Original Article

Bulletin of Pure and Applied Sciences.
Vol.37 F (Geology), No.1, 2018: P.18-37
Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI 10.5958/2320-3234.2018.00002.1

HYDROGEOCHEMICAL CHARACTERIZATION OF GROUNDWATER FROM GP-8 (GODAVARI-PURNA 8) WATERSHED, MAHARASHTRA (INDIA): A GIS APPROACH

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(Received on 08.02.2018, **Accepted on** 27.02.2018)

ABSTRACT

A comprehensive assessment on groundwater quality was carried out in GP-8 (Godavari-Purna 8) watershed, Maharashtra (India) to provide valuable information on current groundwater quality. Physicochemical parameters monitored seasonally (i.e. pre and post monsoon) in 2012, 2013 and 2014 were considered. Monitored parameters were compared with quality criteria for drinking water standards of India. Groundwater quality was also assessed for irrigation purpose. The average concentration of Ca^{++}, Mg^{++} and NO_3^- are exceeded the permissible limit. The concentrations of other contaminants are well below the permissible limits. The groundwater is suitable for irrigation in terms of alkalinity, but is unsuitable for irrigation from the salinity point of view. Spatial distribution maps of various water quality constituents were prepared by interpolation using of Arc-GIS software. Distribution of various constituents in water samples from the study area indicate that TDS, total hardness, calcium, magnesium, chloride and nitrate ions beyond the maximum permissible limit. Accelerating the artificial recharge of rain water in to the groundwater is an important way of reducing contaminant concentrations. This study is important in providing comprehensive information on groundwater quality for decision makers.

Keywords: Groundwater, water pollution, health hazards, irrigation quality index, spatial distribution, GP-8 watershed.

1. INTRODUCTION

Groundwater is a very important constituent of our ecosystem and plays significant role in augmenting water supply to meet the ever increasing demand of domestic, agricultural and industrial uses (Li et al. 2015, 2016a; Wu and Sun 2016). It is now generally recognized that the quality of groundwater is important as its quantity. The suitability of natural water for a particular purpose depends upon the standard proposed by the various international bodies such as World Health Organization (WHO, 1971; 1983), Bureau of Indian standard (BIS, 2003). The preservation and improvement of groundwater quality is of vital importance for human well being as well as for the sustainability of clean environment (Li et al. 2017). However, groundwater gets polluted by several anthropogenic and natural factors such as industrial and domestic wastes, artificial recharge by polluted water, pesticides, fertilizers, intrusion of saline water, soluble pollutant such as arsenic and fluoride present in the rock formations (Li et al. 2013). Taking in to consideration of the fact that groundwater occurs in alliance with geological material, generally high concentration of dissolved constituents are found in groundwater than in surface water because of its greater exposure to soluble material of the geological formations (Wu et al. 2015a). Groundwater passing through igneous rock dissolves only a small quantity of mineral matter because of the relative insolubility of the rock composition (Todd, 1980). The characteristics of groundwater as to whether hard or soft mineralized depend upon on the extent of reaction it made with country rock (Edmunds, 1994). Compared to surface water, the groundwater moves very slowly through the pore spaces found in the surrounding country rocks Thus it gets more residence time and hence more ions will be dissolved into groundwater as a result of the interactions between the groundwater and surrounding rocks. In contrast to surface water bodies, if groundwater body is polluted once, it will remain as it is for a considerable time (up-to tens of hundreds of years) because the natural processing flushing is very slow (Li, 2016).

The quality of groundwater is controlled by several factors, Viz., climate, soil characteristics, interactions with the rocks and the human activities on the ground. The natural sources of various ions in water have been given by Hem (1959). There have already been many groundwater quality related literatures published during the past two decades (Wu et al. 2015b; Li et al. 2014a, b, 2016b, c; Golekar et al. 2012, 2013, 2014, 2017 and Kumbhar et al. 2017), which has been helpful in protecting groundwater and remediation of groundwater pollution. Some of the most recent developments in this filed include:

a) Li et al. (2016d) proposed an end member mixing analysis (EMMA) model which integrated hydrochemical characteristics and stable isotopic signatures of groundwater for analyzing surface water-groundwater connection. This study provided an easy and reliable way of determining quantitatively the contributive ratio of river water percolation to river bank groundwater.
b) Based on the background of the Silk Road revival proposed by China (Li et al. 2015, 2017), Howard and Howard (2016) analyzed the potential threats of this project to water resources management in central Asian countries. They pointed out that judicious planning, good science and a commitment between nations are necessary for the success of the project. This study gave insights into groundwater quality management in central Asia in the context of human activities.
c) Wu et al. (2014) introduced an easy and cost-effective approach for soil salinization assessment. In their study, the relationships between recharge water quality, groundwater level and soil salinization were investigated in detail. It is believed that this study will provide an alternative way for soil salinization investigation.

GP-8 (Godavari-Purna 8) watershed is located in Phulambri mega-watershed, Maharashtra (India). This area is rarely investigated from the view point of groundwater hydrogeochemistry. Where have the major ions in groundwater been originated is never studied. The quality of groundwater for drinking and irrigation purposes is neither assessed previously. Therefore, the aims of the present study are (1) to delineate the general characteristics and spatial distributions of major ions in groundwater, (2) to assess the suitability of groundwater for drinking and irrigation purposes, and (3) to analyze the origin of major ions in groundwater of the study area. This study will provide decision makers with insights into local and regional water quality management.

2. MATERIALS AND METHODOLOGY

Study area

The GP-8 (Godavari-Purna 8) watershed was chosen for hydrogeochemical studies, which is located in Phulambri mega-watershed, part of Aurangabad District, Maharashtra (India). The coordinates of study area is North Latitude 20° 00' to 20° 10' and East Longitude 75° 25' to 75°30'. It occupies an area of 227.5 Km^2. The average annual rainfall in this area varies from 500 mm to 840 mm, and temperature varying up to 40°C in summer and 10.3°C in the winter season.

Hydrogeological setting

It is a hard rock terrain, having undulating topography. Though this area receives sufficient rainfall, it experiences water scarcity for domestic, agricultural and industrial purposes. Groundwater flows in unconfined conditions in weathered and fractured layers at shallower depth, but it flows in partially-confined to restricted conditions of basalts and in the joints and fault / fracture zones within compact basalt flows (Kumar et al. 2011). The groundwater in the study area occurs mainly in confined conditions. Generally, 85% of the Maharashtra state is covered by the Deccan Trap basalt showing uneven distribution of groundwater reserves (Fig. 1).

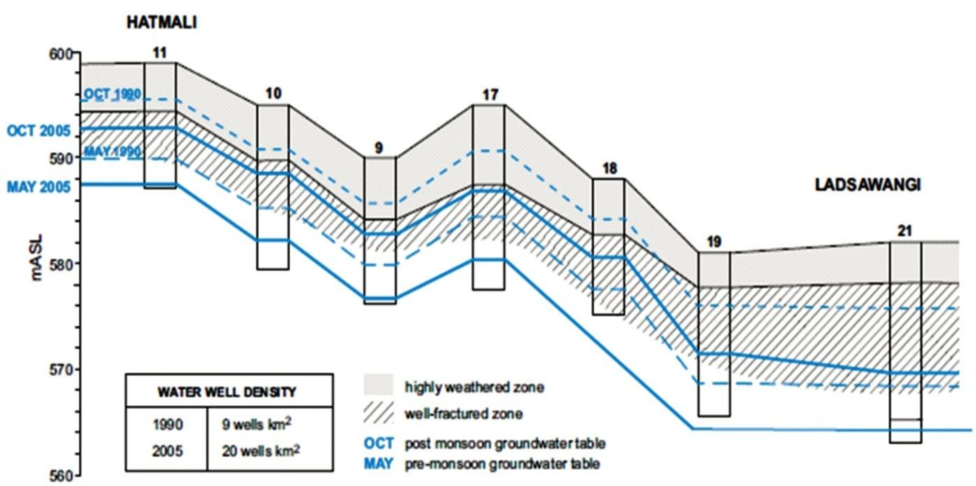


Fig. 1: Variation of groundwater table levels in the main perennially-saturated aquifer of Aurangabad area during 1990 and 2000 (after Foster et al. 2007)

