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THE CHEMISTRY OF GROUNDWATER IN SANGAMNER AREA WITH REGARD TO THEIR SUITABILITY FOR DRINKING PURPOSES

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ABSTRACT

The modern civilization, industrialization, urbanization and increase in population have led fast degradation of water resources. About 80% of all the diseases of human beings are caused by water since it is directly related with human health. Therefore, it is necessary to create awareness among the present and future generation about water quality. In view of this, the Sangamner area of Ahmednagar district, Maharashtra, India is selected to study the chemistry of groundwater quality and its suitability to drinking purposes, where the groundwater is main source for irrigation and drinking. The groundwater samples were collected from fifty seven locations covering the entire study area during pre-monsoon and post-monsoon season. The samples were analyzed for different physico-chemical parameters like pH, EC, TDS, Na^+, K^+, Ca^{2+} , Mg^{2+} Cl^- , HCO^-_3 ,SO_4^{2-},NO_3^- and Fe using standard methods. It was found that the parameters like TDS, Na, Ca, Mg, total hardness and nitrate were exceeded the permissible limit in the majority of the samples particularly from irrigated area. Few samples exceeded the maximum permissible limit of chloride. On the basis of TDS, the ground water is classified as fresh, slightly saline to moderately saline and very saline in character. The comparisons of the groundwater quality in relation to drinking water with Indian standard – drinking water specification – 1991, proves that water quality in most of the villages in the irrigated area is unsuitable for domestic purposes and proper treatment is needed before using it for drinking purpose.

Keywords: Drinking water, permissible limit, physico-chemical parameters, hardness of ground water, nitrate pollution.

INTRODUCTION

The quality of water is of vital concern for man since it is directly linked to human health. The presence of safe and reliable source of water is an essential prerequisite for the establishment of a stable community. The quality of water varies widely with respect to its various uses and the water quality suitable for one purpose may not satisfactory for another. Chemical contamination of drinking water either naturally or by anthropogenic sources is a matter of serious concern as the toxic chemicals do not show acute health effects unless they enter into the body in appreciable amounts but they behave as a cumulative poison showing the adverse health effects after a long period of exposure[1].

The growth of human population coupled with industrialization, urbanization have started putting pressure on the quantitative as well as qualitative aspect of natural resources like soil, water etc. The surface water resources are not acceptable for drinking purpose as they are often contaminated by organic, inorganic and biological constituents, which are dangerous and potentially hazardous to consumers[2,3]. The suitability of groundwater for any particular use depends upon is chemical properties. A huge amount of work has been carried out to determine the ground water quality in different regions and prevalence of many chemical constituents[4,5-9]. Ingestion of polluted water can result various serious health problems[10-14]. Since the study area is in semi - arid region with low rainfall, there is greater dependence on the groundwater. Groundwater is mainly used for drinking, washing and bathing, for livestock raring and for irrigation purposes in the area. However, the establishment of industrial estate by the Govt. of Maharashtra at Sangamner and growth of sugarcane and allied industries has started deteriorating the groundwater quality in some parts of the study area[5]. The groundwater is the only alternate as safe and pure water source for drinking as well as other domestic purposes in the area. In view of this, it was decided to study the chemistry of groundwater from Sangamner area with regard to its suitability for drinking purposes.

Study area

Sangamner area is located in the northern part of the Ahmednagar district of Maharashtra State. The tahsil lies between 18°36' N to 19 ° 1'N latitude and 74 ° 1'W to 74 ° 56'W longitude. The Sangamner town is located on the confluence of the Mahalungi and the Pravara River. It is a Taluka head quarter which is at a distance of 150 km from Pune, on Pune - Nasik National Highway No. NH-50 (Fig.1). The area is drained by the Pravara River which is a tributary of Godavari and has its origin in the hilly region of Western Ghats. Geologically, basalt underlay the Pravara basin, which is characterized by thick alluvium (upto 35 m.). Several dams and weirs have been constructed across Pravara River. Because of construction of Bhandardara Dam in the source region of Pravara River, the valley has been brought under intensive agriculture with sugarcane as a single dominant crop. Subsequent to the establishment of co-operative sugar mill at Sangamner in 1967, the agriculture in the area has witnessed rapid changes in the cropping pattern. In addition to sugar industry, several allied industrial units have also come up in the area. The effluents from sugar industry, with little or no treatment have been stored in lagoons and then discharged into the natural stream flowing through the agricultural area for a distance of about 8 to 9 km. This effluent stream finally meets the Pravara River at Sangamner and deteriorate the quality of water. In some remote areas, river and pond water is also used for various domestic purposes including cooking and drinking. The medical facilities in this area are also not appropriate. Majority of the people are farmers residing in the fields along with livestock near the wells and on the bank of river.

