**Hydro-chemistry for the Analysis of Sub-surface Water Quality in North-Eastern Haryana: A Fast-Urbanizing Region**

Sandeep Ravish1, Baldev Setia2, and Surinder Deswal3

1,2,3Civil Engineering Department, National Institute of Technology, Kurukshetra-136119, Haryana, India

Email: [1mmec11081224@gmail.com](mailto:1mmec11081224@gmail.com), [2setia\_b@rediffmail.com,3deswal.leo@gmail.com](mailto:%202setia_b@rediffmail.com,3deswal.leo@gmail.com%20)

**Abstract**: Hydro-geochemical characteristics of sub-surface water in the concerned region comprising of Yamunanagar and Ambala districts of Haryana, India, were estimated. The hydro-geochemical feature of sub-surface water in the concerned region was investigated by collecting 30 sub-surface water samples. Groundwater samples from specific deposits were analysed for physico-chemical elements, i.e. pH, TDS and prime ion contents, i.e. potassium, sodium, magnesium, calcium, bicarbonate, chloride, and sulphate. These ions were as abundance of sodium > calcium > magnesium > potassium, and bicarbonate > chloride > sulphate, respectively. Analysis of chemical dataset represented that the pre-dominant hydro-chemical facies in the area of study was Na+—HCO3—Cl- and ‘Ca2+—Mg2+—HCO3—Cl-’ types. Sub-surface water in the area of study is normally very hard, moderately hard and slightly saline in most of the region. CAI revealed that the most of the water-samples showed positive magnitude showing reverse ion-exchange-process in sub-surface water. Scholler assortment of water pointed that there was longer residence-period of aqua with more prominent base exchange. The outcomes of the appraisals were explained with hydro-geology and the chemical contents in the sub-surface water vary temporally and spatially. As per the observations of year 2017, 13.33%, 66.67% of water samples in TDS, TH, respectively of the study area is suffering from non-suitability of aqua for drinking and irrigation purposes.

**Keywords**: Sub-surface Water, Hydro-geochemistry, Aquifers, and Quality.

**1 Introduction**

During the last few decades, there has been a rapid increase in aqua shortage and need for fresh-aqua in semi-arid and arid areas due to intense irrigation practices, industrialization, urbanization and population increase in various parts of globe. In India most of the people are relying principally on sub-surface water resources for agricultural, industrial, domestic and drinking activities, due to insufficient supply of surface-aqua. In India many cities and myriad large towns derive aqua-supply from sub-surface water for discontiguous purposes via large number of private dug-wells and also from municipality network. Therefore, knowledge on hydro-geochemistry of fresh-aqua is significant to evaluate the pre-eminence of sub-surface water in any rural/urban region or/and basin that impacts the suitability of aqua for industrial, irrigation, and domestic purposes. Significant hydro-geologic elements i.e. biological activity, topographic relief, mineral weathering, and precipitation in a concerned study area are significant for hydro-geochemical reactions and controlling recharge responsible for hydro-chemical constituents polluting the sub-surface aqua. Because of the significance of sub-surface water in domestic and in other purposes, its environmental-aspects i.e. pollution transport have been significantly investigated. Various investigators have studied on pollution of sub-surface water and hydro-geochemical signatures in discontiguous rural/urban as well as in basins that attributed due to human activities principally by domestic and industrial waste-aqua and irrigation activities [1-4]. The aqua pre-eminence may yield knowledge about the inner-hydro-geologic atmospheres via which the aqua has circulated. The hydro-chemical variations of rainfall-aqua rely on various elements i.e. human activities, mineral species dissolution and water-soil interaction [5-6]. The over-exploitation of sub-surface aqua has hazardously influenced its quantity and quality.

