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Hydrogeochemical characteristics and groundwater contamination in the rapid urban development areas of Coimbatore, India

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ABSTRACT

The Singanallur Sub-basin is one of the major waterways and it supplies water to the Coimbatore city. Currently, it is vulnerable to pollution due to an increase of unplanned urban developments, industrial, and agricultural activities that compromise both the quality and quantity. In the present study three major hydrochemical facies were identified (mixed Ca-Mg-Cl, Ca-Cl, and Ca-HCO_3). Irrigation suitability indexes are specifies that the groundwater in the areas has very high salinity hazard and low to medium alkali hazard. The mechanism controlling groundwater chemistry originally regulated by the evaporation process is dominated by reason of arid condition and anthropogenic activities existing throughout the region. The multivariate statistical analysis (Correlation analysis (CA), principal component analysis (PCA) and Hierarchical cluster analysis (HCA)) indicates, most of the variations are elucidated by the anthropogenic pollutant predominantly due to population growth, industrial effluents, and irrigation water return flow. This study demonstrates enhanced information of evolution of groundwater quality by integrating hydrochemical data and multivariate statistical methods are used to understand the factors influencing contamination due to natural and anthropogenic impacts.

1. Introduction

Groundwater is the most vital natural resource, which forms the core of the ecological system. It has become the major source of water supply for drinking, domestic, household, agricultural, industrial, recreational, and environmental activities etc. This has led to an increase in the demand of water supply which is met mostly from the exploitation of groundwater resources. Nowadays groundwater is a very important concern for mankind since it is directly linked with human safety. Determination of physical, chemical and bacteriological quality of groundwater is important for assessing various usages. Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by natural processes such as geological formations and anthropogenic activities. In fact, industrial waste and the municipal solid waste have emerged as one of the leading cause of pollution of surface and ground water [13]. Globally many researchers have carried out a study on groundwater quality and pollution sources influenced by industrial and natural process [21–23,28,44,50]. The principles governing the chemical characteristics of groundwater and influence of anthropogenic activities are well documented in many parts of the India [3,8,11,14,16,19,24,26,27,33,34,38,39,42].

Groundwater contamination in an urban environment is a major issue, especially in industrial urban areas. The Coimbatore city is one of the most industrialized districts and major textile mills for the entire south India. In due Course, its glory gets deteriorated due to various internal and external diseconomies which were adversely influenced by the textile industries. On parity with a textile industry, engineering industry also dominated the economy of the district in the past. As against the receding trend of the textile industry, engineering industry still holds its unique position in spite of tremendous growth experienced in the country for the past few decades by different sectors of the economy. The groundwater of Coimbatore has been deteriorated due to industrialization along with agricultural activities and rapid urbanization in its surroundings areas [6]. Increased population and industrial activities make it essential to assess the quality of groundwater system to ensure the long-term sustainability of resources [46].

The Singanallur area is also predominantly an industrial zone with dense population and agriculture activities. In this region, there is no proper drainage or sewerage system and hence the sewage is discharged into the river. Thus the polluted water reaches the different tanks which form the part of the Noyyal river system [32]. A decrease in various quality characteristics clearly indicates the possibilities of pollution due to industrial activities such as leather tanning, textiles,

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and foundries in and around Coimbatore city [20], with population density, has also a strong impact of surface water pollution as well as groundwater. The evolution hydrochemistry of groundwater in Singanallur region is inadequate because most of the studies focused for drinking and irrigation suitability on a few regions of Coimbatore district [17,18,20,32,45]. Singanallur stream as it receives waste water discharge from point sources such as spinning mills, four mills, small scale industries, and congested residential areas unrestricted domestic sewage effluents [9] and the higher pollution load discharged into stream was carried out to the tank ultimately resulting in deterioration of surface water, as well as groundwater in an aquatic environment. [15], accounted that a domestic and untreated industrial discharges into the Singanallur lake is probably responsible for the high concentration values of electrical conductivity, COD, alkalinity, and turbidity. Many of the earlier works in the city provide a preliminary and superficial assessment of groundwater quality without characterizing the exact causative factors controlling the water quality and the samplings are random. But, the present manuscript has taken the large extent of the study region covering urban settlement, industrial zone, irrigational zones etc., for understanding the water quality changes due to anthropogenic influences through graphical representations and multivariate statistical techniques.

2. Study area

2.1. Geological and hydrogeological setting

The study area, Singanallur is located within latitudes 10°59'42'N to 11°1'30''N and longitudes 77°0'18''E to 77° 2'6''E (Fig. 1). Singanallur Lake is one of the major parts of Coimbatore district. The lake is fed by canals derived from Noyyal River. The length of the lake extends to 3102 m and water spread area of 1.153 km^2 and has an average depth of 4.25 m. The altitude is 362 m. The mean annual precipitation is estimated of 614–647 mm with the Northeast and the Southwest monsoons contributing to 47% and 28% respectively to the total rainfall. The average maximum and minimum temperature is 39.4 °C and 20.7 °C respectively. There are four major types of soil can be identified mainly for black cotton soil, reddish brown/brown loamy soil, alluvium and colluvium. Lithological of Coimbatore is wide range of high grade metamorphic rocks of the peninsular gneissic complex which are extensively weathered and overlain by recent valley fills and alluvium at various places. The major rock types are charnockites, granites, complex gneisses mainly hornblende biotite, gneiss and silimanite gneiss with basic and ultra basic intrusive, crystalline lime stones, syenite, pegmatite and quartz veins. Kankar is followed by top soils in many places. The important aquifer systems in the regions are mainly constituted by unconsolidated formations and weathered with fractured crystalline rocks. Groundwater occurs at shallow levels under semi-confined and unconfined formation.

