IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 10, Issue 12 Ver. IV (Dec. 2016), PP 46-52
www.iosrjournals.org

Assessment of Irrigation Suitability of Semi-Arid Region of Gondia District, Maharashta India

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Abstract: *The An investigation has been carried out to understand the hydrochemistry of the groundwater of semi-arid region of upper Wainganga basin and its suitability for irrigation uses. A total of 64 groundwater samples were collected during pre-monsoon season. The water is neutral to alkaline in nature with pH ranging from 7.0 to 8.6 with high electrical conductivity (EC) and total hardness. Higher concentration of nitrate was observed in 70% of samples. The irrigation suitability of groundwater of study area measured with different irrigation indexes like EC, sodium percentage, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and permeability index (PI). The interpreted results were indicated that most of the groundwater samples are suitable for irrigation uses but not suitable for drinking purpose. Chemical fertilizers, rice mills and anthropogenic activities are contributing to the high nitrate, chloride and sodium concentrations in the groundwater of the study area. Groundwater quality in the study area is altered by anthropogenic activities, and proper groundwater management strategies are necessary to protect sustainably these valuable resources.*

Keywords: *Hydrochemistry, groundwater, irrigation suitability, Gondia district, India*

I. Introduction

Over the few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for agriculture and domestic activities. Irrigation of agricultural lands accounted for 70% of the water used worldwide. In several developing countries, irrigation represents up to 95% of water uses, and plays a major role in food production and food security. As there are very limited water resources in the India, the water scarcity problem has been recently exacerbated by low rainfall. The increased demand for water for irrigation has been partly met by excessive withdrawal of groundwater beyond the safe yields. The dependence on groundwater for irrigation purpose is increasing in many regions because of limited surface water as perennial rivers and frequent failure of monsoon. It leads to overexploitation of the groundwater resource and degraded water quality.Numerous studies in India have been concentrated on groundwater quality monitoring and its suitability for drinking, domestic, and agricultural uses [1, 2, 3, 4]. Several studies have also reported groundwater contamination by nitrate due to agricultural activities [5, 6] and the soil contamination due to irrigation water quality [7]. Excessive solutes in irrigation water are a common problem in semi-arid areas where water loss through evaporation is maximal. Salinity problems encountered in irrigated agriculture are most likely to arise where drainage is poor, which allows the water table to rise close to the root zone of plants, causing the accumulation of sodium salts in the soil solution through capillary rise following surface evaporation.

Each groundwater system is known to have a unique chemistry, which is acquired as a result of several factors such as soil–water interaction, dissolution of mineral species, duration of solid–water interaction, and anthropogenic sources [8, 9]. Various parameters such as Na%, sodium absorption ratio (SAR), residual sodium carbonate (RSC), Wilcox, and US Salinity Laboratory (USSL) classifications have been used for evaluating the suitability of groundwater for irrigation purposes [10, 11, 12, 13, 14]. The objective of this scientific investigation is to study the chemical and physical suitability of groundwater for irrigation in Gondia District, Maharashtra, India. The water samples were analyzed for major cations i.e., Na^+, K^+, Ca^{2+}, Mg^{2+}, and anions i.e.,Cl^-, HCO_3^-, SO_4^{2-}, NO_3-, and other physical parameters i.e. total dissolved solids (TDS), electrical conductivity (EC), total hardness, total alkalinity and pH.

