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An evaluation of physico-chemical parameters of ground water of rural areas of Varanasi district of eastern Utter Pradesh, India

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Abstract
In the present study, detail investigation of groundwater for the suitability of drinking purposes in Varanasi area. For this purpose, 42 groundwater samples from shallow hand pump and deep hand pump wells and tube wells were collected and analyzed. The pH values reveal that the groundwater is alkali in nature. The quality assessment shows that in general, the water is suitable for domestic purposes. Total dissolved solids of all of analyzed groundwater samples were falling in the category of fresh water. HCO_3^- and Cl^- are dominant anions and Na^+ and Mg^{2+} as the dominant cations in the water chemistry. The sequence of the abundance of the major ions is in the following order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+ = HCO_3 > Cl > SO_4 > CO_3 > F^-$. The concentration of major ions in groundwater is within the permissible limits for drinking except fluoride. The amount of total dissolved solids was less than 300 mg/L, indicating a "fresh environment". In majority of the samples, the analyzed parameters are well within the desirable limits and water is potable for drinking purposes. However, concentrations of Total hardness, Na^+, Mg^+, K^{2+} and fluoride exceed the desirable limit at few sites.

Keywords: groundwater quality, fluoride, Varanasi

Introduction

Groundwater forms the major source of water supply for drinking purposes in most parts of India. It accounts for about 88% safe drinking water in rural areas, where the population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exist. The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region. Water quality is the characteristics of water which influence its beneficial use as well as the sustainability of ecosystem. Water resources are of critical importance to both natural ecosystem and human development (Lianthuamluaia, 2013) [11]. Ground water quality is being increasingly threatened by rapid increase in population and growth of industrialization, use agricultural chemicals and disposal of urban and industrial wastes. It has been estimated that once pollution enters the subsurface environment, it may remain concealed for many years, becoming dispersed over wide areas of groundwater aquifer and rendering ground water supplies unsuitable for consumption and other uses. The deterioration of ground water quality is of immediate concern in the districts, cities and towns of the country. (Venugopal *et al*. 2008: Salve *et al*. 2008; Ramakrishnaiah *et al*. 2009, Jain *et al*. 2010; Chatterjee *et al*. 2010; Maruthi *et al*. 2010; Singh *et al*. 2011; Raju *et al*. 2011; Singh *et al*. 2012; Singh *et al*. 2013; Tiwari and Singh 2014) [29, 17, 9, 4, 12, 23, 16, 21, 22, 25]. Today, water quality issues have become a significant concern due to the growth of population, urban expansion and technological development. Water can be easily contaminated in different ways through unregulated or regulated but not well designed and monitored disposal (Ozlem Tunc Dede *et al*. 2013) [15]. Public ignorance of environment and related considerations, lack of provisional basic social services, indiscriminate disposal of increasing anthropogenic wastes, unplanned application of agrochemicals, and discharges of improperly treated sewage/industrial effluents; result in excess accumulation of pollutants on the land surface and contamination of water resources (Tiwari *et al*. 2013) [27]. World Health Organization (WHO) reported that in developing countries over three million people (90 % are children under 5) die every year because of waterborne diseases. Access to safe drinking water remains an urgent necessity, as 30 % of urban and 90 % of the rural Indian population still depends completely on untreated surface or groundwater resources (Kumar *et al*. 2005) [10]. Access to drinking water in India has increased over the past few decades with the tremendous adverse impact of unsafe water for health (Singh *et al*. 2013) [22]. Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari & Singh 2014) [25]. Thus, proper assessment and reporting of groundwater quality is an important issue. In the present work attempts have been made to detect groundwater quality for drinking uses.

Materials and methods
Study Area
Geographically the district Varanasi is situated at $25^0$18' of Northern latitude, 83^0 03' of Eastern longitude and at an altitude of 128.83 m above the mean sea level in the Indo-Gangatic plain of eastern Uttar Pradesh. The mean annual precipitation is 1100 mm. The mean relative humidity of this area is about 68% with maximum 82% and minimum 30% during July to September and April to early June, respectively. The minimum and maximum average temperature of the area range from 4.4^0C to 28.2^0C, respectively.

