Int. J. Environ. Res., 8(4):1145-1158, Autumn 2014
ISSN: 1735-6865

Assessment of Impact of Urbanization on Groundwater Resources using GIS Techniques- Case Study of Hyderabad, India

Wakode, H. B.[1*], Baier, K.[1], Jha, R.[2], Ahmed, S.[3], Azzam, R.[1]

[1]Department of Engineering Geology and Hydrogeology, RWTH Aachen University, Aachen, Germany

[2]Department of Civil Engineering, National Institute of Technology, Rourkela, India

[3]Indo-French Centre for Groundwater Research, CSIR- National Geophysical Research Institute, Hyderabad, India

Received 24 Dec. 2013; Revised 10 Feb. 2014; Accepted 25 March 2014

ABSTRACT: Hyderabad is one of the fastest growing Indian megacities which have significant impact on its environment. The surface and groundwater resources are severely affected by uncontrolled expansion and densification of the city. For the better understanding, recovery and to prevent future deterioration of these significance resources, it is necessary to have knowledge of the impact of urban growth in various ways on environment. Historical groundwater level and quality data obtained from different sources as well as by field study data is used for this analysis. In some cases missing data points were interpolated and verified by providing certain criteria. The map of rate of groundwater level change per year showed the locations of recharge activity by sewage and other effluents as well as overexploitations by industrial and some upper middle class residential areas. The results obtained from groundwater quality analysis are then compared with the BIS (Bureau of India) as well as WHO (World Health Organization) standards for drinking water. It had been observed that many water samples had heavy metal elements and bacterial formation above permissible limits and it is not suitable for drinking purpose. The water samples obtained from locations which do not qualify for drinking water use according to WHO as well as BIS standards are identified. These results are then overlapped with map of rate of groundwater level change to establish the relation between urban groundwater recharge and its effect on groundwater quality.

Key words: Groundwater pollution,Groundwater level change,Groundwater quality,Urban recharge, Hyderabad, India

INTRODUCTION

The urban environment quality is deteriorating day by day with the largest cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure. Hyderabad, the capital city of Andhra Pradesh, is facing a rapid change in the environmental quality. Rapid urbanization brings with it many problems as it places huge demands on land, water, housing, transport, health, education etc. (Gyananath *et al.*, 2001). Urbanization, in general, has four immediate repercussions on the hydrological cycle: These include flooding (e.g. as a result of increased soil sealing), water shortage (e.g. due to rising consumption), changes in the river and groundwater regimes as well as water pollution (Rogers, 1994; Strohschön *et al.*, 2013; Wakode *et al.*, 2013). Fresh water being one of the basic necessities for sustenance of life, the human race through the ages has striven to locate and develop it. Water, a vital source of life in its natural state is free from pollution but when man tampers the water body it loses its natural conditions. Due to rapid urban growth, surface as well as groundwater resources are severely affected quantitatively as well as qualitatively in Hyderabad (Wakode *et al.*, 2013). Urban areas generate both nonpoint and point sources of contaminants. Point sources that have an impact on surface water include industrial and municipal waste discharges; those that affect groundwater quality include leaky underground storage facilities, as well as miscellaneous accidental spills of organic or inorganic contaminants (Jha *et al.*, 2008). Ground water has become an essential resource over the past few decades due to the increase in its usage for drinking, irrigation and industrial uses etc.

*Corresponding author E-mail: wakode@lih.rwth-aachen.de

The quality of ground water is equally important as that of quantity (Asadi *et al.*, 2007). Groundwater occurs almost everywhere beneath the earth surface not in a single widespread aquifer but in thousands of local aquifer systems and compartments that have similar characters. Knowledge of the occurrence, replenishment, and recovery of groundwater has special significance in arid and semi-arid regions due to discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources. The rapid growth of urban area has two basic effects on groundwater resources such as: effects on natural recharge of aquifers due to sealing of ground with concrete and pollution of groundwater due to leakage from drainage and industrial wastage and effluents (Putra and Baier, 2009; Baier *et al.*, 2013). Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and on sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality (Vasanthavigar *et al.*, 2010). The quality of water is of vital concern for mankind, since it is directly linked with human welfare as well as socioeconomic development of any area. Poor quality of water adversely affects the plant growth and human health (Karanth, 1987; Kumar *et al.*, 2009; Singh *et al.*, 2011). Water pollution not only affects water quality but also threats human health, economic development, and social prosperity (Milovanovic, 2007). Many naturally occurring major, minor and trace elements in drinking water can have a significant effect on human and animal health either through deficiency or toxicity due to excessive intake (Frengstad *et al.*, 2001). Also, the effluents from industrial as well as from domestic sewage can percolate and make the groundwater unsafe for drinking purpose. Hence, evaluation of effect of urban growth on groundwater quantity and quality is important for the development of civilization and to establish database for planning future water resources development strategies.

Although, Hyderabad has got several sources of surface water like the Musi River and many lakes like the Hussain Sagar in the middle of Hyderabad, Durgam Cheruvu in Madhapur or Osman Sagar in the south-western part of the city, the water supply is insufficient due to increasing population and pollution of the own water resources. Since the 1960s, Hyderabad has to "import" water from sources outside the local catchment area, for example the Singur reservoir (located in the district of Medak) or the Nagarjuna Sagar reservoir which contains water of Krishna River. Nowadays, the water has to cover a distance of about 120 km to get to Hyderabad and satisfy the city's water demand (Rooijen *et al.*, 2005). Due to a further increase of the population, more plans for water harvesting (CGWB, 2012) and importing water from foreign water basins were planned. Fig. 1 can give an idea about the increasing thirst for a water of the city, which is increasing along with the urban growth. The figure shows the gap between demand and supply of water through different sources and its projection for future provided by Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB, 1995; Rooijen *et al.*, 2005).

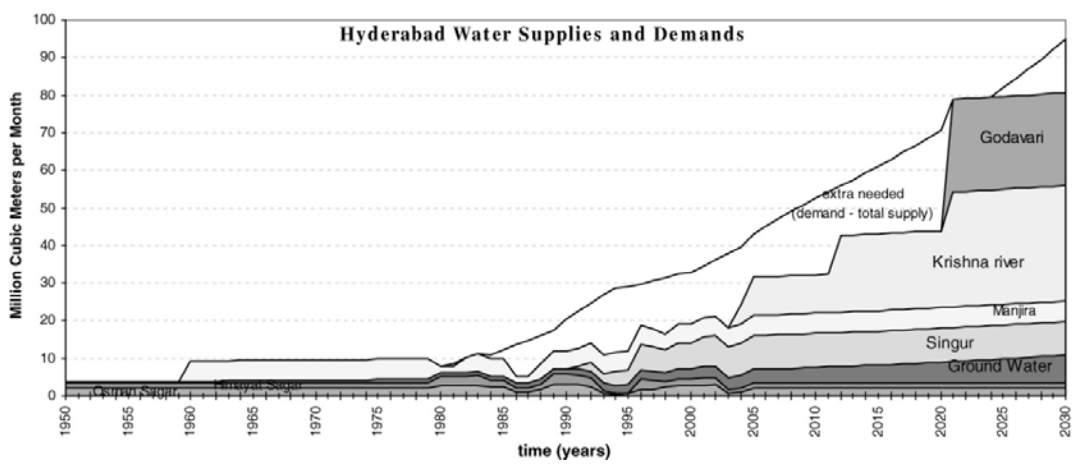

Fig. 1. Water delivery rates from the different water sources for urban water supply in Hyderabad in the period 1950–2030. For the period of 1980–2003 more detailed water delivery data were used (HMWSSB, 1995; Rooijen *et al.*, 2005)