3. Climate and environmental issues

Singanallur has the highest population density in the region while other parts of Coimbatore have a low population density. 1012 families are residing in the area and the total populations of 3550 of which 1782 are males while 1768 are females and the total number of rural habitations is 2238 (Census, 2011). The major occupation of the people is agriculture and industries, mainly textile and engineering industries. Singanallur is one of the major tanks and wetland areas of Coimbatore. It receives more amount of water from river Noyyal and Sanganur drain and sewage. The registered irrigated areas is 337.1 (ha) and 15,974 acres of agricultural lands, in and around the city, are irrigated by the Noyyal river system. The river and the river-fed wetlands support a large number of plants. The wetlands are main sources of freshwater for drinking, domestic and agricultural uses. In the recent years it cannot be considered for drinking and domestic purposes due to variety of pollutants and contaminants from multiple sources such as industrial outflows, irrigation return flow, domestic discharges and hospital disposals, aggregating the situation water pollution and contamination. Most of these wetlands get dried in summer and serves as a dumping yard for garbage and industrial wastes. According to 2006 report, the lake was encroached by water hyacinth and polluted due to effluents released into the lake. Water-borne diseases have reported in many places of the area where proper sanitation facilities are lacking. This along with garbage dumping and encroachments has led to degradation of water bodies and depletion in the groundwater table. Lack of proper waste management infrastructure and deterioration of water bodies are the main environmental problem in the Singanallur areas. Groundwater level has gone down significantly in a few places. Recent reports with the Tamil Nadu Water Supply and Drainage Board suggests that the average drop in water level is five meters. Categorization based on groundwater extraction the Singanallur region has over exploited as per Central Ground Water Board [7] report. Coimbatore corporation plans to improve water supply to Singanallur region in July 2014.

4. Methodology

The sampling plan for this study was planned to collect site-specific information related to the influence of industrial and agricultural activities near the sampling sites. The samples have been collected in a monthly interval for a period of 12 months (April 2015 to March 2016) since, the whole 12 months period has no rainfall and the hottest climate prevailed, the variation in the monthly interval could not be differentiated. Therefore the values are shown an average of 12 months. Depth to water level is shallow between 15.4 and 18.6 m below ground level (mbgl). pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) are taken in the field immediately after tapping water samples by using Hanna water quality meter (HI-9828, USA) and then kept in 500 mL polyethylene bottles. The groundwater samples collection and analysis were followed by standard methods [1]. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations were determined by complex-cation using EDTA (Ethylenediamineteracetate) with the ammonium purpurate as an indicator for the determination of Ca2+ content alone, and “Eriochrome Black T” for both Ca^{2+} and Mg^{2+}content. Digital flame photometer was used to identify the sodium (Na^+) and potassium (K^+) contents. Chloride (Cl^-) ion was determined with the standard silver nitrate (.01N) titration method and in the presence of 1 mL of potassium chromate (5%) as an indicator. The determinations of carbonate and bicarbonate concentrations were estimated by volumetric methods using .01N H_2SO_4. Sulfate (SO_4^{2-}) and NO_3^- was estimated by using the UV–Visible spectrophotometer. The analytical results checked using charge-balance error for major ionic contents, calculated using Microsoft Excel and the software package AQUACHEM, did not exceed 8%.

The irrigation suitability of groundwater was examined based on Total Hardness (TH), Sodium Adsorption Ratio (SAR) in associated with electrical conductivity values, Sodium Percentage (Na%), Permeability Index (PI) and Magnesium Ratio (MR) as calculated by the following formulas,

$$TH\,(asCaCO_3) = (Ca^{2+} + Mg^{2+})meq/l \times 50$$

$$SAR = Na/\sqrt{\frac{(Ca + Mg)}{2}}$$

$$Na\% = \frac{(Na + K)}{Ca + Mg + Na + K} \times 100$$

$$PI = \frac{(Na + \sqrt{HCO3})}{(Ca + Mg + Na)} \times 100$$

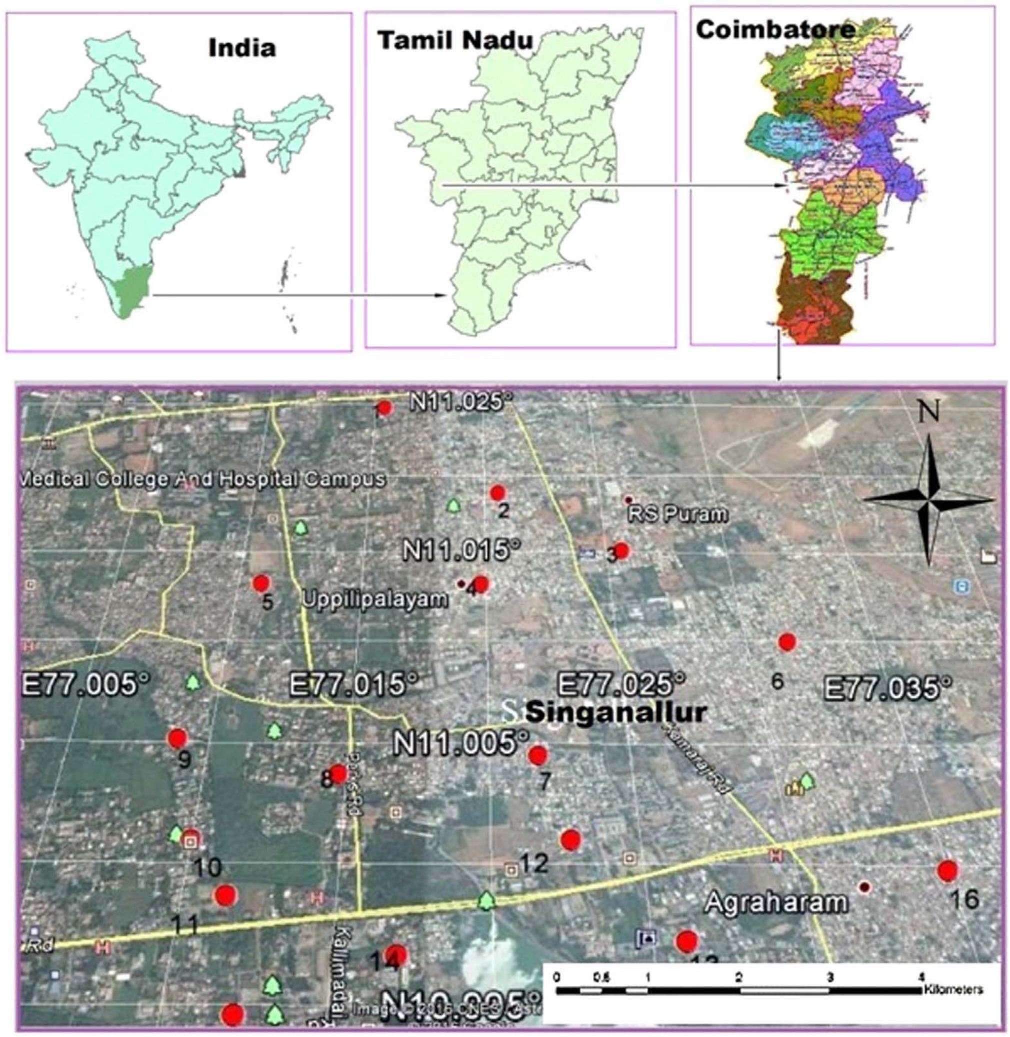

Fig. 1. Location map of the study area.

