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Full Length Research Paper

Irrigation impacts on the chemistry of soils in the study area

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Irrigation plays an important role in the present agriculture scenario. It is a major source which helps millions of rural poor in the world to earn their livelihood. Unplanned and unscientific use of both water and soil resources have led to severe deterioration. As a result of this, a greater threat is being posed to social, economic and political stability of many developing countries including India. Introduction of large scale irrigation, excess use of chemical fertilizers and pesticides, deforestation and over grazing, leads to accelerated soil degradation. In view of this, Sangamner area of Ahmednagar district, India is selected to study the impact of irrigation on the chemistry of soils. The soil samples were collected from 62 locations covering the entire study area. The samples were analyzed for PH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, and SO_4^{2-} from saturation extract. The exchangable cations like Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} were determined by neutral ammonium acetate extract. pH ranged from 8 to 9.7 reflecting alkaline nature of soils. Higher EC in the downstream part reflects low flushing rate and sluggish groundwater movement in the area. The concentration of soluble cations are in the order $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$, whereas Cl^{-} is predominant followed by SO_4^{2-} and HCO_3^{-} in the soluble anions. Out of the total exchangeable cations, Ca^{2+} is dominating over the rest of the cations. Salinisation, sodiumization, waterlogging, nitrate pollution and boron toxicity have been identified as the possible impacts of irrigation on the chemistry of soils in the area. The soils from the study area are easily waterlogged during the rainy season. The problem is further aggravated due to decrease in depth of water table by injudicious irrigation and canal seepage. There is an urgent need to focus attention on the protection of soils particularly in the irrigation sector. Frequent awareness and training programs for farmers can be arranged to avoid further degradation of soils.

Key words: Soluble cations and anions, sodium absorption ratio (SAR), exchangeable cations, exchangeable sodium percentage (ESP), boron toxicity.

INTRODUCTION

Soil and water are the important resources for all life forms. However, there is need to manage these resources judiciously to ensure sustainability on the long term basis. This is because with increase in population, there is large scale degradation of these resources. As a result of this, a greater threat is being posed to the social, economic and political stability of many developing countries including India. Soil degradation is a widespread problem in India. About 148 mha of land area is degraded by different soil degradative processes. The major threats to Indian soils emerge from loss of organic matter, ero-sion, nutrient imbalance, compaction, salinisation, water logging, decline in biodiversity, urbanization and contami-nation with heavy metals and pesticides (Patra et al., 2011). Anthropogenic activities such as the introduction of large-scale irrigation, excess use chemical fertilizers and pesticides, deforestation and overgrazing leads to accelerated soil degradation.

However, irrigation plays an important role in the present agriculture scenario. Irrigation is one of the most important agricultural practices developed by man. It also provided the eco-nomic base for many ancient civilizations. However, irrigation is a direct source of livelihood of millions of the rural poor in the world. In the process of storing, diverting, irrigating, consuming and draining water, the natural hydrology of watershed is changing significantly. Such changes make an impact on the natural environment (Rao, 1975). However, irrigation has many positive, social, health and environmental effects. Although, many of the environmental impacts of irrigation are negative, irrigation plays a critical role in providing food and fiber for the growing population. As such, importance of irrigation can hardly be over emphasized.

The general objective of irrigation is to provide suitable moisture environment in the soil for plant growth (Willardson, 1972). A tendency among the farmers in dry regions is to over irrigate. Over-irrigation causes rise in the groundwater levels, thereby resulting in waterlogging of the area. This leads to continuous decline in agricultural productivity. It is known that all irrigation creates a certain risk of soil degradation. However, the degree of such degradation depends upon the composition of soil to be irrigated, quality of irrigation water and management practices adopted (Abott, 1997). The excess use of irrigation water leads to soil salinisation, soil alkalinezation, waterlogging, increase in groundwater salinity and depletion in soil fertility. It also changes soil physical properties and creates health hazard. Several authors (Sehgal and Abrol, 1994; Hopkin and Richardson, 1999; Salama et al., 1999; Bari and Anwar, 2000; Cruz and Silva, 2000; Meena et al., 2010; Sharma et al., 2011; Deshmukh, 2012a) studied the various aspects of irrigation-induced problems such as salinisation and/or alkalization, waterlogging, hydrochemical diversity, boron toxicity and nitrate pollution on soil and water chemistry. Thus, a fairly good amount of literature is available on irrigation on soil and water chemistry. However, little or no attention has been paid on such studies in the Sangamner area. Therefore, the present investigation will be useful in finding the remedial measures of the problems created by man-made activities in the area. Moreover, Sangamner area is also experiencing such irrigation-induced problems with its unique landform configuration displaying prohibitive slopes, though it has been practising irrigation for the last 40 years. Scanty and low rainfall condition in the area developed typical condition. However, irrigation not only caused the overall change in the economy as well as general development of the area, but also affected agricultural ecosystem. Lack of proper management of water, land and the water resources have started deteriorating the system, particularly in the downstream part of Pravara River. In view of this, it was decided to study irrigation impacts on the chemistry of soils in the study area.