The figure clearly shows that groundwater will also need share its contribution as much as possible and fact that assumption of a further increase of population, new resources, which can be used to satisfy the demand, have to be found and connected. On the other hand, it is necessary to conserve the valuable water resources which are already degrading due to rapid urbanization. Unfortunately, the city has lost due to urban encroachment and pollution, 18 water bodies of over 10 hectare size and 80 tanks of below 10 hectare size during 1973-1996 and many more after that (Ramachandraiah and Prasad, 2004). The land-use pattern has changed drastically in this region with an increase in the built-up area at the expense of other land uses and also causing rapid deterioration of groundwater quality related mainly to the increase in built-up land with un-sewered sanitation (Khan *et al.*, 2010). Considering such a stress on water resources, it is important to study the effect of urbanization on water resources and especially, on easily available groundwater source in the vicinity. This analysis is another step in the overall study of Interaction between urbanization and water resources.

The study area-Hyderabad is the capital and largest city of the southern Indian state of Andhra Pradesh. The Hyderabad urban agglomeration (HUA) includes the Municipal Corporation of Hyderabad (MCH), Secunderabad Cantonment, and ten surrounding municipal towns. Since it has been founded as the capital of the Deccan region, Hyderabad has had a big relative importance as a political and economic centre from the very beginning, and soon was the biggest city in the region. But it was not until the 1940s that the city crossed the one-million mark of inhabitants. Hyderabad was established along the banks of Musi River, which now, no longer exist due to urban encroachment and direct release of urban drainage in it (Rooijen *et al.*, 2005). The city has expanded up to 650 km^2 and it is growing in all possible directions. The study area for this analysis is bounded by 17°132 43 N to 17°342 353 N latitude and 78°152 33 E to 78°392 193 E longitude, covering a total area of 1708.428 km^2. It covers Hyderabad urban agglomeration and parts of Rangareddy district as shown in Fig. 2.

Hyderabad has 6,809,970 inhabitants and spread around 650 square kilometres, along the banks of the Musi River. It has a metropolitan population of 7.75 million, making it the fourth most populous city and sixth most populous urban agglomeration in India (Census of India, 2011). In case of Global ranking, it will be at 31st place with population of 11.6 million due to high population growth rate in 2025. Like any other urban agglomeration in India, Hyderabad is also experiencing a rapid increase in population. From 1.09 million in 1950, the urban population has now touched the mark of 7.75 million in 2011. It is estimated that population figure is likely to reach 11.65 million by 2025 (UN, 2012). The following graph in Fig. 3 shows the urban population growth since 1950 and projected up to 2025 in the United Nations report "World Urbanization Prospects- The 2011 Revision."

The urban growth of Hyderabad mostly includes residential as well as industrial growth. There are a number of industrial estates, three directly in the Hyderabad district and about 19 in the Rangareddy district belonging to the Hyderabad agglomerations which were mainly established between 1975 and 1985. Main industrial sectors include chemical and bulk drug, metals, timber, plastics, rubber and textile industry as well as electronic industry. Hyderabad hosts several

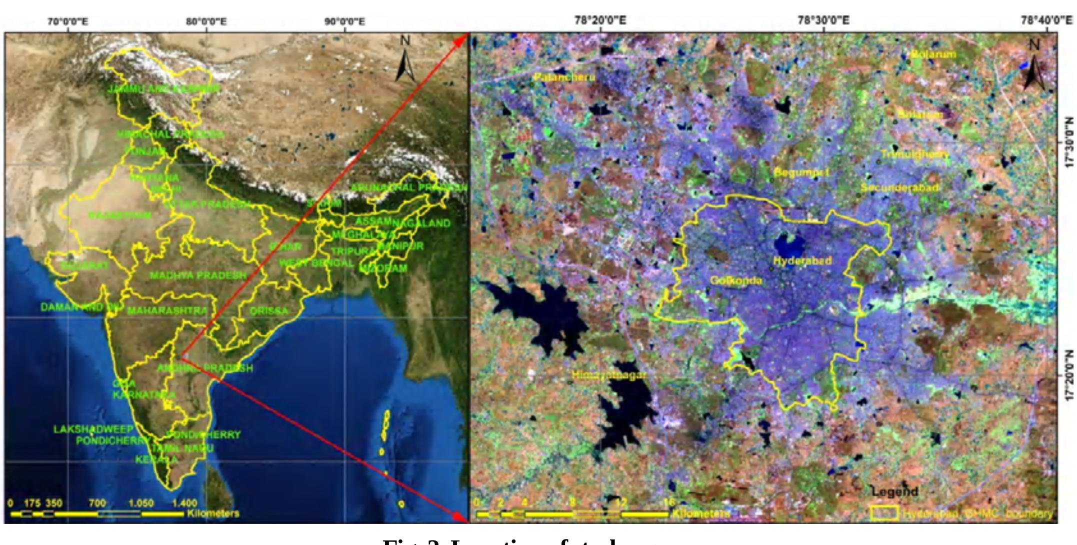

Fig. 2. Location of study area

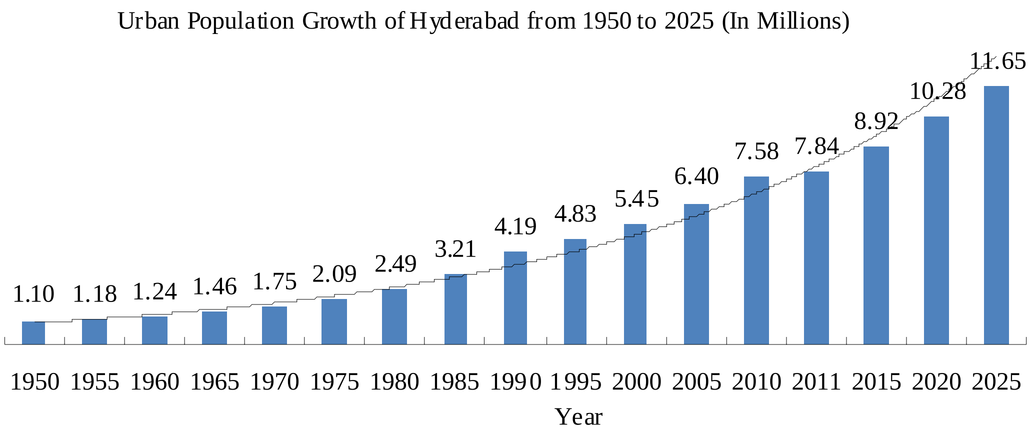

Fig. 3. Population growth of Hyderabad

major companies and public sector enterprises with central research and training institutions as well as universities and professional colleges. The dynamic city has emerged as a knowledge hub making rapid strides in information technology ("Cyberabad"), biotechnology and medical care but also in tourism (Taubenböck *et al.*, 2007).

