Article

Assessment of impact on the groundwater quality due to urbanization by hydrogeochemical facies analysis in SE part of Pune city, India

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Abstract

The groundwater from the south-eastern part of Pune city has been assessed for the seasonal variation in their quality parameters. Using Piper diagram the hydrogeochemical facies were identified and the groundwaters were classified with regards to the changes in their major chemical compositions. Based on the hydrogeochemical facies it has been found that the groundwater regime is severly deteriorated by the anthropogernic activities. Although the area of Manjari, Hadapsar and uruli Devachi show high influx of pollutants in rainy season the Mantarwadi and Fursungi area have strong influence of leachate throughout the year.

Keywords groundwater; hydrogeochemical facies; Piper diagram; pollution.

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1 Introduction

Dissolved major elements in the water generally express the intensity of water-rock interactions in the area as they play important role in the study of chemical weathering rates (Meybeck, 2003). Although several sources contribute to the dissolved contents of groundwater the major elements released via various sources are used as proxies for weathering rates for which the identification of their different origins is required (Drever, 2005). Since the factors controlling the chemical composition of water have been primarily related to the composition of the soils and rocks, studies comprehending the hydrogeochemical processes operating in the given geological and geochemical regimes were initiated by many workers (Drever, 1982; Velbel, 1985; Schott and Berner, 1985; Katz and Choquette, 1991; Pawar, 1993; Drever and Clow, 1995). Although the dissolved constituents in groundwater are primarily controlled by the original chemical characters and temperature of the water entering the zone of saturation; the distribution, solubility and exchange capacity of minerals in the rock; the porosity and permeability of the aquifer and the flow path ways of the water (Back and Hanshaw, 1965; Freeze and Cherry, 1979; Appelo and Postma, 1996; Mazor, 1997 etc.) the geological formations, water-rock interactions and relative mobility of ions are the prime factors determining the geochemistry of groundwater (Yousef, et al. 2009). Apart from the natural geological and geochemical sources like addition of salts via precipitation and water rock interactions, the human activities (point and non point pollution sources) alter significantly the groundwater quality (Subramanian, 1987) and large varieties of inorganic constituents are seen dissolved in the groundwater. In present study, the groundwater from the south-eastern part of Pune city has been assessed for the seasonal variation in their quality parameters.

2 Materials and Methods

2.1 Study area

Pune, the seventh largest city in India by population, covering approximately 243.84 km^2 area, lies between latitudes $18^0$22'N & $18^0$35' N and longitudes $73^0$50'E & 74^0E (Fig. 1) with an average altitude of 559m above the mean sea level. The solid waste disposal site (20km SE of Pune) is a non-engineered open dump looking like a huge heap of waste up to a height of 20m located about 20km SE of Pune on the eastern slopes of a small topographic high. The study area (Fig. 2) includes five localities viz. Manjari, Hadapsar, Fursungi, Mantarwadi and Uruli-Devachi (between latitudes $18^0$27'N & $18^0$32'N and longitudes $73^0$55'E & 74^0E). In most of these localities, except Hadapsar, groundwater is mainly used for drinking and irrigation purposes. The analyses of water samples at fifty one (51) sampling stations (from June 2007 to May 2008) was carried out for thirty seven (37) physicochemical and biological parameters to assess the present status of groundwater quality in eastern part of Pune metropolis.

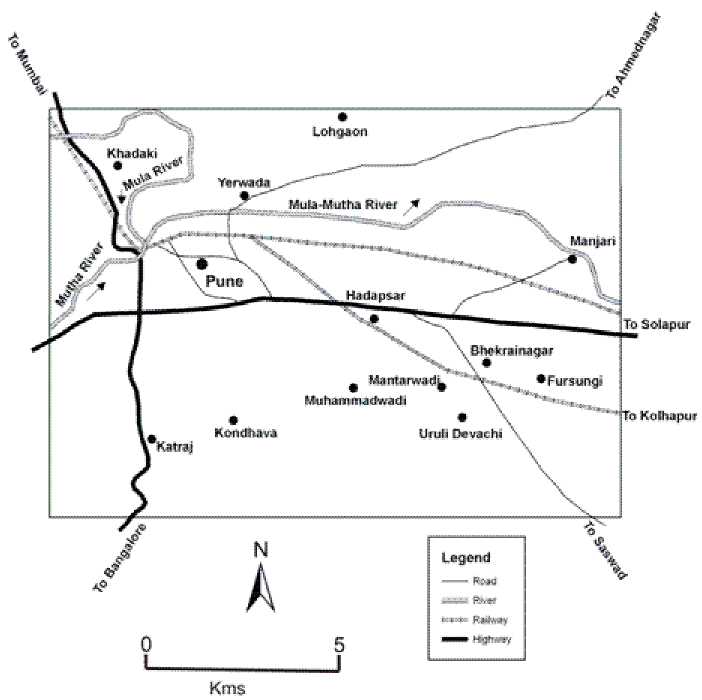

Fig. 1 Location map of Pune.

