International Journal of Chemical Studies 2019; 7(5): 1302-1309

International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(5): 1302-1309

Received: 24-06-2019
Accepted: 28-07-2019

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Impact assessment of edaphic factors on groundwater quality

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DOI: https://doi.org/10.22271/chemi.2019.v7.i5w.7123

Abstract
Fifteen water abstraction structures along the two streams adjacent to the NIASM site were selected for studying the geochemistry of the groundwater and abiotic factors responsible for their distribution. The results indicated that the groundwater is alkaline with high electrical conductivity (EC). The Total Hardness is below the prescribed drinking water limit whereas Na concentrations are far below the permissible limit. The sodium absorption ration (SAR) distribution pattern indicated downstream increase in the areas due to surfacial obstruction of the natural drainage system. EC of water shows a positive correlation with major cations Ca + Mg (R^2= 0.63) and Na + K (R^2= 0.61) which indicates a strong lithological control on the major oxide cations of the groundwaters. There is a strong positive correlation between EC and Cl (R^2= 0.96) while the correlation between EC and HCO_3 is weak (R^2= 0.12) indicating that the amount of chloride in the groundwater controls the EC. The samples showed considerable scatter with a weak correlation (R^2= 0.19) between NO_3-N and EC. Such variation in the NO_3-N concentration from the groundwaters reflects the role of physical process such as evaporation and /or anthropogenic additions to the groundwater. The SO_4 concentration showed no distinct correlation with EC (R^2= 0.07) indicating that its concentration did not contribute to the conductivity of groundwaters from the NIASM site. Based on the SAR values, the groundwater for irrigation purposes are classified as 'good' and most of them belong to the Ca+Mg>Na+K; HCO_3+CO_3>Cl+SO_4 facies.

Keywords: Groundwater quality, edaphic factors, groundwater facies

1. Introduction

Maharashtra is predominantly an agrarian State and most of its area constitutes the hard-rock terrain. The rain-shadow drought prone region (DPR) constitutes an important agroclimatic region of the state. Over dependence on groundwater in the DPR has led to its overexploitation, falling water levels and degrading groundwater quality (Duraiswami *et al*. 2012a, b) [7], and an effective insitu water security intervention using artificial recharge was established in two select river basins (Duraiswami *et al*. 2016) [9]. The NIASM watershed falls in the rain-shadow, drought prone region of the Maharashtra state. The region experiences arid megathermal type of climate that is responsible for water scarcity and salinity in the region. Dug wells and bore wells in shallow basaltic aquifer are the primary source of drinking water and irrigation in the area. The groundwater quality in the Karha Basin is important as several saline tracts and pockets of saline water are encountered in the basin (GSDA, 1992). Based on remote sensing techniques and ground truth verifications, Krishnamurthy *et al*. (2004) [12] were able to delineate small facture recharged fresh water pockets in the saline tract between Morgaon and Tardoli. Besides this subsurface modeling of salinity using the modified GLADIT score was attempted by Duraiswami *et al*. (2008) [5-6]. Dug wells and bore wells are the primary source of drinking water and irrigation in the area. Recently, attempts at inter-basin water transfer and surface water/groundwater interaction in the basaltic aquifers of the Upper Nira River Basin, Maharashtra has been studied but the changes in impact assessment of edaphic factors on groundwater quality needs to be undertaken (Krishnamurthy *et al*. 2016) [13]. Study of the groundwater quality is an important bearing on their elemental composition effecting the livestock, fisheries and fodders. The ill effects of various toxic elements their threshold concentration and uptake, mobility in livestock and human being, soil and plant systems are well known (Ghosh *et al*. 2006) [10]. Current emphasis on hydro-geochemistry is related to the chemistry of trace elements controlling the movement, distribution and fate in plants and soils of native pools and anthropogenic addition of elements causing the stresses in different forms. Purpose of this study is to collect detailed geohydrological baseline data at the

NIASM site so that its role vis-a-vis abiotic stresses can be evaluated for setting up the different experiments by the different groups of scientists to demonstrate the farmers and policy planners.