The hydrogeology of Hyderabad plays important role in defining characteristics of groundwater. Hyderabad forms part of the Pre-Cambrian peninsular shield and is underlain by the Archaean crystalline complex, comprising of granites intruded by dolerite dykes. A thin veneer of alluvium of recent age occurs along the Musi River. Granites exhibit structural features such as fractures, joints, faults and fissures. Ground water occurs under phreatic conditions in weathered zone and under semi-confined to confined conditions in the fractured zones. Ground water was exploited through shallow, large diameter dug wells until 1970 to meet domestic and irrigation requirements. Presently ground water is being exploited through shallow and deep bore wells with depth ranging from 100-300 m. The effects of urbanization and industrialization in Hyderabad led to the contamination of ground water. Due to inadequate sewerage system and treatment capacities, the domestic sewerage and industrial effluents are letting directly into the nalas and streams, causing severe ground water contamination (Gumma *et al.*, 2011). Groundwater quality in Hyderabad has special significance and needs great attention of all concerned since it is the major alternate source of domestic, industrial and drinking water supply (Asadi *et al.*, 2007).

MATERIALS & METHODS

The information about groundwater level and quality measurements of previous years are the required basic data for this study. Groundwater Department of Andhra Pradesh State and Central Groundwater Board (CGWB) of India are the two main government organizations responsible for regular measurements, maintenance and distribution of such kind of data in India. Also, research organizations like National Geophysical Research Institute (NGRI) in Hyderabad keeps some data records according to their research objectives.

Monthly groundwater level data measured at different observation wells by Groundwater Department of Andhra Pradesh State and Central Groundwater Board of India, Hyderabad (CGWB) for the period of 2003-2012 was obtained. Also, the freely available groundwater level and quality data from the web portal (http://gis2.nic.in/cgwb/Gemsdata.aspx) of Central Groundwater Board was accessed and downloaded for the analysis. The direction of groundwater flow provides vital information about the movement of groundwater and helps to identify the areas which recharge the groundwater supply wells, streams, lakes and rivers. And thereby, identification of the land-use activities in the recharge area which are responsible for the threat to the groundwater quality or amount can be possible. Since contaminants generally move in the direction of groundwater flow, it can be also predicted how contaminants might move through the local groundwater system. For this purpose, the mean annual groundwater level for wells using the data obtained from 1998 to 2012 was calculated to prepare the contour map of groundwater levels. Additional to the annual mean of the groundwater level, the water level of the Musi River was used for the interpolation of the groundwater level. The groundwater level above mean sea level was calculated using the digital elevation model (ASTER-GDEM) for the point location of wells. It was then interpolated from the well locations with a spline interpolation method as shown in Fig. 5. Groundwater level for the month of May as Pre-Monsoon and November as Post-Monsoon were considered for further analysis. Pre and Post monsoon groundwater levels were used to calculate rate of water table fluctuation in m/year from the available data. Overall, pre and post monsoon groundwater level data of 89 bore wells from the period 2003-2012 was used. The geographic locations of the observation wells from which the measurements are taken, are shown in Fig. 4.

In some cases the groundwater level data obtained from government organization had missing data points due to obstructions, faulty instruments and other problems. For better accuracy of the analysis, missing data points were calculated by interpolation from the preceding and successive month's data points. Before using the interpolated data points for missing data, the accuracy of interpolation for the available data points of same well was evaluated for the percentage error. And only when the interpolated values of missing data were used if the criteria of error up to +/- 20% or +/ - 3m for the actual observed values was satisfied. The obtained data of groundwater level was used for time series analysis to calculate the rate of water table fluctuation in m/year for the period of 2003-2012. The calculated values were spatially interpolated using Inverse Distance Weighing (IDW) technique to prepare the map of rate of groundwater table fluctuation for the period of 2003-2012. From this map, the regions where continuous groundwater table recharge or depletion was happening are identified. The resulting map was then superimposed with results of groundwater quality to derive the relation between groundwater recharge or depletion and its effect on groundwater quality.

Analysis of quality of groundwater for drinking purpose was also one of the objective for this study. Overall, 43 groundwater samples were collected during pre-monsoon season of 2011, 2012 and 2013 from continually used public and private bore wells and hand pumps located at different locations during field work. The geographic coordinates of the locations of these samples were determined using a GPS and are shown in Fig. 4. The water samples were analysed for physical, biological and chemical parameters. Physical

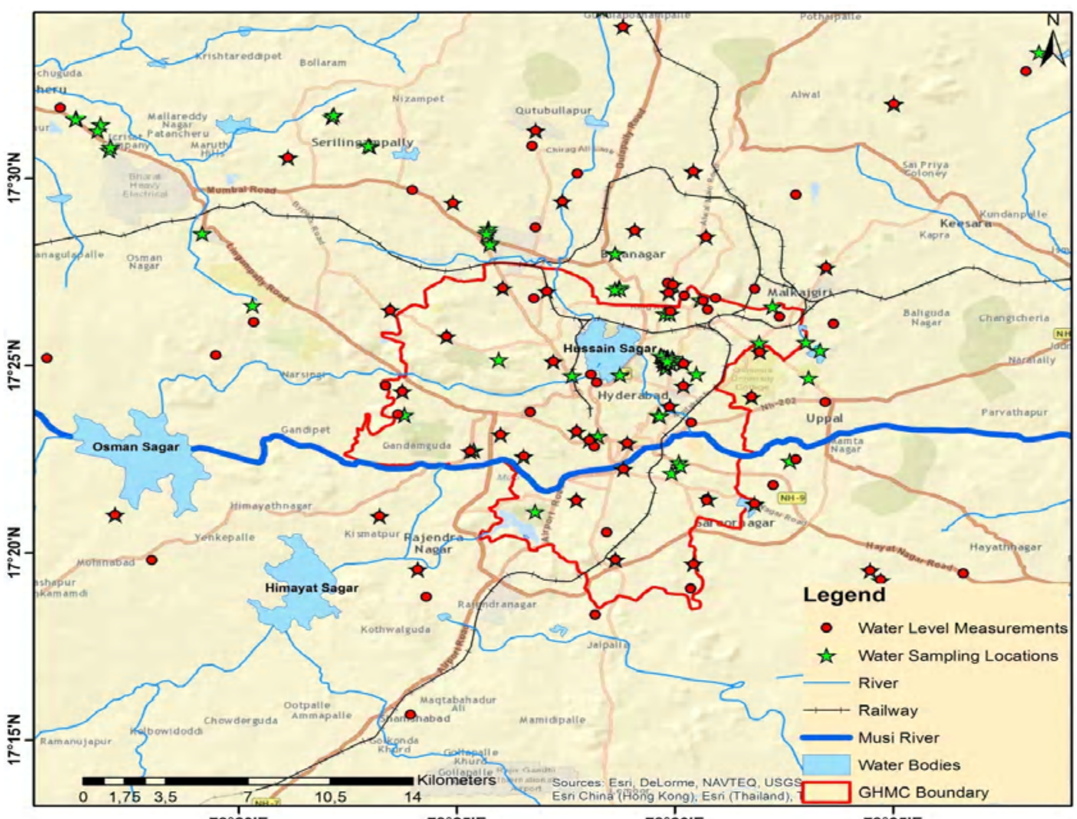

Fig. 4. Geographic Location of Groundwater Level and Quality Measurements

parameters like Temperature, pH, Total dissolved solids, Electrical Conductivity and Total Hardness were directly measured on site with HANNA HI 9828 version 1.8, a portable multi-parameter measuring instrument with 4m probe cable. Then the water samples were analysed in the laboratories of National Geophysical Research Institute (NGRI), Hyderabad and The Institute of Health Systems, Water Quality Testing Laboratory, Hyderabad for different geochemical parameters using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method. The microbiological parameters were analysed according to methods of American Public Health Association Standards (Brown *et al.*, 1970; Apha, 1985; 1998) and the procedures for the analysis are based on World Health Organization (WHO) guidelines.