MATERIALS AND METHODS

The study area

Sangamner area is located in the northern part of the Ahmednagar district of Maharashtra State, India. The tahsil lies between 18°36' N to 19°1' N latitude and 74° ‘ W to 74° 56’ W longitude. The Sangamner city is located on the confluence of the Mahalungi and 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 (Figure 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 (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 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 the sugar industry, several allied industrial units have also come up in the area. The effluents from the 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 nearby dug/bore wells, thereby adversely affecting natural groundwater quality.

Procedure

Selected 62 surface soil samples (0-20 cm) were collected during June 2011 in cloth bags as per the standard procedure recommended by United States Department of Agricultural Sciences (U.S. Salinity Laboratory Staff, 1954). Quartering technique was used for preparation of the soil samples. The samples were dried in air and passed through 2 mm sieve. The processed soil samples were analyzed for their chemical characteristics as per the standard procedures. The soil pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-},Cl^{-} and SO_4^{2-} were determined from the saturation extract (1:5 soil water ratio) of soils (Richards, 1968). The exchangeable cations namely: Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were determined from neutral ammonium acetate extract of the soils as per the standard procedures (Jackson, 1973). In addition, the SAR and ESP were also calculated. The boron was determined spectrophotometrically in order to study the impact of irrigation on the chemistry of soils. The chemical properties of soils were analyzed and presented in Tables 1 and 2.