2. Study area

The NIASM site under study is located between N 18º8’59.279" and 18º9'45.845" and E 74º29'30.38" and 74º30'38.299" and lies between Karha Basin of Bhima River in the north and Nira River Basin in the south. It lies in the Drought Prone Area of plateau region of western Maharashtra on a water divide with a smooth but slightly undulating topography within the limits of village Malegaon Khurd, Baramati Taluka of Pune district. The area is known for its frequent scarcity. The site is well connected by road with major cities in the State (Fig. 1). The relief of the area gradually reduces from north to south. The side of the area is drained by two streams and generally exhibit dendritic drainage pattern especially in the lower order streams. A prominent percolation tank is built across the western stream while an earthen dam is built across the eastern stream.

Fig 1: Location of study area Malegaon in Baramati, Pune district.

3. Material & Methods

Eleven water samples from dug wells (NW1,2,4,5,6,7,8,10,11,12,13), two from dug-cum-bore wells (NW3,14), one each from canal water plus groundwater (NW9) and canal water (NW15) were collected in 1-liter polyethylene bottles for studying the geochemistry of the groundwater. The locations of abstraction structures as well as sampling sites are marked on the map (Fig.2). Chemical characteristics of the groundwater samples were determined according to the prescribed procedure (APHA, AWWA and WPCF, 1981) [1] and the results are given in Table 1.

Fig 2: NIASM site with water abstractions structures. Sample numbers (NW) indicated are used for water quality studies.

Table 1: Geochemical analysis of groundwater from the NIASM watershed. All values are in mg/l except where mentioned.

Number	NW1	NW2	NW3	NW4	NW5	NW6	NW7	NW8	NW9	NW10	NW11	NW12	NW13	NW14	NW15
Use	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Irrigation**	**Domestic**	**Horticulture**	**Horticulture**	**Horticulture**	**Irrigat ion**
Source	**DW**	**DW**	**DW-BW**	**DW**	**DW**	**DW**	**DW**	**DW**	**DW+CW**	**DW**	**DW**	**DW**	**DW**	**DW-BW**	**CW**
Temp (˚C)	27	27.5	27.5	28.5	28.5	29	29	28	28	27	27	28	28	28	28
pH	7.6	7.6	7.9	7.8	7.8	7.8	8.0	8.3	7.9	8.6	8.2	8.3	8.1	8.1	8.2
E.C. µs/ cm^2	2400	2340	2110	1930	1570	1410	1410	1030	470	1390	1270	880	1000	840	256
Density* g/cm^3	0.99717	0.99696	0.99692	0.99691	0.99659	0.99647	0.99648	0.99674	0.99655	0.99704	0.99708	0.9967	0.99673	0.99671	0.99638
Dissolved solids*	892.5	801.07	747.23	1110.9	687.15	721.94	727.84	689.84	445.07	715.84	766.26	632.34	672.23	649.1	211.87
Total Hardness	240	234	106	136	128.44	130.46	124.44	106.35	70.242	102.3	112.33	100.33	116.38	80.264	20.073
Ca	175.2	125.8	124.6	188.4	87.61	103.2	102.6	95.7	82.3	103.5	110.1	102.3	104.1	99.45	42.8
Mg	2.95	2.95	2.93	2.94	2.88	2.87	2.86	2.75	2.56	2.84	2.75	2.69	2.69	2.65	2.12
Na	121.6	128.3	91.46	124.3	104.6	116.6	113.2	103.3	39.17	106.8	121.7	86.3	81.6	87.27	17.4
K	0.58	0.44	0.36	0.14	0.05	0.47	0.09	0.73	0.00	0.19	0.27	0.29	0.07	0.00	0.67
Alkalinity	285	245	225	520	260	260	280	310	215	275	315	285	320	330	78.5
CO_3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
HCO_3	285	245	225	520	260	260	280	310	215	275	315	285	320	330	78.5
Cl	227.3	220.1	225	196	151.9	160.5	147.7	96.56	28.4	150.4	144.8	75.26	80.94	46.86	11.36
SO_4	70.57	70.45	70.72	70.49	70.68	70.62	70.89	72.19	72.9	71.28	71.6	72.54	72.32	72.77	58.48
NO_3–N	9.33	8.08	7.16	8.62	9.37	7.72	10.53	8.61	3.21	5.88	9.33	7.96	10.51	10.1	0.54
Salinity Hazard	Very High	Very High	High	High	High	High	High	High	High	High	High	High	High	High	Medium
SAR	2.50	3.09	2.21	2.46	3.00	3.09	3.01	2.84	1.16	2.83	3.13	2.30	2.16	2.36	$704x10^{-3}$
Exch. Sodium ratio	0.589	0.856	0.616	0.561	0.987	0.942	0.919	0.898	0.395	0.86	0.925	0.705	0.655	0.733	0.328
Magnesium Hazard	2.7	3.72	3.73	2.51	5.14	4.38	4.39	4.52	4.88	4.33	3.96	4.16	4.09	4.21	7.55
Res. Sodium Carbonate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Type	Ca-Cl	Ca-Cl	Ca-Cl	Ca-HCO_3	Ca-HCO_4	Ca-Cl	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3

