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Impact of irrigation on the environmental geochemistry of groundwater from Sangamner area, Ahmednagar district, Maharashtra

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Abstract
In an attempt to evaluate the impact of irrigation on the environmental geochemistry of ground water 136 samples from Sangamner area were analyzed. The chemical characteristics of ground water have been found to be dominated by Ca +Mg >Na + K -HCO3 + CO3 hydro-chemical types followed by Na + K-HCO3 + CO3 and Na + K - SO4 + Cl + NO3 indicating dominance of cation and anion exchange process on both spatial as well as temporal scales. Rapid chemical changes evidenced by diverse hydro-chemical characteristics in the irrigated agricultural zone have lead to faster chemical evolution of ground water. As against this, in the non-irrigated agriculture less hydro-chemical diversity reflected slow process of chemical evolution of ground water. In general, the majority of the ground water samples belong to medium conductive class I in non-irrigated agriculture and, medium conductive class II and high conductive class III in irrigated agriculture area indicating impact of irrigation.

Hydro-chemical diversity, salinization of ground water and boron toxicity has been identified as the impact of irrigation in the area. On the basis of TDS the ground water is classified as fresh, slightly saline to moderately saline and very saline in character. In general saline (slightly, moderately and very saline) ground water is confined to irrigated agriculture and that of fresh to non-irrigated agriculture zone. Increased salinization has caused large-scale variations in the hydro-chemical characteristics of water and increase in the concentrations of fertilizer derived constituents in ground water. Educating the farmers to adopt better farm management practices have been suggested to reduce the problem of environmental degradation.

INTRODUCTION

The quality of water is of vital concern to the mankind, as it has direct link with human welfare. With the rapid growth in human population coupled with industrialization, there is increase in urbanization too. This has not only stated putting pressure on the quantitative aspects of natural resources like water, soil etc. but even on the quality characteristics. Therefore, quality of groundwater is as important as the quantity. In the agriculture sector, large quantities of chemical fertilizers, pesticides, and insecticides used to enhance the crop yield, on leaching enter the aquifer thereby polluting the groundwater. In many areas, overuse of irrigation water and chemical fertilizers besides mono culture type of cropping pattern have started depleting and deteriorating water as well as soil quality. Several studies have attempted to interpret the quality of irrigation water and evaluate the effect of agricultural land use on ground water (Pionke et al 1985; Kaufmann, 1977; Ritter et al 1984; Pawar and Shaikh 1995, Datta et al 1998; Pawar et al. 1999 and Moncaster et al 2000). However, there is little scientific information available regarding overall groundwater quality and the impact of irrigation on geochemistry of groundwater from Sangamner area in Ahmednagar district of Maharashtra. Wide range of natural and human-induced factors causing changes in the chemical quality of groundwater are also not known. This information is useful in educating farmers to adopt better farm management practices that in turn will reduce the problems of environmental degradation. In view of this, the present work was carried out in Sangamner area.

