sands are also present. The soils are alkaline and are deficient in nitrogen and organic matter. Tube well data show that there are alternate beds of sand and clay, with varying thickness. It is also revealed that there is occurrence of gravel and boulders at a depth varying from 60 m to 90 m.

Groundwater and Water supply: The water supply in Ludhiana is through groundwater of tube wells. The city has ample of groundwater and therefore the drinking water supply is based on deep tube wells. The depth of groundwater varies from 10 to 30 m in various parts of the city. There are about 80 functional deep tube wells, which are operated round the clock to meet the drinking water requirements of the people. The average per capita consumption of water comes to 25-30 gallons/day. Apart from municipal sources of water supply, a large number of consumers also have shallow hand pumps for augmenting their water requirements. There is no source of surface water in the study area (Ludhiana). All the requirement of water is met by the groundwater available in the area. The groundwater is mostly used for drinking purposes as well as for industrial, irrigation and other uses in the region.

Wastewater generation: The wastewater generated in the city either accumulating or flowing to the Buddha Nala passes through Ludhiana city. This drain acts as the carrier of wastewater from water polluting industries and city sewage. The Buddha Nallah is a tributary of river Satluj.

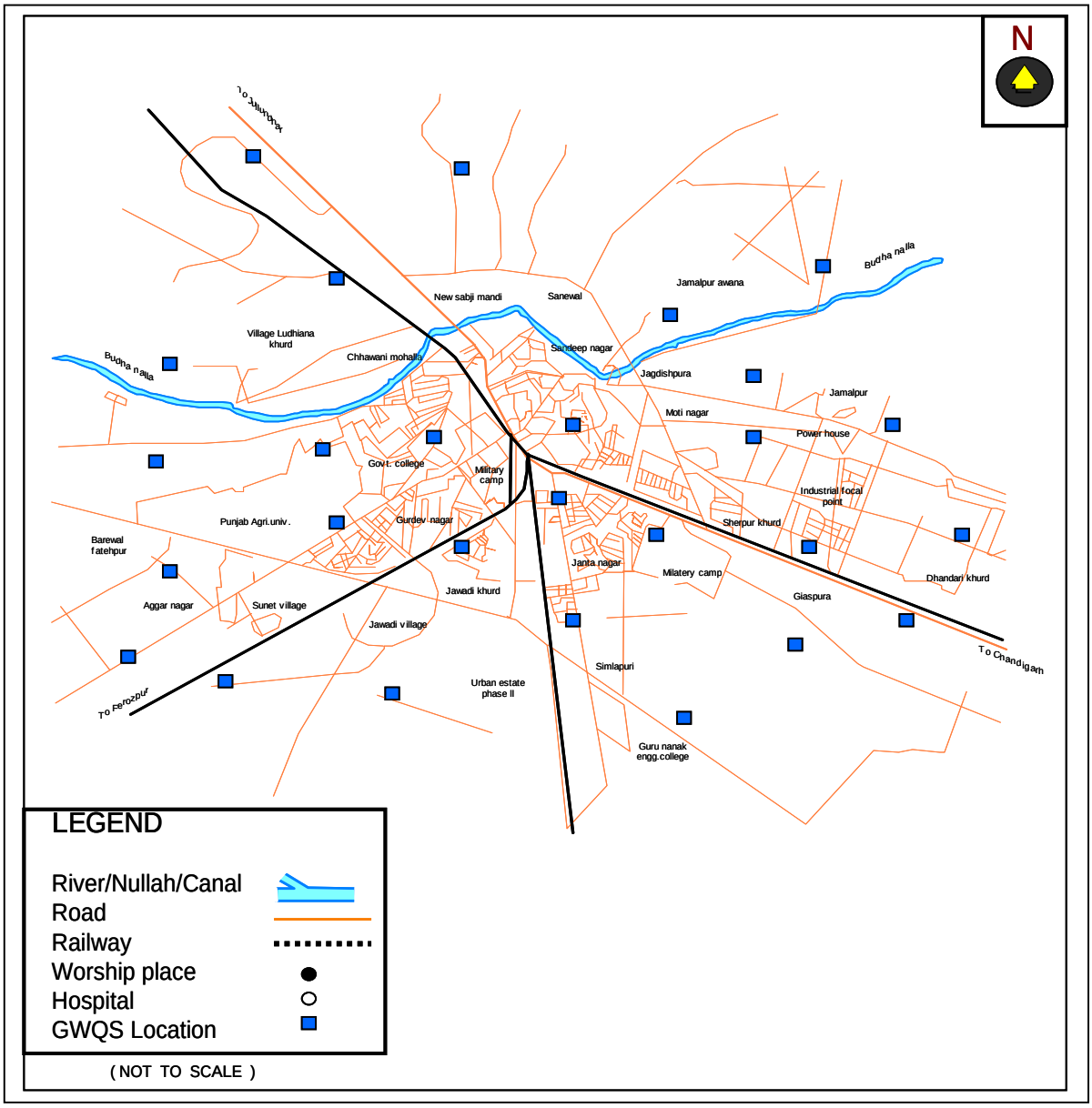


Figure 9: Map of Ludhiana City

3.5.2 Groundwater Quality Survey in Ludhiana

Based on the information related to physiography, surface and subsurface hydrology, potential of groundwater, depth of shallow and deep aquifers, direction of groundwater flow the sampling locations were identified. The identification of industrial areas, residential areas, petrol pumps and bulk storage of petroleum products, if any, municipal solid waste disposal sites (landfill sites) and background area were done for the selection of identified tube wells. The samples were collected for groundwater in Pre-monsoon (May) and Post-monsoon (November) and identified about 29 numbers of locations to cover proportionately in shallow and deep aquifer regions of the city. The first round of sampling during pre monsoon season for Ludhiana city was carried

out in May and the second round of sampling during post monsoon season was carried out in November. The overall sampling includes various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation. Location and other details for sampling points are described in Table 10.

Table 10: Description of groundwater sampling locations in Metropolitan City-Ludhiana

A Zone	B Zone	C Zone	D Zone
A1: 1.Darresi (T.W. No. 4), In front of Police Chowki No. 4. 2.Fatehgarh, In front of Chand Cinema (T.W. No. A-11).	**B1:** 1.Kidwai Nagar Park, Near Zone B1 Office. 2.Guru Angad Devji Park, Cheema Chowk. 3.R.K. Road, Near PSEB, Industrial Area A. 4.Narinder Nagar, Shingar Cinema Road.	**C1:** 1.Janata Nagar, Near Durga Factory. 2.Kotmangal Singh, Near Gurpal Nagar, Gali No. 25. 3.Langar Hall Daba, Near Gurdwara, New Amar Nagar.	**D1:** 1.Shahi Mohalla, Near Damoria Bridge. 2.Kitchlu Nagar. 3.Humbra Road, Mandeep Nagar.
A2: 1.New Shivpuri (T.W. No. 1) 2.Sardar Nagar, Near Corporation Dispensary (T.W. No. A-14).	**B2:** 1.Sherpur Zone b2 Office. 2.Kailash Nagar, Near Cancer Hospital (Oswal).	**C2:** 1.Char Acre Colony, Near Char Acre Scheme, Dashmesh Nagar. 2.2.5 No. Police Post, Gill Road, Near Vishwakarma Mandir Chowk. 3.Quality Centre, Industrial Area B, Near Nirankari Mohalla.	**D2:** 1.Model Town (T.W. No. 14). 2.Model Town Market.
A3: 1.Sabzi Mandi (T.W. No. 54). 2.Punjabi Bagh, Near Salim Tapri (T.W. No. A-51).	**B3:** 1.Dairy Complex, Tajpur Road. 2. MIG Sector 32-A,, Urban Estate, Samrala Road		**D3:** 1.Bhai Randhir Singh Nagar, G-Block North (T.W. No. 3). 2.Gurdev Nagar, Near Sarabha Nagar.
A4: 1.Gagan Deep Colony, Near Galewal Road. 2.Janta Colony (Park No. 5), Rahon Road.			

Note: HP- Hand Pump, BW - Bore Well; OW - Open Well, TW- Tube Well

The industrial areas, residential areas, municipal solid waste disposal (land fill) areas have also been identified and samples collected accordingly. There is no bulk storage depot of Petroleum products in Ludhiana city.

3.5.3 Observations on status of Groundwater Quality in Ludhiana

The groundwater quality of the Metropolitan City of Ludhiana has been assessed to see the suitability of groundwater for domestic applications. The groundwater samples from hand pumps and tube wells were collected during pre- and post-monsoon seasons and analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of K, iron, manganese and lead at few locations. The ranges of each parameter and percent violation of samples along with observations/comments on groundwater quality are presented in Table 4 of Annexure I. No poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the Ludhiana metropolitan city.

3.6 Coimbatore Metropolitan city

3.6.1 Environmental Profile of Coimbatore

General feature & Topography: The metropolitan city of Coimbatore is one of the important industrial towns of South India**.** The metropolitan city is situated at $11^{o}00'$ N latitude and $77^{o}00'$ E longitude and occupies an area of about 140 km^2. The Coimbatore district is flanked on the northwest and south by steeply raising mountains of Western Ghats. Of these, the Nilgiris on the north west and Anamalai on the south are the important ranges, which attain a height of over 2500 m above mean sea level and the highest elevation in the valleys adjoining the hills is 600 m above mean sea level. In between the hill ranges east west trending mountain ranges pass and it is known as Palghat gap. Beside these western ghat ranges the other hill ranges of the district are Vellingiris and Botuvampatti hills. The Vellingiris are the spurs of the Nilgiri Mountains lying on the west and north west of the district. Boluvampatti hills lies on the northeastern side of the district. The city map has been shown in Figure 10.

Population: It is the 18^{th} largest town in India (population wise), and the 2^{nd} largest town in the state of Tamil Nadu after Chennai and is also called as 'Textile City' and the 'Manchester of South India'. The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Coimbatore is 14,46,034.

Climate: Generally sub-tropical climatic condition prevails throughout the district and there is no sharp variation in climate. The temperature slowly rises to its maximum up to May and afterwards shows a general decline. The maximum temperature ranges from 36 to 41°C and the minimum temperature varies from 14 to 31°C. The district receives rain both in southwest and northeast monsoon. The average annual rainfall of the district is 647 mm.

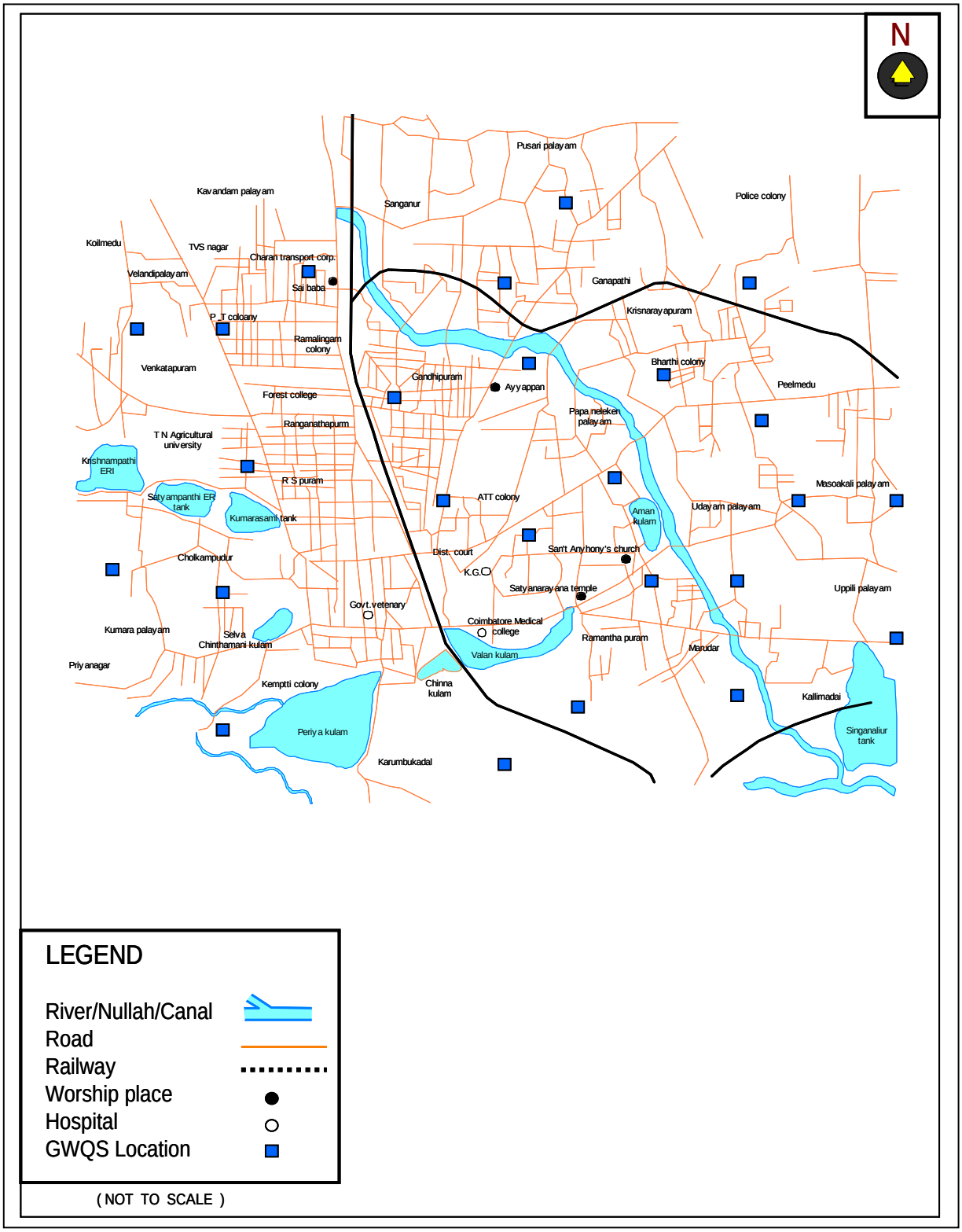
Geology and Soil Type: A wide range of high-grade metamorphic rocks of the peninsular gneissic complex underlies Coimbatore district. These rocks are extensively weathered and

overlain by recent valley fills and alluvium at places. The major rock types occurring in the district are granites, complex gneise mainly Hornblende – Biotite gneiss, Sillimanite gneis which are associated with basic and ultra basic intrusives, crystalline limestone, syenite, pegmatite and quartzite veins. There are six different types of soils, viz., red calcarious soil, black soil, red non calcarious soil, alluvial and colluvial soil, brown soil and forest soil. In Coimbatore district groundwater occurs in all geological formations for the oldest Archean to recent alluvium. Diversified geological formation, lithological variation, tectonic complexity, geo-morphological and hydro-meteorological dissimilarities prevailing in the district raise to a variety of groundwater situations. However in relation to mode of occurrence, the hydro-geological frame work met with in the district have been divided into two categories namely fissured and fractured formation both in gneiss and charnockite formations and porous formations. In hard rock formations, occurrence of groundwater depends upon secondary porosity, viz. zone of weathering, fissures, fractures, joints etc. Due to heterogenetic nature, these features generally do not occur uniformly in space and depth. They do not usually contain large and extensive groundwater reservoir. However, under favourable conditions, considerable quantity of groundwater storage is feasible in different lithological units. The most common rock types encountered in this district are gneiss and Charnockite.The porous formations in the district are represented by alluvium, colluvium and laterites. Colluvial material derived from nearby hill ranges, comprising sands and gravels, underlies the area to the western part of Coimbatore. The thickness of the layer is varies from 20 to 70 m. In these areas the groundwater is developed by means of dug wells and bore wells from the groundwater occurs under phreatic condition in the shallow aquifer, which occurs to depth ranging from 30 to 60 m. In alluvial formation groundwater occurs under water table conditions or semi-confined conditions and the formations are highly porous, permeable and developed into potential water bearing zones.

Water supply: Water requirement for Coimbatore city is mainly met from Siruvani and pilloor reservoirs. The estimated total water supply to the city is about 145 mld and covers most of the localities within the corporation area. The water supply through Siruvani reservoir is 80 mld and 65 mld through Pilloor reservoir. Also, the water supply is met through corporation bore wells. The corporation area has been divided into 72 wards for water supply distribution.

Wastewater generation: The total municipal wastewater generation in the city is about 110 mld. Only 40% area is covered through underground drainage system. In other areas of the city people are using septic tanks and soak pits. In most of the places, sewage is discharged into open drains either lined or unlined and low lying areas without any treatment. Ultimately wastewater from densely populated areas of both domestic and industries reaches at Vellalur pond near by Noyyal River. The city has no sewage treatment plant.

Municipal Solid Waste: Solid waste generation in Coimbatore city is about 800 MT/day. The solid waste disposal in Coimbatore city is not thoroughly systematic and the waste from house holds and industries is dumped in municipal waste containers located at various places of the city, low lying areas and near the roads. Initially the solid waste is transported to temporary waste transfer stations located at Ondipudur, Sathyamangalam road at Krishnarayapuram and Peelamedu. Ultimately the solid waste is transferred to main sanitary landfill at Vellalur, a place outside the Coimbatore municipal corporation. There is no proper system of monitoring the dumping activities.



LEGEND

River/Nullah/Canal

Road

Railway

Worship place

Hospital

GWQS Location

(NOT TO SCALE)

Figure 10: Map of Coimbatore City

Industries: The metropolitan city of Coimbatore is a burgeoning industrial centre with its famous textile mills, engineering industries and large number of small-scale industries. It is estimated that there are approximately 16000 registered industrial units in the metropolitan city of Coimbatore, out of which only about 8500 units are functional at present. Most industries are located in Peelamedu, Ganapathy, SITRA, Singanallur, Sidhapudur, Kurichi Industrial Estate (SIDCO) and Velandipalayam. Textiles, Foundries, Motor pumps, Electrical and Electronic appliances, Automobile components, Washing machines, Wet grinders, General engineering industries, Food processing units and readymade garments predominate in the area.

3.6.2 Groundwater Quality Survey in Coimbatour city

Groundwater samples from the metropolitan city of Coimbatore were collected each during pre-monsoon (June 2003) and post-monsoon (December 2003) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation. The details of sampling locations and source and depth wise distribution are given in Table 11.