Geological setting

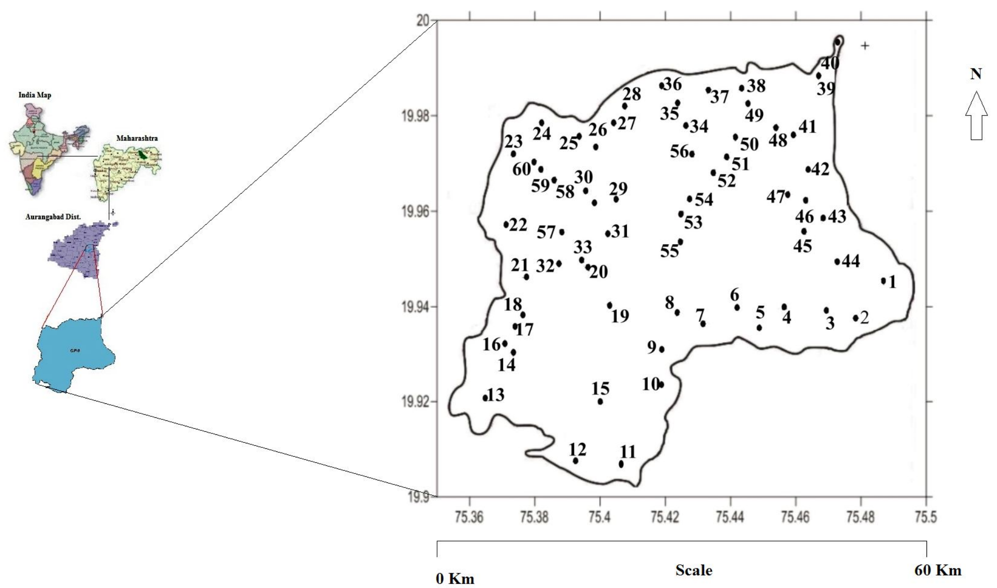
The entire study area is covered by Deccan trap lava flows of upper Cretaceous to lower Eocene age. The chief geological formation occurring in Aurangabad district is basaltic lava flows. On the basis of their lithological characters different flows and flow units have been differentiated such as vesicular, amygdaloidal, porphyritic and compact. These flows are horizontal and each flow has two different units viz. vesicular and amygdaloidal nature is found in the upper unit while compact nature in lower unit. The vesicles are either rounded or irregular in shape and are often filled with secondary minerals such as quartz and zeolites. The bottom of the flow is marked by pipe amygdales capped by a surface comprising the ropy structure. Red bole beds were occurred as lenticular units. These are used as marker horizons in differentiating flows. The Deccan trap lava sequence is grouped under Sahyadri Group, which was formed during the Upper Cretaceous to lower Eocene age. The lava assemblage of Sahyadri group consisting of alternate sequence of Pahoehoe and 'aa' flows (G. S. I. 1976 and Golekar et al. 2013). The Sahyadri Group is further divided into Ajanta and Upper Ratangarh formations (G. S. I., 1976). Ajanta formation comprises eleven 'aa' flows, five compound Pahoehoe flows and Megacryst lava flows. Ratangarh formation constituting compound flows of phyric and feldspar phyric type separated from the lower Salher formation by giant phenocryst basalt, which is also known as Megacryst horizon.

Sample collection and analysis

Groundwater samples have been collect from 60 dug wells in the GP-8 watershed during pre monsoon and post monsoon, continuously for 3 years (Figure 2). Groundwater samples were collected in pre cleaned plastic polyethylene bottles. Prior to sample collection, the plastic bottles were rinsed two to three times with the respective groundwater sample. The analysis of water samples by adopting standard procedure (APHA 1998). The analysis of groundwater for its quality includes the determination of Electrical Conductivity (EC), Total Dissolved Solids (TDS), Ca^{++}, Mg^{++}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2+} and NO_3^{-}. The methods followed for the determination of various physical and chemical parameters are depicted in Table 1.

Table 1: Methods followed for the determination of various physical and chemical Parameters of groundwater

Sr. no.	Constituents	Equipment and method used	Drinking water standard
1	pH (Hydrogen ions concentration)	pH meter	6.5 -8.5
2	Electrical Conductivity (EC)	Conductivity meter CM 183	1400 µs / cm
3	Total Hardness	Titrimetric	300 mg / L
4	Total dissolved solid (TDS)	TDS meter CRM 183	500 mg / L
5	Calcium (Ca^{++})	Titrimetric	75 mg / L
6	Magnesium(Mg^{++})	Titrimetric Calculation	30 mg / L
7	Sodium (Na^{+})	Flam photometer	200 mg / L
8	Potassium(K^{+})	Flam photometer	10 mg / L
9	Chloride (Cl^{-})	Titrimetric	250 mg / L
10	Nitrate (NO_3^{-})	Spectro photo meter	45 mg / L
11	Sulphate (SO_4^{2-})	Spectro photo meter	200 mg / L



Location map of GP-8 (GODAVARI-PURNA 8) Watershed, Phulambri mega-watershed, Aurangabad District Maharashtra (India)

Fig. 2: Location map of the study area
(Godavari-Purna 8 Watershed, Maharashtra, India)

3. RESULT AND DISCUSSION

The groundwater quality data of pre monsoon 2012, pre monsoon 2013, pre monsoon 2014, post monsoon 2012, post monsoon 2013 and post monsoon 2014 has been used for preparation of spatial distribution of various water quality constituents. Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 indicate spatial variation for pH, EC, TDS, TH, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, NO_3^{-} and SO_4^{2-}, respectively, regarding the study area.

Hydrogeochemical characterization of groundwater

pH

The pH of groundwater sample measures its hydrogen ion concentration and indicates whether the sample is acidic, neutral or basic. The pH of groundwater sample from the study area varied from 6.3-8.5, 6.5-8.5, 6-8.5 (Fig. 3) for pre monsoon season 2012, 2013 and 2014, respectively. In the post monsoon season 2012, 2013, 2014 pH values varies from 6.5-8.5, 6.6-8.5, 6.5-8.5. The acidic nature of the basin is seen at the southwestern areas for both the seasons, whereas the alkaline nature of the basin is noticed in the North eastern and Northwestern part.

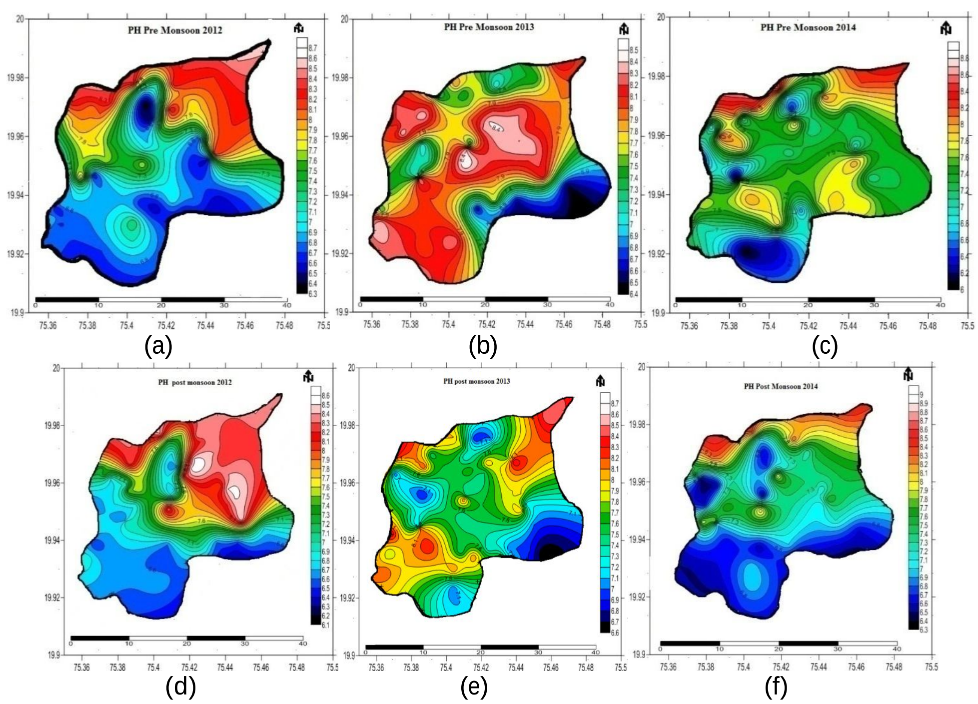


Fig. 3: Spatial variation map of pH in groundwater from the study area

Electrical conductivity (EC)

Electrical Conductivity (EC) of the water is due to the fact that water is an electrolytic solution. Electrical conductivity is directly proportional to the amount of dissolve salts. Electrical conductivity is a measured in micro Siemens/cm (µS/cm). In the present study, EC during pre monsoon 2012, 2013 and 2014 ranges from 399-1768, 441-1996 and 389-1821 µS/cm, respectively. Whereas the post monsoon 2012, 2013 and 2014 it ranges from 325-1687, 256-1450 µS/cm and 300-1770 µS/cm, respectively. The spatial distribution maps of EC reveal that high EC values are recorded at north and northwest region, while lower values are observed at south eastern to south west part in both the seasons (Fig. 4). The high EC values on the Northern part may be due to the addition of some salts from the agricultural practices. The lower EC values observed during the post monsoon than the pre monsoon season is due to the dilution of soluble salts through rainwater.

