The history of dissolved oxygen environmental sciences essay

IntroductionA lot of research is happening all around the world on rapid urbanization of cities in the last two decades. The research is mainly focused on the rate of growth of such cities and availability of natural resources to sustain the growth (Xu et al. 2002; Kraas and Nitschke 2008). Urbanization basically means increase in number of people in cities and change of vast areas of agriculture, open lands and water catchment areas in to human settlements, commercial sectors and industries. Due to rapid urbanization, three main problems may come up for a growing city viz. water table fluctuation, groundwater contamination and evident instability of man-made structures (Putra and Baier 2008; Vasquez-Sune et al. 2005) Varanasi, one of the oldest cities of the world, famous for being the holiest city in India, is characterized by numerous temples, narrow streets and most important of all, the River Ganga. The River Ganga is the life line of the Gangetic plain in northern India. So much so that Ganga basin is the most populated river basin in the world, with over 400 million people and a population density of about 390 inhabitants per square kilometre. Unfortunately, Ganga is also among the top five most polluted rivers in the world. Faecal coliform levels of more than 100 times the maximum permissible limit of the Indian government limits has been recorded in samples taken from the River in many places (Sankat Mochan Foundation, Varanasi). The main cause of such heavy contamination of the river water is disposal of untreated waste water of cities, industries and also disposal of solid waste in the river. The city of Varanasi, much like most of the cities and villages in the Gangetic plain, depends on the River Ganga and its tributaries and the groundwater of the region for their water needs. The potable water sources for the people in Varanasi are the groundwater and the water from River Ganga. Needless to say, pollution of Ganga will affect the quality of groundwater of the city as well. But even if it doesn’t, groundwater of Varanasi is in danger of contamination. Rapid urbanisation and unplanned growth of the city and rapid increase in population has added up to make Varanasi a very congested city. Narrow streets getting narrower and people buying more and more vehicles every day is adding to the problem. Also, more people results in more waste generation and since there is no adequate way of processing it, everything is dumped into surface water bodies or landfills creating further sources for contamination of both surface and groundwater resources. Areas where connectivity to the central sewer system does not exist, waste water is dumped into local septic tanks and since the geology of Varanasi area is so conducive for water percolation (due to high porosity and permeability), there are no prizes for guessing that the contaminants are going through to the groundwater below by various sources. The surface water sources where waste is being dumped are also major sources of contamination. Study AreaVaranasi is situated on the western banks of meandering River Ganga, which flows from south to north direction in the city area. Geomorphologically, the city is a part of central Ganga plain of the Indian subcontinent (Figure 1). In the study area, the Ganga has two tributaries viz. Assi Nala and the River Varuna. Varuna is located in the north-eastern part of the city and Assi is located in the southern flank as shown in the map (Figure 1). The average elevation of the city area is about 76 m above mean sea level. The whole area has largely a very even topography with low relief kilometre scale undulations. The study area lies between the latitude 25°14’53" N to 25°23’1" N and between longitude 82°55’35" E and 83°4’25" E. The climate of this region is tropical with a marked monsoonal effect. Around 80% of the annual rainfall in the region is received in the months of July and August. Summer temperatures can go up to 47°C and in winter, the temperature drops to 4°C with an average annual temperature of 24°C. GeologyVaranasi city is spread over an area of 100 km2 and located on the Indo-Gangetic Plainunderlain by Quaternary alluvial sediments of Pleistocene to recent times. In the study area, unconsolidated sediments form a sequence of clay, silt and sands of various grades. The origin of these sediments is from alluvial deposits. Nodular calcareous concretions (kankars) are sometimes intercalated with the sands forming good aquifers at various depths. The origin of kankar may be the precipitation of calcium carbonate from the groundwaters (Raju et al. 2010). The Quaternary alluvial deposits are divided into older and newer alluviums. In the city area, the older alluvial deposit consists of fairly consolidated clay with kankar and polycyclic sequence of fine to medium sand with gravel. The older alluvium is thick succession found throughout the area and is characterised by gray micaceous sand in the west and yellowish concretized clay in the east side. The gray sands consist of clear angular feldspar, micas, hornblende, garnet, kyanite, hypersthene, toutmaline