RESULTS AND DISCUSSION

Soil salinisation

Increase in the concentration of dissolved salts in the

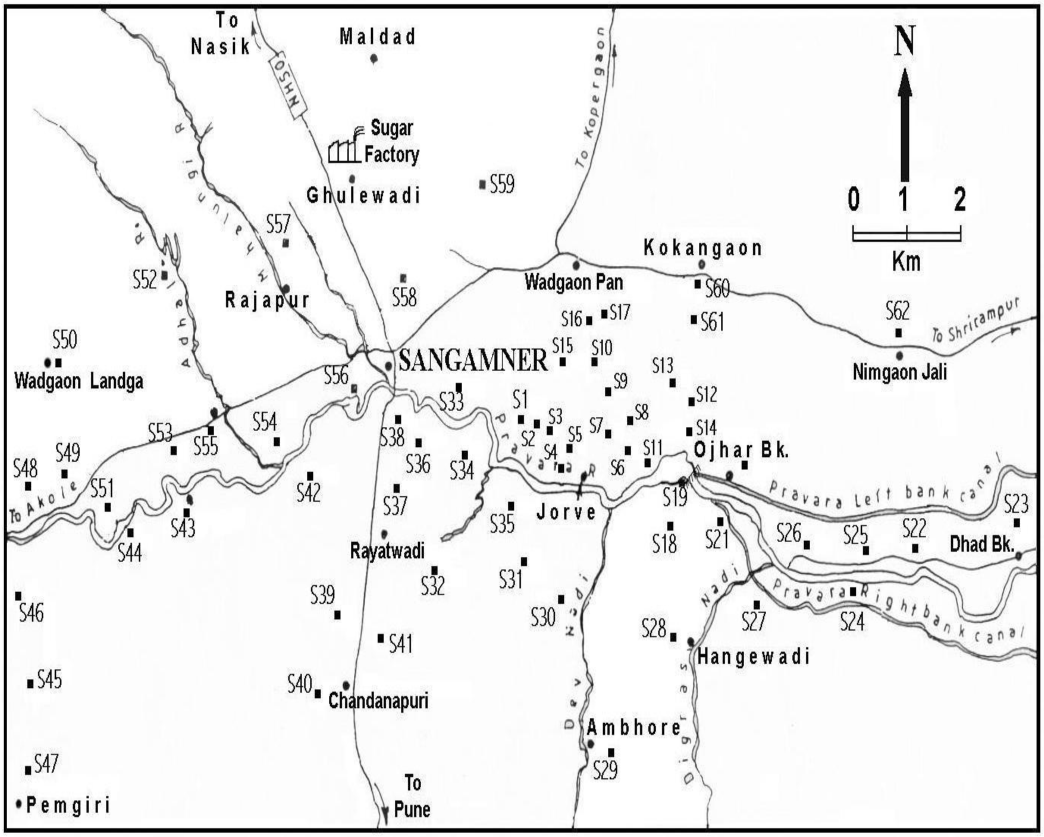

Figure 1. Location map showing the sampling stations of the area.

Table 1. Saturation extract analysis of the soils from Sangamner area.

S. No.	pH	EC dS/m	Saturation extract analysis (1:5 soil water ratio) meq/l								SAR
			Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	
S1	8.6	2.84	1.52	0.44	11.59	0.10	1.6	2.4	24.12	5.22	11.71
S2	8.6	25.4	26.78	3.75	235.9	1.29	1.2	1.8	125.3	11.44	60.38
S3	8.5	36	43.56	36.07	280	0.78	0	4	553.5	11.60	44.37
S4	8.3	19.8	22.67	13.04	76.16	0.26	0	1.6	65.34	10.94	18.02
S5	8.5	8.1	4.46	4.91	28.14	0.10	0.8	2.8	10.8	9.79	13.00
S6	8.9	22.1	26.78	4.02	145	0.75	0	2	58.14	11.54	36.91
S7	8.5	26.1	33.03	8.93	225.9	0.52	0	2.2	182.7	10.79	49.32
S8	8.6	17.3	17.85	6.70	71.19	0.26	0	2.8	36	10.80	20.32
S9	8.4	8.3	11.16	4.01	37.25	0.18	0.4	0.4	22.5	10.62	13.53
S10	8.8	11.8	13.39	1.78	134	0.26	0	2.2	50.4	10.62	48.84
S11	8	7.9	5.89	4.10	28.14	0.18	0	3.2	25.02	9.33	12.59
S12	9.5	8	0.54	3.04	58.77	0.06	1.6	4.8	27.18	10.55	43.98
S13	8	6.4	2.32	2.14	24	0.10	1.2	2.8	8.64	9.09	16.06
S14	8.6	11.6	24.64	7.50	48.82	0.26	0	2.4	35.1	12.08	12.18
S15	8.5	6	3.57	3.93	31.44	0.10	0	2.6	8.64	10.00	16.24
S16	8.5	46.8	35.35	48.75	323	0.62	1.2	3.8	245.7	12.00	49.78
S17	8.4	4.1	3.57	1.79	20.69	0.11	1.2	4.8	8.1	9.78	12.64
S18	8.4	2.9	1.43	1.79	12.39	0.07	1.2	3	3.37	10.16	9.77
S19	9.1	1.6	1.96	0.89	8.278	0.07	1.2	3.6	4.86	3.87	6.93

Table 1. Contd.