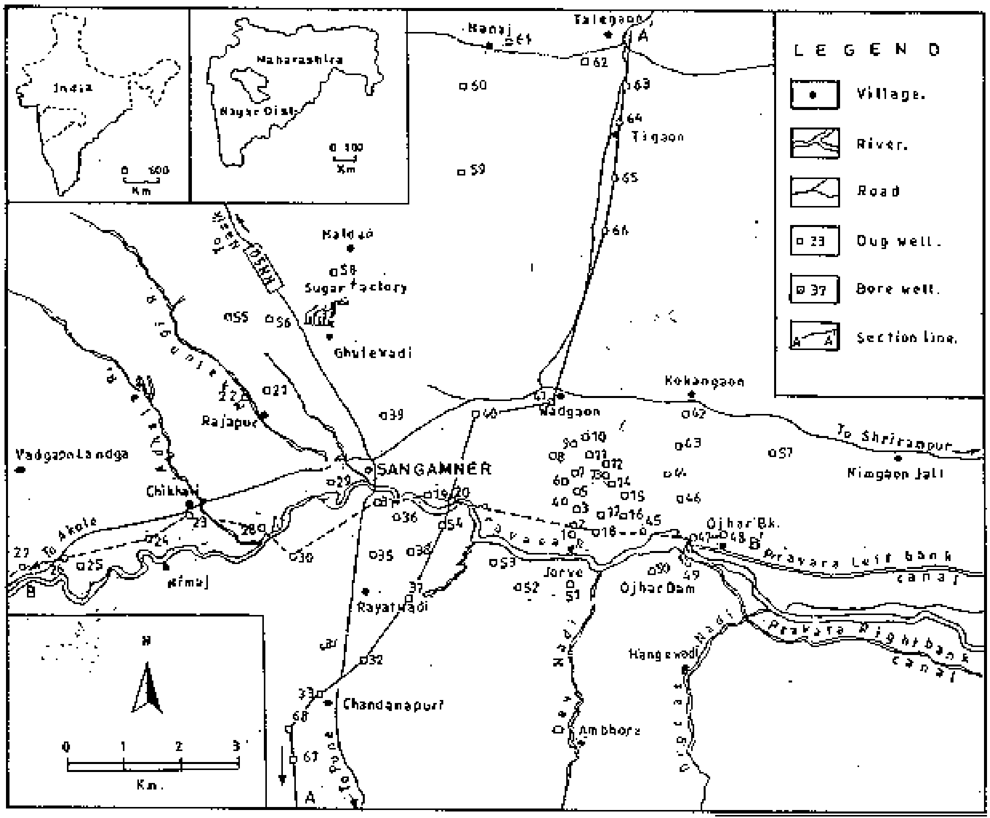

Figure 1. Location map showing sampling wells in Sangamner area, Maharashtra, India.

THE STUDY AREA

The Sangamner area is located in the Ahmednagar district of Maharastra. 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, basalts underlay the Pravara basin, which is characterized by thick alluvium (up to 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 sugar cane 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. While flowing through the natural stream, the effluent infiltrates through the soil zone into the near by dug / bore wells thereby adversely affecting natural groundwater quality. In addition to this, the over use of irrigation water, practicing mono culture type of cropping pattern and enhanced use of chemical fertilizers have started showing adverse effects on the soil as well as water resources of the area.

Groundwater is developed by the dug wells of varying size and shape and to a smaller extent by bore wells. Majority of dug wells is circular in shape with diameter up to 4 - 5 meters. Depending upon the thickness of soil cover or alluvium, the dug wells are fully or partly lined by stone or brick or cement. By and large, brick lining is common. This is because brick manufacturing is the second major occupation in the area possibly due to availability of raw material i.e. alluvium and proximity to cities like Pune and Nasik. Dug wells density is higher in the downstream part of the basin because of shallow water table. Due to rugged topography and scarcity of water in summer in the upper part, the farmers practice old methods of agriculture. On the contrary, the agricultural land on the banks of Pravara river and in the downstream part of the basin is extensively irrigated with sugar cane as the dominant crop followed by vegetables, onion, tomato and cattle feed like alfalfa (*Medicago sativa* L). Due to salty taste people from the area do not use the groundwater for drinking or even for cattle rearing. The soil degradation has also occurred wherever such water is used for agriculture. In view of the above it was decided to evaluate the control of natural and human induced factors on the composition of groundwater from the study area.

METHODOLOGY

A network of 68 groundwater-sampling stations spread over two seasons was established in the study area to monitor the chemical changes in the properties of groundwater. The 54 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. During the survey information concerning land use, type of crops, amount of fertilizer used, the water quantity, source of water used for irrigation and frequency of application of water was collected. The samples from dug / bore wells were collected on the basis of its use for irrigation as well as for drinking 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 samples were collected over two seasons i.e. Post-monsoon i.e. winter (December - 99) and Pre-monsoon i.e. summer (June - 2000). The analysis was carried out in the laboratory by using the procedures given by APHA, AWWA, WPCF (1987). Using titrimetric methods, the analysis of chloride (Cl^-), total alkalinity as $CaCO_3$ Calcium ($Ca2^+$) and total hardness as $CaCO_3$ (TH) was performed. While nitrate, phosphate, sulphate, silica and boron were analyzed by spectrophotometric methods (Hitachi-2000, UV-visible spectrophotometer), the alkali elements like sodium and potassium were detected by flame photometer (Corning 400). Using Stiff Computer program the charge balance error (CBE) was calculated to check the analytical accuracy. The charge balance error up to 10% was considered valid.

Table 1. Summary of physico-chemical characteristics of groundwater from Sangamner Area, District Ahmednagar, Maharashtra.

Post monsoon – 1999					Pre monsoon – 2000			
Parameter	Min.	Max.	Average	Std. Dev	Min	Max	Average	Std. Dev
PH	7.6	8.6	8.1	0.3	7.9	8.9	8.4	0.2
EC μS/cm	360	10,360	4026.5	2422	513	11,100	4283	568.3
TDS(ppm)	230.4	6630.4	2577	1571.2	328.32	7104	2741.24	363.68
Na epm	0.7	16.5	7	4.72	0.30	21.4	6.49	5.39
K epm	0.01	0.09	0.04	0.1	0.1	0.64	0.05	0.1
Ca epm	0.64	8.6	2.31	1.54	1.8	24.21	9.98	5.121
Mg epm	0.56	12	6.53	2.67	0.6	38.47	13.88	10.12
Cl epm	0.25	16.9	4.38	3.51	1.26	42.59	14.42	11.44
HCO_3 epm	1.34	12.37	6.52	3.1	2.22	11.83	7.22	2.46
SO_4 epm	0.57	3.54	2.62	0.9	0.36	3.11	2.01	1.03
NO_3 ppm	0.21	196	103.5	51.49	0	121.5	81.28	41.94
B ppm	0	6.28	2.33	1.48	0.05	5.1	1.33	1.29

Table 2. Classification of groundwater on the basis of electrical conductivity.