and zircon indicating Himalayan sources (Shukla and Raju 2008). The newer alluvium is present adjacent to the drainage areas of river Ganga. The surroundings are subjected to floods every year during rainy season which results in fresh deposition of silt, clay and loam. The alternating sand and clay layer in the thick Quaternary deposits in the Varanasi area has created a multitier aquifer system. The shallow aquifers occur under water table condition where as the deeper aquifers occur in semi confined to confined condition. Dug wells, hand pumps and bore wells, all are used in the city area for extraction of groundwater. The diameter of dug wells ranges from 2 to 7 m and their depths ranges from 7 to 32 m. The hand pumps have depths ranging from 40 to 60 m and the deep borewells generally have a depth range of 60 to 250 m below ground level. The hand pumps mainly tap the unconfined aquifers and the deeper bore wells get their water from semi-confined and confined aquifers. The major source of recharge is the rain water. The water quality of the aquifers at different depth is different as shallower aquifers get affected much more and faster by surface contaminants. Fast urbanization has caused the water levels to go down and many places in the area show a lowering trend of the water table. Average hydraulic gradient is 0. 35 m/km which indicates porous nature of near surface formations in the area (Pandey 1993). Materials and MethodsA survey was conducted in June 2011 in which 34 groundwater samples from different areas of the city were collected. The collection of samples was done following the APHA (AWWA 1998) guidelines for testing for various geochemical parameters of the groundwater in the study area. The geographical coordinates of the sample locations were also recorded using a handheld GPS device and the locations are shown in the map in Figure 2. The samples were also tested in situ on field using a multi-parameter water quality meter (Hanna HI 9828) for various physical parameters like pH, TDS, Electroconductivity etc. The water samples were then collected in acid-washed polyethylene 250 ml bottles. The samples were then taken to the Laboratory and were analyzed in ICP-MS for various elemental concentrations including heavy metals like Arsenic, Zinc, Copper etc. Groundwater quality data from the December 2003 Report entitled " Study on Surveillance of Drinking Water Quality in 25 Selected Cities/Towns in

India" published by the National Environmental Engineering Research Institute, Nagpur (NEERI 2003) was used in the present work to assess a trend, if any, of the groundwater quality of Varanasi city. The sample locations of this survey are shown in Figure 2. The analysis of the samples was sponsored by the Ministry of Urban Development, Government of India and the study was done in various cities in India. In the survey done by NEERI, groundwater samples from Tubewells and Hand pumps were collected in three different seasons in December 2001 (Winter), May 2002 (Summer/Pre-Monsoon), and July 2002 (Post-Monsoon). The samples were analyzed for all general physical parameters like pH, TDS, Turbidity, Conductivity, Total Alkalinity and Hardness. The samples were also analyzed for major cationic and anionic concentrations, also including heavy metal concentrations. In the present study, the results for samples collected in the May 2002 (Summer/Pre-Monsoon) period are used. Groundwater quality data published in the work done by Raju et al. (2009), was also included in this study to relate the results with the above mentioned studies. The published work is entitled " Groundwater Quality in the Lower Varuna River Basin, Varanasi District, Uttar Pradesh" and it was published in the Journal of Geological Society of India in the year 2009. The sample locations from Raju's work (Figure 2) falling in our study area are taken in this study for comparison of results and searching a trend, if any. All these data sets were used to create interpolation diagrams for various parameters using GIS software. The interpolation technique selected for this purpose was the Inverse Distance Weighting (IDW) interpolation technique as it was giving the most uniform and viable results for the amount of data in hand. IDW works on the assumption that locations that are close to each other are more alike than those which are further apart. It predicts a particular value for a location on the basis of given values for locations around it. It gives more weight to locations closest to the prediction location and the weight diminish as the distance of the given location increase, hence the name inverse distance weighted. For spatial interpolation of data, Kriging method is generally preferred but it was not used in the present work due to the far off and non-uniform distribution of sample locations in the Author's survey conducted in 2011. The resulting diagrams were used for various interpretations done in the study. The object of the interpolation diagrams was to locate areas with high values of some parameter and to interpret the cause of such occurrence. Results and DiscussionpH Number of hydrogen ions or protons present in an aqueous solution represents the pH value of a solution (Hem 1991). It is expressed as the negative logarithm of the hydrogen-ion concentration in water. The BIS permissible limit of value of pH for water is 6. 