EXPERIMENTAL

A network of 57 groundwater-sampling stations distributed over mainly the irrigated region of the Sangamner area. The samples were collected for two seasons i.e. pre monsoon (May) and Post monsoon (November). The 43 of them were from irrigated area and 14 from non-irrigated area. Sampling locations were chosen on the basis of pilot geological and hydro-geological survey of the area. The samples from dug / bore wells were collected on the basis its use for drinking / domestics purposes. The samples were collected in polyethylene bottles of one-liter capacity. The care was taken to collect samples after pumping for some time. The pH, electrical conductivity (EC) and temperature were measured in the field. The samples were then brought to the laboratory for further chemical analysis. The analysis was carried out in the laboratory by using the procedures given by APHA, AWWA, WPCF[15]. Using titrimetric methods performed the analysis of chloride (Cl^-), total alkalinity as $CaCO_3$, Calcium (Ca^{2+}) and total hardness as $CaCO_3$ (TH). While nitrate, phosphate and sulphate were analyzed by spectrophotometric methods (Hitachi-2000,UV-visible spectrophotometer), the alkali elements like sodium (Na) and potassium (K) were detected by flame photometer (Corning 400). Using Stiff Computer program for calculating the charge balance error (CBE) was calculated to check the analytical accuracy. The charge balance error up to 10% was considered valid.

RESULTS AND DISCUSSION

The results of the physicochemical analysis of groundwater are presented in Table 1 and 2. Table 3 shows the critical parameters exceeding the Indian standard – drinking water specification – 1991[16], permissible limits along with the permissible limits for these parameters.

Variation in pH and electrical conductivity

pH of groundwater ranges from 7.1 to 8.8 and 7.4 to 8.9 during pre and post monsoon seasons respectively, which indicates weakly to moderately alkaline nature of groundwater. The slight increase of pH can be attributed to the higher proportion of bicarbonates and discontinued supply of CO_2 to cessation of rainfed recharge to the aquifer[17]. This increase in pH also be related to higher ionic content of groundwater. From Table 3, it is observed that 12.28 % and 26.31% samples exceeds the permissible limit in pre-monsoon and post-monsoon seasons respectively prescribed by drinking water standard[16]. The pH of groundwater has no direct effect on health but all bio chemical reactions are sensitive to the variation in pH.

The **c**onductivity measurement is an indicator of ionic concentration of water. It depends upon temperature and concentration and types of ions present[18]. The ground water from study area was showing higher EC values which indicates increase in the mineralization content of water. The EC values ranges from 840 to 11350 μS/cm and 620 to 9200 μS/cm during pre and post-monsoon respectively. Lowering of EC values in post - monsoon could be due to dilution effect caused by rainfed recharge during the monsoon season leading to higher groundwater level. The higher values in EC during pre monsoon reflects concentration effect. The maximum limit of EC in drinking water is prescribed as 1500 μS/cm as per WHO standard[19]. It is observed from the Table 3 that 84.21% and 73.68 % samples during pre and post-monsoon respectively have exceeded the recommended permissible limit.

Variation in Total Dissolves solids (TDS)

TDS is the concentrations of all dissolved minerals in water indicate the general nature of salinity of water. The TDS ranges from 546 to 7377 mg/l for pre -monsoon while it varies from 403 to 5980 mg/l in post-monsoon. The TDS of ground water sample in the pre-monsoon season is found to be higher as compared to the TDS of the post -monsoon season. Increase in TDS in pre- monsoon confirms the interference drawn about higher EC values in this season. It is observed that 56.44 % in pre – monsoon and 52.63% in post monsoon samples have exceeded maximum permissible limit (Table 3) prescribed by the drinking water standard[16].

As far as study area is concerned, salinization of water is recognized as a serious problem in the irrigated sector. On the basis of TDS, Hem[18] has classified the water into four categories.

- < 1000 mg/l : fresh water
- 1000-3000 mg/l : slightly saline
- 3000-10000 mg/l : moderately saline
- 10000-35000 mg/l : very saline
- >35000 mg/l : brine.

By using this criterion, salinity classification is proposed for the groundwater from the study area (Table 4). It is observed from the table that out of 57 well samples during post – monsoon, 15 samples (26.31%) belongs to fresh water category. Out of the remaining, 23 wells (40.35%) represented slightly saline and 19 wells (33.33%) moderately saline types of ground water. Higher percentages (40.35%) of wells in pre-monsoon season i.e. belongs to each of moderately saline and slightly saline type of ground water. It is observed from Table 4 and Fig. 1 that salinization of groundwater is restricted to irrigated area. Further, within the irrigated area, it is also observed that backwater area of Ojhar weir shows more degradation of water quality and the groundwater is not suitable for drinking purpose in this area. Intensive salinization in the downstream part can be attributed to water logging in the area. The higher salinity of groundwater has repressive effect on the thickness of double layer and the result is flocculation of clay particles[20]. The saline water which is not suitable for drinking purpose produced possibly due to evaporation under quasi-stagnate condition as the water table is located at shallow depth (average depth about 1-1.5m). The data presented in Table 4 shows that the area with TDS between 500 and 1000 mg/l (S. No. W1, W15, W16, W18, W44, W45, W47, W48, W49, W51, W54, W55 and W56) lies in the upslope part, which is predominantly non-irrigated agricultural region. Two samples from this zone show TDS values below 500 mg/l (S. No. W52 and W57) during Post – monsoon season. Low salinity of groundwater observed in the upstream part indicates faster circulation of groundwater attributable to physiography of the area.