Sampling and analysis
Forty two groundwater samples were collected from some villages of four blocks from Varanasi District, Utter Pradesh after the South - West monsoon. The Location map and Global Position of study areas will be show in figure 1 and table 1 respectively. The samples were collected from well, shallow hand pump and deep hand pump in area of high intensity cropping system where, the long history of phosphatic fertilizer application which is extensively used for drinking purposes. Water samples are collected in clean plastic bottles of 500 mL capacity bottles are soaked in 1:1 diluted HCl solution for 24 hours, washed with distilled water, and are washed again prior to each sampling the filtrates of sample and immediately transported to the laboratory where they stored at 4◦C until analysis. The water samples were analyzed at the Soil and Water Testing Laboratory of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. For All samples, electrical conductivity (EC) and pH values were obtained using EC and pH meters (ELICO).The parameters analyzed include the major ions sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^-), bicarbonate (HCO_3^-) and fluoride (F) Total dissolved solids (TDS), which were computed by multiplying the EC with a factor (EC X 640) that depend on the relative concentrations of ions. Total alkalinity (TA), CO3 and HCO_3 were estimated by titrating with HCl. Total hardness (TH), Calcium (Ca), and Magnesium (Mg) were analyzed titrimetrically using standard EDTA; Sodium (Na^+) and Potassium (K^+) were measured by flame photometry; chloride (Cl) was estimated by standard $AgNO_3$ titration; sulphate ($SO_4^{2-)}$) was analyzed by spectrophotometer; fluoride (F) concentrations in mgL^{-1} in groundwater samples is determined using Ion Selective Electrode Meter (Orion 96-09 model, Thermo electron Corporation).

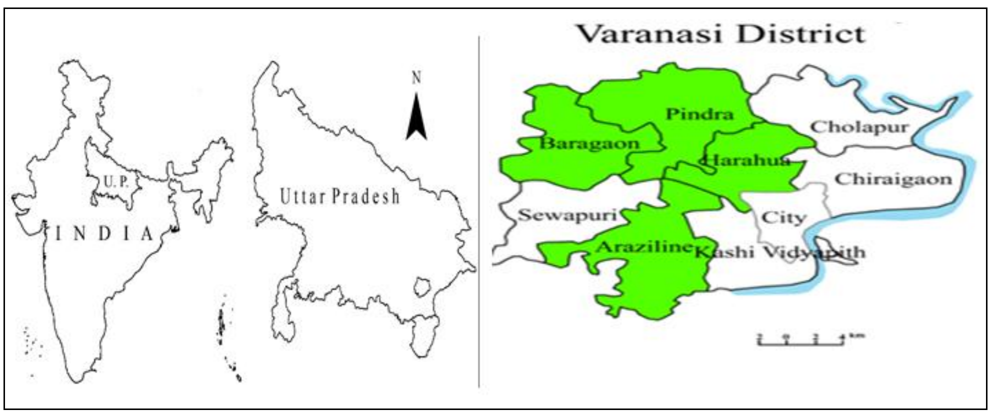

Fig 1: Geographical Representation of Study Area

Table 1: Location and global position of groundwater samples of Varanasi

S. No.	Location	Global Position	S. No.	Location	Global Position
1	Pura Raghunathpur	N$24^0$15.039' E $83^0$54.081'	22	Deura	N 24^0 24.538' E $83^0$53.112'
2	Pura Raghunathpur	N$24^0$15.039' E $83^0$54.081'	23	Deura	N$24^0$24.433 ' E $83^0$52.936'
3	Pura Raghunathpur	N 24^0 14.926' E $83^0$53.282'	24	Kashipur	N 24^0 24.590' E $83^0$52.988'
4	Raghunathpur	N 24^0 14.994' E $83^0$53.315'	25	Kashipur	N 24^0 24.259 'E $83^0$52.676'
5	Raghunathpur	N 24^0 14.879' E $83^0$53.321'	26	Kashipur	N 24^0 24.578 'E $83^0$52.978'
6	Raghunathpur	N 24^0 14.932 'E $83^0$42.901'	27	Gaura	N 24^0 25.278' E $83^0$51.678'
7	Sagunaha	N 24^0 14.816 'E $83^0$52.419'	28	Gaura	N 24^0 25.647' E $83^0$51.223'
8	Sehmalpur	N 24^0 27.636 'E $83^0$50.727'	29	Gaura	N 24^0 14.221 'E $83^0$52.110'
9	Sehmalpur	N 24^0 27.737' E $83^0$50.302'	30	Gaura	N 24^0 14.918' E $83^0$52.313'
10	Sehmalpur	N 24^0 27.767 'E $83^0$50.411'	31	Pura Raghunathpur	N 24^0 15.069'E $83^0$54.181'
11	Sehmalpur	N 24^0 27.678 'E $83^0$51.179'	32	Pura Raghunathpur	N 24^0 14.239' E $83^0$53.481'
12	Bhatauli	N 24^0 27.676' E $83^0$51.312'	33	Raghunathpur	N 24^0 14.894 'E $83^0$53.415'
13	Awashanpur	N 24^0 16.379 'E $83^0$56.176'	34	Raghunathpur	N 24^0 14.779 'E $83^0$53.221'
14	Awashanpur	N 24^0 14.932' E $83^0$42.901'	35	Sagunaha	N 24^0 14.616' E $83^0$52.619'
15	Ghamahapur	N 24^0 27.767' E $83^0$54.419'	36	Bhatauli	N 24^0 27.69 'E $83^0$52.512'
16	Dharmalpur	N 24^0 24.282' E $83^0$52.120'	37	Bhatauli	N 24^0 27.66' E $83^0$50.612'
17	Dharmalpur	N 24^0 24.220 'E $83^0$52.089'	38	Gaura	N 24^0 14.718 'E $83^0$51.313'
18	Dharmalpur	N 24^0 24.179 'E $83^0$52.147'	39	Kashipur	N 24^0 24.359' E $83^0$51.576'