5 to 8. 5 (BIS 2004). Although in the first edition of the Guidelines of Drinking Water Quality published by the WHO in 1984, the acceptable pH range was 6. 5-8. 5, in the 2008 guideline, no health based guideline value is proposed citing the reason that pH usually has no direct impact on consumers (WHO 1984; WHO 2008). The pH values of the samples collected in the 2011 survey range from 6. 25 to 6. 85 with a mean value of 6. 58 in the study area. pH of groundwater of the samples collected nearby DLW (Diesel Locomotive Works) area (Figure 2) were found to be below the BIS permissible limit. All the samples labeled DLW (except for three which are located just south of the DLW site) and samples labeled Lahartara-7, 8 & 9 located near the DLW site have shown pH levels lower than 6. 5 (Figure 2). In the survey conducted by Raju, the pH values ranged from 6. 8 to 8. 2 with an average of 7. 44 among the sample locations included in this study. In the survey conducted by NEERI in May 2002, the pH values ranged from 6. 8 to 7. 84 with an average value of 7. 41. This shows significant change in the average value of pH between the years 2002 and 2011. Although, no significant change is visible between the NEERI's survey results and Raju's survey results. It is to be noted that the 2011 survey mainly contains samples from the outer parts of the city and not the central city area of Varanasi whereas; NEERI survey was done in the whole city including the central and outer parts of the city. In the Figure 4, it can be seen that the pH values show a declining trend specifically in the outskirts of the city. Lower pH values of groundwater in and around the DLW area is an indication than the waste generated by the Locomotive factory could be responsible for the declining quality of the groundwater in the area. Dissolved OxygenThe dissolved oxygen content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated (WHO 2008). No health-based guideline value is recommended by the WHO or the BIS (WHO 2008; BIS 2004). However, the Central Pollution Control Board of India prescribes that Grade-A water, i. e. the water used for drinking purposes should have dissolved oxygen values of 6 mg/L or higher (CPCB). All the samples in the study area had dissolved oxygen values of less than 6 mg/L, ranging from 0. 91 mg/L to 5. 62 mg/L in the 2011 survey. No results for Dissolved Oxygen for groundwater in the central area of the city is available for this study and therefore no concrete statement can be made for the status of the water in central parts of Varanasi. Although, low dissolved oxygen values were seen in outer parts in all directions which is a cause for concern (Figure 3). ECElectroconductivity (EC) value of a solution is dependent on temperature, ionic concentration, and types of ions present in the water (Hem 1991). Thus, the EC gives a qualitative picture of the quality of groundwater. The EC value of the samples collected in the 2011 survey range from 609 µS/cm to 1, 436 µS/cm with a mean value of 889 µS/cm. In Raju's survey, the EC values range from 590 µS/cm to 2150 µS/cm with an average of 1021. 9 µS/cm. The EC value of the samples collected in the NEERI survey in May 2002 range from 314 µS/cm to 2250 µS/cm with a mean value of 783. 6 µS/cm. The interpolation diagrams for the EC values can be seen in Figure 5. The sample locations in the central part of the city show an increasing trend of EC values as shown in NEERI survey and Raju's work. High EC in central part of the city indicates high concentration of foreign materials and it depicts that the high population density of the central part of the city is affecting the quality of the groundwater in the area. TDS The weight of the residue consisting of pollutants (dissolved ions) left behind after all the water from a water sample is evaporated is a measure of the TDS and reflects the general nature of the groundwater quality and extent of contamination (Annon 1946; Robinnove et al. 1958; Davis and de Wiest 1966; AWWA 1998). The BIS permissible limit (BIS 2004) for TDS is 2000 mg/l. However, WHO has not set any health based limit in the latest guidelines. According to the their report the palatability of water with a TDS level of less than 600 mg/litre is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/litre (WHO 2008). In the 2011 survey, TDS values in the study area vary from 305 mg/L to 718 mg/L with a mean of 450 mg/L. In the results published by Raju et al., the TDS values ranged from 304 mg/L to 1175 mg/L with an average of 543. 28 mg/L. In the NEERI survey conducted in May 2002, the TDS values range from 142 mg/L to 1238 mg/L with a mean value of 444. 