II. Study Area

On north-eastern side of Maharashtra, Gondia district is situated between 20°39 and 21°38 north latitudes and 79° 52’ to 80°42 east longitudes and share borders with Madhya Pradesh on north and Chhattisgarh in east (Fig. 1). The total area is about 5859 sq.km. The district falls under the Wainganga basin with rivers like Bagh, Chulbandh, Gadhavi and Bavanthadi are the tributaries of river Wainganga. The Gondia district is characterized by a hot arid climate. The normal annual rainfall over the district ranges from 1300 mm to 1500 mm. The Wainganga valley forms a central depression in the district occupying half of its area. The valley floor is formed over Achaean crystalline terrain and is covered by riverine alluvium. Hydrogeologly, major part of the district is occupied by the crystalline rocks of Pre-Cambrian formations that is Archaean. A map depicting the geological features is shown in Fig 2. The Archeans are represented by Amgaon Group consisting of Augen Gneisses, Amphibolites, Pegmatite and these formations are confined to the N & NE corner of the district around Amgaon. The Amgaon group is followed by Dharwars (Lower Precambrian) are represented by Sakoli Group of rocks; the latter forms the major stratigraphic unit in the district. The Sakoli Group consists of Quartzites, Schists, Phyllites, Metavolcanics and BIF and is confined to the NW and SW part of distric. The areas surrounding Salekasa, Wadegaon, Murdoli, Deori and Chinchgarh rocks consisting of Rhyolites, Andesites, and basic volcanics are present which respectively represents Bijli, Pitepani and Sitagota formations of the Dongargarh Group. Paddy is the staple food crop of the district and there is various rice mills located in this area.