19	Sahapur	N 24^0 25.734 'E83^{0}250719'	40	Kashipur	N 24^0 24.269' E 83^{0}51.476'
20	Sahapur	N 24^0 25.994 'E 83^{0}50.362'	41	Gaura	N 24^0 14.918' E 83^{0}52.313'
21	Sahapur	N 24^0 25.694 'E 83^{0}50.462'	42	Gaura	N24^{0}14.918' E 83^{0}52.313'

Method of fluoride analysis

Fluoride content in water was determined electrochemically, using the direct ion sensitive electrode meter method. In this method, 25 mL of water sample and 25 mL of the TISAB solution (total ionic strength adjustment buffer which prepared 58 ml of glacial acetic acid and 12g of sodium citrate were added to 300 mL distilled water and pH of the solution was adjusted to 5.2 using 6N sodium hydroxide and then cools and diluted to 1000 mL.) were taken in a 100 mL plastic beaker. The ratio of aliquot and TISAB Solution should be 1:1.

Results and discussion

Major Ions Chemistry and Drinking Water Quality

The pH value of the groundwater samples ranged from 7.6 to 8.9 with an average value 8.4 which indicates that the groundwater are alkaline in nature, but well within the limits prescribed by WHO (2004) [31] and BIS (2003) 8.50. Electrical conductivity (EC) tells about the conducting capacity of water which in turn is determined by the presence of dissolved ions. Higher the ionisable solids, greater will be the EC.EC is a measure of total dissolved solids (TDS) i.e. - it depend upon the ionic strength of the solution. Increase in the concentration of dissolved solids, increases the ionic strength of the solution. The measured EC of the groundwater in the study area varies from 254 to 944 µS $cm^{-1}$with an average value of 627 µS cm^{-1}. Concentration of total dissolved solids (TDS) in the groundwater of the study area ranged from 162 to 604mg $L^{-1}$with an average value of 403 mg L^{-1} (Table 2). Water can be classified in to fresh (TDS <1,000 mg L^{-1}), brackish (>1,000 mg L^{-1}), saline (>10,000 mg L^{-1}) and brine (1,00,000 mg L^{-1}) categories on the basis of TDS concentration (Freeze and Cherry 1979). Based on this classification the groundwater samples of the study area belong to fresh “fresh environment” and all groundwater evaluated is therefore suitable for drinking purposes. The order of dominance of the cations of the study area is Na >Mg >Ca > K and of the anions is HCO_3>Cl >CO3 >SO_4> Fluoride. Ca ranges from 18 to 80 mg $L^{-1}$and Mg ranges from 22 to 283 mg L^{-1}. Na concentration of the study area varies from 131 to 695 mg L^{-1} and K values range from 4 to 105 mg L^{-1}. HCO_3 is the dominant anion, which ranges from 146 to 444 mg L^{-1}, Cl content is in the range of 11 to 170 mg L^{-1}, CO_3 ranges from 12 to 66 mg L^{-1}, SO_4 ranges 3.5 to 46.6 and fluoride range from 11 to 4.63.