$$Magnesiumratio = \frac{(Mg)}{(Ca + Mg)} \times 100$$

Piper trilinear diagram, USSL (United state Salinity Laboratory) diagram and Wilcox plot (1955) were performed to recognize the various hydrogeochemical characters in the groundwater for drinking and irrigation suitability, they are made using Aqua-Chem software. Multivariate statistical methods such as correlation matrix, principle component analysis, and hierarchical cluster analysis were performed using IBM SPSS 20 software.

5. Results and discussion

5.1. Groundwater chemistry and drinking quality

The chemical characteristics of the groundwater in addition to the pH, electrical conductivity, and TDS were statistically analyzed and the result is compared to drinking water suitability standards are given in Table 1. The pH of the groundwater in the study area varies from 7.20 to 8.36 with an average value of 7.84, indicating alkaline nature of the samples. The EC values varied from 1258 µS/cm to 10008 µS/cm with an average value of 4953 µS/cm, which is directly related to the ionic concentrations present in the groundwater and its higher values contribute to higher salinity and total dissolved concentration. According to CGWB report [5] in the Singanallur parts, EC values has been measured exceeding 2250 µS/cm.

The TDS values vary between 805 to 6405 mg/l with a mean value of 3170 mg/l, for drinking purpose the maximum allowable TDS guideline value prescribed by the WHO [49] is 1000 mg/l. The majority of groundwater samples come under slightly saline to moderately saline water type (Table 2) and not suitable for drinking purpose; as the value of TDS in them is greater than 1000 mg/l. The high TDS may be due to the percolation of channel water containing solids, agricultural wastes, and industrial seepages. Though the country rocks are also the most important sources of increasing dissolved solids in the

Table 1
Drinking water standard specifications given by WHO (2004), ISI (1983) and BIS (1991) and statistical information of ion concentrations.

Parameter	Min	Max	Average	WHO 2012	ISI 1983	BIS 1991
pH	7.2	8.36	7.843	6.5–8.5	6.5–9.2	6.5–8.5
EC (µS/cm)	1257.813	10008.63	4953.321	1500	–	–
TDS (mg/l)	805	6405	3170.125	1500	1500	1500
Ca (mg/l)	118	1250	537.063	200	200	200
Mg (mg/l)	140	1106	450	150	100	100
Na (mg/l)	170	837	449.938	200	150	150
K (mg/l)	6	23	14.125	12	–	–
CO3 (mg/l)	0	43	18.188	200	–	–
HCO3 (mg/l)	289	954	529.688	500	400	400
Cl (mg/l)	116	1753	791.313	600	1000	1000
SO4 (mg/l)	46	452	247.625	250	400	400
NO3 (mg/l)	1	34	11.813	45	45	45

Table 2
Groundwater classification according to total dissolved solids (TDS).

S.No	Ground water Class	TDS Range (mg/l)	Number of samples		Sample Number
			In. No	In %	
1	Fresh water	< 1000	1	6.75	15
2	Slightly saline	1000–3000	8	50	3, 6, 7, 8, 10, 11, 14, 16
3	Moderately saline	3000–10000	7	43.25	1, 2, 4, 5, 9, 12, 13, 16
4	Very saline	10000–30000	–	–	–
5	Brine	> 30000	–	–	–

groundwater. The concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} ions vary from 118 to1250 (mean value of 537 mg/l), 140–1106 (mean value of 450 mg/l), 170–837 (mean value of 449 mg/l) and 6–23 (mean value of 14 mg/l) respectively. Thus the order of cation abundance is $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. Cationic concentrations indicate, about 70% of the groundwater samples are beyond the permissible limit of 200, 150, 200 and 12 mg/L respectively.

Among the anions, the chloride is the most dominant ion in the groundwater. The chloride concentration in the study area ranges from 116 to 1753 mg/l and with an average value of 791.3 mg/l. Chlorides are one of the most important inorganic anions present in ground water. Relatively the higher concentration of chloride (1646–1753 mg/L) is observed from the groundwater samples 1, 2, 4 and 9 which contributes approximately 75 to 80% to the total anionic concentration due to an influence of poor sanitary conditions, chemical fertilizers, irrigation return flow and industrial effluents. According to WHO [49], the maximum permissible limit of chloride value is 250 mg/l, from the study area seven samples exceed the permissible limit and unsuitable for drinking purpose and all other samples are well within the allowable limits for drinking. The concentration of bicarbonate is observed from 289 to 954 mg/L. the higher concentration of HCO_3^- compared to chloride concentration in the groundwater infers that mineral dissolution also occurs.

The SO_4^{2-} ranges were noted between 46 to 452 mg/l and with an average value of 247.6 mg/l, which is very important and widespread environmental problem in many irrigated agricultural regions. The highest sulfate concentration of more than 400 mg/l in the groundwater samples 1, 2 and 9 indicates the influence of accumulation of soluble salts in the soil, anthropogenic activity and the addition of excessive sulfate fertilizer. The range of NO_3^- is 1.05–34.6 mg/L with an average of 12 mg/L falling below the WHO recommended a value of 45 mg/L. In natural conditions, the concentration of NO_3^- does not exceed 10 mg/L in the groundwater, so beyond the 10 mg/L, is an indication of anthropogenic pollution, it mainly due to poor sanitary conditions, indiscriminate use of higher fertilizers for higher crop yields [43]. To understand the hydrochemical evolution of groundwater in the study area is determined by plotting of major ions in the Piper trilinear diagram [31] (Fig. 2). In the lower right triangle, all but 3 samples show Cl^- contents making up at least 80% of the total anion load and only two samples have Mg^{2+} contributions and rest of the samples have no dominant type, indicating mixed water without any cation exceeding 50%. The dominant water types are in the order of mixed Ca-Mg-Cl > Ca-Cl > Ca-HCO_3. The vast majority of samples are mixed Ca-Mg-Cl dominant fluids. It indicates, mixing of high salinity water caused from surface contamination sources, such as the liquid and solid waste discharged into the nearby land and channel [15], domestic wastewater, septic tank effluents, and irrigation return flow with existing water followed by ion exchange process. However, Ca-Cl and Ca- HCO_3 water types suggest mineral dissolution, an interaction between rock and water and recharge of freshwater [26].