The groundwater samples were collected from five localities viz. Manjari, Hadapsar, Fursungi, Mantarwadi and Uruli Devachi in three consecutive seasons i.e. rainy season (August 2007), winter season (December 2007) and summer season (April 2008). The water samples were collected in 2-liter air tight polythene canes which were washed thoroughly with the water to be analyzed and were brought to the laboratory for the determination of various water quality parameters. The parameters like color, temperature, pH, electrical conductivity, total dissolved solids (TDS) were determined in the field itself by using electronic soil-water analysis kit. The parameters like salinity, alkalinity (TA), acidity, free carbon dioxide (free CO_2), hydrogen sulphide (H_2S), ammonical nitrogen (NH_4-N), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), carbonate (CO_3^{--}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{--}), nitrate (NO_3^-), phosphate (PO_4^{---}), calcium (Ca^{++}), magnesium (Mg^{++}) , sodium (Na^+), potassium (K^+), hardness, iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), lead (Pb), boron (B), most probable number (MPN) and E-coli were determined in the laboratory by using the standard methods (APHA, 1998). Earlier study by Sayyed and Wagh (2011) suggested that most of the abstracted groundwater samples from this study area were suitable for irrigation except from Uruli Devachi area.

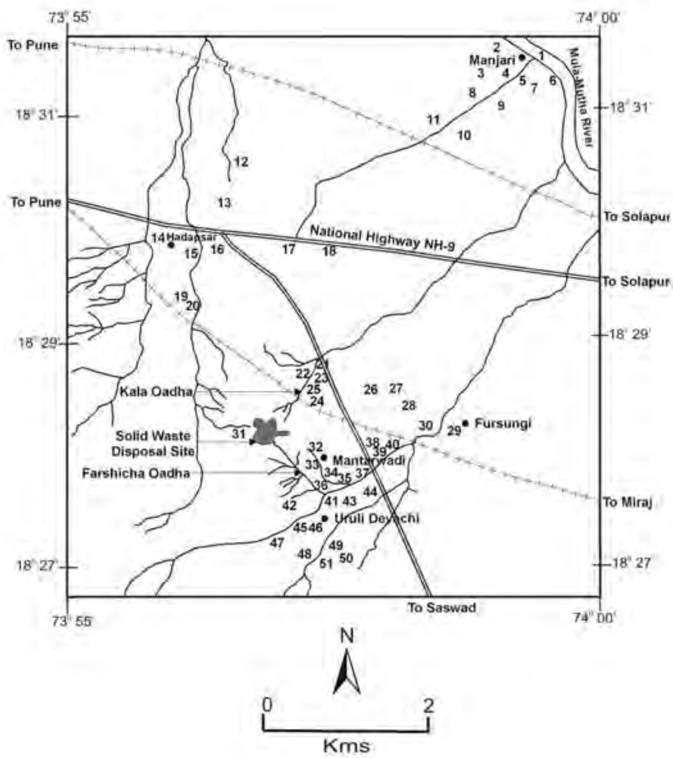

Fig. 2 Sampling location map.

2.2 Hydrogeochemistry of Deccan basaltic aquifers

Geochemistry of basaltic groundwater is chiefly influenced by silicate mineral weathering processes which include chemical alteration of pyroxenes (augite), feldspars (labradorite plagioclase) and other primary minerals (like olivine) to clays, aluminium and iron oxides, amorphous or crystalline silica, carbonates and zeolites, which release variety of ions in solutions. Evaporative enrichment of recharging waters, oxidation and ion-exchange reactions and the uptake of ions from, and decomposition of, organic matter, are processes that have a minor influence on the composition of the basalt groundwater. Petrographically Deccan basalts are chiefly composed of labradorite and augite with subordinate quantities of olivine. The mole ratios of different cations and anions in the parent basalt depend on the anorthite content of the plagioclase (Garrels and Christ, 1965) as plagioclase forms a solid solution between anorthite ($CaAl_2Si_2O_8$) and albite ($NaAlSi_3O_8$). The chemical reaction for plagioclase with 50% anorthite content is given as:

$4Ca_{0.5}Na_{0.5}Al_2Si_2O_8(s)+6H_2O+9CO_2 = 3Al_2Si_2(OH)_4(s)+2Na+2Ca+6HCO_3+4SiO_2$ (1)

(mNa/mCa = 1:1) Labradorite ($mHCO_3/mSiO_2$ = 3 : 2)

Thus the groundwater would acquire Ca^{++}, Na^+ and HCO_3^- in appropriate proportions (Naik et al., 2008) due to natural water–rock interactions, if not contaminated (Reaction 1).