Also, the analytical report of 133 groundwater samples collected at 61 different locations tested during the period of 2002-2010 by Groundwater Department of Andhra Pradesh and NGRI, Hyderabad was obtained for further analysis. The physical, biological and chemical parameters which were analysed and the drinking water limits provided by Indian Standards IS-10500:2012 (BIS, 2012) and World Health Organization limits (WHO, 2011) are provided in the following Table 1.

RESULTS & DISCUSSION

The contour map of groundwater level shown in Fig. 5 provides the direction of groundwater flow in the study area. It shows that the groundwater level in the study area varies from 442.80 m ASL to 688.65 mASL. Inside the Greater Hyderabad Municipal Corporation (GHMC) boundary, highest groundwater level is present at only Jubili Hills region and the groundwater is flowing from this region to Eastern, Western and Southern direction towards Musi River. In the Northern region of Musi River, the groundwater flows from the North-West direction to the South-East direction into the Musi River.

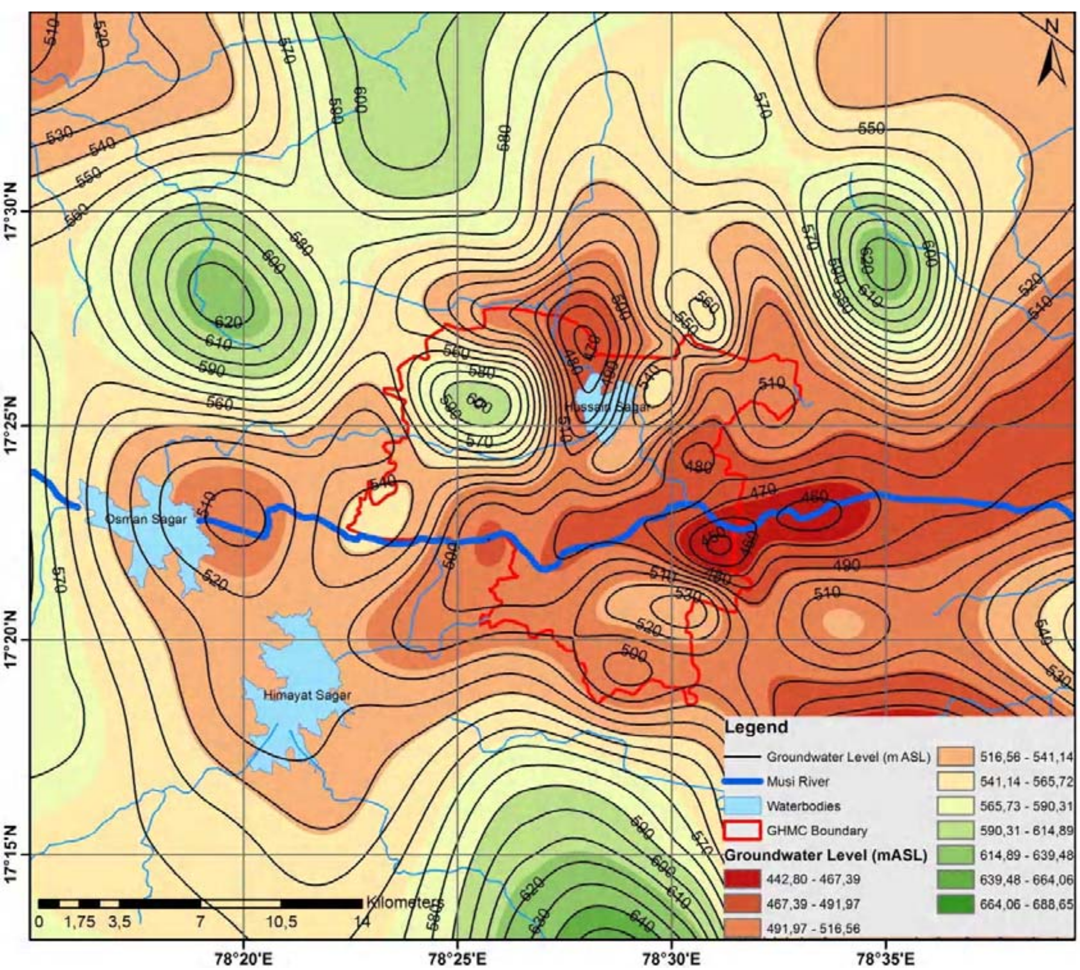

Fig. 5. Map of Groundwater Contours in Hyderabad

Table 1. Limits for drinking water after BIS and WHO

Parameter	Unit	BIS (IS 10500:2012)[a]		WHO[b]
		Desirable Limit	Permissible Limit	Max. Allowable Concentration
Colour	Hazen	5	15	-
Turbidity	NTU	1	5	-
Total Dissolved Solids	mg/L	500	2000	500
pH	-	6.5 to 8.5	No relaxation	6.5 to 8.5
Aluminium (as Al)	mg/L	0.03	0.2	0.2
Ammonia (as N)	mg/L	0.5	No relaxation	-
Antimony (as Sb)	mg/L	-	-	0.02
Barium (as Ba)	mg/L	0.7	No relaxation	0.7
Bicarbonate	mg/L	-	-	-
Boron (as B)	mg/L	0.5	1	2.4
Cadmium (as Cd)	mg/L	0.003	No relaxation	0.003
Calcium (as Ca)	mg/L	75	200	-
Chloride (as Cl-)	mg/L	250	1000	250
Cobalt (as Co)	mg/L	-	-	-
Copper (as Cu)	mg/L	0.05	1.5	2
Cyanide (as CN)	mg/L	0.05	No relaxation	0.07
Fluoride (as F)	mg/L	1	1.5	1.5
Iron (as Fe)	mg/L	0.3	No relaxation	0.3
Lead (as Pb)	mg/L	0.01	No relaxation	0.01
Magnesium (as Mg)	mg/L	30	100	-
Manganese (as Mn)	mg/L	0.1	0.3	0.5
Mercury (as Hg)	mg/L	0.001	No relaxation	0.006
Mineral Oil	mg/L	0.05	No relaxation	-
Molybdenum (as Mo)	mg/L	0.07	No relaxation	0.07
Nickel (as Ni)	mg/L	0.02	No relaxation	0.07
Nitrate (as NO_3)	mg/L	45	No relaxation	50
Potassium (as K)	mg/L	-	-	-
Residual, free chlorine	mg/L	0.2	1	-
Selenium (as Se)	mg/L	0.01	No relaxation	0.04
Sodium (as Na)	mg/L	-	-	200
Sulphate (as SO_4)	mg/L	200	400	-
Sulphide (as H_2S)	mg/L	0.05	No relaxation	0.05
Total arsenic (as As)	mg/L	0.01	0.05	0.01
Total chromium (as Cr)	mg/L	0.05	No relaxation	0.05
Total Hardness (as $CaCO_3$)	mg/L	200	600	500
Uranium (as U)	mg/L	-	-	0.03
Zinc (as Zn)	mg/L	5	15	5

a: BIS, Bureau of Indian Standards (2012): IS10500:2012
b: WHO (2011): Guidelines of Drinking-water Quality

The results obtained after the analysis of groundwater table fluctuation and analysis of groundwater quality were superimposed and compared with each other to derive the relation between these two effects on groundwater due to urban growth in Hyderabad.