8 mg/L. In Figure 6, it can be seen that in some areas of the city, the water has moderate to high levels of TDS but it is not unusable for potable use. A few samples in the central city area did show TDS value greater than 1000 mg/L but in general, it is lower than that in most places in the city. Also, the average TDS values have not changed much in the past decade. Hardness TH, Hardness in water is caused mostly by dissolved calcium and magnesium, the end product of dissolving limestone from soil and rock materials. Hard water is beneficial to health. However, high hardness can cause lime build up (scaling) in pipes and water heaters. It also reacts with soap to form a " scum" which decreases the soap’s cleansing ability (Fletcher 1986). The desirable limit for TH is up to 300 mg/l, but it is acceptable up to 600 mg/l (BIS 2004). No health-based guideline value is proposed for hardness by the WHO. However, the degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale deposition (WHO 2008). The hardness values for the 2011 survey were calculated using the concentration values of Calcium and Magnesium ions. The values calculated using the values of concentration of Calcium and Magnesium ions range from 213. 6 mg/L to 507. 04 mg/L with a mean value of 318. 51 mg/L. Hardness in samples collected by Raju et al. ranged from 169 mg/L to 630 mg/L with an average of 319. 28 mg/L. In the NEERI survey, the hardness values range from 136 mg/L to 620 mg/L with a mean value of 261. 7 mg/L. In general, the groundwater of Varanasi area is moderately hard to hard, as all water with hardness more than 300 mg/L is considered as hard water. But, the water is acceptable for use according to the BIS standards. The central city area has shown higher hardness values in the NEERI survey done in May 2002. Some samples had higher hardness than the BIS maximum permissible limit as well (Figure 7). Also, no significant change in the values of hardness is seen when the interpolations diagrams of the different surveys were compared. NaIn general, weathering, dissolution and base-exchange processes control the levels of cationic concentrations in groundwater. High sodium waters can be explained by the combination of dilution factors, ion exchange, and sulphate reduction (Krothe and Oliver 1982). No health based guideline value is there for sodium concentration. However, concentrations in excess of 200 mg/L may give rise to unacceptable taste (WHO 2008). In the 2011 survey, sodium has shown a range of 27. 2 mg/L to 165. 6 mg/L with a mean of 65. 89 mg/L. In the selected samples from Raju’s work, the concentration values of sodium ranges from 20 mg/L to 200 mg/L with an average value of 72. 5 mg/L. In the NEERI survey, the concentration ranges from 15 mg/L to 135 mg/L with a mean of 41. 8 mg/L. KIonic Potassium is generally present in low concentrations in groundwater (Sravanthi and Sudarshan 1998). However, excessive fertilizer usage can increase its concentration in surface as well as groundwater. The concentration values in the 2011 analyzed samples ranged from 1. 4 mg/L to 11. 3 mg/L with a mean value of 4. 44 mg/L. In Raju’s work the concentration values range from 2. 8 mg/L to 75mg/L with an average value of 7. 6 mg/L. The NEERI survey done in 2002, the concentration ranged from 2 mg/L to 54. 5 mg/L with a mean value of 6. 99 mg/L. A few samples in

NEERI survey and Raju's work had considerably higher values of concentration of Potassium but in general the concentration stayed low in most of the areas. This could mean local contaminant source for the areas where high Potassium was found. Ca & MgCalcium and Magnesium are the main causes of Hardness in water. BIS has set maximum permissible limits for concentration of Calcium and Magnesium at 200 mg/L and 100 mg/L respectively (BIS 2004). In the WHO guidelines, no exact limit has been set for these cations. The guideline do talk about the possible contribution of drinking-water to total daily intake of calcium and magnesium and examines the case that drinking-water could provide important health benefits, including reducing cardiovascular disease mortality (magnesium) and reducing osteoporosis (calcium), at least for many people whose dietary intake is deficient in either of those nutrients (WHO 2008). The concentration of calcium in the analyzed samples in the 2011 survey ranged from 20. 4 mg/L to 114 mg/L with a mean value of 56. 17 mg/L. Magnesium concentration is varying between 21. 3 mg/L to 81. 5 mg/L with a mean value of 42. 98 mg/L. Raju's survey (Raju et al. 2009) showed the concentration of calcium ranging from 33 mg/L to 103 mg/L with an average of 58. 8 mg/L and the magnesium concentration ranged from 8. 2 mg/L to 92. 5 mg/L with an average value of 41. 94 mg/L. In the NEERI survey, the calcium concentration was recorded between the values of 21 mg/L to 83 mg/L with a mean of 40. 4 mg/L and the magnesium concentration ranged from 8 mg/L to 126 mg/L with a mean of 39. 