*calculated; DW-Dugwell; BW-Borewell; CW-Canalwater

4. Results and Discussion
4.1 Site Characteristics
The NIASM site belongs to the rain-shadow drought prone region (DPR) of the State and is part of the Karha River Basin which is a closed basin that originates in hill range away from the Western Ghats and is seasonal, monsoon fed and drains into the Nira River Basin. On the basis of PET and Moisture Index, the climate of the area can be classified into the Arid Megathermal type (Paranjape, 2001). The total annual average rainfall is around 600 mm with 25-30 days gap between consecutive rain spells (Dhokarikar, 1991) [3]. Although the quantum of rainfall is adequate to recharge, the long gap between rain spells and the barren hard rock terrain with limited soil cover is conducive to large surface run-off with little or no infiltration and percolation into the sub-surface. Moreover the presence of a low weathered mantle on shallow hard rock and un-jointed nature of the lava flows prove to be impediments to occurrence and movement of the groundwater at the NIASM site. This aspect is further complicated by the fact that the NIASM site is on ridge-like mound (Water divide) which encourages the away movement of the groundwater leading to the absence of a phreatic water table below.

4.2 Hydrogeology
The shallow basaltic aquifer is the main aquifers in the study area. Lithological sections of select dug wells from the study area were measured in the field and are depicted in Figure 3.Water level fluctuations in observation wells that tap the shallow, unconfined basaltic aquifers indicate saturation of aquifer during monsoon and desaturation during summer. The yields of the dug wells in basaltic aquifer in the study area vary from 2.60 to 165 kl/day depending on the amount of precipitation and season (Joshi, 2005) [11]. The depth of dug wells varies from 4 to 12 m and the depth to groundwater ranges from 2 to 10.5 m bgl. A representative water abstraction structure (dug well) is shown in Figure 4.

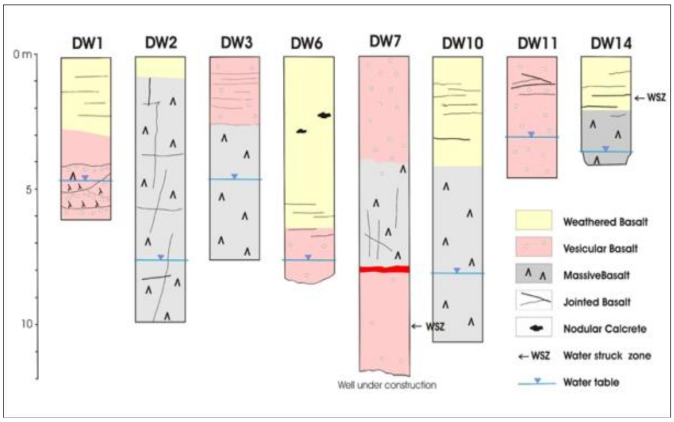

Fig 3: Representative lithological sections of dug wells (DW) from the study area.

Fig 4: Field photographs of water abstraction structures (dug wells) from the study area.

The crust in compound flow is an important water-bearing horizon as these contain vesicles and large irregular voids. Besides this, the zone of secondary porosity is the main locales of groundwater. The nature of joints, their frequency and their interconnection determines the aquifer parameters of the flows (Duraiswami, 2000; Duraiswami *et al*., 2012b) [4, 8]. Flow top breccias and red bole constitute an important aquiclude in the region. The detailed inventory of the dug wells tapping the basaltic aquifers from the study area indicate that the well density in the study area varies from 2 per km^2 to as high as 5 per km^2. In general, the density of wells is high along the stream course as shown in figure 2.