Class	Conductivity range	Winter (No. of wells)	Summer (No. of wells)
Low conductive	<500 μS/cm	2 (W67, W68) i.e.2,94% wells	Nil
Medium conductive (Class I)	500 - 1000 μS/cm	9 [Total 13.23% wells] (W26, W27, W55, W56, W62, W63, W64, W65, W66)	7 [Total 10.29% wells] (W5, W27, W32, W55, W56, W63, W65)
Medium conductive (Class II)	1000 – 3000 μS/cm	14 [Total 20.58% wells] W32, W33, W39, W40, W41, W47, W48, W49, W52, W53, W57, W58, W59, W60)	21 [Total 30.88% wells] (W3, W7, W26, W39, W40, W41, W47, W49, W52, W53, W54, W57, W58, W59, W60, W61, W62, W64, W66, W67, W68)
High conductive (class III)	>3000 μS/cm	43 [Total 63.23% wells] (W1,W2,W3,W4,W5,W6,W7,W8, W9,W10,W11,W12,W13,W14,W15 ,W16,W17,W18,W19,W20,W21, W22,W23,W24,W25,W28,W29, W30,W31,W34,W35,W36,W37, W38,W42,W43,W44,W45,W46, W50,W51,W54,W61)	40 [Total 58.82% wells] (W1,W2,W4,W6,W8,W9,W10, W11,W12,W13,W14,W15,W16, W17,W18,W19,W20,W21,W22, W23,W24,W25,W28,W29,W30, W31,W33,W34,W35,W36,W37, W38,W42,W43,W44,W45,W46, W48,W50,W51)

RESULTS AND DISCUSSION

Hydrochemical variations in pH and EC

The data obtained by carrying out chemical analysis for groundwater is presented in Table 1. It is observed that the average pH of the groundwater varies from 8.1 in post-monsoon to 8.4 in pre-monsoon season. This reflects weakly alkaline characteristics of groundwater. Slight increase in pH during pre-monsoon can be attributed to discontinued supply of CO_2 due to cessation of rain-fed recharge to the aquifer. This increase in pH can also be related to higher ionic content of water in this season. The electrical conductivity (EC) of water ranges between 4026 μS/cm in post-monsoon and 4283 μS/cm in pre-monsoon. Increase in EC in pre-monsoon confirms the inference drawn about higher pH values in this season. On the basis of EC, the groundwater from the Pravara basin can be classified as given in Table 2.

It is seen that majority of the samples (i.e. 63% in post-monsoon and 59% in pre-monsoon) belong to High Conductive class III (>3000 μS/cm) given by Sarma and Swamy (1981) indicating built of salinity in the groundwater. The higher values of EC from downstream areas reflect low flushing rate and sluggish groundwater movement. Due to rolling topography and relatively higher gradients in the upstream areas of the catchment the conductivity values are of lower order, which imply comparatively higher rates of flushing of salts from these areas. The remaining samples belong largely to Medium Conductive class II, followed by Medium Conductive class I. Only two samples (S.Nos. W67 and W68) in post- monsoon season belong to Low Conductive class (i.e. <500 μS/cm). These samples have been collected from non-irrigated agricultural areas situated on the plateau. The same samples in pre-monsoon show direct shift to Medium conductive class suggesting control of evaporation on the hydrochemical diversity in the area.

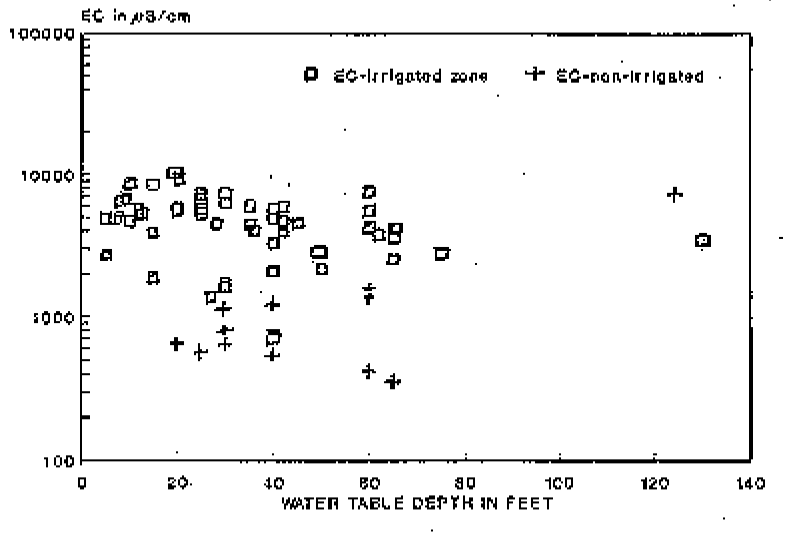

Figure 2. Depthwise variations in EC of groundwater from Sangamner area.