Gibb's plot [12] is mainly used to understand the relationship

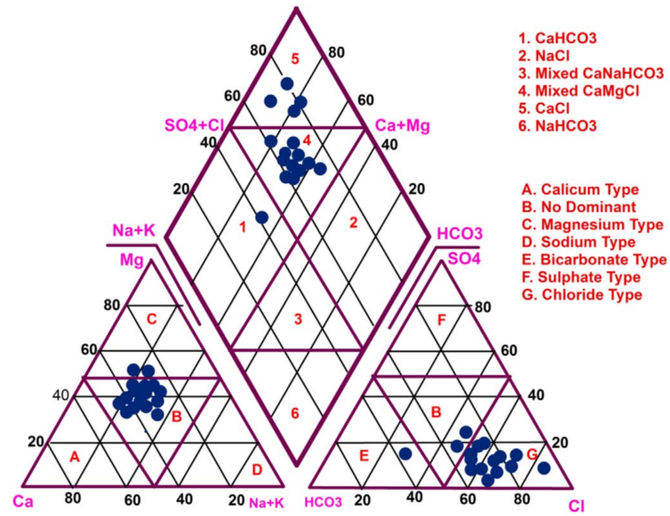

Fig. 2. Hydrochemical facies of the study area.

between water composition with their respective aquifer characteristics such as rock-water interaction, rainfall dominance (chemistry of precipitated water) and evaporation dominance (rate of evaporation) for groundwater chemistry. Fig. 3 shows a majority of the samples irrespective of the formation falls in the evaporation dominance by causes of semi- arid environmental climate conditions and surface contamination sources, primarily an excessive use of fertilizers, irrigation return flow, industrial outflows and domestic discharges may also be the associated factors which ultimately lead to the increase of salinity with Na^+ and Cl^- in due to evaporation. Some of the samples falling in the rock-water interaction zone, it gave an indication of chemical weathering of rock-forming minerals are influencing the groundwater quality by dissolution of rock through which water is circulating under the subsurface [37] and the chemistry of the groundwater in the Coimbatore district is mainly controlled by complex geochemical mechanisms [35]. The samples falling outside the plot indicate may be due to the other process of anthropogenic activities, which addressed the similar observation of [41].

6. Irrigation suitability

The excessive amount of dissolved salts such as sodium, magnesium, chloride and bicarbonate in irrigation in water can change the osmotic pressure in the root zone which affects the agricultural soil and hence plants physically and chemically leading to reduced yield and consequently hindering the plant growth [4]. The growth and continuation of successful irrigation projects not only depend on the supply of irrigation water to the land but also aim in controlling the solutes and alkali of the soil [29]. Hence, methods of Wilcox [48], United States Salinity Laboratory [10,47] and Paliwal [30] have been used to classify and understand the groundwater characters, as the suitability of irrigation depends on the mineralization water and its effect on soil and plants.

Hardness is an important factor in determining the suitability of water samples for domestic, and irrigation purposes as it is involved in making the water. Based on the Sawyer et al. (2003) water is classified as, soft, hard, moderately hard and very hard. The classification of groundwater based on total hardness indicates all samples are very hard in nature. For the maximum permitted limit of total hardness for drinking is specifies as 500 mg/l. However, for irrigational purposes, more than 1000 mg/l of hardness is also accepted. The correlation between SAR and EC were plotted on the USSL diagram (Fig. 4). It indicates that most of the groundwater samples are plotted in C4S2 type, indicating the high salinity and medium sodium hazard. The EC values of the groundwater in these areas measures up to 3000 μS/cm.

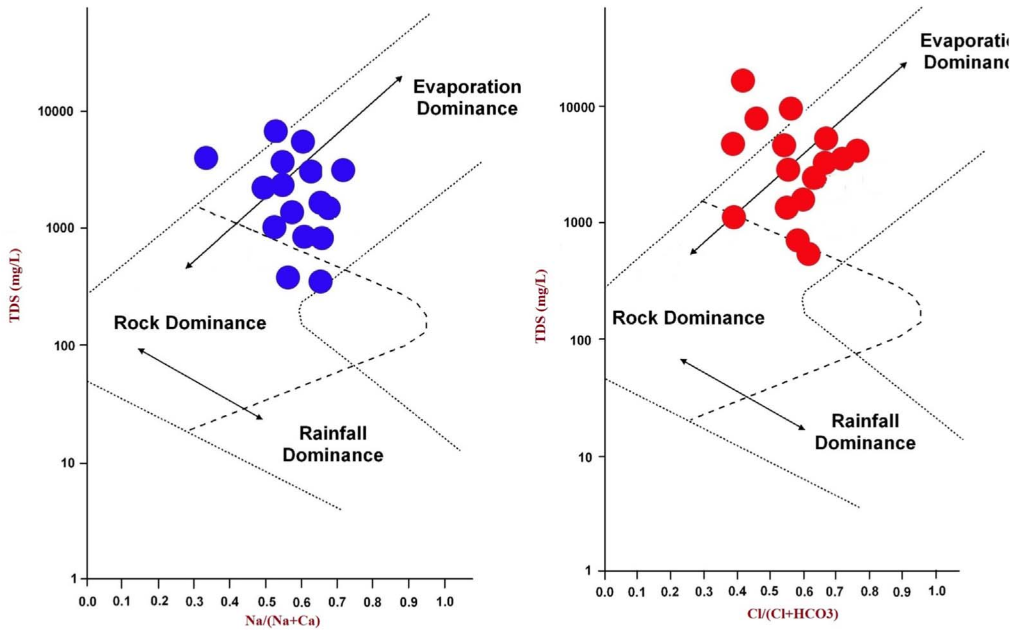

Fig. 3. Mechanism controlling groundwater chemistry.