Table 11: Description of groundwater sampling locations in Metropolitan City Coimbatore

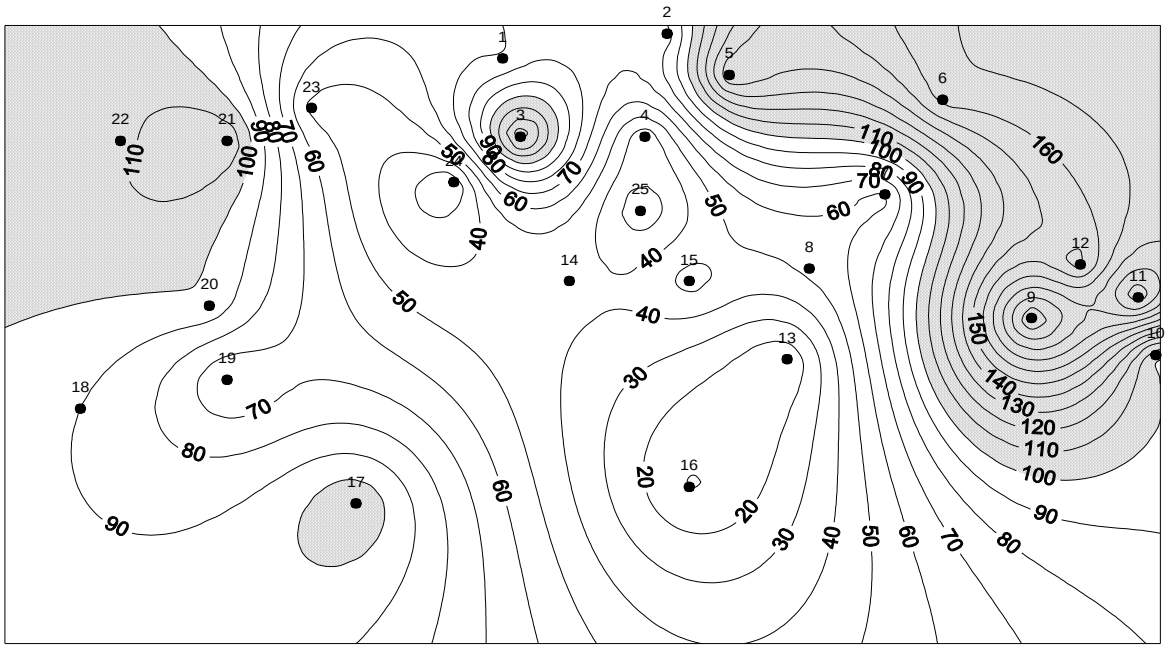
Sl. No.	Location	Identification	Source	Depth, m	Water Use	Land Use/ Specific Activity
1	Ganapathy	Near CRI Pump Road	BW	121	Domestic	Industrial
2	Bharathi Nagar	Rajarajeswari Temple	OW	15	Domestic	Residential
3	Krishnarayapuram	Near Waste Transfer Site	BW	24	Domestic	Commercial/ Solid waste Disposal
4	Pewelamedu	Ranga Nagar No.7 Residence	BW	45	Domestic	Industrial
5	Villankurichi	Kuppusamy Gounder Garden	OW	36	Domestic	Residential
6	Sitra (Kalappatti)	Panchayat Office	BW	106	Domestic	Industrial
7	Valluvar	Murugan Temple	BW	75	Domestic	Residential
8	Singanallur	Near LGB	OW	30	Domestic	Industrial
9	Ondipudur	9/47B Gandhi Nagar Residence	BW	30	Domestic	Residential
10	Irugur	BPCL side Sentha-Marai Garden	OW	18	Domestic	Agricultural
11	Irugur	IOCL, HPCL opposite	OW	30	Domestic	Agricultural
12	Irugur	Near IOCL, HPCL By-pass	OW	30	Domestic	Agricultural

		Road				
13	Kallimadai	Trichy Road near Boat House	OW	30	Domestic	Industrial
14	Puliyakulam	Opp. Lakshmi Medicals Residence	BW	45	Domestic	Residential
15	Souripalayam	Opp. ESI Hospital	OW	30	Domestic	Residential
16	Vellalur	Asokar St. Karuppasamy Gounder	OW	13	Domestic	Residential
17	Kurichi	Palaniappa Layout Public BW	BW	30	Domestic	Industrial
18	Perur	Panchayat Office	BW	90	Domestic	Residential
19	Selvapuram	Kannan Nilayam Residence	BW	69	Domestic	Residential
20	Chokkam Pudur	Near Mariamman Temple	BW	121	Domestic	Residential
21	Venkatapuram	241/1, Saral Nursery Garden	BW	21	Domestic	Commercial
22	Velandipalayam	No.18/19, Simson Nagar Extension	BW	75	Domestic	Industrial
23	Kavundampalayam	Corporation Toilet Side MTP Road	BW	30	Domestic	Commercial
24	Gandhipuram	Saibaba Colony Residence	BW	45	Domestic	Commercial
25	Sidhapudur	No.51, Ambika Layout	BW	45	Domestic	Industrial

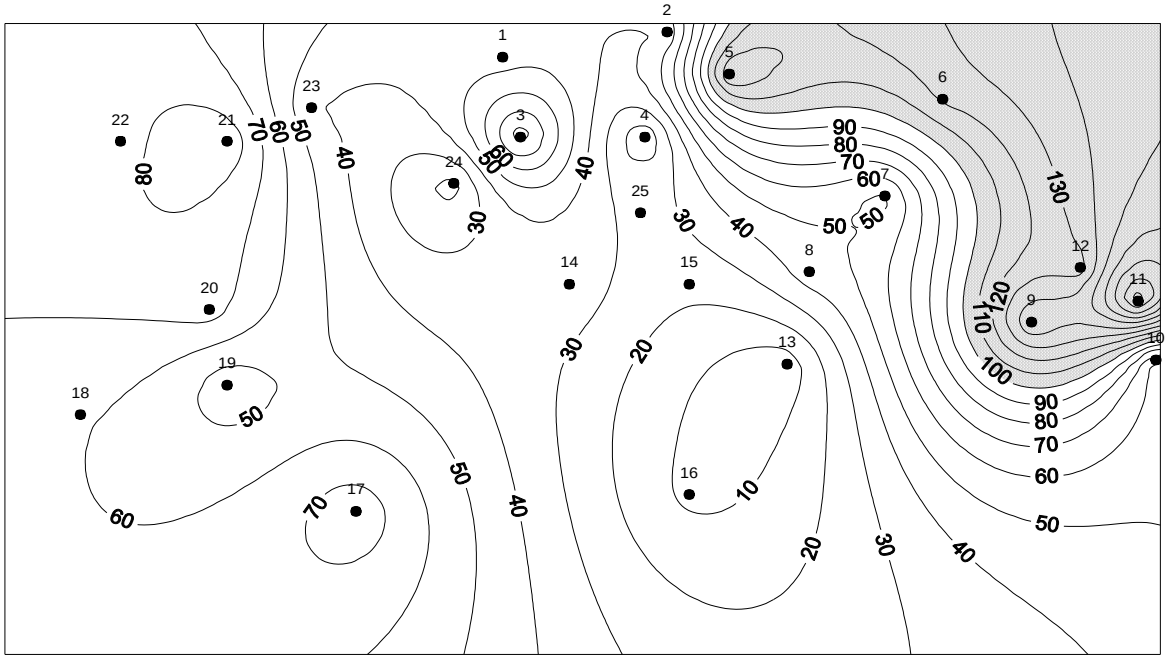
Note: BW - Bore Well; OW - Open Well; HP- Hand Pump

3.6.3 Observations on status of Groundwater Quality in Coimbatore city

The groundwater quality of the Metropolitan City of Coimbatore has been assessed to see the suitability of groundwater for domestic applications. The samples collected were analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-nuclear aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards and hydro-chemical facies were determined. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of electrical conductivity, total dissolved solids, hardness, calcium, magnesium, chloride, sulphate, nitrate, fluoride, iron, nickel, chromium and lead vis-à-vis drinking water quality standards. No poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city. The ranges of each parameter along with observations/comments on groundwater quality are presented in Table 5 of Annexure I. An attempt has also been made to show TDS and Nitrate distribution in Coimbatore Metropolitan city during pre and post Monsoon season (Figure 11 & 12).

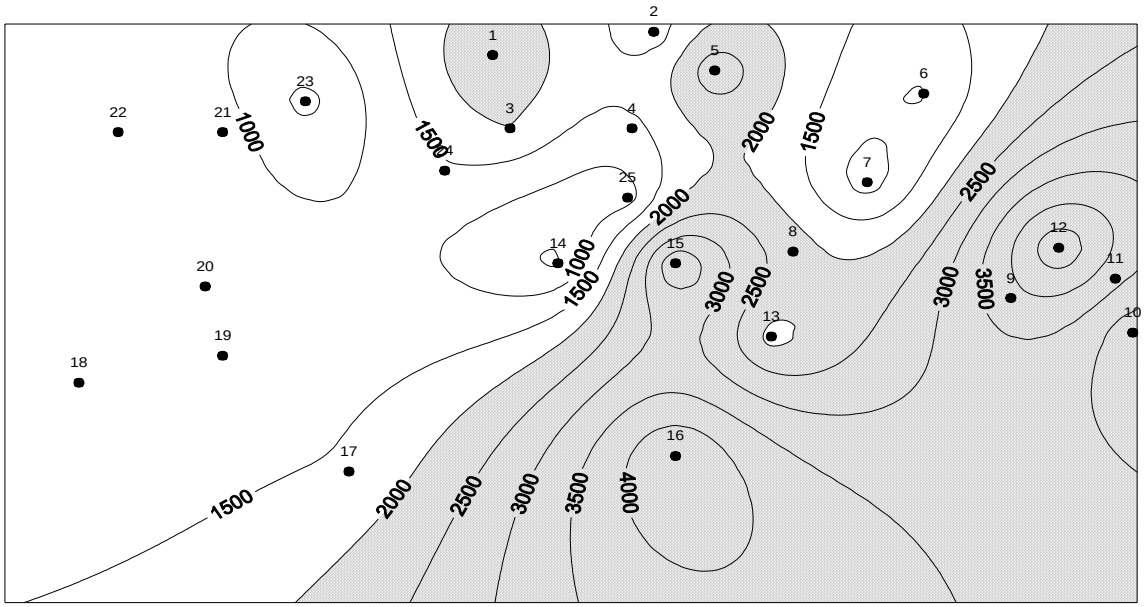


Nitrate distribution in ground water of Metropolitan City - Coimbatore (Pre-monsoon 2003)

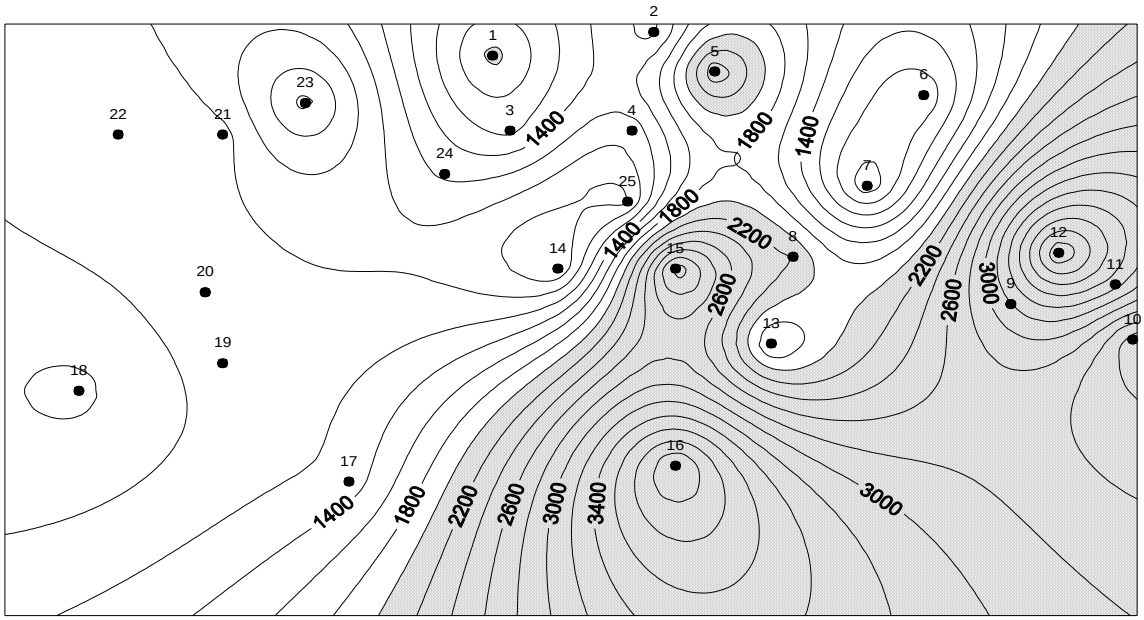


Nitrate distribution in ground water of Metropolitan City - Coimbatore (Post-monsoon 2003)

Figure 11: Nitrate distribution in Coimbatore Metropolitan City



TDS distribution in ground water of Metropolitan City - Coimbatore (Pre-monsoon 2003)



TDS distribution in ground water of Metropolitan City - Coimbatore (Post-monsoon 2003)

Figure12: Total Dissolved Solids (TDS) distribution in Coimbatore Metropolitan City

3.7 Chennai Metropolitan City

3.7.1 Environmental Profile of Chennai

Topography: The metropolitan city Chennai is the biggest city of South India with ancient culture and traditions. It is bounded by Bay of Bengal in the East and Chengai-MGR district in all the other directions. The metropolitan city of Chennai is located at $13^{o}04'$ N latitude and $80^{o}17'$E longitude and occupies an area of about 173 km^2. The city is located in the coastal plains. Major part of the city is having flat topography with very gentle slope towards east. The altitudes of land surface vary from 10m above msl in the west to sea level in the east. Fluvial, marine and erosional landforms are observed in the area. City map has been shown in Figure 13.

Population: It is the 4^{th} largest town in India (population wise), and the largest in the state of Tamil Nadu. The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Chennai is 64,24,624.

Climate: Chennai city enjoys a tropical climate with mean annual temperature of 24.3^0 C (min) to 32.9 ^{0}C (max). The hottest and driest part of the year is April-May, when temperature rises to 42^0 C. The humidity is usually in the range of 58 to 84% and sea breeze in the evening hours is a blessing to combat the high temperature and humidity during summer months. The Northeast monsoon during the months of October, November and December chiefly contributes the rainfall for the city. Most of the precipitation occurs in the form of one or two cyclones caused due to depressions in Bay of Bengal. The southwest monsoon rainfall is highly erratic and summer rains are negligible. The average annual rainfall in the region is the range from 1286 to 1233 mm.

Water Resources: The number of water bodies existed in the area in the early period of this century has been filled up with garbage (e.g., Vallur kottam area), transported sand and clay. Adayar River originates at the confluence (Thiruneermalai) of two streams that drain the upstream area of Chembarambakkam tank. It is a small river having a length of about 42 km and a catchment area of 800 km^2. The river carries flow through out the year with an average discharge of 89.43 MCM/year at Kattipara cause way. It drains the southern part of the district and remains flooded during monsoon. During high tides, the backwaters from the Bay of Bengal enter inland up to 3-4 km. Cooum is another main river flowing through the middle part of the area and carries only drainage water, which is highly polluted. It originates as surplus water from the Cooum tank in Tiruvellore taluk. The flow of Cooum River at Korattur is 40.2 MCM/year for an average duration of 31 days in a year. Otteri Nulla is another small stream flowing in the northern part of the city. Buckinghum canal is the main man-made channel used for navigational purposes in the area north of Ennore, but acts as sewerage carrier in the city.

Geology: The Chennai area is underlain by various geological formations from the ancient Archeans to Recent alluvium. The geological formations of the area can be grouped into three units, namely the Archean crystalline rocks, consolidated Gondwana and tertiary sediments and the Recent Alluvium. Most of the geological formations are concealed since overlain by the alluvial material except for a few exposures of crystalline rocks like charnockites along the

railway track in Guindy area. The Archean crystalline rocks of the area comprise of C ks

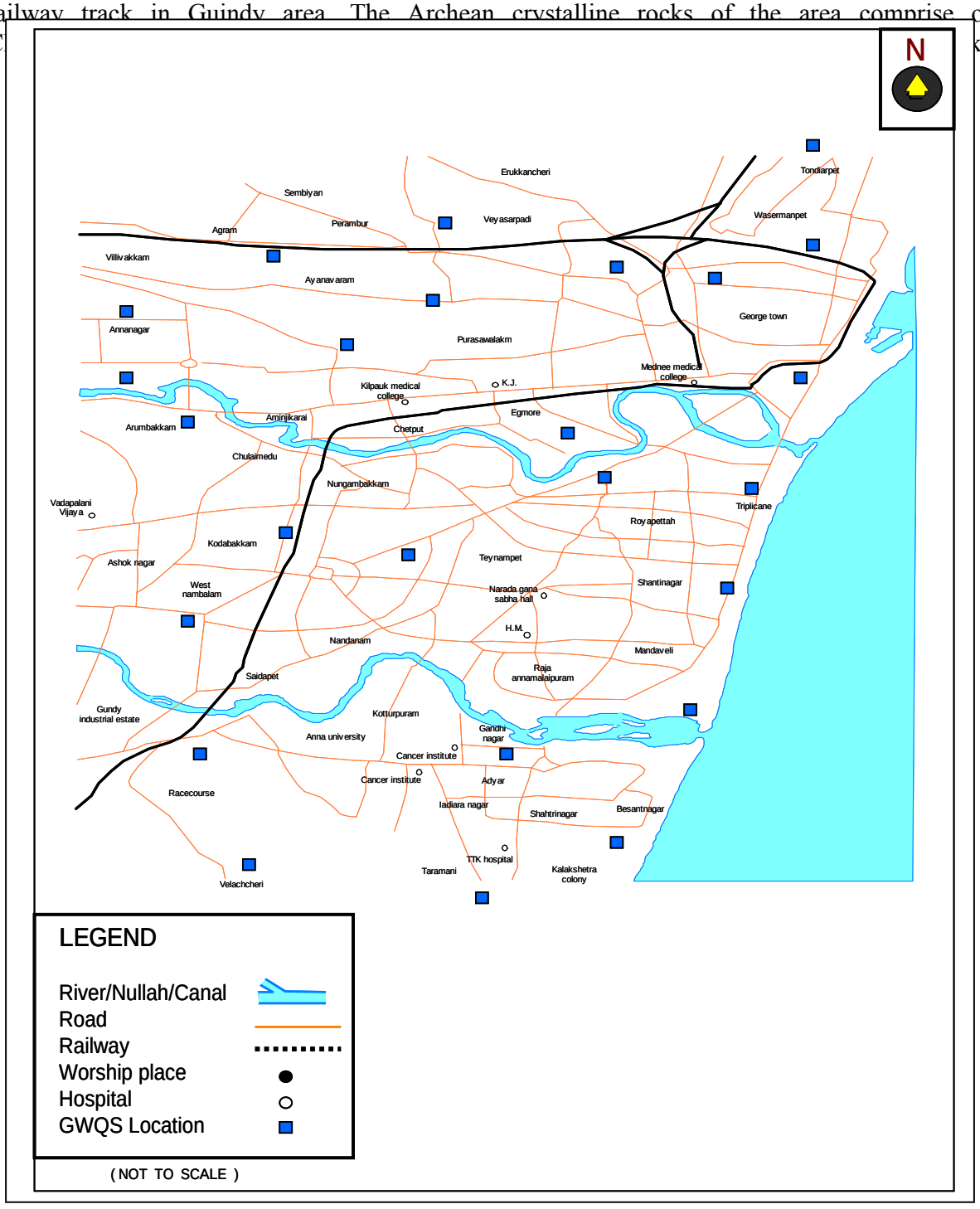


Figure 13: Map of Chennai City

are seen along the Adayar River bed outside Chennai, but no exposures are observed in the city. Sandstones, shales and clays represent the Gondwana sediments. The shales and clays are highly consolidated. The Gondwana shales are exposed in Adayar River near Ramavaram. The Tertiary

sandstones are reddish brown to grayish white and white in colors friable and mottled. The occurrence of Tertiaries in Chennai is not well demarcated. The Recent alluvium covers the major part of the city, but for the localized crystalline pockets in south Chennai in Gandhi Mandapam-Saidapeta Railway station area. The alluvium consists of sand, silts and clays. The thickness of alluvium varies from place to place and a maximum of 28m is encountered in North Madras near Perambur. Kilpauk water works area has 24 m thick alluvium. Groundwater in Chennai city occurs in all the geological formations viz. the Archaean crystallines, Gondwanas, Tertiaries and Alluvium and is developed by means of ring wells, dug wells, filter points, bore wells and tube wells. The average water levels are around 5 m. The Adayar river alluvium is 10 to 20 m in thickness and the occurrence of granular zones at depth varies from place to place. Cooum alluvium varies from 10 to 28 m in thickness and is more granular in Kilpauk-Perambur areas. Beach ridges and sand dunes in Tiruvanmiyur constitute good freshwater aquifers.