Table 2: Statistics of chemical compositions of major hydro geochemical facies

Chemical parameters	Units	Range (mgL^{-1})		Mean	SD	CV
		Minimum	Maximum			
pH	-	7.6	8.9	8.4	0.290	3.45
EC	(µS/cm)	254	944	627	21.60	3.44
Ca^{2+}	(mgL^{-1})	18	80	44	1.50	3.41
Mg^{2+}	(mgL^{-1})	22	283	145	4.97	3.43
K^+	(mgL^{-1})	4	105	39	1.32	3.38
Na^+	(mgL^{-1})	131	695	397	13.59	3.42
CO_3^-	(mgL^{-1})	12	66	34	1.77	5.21
$HCO3^-$	(mgL^{-1})	146	444	252	8.64	3.43
Cl^-	(mgL^{-1})	11	170	47	1.61	3.43
SO_4^-	(mgL^{-1})	3.5	46.6	15.4	0.52	3.38
Fluoride	(mgL^{-1})	0.11	4.63	1.29	0.444	34.42
TDS	(mgL^{-1})	162	604	401	13.59	3.38
TH	(mgL^{-1})	216	1236	707	24.25	3.42

Table 3. Comparison of groundwater samples with BIS (2003) and WHO (1993) standards

Parameters		BIS (2003)		WHO (1993)		Percentage of samples above the maximum permissible limit
		Highest desirable limit	Maximum permissible limit	Highest desirable limit	Maximum permissible limit	
Ph	-	6.5–8.5	6.5–9.2	6.5–8.5	6.5–9.2	Nil
TH	(mgL^{-1})	300	600	100	500	57.14
TDS	(mgL^{-1})	-	500	-	-	
Ca^{2+}	(mgL^{-1})	75	200	75	200	11.90
Mg^{2+}	(mgL^{-1})	30	100	50	150	71.42
Na^+	(mgL^{-1})	–	–	–	200	88.05
K^+	(mgL^{-1})	–	–	–	200	85.71
Cl^-	(mgL^{-1})	250	1000	200	600	Nil
F^-	(mgL-1)	0.6-0.9	1.5	-	-	23.80
SO_4^{2-}	(mgL^{-1})	150	400	200	400	Nil

Suitability of Groundwater for Drinking and Domestic use

The physical and chemical parameters of the analytical results of groundwater were compared with the standard guideline values recommended by the World Health Organization (WHO, 1993) [32] and Bureau of Indian Standards (BIS, 2003) for drinking and public health standards (Table 1). The pH of the groundwater samples (7.6–8.9) are within the safe limit of 6.5–8.5, prescribed for drinking water. The values of TDS exceed the desirable limit of 500 mg L^{-1} in 21.42 % of groundwater samples. The total hardness (TH) is the properties of water by which it prevents the lather formation with soap and increasing the boiling point of water. Hardness of the water is the property attributed to the presence of alkaline earths. Water can be classified into soft (75 mg L^{-1}), moderately hard (75–150 mg L^{-1}), hard (150–300 mg L^{-1}) and very hard (>300 mg L^{-1}) based on hardness (Sawyer and McCarty, 1967).The total hardness of the analyzed groundwater of the study area varies between 216 and 1236 mg L^{-1} (average 707 mg L^{-1}) indicating moderately hard to very hard types of groundwater. The analytical data indicate that 57.14 % groundwater samples is come under moderately hard to very hard. The higher hardness may cause encrustation on water supply distribution systems. There is some suggestive evidence that long term consumption of extremely hard water might lead to an increased incidence of urolithiasis, anecephaly, parental mortality, some types of cancer and cardio-vascular disorders (Agrawal and Jagetia 1997; Durvey *et al*. 1991) [1, 6]. Concentrations of Cl^- and $SO4^{2-}$are well within the desirable limit mg L^{-1}.The fluoride is beneficial to certain extent when present in the concentration of 0.8 to 1.0 mg $L^{-1}$for classification of dental enamel especially for children below 8 years (Tiwari *et al*. 2003) [36] whereas causes dental fluorosis if present in excess of 1.5 mg L^{-1} and skeletal fluorosis beyond 3.0 mg L^{-1} if water consumed for a prolong period i.e. 6 months to several years (Nawlakhe and Bulusu 1989) [13]. Higher fluoride concentration causes dental and skeletal fluorosis such as mottling of teeth, deformation of ligaments and bending of spinal cord (Tiwari and Singh 2014) [25]. The analytical data of fluoride indicate that 23.80% of groundwater samples had crossed maximum permissible limit of 1.5 mg L^{-1} prescribed by (WHO 1997, BIS 2003) [30] Concentration of $Ca^{2+}$and $Mg^{2+}$are exceeding the desirable limits of 75 mg L^{-1} and 30 mg L^{-1} in 11.90 % and 14.28 % of the groundwater samples respectively. However, concentrations of both these ions are within the maximum permissible limit of 200 mg L^{-1} and 100 mg L^{-1} (BIS 2003). Sodium and potassium are the most important elements occurring naturally. A higher sodium intake may cause hypertension, congenial heart diseases and kidney problems (Singh *et al*. 2008) [20] and the excess amount of potassium present in the water sample may lead nervous and digestive disorder (Tiwary 2001). The recommended permissible limit for sodium and potassium concentration in drinking water is 200 mg L^{-1} (WHO 1997). Concentrations of K^+ are within the recommended limit of 200 mg L^{-1}. However concentrations of Na^+ exceed 85.71 % of water samples of Maximum permissible limit 200 mg L^{-1}. (WHO (1993) [32].