Variation in chemistry of cationic constituents in groundwater

Ca, Mg, Na and K are the four important cations present in groundwater. Calcium concentration in the groundwater varies from 20 to 480 mg/l and 56 to 328 mg/l during pre and post-monsoon respectively. Ca is found to be higher during post-monsoon season is due to dissolution of precipitates of $CaCO_3$ and Ca Mg $(CO_3)_2$ during recharge. It is found from the Table 3, 14.83% and 28.07% samples in pre and post-monsoon respectively have exceeded the permissible limit, specified by drinking water standared[16] and WHO[19]. Therefore, constant use of these well waters for drinking purpose may lead to kidney stones or joints pains in population.

The Mg value varies from 200 to 406 mg/l and 10 to 457 mg/l during pre and post-monsoon respectively. It is observed that 50.87% and 66.66% samples in pre and post-monsoon respectively have exceeded the maximum permissible limit (Table 3) prescribed by drinking water standard[16]. Excess of calcium and magnesium shows the hardness in water and is not good for drinking purpose. Although magnesium has been called one of the most important electrolytes in the body and may be connected to lower occurrence of osteoporosis, high concentrations of magnesium can cause diarrhea and it has a high solubility and is geologically abundant[21].

The sodium content of the groundwater ranges from 21 to 440 mg/l in pre-monsoon season and 10 to 829 mg/l in post - monsoon season. WHO (1979) has given the guideline value for sodium as 200 mg/l. It is observed that 77.19 % and 42.10% samples in pre and post monsoon have exceeded the permissible limit. Sodium imbalance in drinking water has been reported to cause a large number of lives threatening diseases. Hence, the excess consumption of sodium has been recognized as risk factor in hypertension[19].

The K concentrations are negligible although slight increase is noticed in post-monsoon season (Table 1 and 2).

Variation in chemistry of anionic constituents in groundwater

The anions in the groundwater include HCO_3, Cl, SO_4 and NO_3. The Cl value ranges from 48 to 1204 mg/l and 69 to 1533 mg/l during pre and post-monsoon respectively. Cl is found to be higher in post-monsoon indicate leaching from upper soil layers derived from industrial and domestic activities and dry climates. Very few samples 3.5% and 17.54% samples in pre and post-monsoon respectively have crossed the maximum permissible limit (Table 3) prescribed by drinking water standard[16].

The SO_4 content of the groundwater ranges from 2.4 to 180 mg/l in pre-monsoon and in the post – monsoon it varies from 19 to 180 mg/l. Sulphate is higher in post-monsoon season may be due to action of leaching and anthropogenic activities. SO_4 is not active in summer season because it is mainly derived from fertilizer sources and farmers do not generally use fertilizers in summer. The entire samples in the study area are within the maximum permissible limit specified by drinking water standard[16] and WHO[19]. Higher concentration of sulphate in water can cause malfunctioning of the alimentary canal and shows cathartic effect on human body[22]. Excess sulphate problem does not exist in the area. Similar observation were found for iron concentration in the area.

In the present study, bicarbonate (HCO_3) value ranges from 162 to 772 mg/l and 204 to 768 mg/l during pre and post-monsoon respectively. HCO_3 was higher during post- monsoon season may be due to action of CO_2 upon the basic material of soil and rock since the origin of HCO_3 can be related to the aquifer lithology.

Nitrate concentrations are higher in pre - monsoon than in post – monsoon (Table 3). It is observed from Table 3 that the minimum concentration as low as 2mg/l and maximum as high as 100mg/l. In irrigated area, 28 samples (49.12%) and 10 samples (17.54%) in pre – monsoon and post – monsoon respectively have exceeded the permissible limit of nitrate (>45mg/l) drinking water standard[16]. The high values of nitrate are observed in the irrigated area which can be attributed to excessive use of chemical fertilizers in the sugarcane-cultivating tract. The groundwater from the villages like Kanoli, Manoli, Rahimpur, Jorve have high concentrations of nitrate (Fig 1). It is also significant to note that area which is thickly populated with residential colonies and industrial sector have high nitrate concentration. The groundwater sample near the Sangamner town as well as sugar factory region have elevated concentration of nitrate.

It is further observed that in the intensive irrigation areas, excess use of nitrogenous fertilizers has hastened the process of NO_3 built up. Around sugar factory areas mixing of effluents with groundwater is responsible for high order of nitrate values. It is also observed that nitrate pollution is localized to certain areas in the rural belt. This is attributed to the nitrogen excreted by cattle in the farm and dairies where large number of buffaloes and cows are housed in relatively small areas. In some villages during summer, it is a common practice to allow cattle herds swimming in the ponds or washed near wells. An excreta of these animals gets accumulated and is leached by rainfall causing higher nitrate pollutions of waters. The extent of such groundwater pollution depends on bio gradation, soil and rock strata characteristics through percolation take place.