Depth-wise variations in EC indicate that in the non- irrigated agriculture EC increases with depth. However, in irrigated agriculture, there is no control of depth on EC suggesting role of evaporation (Figure 2).

Hydrochemical variations in cationic parameters

Amongst the cationic parameters, Ca and Na are the most predominant constituents. The Na values of post-monsoon season average up to 7.00 epm and that of pre-monsoon up to 6.49 epm. Ca trend is reverse to Na as the average values range from 2.31 epm in post-monsoon to 9.98 epm in pre-monsoon season. Increase in the values of Ca on temporal scale, implies concentration-dilution effect related to climate. However, decrease in Na during pre-monsoon suggests possibility of cation exchange causing adsorption of Na on clays. The Mg concentration varies between 6.53 (post-monsoon) and 15.35 epm (pre-monsoon) season. Mg is expected to come from incongruent dissolution of pyroxene in the basaltic lithology. However, similarity in the trends of Ca and Mg shows that they have common source. This is to say that both of them have been largely derived from rock-water interaction in alluvial lithology. In the alluvium, the Ca and Mg have been associated with the carbonate nodules forming comparatively higher proportion (Soman and Jog; 1988). This inference is further evidenced by occurrence of calcareous soils in the area. Absence of similarity in the trends of Na and Ca therefore suggests that plagioclase feldspar from the basaltic lithology has comparatively less control on the composition of groundwater from the study area. The K concentrations are negligible although slight increase is noticed in pre-monsoon season.

Hydrochemical variations in anionic parameters

The anions in the ground water include HCO_3, Cl, SO_4 and NO_3. In general Cl > HCO_3 in majority of samples, which is followed by SO_4 and NO_3. It is to be noted that Cl, SO_4 and NO_3 do not occur in the chemical composition of basaltic lithology. Therefore, origin of only HCO_3 can be related to the aquifer lithology and the remaining anions to non-lithologic i.e. possibly anthropogenic sources. The concentration of Cl ranges between 4.38 epm in post-monsoon season and 14.42 epm in pre-monsoon. As against this the SO_4 concentration varies from 2.62 epm (Post-monsoon) to 2.01 epm (Pre-monsoon). Similarly, NO_3 values also show-decreasing trend from 103.5 ppm (post-monsoon) to 81.28 ppm in pre-monsoon season. Thus, SO_4 and NO_3 depict reverse trend when compared with Cl. From these trends it can be inferred that the source of SO_4 and NO_3 is not active in summer season. This is to say that both of them are derived from fertilizer sources and farmers do not generally use fertilizers in summer. As against this Cl and HCO_3 concentrations increase in summer implying concentration effect. It is to be also noted that these dissolved constituents are not utilised by the crops since they are not in the category of essential nutrients. In addition the high proportion of Cl ions in comparison with HCO_3 indicates anion- exchange as a most significant geochemical process in the area. In general, a gradual increase in the mineralization of ground water and shift from dominant anion HCO_3 to SO_4 + Cl are observed from water divides to valley floor areas possibly due to decreasing rate of ground water circulation and increasing rock-water interaction. Thus, decrease in rate of flushing of the aquifer is the dominant factor causing major impact on geochemistry of groundwater from the area.

IMPACT OF IRRIGATION ON GROUNDWATER QUALITY

Several authors have brought out the effect of intensive agriculture on the geochemistry of groundwater. These include nitrate / fertilizer pollution, (Andersen and Kristiansen, 1984; Pawar and Shaikh, 1995; Datta et al 1998;), impact of nitrogen fertilizers on weathering process (Semhi et al 2000), migration and attenuation of agrochemicals (Moncaster et al 2000) and increase in trace element concentrations in the groundwater (Pawar and Nikumbh, 1999). Majority of these studies highlights the impact of agro-chemicals on groundwater chemistry. However, there is very little effort made to understand other associated impacts. Therefore, in this article other impacts have also been discussed.

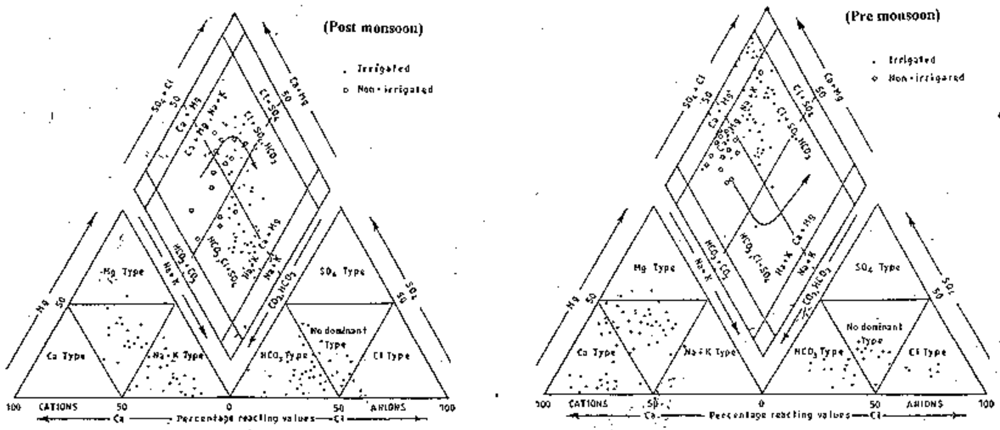

Figure 3. Piper's Trilinear diagram showing hydrochemical diversity in Sangamner area, pre-monsoon and post-monsoon periods.