Fluoride Geochemistry

The rock porphyritic granite gneissic which contain considerable amounts of fluorite minerals especially Fluor-apatite and biotite mica, form the source of fluoride ions to the percolating groundwater. Fluorite (CaF_2) has been generally considered as source of groundwater fluoride, especially in granitic terrains (Deshmukh and Chakravarti, 1995) [5]. However, its dissolution in freshwater is low and, furthermore, its dissolution rate is remarkably slow (Nordstrom, 1989) [14]. When groundwater reacts with granite gneissic rocks for a prolonged period, the fluoride concentrations are continuously enriched, even after the groundwater reaches an equilibrium state with respect to fluorite (CaF_2) due to the removal of Ca^{2+} by precipitation of calcite ($CaCO_3$). Sodium carbonate type water ($NaHCO_3$) in weathered rock formations allows precipitation of calcite from Ca^{2+} and CO_3^{2-} ions and accelerates the dissolution of CaF_2, thereby releasing fluoride into the groundwater as fallow equation (Saxena and Ahmed, 2003) [19].

$$CaF_2 + 2NaHCO_3 \rightarrow CaCO_3 + 2Na^+ + 2F^- + H_2O + CO_2$$

In an acidic medium fluoride is adsorbed in clays; however, in an alkaline medium, it is desorbed and thus alkaline pH is more favorable for fluoride (Saxena and Ahmed, 2003) [19]. It is clear that, if the pH is constant, the activity of fluoride is directly proportional to the amount of HCO_3^-. This relationship is independent of Ca because of the low solubility product CaF_2. A positive correlation is observed between HCO_3^- and fluoride. Groundwater in contact with calcite and fluorite solid phases develops equilibrium reactions. The saturation of groundwater with respect to calcite and fluorite is explained as fallowing EURO, 1973) [7].

$$CaCO_3 + 2F^- + H^+ \rightarrow CaF_2 + HCO_3^-$$

Interpretation of hydro chemical analysis of groundwater samples reveals that the groundwater in Varanasi is within the class of excellent to good based on TDS with reference to water class, soft to hard base on total hardness and fresh with regards to the nature of groundwater based on TDS.

References

1. Agrawal V, Jagetia M. Hydrogeochemical assessment of groundwater quality in Udaipur city, Rajasthan, India. Procee Nat Conf Dimension Environ Stress India. Dept. of Geology, MS University, Baroda, 1997.
2. Akoteyon IS, Omotayo AO, Soladoye O, Olaoye HO. Determination of water quality index and suitability of urban river for municipal water supply in Lagos-Nigeria. Eur J Sci. Res. 2011; 54:263-271.
3. BIS. Indian standard drinking water specifications 2003; IS10500:1991, edition 2.2 Bureau of Indian Standards, New Delhi, 2009.
4. Chatterjee R, Tarafder G, Paul S. Groundwater quality assessment of Dhanbad district, Jharkhand. India. Bull Engi Geo Environ. 2010; 69:137-141.
5. Deshmukh AN, Chakravarti PK. Hydro chemical and hydrological impact of natural aquifer recharge of selected fluorosis endemic areas of Chandrapur district. Gondwana Geol Magaz. 1995; 9:169-184.
6. Durvey VS, Sharma LL, Saini VP, Sharma BK.