It is known that nitrate directly does not affect human health. However, when certain bacteria are present in the digestive tract may convert the nitrates into highly toxic nitrites. In turn, nitrate can lead to Blue Baby syndrome (*Methamoglobinema*) which can be fatal during first three months of life[10]. There is need to generate public awareness about nitrate pollution in the area.

Hardness of groundwater

The maximum permissible limit of total hardness for drinking water is specified as 600 mg/l (Drinking water standard[16]). The Total Hardness values ranges from 70 to 2001 mg/l and 220 to 2641 mg/l during pre and post-monsoon respectively. Variation of hardness is more in post-monsoon samples as compared to pre-monsoon season due to leaching of calcium and magnesium bicarbonate through recharge. The study shows that 54.38% and 70.71% samples in pre - monsoon and post - monsoon respectively have exceeded maximum permissible limit (Table 3) prescribed by drinking water standard[16]. Therefore, it is found in the study area that majority of the samples in the downstream part of the irrigated area have exceeded the permissible limit of total hardness. Hence, groundwater from this area is not suitable for drinking purpose.

On the basis of hardness, groundwater can be classified into four categories[18]. These are:

- very hard : <300 mg/l
- Extremely hard class I : 300-600 mg/l
- Extremely hard class II : 600-1200 mg/l
- Extremely hard class III : >1200 mg/l

In the study area, the groundwater has been classified as per above classification. It is observed that the groundwater can be described as very hard to extremely hard category.

As seen from the Table 5, in post - monsoon, 30 samples (52.63%) out of 57 show very hard category. 16 samples (28.07%) belong to extremely hard class I, 11 Samples (19.29%) to extremely hard class II type groundwater. However, in pre monsoon 7 samples (12.28%) shows very hard category. 18 samples (31.57%) belong to extremely hard class I, 14 samples (24.56%) to extremely hard class II and 18 samples (31.57%) belong to extremely hard class III. The samples having extremely hard class III type of water are found in pre monsoon. It is observed that the hardness of groundwater in the study area is more severe in pre - monsoon season. This fluctuation in the total hardness is attributable to seasonable changes in PCO_2 in the atmosphere of the unsaturated zone[23]. Due to elevated hardness, however, problems to be expected may be solved by softening of groundwater.

CONCLUSIONS

Intensive irrigation has serious effect on the quality of groundwater in the area. Comparison of data with the water quality standard indicated that parameters like TDS, Na, Ca, Mg, total hardness and nitrate have exceeded the prescribed limits in the majority of the samples particularly from the irrigated area. The number of wells exceeding the standard limit is higher in pre - monsoon than in post - monsoon season. TDS of groundwater indicate slightly saline to moderately saline to very saline groundwater properties which suggests that the quality of groundwater from irrigated land use is almost unsatisfactory for drinking purpose. Majority of samples from the irrigated agriculture have exceeded the permissible limit of nitrate. Intensive irrigation along with monoculture type of cropping pattern besides excess use of nitrogenous fertilizers are possible causes of high concentration of nitrate in the groundwater. The groundwater can be categorized as very hard to extremely hard category. In view of this, appropriate farm management practices based on judicious use of resources, controlled use of fertilizers and mixed culture type of cropping pattern need to be adopted to overcome the problem of drinking water quality in the study area.

Table-1: Physico-chemical data for the ground waters from Sangamner area, Ahmednagar district, Maharashtra (Pre - monsoon).