The rate of groundwater table fluctuation during the period of 2003-2012 was calculated by applying time series analysis. The values were used to prepare rate of groundwater table fluctuation map using the Inverse Distance Weighting (IDW) spatial interpolation method. The effect of urban growth on groundwater level can be examined by studying the map shown in Fig. 6.

From Fig. 6. it can be noticed that rise and depletion of the groundwater table in different patches had been occurred during 2003-2012 inside the urban region as well in the surrounding area. The groundwater withdrawal for urban use has clearly caused drops in the groundwater table in Hyderabad (Rooijen *et al.*, 2005). This study is mainly concerned about the impact on groundwater mainly by urban area. In case of groundwater depletion by urban settlement, there are mainly 3 regions with high rate of groundwater depletion as follows:

- Region 1: Includes parts of High Tech City, Jubilee Hills, Madhapur and Sanjeeva Reddy Nagar
- Region 2: Includes parts of Maredpally, Malkajgiri, Nacharam and Moula Ali
- Region 3: Includes parts of Gudimalkapur, Kulsumpura, Langarhouse and Mehandipatnam

In the Region-1, the groundwater table has been depleted with the highest rate of 2.452 m/yr at Begumpet. Also, the overall rate of groundwater table depletion was within the range of rate of 1.098 to 0.302 in the area covered by Madhapur and Jubilee hills. Urban growth in this region has severely increased the pumping of groundwater for residential as well as industrial purpose. The newly established High Tech City for the complexes of Information and Technology industries may have also increased the withdrawal of groundwater from this region for the construction and other industrial purposes. The groundwater table has been depleted in this region with the average rate of 1.096 m/year.

In the Region-2, the groundwater table has been depleted with the highest rate of 0.469 m/year at Moula

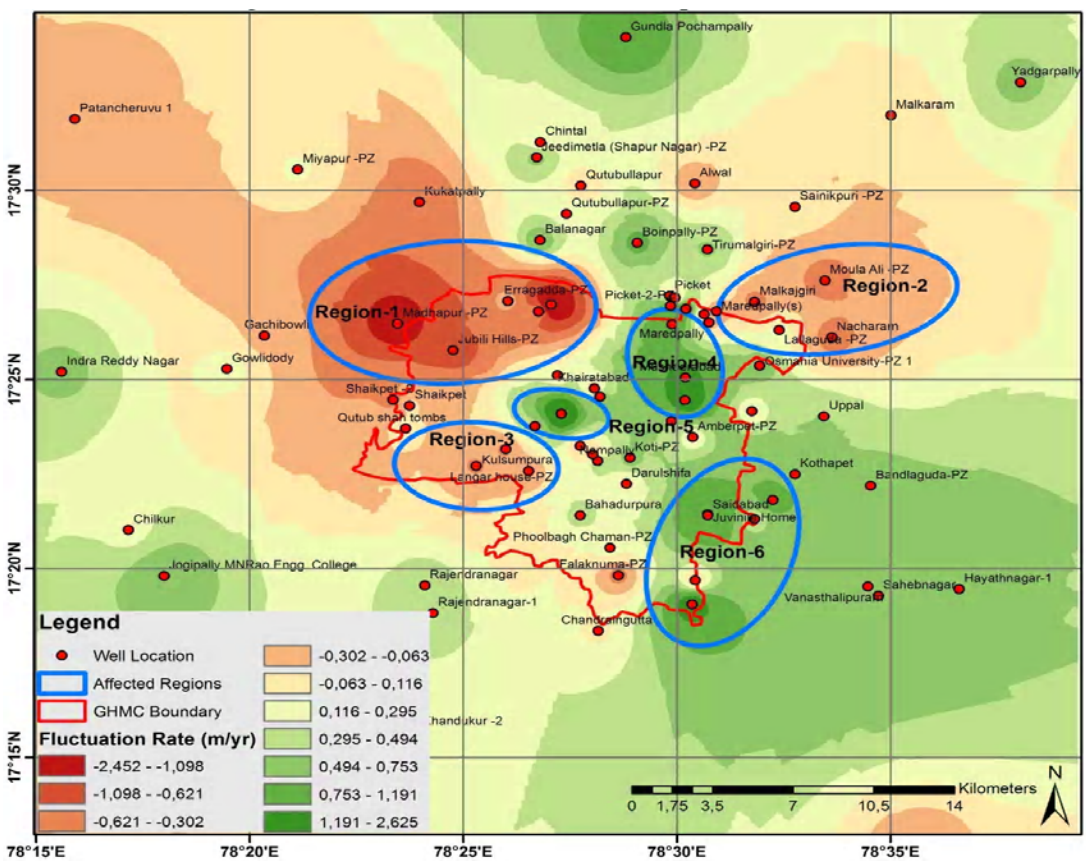

Fig. 6. Rate of groundwater table fluctuation for the period of 2003-2012 (in m/yr.)

Ali. The area covered in between Maredpally and Malkajgiri has mostly covered by the range of depletion rate of 0.302 to 0.063 m/year. The urban growth in this region mainly includes growth of small scale industries as well as high population density urban residential area (Wakode *et al.*, 2013). The average of groundwater depletion rate for the Region-2 is 0.434 m/year.

The Region-3 mainly includes the area covered by Gudimalkapur, Kulsumpura, Langarhouse and Mehandipatnam. It includes the old city residential area in the vicinity of historical Golkonda Fort surrounded by some small scale businesses. The main use of groundwater in this region is for household purpose only. The groundwater table in this region is continuously depleting with the average rate of 0.351 m/year.

In spite of these regions, Patancheru is one of the urban areas where connection between industrial development and its effect on groundwater can be made. Patancheruvu is the major Industrial hub of Andhra Pradesh state. Major industries like Asian paints and Kumkuma paper packs (paper bags) are located in this area. The area is also home to a large number of pharmaceutical manufacturers (GHMC, 2011). The groundwater table in this region is continuously depleting with the average rate of 0.234 m/year. Also, a low density residential area has been growing in this region.

In case of rise in groundwater table, there are some patches of regions in the outskirt of Hyderabad which are surrounded by agricultural land. But inside the urban population there are three easily noticeable regions which show higher rate of groundwater table rise as follows:

- Region-4: Includes Musheerabad, Secunderabad, Picket and West Maredpally
- Region-5: Includes Shanti Nagar, Humayun Nagar and Masab Tank
- Region-6: Includes Saidabad, Saroor Nagar and Kanchanbagh

Region-4 has showed the higher rates of groundwater recharge during 2003-2012. The rate of groundwater table fluctuation values varies in between 0.753 to 2.623 m/year. This region is located in the central part of Hyderabad and it is densely populated (Wakode *et al.*, 2013). The groundwater recharge in this region was found higher due to the fact that import of water for household as well as small scale industrial use in this region. Also, there are more than 10 officially registered slums in this region which lack the efficient drainage system (GHMC, 2012). The small scale industries in this region include skin traders, metal traders and plastic traders (Wagner, 2013). The average rate of groundwater table rise in this region is 1.198 m/year. Region-5 has densely populated residential area with some small scale leather industries. Most of the region showed the groundwater recharge rate of the range of 0.895 to 1.364 m/year. The average rate of groundwater recharge in this region was 1.227 m/year. Region-6 also showed high groundwater recharge rate and includes mostly residential area. It is located in the downstream of the Hyderabad city in South-East direction. This region showed the lowest groundwater level as shown in Fig. 5, so the groundwater is flowing from surrounding high water table regions to this area. It had showed the average rate of groundwater recharge as 1.046 m/year.