Groundwater and Water supply: The occurrence of groundwater is limited to thin granular zones in the alluvium and weathered and jointed, fractured rocks of crystalline rocks. The Gondwana sandstones and shales are also compact and fractured and contain appreciable amount of water at places. During the year 2003-04, Chennai faced a severe drought condition due to insufficient rainfall in the city. It is a common practice in the city, that like milk, drinking water cans are supplied regularly to the houses on payment of Rs. 2/- per litre. As the groundwater, which is the inherent source, is now contaminating with seawater or with pollutants or depleting with lack of rains, the people are forced to depend on the ozonised drinking water on payment basis. The predominant source of water supply to Chennai metropolitan city is surface water, i.e. run off during monsoon periods, stored in tanks and then treated and supplied. This is augmented by groundwater and also additional supply of water from Krishna River through Telugu Ganga Project. The flow in these rivers is seasonal and mostly due to northeast monsoon during the months of October, November and December. Chennai Metropolitan Water Supply and Sewerage Board (also called METRO WATER) engaged in the water supply and maintenance of distribution system in Chennai city. The surface water Reservoirs in Red Hills, Poondi, Chambarambakkam and Cholavaram tanks are the main source of water supply. There are number of groundwater well fields at Minjur, Tamarapakkam, Panjetty, Poondi, Kannigaiper and the Koratalaiyar flood plains in Chengai-MGR district tapping the groundwater in the Recent alluvium and supplementing the surface waters, in providing drinking water to the people of Chennai. Besides the well fields, water is also drawn from shallow wells with in the city boundary, much of it by hand pumps. There are about 35 municipal wells inside Chennai city, which are pumped directly into the overhead tanks, which are not connected to public water supply system. A notable feature in the city is that a shallow water table is available in most parts of the city with a depth of about 8 to 10 m. The area North east of the city was taken up for extensive hydro-geological studies and identified a buried channel, which should have been the course of Palar River thousands of years back. In this course, the well fields were identified extending a stretch of about 50 km length and 5 km average, which is suitable for extraction of groundwater. The aquifer is in general 30 m depth and water-bearing stratum is around 10 m depth. The water supply system maintained by Metro Water is presently drawing about 348 mld from both surface water and groundwater systems in years of normal rainfall. The surface run-off from Kortralaiyar, Nagari and Nandi rivers are collected and stored in three interconnected reservoirs namely, Poondi, Cholavaram and Redhills. Runoff from river Arani is also connected in these reservoirs by means of diversion constructed on the river, which is routed through

Kortralaiyar. Another source of drinking water is the supply of Krishna river water to Chennai in the Telugu Ganga Project. The amount of water 141.6 MCM of water will run from Srisailam reservoir with a stretch of 372 km of canals.

Sewarage & wastewater generation: Chennai is the first urban area of the State to have an under ground sewerage system. The system consisted of a network of gravity mains, force mains and pumping stations serving the different drainage areas into which the city was divided. The sewage collected from each area was pumped from one pumping station to other by relay and conveyed to Kasimedu north of harbour from where it was disposed into sea. As the city grew, the system of relay was found unsuitable and modified to zonalised system, covered in six zones of the city, with its own treatment plant. The Chennai city is divided into six zones for establishing the Sewage Treatment Plants as detailed below:

Zone	Location	Capacity (mld)	Irrigated area (ha)
I	Kodungaiyur	80	198
II	Kodungaiyur	80	--
III	Koyembedu	35	42
IV	Nesapakkam	23	8
V	Perungudi(Pallikaranai)	45	28
VI	Villivakkam	5	--
Total		268	

Due to inadequacy of the system, the sewage water overflows from pumping stations and join the Cooum, Buckingham canal and Adayar rivers. The Cooum and Adayar rivers also receive partially treated effluents from the treatment plants. Zone I serves the northwest of the city and is bounded by the Bay of Bengal to the east, the city limits to the north, the Buckingham canal to the west and Pycrofts road to the south. Sewage from this zone is presently diverted to the sea. Zone II is the largest of the 5 systems bounded by Buckingham canal on the east, Anna Salai/Adyar River in the south, Kodungayur to the south. Zone III is crucial to the water quality of Cooum River. The sewage from this zone is presently diverted to Koyambedu. Zone IV is bounded by the city boundary to the west and Adayar to the south, Arcot road to the north and zone III to the east. The sewage is diverted to treatment unit at Nesapakkam. Zone V is bisected by Adayar River with the northern section containing older parts of the city.

Industries: The majority of the industries are located in Guindy Industrial estate, SIDCO Nagar (Ambattur area), Basin Bridge, Korukkupeta, Tondiar Peta, Chromepeta (after Velachari), and Perambur etc. The most pollution causing industries like chemicals, oil refinery, oil storage tanks etc. are located in Northeast Chennai in Basin bridge area, Korukkupeta and Tondiar peta areas. Besides the above, some of the other major industries spread in Chennai are Standard Motors, Ashok Leyland, TVS, TI Cycles, Dunlop Rubber factory, Surgical instruments factory, Manali Refinery complex, Food factories, Beverage factories, wood, paper and paper products, Machinery tool industries, Transport equipments, Electrical machinery industries etc, Madras port is having 23 berths for handling the cargo in Bay of Bengal. The main exports from Madras seaport are hides and skins, ores, tobacco, food grains, cotton piece goods, bone and bone metal, sugar, chemicals, granites etc. The main imports in the port are food grains, iron and steel, fertilizers, paper, chemicals etc. The Chennai city is having Madras Petrochemical Ltd (Oil

refinery), which produces petrol, diesel, tar, etc. from the petroleum crude oil. The petroleum storage tanks of Indian Oil Corporation Ltd., Bharat Petroleum Corporation Ltd., and Hindustan Petroleum Corporation Ltd. Located near IOC Nagar, Tondiar Peta and Korukkupeta areas.

3.7.2 Groundwater Quality Survey in Chennai city

Groundwater samples from the metropolitan city of Chennai were collected each during pre-monsoon (June 2003) and post-monsoon (December 2003) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation The details of sampling locations and source and depth wise distribution are given in Table 12.

Table 12: Description of groundwater sampling locations in Metropolitan City-Chennai

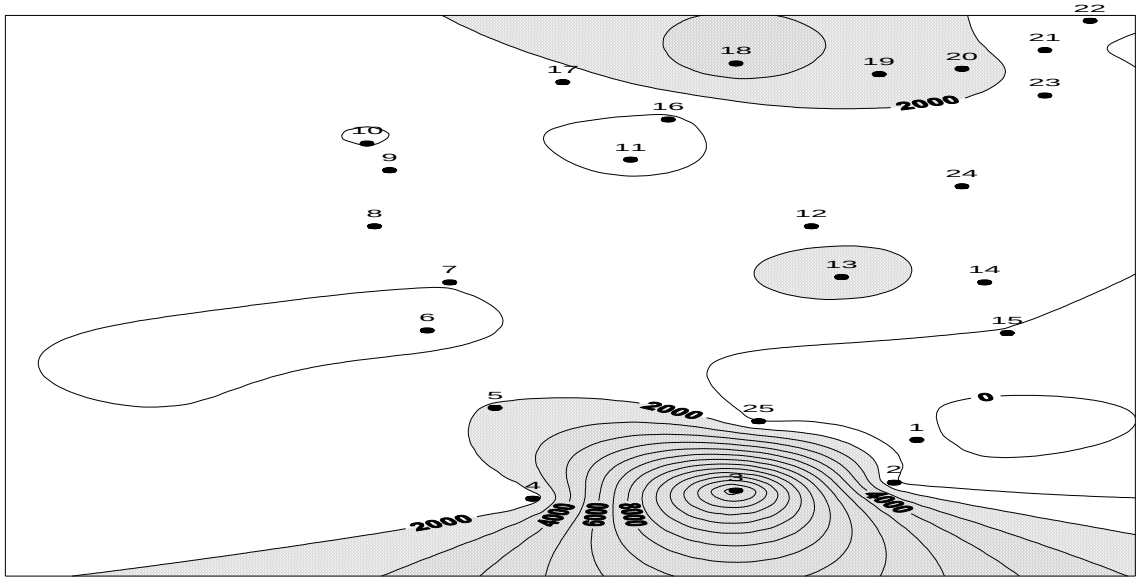
Sl. No.	Location	Identification	Source	Depth, m	Water Use	Land Use/Specific Activity
1	Besant Nagar	Sri. Varasiddi Vinayaka Temple	HP	12	Drinking	Urban
2	Tiruvanniyur	Marudeeswara Temple	HP	15	Drinking	Urban
3	Taramani	New Iyangar Bakery	HP	36	Drinking	Urban
4	Velacheri	Dandeswaran Temple	HP	30	Drinking	Urban
5	Guindy Industrial Estate	Public Hand Pump	HP	33	Drinking	Industrial Area
6	K K Nagar	Vignesh Travels	HP	36	Drinking	Urban
7	Vadapalani	Water Servicing Station	HP	36	Drinking	Urban
8	Koyambedu	Kalyana Mandapam	OW	12	Drinking	Urban
9	Anna Nagar (West)	849, J Block	HP	24	Drinking	Urban
10	Villivakkam	Public Hand Pump	HP	45	Drinking	Industrial Area
11	Ayanavaram	Opp. Sri Balaji Stores	HP	42	Drinking	Urban
12	Egmore	Shishu – The Play School	HP	30	Drinking	Urban
13	Roypet	Central Chennai Corp. Dispensary	HP	48	Drinking	Urban
14	Triplicane	Public Hand Pump	HP	30	Drinking	Urban

15	Santhome	Santhome Church Compound	HP	10	Drinking	Urban
16	Perambur	Public Hand Pump	HP	15	Drinking	Urban
17	Sembiyam	Public Hand Pump	HP	36	Drinking	Urban
18	Erankancheri	Public Hand Pump	HP	42	Drinking	Urban
19	Stanley Nagar	Public Hand Pump	HP	45	Drinking	Petroleum Storage
20	Kurukumpeta	Opp. Indian Oil Corporation	HP	24	Drinking	Petroleum Storage
21	Tondiar Pet	Public Hand Pump	HP	36	Drinking	Urban
22	Toll Gate	Public Hand Pump	HP	42	Drinking	Urban
23	Washerman Pet	Public Hand Pump	HP	33	Drinking	Urban
24	Park Town Area	Public Hand Pump	HP	45	Drinking	Urban
25	IIT Madras Campus	Near Q.No. D1/42	HP	45	Drinking	Urban

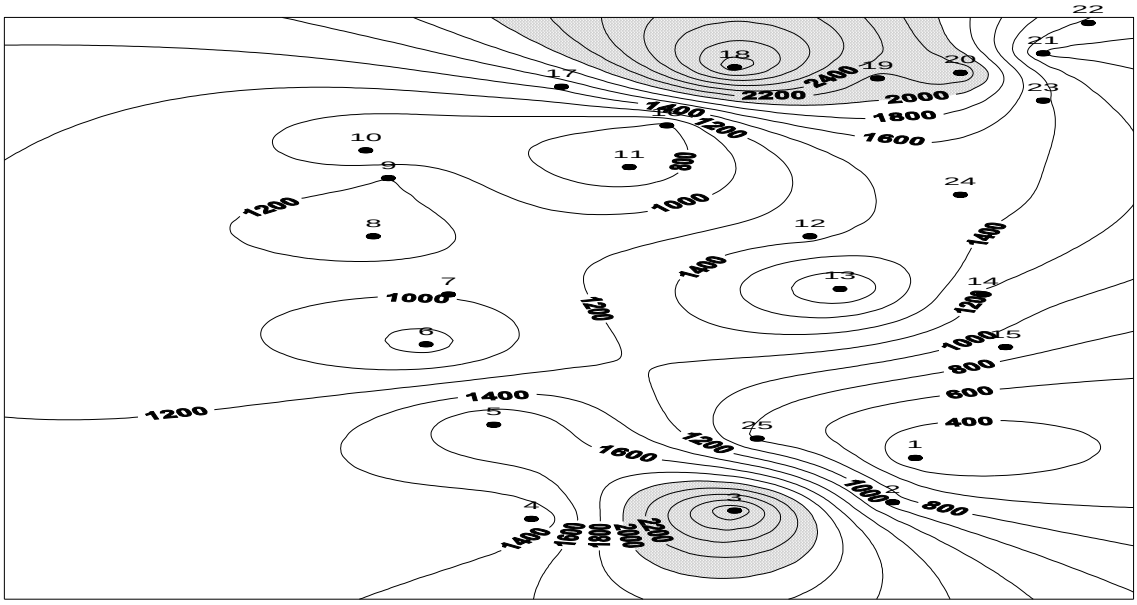
Note: HP - Hand Pump; OW - Open Well

3.7.3 Observations on status of Groundwater Quality in Chennai city

The groundwater quality of the Metropolitan City of Chennai has been assessed to see the suitability of groundwater for domestic applications. The samples collected during pre- and post-monsoon were analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-nuclear aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards and hydro-chemical facies were determined. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of electrical conductivity, total dissolved solids, alkalinity, hardness, calcium, magnesium, chloride, sulphate, fluoride, iron, manganese, nickel, lead and cadmium vis-à-vis drinking water quality standards. Pesticides analysis indicated the presence of Aldrin, α-BHC, δ-BHC and Endosulphan at few locations in groundwater of the metropolitan city. The presence of these pesticides in groundwater may be attributed to their use in agricultural activities and for vector control programmes. No Organo-phosphorous pesticides and poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city. The ranges of each parameter along with observations/comments on groundwater quality are presented in Table 6 of Annexure I. An attempt has also been made to show TDS and Nitrate distribution in Chennai Metropolitan city during pre and post Monsoon season (Figure 14 & 15).

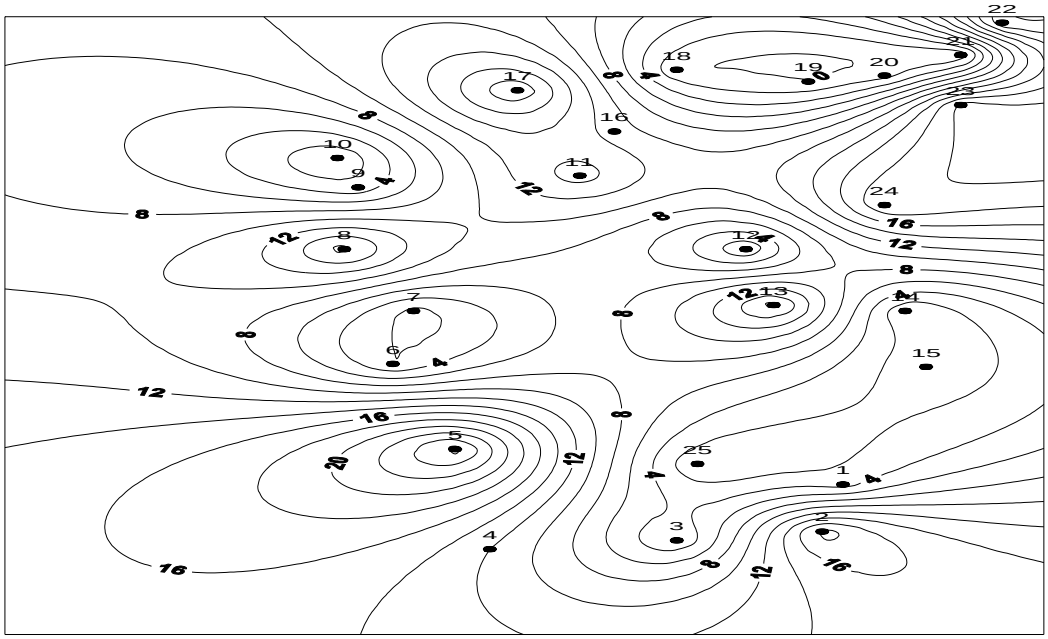


TDS distribution in ground water of
Metropolitan City - Chennai (Pre-monsoon 2003)



TDS distribution in ground water of
Metropolitan City - Chennai (Post-monsoon 2003)

Figure 14: TDS distribution (pre and post monsoon) in Metropolitan city of Chennai



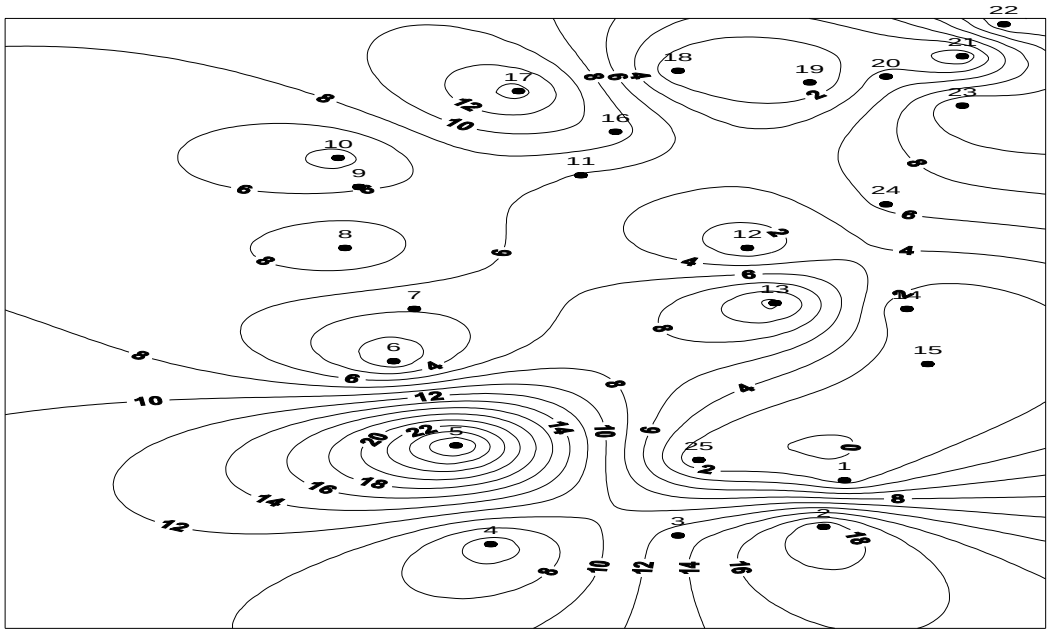


Figure 15: Nitrate distribution (pre and post monsoon) in Metropolitan city of Chennai

3.8 Madurai Metropolitan City

3.8.1 Environmental Profile of Madurai

Topography: Madurai city, which is more than 2500 years old, was once the mighty capital of the ancient Pandya Kingdom. This city has been famous as the seat of Tamil Literature in Southern India and conferences of scholars – Sangams - were held here from remote ages. In one of those gatherings of scholars, Lord Sundareswarar himself is said to have played the part of a poet. The metropolitan city of Madurai is located at $9^{o}58'$ N latitude and $78^{o}10'$ E longitude and occupies an area of about 140 km^2 .The metropolitan city, situated on the banks of the River Vaigai, is the 24^{th} largest town in India (population wise) and third largest in the state of Tamil Nadu after Chennai and Coimbatore. City map of Madurai metropolitan is shown in Figure 16.