S20	8.7	5.6	2.86	2.50	24.84	0.10	4	2.8	12.42	8.83	15.18
S21	9.7	6.3	0.89	1.52	18.21	0.10	1.2	4.4	28.8	4.86	16.59
S22	9.1	2.16	1.61	0.18	8.29	0.06	0.8	4	4.32	4.69	8.77
S23	8.5	0.1	1.96	1.37	10.34	0.05	0	2.4	6.3	1.58	8.01
S24	8.6	1.1	1.16	1.52	5.38	0.10	0	3.6	3.06	0.91	4.65
S25	8.4	0.1	3.48	2.23	8.62	0.08	0	2.8	8.1	4.69	5.10
S26	8.7	4.7	1.25	0.89	11.58	0.06	0.4	2.8	4.14	3.49	11.19
S27	7.8	3.9	24.19	20.44	20.28	0.98	0	3.2	65.52	8.77	4.29
S28	8.6	5.5	1.16	2.23	4.97	0.08	0	2.4	4.5	1.74	3.82
S29	8.4	0.2	1.79	0.54	2.90	0.06	0.4	3	3.6	1.68	2.69
S30	8.9	1.42	0.80	0.80	4.14	0.03	1.2	2.4	2.7	1.79	4.62
S31	8.3	1.75	2.68	1.70	5.38	0.08	0.4	2.8	6.88	1.89	3.64
S32	8.4	0.82	2.23	1.79	2.48	0.05	-	2.8	4.8	1.48	1.75
S33	8.6	1.11	1.34	1.25	6.62	0.03	0.4	2.8	4	2.04	5.82
S34	8.2	0.44	1.16	1.16	2.07	0.02	0.8	2.2	1.6	0.35	1.92
S35	8.3	0.52	1.16	0.45	2.90	0.04	0.4	3.4	1.6	0.33	3.23
S36	8.2	3	3.12	3.12	6.62	0.08	0.8	2.6	8	3.91	3.75
S37	8.1	2.07	3.30	2.14	4.97	0.16	0.4	3	6.4	1.84	3.01
S38	8	4.17	4.46	3.93	7.04	0.15	0.4	2.4	16.16	1.75	3.43
S39	8.4	1.54	2.05	0.62	6.62	0.06	0.8	2.8	6.56	0.61	5.72
S40	8.2	1.88	2.86	2.05	1.24	0.23	0.4	3	4.48	1.21	0.79
S41	8.2	0.77	1.34	0.98	1.66	0.05	0.8	2.2	2.72	0.56	1.54
S42	8.2	0.79	1.52	1.52	1.24	0.05	0.4	3.4	1.6	0.05	1.01
S43	8.4	0.39	0.89	0.81	1.24	0.05	0.4	2.8	1.28	0.09	1.35
S44	8.8	0.66	0.89	0.36	7.04	0.04	0.4	2.6	1.6	0.20	8.90
S45	8.4	0.44	1.70	0.27	1.86	0.02	1.6	2.4	3.52	1.86	1.88
S46	8.3	0.71	1.34	0.80	1.66	0.05	0.4	2.4	1.76	0.12	1.60
S47	8.4	0.503	0.89	0.72	2.07	0.01	0.4	3.2	1.12	0.01	2.30
S48	8.5	0.383	0.98	0.80	1.66	0.01	0.4	3.6	1.6	0.06	1.75
S49	8.4	0.836	0.98	0.80	2.42	0.06	0.4	2.8	1.6	0.79	2.56
S50	8.4	0.57	1.52	0.62	1.45	0.03	0.4	2	1.28	0.80	1.40
S51	8.5	1.74	0.62	1.61	8.69	0.04	0.4	2.8	5.6	1.76	8.23
S52	8.6	0.45	1.16	0.45	2.28	0.08	0.4	1.8	7.52	0.45	2.54
S53	8.5	4.61	0.98	2.01	15.31	0.06	0	2	11.36	2.57	12.51
S54	8.9	1.7	0.62	0.89	6.83	0.05	0.4	3	2.88	1.28	7.84
S55	8.8	1.12	0.71	0.63	4.97	0.04	0.4	2	5.28	0.22	6.07
S56	8.6	1.84	0.80	1.25	9.93	0.04	0.8	2.2	4.64	0.76	9.81
S57	8.4	1.3	1.79	0.27	6.21	0.04	0	2.8	3.6	1.22	6.13
S58	8.8	0.94	0.98	1.07	7.24	0.02	0.4	2.6	4	1.36	7.15
S59	8.4	0.44	0.98	1.07	1.86	0.06	0.4	3.4	0.96	0.06	1.84
S60	8.7	0.41	0.89	1.25	1.45	0.22	0	2.2	1.6	0.37	1.40
S61	8.4	0.57	1.61	0.18	2.48	0.05	0	3	1.76	0.77	2.63
S62	8.6	1.04	0.98	0.71	4.35	0.05	0.4	2.8	4.8	1.63	4.72

