Visakhapatnam urban agglomeration, on the east coast of India, is a fast-growing industrial city, where groundwater is an important source of water and the problems of inadequate potable water supply and lack of full-fledged modern sanitation systems are threatening public health. This study is aimed at assessing the quality of groundwater in Visakhapatnam, by testing samples for physico-chemical, heavy metal and bacteriological parameters. The sampling was carried out at forty borewells spread across the city and its suburbs. All these groundwater tapping points are in public areas and are under regular use, 35 of them with hand-pumps and the other five fitted with electric pumps.

The sampling was done in February-March 2010 and tests for sixteen physico-chemical parameters (pH, Electrical Conductivity (EC), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Alkalinity, Total Hardness, calcium, magnesium, chlorides, sulphates, phosphates, nitrates, fluorides, sodium, potassium and Dissolved Oxygen (DO)) thirteen heavy metal parameters (aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, vanadium and zinc) and six bacteriological parameters (Heterotrophic Plate Count (HPC), Total coliform (TC), Faecal coliform (FC), Faecal Streptococci (FS), Staphylococci, Thermophiles) were carried out. A second set of samples were collected the next year, in February-March 2011, and tested for the sixteen physico-chemical parameters and the six bacteriological parameters, to identify whether there is any marked change in them. Only residential localities are chosen for this study, since the core of the industrial area is highly polluted and is therefore anyway not being used for habitation.

The forty sampling points are categorised under five broad classifications based on their geographical location and the environmental conditions around them: industrial zone, urban residential zone, urban slums, coastal zone and municipal solid waste disposal site. A summary of zone-wise results based on the basic statistical
analyses of all test results and water quality index (WQI) calculations for the forty sampling points is given below

a) Electrical conductivity of all the groundwater samples in Zone-1 (Industrial Zone) is exceeding the permissible limit. TSS values at two locations are high. Nine of the ten locations had TDS in excess of the desirable limit. Phosphates values at all the ten locations are above the limit set by EEC. The Dissolved Oxygen content falls short of the minimum desirable value at seven locations. Aluminum content is in excess of the desirable limit of BIS at all the ten locations. Arsenic concentrations are also in excess of the respective limit in nine of these locations. In regard to Iron, Lead and Nickel, all the samples failed to meet the desirable standards. Out of the ten locations, samples from Mindi had the worst values in the case of EC, TDS, TH, Calcium, Magnesium, Chlorides, Dissolved Oxygen, Arsenic, Iron, Manganese and Nickel. The presence of the smelter in the vicinity could be the cause. Akkiredypalem, the adjoining locality at a slightly higher contour, also returned poor results. The WQI figures lead to a classification of seven locations as very poor and the balance three locations as poor. Bacteriological contamination is relatively lower, when compared to the other Zones.

b) Out of the ten localities in the large chunks of residential areas, categorised here as Zone-2 Urban Residential, MVP Colony is closest to the coast and at the lowest contour. The poorest results were seen here in respect of EC, TDS, Sulphates, Phosphates, Nickel, Fluoride and Sodium, while TH, Calcium, Magnesium, Chlorides and Potassium also were high. On WQI considerations, two locations (MVP Colony and Maddilapalem) are to be categorised as having very poor quality of groundwater. Substantial bacteriological contamination is observed all over this Zone, possibly due to proximity of the borewells to residential septic tanks.

c) Zone-3 is a strip of coastal area, interspersed with hill ranges, poorly populated and thickly vegetated stretches. The coastal Jalaripeta, a fishermen colony, returned the poorest quality of groundwater on a physico-chemical basis, the values of EC, TDS, TH, Calcium, Magnesium, Chlorides, Sulphates, Nitrates and Fluorides being the highest in this Zone of ten sampling locations. The concentrations of heavy metals are however highest at other locations such as Chinawaltair (Cadmium,
Chromium, Copper, Lead and Nickel), Yendada (Arsenic and Manganese) and Pedarushikonda (Zinc). Based on the computed WQI, Jalalipeta, Sagarnagar and Yendada had the poorest groundwater quality. The high EC values correlate with high TDS and concentrations of various salts such as sodium, potassium and chlorides. Uncontrolled extraction of groundwater can be leading to seawater incursion into the coastal aquifers. The high bacteriological counts of the water samples in this Zone are due to the absence of proper sanitary drainage.