The results of groundwater quality analysis of in total 176 samples collected at 103 different locations during the period of 2003-2012 were studied and compared with drinking water quality standards provided by WHO and BIS. The overall result of groundwater quality analysis is provided in Table 2.

The physico-chemical parameters were analysed and the results were compared with the standards. An objectionable colour or odour was not detected in any groundwater sample. The limits for the pH value are 6.5–8.5 according to guideline value of BIS and WHO. The pH value for samples collected at Qutub Shah Tombs, Nampally, Bagh Lingampally and Chilkur in 2005; and at Ibrahimpatnam in 2008 and 2010 exceeded the limit of 6.5 and showed alkaline properties. Although the pH has no direct influence on the consumer's health, it is one of the most important operational water quality parameters. A low pH value can have a metallic taste or lead to corrosion. High pH levels are undesirable since they may impart a bitter taste to the water as well as it may also depress the effectiveness of disinfection by chlorination, thereby requiring the use of additional chlorine or longer contact times (Chandra *et al.*, 2012). The pH value for rest of the samples was within limits. The electrical conductivity (EC) is the measure of the ability of an aqueous solution to convey an electric current. This ability depends upon the presence of ions, their total concentration, mobility, valence and temperature. The measurement of EC values varied between 270 and 16490 µS/cm of ground water samples. No conclusion can be drawn as no limits are defined for EC by BIS or WHO for drinking water purpose. A possible reason high EC values could be leakages and percolation of sewage water. Turbidity is a measurement of the cloudiness of water, measured by passing a beam of light through the water and measuring photo-metrically. Cloudiness is caused by material suspended in water. Clay, silt, organic matter, plankton and other microscopic organisms cause turbidity in natural water.

Table 2. Overall result of groundwater quality analysis compared with BIS and WHO (Schmitz, 2012; Uerschels, 2012; Adrian, 2013; Wagner, 2013)

Parameter	Unit	Measured Range of Values		No. of Sample Exceeded Limits		No. of Samples Tested
		Min	Max	BIS[a]	WHO[b]	
pH	-	6.3	9.3	6	6	176
Electrical Conductivity	µS/cm	270	16490	NG[c]	NG[c]	159
Total Dissolved Solids	mg/L	82	16500	4	64	90
Total Hardness	mg/L	81	3178.71	27	38	176
Aluminium (as Al)	mg/L	0.001	0.181	0	0	19
Ammonia (as N)	mg/L	0	80	1	NG[c]	5
Antimony (as Sb)	mg/L	0	0.001	NG[c]	0	14
Barium (as Ba)	mg/L	0.066	0.172	4	4	5
Boron (as B)	mg/L	0.12	0.677	0	0	19
Cadmium (as Cd)	mg/L	0.000	0.019	3	3	38
Calcium (as Ca)	mg/L	6	744.6	6	NG[c]	159
Chloride (as Cl^-)	mg/L	1.27	6898.96	3	34	147
Cobalt (as Co)	mg/L	0.0002	0.012	NG[c]	NG[c]	19
Coliform Bacteria	MPN/100mL	0	150	8	8	24
Copper (as Cu)	mg/L	0.007	0.726	0	0	38
Fluoride (as F)	mg/L	0.1	30	37	37	153
Iron (as Fe)	mg/L	0.109	8.29	15	15	38
Lead (as Pb)	mg/L	0.003	0.19	32	32	38
Magnesium (as Mg)	mg/L	3	360.66	11	NG[c]	169
Manganese (as Mn)	mg/L	0.004	1.062	7	7	38
Molybdenum (as Mo)	mg/L	0.002	0.017	0	0	19
Nickel (as Ni)	mg/L	0.007	0.138	23	3	38
Nitrate (as NO_3)	mg/L	0.2	151.78	25	23	144
Nitrite (as N)	mg/L	0.086	0.476	NG[c]	0	5
Potassium (as K)	mg/L	0.41	295	NG[c]	NG[c]	166
Selenium (as Se)	mg/L	0.01	0.069	16	1	19
Sodium (as Na)	mg/L	8	2666.29	NG[c]	12	158
Sulphate (as SO_4)	mg/L	2.1	624	4	NG[c]	131
Total arsenic (as As)	mg/L	0.001	0.007	0	0	24
Total chromium (as Cr)	mg/L	0.008	0.185	20	20	38
Zinc (as Zn)	mg/L	0.02	8.963	0	3	38

a: Bureau of Indian Standards (2012): IS10500:2012
b: WHO (2011): Guidelines of Drinking-water Quality
c: NG= No Guidelines

This has been recognized as a valuable limiting factor in the biological productivity of the water bodies (Chandra *et al.*, 2012). The turbidity value for one sample collected in vicinity of Musi River exceeds the limits and had a value of 13 NTU, whereas in other samples values were recorded below the limit of 5 NTU. In natural water, dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese etc. and they originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals (Esmaeili and Johal, 2005). WHO recommends a value less than 500 mg/L for palatability of water. Above 1000 mg/L, drinking water becomes unpalatable (WHO, 2011). The BIS 10500:2012 specifies that values above 500 mg/L decrease the palatability. Also gastro intestinal irritations could be caused above this value. The total dissolved solids (TDS) in the groundwater samples range between 82 and 16500 mg/L. Water samples respectively one from Musi in 2011, one from Musheerabad in 2009 and 2 samples from Bholakpur in 2013 had exceeded the permissible limit from BIS as well as WHO in case of TDS. The TDS values were in compliance with the range of described by Mondal *et al.* (2005) for former tannery sites. Thus, the TDS values are considered to indicate a contamination that might have been caused by the former Tanning activities in in Bholakpur. The values for total hardness varied from 81 mg/L to 3178.71 mg/L. The results showed that 26 water samples out of 176 recorded higher amount of total hardness than the limits provided by BIS and WHO standards. Calcium and magnesium cause hardness, which is indicated by precipitation of soap scum. There is no direct influence on the health, but problems of scale depositions may occur due to water with a high hardness. The degree of hardness is important for aesthetic acceptability by consumers (WHO, 2011).

After analysing chemical parameters of samples, it was observed that Aluminium, Boron, Copper, Arsenic and Molybdenum contents were within the limits provided by WHO and BIS. There were no guidelines for comparison of Cobalt and Potassium provided by either BIS or WHO for drinking purpose. Also there were no guidelines values for Ammonia, Sulphate, Calcium and Magnesium provided by WHO for comparison. So these parameters were only compared with the BIS standards. On the other hand, only WHO guidelines were available for Antimony, Nitrite and Sodium for evaluation. The water sample collected in the vicinity of Musi River in 2011 showed high amount of ammonia (80 mg/L), whereas in the other samples ammonia was absent. Ammonia was not detected in the other groundwater samples as shown in Table 2. Antimony and Nitrite values were within the permissible limit of WHO guidelines. Amount of Cadmium had been noted above the permissible limits of WHO and BIS in 3 samples (2 at Bholakpur in 2013 and 1 at Balanagar in 2011) out of 38 samples. Cadmium is normally used in the steel industry, as a stabiliser in PVC, in nickel–cadmium batteries and as a pigment for colours (cadmium yellow CdS). Another source of cadmium is electronic waste (WHO, 2010). The amount of calcium exceeded the limit of 200 mg/L in 6 samples from Musi, Qutubullapur, Ibrahimpatnam, Gudimalkapur, Balanagar regions.