The water is moderate alkaline with very high salinity. High sodium and salinity levels are bad for irrigation because sodium is the component of a harmful salt and also causes poor physical conditions of the soil. A high amount of salts in irrigation water can modify the osmotic pressure in the root zone, which will result in limiting the amount of water taken by the plant and consequently hindering the plant growth [50]. In addition, the presence of black cotton soil coupled with kankar in the rocky areas, the quality of water is poor. The poor quality persists till the bottom of the highly weathered zone, which is noted up to 12 m below ground level. C4S1 and C3S1groups, representing the high salinity and low sodium hazard, indicates acceptable quality for irrigation. Groundwater belonging to these groups can be used for irrigation activities with salinity control. The same results observed that the computed Na% versus EC values. Wilcox diagram (Fig. 5) shows, 69% of the groundwater samples are fall into unsuitable condition, 25% of the samples fall in the doubtful to unsuitable condition and one sample belongs to the good to a permissible field.

Permeability index (PI) is a significant parameter for groundwater with relation to the soil for improvement of agriculture. Sodium, bicarbonate, calcium, and magnesium concentration in the soil are more responsible for influencing the soil permeability. Magnesium ratio is also important to assess the suitability of water quality for irrigation. Magnesium damages soil structure when water contains more sodium and high salinity [8]. If magnesium ratio exceeds the

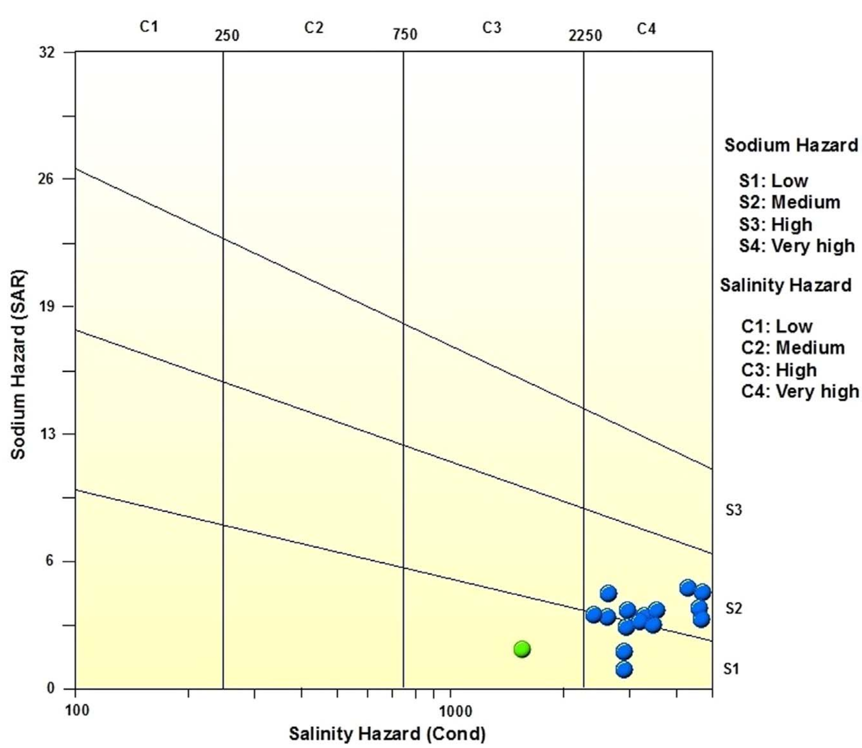

Fig. 4. US Salinity classification for irrigation.

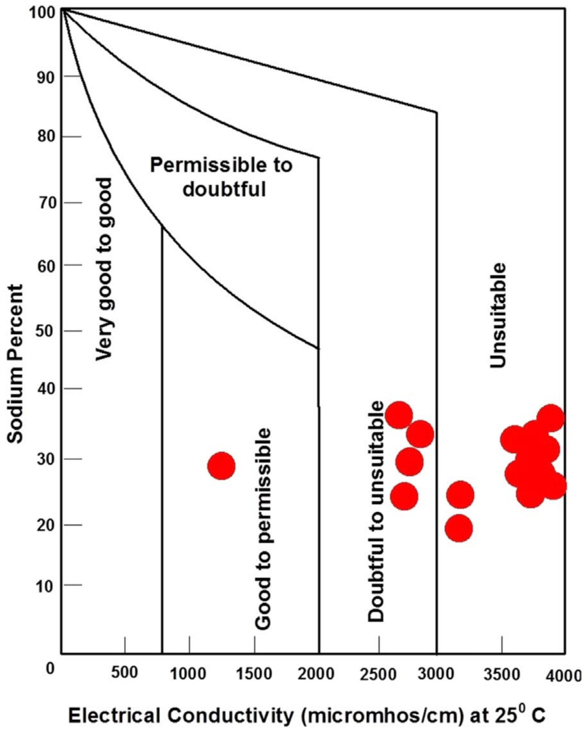

Fig. 5. Wilcox plot.

value of 50, the water associated with such a value is considered to be harmful and hence it is unsuitable for irrigation, because it harmfully affects the crop yield as the soils become more alkaline [11]. In the study area, the magnesium hazard values ranged from 40.6 to 61.42 and it exceeds the value of 50 in 13 groundwater samples, which are not suitable for irrigation.

7. Multivariate statistical analysis

Multivariate statistical techniques have been extensively used to facilitate the solution of environmental problems and suggest evidence for the understanding of some natural and anthropogenic processes. Correlation analysis (CA), principal component analysis (PCA) and Hierarchical cluster analysis (HCA) have been broadly used as unbiased methods in the analysis of water-quality data for drawing meaningful information [40].

Pearson correlation analysis is commonly used to evaluate and establish the strength of a linear relationship between two variables. The correlation coefficients among various water quality parameters were calculated and the values of the correlation coefficient are given in Table 3. The resultant matrix illustrates that EC and TDS shows a good positive correlation with Ca, Mg, Na, Cl, SO_4 and NO_3, which indicates that these ions are mainly derived from the source of large amount of chemical fertilizers used in agriculture, domestic discharges, and industrial effluent.