Population: The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Madurai is 11,94,665.

Climate: Hot and humid, Madurai has the typical climate of the rest of the Deccan plateau. Normally, Sub tropical climate prevails over the city without any sharp variation. The average annual rainfall of the city is 867 mm from four distinct seasons, viz., and South West monsoon, North East Monsoon, Winter Season and Hot Summer Season. The precipitation is uncertain, uneven or unequally distributed. A perceptible change in the pattern of rainfall is noticed, traversing from Western Ghat Region, through Periyakulam, Usilampatti Taluks to Madurai and Melur regions in the east. The temperature rises slowly to maximum in summer months up to May and after which it drops slowly. The mean monthly maximum temperature ranges from 29.2 to 41.8°C and the mean monthly minimum temperature from 13 to 24°C.

Geology: Geologically, the entire Madurai District can be broadly classified into hard rock and sedimentary (alluvial) formations. Hard rocks underlie more than 90% of the district. Generally, hard rock does not contain potential aquifers to store large quantity of water and to transmit to other areas. Alluvial deposits such as sand, silt, stiff clay, gravel etc., are transported sediments by the river are found on either side of Vaigai near Madurai and Vadipatti blocks. These formations are overlying the hard rock as a thin layer. There are six different types of soils in the district, i) Thin red soil, ii) Deep red soil, iii) Red storile soil, iv) Laterite soil, v) Black soil and vi) Red sandy soil. The metropolitan city of Madurai contains red sandy soil. Gneissic type: Groundwater occurs under water table or phreatic conditions in weathered, jointed and fractured formations. The pore space developed in the weathered mantle (disintegrated material) acts as shallow granular aquifers and forms the potential water bearing and yielding zones. Water table is very shallow in canal and tank irrigated regions whereas it is somewhat deeper in other regions. Charnockite type: Groundwater occurs under water table or phreatic conditions but the intensity of weathering, joint, fracture and its development is much less when compared to gneissic formations. As a result, these are not termed, as potential water bearing zones excepting in a region where the intensity of weathering coupled with development of joints and fractures is greater. Sometimes the occurrence of kankar material over charnockite hampers the permeability and well yielding capacity. In alluvial formation, groundwater occurs under water table or semi confined conditions. These formations are highly porous, permeable and develop into potential water bearing zones. Valleyfill sediments groundwater occurs under water table or semi confined

conditions. The Valleyfill sediments are highly porous and permeable and the sandy material facilitates vertical infiltration. There is considerable diversity in the nature of formation even within the short distance. The sedimentary tract of Vaigai alluvium is restricted to either side of the river Vaigai and the thickness of alluvium is estimated to be around 20 m. There is not much variation in the lowest and highest water level conditions over the years in Madurai (North and South), Water requirement for Madurai city is mainly through sub surface (Infiltration Wells) and Vaigai reservoir, which is about 75 km from Madurai.

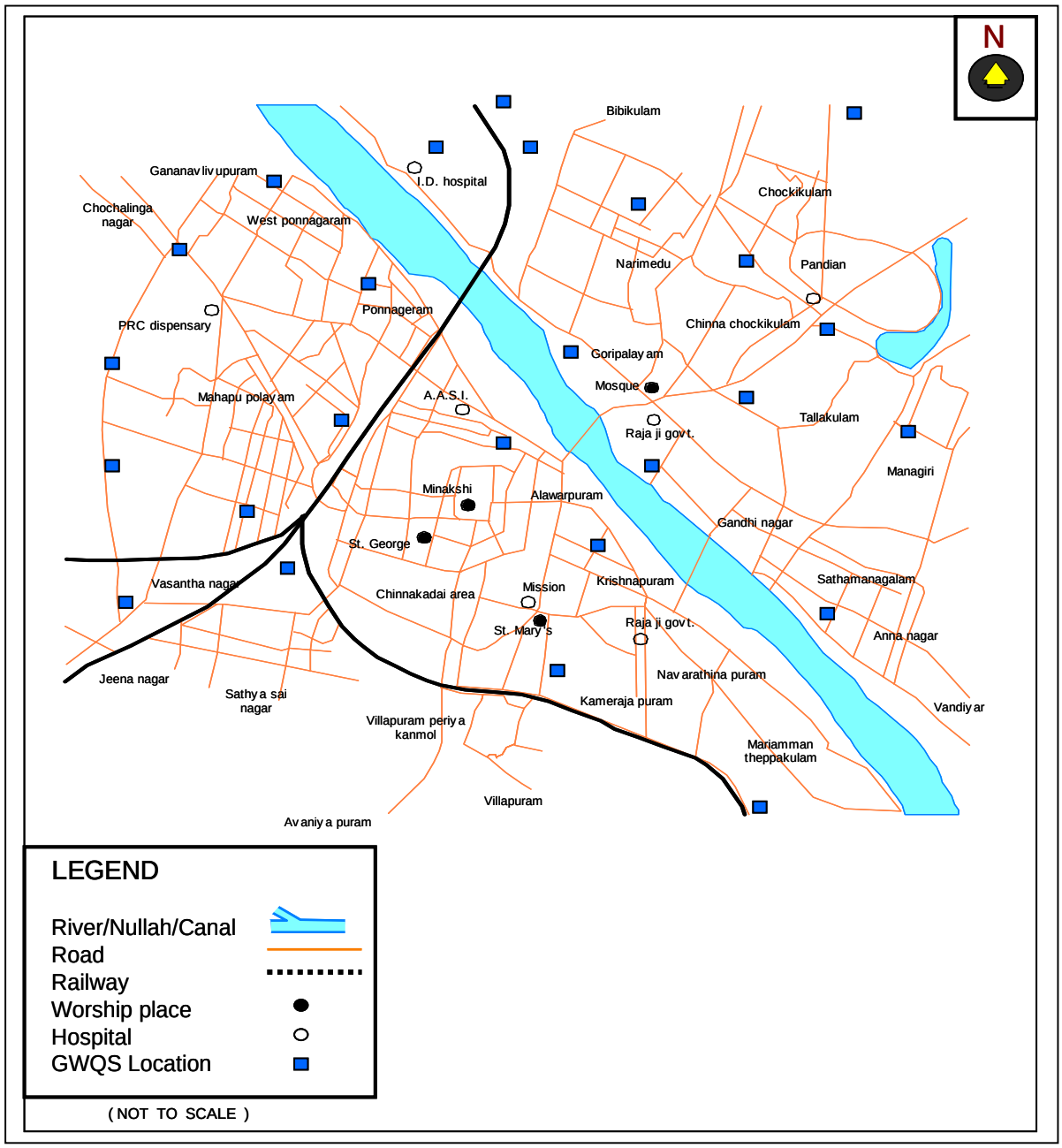


Figure 16: Map of Madurai City

Water resources and Water supply: The flow in the river Vaigai is seasonal and surface flow could be seen only during peak monsoon seasons. Further, vagaries of monsoon directly affect the flow of surface water into the reservoirs, anicuts, lakes etc., and naturally the cultivators have to look for alternative source, viz, groundwater to meet their irrigation requirements. The water supply through sub surface source is 23 mld and from Vaigai reservoir is 68 mld during normal season. But during summer season, the supply is only from Vaigai reservoir and corporation bore wells. The total water supply to the city is about 91 mld through corporation and covers most of the localities within the city area. The corporation area has been divided into 72 wards for water supply distribution.

Wastewater generation: The total municipal corporation wastewater generation in the city is about 80 mld. Only 60% area is covered by underground drainage system. In other areas, people are using septic tanks and soak pits. In some places, the sewage is discharged into open drains either lined or unlined, low lying areas and along the Vaigai riverside without any treatment. Ultimately the wastewater from densely populated areas of both domestic and industries joins at Aveniyapuram and treated by anaerobic system. The treated water is used for growing grasses and other horticultural activities.

Municipal Solid waste: The approximate solid waste generation in Madurai city is about 400 MT/day. The solid waste from house hold and industries in Madurai city is dumped in municipal waste containers located at various places of the city, low lying areas and near the roads, from where it reaches to temporary waste transfer stations at Mattuthavani, Chinna Kanmoi and Sammattipuram. Ultimately, the solid waste is transferred to main sanitary landfill at Aveniyapuram, a place outside the Madurai municipal corporation area. There is no proper system of monitoring the dumping activities.

Industries: The metropolitan city of Madurai is a burgeoning industrial centre with its famous textile mills, & engineering industries. It is estimated that there are approximately 11,000 registered industrial units in the metropolitan city of Madurai, out of which only about 5000 units are functional at present. Most of the Industries are located in Pudur (SIDCO) Industrial Estate, Sellur, Aveniyapuram, Kochadai and Anuppanadi. Textile mills, Dyeing units, Powerlooms, Handlooms, Engineering and Mechanical industries, Electrical and Electronic appliances, Steel rolling mills and small scale industries like Food products, Readymade Garments, Wooden industries, Printing, Moulding industries predominate in the area. There are two petroleum, diesel and kerosene, storages (IOCL and HPCL) existing in Vilangudi and near by Railway station. The other one storage (BPCL) exists in Kappalur, which is located 15 km outside the Madurai city area. The total number of petrol pump of different agencies in the metropolitan city is 36.

3.8.2 Groundwater Survey in Madurai city

Groundwater samples from the metropolitan city of Madurai were collected each during pre-monsoon (June 2003) and post-monsoon (December 2003**)** seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation The details of sampling locations and source and depth wise distribution are given in Table 13.

Table 13: Description of groundwater sampling locations in Metropolitan City – Madurai

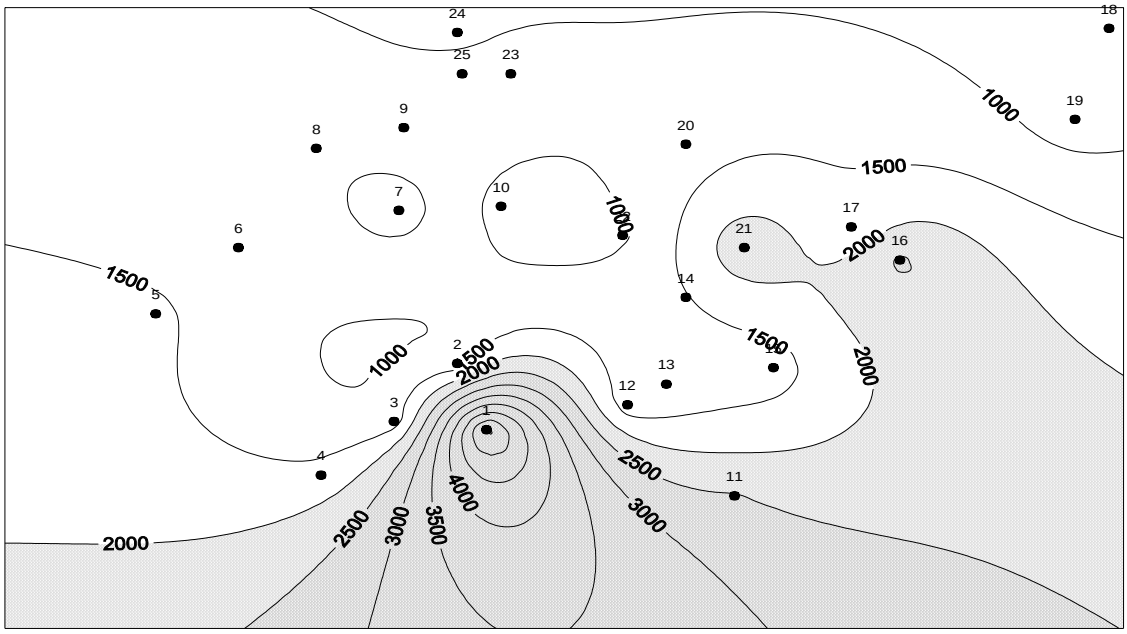
Sl. No.	Location	Identification	Source	Depth, M	Water Use	Land Use/ Specific Activity
1	Aveniyapuram	Tuticorin By-pass Road Mani Cement Works	OW	13	Domestic	Residential/ Landfill site
2	Andalpuram	Below Railway Over Bridge	BW	45	Domestic	Residential/ Waste disposal
3	TVS Nagar	C-31/57, Rajam Road Residence	BW	75	Domestic	Residential
4	Muthupatti	RMS Colony	BW	45	Domestic	Residential
5	Pasumalai	Residence Near Post Office	OW	30	Domestic	Residential
6	Madakulam	Kabali Eswariamman Temple	OW	9	Domestic	Residential
7	Chokkalinga	7th St. near Police Station	BW	45	Domestic	Residential/ Waste disposal
8	Virattipattu	Balaganapathi Temple	BW	45	Domestic	Industrial
9	Pethaniapuram	1st Cross Street	BW	45	Domestic	Residential
10	West Ponnakaram	Opp. Ganapathy Pillai House, Main Road	BW	90	Domestic	Residential/ Petro.storage
11	Anuppanadi	Near TWAD Tank	BW	60	Domestic	Industrial
12	East Madurai	Chinthamani Road, Near Agrochemicals Shop	BW	60	Domestic	Industrial
13	Balarangapuram	Opp. Nageswariamman Temple	BW	90	Domestic	Residential /Waste disposal
14	Alwarpuram	River Side Public BW	BW	45	Domestic	Residential
15	Sathamangalam	Opp. Arvind Eye Hospital	BW	121	Domestic	Residential
16	K.K. Nagar	Opp. Kalaivani Tailors, LIC Colony	BW	60	Domestic	Residential/ Waste disposal
17	Pudur	SIDCO, Ramavarma Nagar 6th St.	BW	45	Domestic	Industrial
18	Jawaharlal Puram	Residence Well	OW	18	Domestic	Residential
19	Kodikulam	Surya Nagar Lime Factory	OW	12	Domestic	Residential

20	Bibikulam	Corporation Toilet BW	BW	90	Domestic	Residential
21	Chinna Chokikulam	OCPM School opp. Police Quarters	BW	60	Domestic	Residential
22	Sellur	Tagore Nagar Tank Bund Side	BW	75	Domestic	Industrial
23	Vilangudi	Residence No. 6/26, IOC Nagar	BW	21	Domestic	Residential/ Petroleum storage
24	Vilangudi	KPS Garden	OW	15	Domestic	Residential/ Petroleum storage
25	Vilangudi	Panchayat Ofiice	OW	15	Domestic	Residential/ Petroleum storage

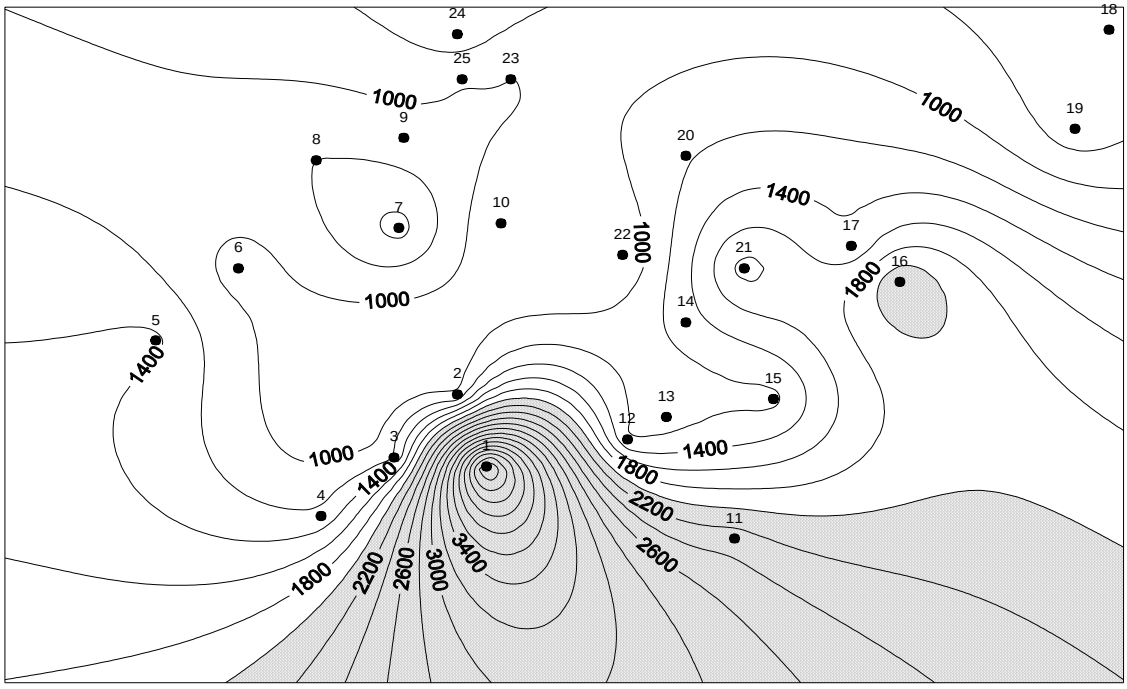
Note: BW - Bore Well; OW - Open Well, TW- Tube well; BW- Bore well

3.8.3 Observations on Groundwater Quality in Madurai city

The groundwater quality of the Metropolitan City of Madurai has been assessed to see the suitability of groundwater for domestic applications. The samples collected during pre- and post-monsoon seasons were analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards and hydro-chemical facies were determined. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of electrical conductivity, total dissolved solids, alkalinity, hardness, calcium, magnesium, chloride, sulphate, fluoride, iron, manganese, nickel, lead and cadmium vis-à-vis drinking water quality standards. Pesticides analysis indicated the presence of Aldrin, α-BHC, β-BHC and γ-BHC in groundwater of the metropolitan city. The presence of these pesticides in groundwater may be attributed to their use in agricultural activities and for vector control programmes. No organo-phosphorous pesticides and poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city. The range of each parameter along with observations/comments on groundwater quality is presented in Table 7 of Annexure I. An attempt has also been made to show TDS and Nitrate distribution in Madurai Metropolitan city during pre and post Monsoon season (Figure 17 & 18).