In Yamunanagar and Ambala districts (Haryana) environs, the source of about ninety percent of domestic and agricultural aqua is from sub-surface aqua resources. However, this aqua-resource is facing issues including pre-eminence danger in several regions where the exposure to contamination from irrigation and other ion contamination in deep/shallow sub –surface aqua aquifers makes the aqua unsuitable for consumption of human. Land-use for agricultural and urbanization activities in the Yamunanagar and Ambala districts vicinity has enhanced at an alarming-rate in last few-times. In sophisticated multi layered alluvium deposits, the shallowest Pheratic-aquifer is often most susceptible to saline intrusion and most permeable to human contamination. A number of investigations on sub-surface aqua pre-eminence with respect to domestic and agricultural uses have been recorded in discontiguous parts of India [1,7-21]. The investigation region is pre-dominantly an irrigation-zone with dense-irrigation practices and also situated near the hill-cum-plain area. The majority of the inhabitants in this area rely on irrigation (such as agricultural and cultivators workers). Both for domestic and agricultural practices, substantial quantity of sub-surface aqua is consumed in this region. The investigation of sub-surface water-samples from a concerned region offers clues to several hydro-geochemical variations that the meteoric sub-surface aqua under-goes before acquiring different hydro-geochemical signatures. Therefore, this investigation formed the base-line attempt on the hydro-geochemistry or geo-chemical process of groundwater, suitability of sub-surface aqua resources and aptness for agricultural and domestic in the Yamunanagar and Ambala districts, Haryana region.

**2 Materials and Methods**

**2.1. Region of Study**

The Yamuna is the main river of Haryana running from northeast to southwest direction. The study region is principally drained by one perennial river Yamuna in the North-Eastern part of the Yamunanagar district and 03 non-perennial rivers such as Tangri (Dangri), Markanda, Ghagghar and their tributaries. Yamunanagar, Ambala districts and their vicinity are situated at an average elevation of about 255-300 m above the MSL. The study region covers an about 3330 sq.km region in and around Yamunanagar and Ambala districts and located between the 76° 30′ to 77° 28′ E longitude and 30°06′ to 31°35′ N latitude, (Fig. 1). Geomorpho-logically, the study region is situated in the north-west part of the Indian sub-continent. Its climate is sub-humid, hot summer, dry and mild winter and sub-tropical monsoon with a marked seasonal influence. The districts receive about eighty one percent of its annual average precipitation of around 2,183 milli-meters from the south-west monsoon during July to September month. In winter, the minimal temperature drops to 6.8 degree celsius, and in summer, the maximal temperature rises to 48.8 degree celsiuswith the annual average temperature being 24.1◦C. The area of study spreading over 3330 sq.km is part of the Indo Gangetic plain comprise of sedimentary rocks of Tertiary to Quaternary alluvium deposits, which occupy the southern and north part of the region [22]. In the region investigated, however, in alluvium formations, the permeable granular zones consist fine to medium grained sand and occasionally coarse sand and gravel. The aquifers form highly potential aquifers and comprise of sand, silt, gravels and kankar associated with clay. The formation of the kankar may be the rainfall of the CaCO3 from the sub-surface water and origin of clays, sand, and silt is from alluvium deposits. The sand beds without or with kankar in the region form zones of the principal aquifer of the multi tier aquifer-network. The deeper-aquifers are in conditions of confined to semi-confined, as benchmarked to shallow sub-surface aqua under Pheratic-condition. As stated sooner, the sedimentary deposits occur in almost the overall area and are presented by Tertiary and Quaternary deposits. Sub-surface water occurs in these deposits under confined conditions as well as under aqua table and is extracted by means of bore-wells, bore-cum-dug wells and hand pumps. Both hand-pumps and tube-wells are used for sub-surface aqua eduction for discontiguous purposes in the study region. The hand pumps diameter varies from two to eight metre and varies in depth from 65- 210 feet. The usual depth of tube wells varies from 70- 250 feet below sub-surface level. The intensive extraction of aqua due to urbanization elements and populace increase in Yamunanagar and Ambala presents a decreasing trend of the aqua-level in various parts of the perusal region. The availability of sub-surface aqua and nature of occurrence in the perusal region has been monitored by conducting hydro-geologic studies.

.