Hydrochemical diversity

In order to characterise the hydrochemical diversity of groundwater as affected by intensive irrigation in the Pravara basin, the data were plotted on Piper's Trilinear diagram (Figure 3). In the diagram in all 68 samples, (out of which 54 are from irrigated and 14 from non-irrigated agriculture) have been plotted. It is seen from the figure that out of 54 samples collected from irrigated agriculture during post-monsoon, 16 samples (30.18%) belong to Ca + Mg > Na+K (alkali earths exceeds alkali) and 38 samples (68.81%) belong to Na+K > Ca+Mg cation hydro-chemical facies. Similarly, 17 samples (32.07%) represent Cl + SO_4 > HCO_3 + CO_3 and 36 samples (67.92%) belongs to HCO_3 + CO_3 > Cl + SO_4 + NO_3 anion hydro-chemical facies. Thus, on the spatial scale, the groundwater from the study area shows chemical evolution path characterised initially by Ca+Mg - HCO_3 +CO_3 type to Na+K - HCO_3+CO_3 type that is further followed by Na+K - SO_4 + Cl + NO_3 type particularly in post monsoon season. On the temporal scale, change in the water types from Ca+Mg in the pre-monsoon to Na+K in post-monsoon indicates cation exchange process. Similarly, HCO3 + CO3 type changes to Cl+SO4 from post-monsoon to pre-monsoon suggesting anion exchange process. It is interesting to note that in the non-irrigated agricultural area the groundwater predominantly shows Ca+Mg - HCO_3 +CO_3 chemical type in both the seasons except slight increase in percentage of samples belonging to Cl+SO4 anion facies in post-monsoon. Thus, in the irrigated agriculture, groundwater shows rapid chemical evolution as evidenced by diverse hydrochemical water types. The non-irrigated agriculture however, shows less hydrochemical diversity reflecting slow process of chemical changes in the water under natural conditions.

Salinisation of groundwater

Increase in the concentration of dissolved salts in the water attributable to both, natural and human induced factors, leads to the process of salinization (Salama, 1999). In the irrigated sector, salinization of water is recognized as a serious problem. On the basis of TDS, saline water is defined by Mehta et al (2000). The waters with TDS contents ranging from 400 to > 3000 mg/L have been designated as saline waters. Hem (1991) has classified the waters into four categories based on TDS values. The are, slightly saline (1000-3000 mg/L), moderately saline (3000-10000 mg/L), very saline (10,000-35,000 mg/L) and briny (> 35,000 mg/L TDS). By using the same criterion following salinity classification is proposed for the ground waters from study area (Table 3).

Table 3. Groundwater Salinity Classification on the basis of TDS.

Nature of water	TDS mg/l	Winter	Summer
Fresh water	> 1000	W26, W27, W55, W56, W58, W59, W60, W62, W63, W64, W65, W66, W67, W68 = 14 (20.58%)	W5, W27, W32, W55, W56, W59, W60, W63, W64, W65, W66, W67 = 12 (17.64%)
Slightly saline	1000 - 3000	W1,W7,W8,W21,W29,W30, W32,W33,W35,W36,W37,W39, W40,W41,W42,W44,W45,W46, W47,W48,W49,W50,W52,W53, W57,B61 = 27 (39.70%)	W3,W7,W8,W21,W29,W33, W35,W36,W40,W41,W42,W45 W46,W47,W48,W49,W52, W53,W54,W57,W58,B61,W62, W68 = 26 (38.23%)
Moderately saline	3000 - 10000	W2,W3,W4,W5,W6,W9,W10, W11,W12,W13,W14,W15,W16, W17,W18,W19,W20,W22,W23, W24,W25,W28,W34,W38,W43, W51,W54 = 27 (39.70%)	W1,W2,W4,W6,W9,W10,W11, W12,W13,W14,W15,W16,W17 W18,W19,W20,W22,W23,W24 W25,W28,W30,W31,W34,W37 W38,W43,W44,W50,W51 = 30 (44.12%)
Very saline	10000 – 35000	Nil	Nil
Brine	> 35000	Nil	Nil