The PCA results comprising the loadings, Eigenvalues, percentage of total variance are summarized in Table 4. PCA extracts correlations and reduces the number of data into components that explain a portion of the total variance between chemical parameter. The four factors explain 95.4% of the total variance for the log-transformed data. the explained vaince is mainly related to the chemical parameters loadings are classified as ‘strong’ (> .75), ‘moderate’ (.75 to .50) and ‘weak’ (.50 to .30). PCA 1, which explained 77.8 of the total variance, had strong positive loadings particularly Ca, Mg, Na, Cl, SO_4, and NO_3. That are inferred to be related to evaporation and anthropogenic pollution sources from industrial effluents (salinity, Cl^-,Na^+). The other contributing process is suggested as agricultural activities due to presence of NO_3^-, Mg^{2+} and SO_4^{2-} in this factor. The other sources of NO_3^- may be derived from onsite sanitation, municipal wastes [25] and related to related to nutrient contamination owing to the unsewered urban environment and nearby agriculture practices over a period of decades [36]. The sources of Ca^{2+}, SO_4^{2-} and HCO_3^- may be due to dissolution of gypsum and calcium bearing minerals. The PCA 2 explains for 8.8% of the variability and is highly correlated with K^+ and other variables have been low positive and negative loadings. It can be attributed by chemical weathering, leaching and dissolution of secondary salts in the pore spaces, agriculture effluents, and the usual sinks are plants and clays. Factor 3 accounting for 4.8 of the total variance and shows extreme negative scores reflect areas essentially unaffected by the process. Factor 4 contributes 3.9% of the total data variability.

HCA analysis is used for grouping water samples by similar monitoring sites in their chemical composition. In this study, produced a dendrogram chart obtained from Ward's method for grouping the 16

Table 4
Rotated factor loadings for groundwater samples in the study area.

Parameters	PCA1	PCA 2	PCA 3	PCA 4
pH	−.682	.377	.449	.431
EC	**.995**	.004	.017	.082
TDS	**.995**	.004	.017	.082
Ca	**.993**	−.025	−.035	.078
Mg	**.984**	−.055	−.045	.016
Na	**.969**	−.063	.070	.148
K	.243	**.917**	−.307	−.071
CO_3	**.726**	.191	.456	−.450
HCO_3	**.904**	−.033	−.147	.178
Cl	**.973**	.043	−.048	.037
SO_4	**.919**	.129	.200	.041
NO_3	**.899**	−.114	.025	.003
Eigen Value	9.340	1.059	.576	.469
% total variance	77.831	8.829	4.803	3.912
% cumulative variance	77.831	86.660	91.464	95.375

Table 3
Pearson Correlation coefficient of groundwater in the study area.

Parameters	pH	EC	TDS	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3
pH	1											
EC	.634	1										
TDS	.634	**.999**	1									
Ca	.667	**.993**	**.993**	1								
Mg	.696	**.983**	**.983**	**.987**	1							
Na	.591	**.982**	**.982**	**.969**	.955	1						
K	.013	.232	.232	.223	.201	.145	1					
CO_3	.409	.697	.697	.665	.683	.677	.242	1				
HCO_3	.621	**.914**	**.914**	**.914**	**.897**	**.933**	.217	.555	1			
Cl	.650	**.971**	**.972**	**.970**	**.963**	**.919**	.288	.653	**.828**	1		
SO_4	.490	**.916**	**.916**	**.903**	**.858**	**.875**	.276	.727	.760	**.908**	1	
NO_3	.629	**.877**	**.877**	**.893**	**.881**	**.833**	.119	.599	.721	**.903**	**.836**	1

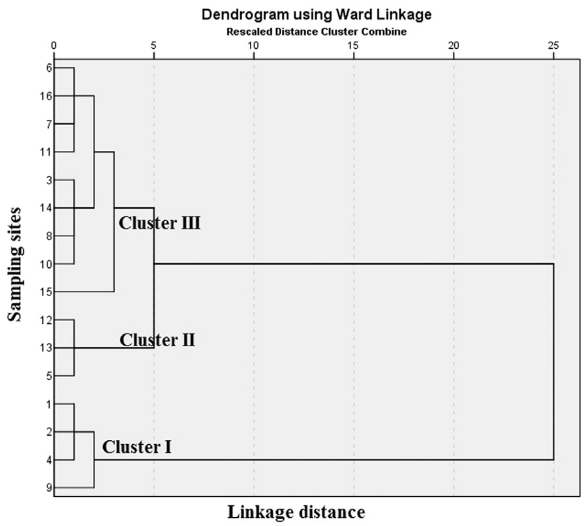

Fig. 6. Hierarchical Cluster Analysis (HCA) results.

sampling sites. According to the results (Fig. 6) Cluster I (Sites 1,2,4 and 9), cluster II (5, 12, and 13) and cluster III (3, 6–8,10,11, 14, 15 and16) correspond to the very high pollution region, high pollution region, and moderate pollution regions respectively. The water analysis results indicated that most of the samples classified as Cluster I have very high TDS (> 5000 mg/l) and concentration other chemical parameters were exceeds the permissible limit of drinking as well as irrigational uses, indicating a strong susceptibility, due to the activities of industrial, irrigational, agricultural and population density. Cluster II was associated with highest average concentrations of NO_3 and SO_4 along with high TDS (4000–5000 mg/L) due to the excessive use of fertilizers and pesticides in agriculture has also resulted in localized enrichment of nitrate in the groundwater. The source of sulfate in water is alkaline rocks, chemical compounds with sulfate from industrial wastewater and sulfate fertilizers [2]. Cluster III (low to moderate TDS (805–3152 mg/L) is nearly similar with linked at a shorter distance and are together linked to Cluster II.