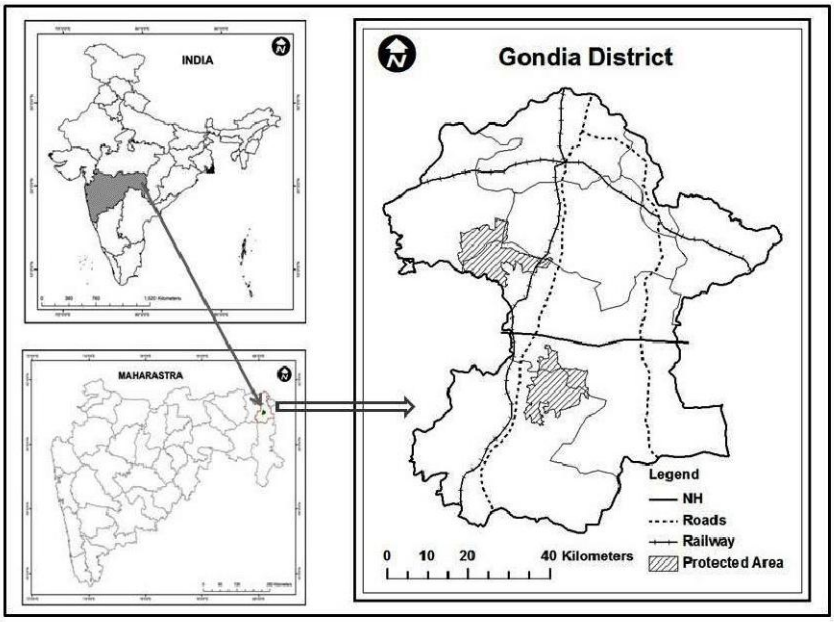

Fig. 1: Location Map of Gondia District

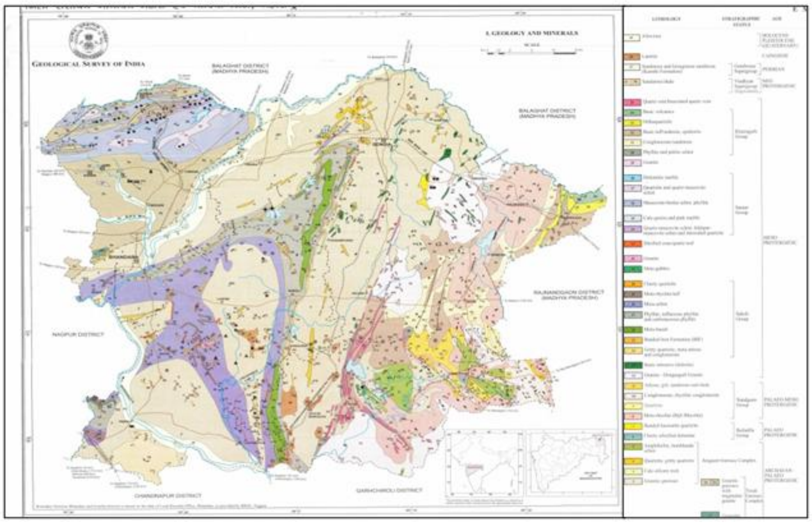

Fig. 2: Geological Map of Gondia & Bhandara Districts

III. Materials and Methods

At the time of sampling, the 500-ml polyethylene sampling bottles were thoroughly rinsed two or three times, using the groundwater to be sampled. The chemical parameters viz. pH and electrical conductivity (EC) were measured, using digital instruments (Systronics, India) immediately after sampling. Sixty four samples were collected from bore and dug wells during summer 2016 from the study area (Fig. 3). The groundwater sampled bottles were labelled, tightly packed, transported immediately to the laboratory, and stored at 4°C for chemical analyses. During the analyses, blanks and standards were run at the start of analysis. The reagents were used of analytical grade. The aqueous solutions were prepared, using double distilled deionized water. The standardization of reagents and solutions was in accordance with standard methods of water chemical analysis [15]. The values of TDS were calculated from EC by multiplying a factor that varies with the type of water [16]. TH, Ca^{2+}, Mg^{2+}, TA, HCO_3^- and Cl^- were estimated by titrimetry, whereas concentrations of sodium (Na^+) and potassium (K^+) in the groundwater were measured by using flame photometer from Elico (India). NO_3^- and SO_4^{2-} was estimated using Chemito UV/VIS spectrophotometer. All the experiments were carried out in triplicate, and the results were found reproducible within a ± 5 % error limit by taking the difference between the TCC and TCA [17].

IV. Result and Discussion

In the present study area, the cation–anion balance is computed for accuracy of complete chemical analysis of groundwater sample. The computed value of the cation–anion balance is observed to be within the limit of ±5%, thus confirming the accepted range of hydrogeo-chemical values. The statistical data is given in table 1.

Physical Characteristic of Groundwater:

The combination of CO_2 with water forms carbonic acid, which affects the pH of the water. The pH in the groundwater is varied from 7.0 to 8.2. The value of EC is a measure of a material's ability to conduct an electric current and varies from 490 to 3152 μS/cm (Table 1). The higher average value of EC in the pre-monsoon suggests the enrichment of salt due to evaporation effect. According to the classification of EC, 70.3% of the total groundwater samples come under the type low enrichment of salts (EC<1,500 μS/cm), 28.1% under the medium enrichment of salts (EC: 1,500 and 3,000 μS/cm), and only one sample of Goda Tola village under high enrichment of salts (EC>1,500 μS/cm). The TDS indicates the inorganic pollution load in the water, is between 240.8 and 2184.5 mg/L. Degree of groundwater quality can be classified as fresh, if the TDS is less than 1,000 mg/L; brackish, if the TDS is between 1,000 and 10,000 mg/L; saline, if the TDS is varied from 10,000 to 1,000,000 mg/L; and brine, if the TDS is more than 1,000,000 mg/L [18]. Accordingly, the quality of groundwater in the present study area is classified as fresh in 70% of samples. In groundwater of study area, TH ranges from 30 to 689 mg/l. According to Dufor and Becker [19] classification based on TH, groundwater classified as soft (0–60); moderately hard (61–120); hard (121–180) and very hard (>180) water. About 93.8 % of samples belongs to very hard type and rest to hard type water. The TA, due to the HCO_3^- ion only, as the pH less than 8.6, is in between 105 and 539.34 mg/l.