It is observed from the table that out of 68 wells sampled during post-monsoon, 14 samples belongs to fresh and 27 each to slightly and moderately saline categories. Higher percentage of wells in pre-monsoon season display moderately saline properties. The wells from non-irrigated agricultural sector largely show fresh water characteristics. This indicates that there is large-scale salinization of ground water in the irrigated area. From the filed evidences it appears that salinization is controlled by physiography, geology and land use. This is because the presence of alluvium, flat topography and intensive irrigation has lead to the problem of salinization in the area. In general, the backwater area of Ozar small-scale dam shows more degradation of water quality. The observations show that the area with TDS between 500 and 1000 mg/L (S.Nos. W26,W55,W56, W58,W59, W60,W62,W66 and W67) lies in the upper part of basin, which is predominantly non-irrigated agricultural region. The samples from this zone show TDS values below 500 mg/L (S.Nos.W27, W63, W64, W65, W66, W67 and W68) during both the seasons. Intensive salinization in the downstream part may be attributed to water logging in the area. The saline water is produced possibly due to evaporation, as the water table is located at shallow depth (average about 1-1.5 m). The low salinity of water observed in the upstream part possibly indicates faster circulation of ground water attributable to physiography.

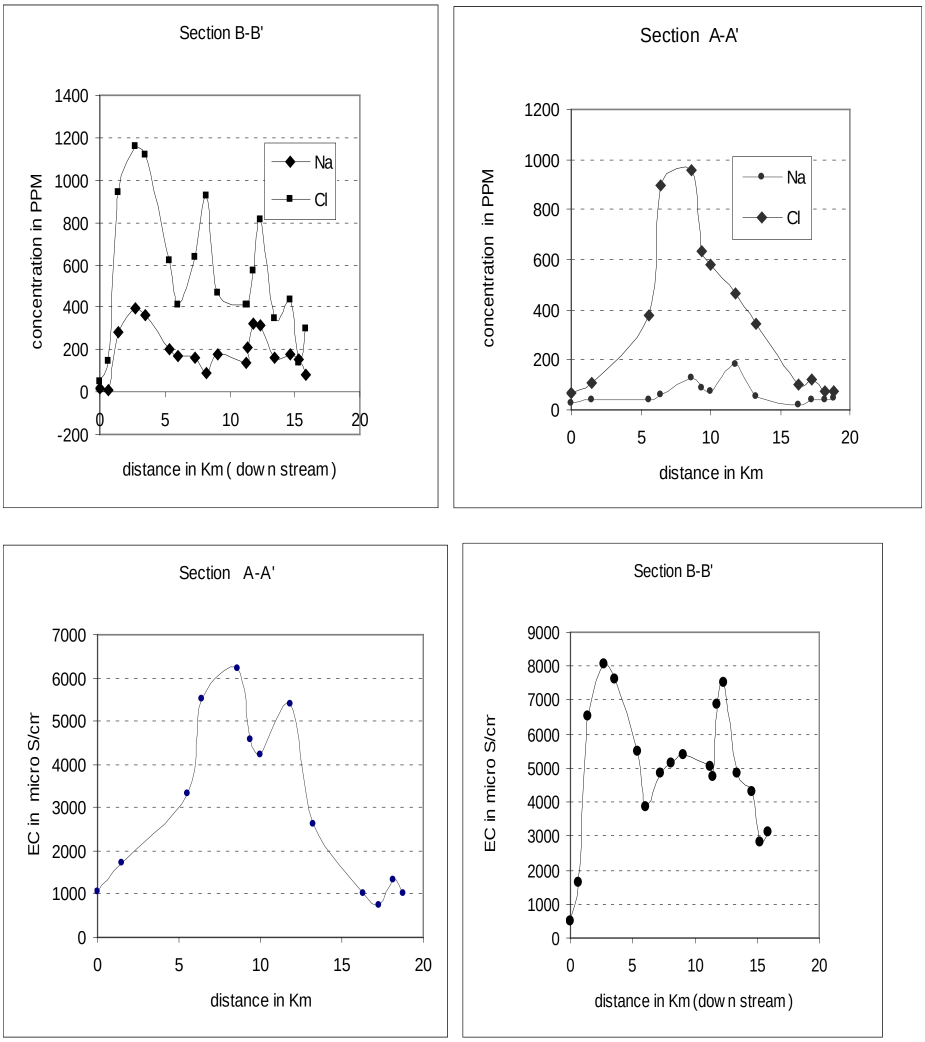

Figure 4. Spatial variations in chemical parameters along A-A' and B-B' sections.

In order to map the zone of saline water the sections A-A' and B-B' were taken as depicted in Figure 1. The plots of the chemical data along these sections have been shown in Figure 4.

It is observed that the concentrations of the parameters increase in the area coinciding with the alluvial aquifer, flat topography and intensive irrigation all along the course of Pravara river. Thus, area under threat from saline water is marked in Figure 5 A and 5 B. It is seen that majority of the area under irrigated agriculture is under saline water conditions. It is to be noted here that increase in use of canal water, practicing of sugarcane type of cropping pattern and negligible exploitation of groundwater have caused water-logged to semi-logged conditions in the area. As a result of this the process of evaporation has hastened salinization of groundwater in the area.