8. Conclusions

This present study integrated hydrochemical characterization and multivariate statistical methods to examine the groundwater quality and to understanding the pollution sources. The physicochemical result indicates that groundwater generally has alkaline, moderately saline and very hard in nature. The abundance of major ions is in the following order: $Ca^{2+} > Mg^{2+} > Na^{+} = Cl^{-} > HCO_3^{2-} > SO_4^{2-} > NO_3^{-}$. The hydrochemical results indicates a drastically increased concentrations of salinity; sulfate, and nitrate are the major problems for drinking and domestic purposes, which are mainly caused by the potential anthropogenic contributions, such as inappropriate discharges of domestic sewages, and excessive application of agricultural fertilizers. The dominant water types are in the order of mixed Ca-Mg-Cl > Ca-Cl > Ca-HCO_3. For irrigation suitability based on USSL, Wilcox plot, SAR, and magnesium hazard it is observed that groundwater in the areas may cause high to very high salinity and medium alkalinity hazard when used for irrigation. Gibbs plot thus suggests that water chemistry is mainly regulated by mixing of salinity water caused by surface contamination with existing water and dissolution of rock-forming minerals. The clustering of urban settlement increases the urban heat and gives direct impact on soil moisture and groundwater. The result from PCA and HCA analysis suggested that most of the variations are explained by the anthropogenic pollutants and the set of natural soluble contents. The major issues affecting the groundwater quality in the Singanallur region are salinity and point source pollutants, especially near the lake; it may lead to groundwater quality deterioration in the surrounding environment and the population growth has affected the land use pattern, which has subsequently affected the quality of the water resource. The results of the present study provide information that can be useful for the water resource management in the Singanallur area particularly with respect to anthropogenic stress. Therefore, recommendations have been made, to avoid using the groundwater in these areas for drinking directly before the required treatment and all types of liquid and solid waste must be treated before being drained into the tank. Local authorities, NGO's and government sectors should be more effective in controlling the contamination in the area.

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References

[1] APHA, Standard Methods for the Examination of Water and Wastewater, 19th ed, APHA, Washington, DC, 1995.
[2] R. Atay, C. Bulut, Beys ¸ehir, Eg ˘irdir, Kovada, C ¸ ivril ve Krakuyu (C ¸ apalı)Go ¨llerinde su kirlilig ˘i projesi, Eg ˘irdir Su U ¨ ru ¨nleri Aras ¸tırma Enstitu ¨su ¨ Mu ¨du ¨ rlu ¨g ˘u ¨ (in Turkish), 2005.
[3] K. Brindha, L. Elango, Impact of tanning industries on groundwater quality near a metropolitan city in India, Water Resour. Manag. 17 (2012) 47–1761.
[4] M. Bob, N.A. Rahman, A. Elamin, S. Taher, Assessment of groundwater suitability for irrigation in Madinah City, Saudi Arabia, Arab J. Geosci. 9 (2016) 38. http://dx.doi.org/10.1007/s12517-015-2024-z.
[5] Central Ground Water Board (CGWB), District groundwater brochure, Coimbatore district, Tamil Nadu, Tech. Rep. Ser. (2008) 5–7.
[6] Central Pollution Control Board (CPCB), Status of Groundwater quality in India, Part-I, ⟨www.cpcb.nic.in⟩, 2007.
[7] Central Ground Water Board (CGWB), District groundwater brochure, Coimbatore district, Tamil Nadu, Tech. Rep. Ser. (2008) 19–26.
[8] S. Chidambaram, M.B.K. Prasad, R. Manivannam, U. Karmegam, C. Singaraja, Environmental hydrogeochemistry and genesis of fluoride in groundwaters of Dindugal district, Tamil Nadu, India, Environ. earth Sci. 68 (2) (2013) 333–342.
[9] S. Dineshkumar, S. Senthilvel, A. Bharani, Impact of point source contamination on Eutrophicated water bodies using streeter phelps oxygen sag-reaction model, Int,J. Innov. Eng. Tec. 692 (2015) 239–241.
[10] L.D. Doneen, Notes on water quality in agriculture, Water Sci. Eng. (1964).
[11] L. Elango, R. Kannan, M. Senthil Kumar, Major ion chemistry and identification of hydrogeochemical processes of groundwater in part of Kancheepuram district, Tamil Nadu. Indian J. Environ. Geoscinces 10 (4) (2003) 157–166.
[12] R.J. Gibbs, Mechanisms controlling world water chemistry, Science 17 (1970) 1088–1090.
[13] D.P. Gupta, Sunita, J.P. Saharan, Physiochemical analysis of ground water of selected area of Kaithal city (Haryana) India, Researcher 1 (2) (2009) 1–5.
[14] C.K. Jain, A. Bandyopadhyay, A. Bhadra, Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India, Environ. Monit. Assess. 166 (2010) 663–676.
[15] M. Jeyaraj, K. Ramakrishnan, A. Jai, S. Arunachalam, P.N. Magudeswaran, Investigation of physico-chemical and biological characteristics of various lake water in coimbatore district, Tamilnadu, India, Orient. J. Chem. 32 (4) (2016) 2087–2094.
[16] D.M. Joshi, A. Kumar, N. Agrawal, Assessment of the irrigation water quality of river Ganga in Haridwar District, Rasayan J. Chem. 2 (2) (2009) 285–292.
[17] K. Jothivenkatachalam, A. Nithya, M.S. Chandra, Correlation analysis of drinking water quality in and around Perurblock of Coimbatore district, Tamil Nadu, India, Rasayan J. Chem. 3 (4) (2010) 649–654.
[18] S. Kalaivani, K. Ramesh, Groundwater quality assessment using WQI in South Coimbatore district, Tamil Nadu, India, Int. J. Chem. Tech. Res. 7 (1) (2015) 316–322.
[19] N.S. Magesh, S. Krishnakumar, N. Chandrasekar, J.P. Soundranayagam, Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India, Arab J. Geosci. (2012). http://dx.doi.org/10.1007/s12517-012-0673-8.
[20] P.N. Magudeswaran, T. Ramachandran, Ground water quality in Coimbatore, Tamilnadu Noyal River Environ. Pollut. Control J. 8 (6) (2005) 40–44.
[21] M.A. Massoud, M. El-Fadel, M.D. Scrimshaw, J.N. Lester, Factors influencing development of management strategies for the Abou Ali River in Lebanon I: spatial variation and land use, Sci. Total Environ. 362 (2006) 15–30.
[22] Z. Mehdi, S. Fuzieh, R. Ezzat, Hydrogeochemical characterization of major factors affecting the quality of groundwater in southern Iran, Janah Plain, Chem. der Erde 74 (2014) 671–680.