4.3 Groundwater Characteristics
The groundwater from the study area is alkaline in nature (pH: 7.6 to 8.6). Their electrical conductivity ranges from 470 to 2400 micromohs/cm. Based on the electrical conductivity the samples from the present study falls within 3 categories viz. 1 sample (NW9-mixed sample between groundwater and canal water) representing medium (C2 - 250 to 750 micromohs/cm), 11 samples representing high (C3- 750 to 2250 micromohs/cm) and 2 samples (NW1 & NW2) representing to very high (> 2250 micromohs/cm) salinity which could be attributed to agriculture return flow from occasional application of canal waters for irrigation. The canal water (NW15) analysed in the present study has an electrical conductivity of 256 micromohs/cm. The total dissolved solids (TDS) of the groundwater vary from 649 to 1111 mg/l. Distribution pattern of electrical conductivity zones along the NIASM watershed is shown in Figure 5. The Total Hardness of groundwater quality is mainly due to Ca and Mg which is released from the weathering of plagioclase, augite and olivine present in basalts. It varies from 70 to 240 mg/l which is below the prescribed drinking water limit of 600 mg/l. The spatial variation in the Total Hardness values along the NIASM watershed is shown in Figure 6.

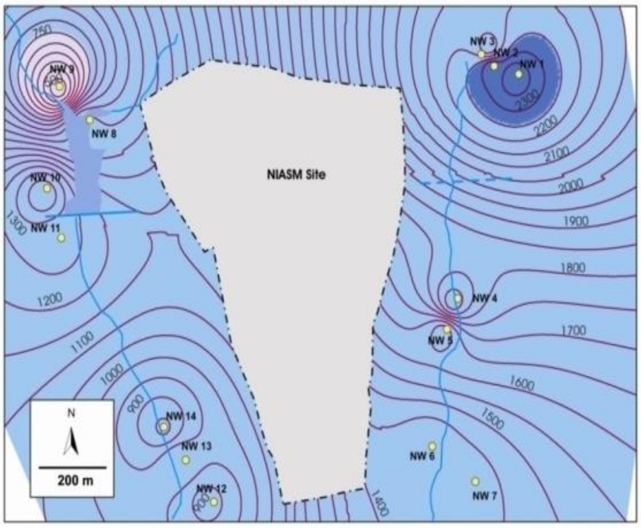

Fig 5: Map showing the electrical conductivity zones along the NIASM watershed with the highly saline areas (EC > 2250 micromohs/cm) at north-east side of the site.

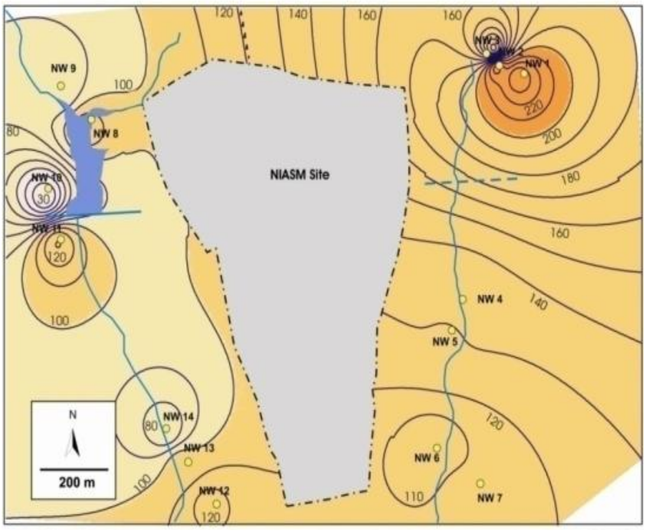

Fig 6: Map showing the spatial variation in the Total Hardness values along the NIASM watershed.

Calcium concentration ranges from 82 to 175 mg/l while Mg concentration is subordinate to Ca and has limited range from 2.56 to 2.95 mg/l. These values are far below the permissible limit of 100 mg/l for Mg by the Bureau of Indian Standards (1990). Sodium concentrations range from 39 to 128 mg/l and are well below the prescribed limit of 200 mg/l set by World Health Organisation (WHO). The higher concentration of sodium vis-à-vis calcium may also be partly accounted for by the precipitation of calcite in the semi-arid dry climate. The chloride (Cl) content at NIASM watershed is variable (28 to 227 mg/l) in the groundwater. High chloride of > 200 mg/l is associated with three wells to the northeast of the site (Fig. 7) and can be attributed to effluents and excessive irrigation with poor drainage. However, in the NIASM watershed the high EC-Cl water appears to be genetically associated with the highly saline waters from Karhavagaj (Duraiswami *et al*., 2008b) [5-6].