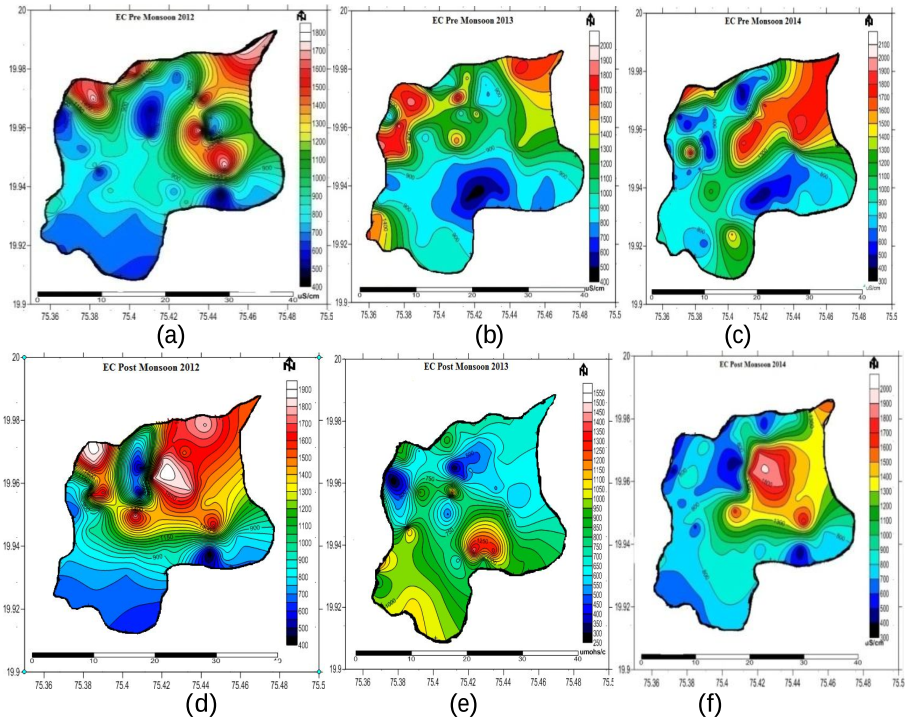


Fig. 4: Spatial variation map of EC in groundwater from the study area

Total dissolved solids (TDS)

In the present study, Total Dissolved Solids (TDS) values of pre monsoon ranges from 259.35-1149.2 mg/L, 286-1297.4 mg/L and 252.85-1183.65 mg/L, whereas in post monsoon it ranges from 211.25-1096.5 mg/L, 166.4-942.5 mg/L and 195-1105.5 mg/L. The spatial distribution maps of TDS reveal that low TDS values are seen at the south-to-south western region while the higher values are seen at North to North eastern part of the basin in both the seasons (Fig. 5).

Total Hardness

Groundwater hardness is defined as the sum of divalent cation in solution but depends largely upon the concentrations of aqueous calcium and magnesium (Taylor and Howard, 1994). Hardness of water is caused by the presence of carbonates and bicarbonates of calcium, magnesium, sulphate, chlorides and nitrates. Hardness is temporary, if it is caused by carbonates and bicarbonates salts of the ions, it can be removed easily by boiling. Permanent hardness is caused mainly by sulphate and chloride of the metals. Water of high hardness is not suitable for household cleaning purpose and it increases the boiling point of water. A low pH of groundwater favors the dissolution of carbonate mineral, which in turn enhances the hardness by dissolving carbonate minerals in the country rock (Todd, 1980). Based on the hardness (Sawyer and McCarty, 1967), water is classified into soft, moderately hard, hard and very hard.

In the present study, the hardness for the pre monsoon 2012, 2013 and 2014 ranges from 600-979 mg/L, 600 to 989 mg/1 and 635-998 mg/L, respectively. In the post monsoon, it ranges from 445 mg/L to 958 mg/L, 526-971 mg/L, 544-973 mg/L of 2012, 2013 and 2014, respectively. From the spatial distribution of hardness of GP-8 watershed (Fig. 6), it is noticed that for both the seasons, the high values are seen at the northern region whereas higher values are seen at eastern part of the basin.

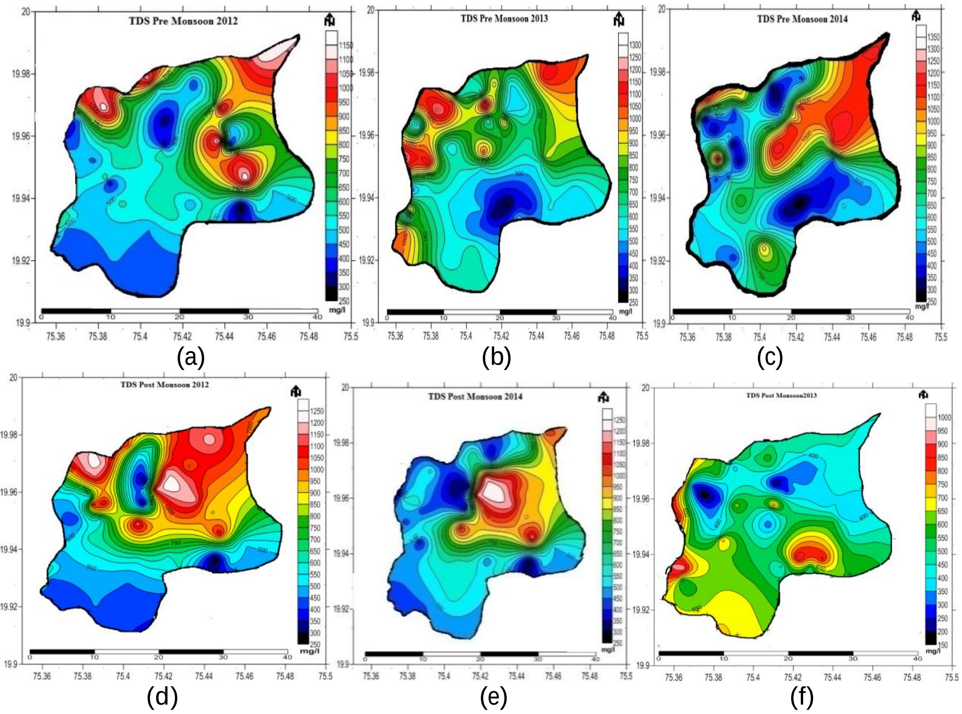


Fig. 5: Spatial distribution mps of TDS in groundwater from the study area

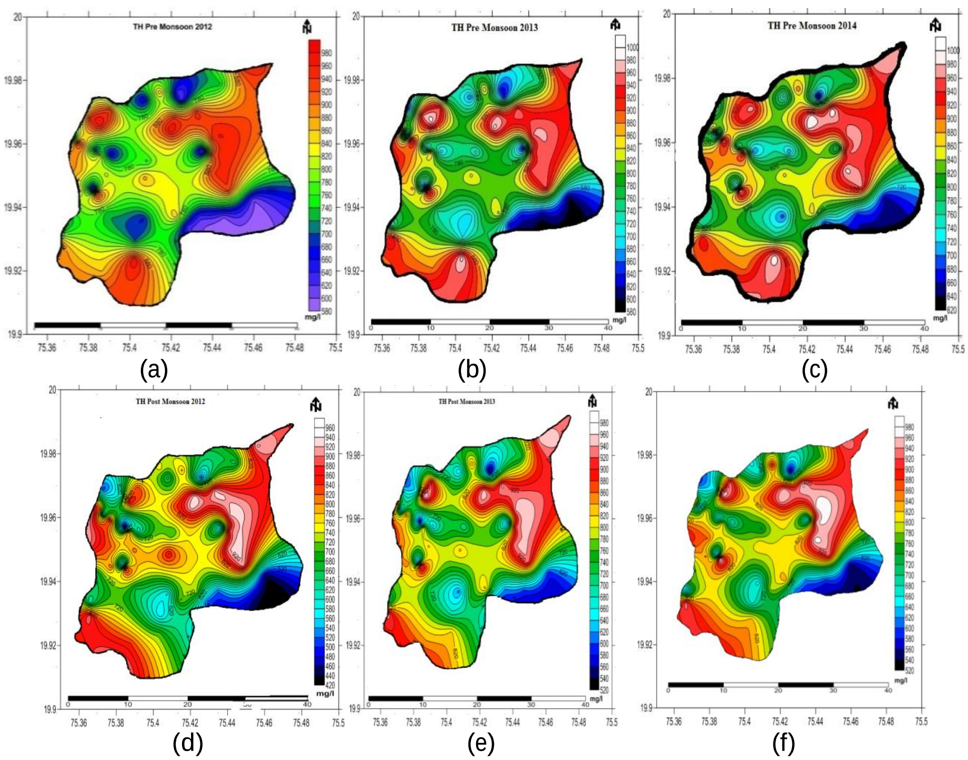


Fig. 6: Spatial distribution map of total hardness in groundwater from the study area

Calcium

Calcium is a major constituent of rocks and soils. The principal sources of calcium in groundwater are silicate minerals like feldspars, pyroxenes and amphiboles among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks. Hardness of water is due to the presence of calcium with magnesium and concentration up to 1800 mg /L and does not impair any physiological reaction in man (Lehr et al. 1980). The low content of Calcium in drinking water causes defective teeth. It is essential for nervous system, cardiac function and in coagulation of blood (Khurshid et al. 1998).