Handbook on the methodology of water quality assessment, Rajasthan Agriculture University, Bikaner, 1991.
7. EURO. Reports and Studies No. 2. Sodium, chlorides and conductivity in drinking water. Copenhagen, WHO Regional Office for Europe, 1973.
8. Freeze RA, Cherry JA. Groundwater. Prentice Hall, Englewood Cliffs, 1979.
9. Jain CK, Bandyopadhyay A, Bhadra A. Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India. Environ Monit Assess. 2010; 166:663-676.
10. Kumar R, Singh RD, Sharma KD. Water resources of India. Current Science. 2005; 89:794-81.
11. Lianthuamluaia, Landge AT, Purushothaman CS, Deshmukhe G, Ramteke KK. Assessment of seasonal variations of water quality parameters of Savitri reservoir, Poladpur, Raigad district, Maharashtra. The Bioscan. 2013; 8(4):1337-1342.
12. Maruthi YA, Rao SR, Chaitanya DA, Hossain K, Kumar RS, Sitaratnam M, Rao RT. Evaluation of water quality in the vicinity of some saltpans, Visakhapatnam district, Andhra Pradesh. The Bioscan. 2010; 3:665-672.
13. Nawlakhe WG, Bulusu KR. Water treatment technologies for removal of excessive fluoride. In C. P. Gupta (Ed.) Appropriate methodology for development and management of groundwater resources in developing countries, New Delhi: Oxford and IBH Publishers Ltd, 1989.
14. Nordstrom DK. Groundwater chemistry and water rock interactions at Stripa. Cosmochimica Acta. 1989; 53:1727-1740.
15. Ozlem TD, Ilker TT, Aral MM. The use of water quality index models for the evaluation of surface water quality: A case study for Kirmir Basin, Ankara, Turkey. Water Qua Expo Health. 2013; 5:41-56.
16. Raju JN, Shukla UK, Ram P. Hydro geochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. Environ Monit Assess. 2011; 173:279-300.
17. Ramakrishnaiah CR, Sadashivaiah C, Rangannaa G. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. J Chemi. 2009; 6:523-530.
18. Sawyer CN, McCarty PL. Chemistry of sanitary engineers, 2nd ed. McGraw Hill, New York, 1967.
19. Saxena VK, Ahmed S. Dissolution of fluoride in groundwater: a water–rock interaction study. Environ Geol. 2003; 40:1084-1087.
20. Singh AK, Mondal GC, Singh PK. Singh S, Singh TB. Tewary BK. Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin, India. Environ Geol. 2008; 54:745-758.
21. Singh AK, Mondal GC, Singh TB, Singh S, Tewary BK, Sinha A. Hydrogeochemical processes and quality assessment of groundwater in Dumka and Jamtara districts, Jharkhand, India. Environ Earth Sci. 2012; 67:2175-2191.
22. Singh AK, Raj B, Tiwari AK, Mahato MK. Evaluation of Hydrogeochemical processes and groundwater quality in the Jhansi district of Bundelkhand region, India. Environ Earth Sci. 2013; 70:1225-1247.
23. Singh AK, Tewary BK, Sinha A. Hydrochemistry and quality assessment of groundwater in part of NOIDA metropolitan city, Uttar Pradesh. J Geo Soc. India. 2011; 78:523-540.
24. Sohani D, Pande S, Srivastava VS. Ground water quality at Tribal Town: Nandurbar (Maharashtra), Indian Journal of Environment and Ecoplanning. 2001; 5:475-479.
25. Tiwari AK, Singh AK. Hydrogeochemical investigation and groundwater quality assessment of Pratapgarh district, Uttar Pradesh. J Geo Soc. India. 2014; 83:329-343.
26. Tiwari AK, Dikshit RP, Tripathi IP, Chaturvedi SK. Fluoride content in drinking water and ground water quality in rural areas of Tehsil Mau district, Chitrakoot. Indian J Environ Prot. 2003; 23:1045-1050.
27. Tiwari AK, Singh PK, Mahato MK. Chemistry of Groundwater and Their Adverse Effects on Human Health: A Review. Indian J Health Well. 2013; 4:923-927.
28. Tiwary RK. Environmental impact of coal mining on water regime and its management. Water Air Soil Pol. 2001; 132:185-199.
29. Venugopal T, Giritharan L, Jayaprakash M, Periakali P. Environmental impact assessment and seasonal variation study of the groundwater in the vicinity of River Adyar, Chennai, India. Environ Monnit Asses. 2009; 149:81-97.
30. WHO. Guidelines for drinking-water quality, Recommendations. World Health Organization, Geneva, 1997, 1.
31. WHO. Water sanitation and hygiene links to health-facts and figures, World Health Organization, Geneva, 2004.
32. WHO. Guidelines for drinking water quality Recommendations, Geneva: World Health Organization. 2nd Edn. 1993; 1:188.