S. No.	WT	pH	EC	TDS	Na	K	Ca	Mg	Cl	HCO_3	SO_4	NO_3	PO_4	Fe	TH
W1	3.03	8.2	4865	3159	300	5.1	92	306	825	582	180	35	0.67	95	1490
W2	3.64	7.8	6240	4056	440	4.8	80	289	850	692	180	36	0.51	40	1390
W3	2.42	8.8	3306	2148	179	5.1	44	41	160	429	121	7	0.2	56	279
W4	6.06	7.8	6980	4537	292	3.2	292	144	993	304	162	53	0.87	35	1322
W5	4.55	7.4	11350	7377	330	1.2	132	406	1204	604	160	60	0.49	ND	2001
W6	3.03	8.1	7416	4820	285	2.1	64	177	512	612	142	81	0.81	8	888
W7	3.64	7.7	5890	3828	310	4	60	116	343	772	131	72	0.51	35	627
W8	12.12	7.4	6742	4382	232	2	236	263	736	560	166	84	0.49	30	1672
W9	13.64	7.4	6447	4190	232	3	160	211	541	740	154	52	0.28	ND	1268
W10	19.7	7.6	4135	2687	224	4.5	64	126	396	480	97	68	0.22	71	678
W11	25.76	7.3	8290	5388	142	2	276	241	1023	300	154	48	0.51	27	1681
W12	18.18	7.7	7420	4823	148	2	480	102	680	560	117	54	0.16	24	1618
W13	10.61	7.6	6690	4348	310	2.2	188	138	780	534	109	46	0.35	29	1037
W14	17.58	7.6	6720	4368	392	0.5	84	143	653	476	98	22	0.51	ND	798
W15	12.73	8	960	624	48	2.2	52	65	243	162	3.4	14	0.18	10	397
W16	10.91	7.8	890	578	80	2.6	44	40	50	390	2.4	20	0.2	18	274
W17	10.61	7.4	5410	3516	350	0.6	80	97	449	582	91	22	0.17	0.25	600
W18	12.73	7.8	3164	2056	180	1.2	44	40	284	246	42	10	0.98	ND	274
W19	12.73	7.4	4950	3217	132	2	116	124	385	486	81	38	1.05	38	800
W20	13.64	7.2	5168	3359	89	4.2	276	176	769	274	94	72	1.01	ND	1413
W21	14.85	7.8	3016	1960	65	0.5	96	121	310	296	49	66	1.01	ND	737
W22	15.15	7.8	3010	1956	75	2	84	109	310	282	53	58	1	ND	658
W23	12.73	7.4	4960	3224	90	2.3	120	155	571	300	54	32	1.01	ND	937
W24	18.18	7.2	4530	2944	168	2	184	143	488	340	84	77	1	36	1048
W25	19.7	7.4	4360	2834	92	1.4	136	165	482	360	92	46	1.01	10	1018
B26	-	7.3	5990	3893	112	1.2	156	207	692	332	93	37	1.02	68	1241
W27	1.52	7.6	6450	4192	105	2.4	180	240	743	308	102	46	1	40	1437
W28	19.7	7.7	3236	2103	142	0.98	48	78	215	506	14	29	0.98	51	440
W29	19.7	7.4	2705	1758	62	2.5	96	97	257	280	26	39	0.99	20	639
W30	14.87	7.4	2890	1878	60	0.8	110	97	257	324	57	65	1.01	42	674
W31	12.77	7.8	3720	2418	79	0.6	104	130	350	328	50	74	0.99	45	794
W32	12.7	7.4	7280	4732	125	6.6	202	347	891	490	166	82	1	60	1933
W33	9.09	7.1	6590	4283	80	2.5	300	215	852	278	141	97	1.15	ND	1634
B34	-	8.1	4280	2782	140	2.1	201	251	805	619	149	60	0.51	52	1535
W35	10.67	8	4265	2772	110	3	60	60	172	440	32	65	0.94	4.5	396
W36	9.09	7.7	1850	1202	54	2.7	56	70	96	342	59	24	0.98	51	428
W37	1.5	7.6	3045	1979	110	2.8	76	92	251	448	82	48	1.03	11	568
W38	12.12	8.2	2890	1878	240	2.9	20	22	73	624	45	17	0.94	17	140
W39	19.67	7.6	4960	3224	115	2	128	120	280	548	90	48	1.04	0.25	813
W40	6.38	8.1	7490	4868	120	4.4	60	134	251	582	3.5	42	0.98	36	701
W41	1.5	7.8	2240	1456	148	4.3	72	78	110	402	180	70	1.02	71	500
W42	6.38	8	2180	1417	148	4	40	44	86	432	3.6	63	0.89	ND	281
W43	9.09	7.6	5720	3718	140	2.4	100	196	391	562	178	68	0.93	ND	1056
B44	-	8.8	910	591	53	0.52	82	40	61	312	82	32	0.23	95	369
W45	7.27	8.7	860	559	42	0.72	48	41	92	224	32	24	0.26	96	289
W46	12.7	8	1920	1248	35	0.65	80	68	90	253	34	52	0.35	102	479
W47	13.6	8.3	1790	1163	45	0.7	85	61	65	267	84	40	0.37	71	463
W48	18.7	8.5	1490	968	60	0.51	69	42	75	202	85	45	0.3	59	345
W49	9.69	8.4	1540	1001	57	0.92	54	68	64	251	104	42	0.47	54	415
W50	23	8.4	2980	1937	65	0.89	80	92	125	356	124	40	0.47	75	579
W51	8.48	8.5	1460	949	58	1.4	74	58	78	281	82	49	0.33	84	424
W52	6	8.6	960	624	45	0.58	82	60	90	261	62	34	0.36	39	452
W53	8.18	8.7	1390	903	52	0.8	79	38	90	234	64	24	0.36	32	354
W54	8	8.5	840	546	47	0.65	78	42	81	241	94	32	0.4	64	368
W55	9.09	8.6	1140	741	31	0.62	74	53	79	241	54	22	0.39	76	403
W56	12.7	8.7	1010	656	21	0.7	88	34	72	214	54	2	0.4	68	360
W57	13.94	8.3	1590	1033	42	0.4	82	20	48	260	49	4	0.35	76	287

Note: 1. All values of the constituents are in mg/l, except pH and EC (μS/cm); 2. Values of Fe are in ppb; 3. W-Dugwell, B- Borewell, TH-Total hardness; 4. Water Table (WT) depth is in meters.