**Fig. 1.** Groundwater sample location map of the area of study with sampling sites.

**2.2. Methodology**

Totally 30 sub-surface water samples have been identified and collected in order to represent the whole study area (Fig. 1) from hand-pumps and tube-wells during April 2017 and appraised to understand the hydro-chemical alterations of groundwater pre-eminence constituents applying standards procedures [23]. Acid-washed (precleaned) poly-ethylene bottles of one-one litre capacity were applied for collection of sub-surface aqua samples. Entire sub-surface aqua samples were appraised for total dissolved solids (TDS), pH, prime anions, and cations. TDS (HACH, HQ40d) and pH (EUTECH Instruments pH meter pH-700) were appraised applying portable-meters. Magnesium (Mg2+) and Calcium (Ca2+) were measured by EDTA (Ethylene-diamine-tetra-acetic-acid) titrimetric method. Bicarbonate (HCO3-) and also chloride (Cl-) were measured by titration-methods. Potassium (K+) and sodium (Na+) were determined by flame-photometer EI-380. SO42- (Sulphate) determinations were measured by the spectrophotometer HACH DR- 2800. The hydro-chemical appraisal accuracy was tested by computing IBEP (Ion-Balance-Error Percentage) where the errors in the groundwater samples were usually within five percent [24-25].

**3 Results and Discussion**

Minimum and maximum levels for the hydro-chemical constituents of sub-surface water is presented in Table 1, benchmarked with BIS guidelines. The profusion of metals is in the following sequence: sodium > calcium > magnesium > potassium and bicarbonate > chloride > sulphate, respectively.

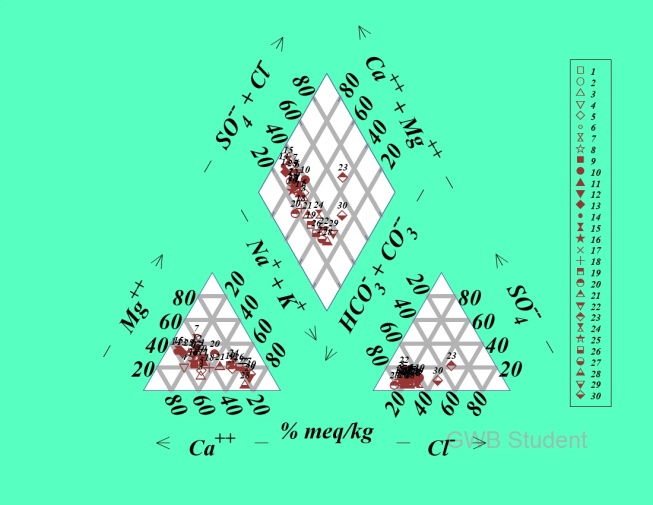
**3.1. Hydro-chemical Indices**

Piper plots [26] are employed by delineating the ratios (in meq) of the prime anions (SO4, Cl, HCO3, CO3) on one tri-angular plot, the ratios of the prime cations (K, Na, Mg, Ca) on another, and superimposing the dataset from the 02 triangle’s on a quadri-lateral. The location of this delineating points out the relative-composition of sub-surface aqua in terms of the cation-anion groups that correspond to 04-vertices of the zone. The hydro-geochemical assessment can be explained from the Piper-diagram (Fig. 2). The sub-surface water-samples were taken from Yamunanagar and Ambala districts of N-E Haryana, India.

**Table 1.** Maximum and minimum levels of the hydro-chemical composition of sub-surface water samples.

|  |  |  |
| --- | --- | --- |
| **Elements** | **Range** | **BIS 2003** |
| **pH** | 7.07-8.12 | 6.5-8.5 |
| **TDS** | 220-2770 | 500-2000 |
| **Ca2+** | 36-188 | 75-200 |
| **Mg2+** | 4.80-88.80 | 30-100 |
| **Na+** | 8.5-521 | \* |
| **K+** | 0.0-20.9 | \* |
| **HCO3-** | 244-1061.40 | \* |
| **SO42-** | 18-460 | 200-400 |
| **Cl-** | 56.80-766.80 | 250-1000 |

All the concentrations are in milligram per litre except pH; \*Well-being based standards concentrations have not been established.