$CaMgFeAl_2Si_3O_{12}(s)+5H_2O+6CO_2 = Al_2Si_2(OH)_4(s)+Ca+Mg+Fe+6HCO_3+SiO_2$ (2)

(mCa/mMg = 1:1) Augite ($mHCO3/mSiO_2$ = 6:1)

Further the release of Ca^{++}, Mg^{++} and HCO_3^- ions is governed by the interaction of groundwater with augite (Reaction 2). These two reactions suggest that plagioclase and augite are the chief sources which supply the major cations (Ca^{++}, Mg^{++} and Na^+) and anions (HCO_3^-) in groundwater from basaltic aquifer (Naik et al., 2008). For other constituents, such as $SO_4^{--}$and Cl^-, rainwater and anthropogenic activities can be important sources (Pawar et al., 1998) including Ca^{++}, Mg^{++} and Na^+.

2.3 Piper diagram

Different graphical and statistical techniques have been developed to describe the concentrations or relative abundances of major and minor constituents and the pattern of variability in the different water samples. Piper diagram (Piper, 1944) has been traditionally and most commonly used to classify the water and waste-water into different water types based upon the anion and cation concentrations in the form of major ion percentage. Piper diagram not only graphically represents the nature of a given water sample, but also correlates its relationship to other samples in order identify lithogenic and anthropogenic contributions to the water and assist in commenting upon the evolution of water chemistry along the flow path.

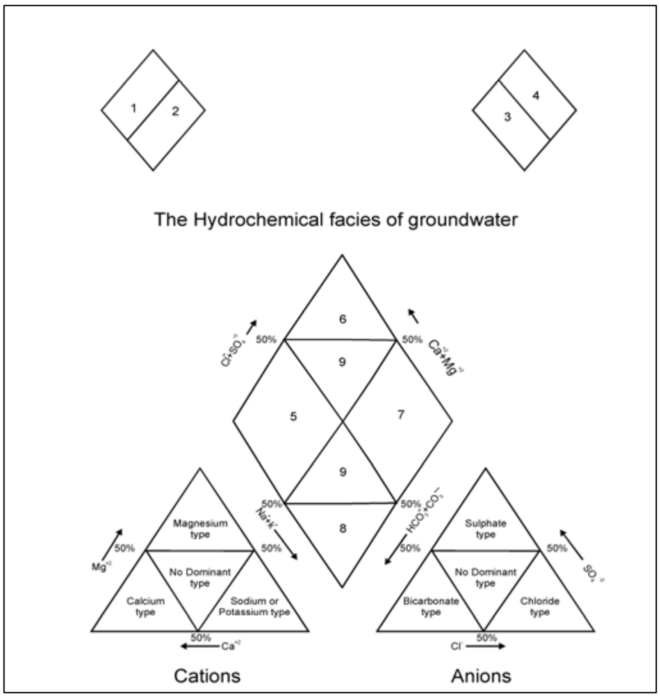

Fig. 3 Classification diagram for anion and cation facies in the form of major-ion percentages. Water types are designated according to the domain in which they occur on the diagram segments.

To construct the Piper diagram, the relative abundance of cations with the % meq/l of Na^++K^+, Ca^{++}, and Mg^{++} is first plotted on the cation triangle. The relative abundance of Cl^-, SO_4^{--} and $HCO_3^-+CO_3^{--}$ is then plotted on the anion triangle. The two data points on the cation and anion triangles are then combined into the quadrilateral field (diamond shaped) that shows the overall chemical property of the water sample (Fig. 3) from which inferences can be drawn on the basis of hydro-geochemical concept. Piper plots are more useful in bringing out the chemical relationships amongst groundwater samples in more definite terms rather than with other possible plotting methods.