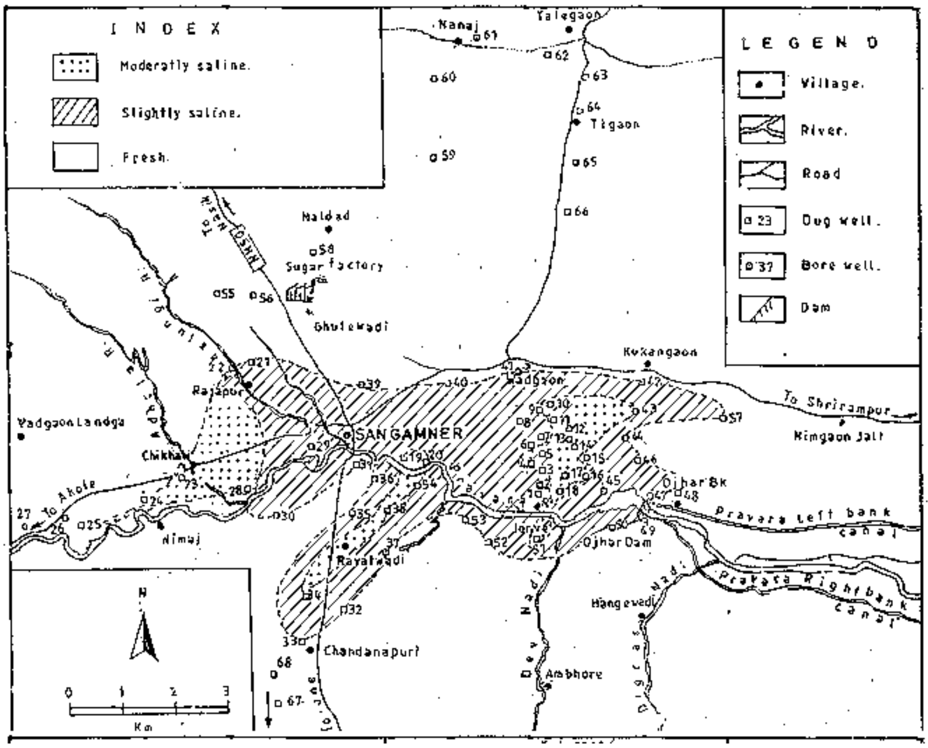

Figure 5A. Distribution of moderately saline, slightly saline and fresh groundwater from the study area (post-monsoon).

Boron Toxicity

Although boron is one of the essential nutrients for plant growth, its deficiency produces striking symptoms in many plant species. For sensitive, semi-tolerant and tolerant crops, the rating of irrigation water on the basis of boron concentration are < 0.33 to > 1.25; < 0.67 to > 2.5 and < 1 to > 3.75 ppm respectively for excellent to unsuitable grades of water (Hem, 1991). In relation to boron toxicity, Tondon (1993) classified the waters into four different classes. Based on this the groundwaters from study area can be classified as given in Table 4.

It is seen from the table that the boron content in 22% samples in winter and 52.94% samples in summer was below 1 ppm. This indicates that majority of the samples in summer have lower values of boron thereby reflecting less toxicity hazard. In contrast, the remaining samples belong to medium, high and very high category of B toxicity. This suggests that in the irrigated agricultural area groundwater is rich in B. However, it is interesting to note that some of the wells from the non-irrigated agriculture have also displayed very high values of B. These high values of B can be attributed to semi-arid climatic conditions in the area (Richards, 1968). Since, non-irrigated area shows occurrence of calcareous soils (Deshmukh, 2000), the high concentrations of B are not expected to cause any toxicity. This is due to the fact that in these soils, B precipitates as calcium borate (Gupta , 1974).

Table 4. **Classification of groundwater from Pravara basin for Boron toxicity.**

Toxicity	Concentration	Post-monsoon	Pre-monsoon
Low	< 1 ppm	W1,W4,W12,W15,W16,W47,W48, W60,B61,W63,W64,W65,W66,W67 = 15 (22%)	W1,W2W5,W10,W24,W26, W27,W28,W29,W30,W31, W32,W33,W34,W35,W36, W37,W38,W40,W41,W42, W43,W44,W46,W47,W48, W49,W50,W52,W55,W56, W58,W60,B61,W62,W66 =36 (52.94%)
Medium	1 to 2 ppm	W3,W9,W11,W27,W32,W38,W39, W42,W43,W49,W50,W51,W52, W59, W62,W68 = 16 (23.52 %)	W3,W4,W7,W8,W15,W16, W17,W23,W25,W39,W45, W53,W63,W64,W65,W67 =16 (23.52%)
High	2 to 3 ppm	W2,W6,W7,W8,W10,W14,W17, W18W19,W21,W22,W23,W31, W35,W36,W37,W40,W41,W44, W46,W53,W54,W55,W56,W58, W33,W34 =27 (39.7%)	W6,W9,W12,W13,W14, W19,W20,W21,W22,W51, W57, W59,W68 =13(19%)
Very high	> 4 ppm	W5,W20,W24,W25,W26,W28,W29, W30,W48,W57 =10 (14.7%)	W11,W18,W54=3(4.4%)