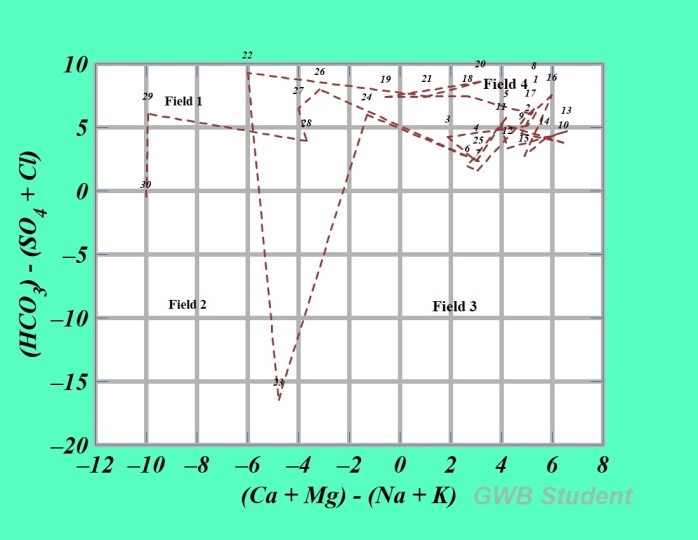
****

**Fig. 2.** Piper-facies plot for sub-surface water samples.

Hydro-geochemical constituent of aqua varies in space and period due to hydro-geochemical processes between the porous medium and the aqua, and due to variations in patterns of flow and composition of recharge. Such alterations in hydro-chemical signature are applied to sub-divide a hydro-some into ‘hydro-chemical indices’ or ‘characteristic fields’ [27]. In investigation region, the majority of the sub-surface aqua samples were concentrated in the ‘calcium-magnesium-bicarbonate’, ‘sodium-bicarbonate’, and ‘sodium-chloride’ type (Fig. 2), pointing the mixed water type, hard water and slightly saline nature of the sub-surface water. In usual, a gradual rise of the sub-surface aqua mineralization and shift from the pre-dominant anion bicarbonate through sulphate to chloride are found in aqua flowing from shallow to greater-depth, due to increasing rock–water interaction and decreasing sub-surface aqua circulation.

**3.2. Hydro-chemical Process Assessment**

A hydro-geochemical plot suggested by Chadha’s [28] has been employed in this investigation to evaluate/optimize the hydro-geochemical processes occurring in the concerned region.



**Fig. 3.** Chadda’s indices hydro-geochemical process evaluation plot (all ions are in meq/l).

Dataset were modified to % reaction concentrations (meq %) and shown as the difference between strong-acidic-anions (SO42- + Cl-) and weak-acidic-anions (CO32- + HCO3-) and the difference between alkali (K+ + Na+) and alkaline-earths (Mg2+ + Ca+) metals for cations. The hydro-geochemical processes recommended by Chadha’s [28] are pointed in each of the 04 zones of the diagram. These are extensively grouped as: Zone 1: sodium-bicarbonate type of base-ion-exchange aquas, Zone 2: sodium–chloride type of end-member aquas (sea-aqua), Zone 3: Ca2+–Mg+–Cl- type of reverse-ion-exchange aquas, Zone 4: Ca-Mg-HCO3 type of recharging aquas. The most of the sub-surface aqua samples fall in Zones 1 (Na-HCO3) and 4(Ca-Mg-HCO3) recommending that the aqua represent type of base-ion-exchange and recharging water and a few of water samples fall in Zone 2 (end-member water). Zone 3 (Ca-Mg-Cl) aquas, which is less prominent in the investigation region. Zone 4 (Ca-Mg-HCO3) aquas, which is more significant in the concerned region. It may be probably attributed when aqua percolates into the sub-surface from the surface and it carries hydro-geochemically mobile calcium and the dissolved CO3 in the form of bicarbonate.