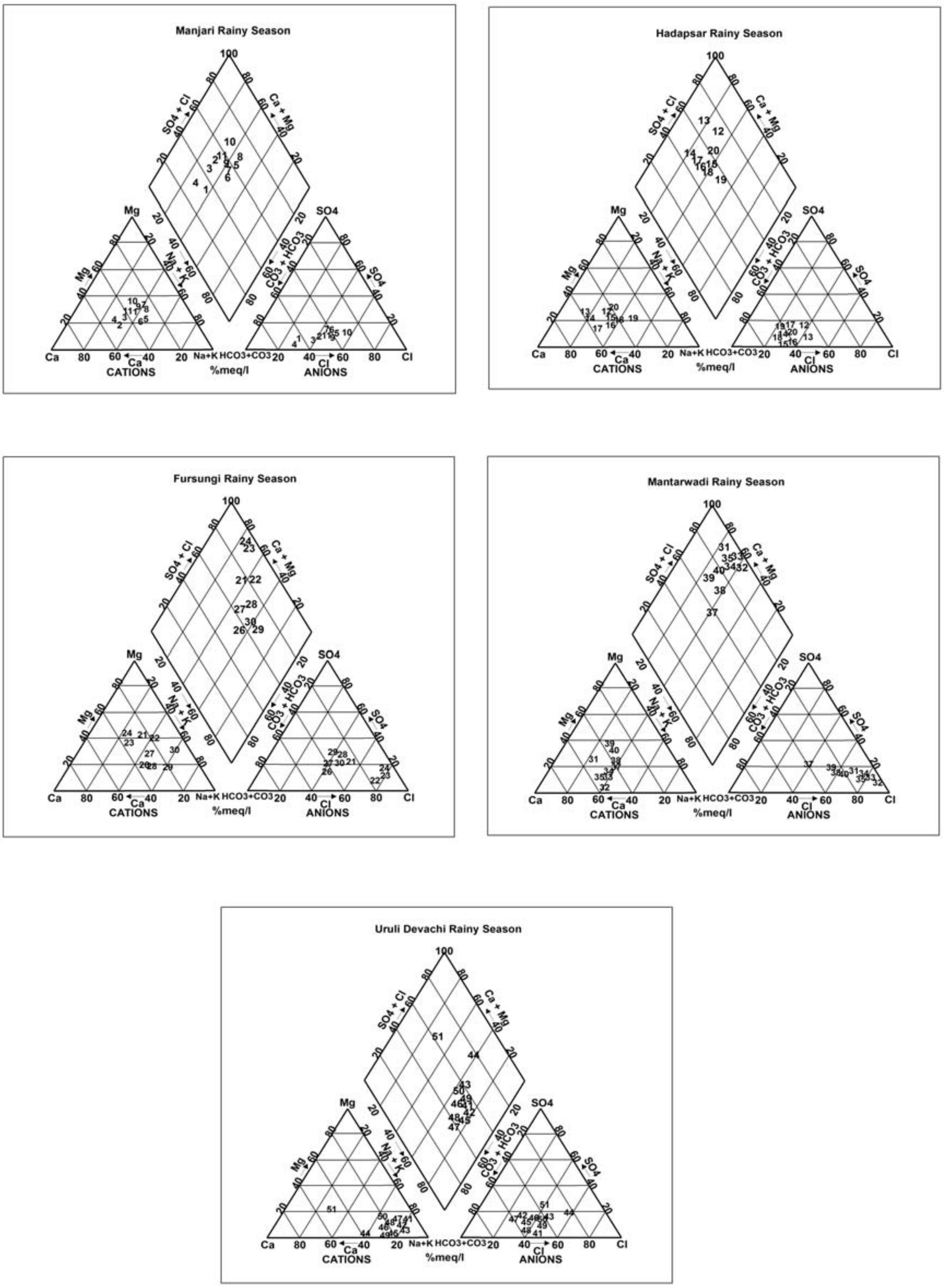

Fig. 4 Piper diagrams showing the major chemical composition of the groundwater in rainy season.