Table 1. Stastical data of the groundwater samples of study area during pre-monsoon season[a]

Parameters	pH	EC	TDS	TA	TH	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
Min	6.6	490	241	105	30	7.4	0.2	10	1.22	128	18	6	1.6
Max	8.1	3152	2184	539	689	278	413	245	116	658	543	485	285
Average	7.1	1293	819	253	395	114	47	90	41	309	157	115	98
Standard Deviation	0.27	481	366	90	144	78	71	50	26	110	101	91	76

[a]EC is in μS/cm at 25◦C and other parameters are in mg/L expect pH

Chemical Characteristic of Groundwater:

The dominant cations are in the order of $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$. The Na^+ concentrations are ranging between 7.4 and 278 mg/L with average of 113.93 mg/L. The concentration of Na^+ (Average 113.93 mg/l) is higher than that of K^+ (Average 47.12 mg/l; Table 1). The higher concentration of Na^+ among the cationic concentrations reflects a rock weathering and/or dissolution of soil salts stored by the influence of evaporation [7] and also indicates its higher solubility behaviour, while the lower concentration of K^+ is because of its fixation on clay minerals [5]. The Ca^{2+} and Mg^{2+} are the most abundant elements in the groundwater. The concentration of Ca^{2+} is between 10 and 245 mg/ L, while that of the concentration of Mg^{2+} is varied from 1.22 to 115.8 mg/L. Ca^{2+} may dissolve readily from carbonate rock and limestone or be leached from soil. However, the dissolved Mg^{2+} concentration is lower than Ca^{2+} in the groundwater. Ca^{2+} is an essential nutritional element for humans and helps in maintaining the structure of plant cells and soils. The higher contribution of Na^+ than that of the contribution of Ca^{2+} to the total cations is expected due to influence of ion exchange.

The dominant anions are in the order of $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. HCO_3^- in water is present mainly in association with Ca^{2+} and Mg^{2+}. HCO_3^- varies from 128.1 to 658 mg/l. The Cl^- is the second largest ion, varies between 17.75 and 543 mg/L (Table 1). In fact, the Cl^- is derived mainly from the non-lithological sources such as poor sanitary conditions, irrigation-return flows and chemical fertilizers and its solubility is generally high. The content of SO_4^{2-} is observed from 6 to 485 mg/L. SO_4^{2-} is a naturally occurring ion in almost all kinds of water bodies and is a major contributor to total hardness. SO_4^{2-} content more than 200 mg/l is objectionable for domestic purposes; beyond this limit, SO_4^{2-} causes gastro-intestinal irritation. The value of NO_3^- in the groundwater is observed between 1.61 and 285 mg/L. About 70.4 % of water samples have NO_3^- concentration above the tolerance limit of 45 mg/l [20, 21]. The NO_3^- is a non-lithological source. In natural conditions, the concentration of NO_3^- does not exceed 10 mg/L in the water, so that the higher concentration of NO_3^-, beyond the 10 mg/L, is an indication of anthropogenic pollution. It is mainly due to influences of poor sanitary conditions and indiscriminate use of higher fertilizers for higher crop yields in the study area [22].

Irrigation Suitability of Groundwater:

The suitability of water for irrigation mainly depends on relative concentrations of salinity (EC) and Na^+ in relation to other cations and anions [5, 7]. On irrigated lands, salinization is the major cause of loss of production and is one of the most prolific adverse environmental impacts associated with irrigation. Saline conditions severely limit the choice of crops, adversely affect crop germination and yields, and can cause soils to be difficult to work. Excessive concentrations of dissolved ions such as Na^+, HCO_3^- and CO_3^{2-} present in the irrigation water affect plants and agricultural soil physically and chemically through lowering of osmotic pressure in the plant structural cells [23]. This prevents water from reaching the branches and leaves, thus reducing the agricultural productivity [24]. Hence, EC and Na concentrations are important in classifying irrigation. The various irrigation parameters are calculated for groundwater samples of study area are given in table 2.