Figure 4 presented the distribution of (Ca2+ + Mg2+)/HCO3- ratio to pH. pH estimates the CO32- nature exist in aqua as CO3, bicarbonate, and H2CO3-, in acidic to basic pH stages. The study area pH showed alkaline-condition. The gradual rise of pH may be due to the elevated content of hydroxyl ions (H+) presence in the concerned region. This may be due to non-availability of neutralizing-ions or strong ion-exchange complex by clay minerals with cation. This process also aids us to determine circulation of the hydroxyl-ions in the sub-surface aqua. Elevated content of H+-ions present in alluvium-aquifers is neutralised by the process of dissolution and weathering. The sub-surface water from the investigation region mostly showed the (Ca + M)/HCO3 proportions below 1.0 in all the water samples. Water-samples with lower proportions indicated additional bicarbonate input from albite mineral weathering, rather than from calcium and magnesium formation-processes alone.



**Fig. 4.** Distribution of pH to (Ca + Mg)/HCO3 ratio.

The (mK + mNa – mCI) vs (mMg + mCa - mSO4) relation-ship gives information on the hydro-geo-logical sprig of Mg and Ca in the groundwater. To pose for meteoric-calcium from the dissolution of CaSO4, an amount of calcium equal to the content of sulphate is sub-tracted from the sum of alkaline-earths metals (magnesium + calcium). Computation of sodium levels depletion posed by exchange of cation was done by supposing that all meteoric-sodium inputs were from sodium-chloride. Because all chloride metals are meteoric in origin, subtracting chloride from the total-sodium estimates the meteoric-sodium concentration. Figure 5 showed the distribution of (Ca + Mg)/HCO3 and (Na +K)/HCO3. It is to be recorded that the ‘X–axis’ traversed the ‘Y-axis’ at 0.90, i.e. the line along which (sodium + magnesium)/bicarbonate is equal to 0.90. The plot showed higher ratio of (Ca + Mg)/HCO3 and (sodium + potassium)/bicarbonate, with calcium + magnesium –bicarbonate– sodium + potassium aqua-type (Fig. 5). The figure showed the pre-dominance of excess (calcium + magnesium) and higher (sodium + potassium). This showed that the region has pre-dominance of excess (calcium + magnesium) and (sodium + potassium), with no important impacting anions indications due to pollution.



**Fig. 5.** The ratio between the (Na + K)/HCO3 and (Ca + Mg)/HCO3.

Majority of the sub-surface water-samples in the concerned region, showing Ca- Mg - Na – K - HCO3 water-type (Fig. 5). This recommends that silicates minerals weathering are the important contributors to the hydro-chemistry of the study area.

**4 Quality of Water**

**4.1. Quality of domestic water**

The hydro-chemical characteristics related to the water-salinity can be evaluated/optimised by the assessments of the following elements: Cl content, and TDS. Desjardin [29] grouped water typology pursuance to the total dissolved solids concentration. Table 2 clearly showed that the higher presentations of the sub-surface aqua-samples in the area of study were observed in freshwater and moderately fresh-brackish water-types. Salinity occurs in sub-surface water due to anthropogenic sources, leaching from top-soil, weathering of rocks and along with minor climate impact [30]. The concentration of sodium and bicarbonate in agriculture sub-surface water influences the area drainage and the soil permeability [31-32].

**Table 2.** Water typology according to their content of TDS [29].

|  |  |  |  |
| --- | --- | --- | --- |
| **Type of Water** | **Limit (mg/l)** | **Number of water samples** | **Percentage (%)** |
| **Slightly-brackish aqua** | 1000-5000 | 04 | 13.33 |
| **Moderately-fresh-brackish aqua** | 500-1000 | 15 | 50 |
| **Freshwater** | >500 | 11 | 36.67 |