1 mg/L. The average values of both calcium and magnesium ions in the three surveys show slight increase from past to present. This increase then suggests increase in the hardness of the groundwater in the study area but not by a large amount. All the samples were also tested for presence of heavy metals like manganese, iron, zinc, copper, cobalt, cadmium, chromium, nickel, lead, arsenic and molybdenum. No cobalt or nickel was found in any of the samples in the 2011 survey. MnManganese is an essential element for humans and other animals and occurs naturally in many food sources. Adverse effects can result from both deficiency and overexposure. At levels exceeding 100 µg/L, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Concentrations below 100 µg/L are usually acceptable to consumers. Even at a concentration of 200 µg/L, manganese will often form a coating on pipes, which may slough off as a black precipitate (WHO 2008). The WHO limit for manganese concentration is 400 µg/l despite its acceptability threshold of 100 µg/L (WHO 2008). The BIS maximum acceptable limit in the absence of another source is 300 µg/l, and the desirable limit is 100 µg/l (BIS 2004). The concentrations of manganese in the 2011 study vary from 1 µg/L to 776 µg/L with a mean of 154 µg/L. In the NEERI survey done in May 2002, manganese was not found in any of the samples. It is to be noted that the presence of higher quantities of manganese in the water samples was found only on the eastern side of the Ganga river, as shown in Figure 8. Since, the central city area was not tested in the 2011 survey, it will be interesting to see what concentrations do the groundwater show there. The high concentration shown in the study on the eastern banks of the river should be studied in more detail to find out the source of such high concentrations of manganese. FeIron is one of the most abundant metals in the Earth's crust. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day. A value of about 2, 000 µg/L does not present a hazard to health. The taste and appearance of drinking water will usually be affected below this level (WHO 2008). In the most recent guidelines, no limit for iron in drinking water is proposed. BIS desirable limit is 300 µg/L but in the absence of another source of water, 1, 000 µg/L is the maximum acceptable limit for iron concentration (BIS 2004). The recorded values in the 2011 survey range from 290 µg/L to 1, 300 µg/L with a mean of 712 µg/L whereas no iron was recorded in any of the samples in the 2002 NEERI survey. In Figure 8 it can be seen that higher concentrations of Iron were found on the eastern banks of the Ganga river. Considerable amounts were also found in the southern parts of the main city. Again the source of high Iron in the eastern banks of the Ganga river should be located in the further detailed studies. Groundwater from the central city area must be collected and tested for Iron concentration and possible change in the past decade. ZnZinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. Although levels of zinc in surface water and groundwater normally do not exceed 10 µg/L and 50 µg/L, respectively, concentrations in tap water can be much higher as a result of dissolution of zinc from pipes. There is no guideline value set by WHO for zinc concentration but drinking-water containing zinc at levels above 3000 µg/L may not be acceptable to consumers (WHO 2008). The BIS has set the maximum permissible limit for zinc at 15000 µg/L (BIS 2004). Zinc is present in considerable concentrations in nearly all the collected groundwater samples. The 2011 survey recorded concentrations range from 2 µg/L to 2, 158 µg/L with a mean value of 246. 97 µg/L. No zinc was found in any of the samples collected in the 2002 survey conducted by NEERI. One sample in the north-west outskirt of the city has shown high concentration of zinc but it was still well below the BIS limit. All other samples have shown some concentration of zinc but none containing concentrations which can affect the potability of the water source. CuCopper is both an essential nutrient and a drinking-water contaminant. It is used to make pipes, valves and fittings and is present in alloys and coatings. Copper sulfate pentahydrate is sometimes added to surface water for the control of algae (WHO 2008). Copper was found in some of the samples in the 2011 survey but in a very minute concentration with a maximum record of 6 µg/L, very much lower than the BIS maximum limit of 1500 µg/L (BIS 2004) and WHO limit of 2000 µg/L (WHO 2008). No detectable amount of copper was found in any of the samples collected in the 2002 NEERI survey. CdCadmium metal is used in the steel industry and in plastics. Cadmium compounds are widely used in batteries. Cadmium is released to the environment in wastewater, and diffuse pollution is caused by contamination from fertilizers and local air pollution (WHO 2008). The WHO limit and the BIS limit for cadmium concentration is equal at 3 µg/L (WHO 2008; BIS 2004). It was recorded in only one sample (Shivpur-5) with a low concentration of 1 µg/L and no amount of it was recorded in any of the samples in the 2002 NEERI survey. CrChromium is widely distributed in the Earth’s crust. It can exist in valences of +2 to +6. In general, food appears to be the major source of intake. Total chromium concentrations in drinking-water are usually less than 2 µg/L (WHO 2008). The maximum permissible limit for chromium proposed by both the WHO and BIS is 50 µg/L (WHO 2008; BIS 2004). In the 2011 survey,