Calcium concentration in the groundwater of GP-8 watershed during pre monsoon 2012, 2013 and 2014 varied from 65-210 mg/L, 75-212 mg/L and 68-189 mg/L, respectively. The average value of Ca in pre monsoon is 96.54 mg/L. Calcium concentration in the groundwater of GP-8 watershed during post monsoon 2012, 2013 and 2014 it varies from 49-151 mg/L, 36-170 mg/L and 57-179 mg/L, respectively. The average value ca in post monsoon is 85.32 mg/L. The spatial distribution maps (Fig. 7) show that calcium concentration in both seasons is high at -Northeastern part and there is a decreasing trend towards southern region irrespective of the fact that the extent has been reduced in post monsoon. In the GP-8 watershed calcium concentration in both seasons fall within the desirable limit of BIS standards. The most pat of the study area covered by the Deccan basalts. In basalt, it is predominantly held in plagioclase feldspar, a solid solution series with anorthite ($Ca\ Al_2\ Si_2O_8$) and albite ($NaAlSi_3O_8$) as an end member. The important calcium bearing pyroxene mineral i.e. augite, is also one of the constituents of basalt releasing calcium in groundwater. The zeolites occurring in the Deccan traps as secondary minerals and montmorillonite clays holding calcium as an absorbed ion on the mineral surface in soils and rocks may also contribute to calcium in groundwater. The average abundance of Ca^{2+} in basaltic rocks is about 77600 mg/Kg (Konrad and Dennis, 1994). This suggests that the basaltic rock is one of the major sources of Ca^{2+} in groundwater from the study area.

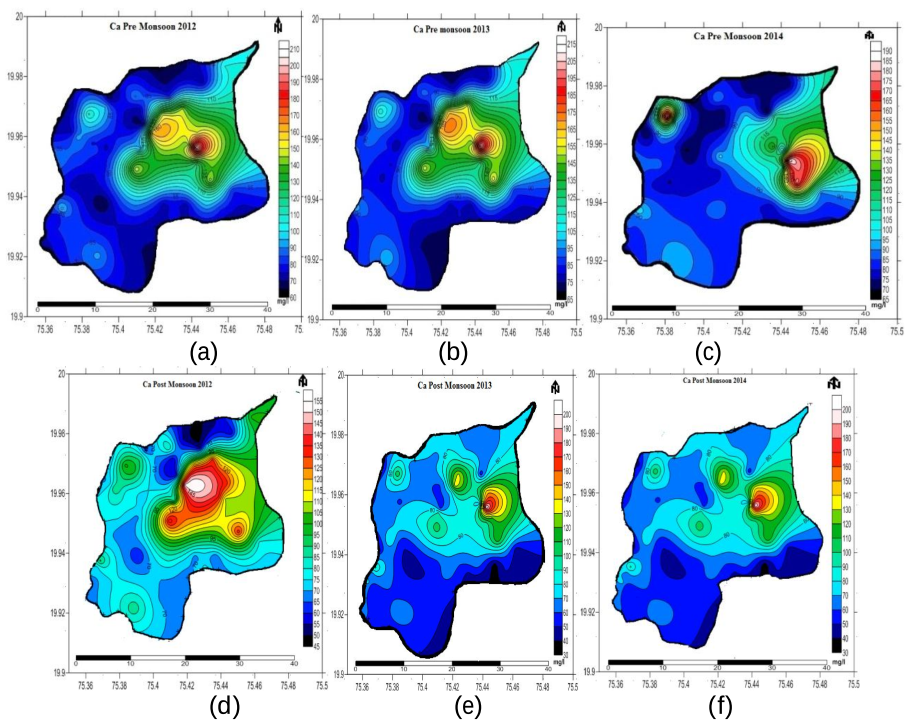


Fig. 7: Spatial distribution map of Ca in groundwater from the study area

Magnesium

Magnesium is one of the most abundant elements in igneous rocks. The chief magnesium bearing minerals are olivine, amphibole and pyroxene groups. Fresh waters contain magnesium less than 40 mg/L. As the magnesium ions are smaller than those of calcium or sodium, it has stronger charge density and greater attraction for water molecules because of which its solubility is ten times than of calcium.

In the study area, magnesium content of groundwater during pre monsoon 2012, 2013 and 2014 ranged from 40-83 mg/1, to 30-92 mg/1 and 40-99 mg/L, respectively. The average value of Magnesium for pre monsoon is 61.98 mg/1. Whereas in post monsoon 2012, 2013 and 2014 it ranges from 30-76 mg/L, 22-75 mg/L and 28-79, respectively. The average value of Magnesium for post monsoon is 51.06 mg/1. The spatial distribution maps of magnesium in both seasons showed in Fig. 8. In Deccan Trap basalts, the magnesium is found in the augite mineral. The magnesium in groundwater from the study area may be due to leaching of this magnesium element during the weathering of basalts.

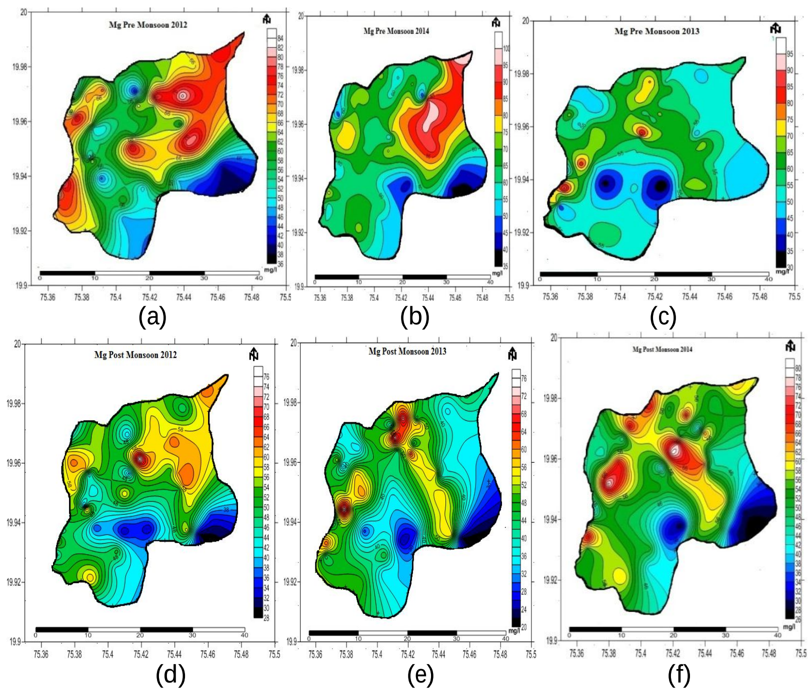


Fig. 8: Spatial distribution of Mg in groundwater from the study area

Sodium

Sodium salts are highly soluble in water and once leached from rocks and soil they remain in solution. The main source of sodium in groundwater is plagioclase feldspars, feldspathoids and clay minerals. It has a tendency to get absorbed on the clay particles but may effectively be exchanged by calcium and magnesium.

National Academy of Sciences report (1977), the higher concentration of sodium can be related to cardiovascular diseases and in women, toxemia associated with pregnancy. Sodium content around 200 mg/L may be harmful to persons suffering from cardiac and renal disease pertaining to circulatory system (Khurshid et a1. 1998). High concentration of sodium affects soil permeability and texture which leads to reduced rate of water intake. Sodium concentration values in the GP-8 watershed during pre monsoon 2012, 2013, 2014 varies from 21 to 132 mg/L, 30-145 mg/L and 27-114 and with an average value of 73.20 mg/L. While in the post monsoon 2012, 2013, 2014 it varies from 19 -125 mg/L, 25 to 139 mg/L and 25-111 mg/L and with an average value of 63.45 mg/L. In the study area, low values are seen in the southeastern region of the basin (Fig. 9) whereas higher values are seen in northeastern region. In Deccan Trap basalts, the sodium is found in the plagioclase feldspars and zeolites minerals. The sodium in groundwater from the study area may be due to leaching of sodium element during the weathering of basalts.