**Table 3.** Hydro-geochemical classification summary.

|  |  |  |  |
| --- | --- | --- | --- |
| **Class** | **Range (mg/l)** | **Number of samples (30)** | **%** |
| **USGS hardness [33]** | |  |  |
| **Very Hard** | >300 | 20 | 66.67 |
| **Moderately Hard** | 150-300 | 09 | 30.00 |
| **Slightly Hard** | 75-150 | 01 | 03.33 |
| **Classification of chloride [37]** | |  |  |
| **Brackish** | 8.46-28.20 | 02 | 06.67 |
| **Fresh Brackish** | 4.23-8.46 | 03 | 10.00 |
| **Fresh** | 0.84-4.23 | 25 | 83.33 |
| **Very Fresh** | 0.14-0.84 | 00 | 00.00 |
| **Base Exchange Indices (BEI) Scholler [35]** | |  |  |
| **(sodium + potassium)g.w. (calcium/magnesium) rock** | | 15 | 50.00 |
| **(sodium + potassium) rock (calcium/magnesium) g.w** | | 10 | 50.00 |

**4.2. Total Hardness (TH)**

TH is expressed as the sum of content of their metals defined in milligram per litre of calcium carbonate. TH increases from metals mixed in aqua. TH is applied as the scale formation rate indicator in hot-aqua heaters in low-pressure boilers. The united state of geological survey TH [33] showed 04 classes of hardness: very hard, moderately hard, slightly hard, and soft. Depositions and scaling issues in air-conditioning plants are accounted with the TH of aqua. The TH of greater than one hundred eighty milli gram calcium carbonate per litre can be categorised as ‘very-hard’ aqua and can pose to scaling issues in air conditioning plants [34]. In the concerned region, 30% of water-samples were ‘moderately-hard group’, 3.33% fall under ‘slightly-hard group’ and 66.67% are in the ‘very-hard group’ (Table 3).

**4.3. Base-exchange Index (BEI)**

Scholler [35] suggested a term known as ‘‘Base-Exchange Index’’ (BEI) to interpret the hydro-geochemical processes taking place in sub-surface water. There are substances which exchange and absorb their ions with ions exist in sub-surface water. Those substances are known as ‘permutolites’, e.g. organic substances and clay-minerals like zeolites, glauconite, halloysite, chlorite, illite, and kaolinite. Halloysite, chlorite, illite, and kaolinite are the clay-minerals in which metals capacity of ionic-exchange is low and are present at edges. This condition is reverse in vermiculite and montmorillonite. However, when the number of metals present on the surface is more, the exchange-capacity is higher. Indices of chloro-alkaline, CAI1 and CAI2 are applied to estimate the extent of base-exchange during interaction of water-rock using equation 1 and 2 [35].

Chloro-alkaline-indices 1 = [chloride – (sodium + potassium)]/(chloride) ...(1)

Chloro-alkaline-indices 2 = [chloride – (sodium + potassium]/(sulphate + bicarbonate + carbonate + nitrate) ...(2)

All metallic content is represented in milli-equivalent per litre.

Where there is no ex-change of potassium (K+) and sodium (Na+) in sub-surface aqua with calcium (Ca2+) or magnesium (Mg2+) in alluvium/rock, both the indices are positive and vice-versa. In the most of the samples reverse-ion-exchange is the pre-dominant process in the area of study. The base-exchange indices point that there is a prominent-exchange of sodium + potassium in sub-surface water into the calcium + magnesium in alluvium from the matrix, whereas the vice-versa is less important and the exchange of sodium + potassium in alluvium to the calcium + magnesium in sub-surface water is less observed [36]. More than 50% of water samples fall in (sodium + potassium) sub-surface water magnesium/calcium alluvium and 50% of the water samples are in (sodium + potassium) alluvium magnesium/calcium. Chloride classification by Styfzands [37] showed that nineteen percentages of water-samples were in the ‘brackish category’, 10% were under the ‘fresh-brackish category’ and 83.33% were fresh in nature in rock (Table 3).