[23] S. Mohamad, F. Arzaneh, J.P. Mohamad, Quality of groundwater in an area with intensive agricultural activity, Expo. Health 8 (2016) 93–105.
[24] R. Mohan, A.K. Singh, J.K. Tripathi, G.C. Chowdhary, Hydrochemistry and quality assessment of groundwater in Naini industrial area, Allahabad district, Uttar Pradesh, J. Geol. Soc. India 55 (2000) 77–89.
[25] P.K. Mohapatra, R. Vijay, P.R. Pujari, S.K. Sundaray, B.P. Mohanty, Determination of processes affecting groundwater quality in the coastal aquifer beneath Puri city, India; a multivariate statistical approach, Water Sci. Technol. (2011). http://dx.doi.org/10.2166/wst.2011.605.
[26] N.C. Mondal, V.P. Singh, Chloride migration in groundwater for a tannery belt in Southern India, Environ. Monit. Assess. 184 (2012) 2857–2879.
[27] N.C. Mondal, V.S. Singh, R. Rangarajan, Aquifer characteristics and its modeling around an industrial complex, Tuticorin, Tamil Nadu, India: a case study, J. Earth Syst. Sci. 118 (3) (2009) 231–244.
[28] T. Nasrabadi, P. Abbasi, Groundwater quality assessment in southern parts of Tehran plain, Iran. Environ. Earth Sci. 71 (2014) 2077–2086.
[29] J.D. Oster, Irrigation with poor quality water, Agric. Water Mgmt 25 (3) (1994) 271–297.
[30] K.V. Paliwal, Irrigation with saline water (new series)Monogram, IARI, New Delhi, 1972, p. 198.
[31] A.M. Piper, A graphic procedure in geochemical interpretation of water analysis, Trans. Am. Geophys. Union 25 (6) (1944) 914–928.
[32] K.L. Priya, J. Nalini, A.G. Prince, Groundwater quality in the Singanallur sub-basin of Coimbatore city, Jr. Ind. Pollut. Control 27 (1) (2011) 15–18.
[33] R. Rajesh, K. Brindha, R. Murugan, L. Elango, Influence of hydrogeochemical processes on temporal changes in groundwater quality in a part of Nalgonda district, Andhra Pradesh, India, Environ. Earth Sci. 65 (2012) 1203–1213.
[34] P.J. Sajilkumar, Evolution of groundwater chemistry in and around Vaniyambadi industrial area: Differentiating the natural and anthropogenic sources of contamination, Chem. derErde74 2014 (2014) 641–651.
[35] P.J. Sajilkumar, E.J. James, Identification of hydrogeochemical processes in Coimbatore district, Tamil Nadu, India, Hydrol. Sci. J. 61 (4) (2016) 719–731. http://dx.doi.org/10.1080/02626667.2015.1022551.
[36] Y.R. Satyaji Rao, A.K. Keshari, A.K. Gosain, Evaluation of regional groundwater quality using PCA and geostatistics in the urban coastal aquifer, East coast of India, Int. J. Environ. Waste Manag. 5 (2010) (Nos. ½).
[37] S. Selvakumar, K. Ramkumar, N. Chandrasekar, N.S. Magesh, S. Kaliraj, Groundwater quality and its suitability for drinking and irrigational use in the southern Tiruchirappalli district, Tamil Nadu, India, Appl Water Sci. (2015). http://dx.doi.org/10.1007/s 13201-014-0256-9.
[38] S. Selvam, Irrigational feasibility of groundwater and evaluation of hydrochemistry facies in the SIPCOT industrial area, South Tamil Nadu, India: a GIS approach, Water Qual. Expo. Health 7 (2015) 265–284.
[39] M.K. Sharma, C.K. Jain, O. Singh, Characterization of point sources and water qualitiy assessement of River Hindon using water quality index, J. Indian Water Resour. Soc. 34 (1) (2014) 33–39.
[40] K. Singh, A. Malik, S. Sinha, Water quality assessment and apportionment of pollution sources of Gomati river (India) using multivariate statistical techniques- a case study, Anal. Chim. Acta 538 (2005) 355–374.
[41] K. Srinivasamoorthy, S. Chidambaram, M.V. Prasanna, Identification of major sources controlling groundwater chemistry from a hard rock terrain: a case study from Mettur taluk, Salem district, Tamilnadu, India, J. Earth Syst. Sci. 117 (1) (2008) 49–58.
[42] K. Srinivasamoorthy, S. Chidambaram, M. Vasanthavigar, Application of multivariate statistical techniques in elucidation of hydrogeochemical data: a case study, Int. J. Ecol. Environ. Stat. 14 (S09) (2009) 98–109.
[43] N. SubbaRao, P. SuryaRao, R.G. Venktram, M. Nagamani, G. Vidyasagar, N.L.V. Satyanarayana, Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River basin,Visakhapatnam District, Andhra Pradesh, India, Environ. Monit. Assess. 184 (2012) 5189–5214.
[44] X. Sue, H. Wang, Y. Zhang, Health risk assessment of nitrate contamination in groundwater: a case study of an agricultural area in northeast China, Water Resour. Manag 27 (2013) 3025–3034.
[45] A. Thangavelu, Mapping the groundwater quality in Coimbatore city, India based on physico-chemical parameters, J. Env. Sci., Taxi, Food sec 3 (4) (2013) 32–40.
[46] V.S. Uday, A. Amar, P.S. Kunwar, & D. Ratnakar, P.S. Netra, Groundwater quality appraisal and its hydrochemical characterization in Ghaziabad (a region of indo-gangetic plain), Utta Pradesh, India, Appl Water Sci. 4 (2014) 145–157.
[47] USSL, Diagnosis and improvement of salinity and alkaline soil. in: USDA Hand Book No. 60. Washington, 1954.
[48] L.V. Wilcox, Classification and Use of Irrigation Waters (Arc 969), US Department of Agriculture, Washington DC, 1955.
[49] World Health Organization. (WHO), Guidelines for Drinking Water Quality, Recommendation, Geneva, 2012, pp. 1–6.
[50] O. Ying, E.Z. Jia, C. Lihua, Estimating impacts of land use on groundwater quality using trilinear analysis, Environ. Monit. Assess. 186 (2014) 5353–5362.