SUMMARY AND CONCLUSIONS

The studies carried out on environmental geochemistry of ground waters from Sangamner area to evaluate the impact of irrigation, have demonstrated that intensive irrigation has serious effect on the quality of water. Both temporal and spatial variations in the ground water have been attributable to the effect of geology and land use on water composition.

In general electrical conductivity varies from 4026µS/cm to 4283 µS/cm indicating increase in the ionic content of ground water in pre-monsoon. Rolling topography and relatively higher gradients in the upstream areas of the basin leading to higher rates of flushing display low EC values. As against this, higher EC values in the central and downstream part of the basin suggest sluggish ground water movement and buildup of salinity due to low flushing rates. Increase in the values of cationic and anionic parameters in pre-monsoon and decrease in post-monsoon season suggests concentration dilution phenomena attributable to climatic factors. Similarity in the trends of Ca and Mg reflects their origin from common source i.e. dissolution of carbonates in the alluvium. On the other hand, absence of any similarity in the trends of Ca and Na indicates that plagioclase feldspar from basaltic lithology has insignificant control over the composition of ground water. High proportion of Cl, SO4 and NO3 in irrigated agriculture sector in comparison with non- irrigated agriculture suggests that these constituents have been derived from fertilizer sources.

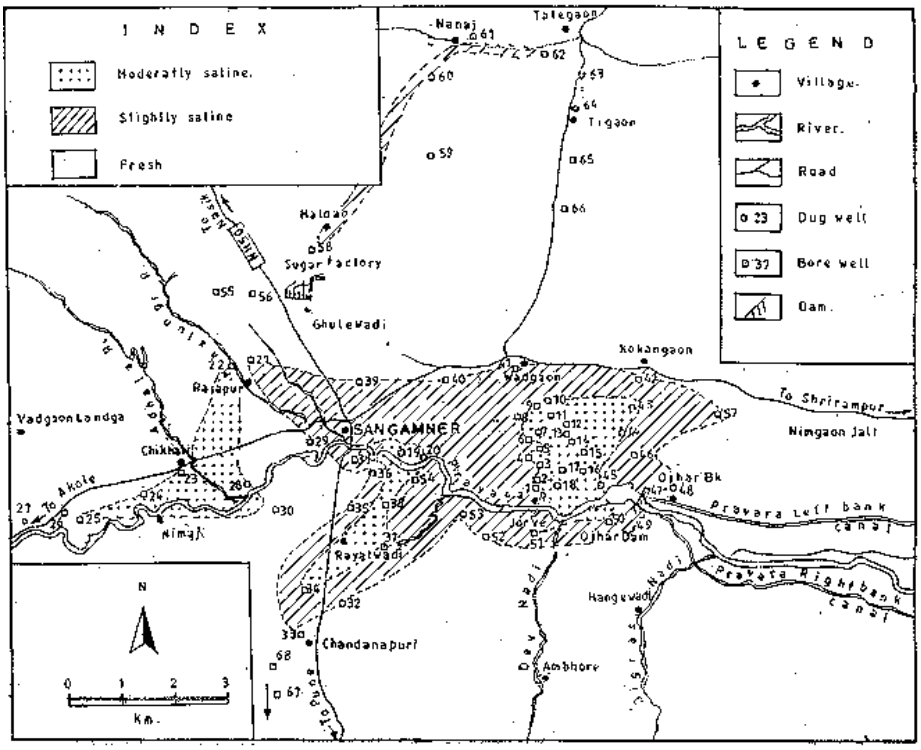

Figure 5B. Distribution of moderately saline, slightly saline and fresh groundwater from the study area (pre-monsoon).

The increase in the EC of ground water coupled with higher concentrations of dissolved constituents have together indicated that there is a large scale impact of irrigation on ground water chemistry. These impacts include hydro-chemical diversity, salinization and boron toxicity. Diverse hydro-chemical characteristics have been evidenced by rapid chemical evolution of ground water from Ca + Mg- HCO3 type to Na + K-SO4 + Cl + NO3 type. The TDS values ranging between 2577 mg/l in post-monsoon and 2741 mg/l in pre-monsoon clearly indicate slightly saline to moderately saline to very saline ground water properties.

The investigations suggest that excessive use of fertilizers and irrigation water in a terrain characterized by low flushing rates, presence of alluvium and flat topography have caused deterioration of ground water quality. Therefore, 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 situation.

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