water attributable to both natural and human induced factors, leads to the process of salinisation (Salama et al, 1999). However, salinisation is usually caused by mismanagement of irrigation. Salinisations badly affect physical properties of soils and plant growth. It also leads to reduction in crop yields. Salinisation causes corrosion of plumbing, industrial boilers and household appliances and thereby increases the water treatment costs, which affect industrial and municipal users. There is deterioration in drinking water quality due to salinisation (Deshmukh, 2011; El-Ashry et al., 1985). Soil salinity is estimated by the ability of water extract of soil to conduct an electric current, that is, electrical conductivity of the soil extract. Several workers (U.S. Salinity Laboratory

Table 2. Exchangeable cations of the soils from study area.

S/N	Exchangeable cations meg / 100 g meq/100g				ESP	Boron ppm Mg/l
	Na^+	K^+	Ca^{++}	Mg^{++}		
S1	9.71	0.38	31.75	18.28	17.47	3.061
S2	25.2	0.31	27.5	23.54	59.15	11.82
S3	16.59	1.20	35	8.014	51.57	4.107
S4	10	0.37	44.75	17.03	21.30	4.262
S5	7.5	0.52	36	21.78	15.13	3.157
S6	11	1.08	31.5	8.01	30.12	14.42
S7	12	0.88	36	7.01	36.32	4.705
S8	9	0.56	30.5	14.27	26.54	7.321
S9	7.2	0.58	38.25	17.28	15.06	3.514
S10	10.35	0.56	32.5	4.5	22.46	9.489
S11	4.5	0.71	37.5	25.05	8.77	2.687
S12	9.2	0.30	18.5	1.25	25.19	6.088
S13	4.5	0.36	23.75	15.52	8.77	8.381
S14	5.09	0.48	33.25	12.77	11.71	3.547
S15	4.5	0.25	23	22.79	10.56	1.806
S16	12.89	0.41	46.5	26.54	38.01	7.604
S17	4.47	0.43	30.75	25.54	11.18	1.753
S18	3.5	0.22	27	21.53	8.39	0.37
S19	5.5	0.24	23.75	20.78	17.10	1.176
S20	7.4	0.31	28.5	23.54	15.47	4.737
S21	8.5	0.38	12.5	3	20.37	0.019
S22	5.5	0.42	21.5	18.53	15.43	1.016
S23	5.68	0.19	28.25	19.53	14.20	0.359
S24	6.46	0.51	24	22.29	19.55	0.172
S25	7.5	0.31	25	31.3	15.40	1.539
S26	8.27	0.35	23	28.3	15.85	1.891
S27	6.2	0.91	27.75	25.05	15.50	1.656
S28	3.87	0.37	23	22.29	8.56	0.023
S29	2.58	0.19	31.75	17.03	6.18	0.022
S30	4.34	0.28	27.5	19.78	9.24	0.824
S31	3.72	0.30	24.25	28.3	6.90	0.37
S32	2.27	0.16	29.5	31.8	3.96	0.146
S33	3.72	0.21	27.75	26.54	6.58	0.589
S34	3.72	0.17	37.5	27.54	6.79	0.022
S35	3.1	0.33	37.75	18.53	5.57	0.023
S36	2.79	0.19	28.75	32.8	5.01	0.653
S37	3.2	0.52	46.5	22.54	7.01	0.021
S38	2.37	0.30	32.5	14.77	7.27	0.023
S39	3.51	0.19	28	22.03	9.79	0.024
S40	2.067	0.63	34.25	25.29	5.66	0.020
S41	1.96	0.25	45.75	19.28	4.29	0.023
S42	1.34	0.22	43.75	16.78	3.42	0.019
S43	1.44	0.30	36.5	20.78	3.56	0.018
S44	6.4	0.28	22.22	28.05	15.10	0.025
S45	2.48	0.19	55.5	4.5	3.26	0.019
S46	1.65	0.24	39.5	47.33	2.21	0.019
S47	2.17	0.14	38.75	22.29	2.68	0.020
S48	1.86	0.43	38.25	23.79	2.26	0.019
S49	2.37	0.30	37.5	26.29	3.08	0.020
S50	1.44	0.16	39.5	20.53	1.95	0.017

Table 2. Contd.