chromium was present in all the samples collected but the concentration values were very small and negligible ranging from 1 µg/L to 5 µg/L. However, in the 2002 NEERI survey, no amount of it was recorded in any of the samples. Due to the low concentration of Chromium, it has have no significant affect on the potability of the water source or the environment in general. PbLead is used principally in the production of lead-acid batteries, solder and alloys. Lead is rarely present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead dissolved from the plumbing system depends on several factors, including pH, temperature, water hardness and standing time of the water, with soft, acidic water being the most plumbosolvent (WHO 2008). Maximum permissible limit prescribed by WHO and BIS for lead is 10 µg/L (WHO 2008; BIS 2004). Lead was found in only one sample (Shivpur-5) in the 2011 survey with a minute, negligible concentration of 2 µg/L, whereas no lead was present in any of the samples collected in 2002 NEERI survey. AsArsenic is found widely in the earth's crust in oxidations states of -3, 0, +3 and +5, often as sulfides or metal arsenides or arsenates. In water, it is mostly present as arsenate (+5), but in anaerobic conditions, it is likely to be present as arsenite (+3). Levels of arsenic concnetration in natural waters generally range between 1 and 2 µg/L, although concentrations may be elevated (up to 12 mg/L) in areas containing natural sources. The WHO permissible limit for arsenic concentration is 10 µg/L (WHO 2008). The BIS maximum permissible limit is however 50 µg/L (BIS 2004). Arsenic was absent in many samples in the 2011 survey and was present in very less quantity upto a maximum of 3 µg/L in a few samples. In the 2002 NEERI survey, no sample had any detectable amount of arsenic in it. Heavy arsenic contamination has been recorded in the Ganga plain but the contamination is only located and concentrated in rural areas. Groundwater in Varanasi city area seems to be arsenic free but the rural areas in the Varanasi district and many parts of the Indo-Gangetic plain have shown presence of high concentrations of arsenic and the people of such villages have reported lesions caused due to arsenic poisoning (Ahamed et al. 2006; Chakrabroti et al. 2004; Ramanathan et al. 2006; Shah 2010). Detailed study in the field of Arsenic contamination must be done in detail with an objective of defining a boundary which can profile the areas with arsenic free and arsenic contaminated groundwater resources. MoMolybdenum is found naturally in soil and is used in the manufacture of special steels and in the production of tungsten and pigments, and molybdenum compounds are used as lubricant additives and in agriculture to prevent molybdenum deficiency in crops (WHO 2008). The maximum permissible limit set by WHO and BIS for molybdenum concentration is 70 µg/L (WHO 2008; BIS 2004). All samples were found to contain small amounts of molybdenum ranging from 1 µg/L to 7 µg/L as per the 2011 survey. In Figure 2, the sample locations of all the surveys included in this study are shown. The figure also shows the general land use map of the city area. The different land use of the city area was mapped during field work done by Blomeyer (2012). With additional help from Google images, different areas were identified. BHU in the map is the area covered by the Banaras Hindu University Campus. Similarly, DLW denotes the Diesel Locomotive Works. These two areas are shown separately because both these areas have their own campuses which are very different when compared with the rest of the city. For example, in the BHU campus, the construction of buildings and roads is done in a planned manner with added consideration to green areas. One can see drastic change in the surroundings when you enter the university campus while coming from the city. There is ample area in the BHU campus for natural groundwater recharge and the density of buildings and people is much lower when compared with the rest of the city. The campus has its own water supply system, sewerage system, playgrounds, gyms, and all other essential commodities and thus the campus acts like a model sustainable city, but of course, considerably smaller in size. The DLW campus has somewhat a similar campus for the people working in the factory itself, but an added aspect in its case is that the adverse affects of waste water coming out of the factory on the groundwater of the area. The slum areas shown in the map in pink is the area where the population density is the highest. Most of this area is the old city with a lot of small houses which are criss-crossed with very narrow streets. The average household size in the slum areas is 10 which is higher than the city average of 7. 