Table-2 : Physico-chemical data of groundwater samples from Sangamner area, Ahmednagar district, Maharashtra (Post - monsoon).

S.No	WT	pH	EC	TDS	Na	K	Ca	Mg	Cl	HCO	SO_4	NO_3	PO_4	Fe	TH
W1	1.8	8.4	890	578	144	2.34	80	12	142	235	72	26	0.019	221	250
W2	0.6	8.2	7905	5138	829	51	120	141	937	666	177	3	0.106	163	880
W3	0.3	8.2	3620	2353	458	8.55	124	163	497	669	174	2	0.044	11	981
W4	2.1	7.4	6610	4297	365	1.54	280	320	950	659	179	12	0.042	12	201
W5	1.5	7.8	9200	5980	760	1.65	326	309	1503	753	180	38	0.043	10	233
W6	0.9	7.9	6720	4368	540	1.57	220	248	923	735	170	14	0.05	ND	157
W7	0.9	7.6	6610	3907	662	2.79	180	185	767	678	172	11	0.019	ND	121
W8	14.	8	5816	3780	476	1.74	202	227	717	768	172	18	0.045	9	143
W9	12.	7.9	5408	3515	495	2.1	196	235	710	737	169	19	0.03	10	145
W10	7.5	8.6	3815	2480	418	1.25	100	124	667	615	144	21	0.036	10	761
W11	9.0	7.9	7212	4688	623	1.37	268	289	1533	457	167	33	0.029	9	185
W12	4.5	8.3	7500	4875	671	1.19	234	321	1480	735	167	24	0.053	11	148
W13	8.1	8.9	6411	4167	681	4.3	140	170	1235	674	166	21	0.117	10	104
W14	4.8	8.3	5209	3386	495	1.2	176	216	1030	745	166	40	0.013	ND	132
W15	1.5	8.3	1400	910	74	0.29	100	76	198	326	38	36	0.017	ND	563
W16	1.5	8.5	1000	650	82	0.4	80	63	85	433	42	2	0.188	ND	460
W17	3.0	8.4	5008	3255	458	2.76	140	160	795	744	165	2	0.237	ND	100
W18	7.5	8.8	800	520	10	0.17	112	43	135	204	42	2	0.134	ND	456
W19	4.5	8.1	4304	2798	318	0.83	236	241	830	566	142	28	0.138	ND	158
W20	2.4	8.2	4612	2998	183	2.85	288	240	950	557	131	30	0.088	ND	170
W21	6.9	8.4	3520	2288	147	0.86	204	214	631	562	125	11	0.032	ND	139
W22	9.0	8.4	5810	3776	188	1.48	304	457	1256	551	161	57	0.05	ND	264
W23	6.0	8.2	5080	3302	322	1.45	308	363	1285	582	118	46	0.013	ND	226
W24	10.	8.3	4612	2997	199	1.03	328	214	837	533	126	38	0.048	ND	170
W25	7.5	8.3	3540	2301	134	0.6	134	276	695	513	144	30	0.029	ND	147
B26	-	8.2	4814	3129	262	0.63	178	258	1008	502	167	39	0.043	ND	150
W27	0.6	8.5	2913	1894	128	2.14	144	198	497	482	115	16	0.05	11	117
W28	12.	8.5	2301	1496	141	0.46	88	136	312	642	63	38	0.263	51	780
W29	12.	8.5	2412	1568	37	0.66	208	152	447	482	58	40	0.357	ND	114
W30	9.0	8.1	2100	1365	65	0.97	182	120	319	523	112	30	0.402	114	948
W31	7.5	8.3	2412	1568	142	0.37	152	232	525	597	104	87	0.05	64	133
W32	4.2	8	5990	3894	209	13.5	284	370	1093	528	163	52	0.052	185	223
W33	4.8	8.3	2716	1765	144	4.85	441	280	1015	546	164	100	0.055	11	225
B34	-	8.1	4260	2769	232	2	188	143	489	594	163	58	0.05	10	105
W35	5.4	8.7	4698	3054	318	0.57	128	141	568	661	161	31	0.057	93	900
W36	3.0	8.8	1580	1030	120	0.48	96	80	113	518	90	3	0.463	10	569
W37	0.3	8.3	2896	1882	171	1.64	144	121	348	510	146	30	0.124	9	858
W38	10.	8.7	1986	1291	297	0.63	56	20	121	673	79	3	0.37	11	220
W39	9.0	8.3	4164	2707	313	1.51	170	125	426	683	164	23	0.099	10	939
W40	4.5	8.9	5574	3623	555	2.76	128	187	717	652	167	12	0.322	12	108
W41	-	8.7	2192	1425	122	0.77	148	121	334	408	131	20	0.161	10	868
W42	4.5	8.6	1789	1163	198	1.08	84	56	170	489	99	48	0.081	11	441
W43	4.5	8.1	4768	3099	295	1.46	138	223	738	732	165	51	0.114	27	126
B44	-	8.6	890	579	61	0.17	98	48	122	316	39	42	0.364	ND	442
W45	3.9	8.7	880	572	43	0.57	80	63	70	351	67	3	0.256	10	459
W46	7.5	8.1	3090	2009	23	0.68	100	56	78	355	50	14	0.358	11	480
W47	3.0	8.3	1390	904	52	0.51	124	73	174	377	55	69	0.151	9	610
W48	10.	8.5	1210	787	63	1.45	102	77	114	357	67	66	0.606	ND	572
W49	1.2	8.8	1296	843	58	0.23	88	69	97	356	62	26	0.14	15	504
W50	7.5	8.4	3216	2090	169	1.25	208	188	560	567	137	20	0.095	530	129
W51	0.3	8.7	810	527	45	0.37	102	65	90	351	43	26	0.209	360	522
W52	7.5	8.7	680	442	41	0.51	80	34	102	285	47	3	0.154	12	340
W53	3.6	8.5	1590	1034	105	0.49	80	126	224	540	78	7	0.287	12	719
W54	3.0	8.6	940	611	53	0.34	88	58	91	382	41	18	0.309	11	459
W55	2.4	8.1	820	533	37	0.74	88	53	110	270	40	18	1.099	11	438
W56	7.5	8	1080	702	25	0.6	144	90	102	467	45	13	0.288	330	730
W57	8.1	7.9	620	403	16	0.23	110	10	69	244	19	2	0.411	257	316