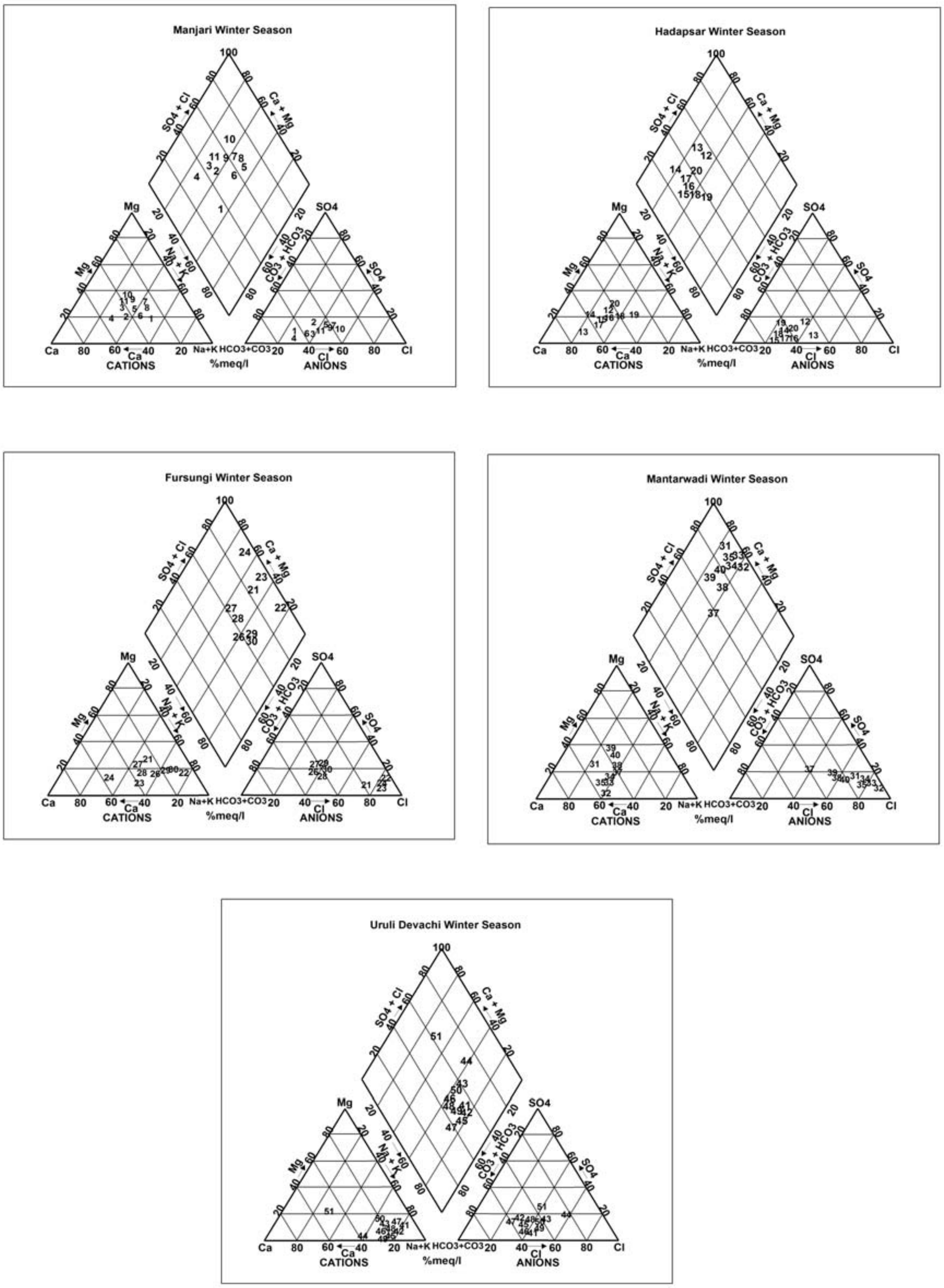

Fig. 5 Piper diagrams showing the major chemical composition of the groundwater in winter season.