In case of Chloride, 3 samples showed the amount exceeded from permissible limits of 1000 mg/L by BIS and 34 samples had exceeded the guidelines of 250 mg/L by WHO. Large contents of chloride in freshwater is an indicator of pollution (Venkatasubramani and Meenambal, 2007). The sewage water and industrial effluent are rich in high chloride and hence the discharge of these wastes result in high chloride level in fresh water (Haslam, 1990). SMCL (Secondary Maximum Contaminant Limit.) of 250 mg/L for chloride is the level above which the taste of the water may become objectionable to the consumer. In addition to the adverse taste effects, high chloride concentration levels in the water contribute to deteriorate on of domestic plumbing, water heaters and municipal water works equipment. High chloride concentrations in the water may also be associated with the presence of sodium in drinking water (Chandra *et al.*, 2012).

Fluoride was observed above permissible limit of 1.5 mg/L by WHO and BIS at 35 different places in different years. Values over 1.5 mg/L may cause dental fluorosis or mottling of permanent teeth in children between the ages of birth to 13 years. Steps should be taken to reduce the risk of dental fluorosis. The Iron content in 14 samples was observed to above the permissible limits of 0.3 mg/L by BIS and WHO. The iron occurs naturally in the aquifer but levels in groundwater can be increased by dissolution of ferrous borehole and hand pump components. Unlike lead and copper, ingesting iron from drinking water is not directly associated with adverse health effects. Although, trace impurities and microorganisms that are absorbed by iron solids may pose health concerns. Lead had been observed above permissible limits of WHO and BIS in 32 samples out of 33 samples. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure. The major sources of lead in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. The rising concentration of heavy metals (such as Fe, Mn and Cu) along with Pb may consider as an indication of industrial pollution. The amount of Magnesium exceeded the limit of 100 mg/L by BIS in the samples 11 samples out of 164. Magnesium is often associated with calcium in all kinds of water, but its concentration remains generally lower than the calcium. Manganese also occurs naturally in groundwater. It was observed that 7 samples (5 from Bholakpur in 2013 and 2 from Balanagar in 2011) contained Manganese above permissible limit of WHO and BIS for drinking water. The occurrence of Manganese can potentially arise from the tanning activities in Bholakpur region. Nickel was observed in 23 samples above permissible limit of 0.02 mg/L by BIS and in 3 samples above WHO standard of 0.07 mg/L. It was mainly observed in 8 samples collected at Patancheruvu in 2011, 11 samples from Bholakpur in 2013, 2 samples from Balanagar in 2011 and one sample each from Malkajgiri and Rasoolpura in 2012.

Nitrate is also one of the pollutants which can be harmful for human health. Nitrate had been observed above permissible limit of BIS in 25 samples and above permissible limit of WHO in 23 samples. Consuming water containing high concentrations of Nitrate can have almost immediate effects on a person (acute toxicity). In addition, nitrate in water used for drinking can lead to methemoglobinemia or "blue baby syndrome." Nitrates most often enter the groundwater through fertilizers, manure, septic systems or nitrate laden waste water percolating downward from holding ponds. Selenium content in 7 water samples was observed above desirable limits of BIS and in 1 sample above WHO standards. Deficiency or exceed amount of Selenium in drinking water may cause harmful effects on human health. Sodium was also observed 12 samples collected at different places above permissible limit of WHO. In case of Sulphate, only one sample from Qutubullapur in 2005 out of 131 samples showed the sulphate content above permissible limit of BIS. Chromium was observed in 20 samples out of 38 above the permissible limits of WHO and BIS. Chromium is a specific pollutant providing evidence of industrial pollution like dye or paint operations. Chromium is used for making steel and other alloys, furnace bricks, and dyes, for chrome plating, for leather tanning preserving of wood, and as a rust inhibitor in cooling towers. It was observed at samples collected at Patancheruvu, Balanagar and Nizampet in 2011 and at Bholakpur in 2013. Zinc is also one of the heavy metal which can be found in some natural water, most frequently in areas where it is mined. It is not considered hazardous to health unless it occurs in very high concentrations. It imparts an undesirable taste to drinking water. In the present study, zinc was observed in 3 samples above guideline of 5 mg/L provided by WHO and it was under permissible limit of 15 mg/L by BIS in all the samples.

Microbiological parameters are also important in defining the suitability of water for drinking purpose. The existence of coliform bacteria in a groundwater is an indicator for faecal pollution of the water. It was observed in 8 samples collected at different places in Malkajgiri in 2012, on the bank of Musi River in 2011 and at Bholakpur in 2013. These samples were also contaminated with E. coli and the standard plate count exceeded the threshold value of 100 cfu/mL. Since the guidelines also demand the absence of total coliform bacteria, this water was obviously not qualified for drinking purpose considering the microbiological parameters.

CONCLUSION

This study have shown that the high urbanization rate of Hyderabad is leading to increase in demand of fresh water for domestic and industrial use and as a result of that, increased volume of sewage water. Groundwater use had been increased to satisfy this increasing demand of fresh water. Over exploitation of groundwater in industrial region for manufacturing had been observed in Patancheruvu, High-tech city and Malkajgiri. Also, the residential region of Jubilee Hills where mostly upper middle class had been settled is also the part of overexploited region. Groundwater table had been depleting in the Western, North-Western and North-Eastern region from Hussain Sagar Lake which is located in the centre of Hyderabad. The rising urban population in this region had been using groundwater as an alternative source due to limited municipal water supply and shortages. On the other hand, the Western and South-Western region from Hussain Sagar had showed the rise in groundwater table during 2003-2012. The main reason behind this rise had been observed to be import of water from different sources and then leakage or direct percolation of sewage or fresh water into the fractured aquifers. The analysis of groundwater quality had showed that in many locations the groundwater had been polluted due to urban recharge from sewage and industrial waste. And in most of the cases, the groundwater samples did not satisfy the WHO or BIS standards for drinking water. The appearance of heavy metals like Lead, Iron, Chromium, Zinc etc. in the water samples showed that the industrial effluents were percolated in the aquifer. Also, after the analysis of microbial parameters and nitrates above permissible limit of WHO and BIS in the sampled water, had also proven the fact that the sewage water from residential areas had also contributed to the groundwater recharge. These water samples had proved that the groundwater in those regions is not suitable for drinking purpose and may cause bad effects on health. This study had showed that the urban growth had made the groundwater resources more vulnerable and in many cases it had been affecting it very badly. Anthropogenic activities had altered the natural cycle of groundwater recharge. The sewage network system and water supply systems needs to be improvised to stop the further alteration and pollution of natural groundwater. Finally, it is recommended that a policy should be developed considering ecological, hydrological and socio-economic aspects of life for this region, with the involvement of all of the stake holders.

ACKNOWLEDGEMENT

This project is funded by Deutscher Akademischer Austauschdienst- German Academic Exchange Service (DAAD) under the program "A New Passage to India". One of the authors would like to acknowledge the help in field data collection provided by Mr Shikhar Kumar, Ms Katrin Wagner, Mr Yorck Adrian and Ms Dorothee Uerschels. Also, authors would like to acknowledge the help and guidance provided by Groundwater Department of Andhra Pradesh, National Geophysical Research Institute, Hyderabad and Central Groundwater Board, Hyderabad.