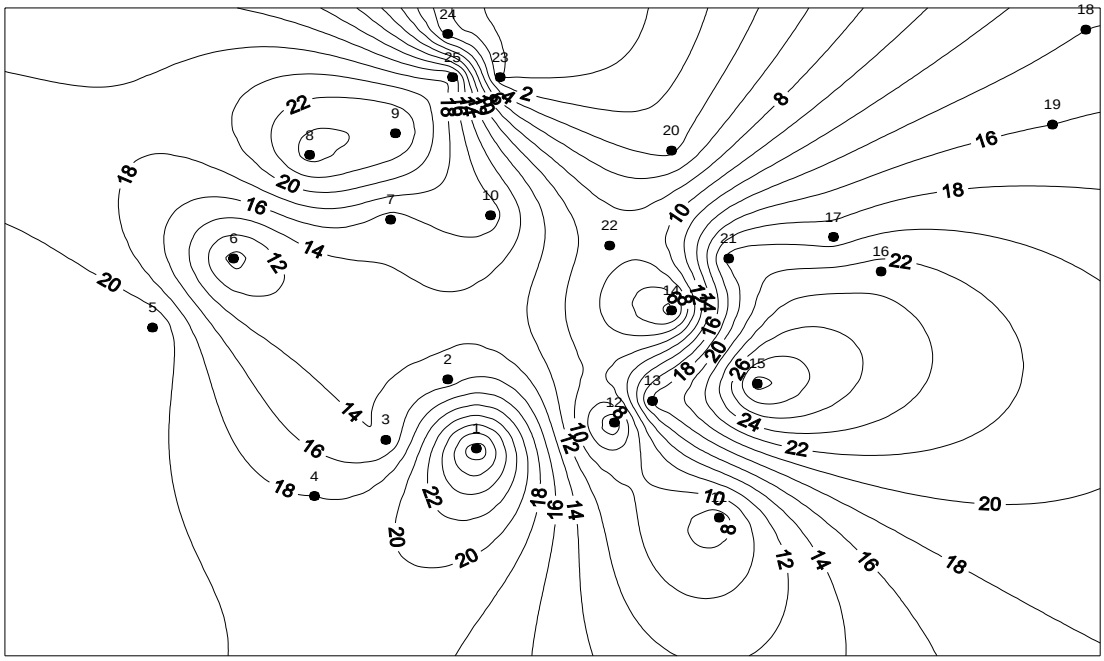


TDS distribution in ground water of Metropolitan City - Madurai (Pre-monsoon 2003)

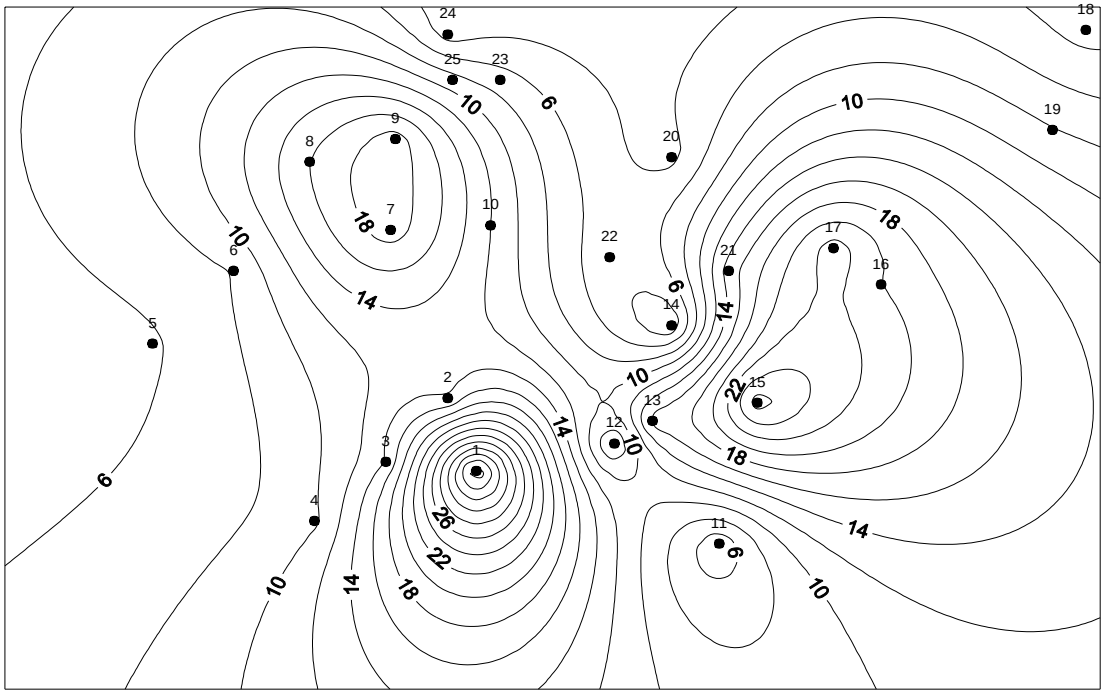


TDS distribution in ground water of Metropolitan City - Madurai (Post-monsoon 2003)

Figure 17: TDS distribution (pre and post monsoon) in Metropolitan city of Madurai



Nitrate distribution in ground water of Metropolitan City - Madurai (Pre-monsoon 2003)



Nitrate distribution in ground water of Metropolitan City - Madurai (Post-monsoon 2003)

Figure 18: Nitrate distribution (pre and post monsoon) in Metropolitan city of Madurai

3.9 Vijaywada Metropolitan City

3.9.1 Environmental Profile of Vijaywada

Topography: The metropolitan city of Vijayawada is one of the important towns of the Andhra Pradesh and is located on the banks of the holy river Krishna. The metropolitan city occupies an area of about 73 km^2 and is located at $16^o31'$ N latitude and $80^o39'$ E longitude. Endowed with a rich variety of soil, the delta area in Krishna District occupied an important place in agricultural production. The Kondapalli hills near Vijayawada and the Jammalavaidurgam hill near Konduru are the two prominent hill ranges around Vijaywada. A city map of Vijaywada metropolitan has been shown in Figure 19.

Population: It is the 34^{th} largest town in India (population wise), and the 3^{rd} largest town in Andhra Pradesh. The population pressure on the city is ever growing. As per 2001 census, the population of metropolitan city Vijayawada is 10,11,152.

Climate: The climate of the City can be classified as tropical with extreme hot summer and cold winter. The normal rainfall of the district is 1028 mm. of which two-third is received during southwest monsoon. The amount of rainfall generally increases from west to east. Of the total rainfall, the southwest monsoon contributes 63% and the northeast monsoon contributes 28%. The southwest monsoon commences from June and end in September and the northeast monsoon period is from October to December. The rainfall in summer is of cyclonic nature with gales. The average maximum and minimum temperatures recorded are 32.3^OC and 23.8°C respectively. The average annual evaporation is 1732 mm. The average relative humidity in the city ranges from 65 to 86% and the lowest humidity of 45% is registered in summer season.

Geology and Soil type: The area has varied lithological formations ranging in age from Archaean crystallines to recent alluvium. Depending upon the occurrence of these rock formations the area can be divided into three lithological provinces. i) The north and western part occupied by crystalline group of rocks comprising of Khondalites, Peninsular gneisses, Dharwars and Proterozoic group of rocks, ii) North-eastern and central part occupied by Sandstones of Gondwana group and iii) Eastern and southern part occupied by River and Coastal Alluvia. There are four types of soils in the area, viz., Black cotton soils (57.6%), Sandy clay loams (22.3%), Red loamy soils (19.4%), and Sandy soils (0.7%). The sandy soils form a fringe along the coast. The black cotton soil is most extensive and occurs in Western part. The sandy clay loams formed along river.

Groundwater: The groundwater occurs under water table to semi-confined conditions in the weathered/fractured zones of Khondalites and sand zones of Alluvium. Its movement is governed by porosity and permeability of the formation. The productivity of the aquifers in Alluvium is directly proportional to the thickness of sand bed and grain size of sand. The tapping of groundwater is being done through filter points and ring wells in Alluvium and open wells/bore wells in Khondalites. The filter points are constructed down to a depth of 10 to 40 m and bore wells to a depth of 40 to 70 m. The yields range from 300 to 1000 lpm for filter points and 100 to 200 lpm for bore wells. Most of the wells are used for domestic purpose due to

urbanization. Ring wells are excavated down to a depth of 3 to 4 m in alluvium and used for domestic purpose.

Waster supply & wastewater generation: The drinking water supply for Vijaywada city is drawn mainly from Krishna River, though groundwater is available in plenty in shallow depths. People are dependent on Krishna River water for drinking due to its sweetness and holiness as well as its freshness. Though River Krishna meets the demands of the people of Vijaywada city, the Municipal Corporation is supplying groundwater as well in some areas of the city, due to the economic constraints in laying pipelines and supplying to far places. Accordingly, the total water supply to the city by Municipal Corporation is 177 mld, out of which 132 mld is drawn from Krishna River and the remaining 45 mld is fulfilled by the groundwater. The City is having a total number of 32 overhead tanks maintained by Vijaywada Municipal Corporation. Prakasam Barrage of length 4,014 feet existing on River Krishna at Vijaywada and meeting all the demands of the delta. Three canals are diverted from Prakasam barrage, namely, Ryves canal, Eluru canal running through middle of the city and Bundar canal flowing parallel to Krishna river in the south of Vijayawada. Besides the mighty River Krishna, another river named Budameru is also passing through the city parallel to Eluru canal. As there is no much flow in this river, it is presently acting as a drain rather than river and finally joining the famous Kolleru Lake in Kaikaluru.

Wastewater generation and treatment: The wastewater produced is around 160 mld. The wastewater is drained by underground draining system in the middle of the city and open draining system in the western side of the city. The major sewage treatment plant (STP) is located at Ajit Singh Nagar in the outskirts of the city and treating nearly 27 million litres per day. Two more sewage treatment plants are under progress at Autonagar and Ramalingeswara nagar. The treated wastewater is used for fodder cultivation in nearby fields and the excess water is let into the Budameru drain or into the downstream of the canals. The major drains in the city are Gundutippa drain, Islampeta drain, and HB drain.

Municipal Solid Waste: The average solid waste generated in the city is 550 tons/day. Vijaywada Municipal Corporation setting an example of generating Wealth from Waste is also using the solid waste properly. The solid waste is being supplied to M/s Excel Industries Pvt. Ltd., Ajitsingh Nagar. The Excel industries is using 150 tons of waste per day by converting the solid waste into manure, called CELRICH, which is a bio-organic soil enricher, thus creating a clean environment to Vijaywada city and a hygienic product to the Plants. M/s Sri uses another 400 tonnes of waste for generating 6 MW power. Ram Energy Systems, which is also adjacent to Excel Industries at Ajit Singh Nagar. The Municipality is also having a Railway dumping yard at Milk project area for waste dumping. Thus, Vijayawada Municipal Corporation has set up an example in utilizing the wastewater and solid waste by proper disposal and utilization.

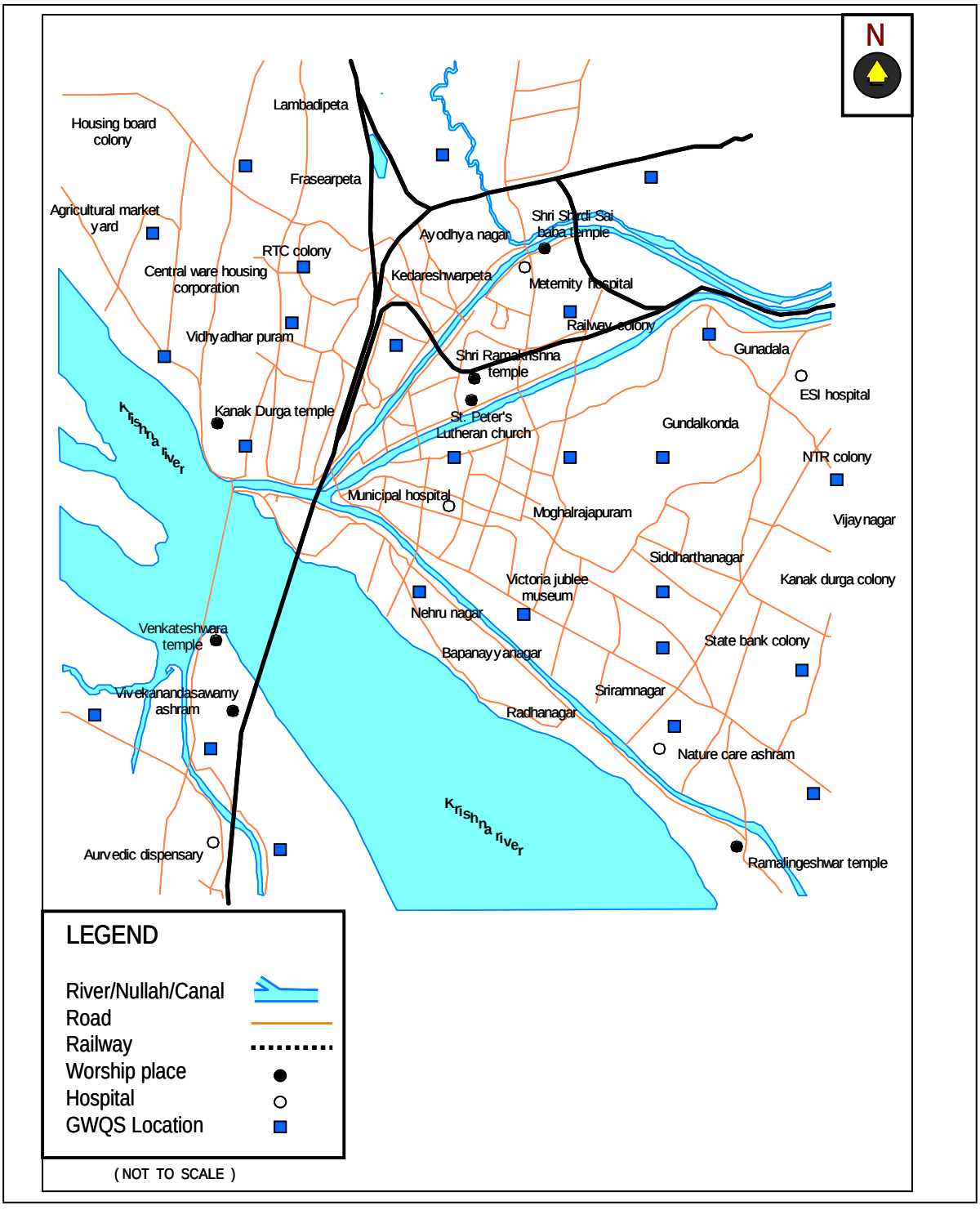


Figure 19: Map of Vijaiwada City

Industries: The metropolitan city of Vijaywada is has number of small and big industries. The most common industries existing in the metropolitan city include rice mills, edible oil,

beverages, tobacco products, cotton textiles, wood and wood products, paper and paper products, leather, rubber, plastic products, motor vehicle spare parts, utensils, scientific instruments, dall and flour mills, chemicals, pharmaceuticals, oil refinery of used motor oils, brawn oil companies, ayurvedic medicines, pickle companies, etc. Most of the industries are located in Industrial estate and Autonagar areas. Milk processing is also a major industry in the city supplying milk in most parts of the district. The NTPC, which is producing thermal electricity, is also just 15 km from Vijayawada city. There are no petroleum storage tanks in the city. The petroleum storage tanks are located at Kondapalli village, which is 25 km away from Vijayawada city. As such, there is no pollution of petroleum leakages in the city area. In the Autonagar area, it is reported that the water is oily, as the automobile servicing units are concentrated in this area and polluting the groundwater with the waste oils.

3.9.2 Groundwater Quality Survey in Vijaywada city

Groundwater samples from the metropolitan city of Vijaywada were collected each during pre-monsoon (June 2003) and post-monsoon (December 2003) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation The details of sampling locations and source and depth wise distribution are given in Table 14.

Table 14: Description of groundwater sampling locations in Metropolitan City - Vijaywada

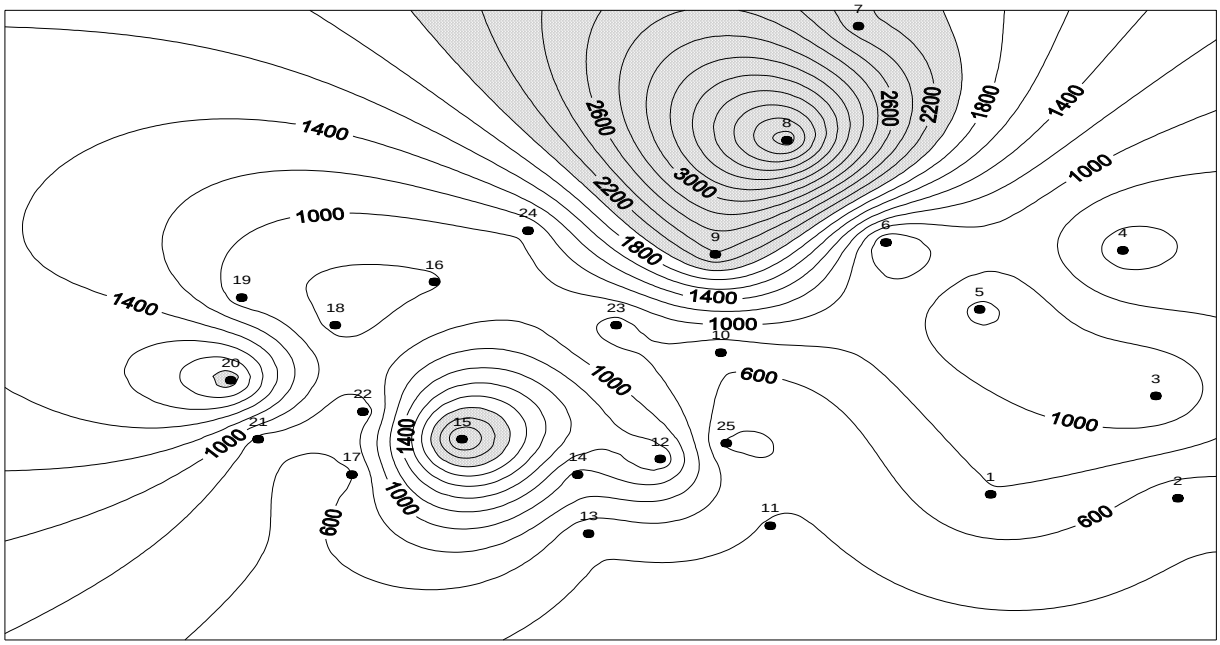
Sl. No.	Location	Identification	Source	Depth, m	Water Use	Land Use/ Specific Activity
1	Benz circle	Opp. Nirmala Convent	HP	36	Drinking	Urban
2	Ashok Nagar Ind. Estate	Opp. Velagapudi Cold Storage	HP	27	Drinking	Industrial Area
3	Auto Nagar	Opp. India Radiators	HP	48	Drinking	Automobile Servicing Area
4	Goldsport Junction	Sri. Lakshmi Rice Store	HP	12	Drinking	Urban
5	Gunadala	Opp. ESI Hospital	HP	10	Drinking	Urban
6	Karmel Nagar	Deepa Nivas	HP	9	Drinking	Agricultural
7	Khandrika	Khandrika Bus Stop Centre	HP	30	Drinking	Urban
8	Payakapuram	Sri. Manasa Fast Foods	HP	21	Drinking	Urban
9	Ajit Singh Nagar	Rajasri Bar and Restaurant	HP	24	Drinking	Urban
10	Satyanarayana Puram	D.No. 23-16-27	OW	5	Drinking	Urban
11	Krishna Lanka	D.No. 41-1/6-2	HP	15	Drinking	Urban
12	Governor Peta	Hotal Paradise	HP	9	Drinking	Urban