Note: 1. All values of the constituents are in mg/l, except pH and EC (µS/cm); 2. Values of Fe are in ppb; 3. W- Dugwell, B- Borewell, TH-Total hardness; 4. Water Table (WT) depth is in meters.

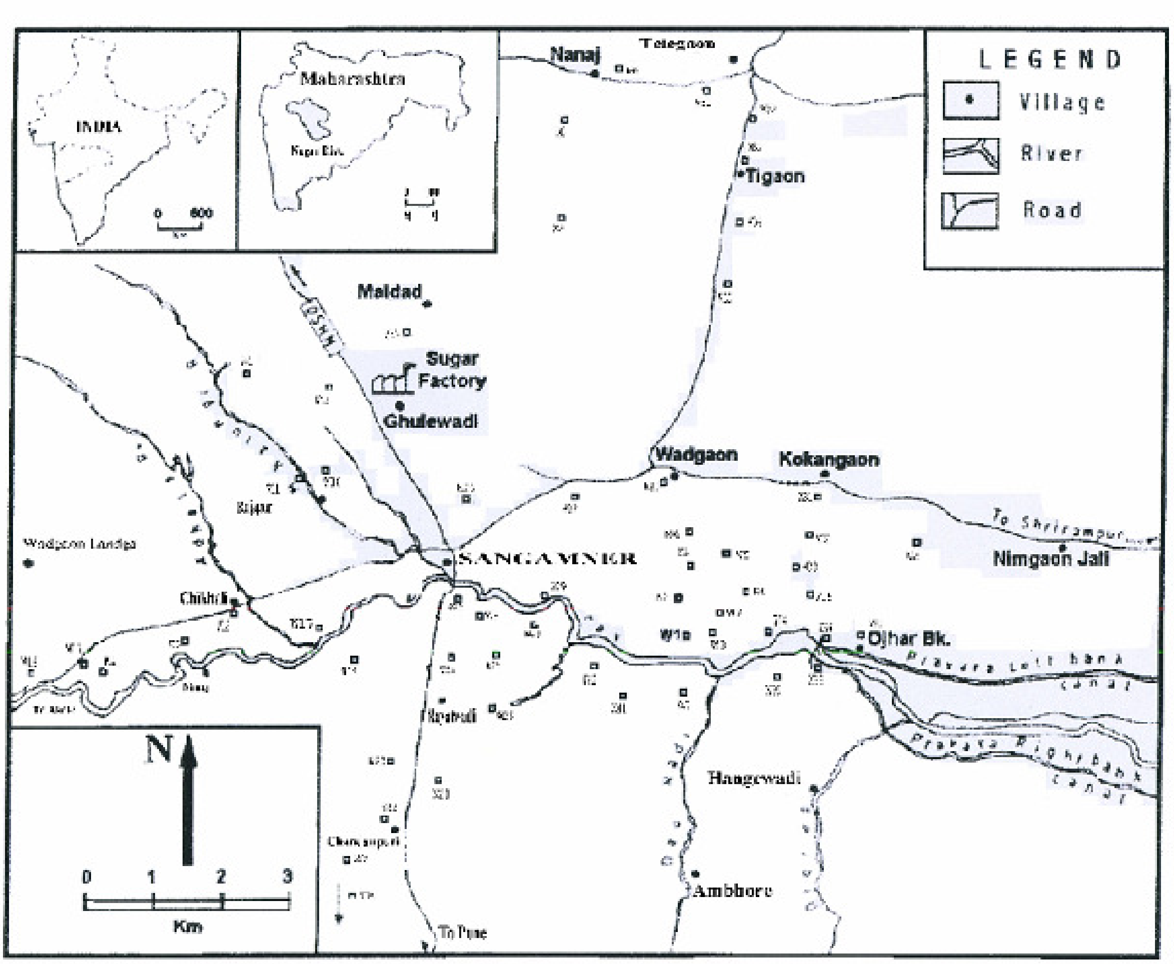

Fig.-1: Location map showing sampling stations in the study area.