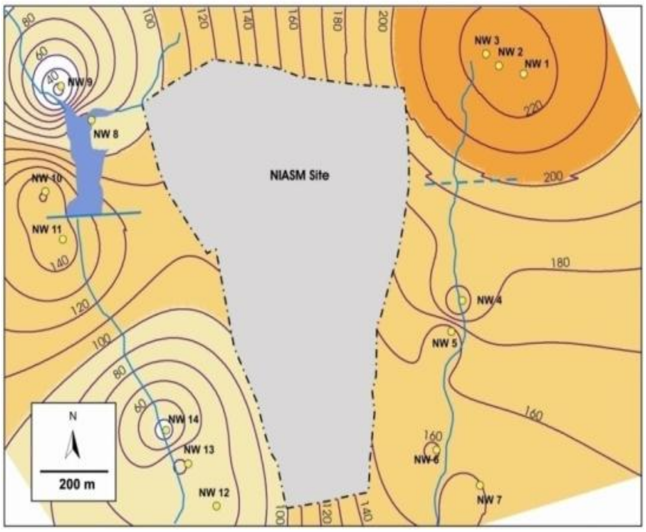

Fig 7: Isochloride map of the NIASM watershed. High chloride of > 200 mg/l is associated with three wells to the northeast of NIASM site.

Nitrate (NO_3) concentration in the groundwater is low (3.2 to 10.5 mg/l) and are in stark contrast to similar irrigated areas of upland Maharashtra (Pawar and Nikumbh, 2000) [15]. Study indicated two dugwells i.e. NW13 and NW14 record slightly higher nitrate in the groundwater (Fig. 8) which is attributable to the application of nitrogenous fertilizers to the horticultural plants. Sulphate (SO_4) concentrations in the groundwater ranges from 70.45 to 72.9 mg/l while carbonate percentage is between 0 to 12 mg/l.

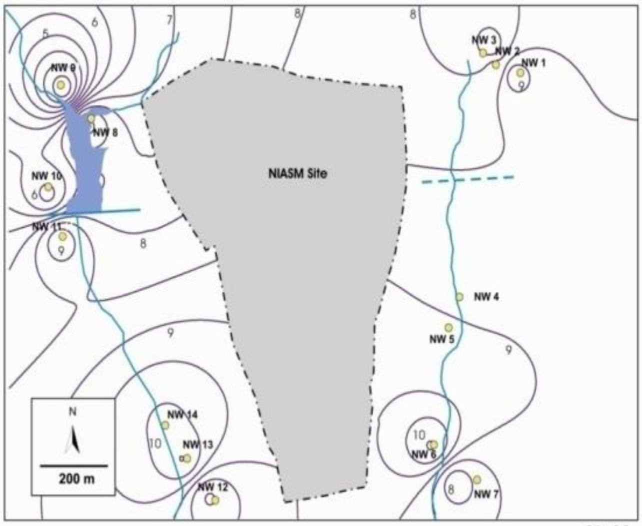

Fig 8: Map showing the distribution of nitrate in groundwater from the NIASM watershed.

The geochemical data generated was used in binary diagrams to understand the genesis and process involved. The electrical conductivity of waters from the NIASM site shows a positive correlation with major cations Ca+Mg (R^2= 0.63) (Fig. 9a) and Na+K (R^2= 0.61) (Fig. 9b). This indicates a strong lithological control on the major oxide cations of the groundwaters. A strong positive correlation is also seen between EC and Cl (R^2= 0.96) (Fig. 9c) while the correlation between EC and HCO_3 is weak (R^2= 0.12) (Fig. 9d) indicating that the amount of chloride in the groundwater controls the electrical conductivity at NIASM Site. Correlation between NO_3-N and EC showed considerable scatter with a weak correlation (R^2= 0.19, not shown in the diagram). Such variation in the NO_3-N concentration from the groundwaters reflects the role of physical process such as evaporation and /or anthropogenic additions to the groundwater. The SO_4 concentration showed no distinct correlation with EC (R^2= 0.07, not shown in the diagram) indicating that its concentration did not contribute to the conductivity of groundwaters from the NIASM site.