Potassium

Potassium is abundant in igneous and metamorphic rocks. The source of potassium content in groundwater is a function of weathering rate of silicate minerals such as orthoclase, microcline, nepheline, leucite and biotic in igneous and metamorphic rocks. The concentration of potassium in most natural water is very low due to the resistance of potassium minerals to decomposition by weathering (Golditch, 1938) and fixation of potassium ions in clay minerals.

In the study area, the potassium concentration in pre monsoon 2012, 2013 and 2014 ranges from 1 to 6 mg/1, 1 to 6 g/L and 1 to 4 mg/L, respectively. The mean value of K for pre monsoon in groundwater from the study area is 2.016 mg/L. In post monsoon 2012, 2013 and 2014 it ranges from 1 mg/L to 5 mg/1 with an average is 2.1 mg/L. If the concentration of potassium is less than 10 mg/L it is called as potable water (Karanth, 1987). This suggests the groundwater is suitable for drinking in terms of potassium. The Spatial distribution maps of potassium in both seasons shows (Fig. 10) that majority area of the GP-8 watershed falls within the category of below 10 mg/L reflecting the suitability of water for drinking use. During both seasons lower values are seen (Fig. 10).

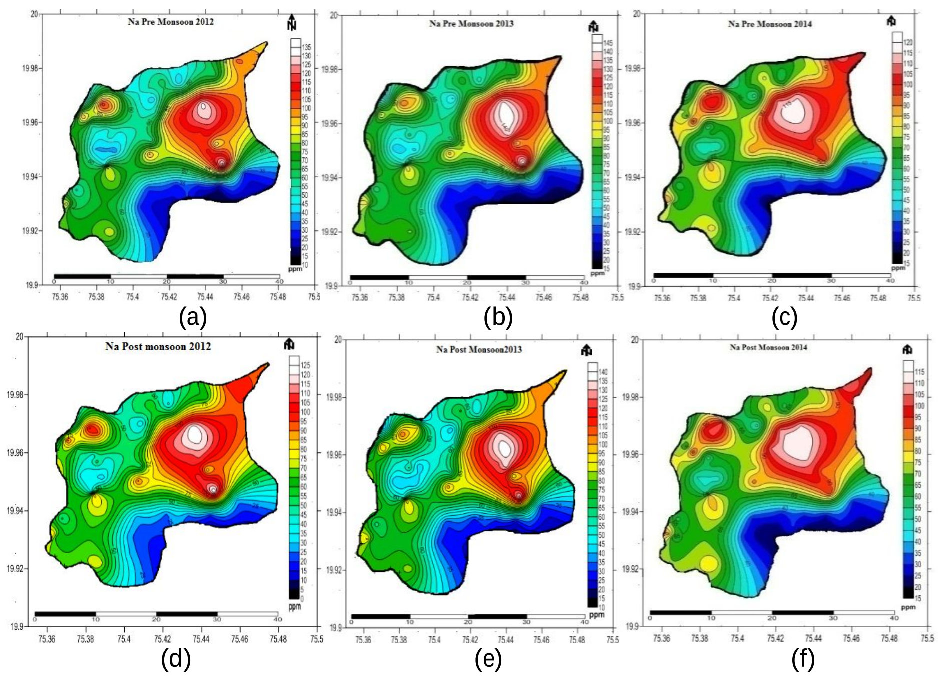
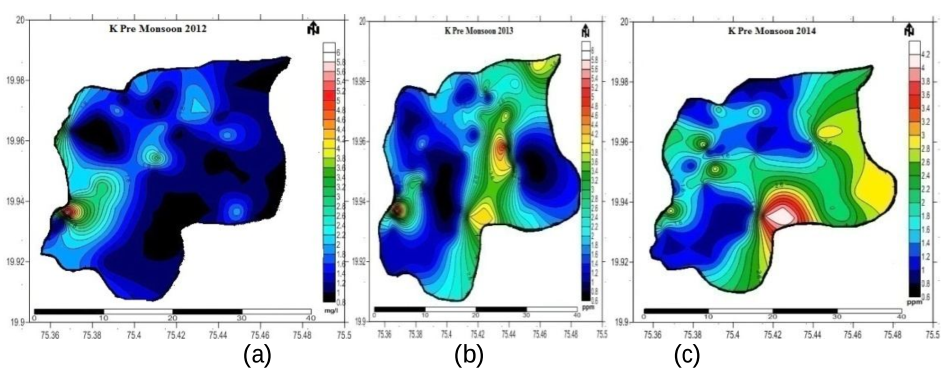


Fig. 9: Spatial distribution map of Na in groundwater from the study area



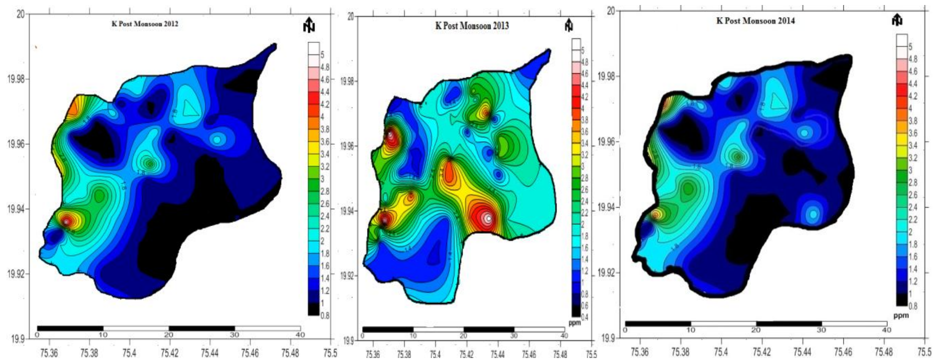


Fig. 10: Spatial distribution map of K in groundwater from the study area

Chloride

Higher concentration of chloride can also corrode concrete by extracting calcium in the form of calcides. Abnormal chloride concentration may result due to pollution of sewage waste and leaching of saline residues in the soil. Chloride concentration values of GP-8 watershed in the pre monsoon 2012, 2013 and 2014 varies from 36 to 188 mg/L, 45-200 mg/L and 42-211 mg/L, respectively. The average concentration of Cl^- in pre monsoon is 86.19 mg/L. During the post monsoon 2012, 2013 and 2013 it ranges from 28 to 179 mg/L, 35-180 mg/L and 40-200 mg/L, respectively. The average concentration of Cl^- in pre monsoon is 80.43 mg/L. The spatial distribution map of chloride concentration during both seasons (Fig. 11) showed that majority area is fresh groundwater types.

Nitrate

The presence of nitrate in groundwater is from decomposition of organic matters like plant debris, animal waste, sewage wastes, nitrate fertilizers and industrial waste chemicals. Natural nitrate concentration in groundwater ranges from 0.1 to 10 mg/1 (Davis and Dewiest, 1960). Nitrate concentration in water more than 45 mg/L may cause methaenoglobinaemia in infants (BIS, 2003). High concentration of nitrates is reported to cause more mortality in pigs and calves and abortion in brood animals. Even though high concentration of nitrate is useful in irrigation, their entries into the water resources increase the growth of certain algae and trigger eutrophication.

In the present study area, the nitrate concentration of groundwater in the pre monsoon 2012, 2013 and 2014 ranges from 30-78 mg/L, 42-86 mg/L and 35- 86 mg/L, respectively. The post monsoon concentration of nitrate for the year 2012, 2013 and 2014 it ranges from 20-74 mg/L, 12-75 mg/L and 31-83 mg/L, respectively. The average concentration of nitrate is 52.29 mg/L and 38.40 mg/L for pre and post monsoon, respectively. In the study area exceeds the highest desirable limits of drinking water standards of WHO and BIS (45 mg/L) in both the seasons (above 45 mg/L). From the spatial distribution of map (Fig. 12) it is observed that majority of the area in the watershed for both the seasons are comes under the medium polluted during post-monsoon and highly polluted during pre-monsoon period.