**5 Conclusions**

Dominance of the anion is in the following sequence: sodium > calcium > magnesium > potassium and that of cations is bicarbonate > chloride > sulphate. The concerned region forms a part of the inland-aquifers, and the elevated level of TDS extended from the north-eastern to south-western part influenced by anthropogenic sources, leaching from top-soil, weathering of rocks and along with minor climate impact. Elevated content of total dissolved solids was also found in the, central and south-western, western, north-eastern, north-western, parts due to the metals leaching. Majority of the sub-surface aqua-samples varied from ‘slightly-hard’ to ‘very-hard’ group. Cl classification by Styfzands showed that all the groundwater samples fall in ‘brackish’ to ‘fresh’ range in the study area. Piper plot showed that ‘calcium-magnesium-bicarbonate’ type is the pre-dominant indices in the sub-surface aqua with few presentations of Na-Cl indicating the recharge and end-members water and showed the mixed water type, hard water and slightly saline nature of the sub-surface water. Chadda’s diagram showed that base-ion exchange, recharging water and end-member water are more common in rock, which has more presentations of recharging water polluted samples. TDS is higher and exceeded the guideline ranges for domestic purpose in few of the aqua-samples in Yamunanagar and Ambala districts. Few sub-surface aqua samples of the investigation region were not-suitable for domestic and drinking purposes and only few sites needs some kind of treatment for better water quality for the human consumption.

**References**

1. Ravish, S., Setia, B., Deswal, S.: Groundwater quality in urban and rural areas of north-eastern Haryana (India): a review. ISH Journal of Hydraulic Engineering <https://doi.org/10.1080/09715010.2018.1531070> (2018).

2. Singh, U. K., Kumar, M., Chauhan, R., Jha, P. K., Ramanathan, A. L., Subramanian, V.: Assessment of the impact of landfill on groundwater quality: A case study of the Pirana site in western India. Environmental Monitoring and Assessment, 141, 309–321 (2008).

3. Raju, N. J., Reddy, T. V. K.: Environmental and urbanization affect on groundwater resources in a pilgrim town of Tirupati, Andhra Pradesh, South India. Journal of Applied Geochemistry, 9(2), 212–223 (2007).

4. Umar, R., Khan, M. M. A., Absar, A.: Groundwater hydrochemistry of a sugarcane cultivation belt in parts of Muzaffarnagar district, Uttar Pradesh, India. Environmental Geology, 49, 999–1008 (2006).

5. Raju, N. J., Ram, P., Dey, S.: Groundwater quality in the lower Varuna River basin, Varanasi district, Uttar Pradesh, India. Journal of Geological Society of India,73, 178–192 (2009).

6. Faure, G. Principles and applications of geochemistry, 2nd Edn. Englewood Cliffs: Prentice Hall (1998).

7. Rout, C., Attree, B.: Seasonal assessment of drinking water quality: a case study of Barara block of Ambala district, Haryana. Adv Appl Sci Res. 2016; 7(1):28-34 (2016).

8. Rout, C., Sharma, A.: Assessment of drinking water quality: a case study of Ambala cantonment area, Haryana, India. Int J Environ Sci.2011; 2(2):933-45 (2011).

9. Raju, N. J.: Hydro-geochemical parameters for assessment of groundwater quantity in the upper Gunjanaeru river basin, Cuddapah district, Andhra Pradesh, south India. Environ Geol. 2007; 52(66):1067-74 (2007).

10. Rao, S. N.: Seasonal variation of groundwater quality in a part of Guntur district, Andhra Pradesh, India. Environ Geol 49:413–429 (2006).

11. Sunitha, V., Sudarsha, V., Reddy, R. B.: Hydrogeochemistry of groundwater, Gooty area, Anantapur District, Andhra Pradesh, India. Pollut Res 24(1):217–224 (2005).

12. Hussain, I, Hussain, J, Dhinsa, S. S.: Groundwater quality variation in Bhilwara District, Rajasthan. Pollut Res 24(3):723–725 (2005).

13. Pulle, J. S., Khan, A. M., Ambore, N. E., Kadam, D. D., Pawar, S. K.: Assessment of groundwater quality of Nanded City. Pollut Res 24(3):657–660 (2005).

14. Sujatha, D., Reddy, R. B.: Quality characterization of groundwater in the south-eastern part of the Ranja Reddy District, Andhra Pradesh, India. Environ Geol 44(5):579–586 (2003).