13	Krishna Lanka	Opp. Central Bus Stand	HP	27	Drinking	Urban
14	Hanuman Peta	Near Govt. General Hospital	HP	30	Drinking	Urban
15	Kotha Peta	Near St. Ani Public School	HP	18	Drinking	Urban
16	Bheemannavari Peta	Sri. Ganganamma Devi Temple	HP	18	Drinking	Urban
17	Vidhyadhara Puram	Near RTC Workshop	HP	38	Drinking	Urban
18	Jogi Nagar	Near Church	HP	45	Drinking	Urban
19	Urmila Subba Rao Nagar	D.No. 76-17-161	HP	30	Drinking	Urban
20	Bhavanipuram	HIG-H1-70	HP	45	Drinking	Urban
21	Hyderabad Highway	NH-9 & HB Colony Junction	HP	45	Drinking	Urban
22	Vidhyadhara Puram	Anita Apartments	HP	30	Drinking	Urban
23	Ayodya Nagar Junction	Opp. Raghavendra Theatre	HP	7	Drinking	Cement Industry
24	Rajarajeswari Peta	Opp. Habeeb E. Medium School	HP	30	Drinking	Urban
25	Governor Peta	Near Surya Hotal	HP	16	Drinking	Urban

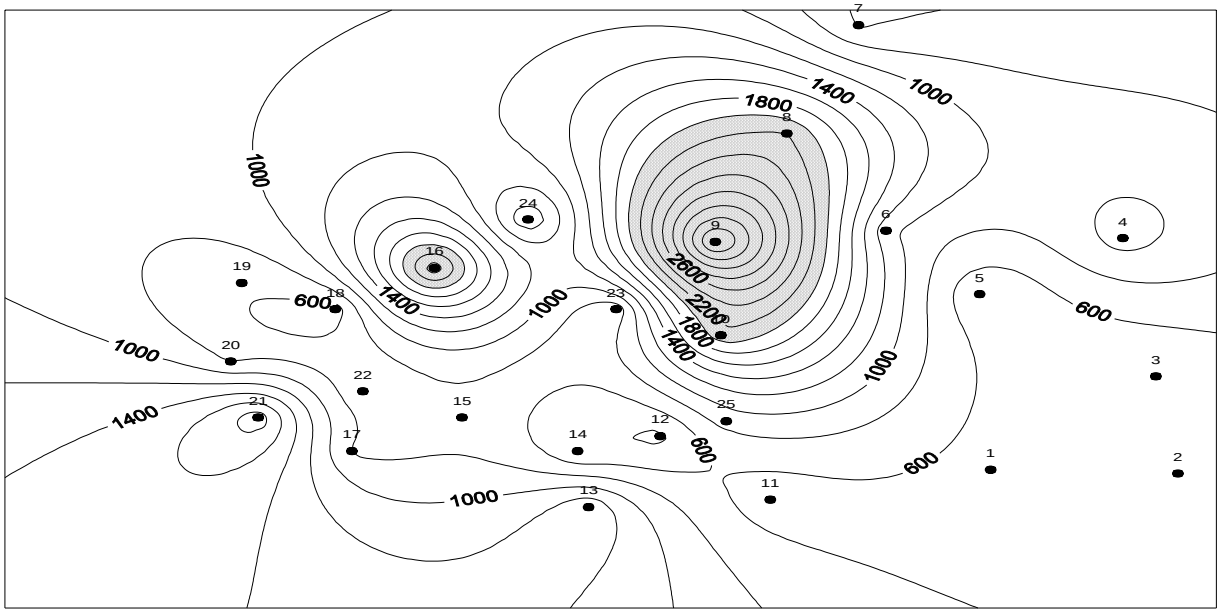
Note: HP – Hand Pump; OW - Open Well; BW- Bore well; TW- Tube well

3.9.3 Observations on status of Groundwater Quality in Vijaywada city

The groundwater quality of the Metropolitan City of Vijaywada has been assessed to see the suitability of groundwater for domestic applications. The samples collected during pre- and post-monsoon seasons were analyzed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and poly-aromatic hydrocarbons. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards and hydro-chemical facies were determined and water types identified. The quality of the groundwater varies from place to place with the depth of water table. The groundwater quality has indicated higher concentration of electrical conductivity, total dissolved solids, alkalinity, hardness, calcium, chloride, fluoride, iron, manganese, nickel, lead and cadmium vis-à-vis drinking water quality standards. The range of each parameter along with observations/comments on groundwater quality is presented in Table 8 of Annexure I. Pesticides analysis indicated the presence of Aldrin, DDD, DDE, α-BHC, β-BHC, γ-BHC, Endosulphan and Methoxychlor in groundwater of the metropolitan city. The presence of these pesticides in groundwater may be attributed to their use in agricultural activities and for vector control programmes. No organo-phosphorous pesticides and poly-nuclear aromatic hydrocarbons were detected in any of the groundwater samples of the metropolitan city. An attempt has also been made to show TDS and Nitrate distribution in Vijaiwada Metropolitan city during pre and post Monsoon season (Figure 20 & 21).

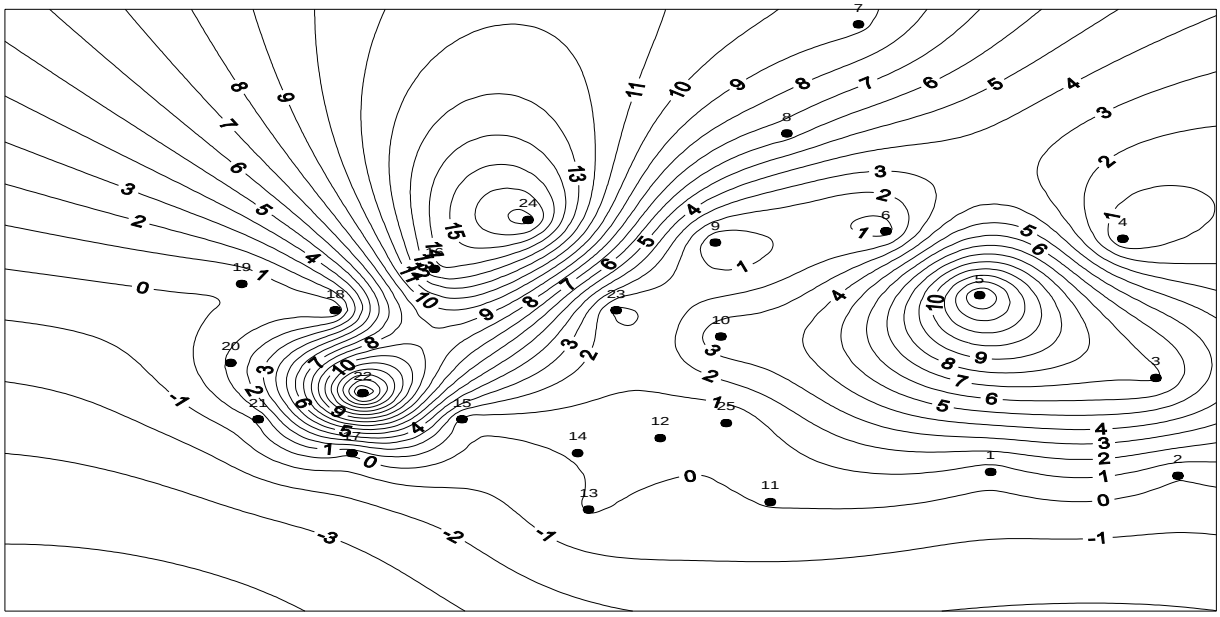


TDS distribution in ground water of Metropolitan City - Vijaywada (Pre-monsoon 2003)

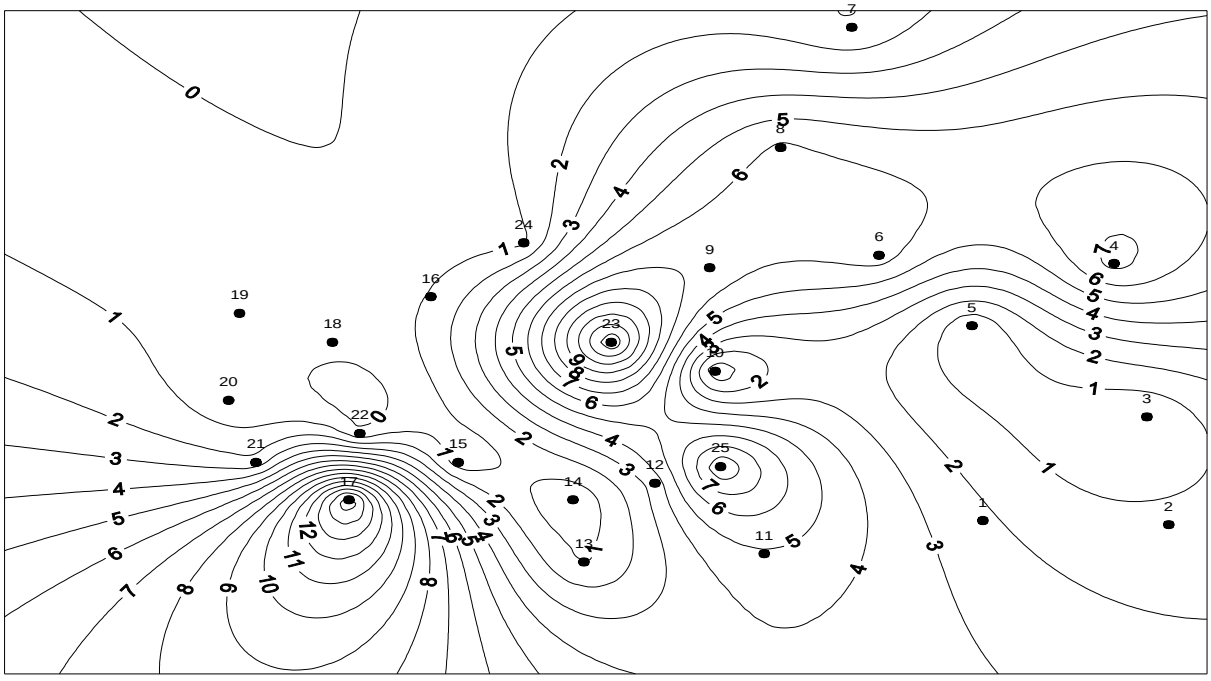


TDS distribution in ground water of Metropolitan City - Vijaywada (Post-monsoon 2003)

Figure 20: TDS distribution (pre and post monsoon) in Metropolitan city of Vijaiwada



Nitrate distribution in ground water of Metropolitan City - Vijaywada (Pre-monsoon 2003)



Nitrate distribution in ground water of Metropolitan City - Vijaywada (Post-monsoon 2003)

Figure 21: Nitrate distribution (pre and post monsoon) in Metropolitan city of Vijaiwada

3.10 Groundwater Quality Compliance/Violation Against Drinking Water Standards with Respect to Critical Parameters

Groundwater quality with respect to critical chemical parameters such as Chloride, Total dissolved solids (TDS), Nitrate-N, Fluoride, Total and Faecal Coliforms and critical heavy (Toxic) metals are presented and summarized. Groundwater quality of these critical parameters, their minimum, maximum ranges are presented in the Figures 22 to 27. Similarly, compliance against drinking water standards of these six parameters are presented in Figure 28 to 33. Groundwater quality with respect to critical heavy metals such as Iron, Chromium, Copper, Manganese and Zinc and their Compliance/violation against drinking water standards in both the seasons are also presented in Figures 34 to 38. The percent compliance exercise includes analysis of total 50 samples in both the seasons at same locations in each metropolitan city. Compliance/

As revealed from the figures (22 to 27), the maximum range of chloride concentration in groundwater is indicating above the 1000 mg/L (Log value) in Chennai Metropolitan city followed by Vijaiwada, Madurai, Coimbatore, and then Agra. Similarly, Total Dissolved Solids indicating very high range (Maximum) in Chennai followed by Vijaiwada, Coimbatore, Madurai and Agra. The Nitrate concentration (log value) revealed that the three metropolitan cities such as Agra, Coimbatore and Meerut indicating above the permissible limit whereas remaining cities such as Lucknow, Ludhiana, Vijaivada, Chennai, and Madurai indicating below the permissible limit. The concentration of Fluoride (Log value) indicated that Agra followed by Vijaivada, Chennai, Madurai and Coimabotore metropolitan cities shown above the permissible limit of drinking water whereas remaining three cities were found within the permissible limit. The Coliform group bacteria did not show any contamination except Lucknow and Meerut Metropolitan cities.

As clear from the Figure 28 that Chloride percent compliance/violation against drinking water standards (BIS/WHO) indicating 18% in Coimbatore city followed by Agra (8%), Chennai (6%), and Lucknow – Vijaiwada (each 4%) whereas Cities like Meerut and Ludhiana did not showed any violation against drinking water standards and indicating chloride concentration within the desirable limit of drinking water standards. As revealed from the Figure 29, the TDS percent Compliance/violation against drinking water standards in eight metropolitan cities indicating highest in Agra (36%) followed by Coimbatore (32%), Chennai (22%), Vijaiwada (18%), and Madurai (10%). The remaining three metropolitan cities (Meerut, Lucknow, Ludhiana) did not indicate any violation with respect to total dissolved solids. Figure 30 revealed that Nitrate violation against drinking water standards only in three metropolitan cities. Agra showed highest (54%), followed by Coimbatore (28%), and then Meerut (14%). The remaining five metros did not indicate any violation. The Fluoride percent compliance/violation against drinking water standards clearly indicated (Figure 31) that Agra is having highest (34%), followed by Chennai (14%), then Madurai and Vijaiwada (each 8%)and then Coimbatore and Meerut (each 4%) while Lucknow and Ludhiana did not show any percent violations. Figure 32 clearly indicates that there is no violation of Total Coliform against drinking water standards except Lucknow (20%), Agra (8%), and Meerut, Chennai (each 2%) while remaining four cities did not indicate any violation. Similarly, Figure 33 indicates that percent violation of Faecal Coliform against drinking water standards only in two Metropolitan cities i.e. Lucknow (28%) and Agra (6%).

Percent compliance against drinking water standards with respect to heavy metals were presented in Figures 34 to 38. It is revealed from the Figure 34 that Iron (Fe) indicates compliance/violations in almost seven metros except Ludhiana. The highest violation was found in Agra (74%) followed by Chennai (32%), Meerut (30%), Vijaiwada (12%), Lucknow (10%), Madurai (4%) and Coimbatore (2%). Percent compliance violation of Copper indicated in Figure 35 indicated Copper concentrations within the permissible limit of drinking water standards in all eight cities. Chromium indicated (Figure 36) compliance/violation in Coimbatore city (4%), while remaining seven cities indicated permissible limit. The Manganese compliance/violation, as revealed from the Figure 37 indicated that out of seven cities attempted, five were violated. The highest violation was found in Chennai Metropolitan (42%) followed by Madurai (16%), Vijaiwada (12%), Agra and Lucknow (each 10%), and Meerut (8%). As clear from the Figure 40, Zinc did not show any violation in any of the Metropolitan city.

Figure 22: Groundwater Quality – Chloride on log scale (Min.-Max. & Average) in Eight Metropolitan cities

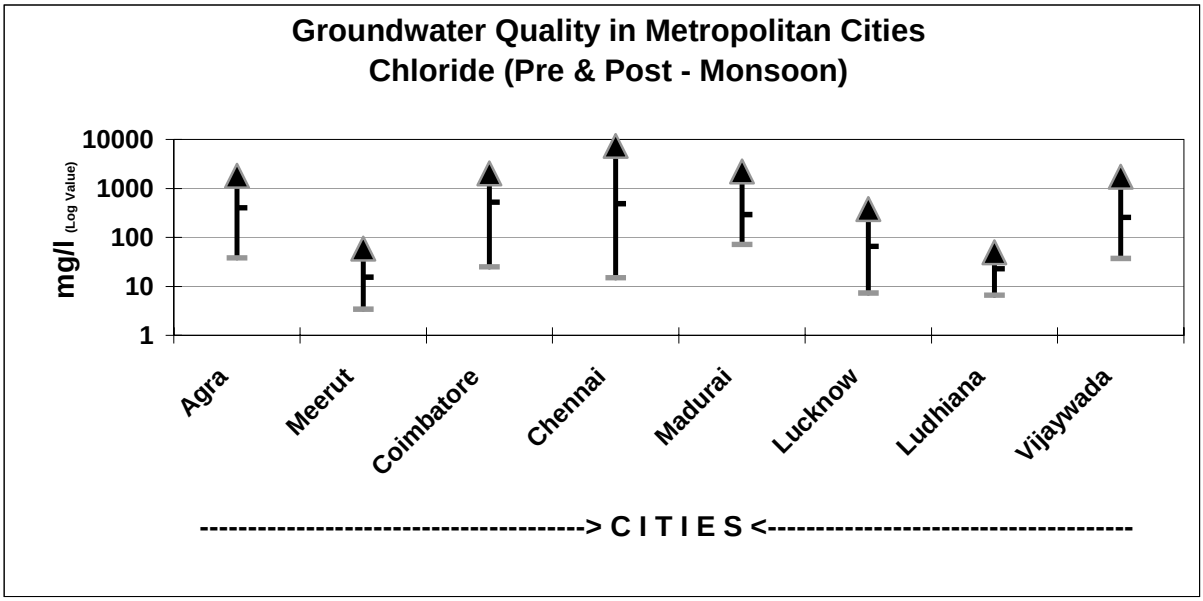


Figure 23: Groundwater Quality – TDS on log scale (Min.-Max. & Average) in Eight Metropolitan cities

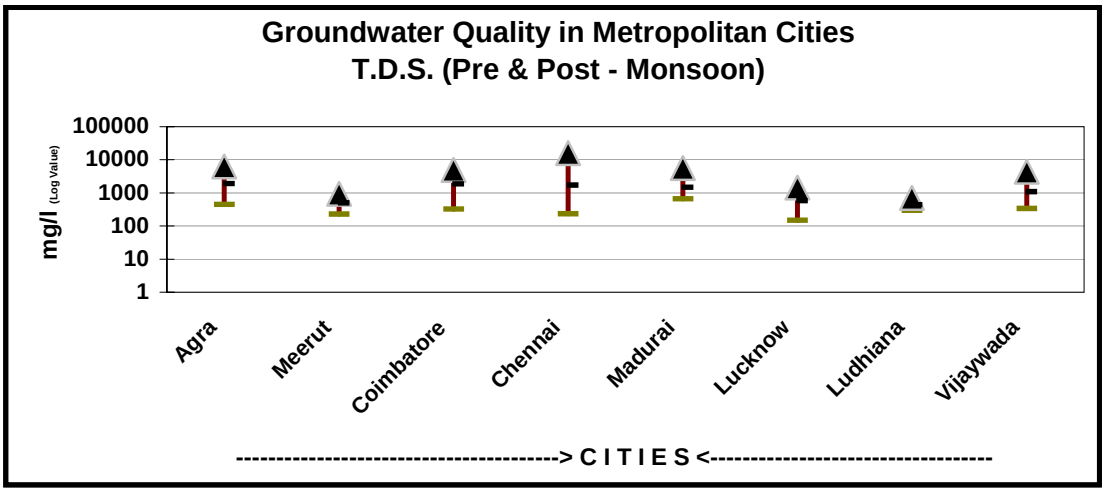


Figure 24: Groundwater Quality – Nitrate on log scale (Min.-Max. & Average) in Eight Metropolitan cities