Sulphate

The sulphate concentration of atmospheric precipitation is only about 2 mg/L, but the sulphate content in the groundwater varies widely due to oxidation and precipitation processes as the water traverse through rocks. The sources of sulphates are sculpture minerals, sulphides of heavy metals which are commonly found in the igneous and metamorphic rocks, gypsum and anhydrite found in some sedimentary rocks. The oxidation and hydrolysis of pyrite also produce sulphuric acid and soluble sulphate. Sulphate concentration around 1000 mg/L is laxative and cathartic (U.S.E.P.A, 1971). Sulphate with sodium interferes with normal functioning of the intestine. Sulphate concentration in groundwater from GP-8 watershed during pre monsoon 2012, 2013 and 2014 ranged from 47.00 to 199.00 mg/L, 60.00-200 mg/L, 63.00-200, respectively. Whereas in the post monsoon season 2012, 2013 and 2014 ranges from 44.00-178.00 mg/L, 49.00-185.00 mg/L and 60.00-190.00, respectively. The average concentration of sulphate in pre monsoon and post monsoon is 121.44

mg/L and 108.95 mg/L, respectively. The spatial distribution maps of sulphate concentration in both seasons (Fig 13) reveal that the entire GP-8 watershed is within the desirable limit of WHO and BIS standards (< 200 mg/L).

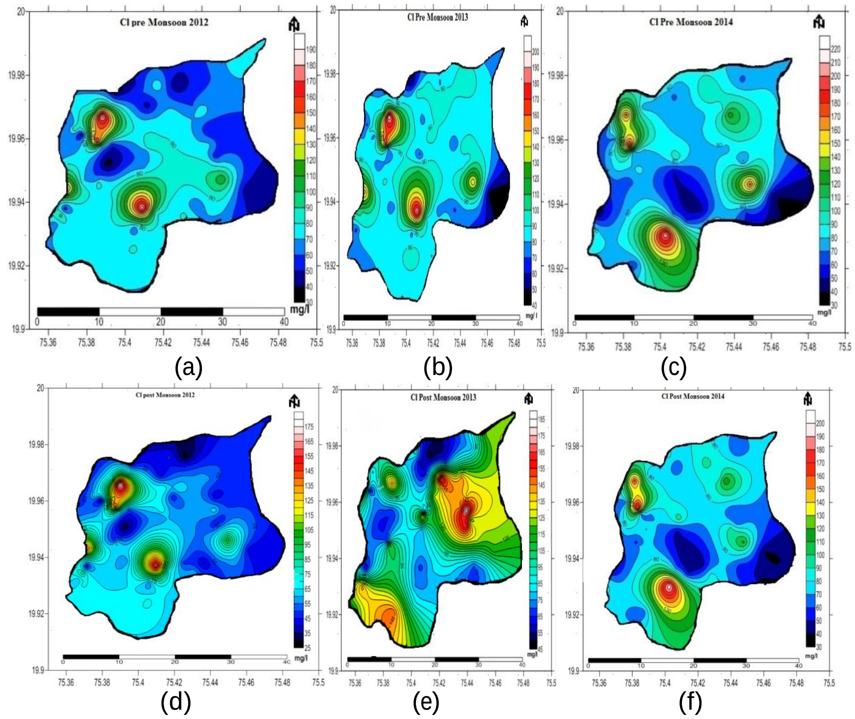


Fig. 11: Spatial distribution map of Cl^- in groundwater from the study area

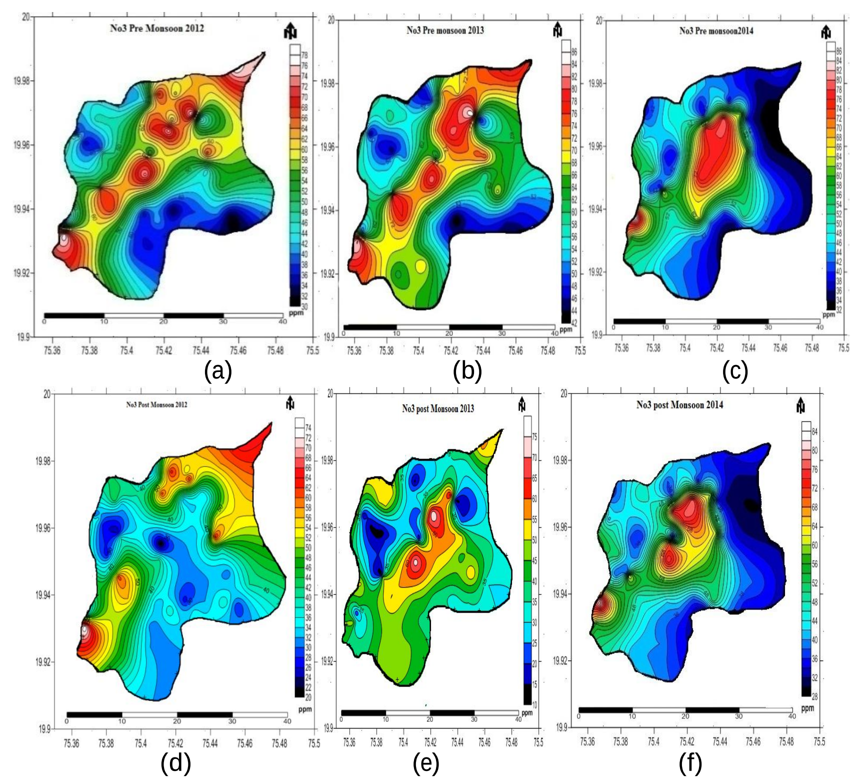


Fig. 12: Spatial distribution of nitrate in groundwater from the study area

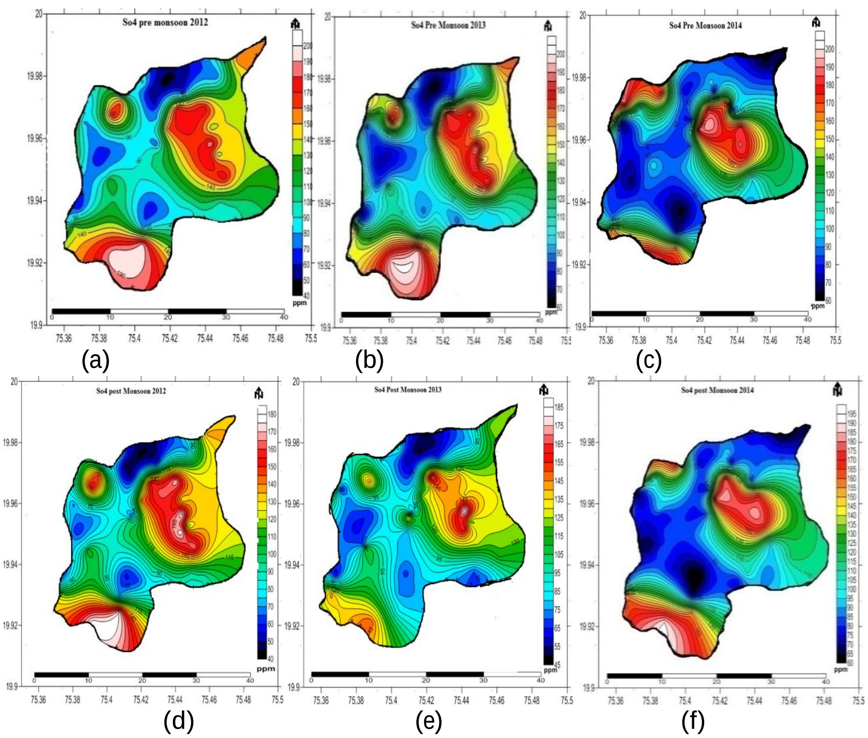


Fig. 13: Spatial distribution map of SO_4^{2-} in groundwater from the study area

Irrigation water quality

In the present study, groundwater quality of GP-8 watershed was assessed specifically for irrigation purpose. Sodium adsorption ratio (SAR) and residual sodium carbonates (RSC) were adopted in the study (Raghunath 1987; Lloyd and Heathcote 1985; Li et al. 2013a, b, 2016c). SAR represents the sodium hazard to crops caused by excessive Na^+ in irrigation water (Raghunath 1987). As shown below, it can be computed as the relative proportion of Na^+ to Ca^{2+} and Mg^{2+} in a water sample with ion concentrations expressed in meq/L.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{1}$$

Water with SAR less than 10 is regarded excellent for irrigation, while SAR higher than 26 indicates unsuitable for irrigation purposes (Raghunath 1987). SAR value in groundwater from GP-8 watershed during pre monsoon 2012, 2013 and 2014 ranged from 0.36 to 1.83, 0.48 to 2.03 and 0.46 to 2.17, respectively. Whereas in the post monsoon season 2012, 2013 and 2014 ranges from 0.33 to 1.85, 0.54 to 2.69 and 0.43 to 2.27, respectively. This suggests that the groundwater quality of the study area is suitable for irrigation in terms of SAR.