Table 2. Irrigation parameters for pre-monsoon samples

Sample No.	% Na	SAR	RSC	PI	Sample No.	% Na	SAR	RSC	PI
1	69.9	8.6	5.5	33.1	33	37.2	2.94	-0.40	28.1
2	33.8	2.0	-4.1	19.6	34	45.0	4.25	-3.14	22.2
3	62.9	5.8	0.9	28.3	35	71.1	8.65	1.38	27.0
4	51.7	4.1	1.9	31.2	36	24.1	1.69	-4.79	20.9
5	66.3	6.7	1.7	27.7	37	56.3	6.89	-5.26	20.0
6	46.8	4.3	-4.0	18.7	38	13.0	0.82	-5.02	21.1
7	25.1	1.8	-6.8	17.6	39	55.6	6.36	-6.06	20.8
8	18.2	1.5	-6.2	18.8	40	82.3	12.17	6.95	36.8
9	63.5	5.2	1.1	27.1	41	72.4	10.29	2.12	27.7
10	54.3	5.3	-2.8	23.9	42	16.6	1.00	-3.68	23.4
11	19.0	1.2	-2.5	25.7	43	46.9	4.03	-0.30	26.4
12	44.1	3.3	-2.4	22.3	44	42.3	3.72	-5.28	19.6
13	25.5	2.2	-9.3	14.2	45	26.8	1.60	-1.59	28.7
14	44.5	4.7	-5.0	20.8	46	16.3	1.04	-2.10	27.7
15	75.1	9.8	2.3	28.3	47	55.3	7.08	-8.50	18.1
16	44.5	3.7	-5.0	18.9	48	63.9	7.97	-2.24	22.6
17	15.2	1.0	-3.3	24.2	49	31.6	0.76	-0.60	34.0
18	47.1	3.7	-1.6	24.2	50	22.2	1.48	-4.30	21.3
19	26.8	1.8	-3.2	23.4	51	16.5	0.65	-4.81	21.6
20	43.3	4.0	-1.1	24.8	52	40.8	2.84	-3.74	20.6
21	13.7	0.5	-1.6	34.6	53	56.1	7.02	-5.50	20.0
22	23.4	1.7	-4.1	21.8	54	54.3	6.58	-3.82	21.2
23	23.1	1.6	-2.7	24.6	55	61.6	6.05	-8.46	20.3
24	15.7	1.4	-9.7	14.9	56	27.7	1.49	-3.69	22.7
25	40.7	3.6	-7.3	17.2	57	11.8	0.81	-6.70	17.6
26	30.9	1.6	-4.3	21.5	58	29.0	1.63	-2.72	24.8
27	5.7	0.4	-6.6	18.7	59	33.7	2.50	-4.69	20.2
28	90.8	15.3	2.3	32.1	60	6.0	0.25	-2.50	29.4
29	87.9	18.0	2.8	27.5	61	56.1	4.30	2.30	33.9
30	21.8	1.2	-6.0	18.4	62	51.7	4.12	1.02	29.6
31	34.7	2.7	-0.7	26.5	63	58.6	5.35	-5.26	20.7
32	14.0	0.8	-2.2	28.0	64	36.6	2.36	-5.76	18.1

Salinity hazard

As the salinity increases in water, it leads to sluggish drainage conditions in soils. Therefore, the higher the salinity hazard, the greater are the harmful effects on plant growth. In the groundwater of study area EC of groundwater is found to be in the range from 490 to 3152 µS/cm. According to the classification of salinity hazard, none of the groundwater sampling points falls in the excellent class for irrigation (Table 3). 90.6% of groundwater sampling points are observed from the permissible class. Hence it needs a special management measure to control salinity for selection of crops of good salt tolerant.

% Sodium

Another ratio related to the sodium hazard is expressed in terms of percentage sodium ($\%\mathrm{Na}^+$) for judging the water quality for irrigation. The % Na^+ is computed taking the ionic concentrations in meq/l.