S51	3.3	0.12	21.25	19.03	4.07	0.028
S52	1.55	0.35	25.25	18.53	2.18	0.834
S53	8	0.16	24.5	22.29	15.33	0.498
S54	5.37	0.34	27.5	17.78	9.50	0.022
S55	4.34	0.28	31.5	21.53	8.18	0.023
S56	4.75	0.18	22.5	22.54	8.28	0.706
S57	5.16	0.23	46.5	34.06	8.36	1.197
S58	6.61	0.18	30.75	44.58	10.86	0.252
S59	2.48	0.36	43.25	29.05	3.80	0.020
S60	1.86	1.36	25	12.52	3.32	0.020
S61	3.72	0.25	36.75	26.8	5.49	0.098
S62	2.07	0.19	52	20.53	2.89	0.021

Staff, 1954; Muhr et al., 1963; Gupta and Gupta, 1997; Hopkins and Richardson, 1999) have proposed various criteria on the basis of EC to assess the degree of salinity of soils. However, Gupta and Gupta (1997) have suggested the salinity appraisal on the basis of EC particularly in relation to plant growth. By using this criterion, salinity classification is proposed for the soils from the study area (Table 3).

It is observed from Table 3 that out of 62 soil samples, 27 (43.54%) samples belong to normal salinity class, which is normal for all crops. The remaining 35 (51.47%) samples have some kind of salinity problem developed in the area. The 12 (19.35%) and 5 (8%) samples have low to moderate salinity categories respectively. Further 9 (14.51%) samples each have high salinity to very high salinity classes. It is observed that the soils from the downstream part of Pravara River and in the backwaters area of Ojhar weir have high to very high salinity classes (Figure 1). The observation shows that the normal soils with EC less than1.5 lie in the upper part of the basin, which is predominantly non-irrigated. On the contrary, it is interesting to note that samples having EC greater than 20 (S/N - S2, S6, S7 and S16) were observed in the downstream part of the area where intensive irrigation is practiced. Also it is observed from the table that the considerable irrigated area is under the threat of soil and groundwater salinisation.

Origin of soil salinity in the area

The locations of soil and groundwater salinisation identified in the area demonstrate the existence of salinity problem. Salinisation is a cumulative effect of various parameters such as climate, topography, geology, over-irrigation, irrigation practices, quality of irrigation water, restricted drainage, use of chemical fertilizers and landuse which have played an important role in the development of saline soils in the area.

Climate: The Sangamner area is characterized by semi-arid climatic conditions with average rainfall not exceeding 500 mm. The area is semi-arid with maximum tempera-ture as high as 42°C. Since it falls under the rain shadow zone having scanty rainfall, thereby leaching of soils does not take place effectively. These salts accumulated within the area are probably added to groundwater during the wet period. In addition, reduction in the flow of the river which is due to impoundment of water at Bhandardara reservoir has further reduced the flowing rates of the salts. Furthermore, the impoundment of water at Ojhar weir along with the siltation has restricted the movement of salts from the area. Thus, high temperature favoring higher rate of evaporation, lack of surface flow condition, congestion of drainage conditions and siltation in the Ojhar weir seems to hasten the process of salinisation of ground water and soils in the area.

Geology: The soils from the area are derived from basaltic rocks, which are rich in bases. Therefore they are potentially able to supply very large amount of calcium, magnesium and sodium salts. Due to intro-duction of irrigation, the dissolution of these bases has been accelerated. As a result of this, the groundwater is then charged heavily with these salts. In addition, the salts leached from the upper parts of the area are further accumulated in the downland leading to salinisation of both soil and groundwater resources. Due to flat topography of alluvial aquifers in the downstream part of the area, free natural drainage is absent. This leads to increased residence time and sluggish ground water movement producing salinisation. In some parts, salts are highly concentrated to the extent that no salt tolerant crops could endure the soil conditions because many acres of land have remained uncultivated.