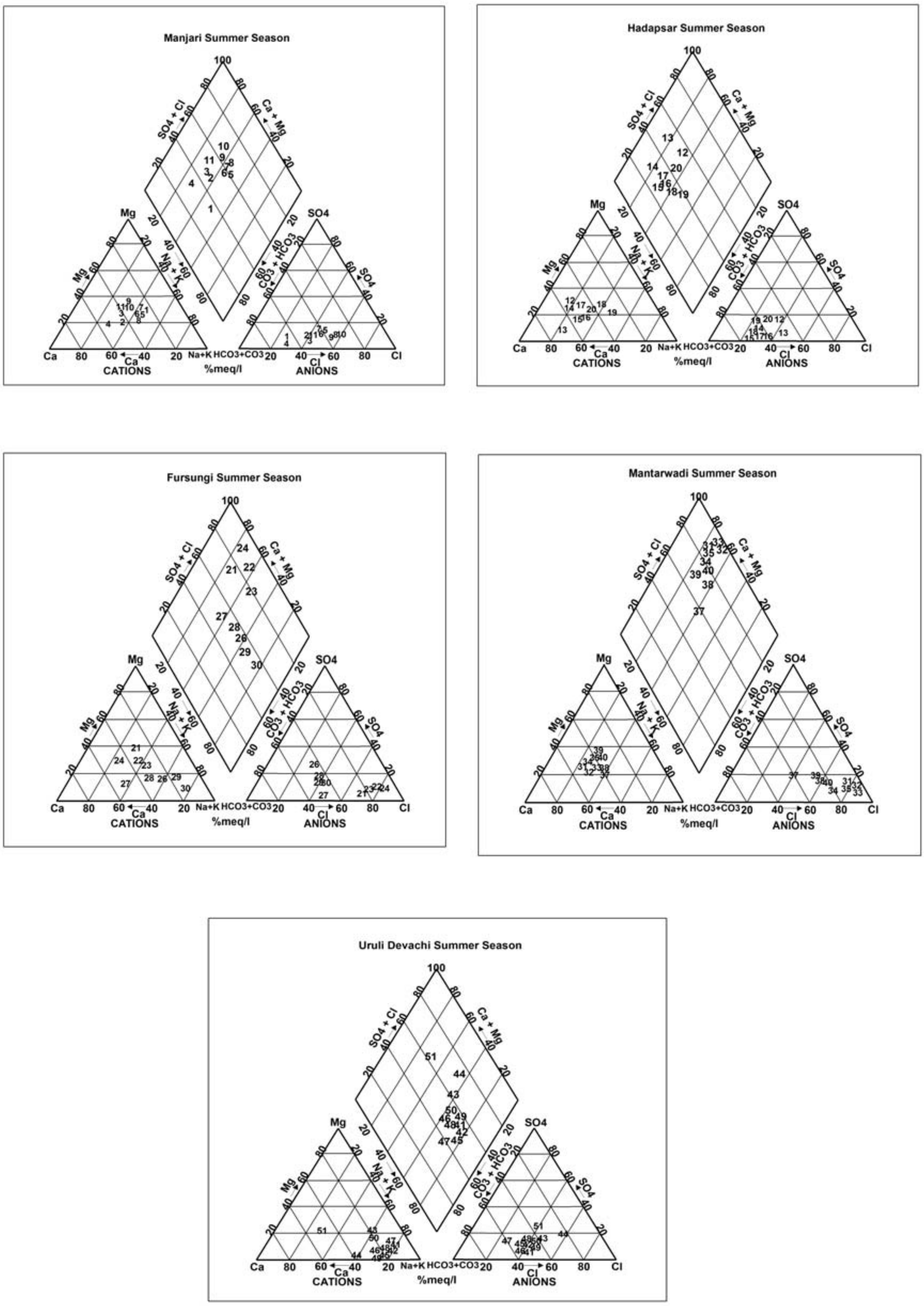

Fig. 6 Piper diagrams showing the major chemical composition of the groundwater in summer season.