REFERENCES

Adrian, Y. (2013). Evaluation of the Millennium Development Goal - Target 7C for the Cities of Varanasi and Hyderabad (India). In Department of Engineering Geology and Hydrogeology: RWTH Aachen University.

Apha, A. (1985). WPCF, 1985. Standard methods for the examination of water and wastewater **16**, 445-446.

Apha, A. (1998). Wpcf. Standard methods for the examination of water and wastewater **20**.

Asadi, S. S., Vuppala, P. and Reddy, M. A. (2007). Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. Int J Environ Res Public Health, **4**, 45-52.

Baier, K., Schimtz, K. S., Azzam, R. and Strohschön, R. (2013). Management tools for sustainable groundwater protection in mega urban areas- small scale landuse and groundwater vulnerability analysis in the South-Chinese megacity Guangzhou. International Journal of Environmental Research, (Accepted).

BIS, B. o. I. S. (2012). Drinking Water-Specifications. New Delhi: Bureau of Indian Standards.

Brown, E., Skougstad, M. W. and Fishman, M. J. (1970). Methods for collection and analysis of water samples for dissolved minerals and gases: US Geol. Surv., Washington, DC.

Census of India (2011). Final Population Totals. Ministry of Home Affairs, Govt. of India.

CGWB, (2012). Central Ground Water Board, Aquifer Systems of India., India.

Chandra, S., Singh, A. and Tomar, P. K. (2012). Assessment of Water Quality Values in Porur Lake Chennai,Hussain Sagar Hyderabad and Vihar Lake Mumbai, India. Chemical Science Transactions, **1**, 508-515.

Esmaeili, H. R. and Johal, M. S. (2005). Study of physico-chemical parameters of water of Gobindsagar reservoir, India. pp. 173-177.

Frengstad, B., Banks, D. and Siewers, U. (2001). The chemistry of Norwegian groundwaters: IV. The pH-dependence of element concentrations in crystalline bedrock groundwaters. Sci. Total Environ., **277**, 101-117.

GHMC, G. H. M. C. (2011). City Development Plan. Hyderabad, India: Greater Hyderabad Municipal Corporation.

GHMC, G. H. M. C. (2012). List of slums in GHMC. Hyderabad, India: Greater Hyderabad Municipal Corporation.

Gumma, R. K., Rao, P. N., Varadaraj, N. and Kumar, G. P. (2011). Ground water scenario in major cities of India. Central Ground Water Board of India.

Gyananath, G., Islam, S. and Shewdikar, S. (2001). Assessment of environmental parameters on ground-water quality. Indian Journal of Environmental Protection, **21**, 289-294.

Haslam, S. M. (1990). River pollution: an ecological perspective: Belhaven press.

HMWSSB, H. M. W. S. S. B. (1995). Sixth Annual Report 1994–1995. Hyderabad, India: Hyderabad Metropolitan Water Supply and Sewerage Board.

Jha, R., Singh, V. P. and Vatsa, V. (2008). Analysis of urban development of Haridwar, India, using entropy approach. KSCE Journal of Civil Engineering, **12**, 281-288.

Karanth, K. R. (1987). Ground water assessment: development and management: Tata McGraw-Hill Education.

Khan, H. H., Khan, A., Ahmed, S. and Perrin, J. (2010). GIS-based impact assessment of land-use changes on groundwater quality: study from a rapidly urbanizing region of South India. Environmental Earth Sciences, **63**, 1289-1302.

Kumar, S., Bharti, V. K., Singh, K. B. and Singh, T. N. (2009). Quality assessment of potable water in the town of Kolasib, Mizoram (India). Environmental Earth Sciences, **61**, 115-121.

Milovanovic, M. (2007). Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe. Desalination, **213**, 159-173.

Mondal, N. C., Saxena, V. K. and Singh, V. S. (2005). Assessment of groundwater pollution due to tannery industries in and around Dindigul, Tamilnadu, India. Environmental Geology, **48**, 149-157.

Putra, D. P. and Baier, K. (2009). Der Einfluss ungesteuerter Urbanisierung auf die Grundwasserressourcen am Beispiel der indonesischen Millionenstadt Yogyakarta. Cybergeo: European Journal of Geography.

Ramachandraiah, C. and Prasad, S. (2004). Impact of urban growth on water bodies: The case of Hyderabad: Centre for Economic and Social Studies Hyderabad.

Rogers, P. (1994). Hydrology and water quality. Changes in land use and land cover: a global perspective, **4,** 231

Rooijen, D. J. V., Turral, H. and Biggs, T. W. (2005). Sponge City: Water Balance of Mega-City Water use and wastewater use in Hyderbad, India. Irrigation and Drainage, **54**, S81–S91.

Schmitz, K. S. (2012). Groundwater Vulnerability Assessment in the Fast Growing Cities Hyderabad and Bhubaneswar, India – Applicability of Different Methods (AVI, GOD, COP and Hölting et al.). In Department of Engineering Geology and Hydrogeology: RWTH Aachen University.

Singh, K., Bharati, V. and Kumar, S. (2011). Physicochemical and bacteriological investigation of Tuikhur Water, Saiha Town, Mizoram, India. Science Vision, **11**, 27-30.

Strohschön, R., Wiethoff, K., Baier, K., Lu, L., Bercht, A., Wehrhahn, R. and Azzam, R. (2013). Land use and Water Quality in Guangzhou, China: A survey of ecological and Social Vulnerability in Four Urban Units of the Rapidly Developing Megacity. International Journal of Environmental Research, **7**, 343-358.

Taubenböck, H., Pengler, I., Schwaiger, B., Cypra, S., Hiete, M. and Roth, A. (2007). A multi-scale urban analysis of the Hyderabad metropolitan area using remote sensing and GIS. In 2007 Urban Remote Sensing Joint Event, Paris, pp. 1-6.

Uerschels, D. (2012). Vulnerability Assessment of the poor to selected effects of the informal sector on water supply and water quality in Hyderabad and Bhubaneswar, India. In Department of Engineering Geology and Hydrogeology: RWTH Aachen University.

UN, U. N. (2012). World Urbanization Prospects: The 2011 revision: United Nations. Department of Economic and Social Affairs. Population Division.

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Ganthi, R. R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environ. Monit. Assess., **171**, 595-609.

Venkatasubramani, R. and Meenambal, T. (2007). Study on subsurface water quality in Mettupalayam taluk of Coimbatore district, Tamil Nadu. Nature, Environment and Pollution Technology, **6,** 307-310.

Wagner, K. X. X. (2013). Impact Assessment of a Potentially Polluted Tannery Brownfield on the Environment and Associated Health Effects on Urban Dwellers in Hyderabad (India). In Department of Engineering Geology and Hydrogeology: RWTH Aachen University.

Wakode, H. B., Baier, K., Jha, R. and Azzam, R. (2013). Analysis of urban growth using Landsat TM/ETM data and GIS—a case study of Hyderabad, India. Arabian Journal of Geosciences, **7**, 109-121.

WHO, (2010). Exposure to cadmium: a major public health concern. 20 Avenue Appia, 1211 Geneva 27, Switzerland: Public Health and Environment, World Health Organization.

WHO, (2011). Guidelines for Drinking-water Quality. WHO Library Cataloguing-in-Publication Data.