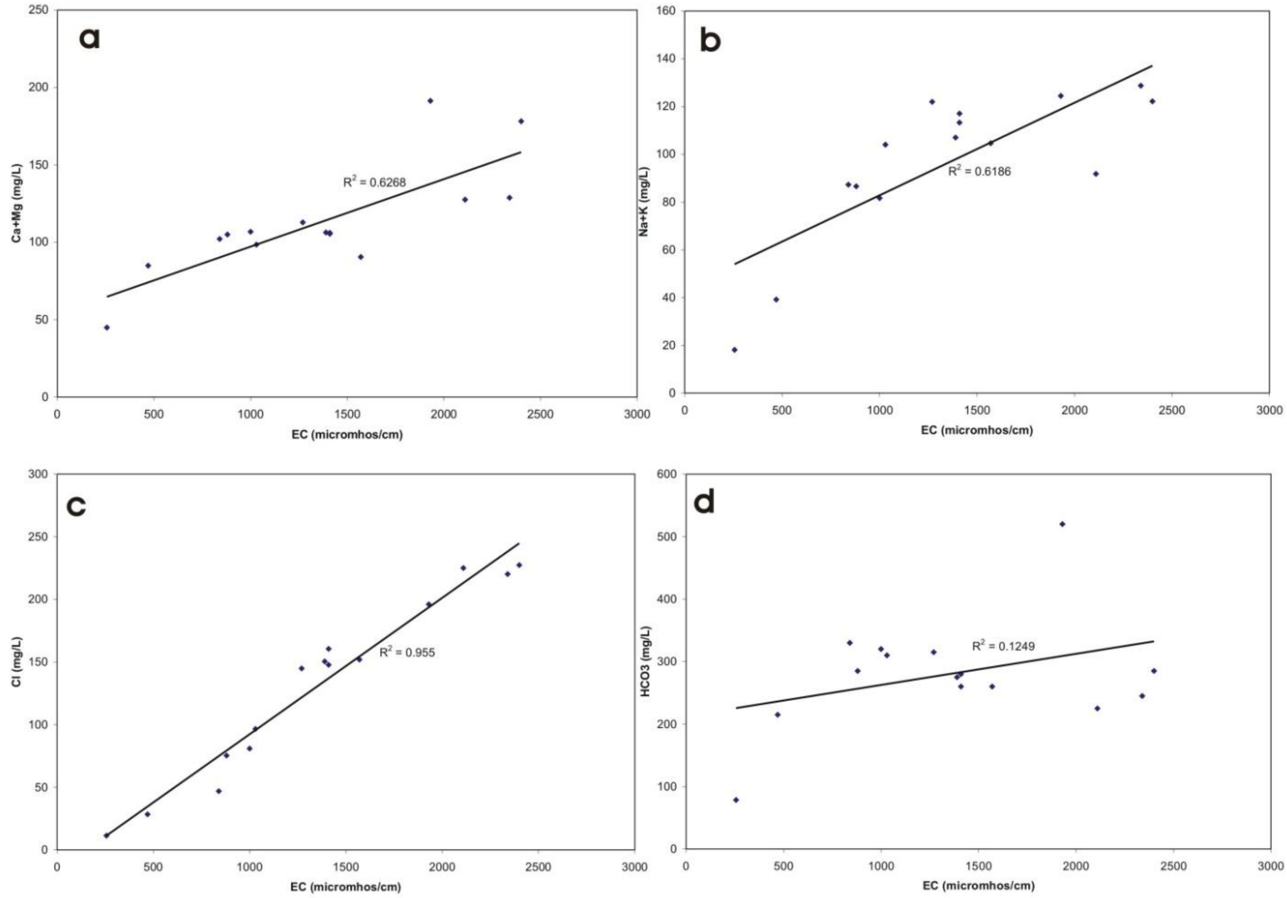

Fig 9: Binary variation diagrams between E.C. and major cations and anions in groundwater from the NIASM watershed.

4.4 Evaluation of groundwater for irrigation

Groundwater along with surface water lifted from canals is the prime source of irrigation waters in and around the NIASM site. The groundwater analysis was used to classify the water into categories suitable for irrigation purpose. The following parameters are evaluated.

4.4.1 Salinity

High electrical conductivity indicates high salt concentration in irrigation waters that ultimately leads to the formation of saline soils. Based on Richards classification scheme the groundwater from the study area are fair (11 samples) to bad (3 samples) for irrigation.