Table-3: Critical parameters exceeding the Permissible limit in the study area.

Parameter	Indian Standard drinking water – specification IS 10500 -1991 (Reaffirmed 2009)		Sample exceeding permissible limit in Pre-monsoon	Sample exceeding permissible limit in Post -monsoon	Range of samples in pre monsoon		Range of samples in Post monsoon	
	Desirable Limit	Permissible Limit	%	%	Min	Max	Min	Max
pH	6.5 to 8.5	No relaxation	7 (12.28)	15 (26.31)	7.1	8.8	7.4	8.9
TDS, mg/L	500	2000	32 (56.14)	30 (52.63)	546	7377	403	5980
Ca, mg/L	75	200	8 (14.83)	16 (28.07)	20	480	56	328
Mg, mg/L	30	100	29 (50.87)	38 (66.66)	20	406	10	457
Cl, mg/L	250	1000	2 (3.50)	10 (17.54)	48	1204	69	1533
SO_4, mg/L	200	400	0	0	2.4	180	19	180
TA (as $CaCO_3$ mg/L)	200	600	7 (12.28)	19 (33. 33)	162	772	204	768
NO_3, mg/L	45	No relaxation	28 (49.12)	10 (17.54)	2	97	2	100
Fe, mg/L	0.3	1	0	0	0	0.01	0	0.53

TH, (as $CaCO_3$ mg/L)	300	600	31 (49.12)	40 (70.17)	70	2001	220	2641

Table-4: Groundwater salinity classification on the basis of TDS (After Hem, 1991) in study area.

Nature of water	TDS (mg/l)	Post-monsoon	Pre-monsoon
Fresh Water	> 1000	W1,W15,W16,W18,W44, W45,W47,W48,W49,W51,W52,W54,W55,W56 and W57 =15 (26.31 %)	W1,W15,W16,W44,W45,W48,w51,W52,W53,W54,W55 and W56 = 11 (19.29 %)
Slightly saline	1000 – 3000	W3,W10,W19,W20,W21,W24,W25,W27,W28,W29,W30, W31,W33,W34,W36,W37,W38,W39,W41,W42,W46,W50 and W53 = 23 (40.35 %)	W3,W10,W18,W21,W22,W24,W25,W28,W29,W30,W31,W34,W35, W36,W37,W38,W41,W42,W46,W47,W49,W50 and W57 = 23 (40.35 %)
Moderately saline	3000 – 10000	W2,W4,W5,W6,W7,W8,W9, W11,W12,W13,W14,W17,W22,W23,W26,W32,W35,W40 and W43 = 19 (33.33 %)	W1,W2,W4,W5,W6,W7,W8,W9,W11,W12,W13,W14,W17,W19,W20, W23,W26,W27,W32,W33,W39,W40 and W43 = 23 (40.35 %)
Very saline	10,000 – 35,000	Nil	Nil
Brine	> 35,000	Nil	Nil

Table-5: Groundwater classification on the basis of Total Hardness in study area.

Category	TH Mg/l	Post – Monsoon	Pre-monsoon
Very hard	< 300	W1,W4,W5,W6,W7,W8,W9,W11,W12,W13,W14,W17,W19,W20,W21,W22,W23,W24,W25,W26,W27, W29, W31,W320,W33,W34,W38, W40,W43 and W50, = 30 (52.63 %)	W3,W16,W18,W38,W42,W45 and W57 = 11 (19.29 %)
Extremely Hard Class - I	300-600	W10,W15,W16,W18,W36, W42,W44,W45,W46,W48, W49,W51,W52,W54,W55 and W57 = 16 (28.07 %)	W15,W17,W28,W351,W36, W37,W44,W46,W47,W48,W49,W50,W51,W52,W53,W54, W55 and W56 = 18 (31.57 %)
Extremely Hard Class - II	600-1200	W2,W3,W28,W30,W35,W37,W39,W41,W47,W53 and W56 = 11 (19.29 %)	W6,W7,W10,W14,W19,W21,W23,W29,W30,W31,W39,W40 andW41 = 14 (24.56 %)
Extremely Hard Class - II	>1200	Nil	W1,W2,W4,W5,W8,W9,W11,W12,W13,W20,W24,W25,W26,W27, W32,W33,W34 and W43 = 18 (31.57 %)

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