Use of chemical fertilizers and nitrate pollution: Heavy application of fertilizers along with irrigation faci-lities has also contributed to salinity problem. Commercial fertilizers yield chloride, sulphate, nitrate, phosphate, calcium, potassium, magnesium, ammonium and sodium ions in various amounts increasing their concentration

Table 3. Soil salinity classification on the basis of EC of soil extract.

Nature of soil	EC (dS/m)	Plant growth	No. of samples and their locations
Normal	< 1.5	Normal for all crops	S23,S24,S25,S29,S30,S32,S33,S34,S35,S41,S42,S43,S44,S45,S46,S47,S48,S49,S50,S52,S55,S57,S58,S59,S60, S61,S62 **= 27 (43.54 %)**
Low Salinity	1.5 – 3	Yields of very sensitive crops restricted	S1, S18, S19, S22, S31, S37, S39, S40, S51, S54 and S56 **= 12 (19.35%)**
Medium Salinity	3 to 5	Yields of many crops restricted	S17, S26, S27, S38, S53 **= 5 (8.06 %)**
High Salinity	5 – 10	Only tolerant crops yield satisfactory	S5,S9,S11,S12, S13, S15, S20, S21 and S28 **= 9 (14.51%)**
Very high salinity	> 10	Only a few very tolerant crops yield satisfactorily	S2, S3, S4, S6, S7,S8,S10, S14 and S16 **= 9 (14.51 %)**

in groundwater. Excessive use of fertilizers particularly in soils under intensive monoculture tends to lose organic matter and their ability to retain moisture. Thus, they become more susceptible to erosion and ultimately losing their fertility and productivity.

The solubility of phosphate fertilizers is low and it is adsorbed on the soil. Potassium ions from the potash fertilizer are also very well adsorbed on the soil. On the contrary, neither physical nor chemical sorption of nitrate ions occurs with nitrogen fertilizers. Their absorption is predominantly biological. However, the plants through the roots absorb part of nitrogen fertilizer and some part is transformed into cell walls of microorganism. However, this mechanism of nitrate removal is insignificant in soil environment. Overall, the nitrate from fertilizer percolates into the groundwater thereby increasing the nitrate pollution. Majority of the irrigated area under study has been occupied by sugarcane. It encourages using excess of irrigation water, over dose of chemical fertilizers irrespective of crop requirement and soil properties. This has disturbed the quality of soil resulting into emergence of saline tract within the irrigated part of the region.

Landuse: In any irrigated area, assessment of current land-use is important because it has direct bearing on the water resource utilization pattern (Rao, 1975). However, in the area, land use pattern, unique geological and topographic system have considerable impact on the soil and groundwater quality. The industrial and urban development in the area is not much significant, though agricultural development along the Pravara River is noticeable. High value crops (monoculture long term crops) like sugarcane, followed by vegetables like tomato, bhendi, cauliflower, cabbage, bringles, etc., have been cropped in the irrigated land use. Such land-use encourages the application of fertilizers and pesticides combined with the changes in the soil and groundwater chemistry. However, in the hilly area, it is observed that part of the traditional agriculture have been responsible for degradation of the land. The degradation includes deforestation coupled with loss of structure, soil erosion and depletion in soil fertility. The barren, rocky and typical stony wasteland is observed in this area. The large patches of scrubs are seen near the villages like Jorve, Kolhewadi, Rahimpur and Ojhar (Figure 1). These scrubs which are *Prosopis juliflora*, reeds, etc., are all along the major drainage/stream courses in the region. Many a times, this vegetation is closely associated with salt affected lands.

Sodiumization

The soils in which the exchange complex contain appreciable quantities of exchangeable Na^+ but may or may not contain excess salts, are called alkali or sodic soils. The process is known as sodiumization/alkalization (Daji, 1996). In this process, the salts such as sodium bicarbonate and/or carbonate predominate are characterized by ESP > 15, with pH usually between 8.5 and 10, EC < 4 and they exhibit poor physical conditions (Tripathi, 1998). These soils are dispersed and the dissolved organic matter present in them is alkaline. They get deposited on the soil surface by evaporation to give rise to ‘black alkali’. Further dispersed clay transported downward through the soil profile accumulates at lower levels. As a result, a few inches of surface soil is relatively coarse in texture and friable, below which clay develops layer of low permeability, with columnar prismatic structure. This further leads to change in soil and water chemistry. Velayutham (1999) has made suggestions to estimate the degree of soil sodicity on the basis of ESP (Table 2). Based on ESP, sodicity classification of the soils for the study area is given in Table 4.