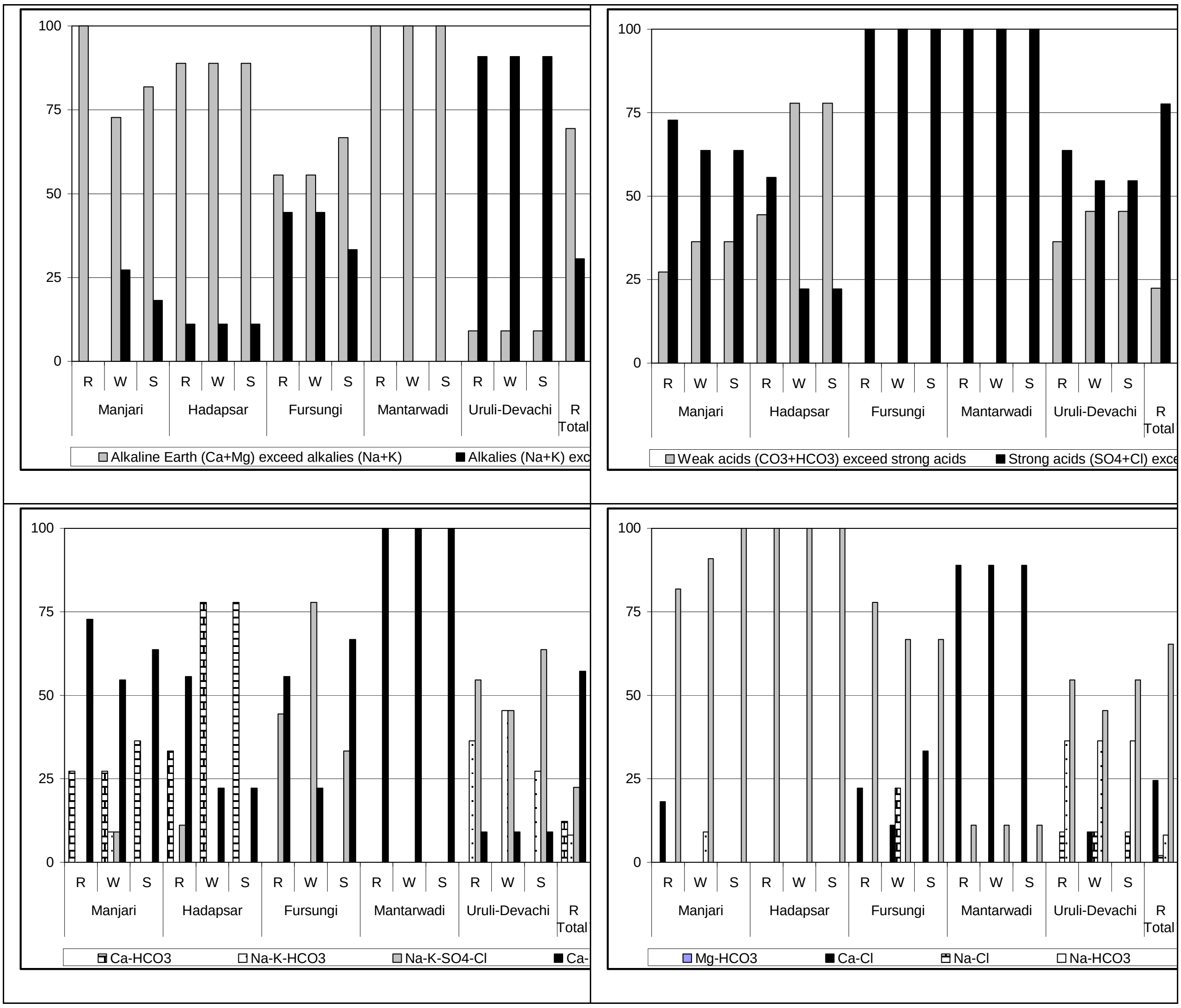

Fig. 7 Classification of hydrogeochemical facies of the groundwater from the different villages in three seasons.

3 Results

The concentrations of chemical constituents of the groundwater samples are plotted on Piper diagram (Figs. 4-6). From the figures the groundwater types were deduced (Table 1) and the percentages of the samples having a particular groundwater types have been calculated (Table 2) which were then plotted graphically to compare the water types spatially and seasonally (Fig. 7) to infer hydro-geochemical facies (Ophori and Toth, 1989; Hem, 1985). It can be found that except Uruli-Devachi the groundwaters from rest of the study area are dominantly of (Ca+Mg) type irrespective of the seasons. Such (Ca+Mg) waters show permanent hardness and do not have bicarbonate hazard for irrigation (Romani, 1981). The Uruli-Devachi area is conspicuous by the presence of (Na+K) type of water and such water has temporary hardness and residual sodium carbonate (Romani, 1981). In terms of the weak acids/strong acids the Hadapsar area shows the presence of groundwater of dominantly weak acid type while rest of the area shows dominantly strong acids, indicating the higher degree of anthropogenic pollution. The areas like Manjari, Fursungi and Mantarwadi have more Ca-Mg-Cl-SO_4 type of water while Uruli-Devachi shows more dominance of Na-K-SO_4-Cl type associated with increased concentrations of chloride and sodium which could be due to evaporation with less prominent recharge; and

Hadapsar area with Ca-HCO_3 type likely because of rainfall recharge processes associated with low EC values. This clearly indicates that the Hadapsar area has very less impact of anthropogenic pollution while rest of the area has considerable impact of anthropogenic activity, although the anthropogenic input in terms of the chemical constituents vary considerably. Further only Mantarwadi area has a groundwater chiefly of Ca - Cl type throughout the year indicating the constant influx of the leachate (as the well waters consistently show reddish brown colour throughout the year) to the water- wells. Rest of the area show mixed type of water from the same basaltic aquifer indicating that quality of shallow groundwater is possibly affected by several factors (Custodio, 1997; Gooddy et al., 1997: Trauth and Xanthopoulus, 1997) which transform the groundwater chemically.

Table 1 Classification of wells based on the water types determined from Piper diagrams.

Ground water type	Manjari			Hadapsar			Fursungi			Mantarwadi			Uruli-Devachi			Rainy Total	Winter Total	Summer Total	Grand Total
	R	W	S	R	W	S	R	W	S	R	W	S	R	W	S				
Alkaline Earth (Ca+Mg) exceed alkalies (Na+K)	11	8	9	8	8	8	5	5	6	9	9	9	1	1	1	34	31	33	98
Alkalies (Na+K) exceed (Ca+Mg)	0	3	2	1	1	1	4	4	3	0	0	0	10	10	10	15	18	16	49
Total	11	11	11	9	9	9	9	9	9	9	9	9	11	11	11	49	49	49	147
Weak acids (CO3+HCO3) exceed strong acids	3	4	4	4	7	7	0	0	0	0	0	0	4	5	5	11	16	16	43
Strong acids (SO4+Cl) exceed weak acids	8	7	7	5	2	2	9	9	9	9	9	9	7	6	6	38	33	33	104
Total	**11**	**11**	**11**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**11**	**11**	**11**	**49**	**49**	**49**	**147**
Ca-HCO3	3	3	4	3	7	7	0	0	0	0	0	0	0	0	0	6	10	11	27
Na-K-HCO3	0	1	0	0	0	0	0	0	0	0	0	0	4	5	3	4	6	3	13
Na-K-SO4-Cl	0	1	0	1	0	0	4	7	3	0	0	0	6	5	7	11	13	10	34
Ca-Mg-Cl-SO4	8	6	7	5	2	2	5	2	6	9	9	9	1	1	1	28	20	25	73
Total	**11**	**11**	**11**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**11**	**11**	**11**	**49**	**49**	**49**	**147**
Mg-HCO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca-Cl	2	0	0	0	0	0	2	1	3	8	8	8	0	1	0	12	10	11	33
Na-Cl	0	0	0	0	0	0	0	2	0	0	0	0	1	1	1	1	3	1	5
Na-HCO3	0	1	0	0	0	0	0	0	0	0	0	0	4	4	4	4	5	4	13
Mixed	9	10	11	9	9	9	7	6	6	1	1	1	6	5	6	32	31	33	96
Total	**11**	**11**	**11**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**11**	**11**	**11**	**49**	**49**	**49**	**147**