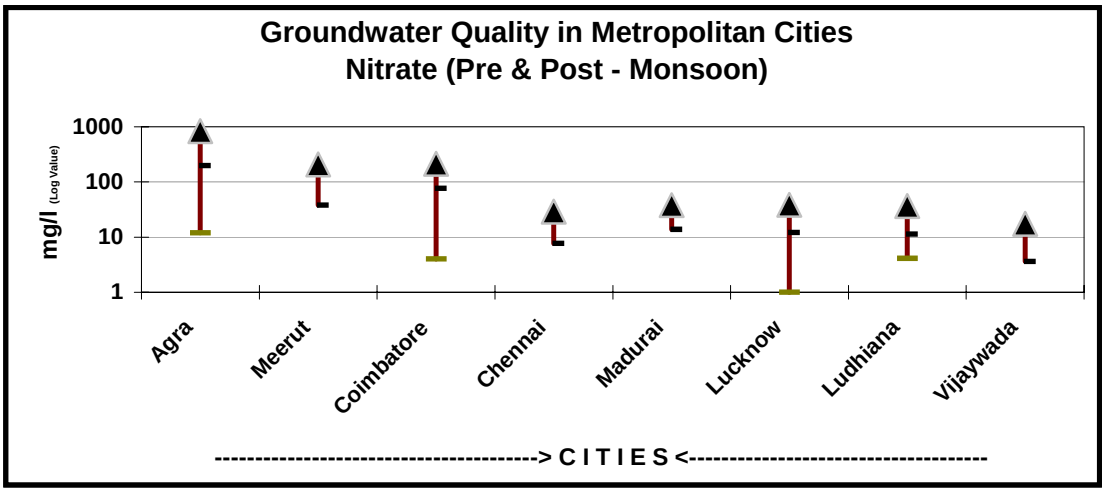


Figure 25: Groundwater Quality – Fluoride on log scale (Min.-Max. & Average) in Eight Metropolitan cities

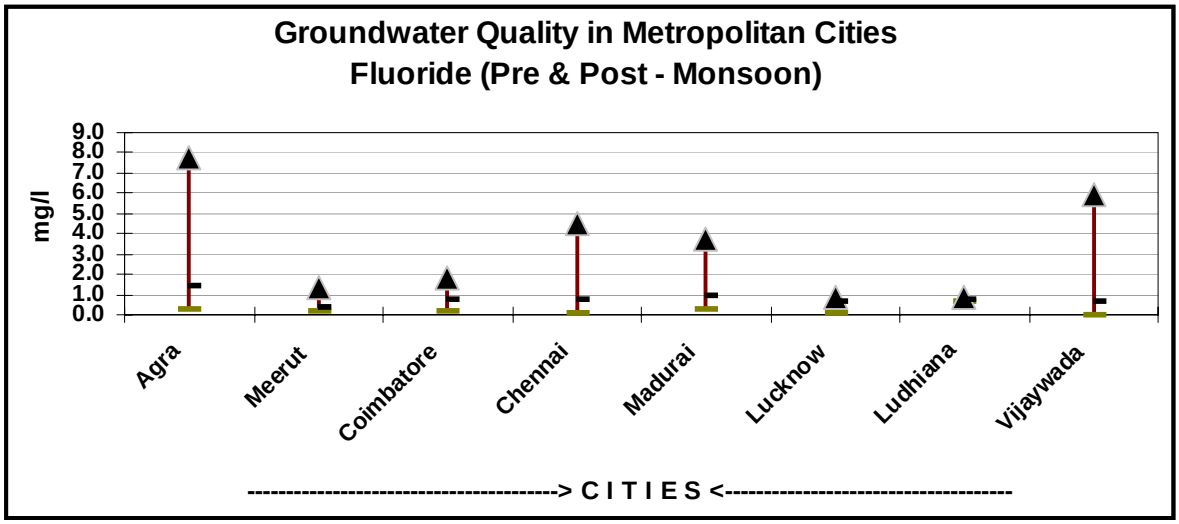


Figure 26: Groundwater Quality – Total Coliform on log scale (Min.-Max. & Average) in Eight Metropolitan cities

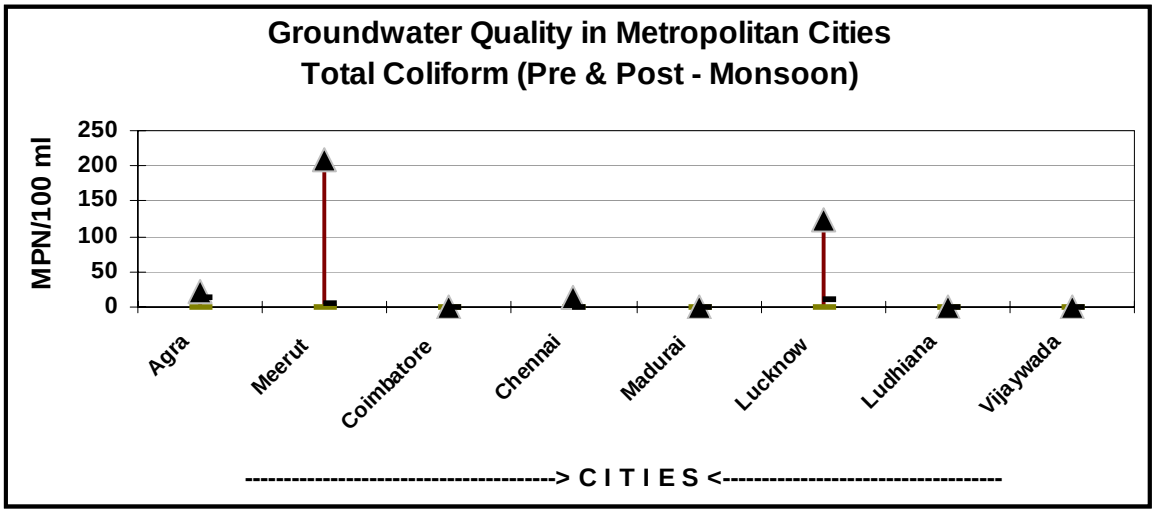


Figure 27: Groundwater Quality – Faecal Coliform on log scale (Min.-Max. & Average) in Eight Metropolitan cities