$\%\mathrm{Na}^+ = (\mathrm{Na}^+ + \mathrm{K}^+) / (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+) \times 100$

Generally, the $\%\mathrm{Na}^+$ should not exceed 60 in water used for irrigation. In the present study, 12 samples has $\%\mathrm{Na}^+$ higher than 60 (Table 3). Thus, 81.2 % of samples found suitable for irrigation.

Table 3: Classification of groundwater quality based on suitability of water for irrigation purpose.

Parameters	**Range**	**Class**	**No. of Samples**	**% of Samples**
EC	< 250	Excellent	0	0 %
	250–750	Good	3	4.7 %
	750–2,250	Permissible	58	90.6 %
	>2,250	Unsuitable	3	4.7 %
Na%	<60	Good	52	81.25
	>60	permissible	12	18.75
RSC	<1.25	Safe	54	84.37
	1.25-2.5	Marginally suitable	7	10.93
	>2.5	Not suitable	3	4.68
SAR	<10	low sodium hazard	61	95.3
	10-18	moderate sodium hazard	3	4.7
	19-26	High sodium hazard	0	0
	>26	Very High sodium hazard	0	0

Residual sodium carbonate

The soil permeability decreases as Ca^{2+} and Mg^{2+} get fixed in the soil by the process of Base Exchange due to the tendency of these ions to precipitate, as the water in the soil becomes more concentrated, as a result of evaporation and plant transpiration. The RSC is defined as the excess of carbonate and bicarbonate amount over the alkaline earths (Ca^{2+} and Mg^{2+}). RSC is used for evaluating the water quality for irrigation purpose along with US Salinity Laboratory's diagram. The RSC can be computed in epm as-

$(\mathrm{Na}_2\mathrm{CO}_3) = (\mathrm{CO}_3^{2-} + \mathrm{HCO}_3^{-}) – (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})$

Eaton [25] and Lloyd and Heathcote [26] suggested the classification of irrigation water on the basis of RSC (table 3). 84.3 % of sample is safe for irrigation purposes.

Sodium hazard

The process of ion exchange reactions in soil is expressed in terms of sodium adsorption ratio (SAR). The SAR is also called sodium hazard or alkali hazard. This is computed by taking the concentration of ions in meq/l.

$\mathrm{SAR} = \mathrm{Na+} / \surd(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})/2$

The sodium hazard (S) is classified as (a) low sodium hazard (S1), when the SAR is less than 10; (b) medium sodium hazard (S2), when it is in between 10 and 18; (c) high sodium hazard (S3), when it varies from 18 to 26; and (d) very high sodium hazard (S4), when it is more than 26. As the sodium hazard increases in water, it makes soil unfit for plant growth due to loss of soil permeability. Therefore, the higher the SAR values, the greater are the risk of sodium on plant growth. The computed values of SAR from the groundwater of the study area are in between 0.2 to 18 and 95.3 % of samples has low sodium hazard (Table 3).

USSL's diagram

The combined effect of EC and SAR on plant growth is shown graphically by the United States Salinity Laboratory [27], which is widely used for classification of water quality for irrigation. The determined values of EC and SAR from the groundwater of the study area are plotted in the USSL's diagram (Figure 3). 71.8% of groundwater sampling points fall in the zone of C3S1, indicating high salinity hazard and low sodium hazard. Whereas, 15.6% of samples in C3S2 indicating high salinity hazard and medium sodium hazard. Thus, this water is considered as moderately good to irrigate salt tolerant and semi-tolerant crops under favorable drainage conditions.