RSC indicates the possibility of removing Ca^{2+} and Mg^{2+} in soil solution. The higher the RSC is, the higher the potential of causing alkaline hazard, because higher RSC indicates that $CaCO_3$ may precipitate from solution and thus increase the concentration of Na^+ (Lloyd and Heathcote 1985). RSC is computed as the following equation with ions expressed in meq/L.

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \tag{2}$$

Water with RSC less than 1.25 is considered suitable for irrigation (Lloyd and Heathcote 1985; Li et al. 2013a, 2016c). This means that the water will not cause alkaline hazard to soils. RSC value in groundwater from GP-8 watershed during pre monsoon 2012, 2013 and 2014 ranged from -13.25 to -4.30, -11.45 to -4.08 and -13.61 to -3.90, respectively. Whereas in the post monsoon season 2012, 2013 and 2014 ranges from -11.46 to -3.39, -9.69 to -2.07 and -11.12 to -3.01, respectively. This suggests that the groundwater quality of the study area is suitable for irrigation in terms of RSC.

In terms of alkaline and sodium hazard, the groundwater from the GP-8 watershed is suitable for irrigation. However, irrigation water quality should also be assessed considering its potential to cause salinity hazard. The USSL produced a USSL diagram which considers the alkalinity and salinity of irrigation water simultaneously (USSL 1954). According to USSL diagram, water with EC lowers than 250 µS/cm is excellent for irrigation and that water with EC higher than 2250 µS/cm is poor for irrigation. As shown in Fig. 14 to Fig. 19, all samples are plotted in zones C2S1 and C3S1, suggesting that the groundwater is medium to high salinity, and it is unsuitable for irrigation in terms of salinity.

Gypsum is the most commonly used for improvement of sodic soil and for reducing the harmful effects of high sodium irrigation water in agricultural areas because of its solubility, low cost, availability and ease of handling (Amezketa et al. 2005). Studies on the effect of gypsum application on saline-sodic soil reclamation have shown that the soil receiving gypsum at higher rate removes the greatest amount of Na^+ from the soil columns and causes a substantial decrease in soil electrical conductivity (EC) and sodium adsorption ratio (Hamza and Anderson, 2003). It has been proved that some organic sources can be applied to reclaim salt and sodic affected soils (Wong et al. 2009). Addition of organic matter and gypsum to the surface soil will decrease spontaneous dispersion and EC down to the subsoil, compared to the addition of gypsum alone (Vance et al. 1998). The present situation in GP-8 watershed is alarming salinity hazard, suggesting use of gypsum as anti-saline fertilizers whereas as high salinity occurs to overcome this problem.

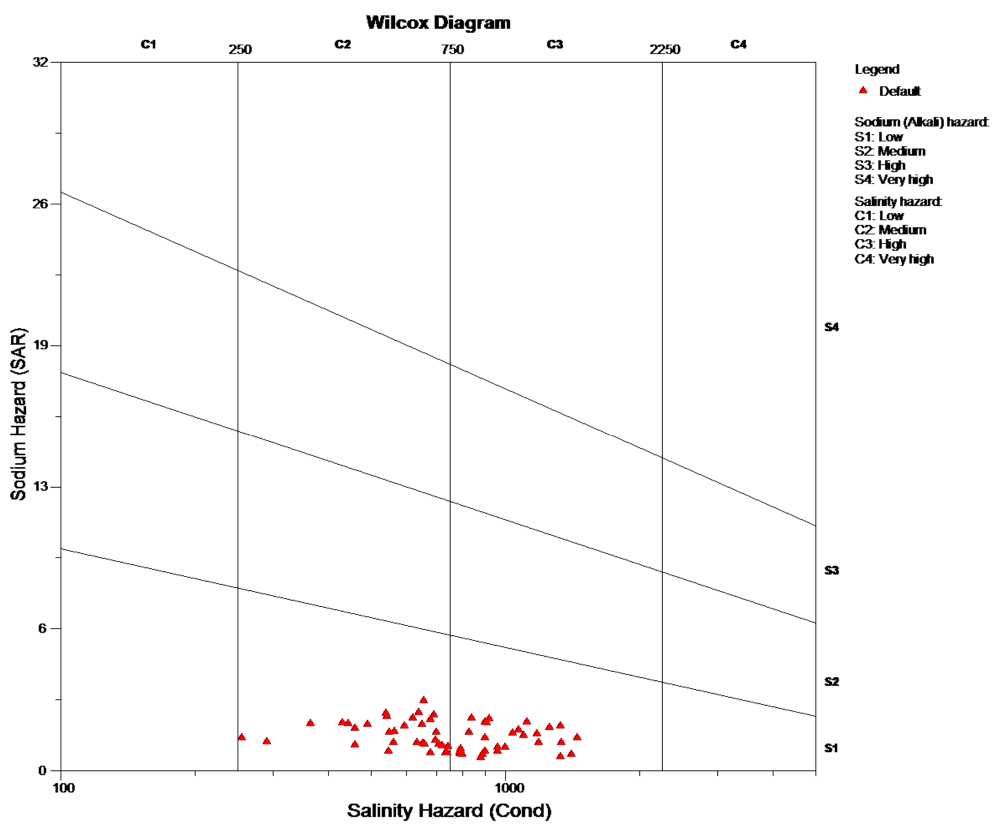


Fig. 14: USSL diagram of the groundwater from the GP-8 watershed

(Post monsoon 2012)

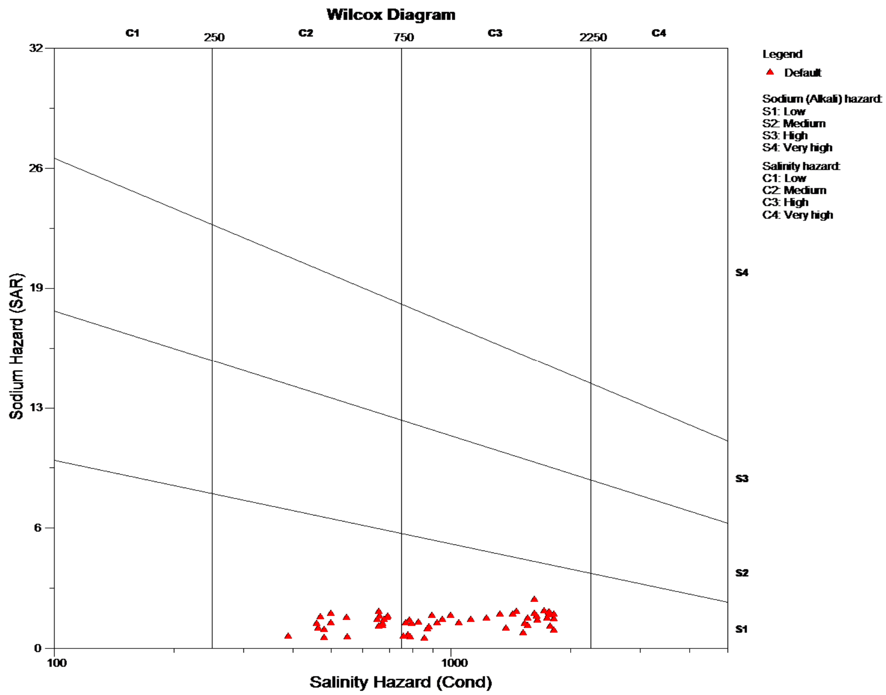


Fig. 15: USSL diagram of the groundwater from the GP-8 watershed (Post monsoon 2013)

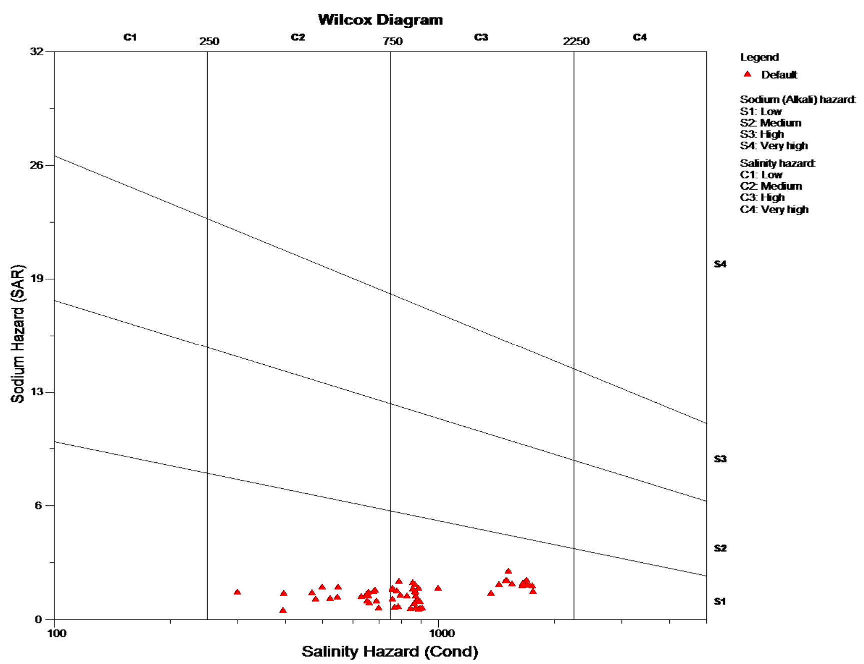


Fig. 16: USSL diagram of the groundwater from the GP-8 watershed **(Post monsoon 2014)**