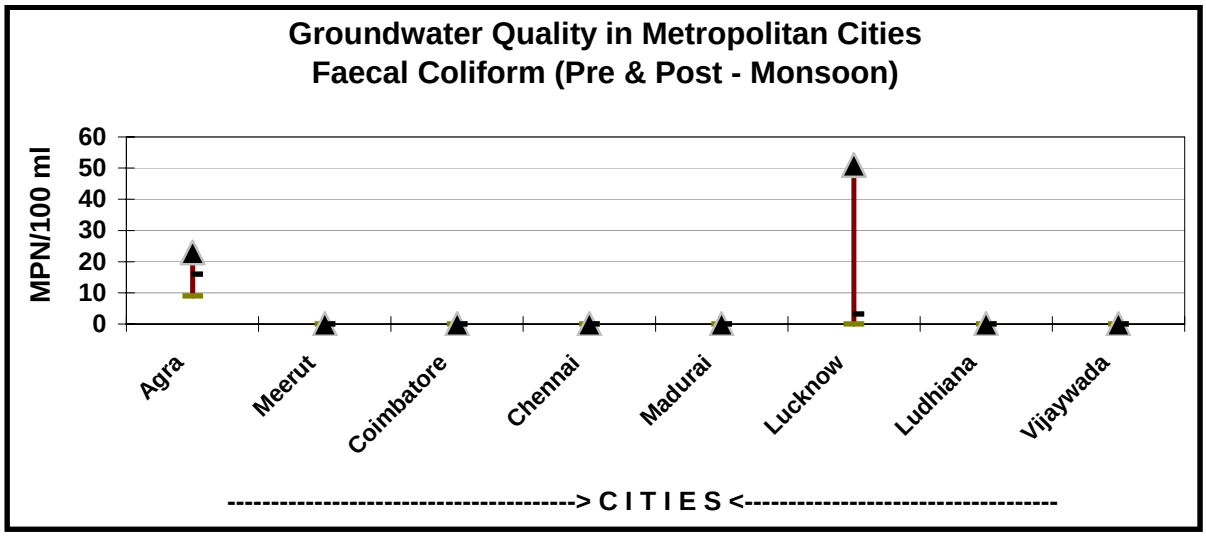


Figure 28: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

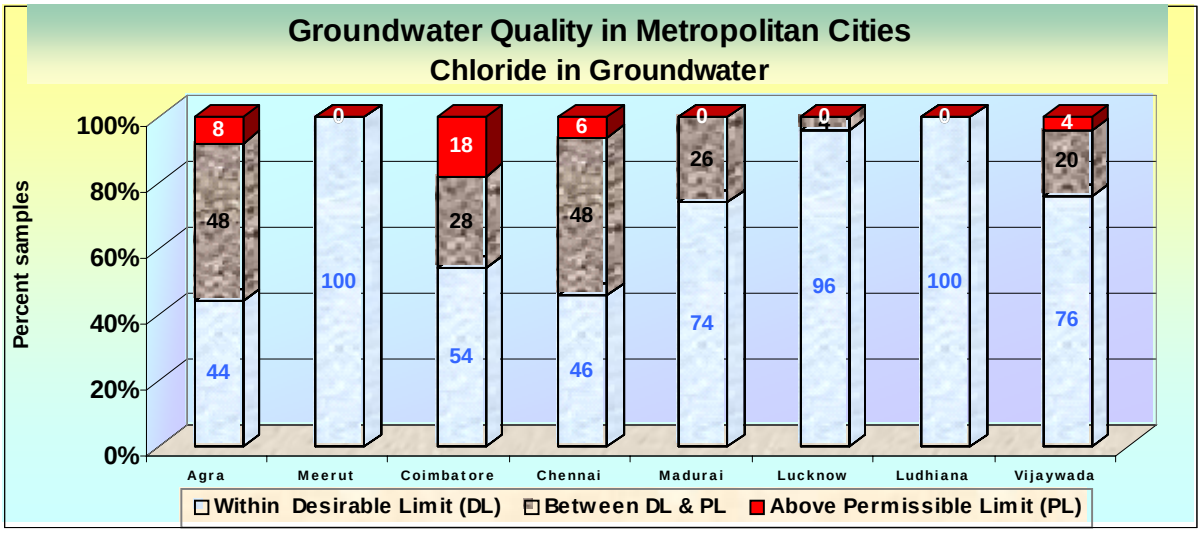


Figure 29: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

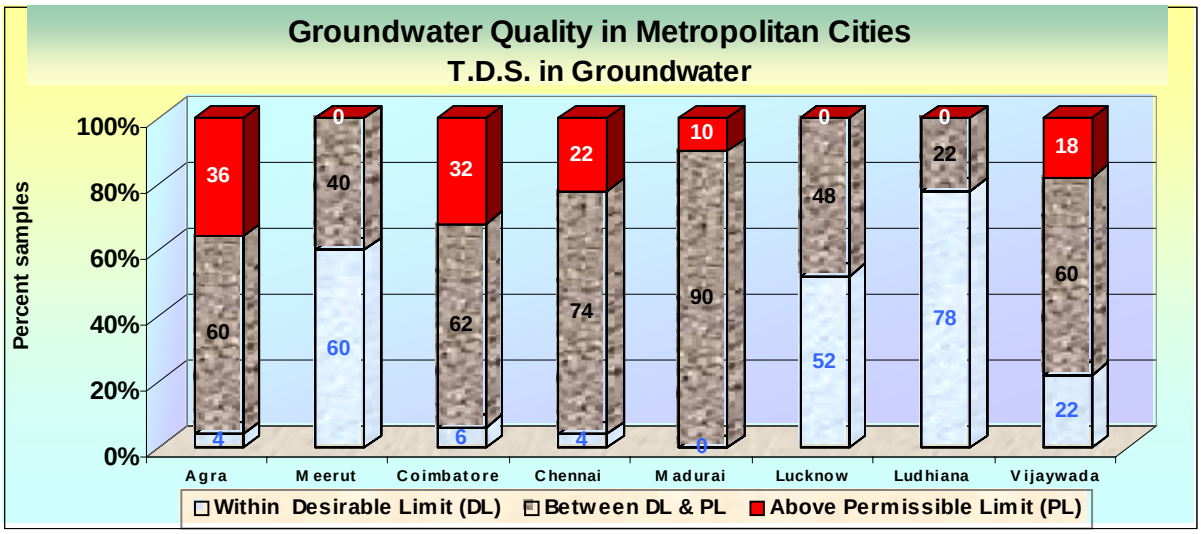


Figure 30: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

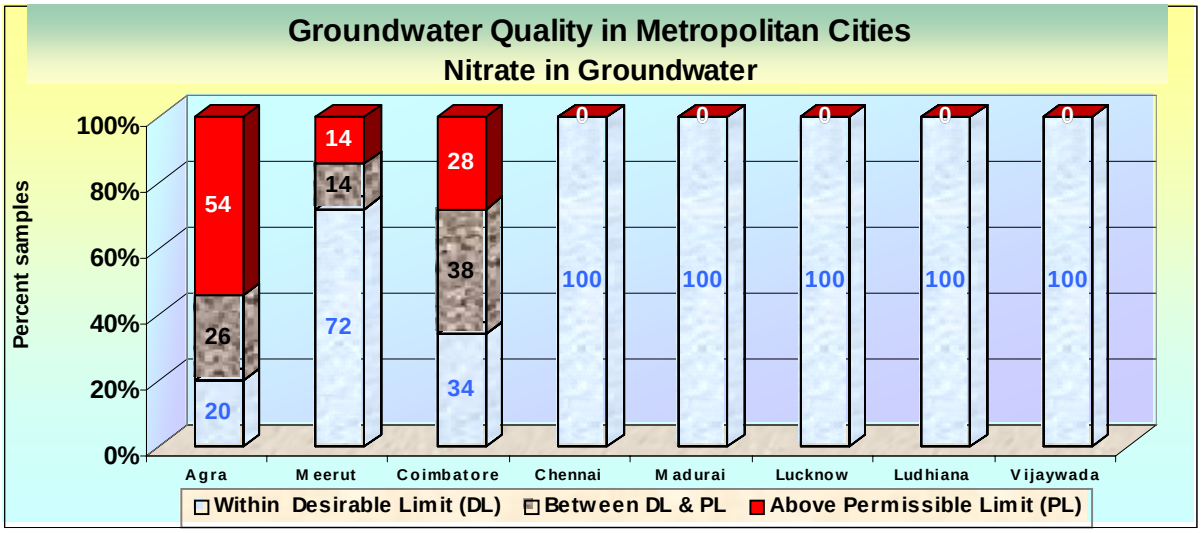


Figure 31: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

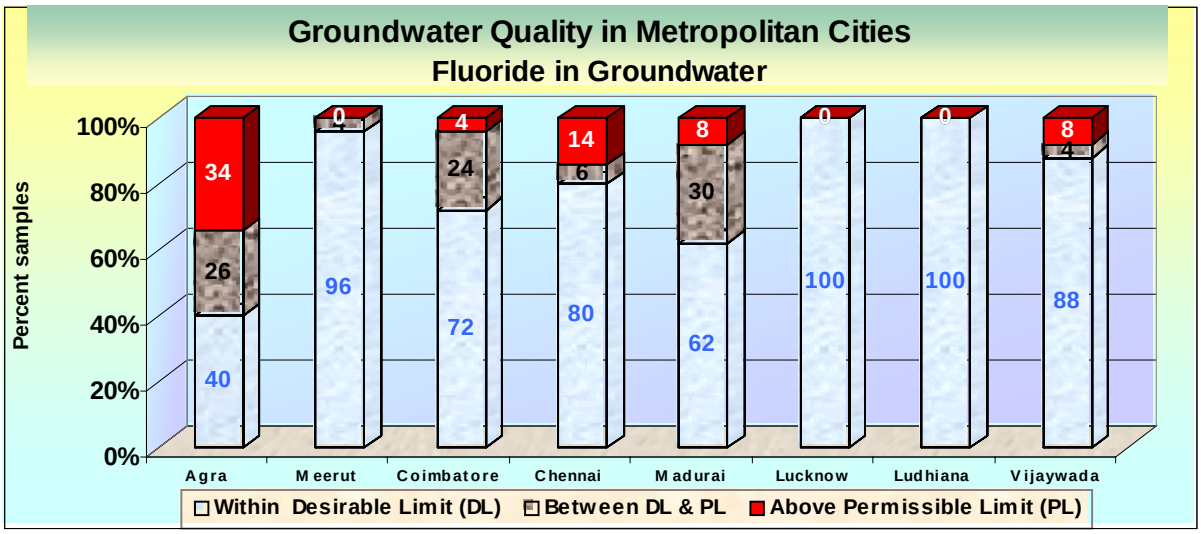


Figure 32: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

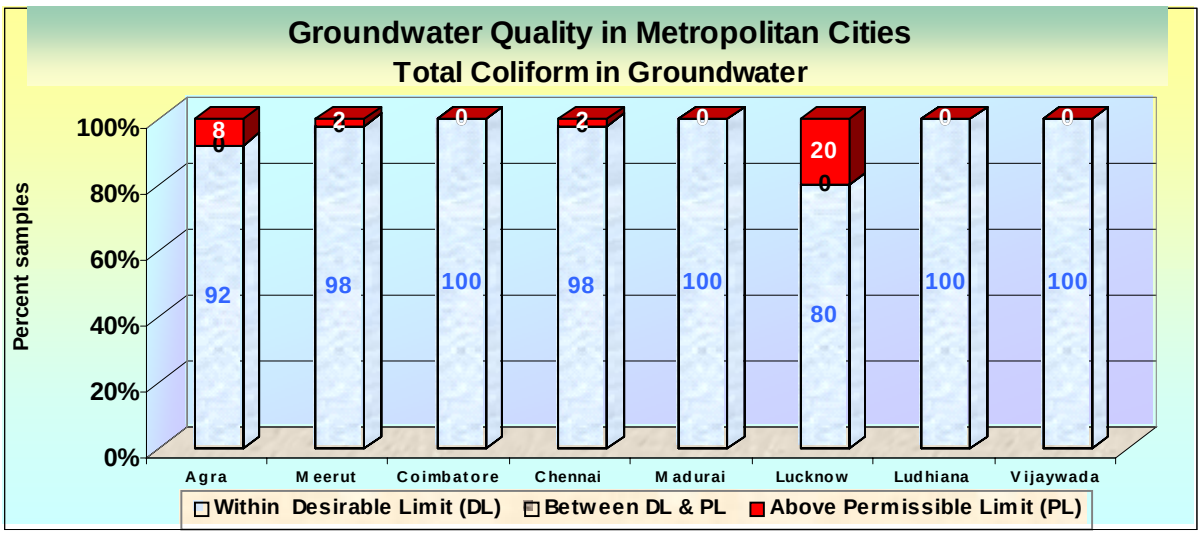


Figure 33: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

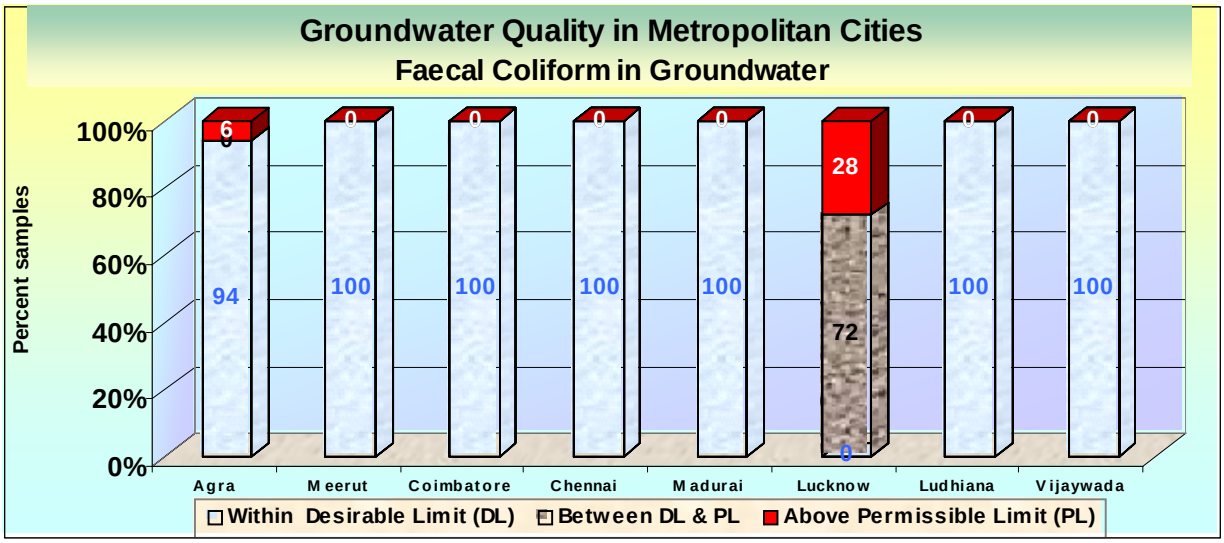


Figure 34: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

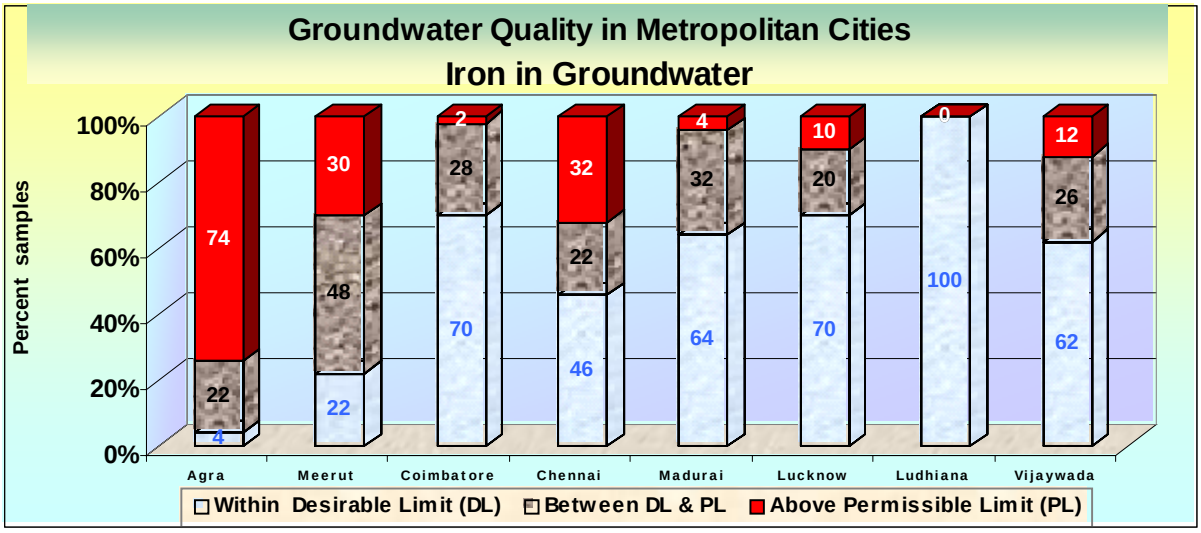


Figure 35: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

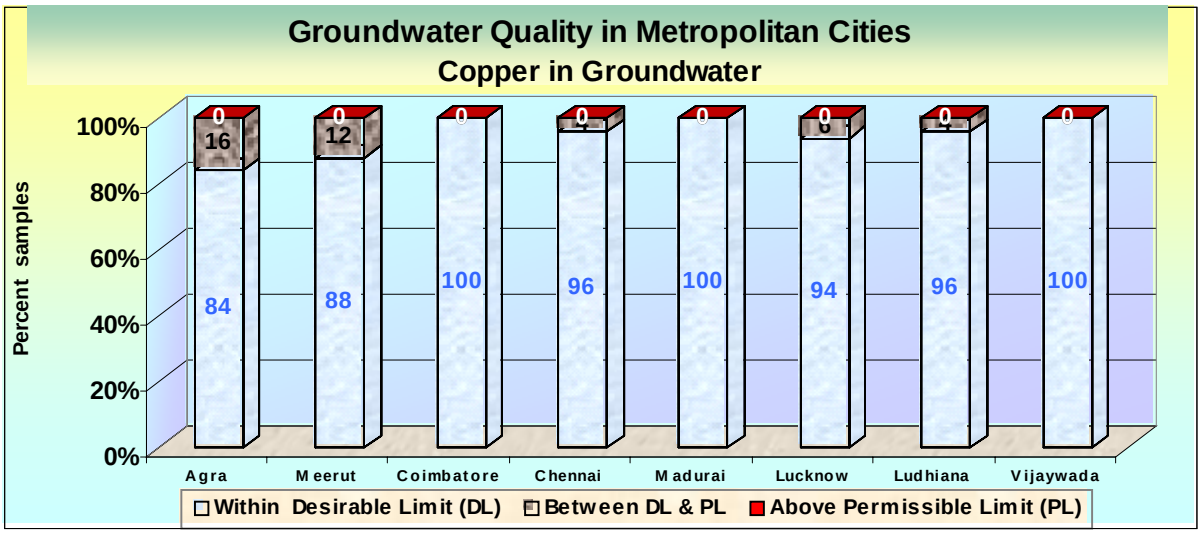


Figure 36: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

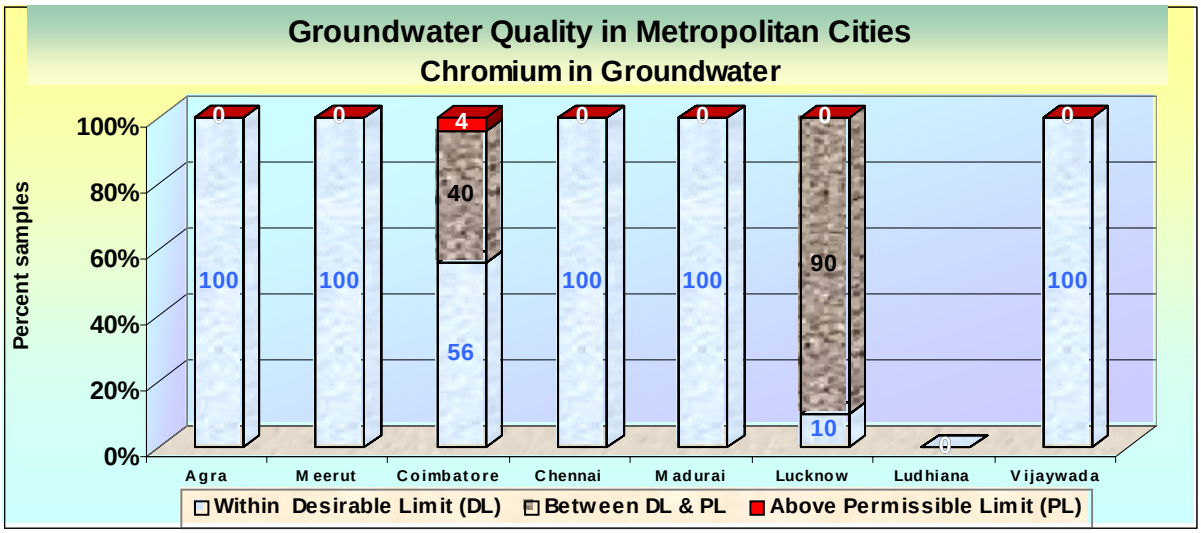


Figure 37: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities

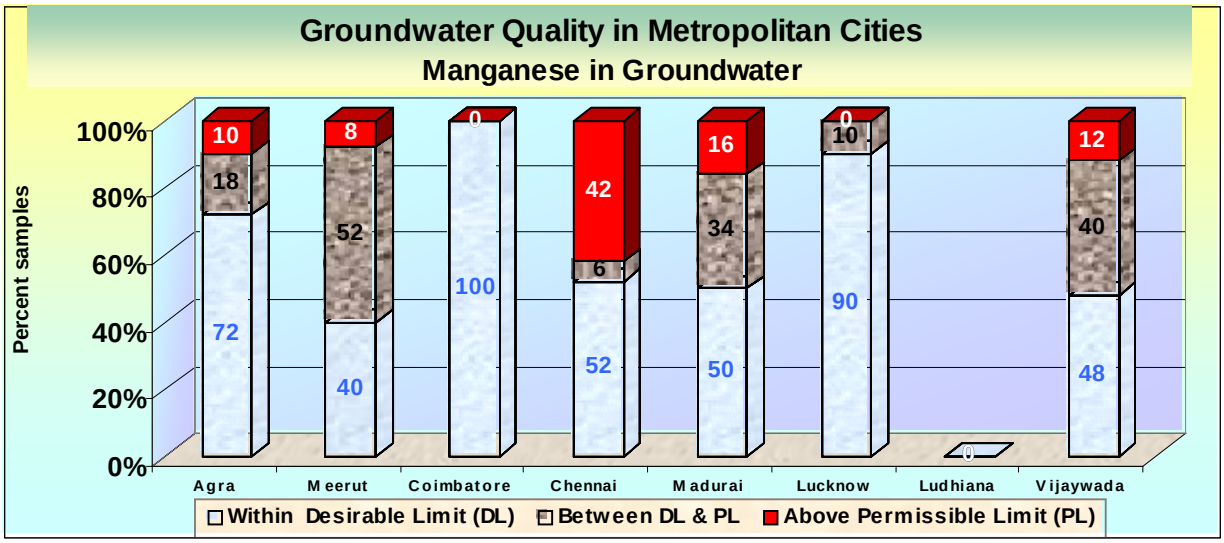
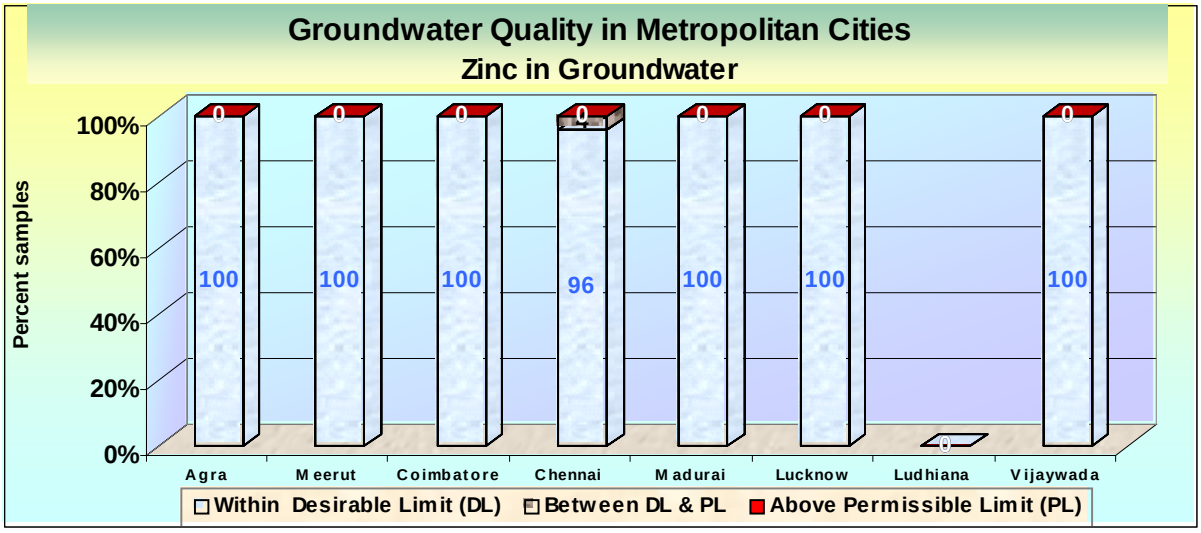


Figure 38: Percentage of samples complying Drinking Water Standards (DWS-IS:10500) in Eight Metropolitan cities



A summary of the Groundwater quality problems in eight metropolitan cities is given in Table 15.

Table15: Groundwater Quality problems in Metropolitan cities

Sl. No.	Name of the Metro city	Major Anthropogenic and Industrial Activities	Groundwater Quality Problem*
1.	Agra, U.P.	Un-collected domestic sewage (about 200 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is about 654 T/D. The industrial activity includes Textiles, Hosiery items, Woolen, Jute, Footwear, Leather, Metal processing, Machinery parts, Marble, Food processing, Foundries and Handicrafts etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High concentration of nitrate, fluoride, total hardness, chloride, TDS, calcium, Sulphate, potassium, magnesium, conductivity and Coliform organisms, whereas concentration of micro-pollutants such as toxic (heavy) metals Fe, Mn, and Cu were exceeding the permissible limit for drinking water during pre and post-monsoon seasons and also pesticides such as α-BHC, Endosulphan and Methoxychlor were detected in some of the samples.
2.	Chennai, T.N.	Un-collected domestic sewage (about 268 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is more than 3873 T/D. The industrial activity includes Hides & Skins, Tobacco, food grains, Iron and steels, Fertilizers, Paper, Chemicals, Sugar, Bone metals and Granites etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High concentration of chloride, TDS, conductivity, Bicarbonate alkalinity, Sulphate, fluoride, calcium (pre-monsoon), total hardness and sodium, whereas concentration of micro-pollutants such as heavy metals Fe and Mn, were exceeding the permissible limit during both the seasons and also pesticides such as Aldrin, α-BHC, δ-BHC and Endosulphan were also detected in some of the samples.
3.	Coimbatore, T.N.	Un-collected domestic sewage (about 140 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is about 800 T/D. The industrial activity includes Textile, Foundries, Motor Pumps, Water tanks, Steel furniture's, Electric and Electrical appliances, Automobile components, Washing machines, Wet grinders, General Engineering industries, Food processing units and Printing machineries etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High concentration of TDS, chloride, Sulphate, nitrate, fluoride, calcium and total hardness, whereas the concentration of micro-pollutants such as heavy metals Fe and Cr are exceeding permissible limit for drinking purposes and also pesticides such as α-BHC only was detected in some of the samples.

Sl. No.	Name of the Metro city	Major Anthropogenic and Industrial Activities	Groundwater Quality Problem*
4	Madurai, T.N.	Un-collected domestic sewage (about 80 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is more than 459 T/D. The industrial activity includes Textile, mills, Dyeing units, Power looms, Handlooms, Engineering and Mechanical Industries, Steel Rolling mills, Small Scale industries like Food products, Readymade Garments, Wooden industries, Printing, Molding industries etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High electrical conductivity, TDS, chloride, Bicarbonate alkalinity, Sulphate and fluoride whereas concentration of micro-pollutants such as heavy metals Cr and Fe at few locations were exceeding the permissible limit during both the seasons and also pesticides such as Aldrin, α-BHC, β-BHC, γ-BHC and δ-BHC were detected in some of the samples.
5.	Meerut, U.P.	Un-collected domestic sewage (about 35 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is about 490 T/D. The industrial activity includes Distillery, SSI units such as sports goods, chemicals, food processing, surgical goods, engineering works, petrochemicals, rubber, plastic, leather goods, flour mills and readymade garments Besides this, three petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High concentration of TDS, nitrate, fluoride and alkalinity whereas the concentration of micro-pollutants such as heavy metals Fe and Mn are exceeding permissible limit for drinking purposes and pesticides such as α-BHC only was detected in some of the samples.
6.	Lucknow, U.P.	Un-collected domestic sewage either on open land or flowing through drains to receiving system. The municipal solid waste generation is more than 475 T/D. The industrial activity includes Chemical, Petroleum storage, Pesticides, Electronic Manufacturing Units, and Breweries etc. Besides this, Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High TDS, conductivity, Potassium, Magnesium, Alkalinity, Total Hardness and Total Coliform.
7.	Ludhiana, Panjab	Un-collected domestic sewage either on open land or flowing through drains to receiving system. The municipal solid waste generation is more than 734 T/D. The industrial activity includes Woolen, Dye, Electroplating, Bicycle, and Textile etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High electrical conductivity and high concentration of Potassium, Magnesium was detected in some of the samples.

Sl. No.	Name of the Metro city	Major Anthropogenic and Industrial Activities	Groundwater Quality Problem*
8.	Vijaiwada, A.P.	Un-collected domestic sewage (about 160 mld) either on open land or flowing through drains to receiving system. The municipal solid waste generation is about 550 T/D. The industrial activity includes Rice mills, Edible Oils, Beverages, Tobacco, Cotton, Paper, Food Processing, Utensils, Drugs, and Pharmaceuticals, Oil refineries, Motor Vehicle Parts, Wood and wood products, Ayurvedic medicines, Leather products, Rubber Products, Thermal Power plants and Milk and Milk Product processing etc. Besides this Petroleum storages (IOCL, HPCL and BPCL) existing in the city.	High electrical conductivity, TDS, Chloride, Bicarbonate alkalinity, Total Hardness, Potassium, Calcium, Magnesium and fluoride whereas concentration of micro-pollutants such as toxic (heavy) metals Fe, and Mn, were exceeding the permissible limit during both the seasons and also pesticides such as Aldrin, DDE, DDD, α-BHC, β-BHC, γ-BHC, Methoxychlor and Endosulphan were detected in some of the samples.

*=Sampling of Groundwater for Pre & Post Monsoon seasons during 2002-2004