4.4.2 Sodium adsorption ratio (SAR)

SAR is a useful parameter to evaluate the degree to which irrigation waters tend to enter into cation exchange in soils. The SAR of groundwater samples from the NIASM watershed range from 1.2 to 3.09 and their distribution pattern are shown in Figure 10. In the stream east of the NIASM site it is seen that the SAR values generally increase downstream which is as expected in a moderately drained, agriculturally dominated landuse - landcover. In contrast, it reduces downstream along the stream west of the NIASM site. High values of SAR are seen in the northwestern part of the study area in and around the MI tank.

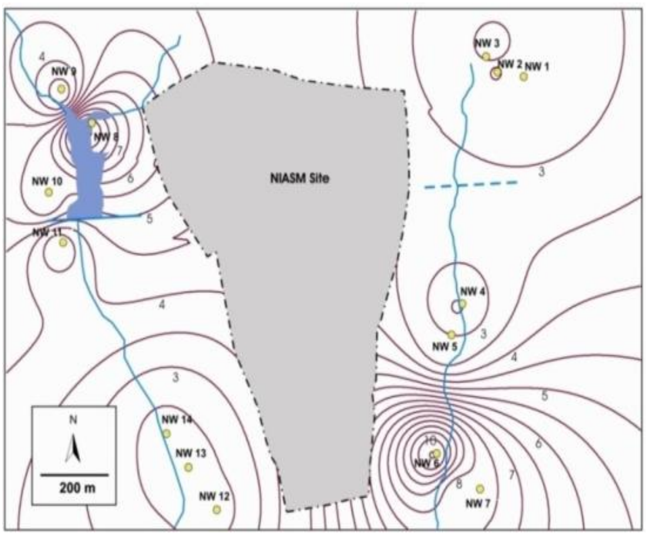

Fig 10: Variations in the Sodium Absorption Ratio for the NIASM watershed.

SAR values plotted against EC in the USSL diagram (Fig. 11) shows that two samples each plot in the C2S1 (low SAR-medium EC) and C4S1 (low SAR- very high EC) category while the remaining samples plot in the C3S1 (low SAR-high EC) category. The use of groundwater from dug wells NW1 and NW2 that plot in the C4S1 (low SAR - very high EC) category should be discouraged for agriculture. Based on the SAR values, the groundwater for irrigation purposes are classified as generally 'good'.

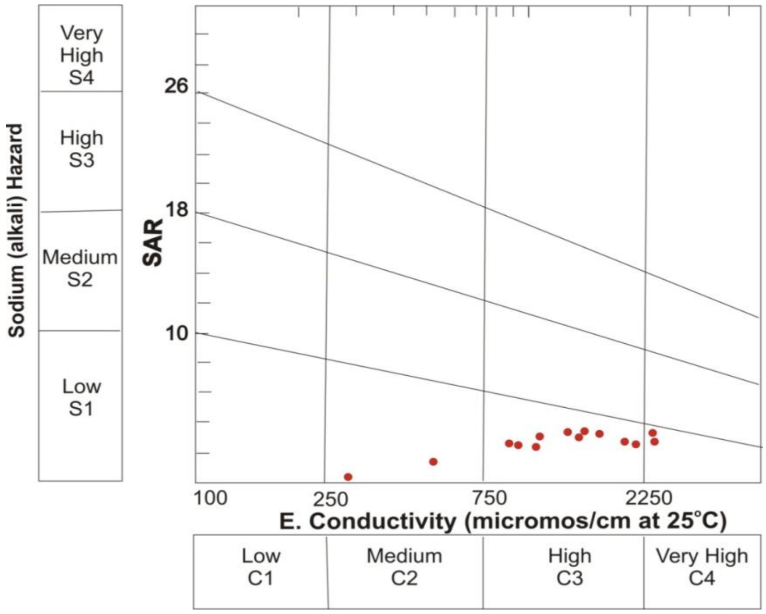

Fig 11: Modified USSL diagram for groundwater samples from the NIASM watershed.