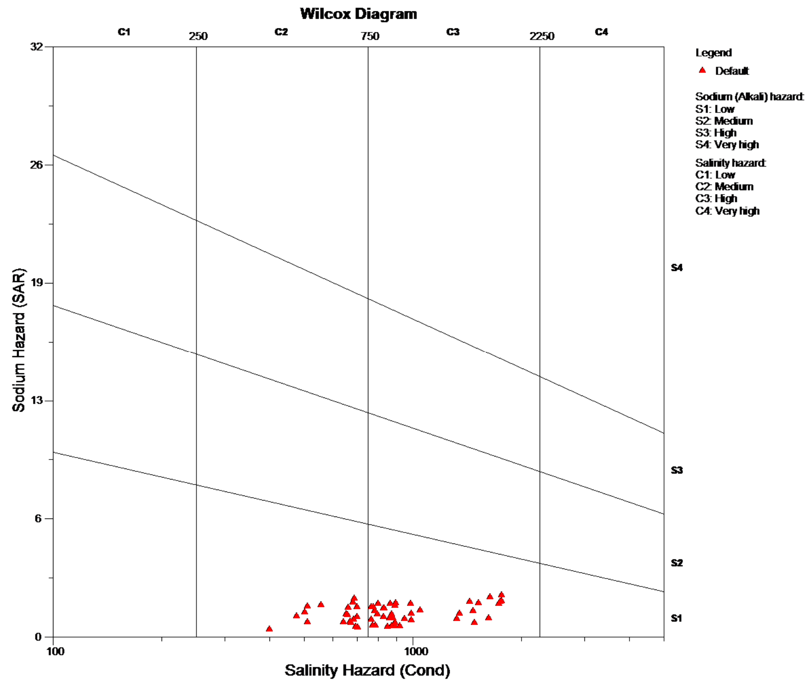


Fig. 17: USSL diagram of the groundwater from the GP-8 watershed (Pre monsoon 2012)

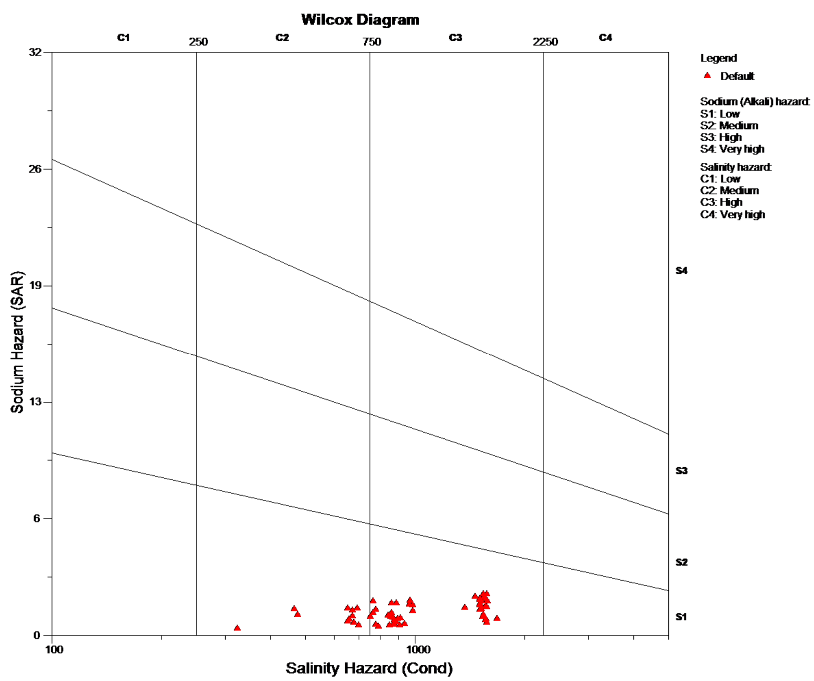


Fig. 18: USSL diagram of the groundwater from the GP-8 watershed

(Pre monsoon 2013)

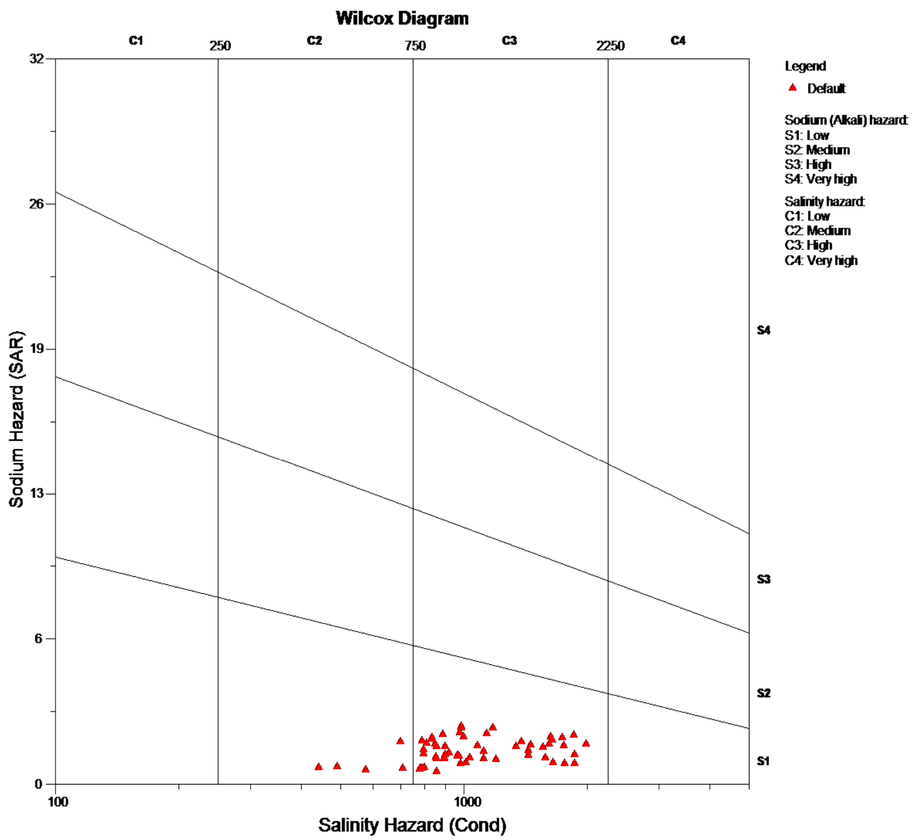


Fig. 19: USSL diagram of the groundwater from the GP-8 watershed (Pre monsoon 2014)

4. CONCLUSIONS

Groundwater quality parameters were assessed for the GP-8 watershed to provide local government agencies and decision makers with comprehensive information on water quality status of the studied area. The acidic nature of the basin is seen at the southwestern areas for both the seasons, whereas the alkaline nature of the basin is noticed in the North eastern and Northwestern part. The values of hardness in all the samples are too high even greater than maximum permissible limit. Similarly Nitrate values are also high. The average concentration nitrate exceeds the permissible limit it indicates that study area could be health risk of methaenoglobinaemia disease. SAR and RSC results showed that that the groundwater from the studied area is suitable for irrigation in terms of alkalinity, but the USSL diagram proves that it is unsuitable for irrigation from the salinity point of view. The high salinity in the groundwater will harm the crops and soil. To protect the crops and soil, it is recommended that the use gypsum as fertilizer to control the salinity hazards.

Acknowledgments: Authors are thankful to the Dr. Deshpande S. M., Head, Department of Geology, Institute of Science, Aurangabad for providing analytical facilities to carry out the hydrochemical analysis of groundwater samples. Sincere thanks to Dr. Babar Md., Associate Professor, Department of Geology, Dnyanopasak College, Parbhani (M.S.) India and Dr. Janardhana M. R., Head, Department of Geology, Yuvaraja's College, University of Mysore (K.S.) India for his constructive suggestions. Author (RBG) officially acknowledge to the Principal, G.B. Tatha Tatyasaheb Khare Commerce, Parvatibai Gurupad Dhere Art's and Shri. Mahesh Janardan Bhosale Science College, Guhagar Dist. Ratnagiri (M.S.), (India)

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