d) Samples from Kotaveedhi had the highest content of TDS, Chlorides, Sulphates and Potassium, apart from highest EC value, amongst the five locations in Zone-4 (Urban Slums). The WQI at four of these locations is in the very poor category, only Gnanapuram being labelled as poor. The unsanitary conditions in the slums can be the underlying reason for these poor results. This densely populated Zone is marked by unhygienic surroundings, including open defecation, and reflects the poor socio-economic status of the population.

e) All the water quality parameters indicate very poor quality of groundwater in Zone-5 (MSW Dump zone). The crude and unscientific disposal of wastes is seriously affecting the air, soil and water environments. The solid waste is dumped in the open and the leachate flow finds its way into a narrow natural valley. Frequent fires generate an almost continuous haze of toxic smoke and the fully and partly burnt material contributes to the pollution of soil and groundwater. The bio-medical waste, collected from a number of hospitals within a 100 km radius, is also disposed here after partial treatment.

An analysis of the results yields the following points:

1. Results against seven of the sixteen physico-chemical parameters are cause for worry: EC, TDS, Calcium, Magnesium, Chlorides and Phosphates exceed the guideline values of WHO / BIS and the D.O. content falling short of the guideline values.

2. Sodium and Potassium are at generally safe levels. pH, TSS, TH, Fluorides, Sulphates and Nitrates are within the desirable limits for drinking water.
3. Three of the thirteen heavy metals are found in excess of the standard limits: Aluminum, Lead and Iron, at most locations. Arsenic levels are high in the industrial zone. Cadmium, Chromium and Nickel are also in excess of the desirable limits at some of the locations.

4. The levels of bacteriological contamination are high in the waste dump site, urban slums and some of the localities in the coastal zone. TC, FC and FS levels indicate faecal contamination and other anthropogenic influences.

5. Close correlation is found between some of the parameters: EC with TDS, Calcium, Total Hardness & Sulphates; TDS with Total Hardness, EC, Calcium, magnesium, Sulphates & Chlorides; Chlorides with EC, TDS, Total Hardness, Calcium & Sulphates; Sulphates with TDS & Magnesium; Phosphates with Alkalinity; Total Hardness with EC, TDS, Calcium, Magnesium, Chlorides & Sulphates; Calcium with Phosphates; Magnesium with EC, TDS, Total Hardness, Calcium, Chlorides & Sulphates; Alkalinity with Chlorides. Negative correlation is seen between Dissolved Oxygen and most of the other parameters.

6. The Water Quality Index figures for all the 40 locations are poor to very poor, considering the test results of both 2010 and 2011. This is an alarming figure considering that a section of the population that depends on these waters for cooking and drinking is at a very potential risk of ill-health and disease.

The following conclusions can be drawn from the results of this study of groundwater quality in Visakhapatnam:

- The physico-chemical parameters of the groundwater that are beyond the upper limits specified by BIS / WHO manifest themselves mainly on account of anthropogenic causes rather than due to geological conditions.
- Indiscriminate disposal of liquid and solid wastes, i.e. domestic and industrial effluents, is elevating the concentration levels of some of the heavy metals.
- The bacteriological contamination is very substantial at many of the sampling locations. The causative factors are essentially anthropogenic, i.e., unsanitary environment.
Recommendations:

Whereas geological factors affecting the quality of groundwater are largely beyond human intervention, the anthropogenic aspects are well within our means for remediation. Bacteriological contamination is especially of concern, since the level of contamination can multiply with time and the effects on human health are usually immediate, sometimes proving fatal. A suggested guideline list for controlling the pollution of groundwater in Visakhapatnam is presented below:

1. Improve overall sanitation in the neighbourhoods and put in place scientifically proven solid waste collection and disposal schemes.

2. Develop sewerage systems for transport of sewage to decentralised sewage treatment plants, without waiting for the city-level systems to develop.

3. Ensure that industries are sited and operated with high regard to the environment.

4. Educate the local population as to the results of the tests on groundwater, the risks involved in using the water and the precautions to be taken at the domestic level and apprise the policy makers of the situation on a continuing basis, so that adequate attention is paid and sufficient funds are allocated.

5. Encourage the use of household water treatment systems, especially where groundwater is the source, and hygienic storage of water at homes.

6. Maximise the coverage of piped protected water supply systems at the community level and minimise the dependence on groundwater, at least for drinking and cooking.

7. Minimise drawl of groundwater, by ensuring minimal wastages at the domestic level, while widely implementing rainwater harvesting to recharge the aquifers.

8. Ensure testing of groundwater at multiple locations at frequent intervals and analyse the results, factoring-in the seasonal, climatic and other parameters such as sanitary conditions and recent changes in the industrial activity, population and anthropogenic activities.