Table 2 Percentages of the wells having different water types based on the water types determined from Piper diagrams.

Ground water type	Manjari			Hadapsar			Fursungi			Mantarwadi			Uruli-Devachi			Rainy Total	Winter Total	Summer Total	Grand Total
	R	W	S	R	W	S	R	W	S	R	W	S	R	W	S				
Alkaline Earth (Ca+Mg) exceed alkalies (Na+K)	100	73	82	89	89	89	56	56	67	100	100	100	9	9	9	69	63	67	67
Alkalies (Na+K) exceed (Ca+Mg)	0	27	18	11	11	11	44	44	33	0	0	0	91	91	91	31	37	33	33
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Weak acids (CO3+HCO3) exceed strong acids	27	36	36	44	78	78	0	0	0	0	0	0	36	45	45	22	33	33	29
Strong acids (SO4+Cl) exceed weak acids	73	64	64	56	22	22	100	100	100	100	100	100	64	55	55	78	67	67	71
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Ca-HCO3	27	27	36	33	78	78	0	0	0	0	0	0	0	0	0	12	20	22	18
Na-K-HCO3	0	9	0	0	0	0	0	0	0	0	0	0	36	45	27	8	12	6	9
Na-K-SO4-Cl	0	9	0	11	0	0	44	78	33	0	0	0	55	45	64	22	27	20	23
Ca-Mg-Cl-SO4	73	55	64	56	22	22	56	22	67	100	100	100	9	9	9	57	41	51	50
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Mg-HCO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca-Cl	18	0	0	0	0	0	22	11	33	89	89	89	0	9	0	24	20	22	22
Na-Cl	0	0	0	0	0	0	0	22	0	0	0	0	9	9	9	2	6	2	3
Na-HCO3	0	9	0	0	0	0	0	0	0	0	0	0	36	36	36	8	10	8	9
Mixed	82	91	100	100	100	100	78	67	67	11	11	11	55	45	55	65	63	67	65
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

When seasonal changes of the water type in different localities are studied some interesting facts have been revealed as there is distinct zoning of the area of study with regards to the changes in the major chemical compositions of their groundwater. In Manjari area the water is almost (Ca+Mg) type in rainy season but during winter and summer few wells show (Na+K) water type, but in Hadapsar area there is no change in the (Ca+Mg) type wells and (Na+K) type wells indicating the source of these ions to be natural. In Fursungi area although most of the wells show (Ca+Mg) type of water their percentage increase in summer clearly suggesting the recharge of water from other sources. All the wells from Mantarwadi area have (Ca+Mg) type which does not change throughout the year while those from Uruli-Devachi have mostly (about 90%) (Na+K) type which also indicate that these two areas have perennial source of contamination. As far as the contents of acids in the water are concerned the Manjari, Hadapsar and Uruli-Devachi areas show consistent decrease in the strong acid components from rainy to summer indicating the high influx of SO_4 and Cl anions to the groundwater in the rainy season while carbonate and bicarbonate addition during winter and summer by weathering of basaltic aquifer. The predominance of strong acids (SO_4 and Cl) in the wells from Fursungi and Mantarwadi areas suggest insignificant addition of carbonate and bicarbonate and there is strong influence of the leachate emerging from the waste disposal site.

4 Conclusions

With the help of Piper diagram a distinct zoning could be established with regard to the changes in major chemical compositions of their groundwaters. Manjari, Hadapsar and Uruli-Devachi areas have high influx of SO_4 and Cl to the groundwater in rainy season while in summer weathering of basaltic aquifer lead to increased concentration of carbonate and bicarbonates. The predominance of SO_4 and Cl in the wells of Fursungi and Mantarwadi areas suggest a strong influence of leachate emerging out of the solid waste disposal site. .

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