3 (JNNURM, Municipal Corporation Varanasi 2006). The Manufacturing Zones, shown in teal, basically shows areas where the small to medium scale, spinning and weaving industries are present. These are the areas where the popular " Banarasi Sarees" are made. Usage of dyes for colouring of the Sarees and then disposal of the waste water in the sewage or in the river makes this area responsible for some pollution and therefore important. The parameters discussed above when compared with the various types of areas around the sampling locations, can point towards the possible source of pollution of a particular kind. The lower than normal pH values of groundwater samples in and around the DLW area is such an indication. EC values in groundwater samples are a great indicator of quality of the water. High EC in soil generally indicates that the Nitrate concentration in the soil is high. Actually, Nitrate concentration in soil and EC values of soil samples are directly proportional to each other (Albert 2012; Singh and Sekhon 1976). Although such correlation is not completely true in water samples, because a lot of other molecules can cause high EC values in water, but because high density urban areas are characterized by high nitrate content (Somasundaram et al. 1993) due to various human activities. The accumulation of nitrate in environment results mainly from point sources from poorly or untreated human sewage (Dar et al 2010). It is not wrong to assume that the high EC samples seen in Raju's survey and NEERI survey in high density areas of the city can be presence of higher concentration of nitrate. Lack of adequate quality of the sewage system, percolation from leakage of extremely old sewage pipe lines, percolation from septic tanks, these are all very probable sources of nitrate contamination in the groundwater. Further studies and field work to confirm nitrate contamination is extremely important because of the fact that mitigation of nitrate concentration is much more difficult when compared to elimination of pathogens and viruses, which can be removed through attenuation processes (Baalousha 2011). The analyses of the samples for concentration of elements like Na, K, Ca, Mg, Mn, Fe, Zn, Cu, Co, Cd, Cr, Ni, Pb, As and Mo was done to find out if there is any new major source of heavy metal contamination in the Varanasi city area. Other than a few samples which contained strangely high amounts of Mn and Fe in the eastern side of the Ganga River, rest of the samples were found to be safe on the basis of the parameters tested in this work. A more rigorous and concentrated work should be done in the eastern side of the Ganga river to locate the source of high content of these metals. Presence or absence of arsenic is of much importance in the Varanasi city area because in many areas near the city in nearly all directions, high concentrations of arsenic have been recorded. In the present study, such scare was not to be found. ConclusionsThe above results collectively show that on accounts of geochemical parameters of the groundwater in the areas of Varanasi city from where samples were collected, the water quality is acceptable for potable use. The low pH values measured in the 2011 survey show that the groundwater of outskirts area of the city is declining in quality. Low pH of samples collected nearby the DLW (Diesel Locomotive Works) factory may suggest decline of quality of groundwater due to the effluents coming out of the factory. When comparing NEERI survey and Raju's survey interpolation diagrams for conductivity values in Figure 7, we can see significant increase in conductivity values in the central parts of the city. These parts are the most densely packed areas of the city with very high population density. This increase in conductivity could be an indication of rising levels of nitrate content. This is an indication that haphazard growth of the city and increase in population is not just lowering the water table in the area but also is affecting the groundwater quality. The TDS and Hardness of the groundwater samples also show slight increasing trend in Figures 8 and 9, indicating a possible increase in nitrate concentration in the groundwater of the area. The increase is again more concentrated in the central areas of the city which is very densely packed solidifying the conclusion. In case of heavy metals, High concentration of Manganese on the eastern banks of the Ganga river is a cause for concern. Detailed study in this area should be done to locate the source of this high concentration. Also, new samples from the central parts of the city must be collected to see whether they show any Manganese concentrations or not and if they do then the source of that contamination should be located. Moderately high concentration of Iron on the eastern banks of the Ganga river must also be investigated. Absence of arsenic in most of the samples was surprising as many studies have been done for Arsenic contamination in and around the Varanasi district in rural areas and very high concentration of arsenic were found in the groundwater in those areas. Although no high concentration of Arsenic was seen in the samples collected in the study area, detailed work in this field is required to find out the arsenic contaminated and arsenic free groundwater. The other metals like Zinc, Copper, Cadmium, Chromium, Lead and Molybdenum were found in some of the samples in minute quantities therefore pose no immediate threat to the people who are consuming the water for potable use. However, the absence of all these metals in the NEERI survey and the presence of them all in the recent 2011 survey shows that the quality of the water is definitely declining and new sources of pollutants are coming up.