4.4.3 Residual sodium carbonate (RSC)

RSC values are especially useful when the groundwater contain low levels of salinity whereas groundwater containing high CO_3 and HCO_3 tend to precipitate Ca and Mg carbonates in the soils when used for irrigation (Duraiswami *et al*., 2012) [7-8]. Precipitation of Ca and Mg in the soils increases the concentration of Na in the soil and results in lower soil permeability affecting crop growth and crop yields adversely. Depending upon the RSC values the groundwater can be classified into three categories i.e. good (<1.25 meq/L), medium (1.25 to 2.50 meq/L) and poor (>2.5 meq/L). In the study area, most groundwater samples show RSC values less than zero and are considered to represent good quality water.

4.5 Groundwater facies

The hydrogeochemical facies as described by Piper (1994) [16] were used to denote the diagnostic chemical characteristics of water in hydrogeological system. The major cations and anions from the pre-monsoon groundwater samples were plotted in the Pipers Trilinear diagram in order to understand the spatio-temporal variation in the hydrogeochemical facies. The data generated in the present study is shown in Figure 12.

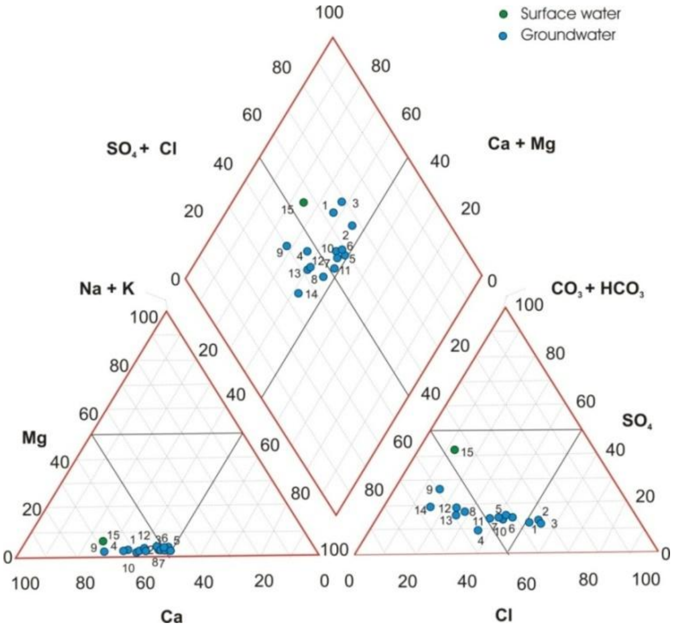

Fig 12: Piper Trilinear diagram to classify chemical types of groundwater samples from the NIASM watershed.

Most groundwater from the study area belong to the Ca+Mg>Na+K; $HCO_3+CO_3>Cl+SO_4$ facies. Weathering regimes (recharge zones) of jointed basaltic aquifers in the DPR generally show this hydrogeochemical facies

(Duraiswami, 2008) [5-6]. However, some groundwater belong to the Ca+Mg>Na+K; Cl+SO_4>HCO_3+CO_3 facies are also present. Besides variation in the chloride and sulphate ions in some samples, most variations in the groundwater reflect values that are well within the range from the Deccan Trap groundwater province. This indicates that the basalt provenance for the major cations is reflected in the chemistry of the groundwater.

5. Conclusions

The NIASM watershed falls in the rain-shadow, drought prone region of the Maharashtra state. The region experiences arid megathermal type of climate that is responsible for water scarcity and salinity in the region. Dug wells and bore wells in shallow basaltic aquifer are the primary source of irrigation in the area. The groundwater from the study area is alkaline and only very few groundwater samples from the present study show high to very high salinity. In the present study based on the SAR values, the groundwater for irrigation purposes are classified as ‘good’ and most of them belong to the Ca+Mg>Na+K; HCO_3+CO_3>Cl+SO_4 facies. Positive correlation of EC with major cations indicates a strong lithological control, however, a strong positive correlation with Cl and a weak correlation with HCO_3 indicate the amount of chloride in the groundwater controls the EC. Higher chloride and nitrate in some samples could be attributed to anthropogenic additions, however, weathering regimes of basaltic rock, and moderately drained, agriculturally dominated landuse - landcover can account for the groundwater quality in the NIASM watershed.

6. Acknowledgements

Authors are thankful to the Director, National Institute of Abiotic Stress Management, Malegaon, Baramati for providing financial assistance and to the Head, Department of Geology, University of Pune, Pune, for providing laboratory facilities during the entire course of study. Authors are also thankful to the Er. Pravin More of NIASM, Baramati for his technical assistance during the course of prepartion of this Manuscript.

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