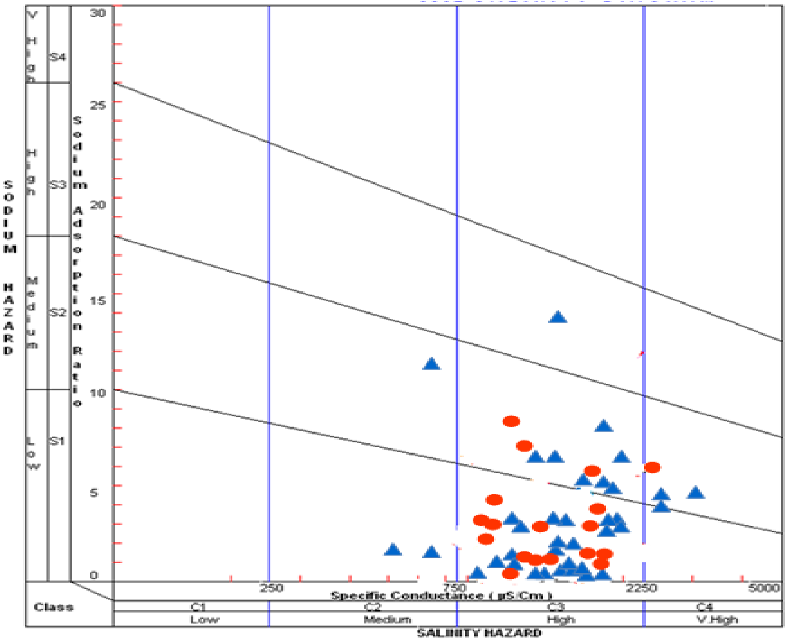

Fig. 3.US salinity diagram for groundwater of study area

Permeability Index (PI)

Doneen [28] has assessed the suitability of water quality for irrigation based on the cations in relation to the alkalies. This relation is referred to as permeability index (PI), which is computed (Eq. 13), taking the ionic concentrations in meq/l.

Permeability Index (PI) = (Na + √HCO3) / (Ca + Mg + Na) x 100 (epm)

The computed values of PI from the groundwater of the study area are below 25 (Table 2). As per PI values (Figure 4), the groundwater samples fall in class I indicate water is good for irrigation purposes [29].

V. Conclusion

Groundwater quality of Upper Wainganga basin is assessed on basic of physico-chemical parameters. 70.3% of the total groundwater samples come under the type low enrichment of salts on basis of EC values. The 70% of groundwaters are freshwaters (TDS\500 mg/l). Na^+ is the dominant cation and the higher contribution of Na^+ than contribution of Ca^{2+} is due to influence of ion exchange anthropogenic activities. About 70.4 % of water samples have NO_3^- concentration above the tolerance limit of 45 mg/. It suggested that majority of samples are not suitable for drinking and it is mainly due to influences of poor sanitary conditions and indiscriminate use of higher fertilizers for higher crop yields in the study area.

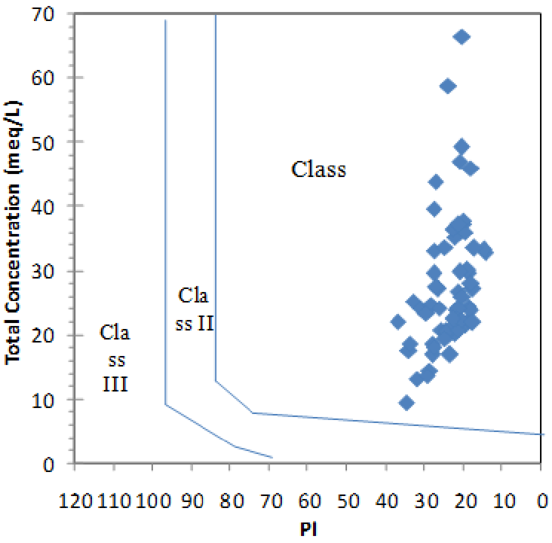

Figure 4. Permeability Index diagram for groundwater of study area

A variety of water quality parameters has been used to evaluate water for irrigation use during summer time when water demand for irrigation increased. Based on salinity, Na%, RSC, SAR, USSL classification, and Permeability Index, a very large portion of the groundwaters are considered suitable for irrigation. Overall, groundwater quality in the upper wainganga Plain is impeded by anthropogenic activities, and proper groundwater management strategies are necessary to protect sustainably this valuable resource.

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