15.Khurshid, S. H., Hasan, N., Zaheeruddin.: Water quality status and environmental hazards in parts of Yamuna–Karwan sub-basin of Aligarh–Mathura District, Uttar Pradesh, India. J Appl Hydrol 14(4):30–37 (2002).

16. Dasgupta, A. M., Purohit, K. M.: Status of surface and groundwater quality of Mandiakadar—part II: agricultural utilities. Pollut Res 20(2):219–225 (2001).

17. Majumdar, D., Gupta, N.: Nitrate pollution of groundwater and associated human health disorders, India. J Environ Health 42(1):28–39 (2000).

18. Rao, S. N., Rao, S. G., Rao, V. S., Reddy, M. P., Devadas, J. D.: Environmental control of groundwater quality in a tribal region of Andhra Pradesh, India. J Geol 71(4):299–304 (1999).

19. Babu, N. P., Rao, S. N., Rao, C. P., Rao, P. J.: Groundwater quality and its importance in the land developmental programmes, India. J Geol 69(4):305–312 (1997).

20. Agarwal, V., Jagetia, M. M.: Hydrogeochemical assessment of groundwater quality in Udaipur City, Rajasthan, India. In: Proceedings of national conference on ‘‘Dimensions of Environmental stress in India’’. Department of Geology, MS University, Baroda, pp 151–154 (1997).

21. Durvey, V. S., Sharma, L. L., Saini, V. P., Sharma, B. K.: Handbook on the methodology of water quality assessment. Rajasthan Agricultural University, India (1997).

22. CGWB.: Groundwater Year Book-India. Central Ground Water Board, Ministry of Water Resources Government of India, Faridabad (2012).

23. APHA.: Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington, DC (1998).

24. Freeze, A. R., Cherry, J. A.: Groundwater. Prentice-Hall Inc, Englewood cliffs, p 604 (1979).

25. Domenico, P. A., Schwartz, W.: Physical and chemical hydrogeology, 2nd edn. Wiley, New York, p 506 (1998).

26. Piper, A. M.: A graphical procedure in the geochemical interpretation of water analysis. Transactions—American Geophysical Union: 1944, 25, 914–923 (1944).

27. Back, W.: Origin of hydrochemical facies of groundwater in the Atlantic Coastal plain. In: 21st international geological congress, Copenhagen 1960, Rept pt. 1, pp 87–95 (1960).

28. Chadha, D. K.: A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. Hydrogeology Journal. 1999, 7(5), 431–439 (1999).

29. Desjardins, R.: Le traitement des eaux. Edition II revue. Edition de l’Ecole Polytechnique de Montre´al, Montre´al (1988).

30. Prasanna, M. V., Chidambaram, S., Gireesh, T. V., Jabir, Ali, T. V.: A study on hydrochemical characteristics of surface and subsurface water in and around Perumal Lake, Cuddalore District, Tamil Nadu, South India. Environ Earth Sci 64(5):1419– 1431 (2011).

31. Tijani, J.: Hydrochemical assessment of groundwater in Moro area, Kwara state, Nigeria. Environ Geol 24:194–202 (1994).

32. Kelly, W. E.: Geoelectric sounding for delineating groundwater contamination. Ground Water 14(1):6–11 (1976).

33. Handa, B. K.: Modified classification procedure for rating irrigation waters. Soil Sci 98(2):264–269 (1964).

34. Hem, J. D.: Study and interpretation of the chemical characteristics of natural water, 2nd edn. USGS Water Supply, 1473, p 363 (1970).

35. Scholler, H.: Hydrodynamic Dam Lekar Collogue Doboronik 1, pp 3–20 (1965).

36. Chidambaram, S.: Hydrogeochemical studies of groundwater in Periyar District, Tamilnadu, India. Ph.D. Thesis, Annamalai University (2000).

37. Stuyfzand, P. J.: Non point sources of trace elements in potable groundwater in the Netherlands. In: Proceedings 18th TWSA water workings. Testing and Research Institute, KIWA (1989).