Table 4. Degree of sodicity of the soils from study area.

Degree of sodicity	ESP	Locations
Slight Sodicity	< 15	S11,S13,S14,S15,S17,S18,S23,S28,S29,S30,S31,S32,S33, S34,S35,S36,S37,S38,S39,S40,S41,S42,S43,S45,S46,S47, S48,S49,S50,S51,S52,S54 to 62**= 40 (64.51%)**
Moderate Sodicity	15 – 40	S1,S4,S5,S6,S7,S8,S9,S10,S12,S16,S19,S20,S21,S22, S24,S25,S26,S27,S44andS53 **= 20 (32.25%)**
Strong Sodicity	> 40	S2 and S3 **= 2 (3.26%)**

It is observed from Table 4 that out of 62 samples, 40 (64.51%) samples show slight sodicity, 20 (32.25%) samples show moderate sodicity and only 2 (3.26%) have strong sodicity. This indicates that there is considerable degree of sodiumization of soil that is restricted in the irrigated area. This problem is more serious in the downstream part of Pravara River where backwater of Ojhar weir has caused waterlogging condition. It is observed that the samples with ESP between 10 and 15 (S/N - S14, S17 and S58) also lie all along the river bank areas where intensive agriculture is practiced. The samples showing ESP values below 5 (S/N - S32, S41, S42, S43, S45, S46, S47, S48, S50, S51, S52, S59, S60 and S62) were collected from local high ground water divide areas (Figure 1) that are necessarily under non-irrigated agriculture landuse. Sodiumization in the downstream part may be attributed to waterlogging in the area.

Origin of sodiumization

The chemical analysis of groundwater showed the predominance of Na^+ followed by Ca^{2+} or Mg^{2+}. The anions found in the order $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$ which suggests that carbonates, bicarbonates and saturated waters cause precipitation of calcium and magnesium have left behind sodium rich solution that is forming sodicity in the area (Deshmukh, 2012b). The absorption of sodium increases with high Mg/Ca ratio of waters resulting in enhanced sodicity (Paliwal and Gandhi, 1976). As regards the study area, the water analysis data indicate that 25% samples have Mg/Ca greater than one, leading to Mg hazard and greater Na% in the area (Deshmukh and Pawar, 2001). The contribution of magnesium often resembles that of sodium. Prolonged irrigation with waters of high Mg/Ca ratio and SAR is expected to raise Mg/Ca ratio of the soil and increase the proportion of Mg and Na on the soil exchange complex (Girdhar and Idnani, 1994). This inference is supported by data on analysis of soils (Table 2) and shows high sodium concentration followed by magnesium. It is further observed that the exchangeable Na^+ is higher in the downstream part compared to Ca^{2+} and Mg^{2+}. The occurrence of exchangeable Na^+ seems to be associated with the clay content of the soils. The soils in the study area are mostly clay to clayey loam (Deshmukh, 2012b).

Waterlogging

Waterlogging is caused by natural as well as man-made factors. Waterlogging is caused due to poor natural drainage as a consequence of unfavorable topography and unfavorable sub-soil geology. It may be due to introduction of irrigation without considering the characteristics of soils and sub-soils. Heavy losses of water are due to seepage from canals, distributaries and water courses. Developmental activities such as construction of roads, bridges, railway lines and building, result into choking of natural drainage, and poor maintenance of existing drainage system and outlets. Hydraulic pressure of water from upper irrigated areas results into seepage in low-lying areas and silting up of river beds (Gupta and Gupta, 1997). In view of this, assessment of waterlogging in the study area was done. The Ministry of Water Resources, Government of India, 1991 suggested the norms for categorization of waterlogged areas. If the depth of water is <2 m, then the area is waterlogged, but if it is between 2-3 m, it is potentially waterlogged, and if it is greater than 3 m, it is safe. Based on these criteria, 65 well samples were analyzed from the study area. It is observed that out of 65 wells, 22 (33.85%) wells are waterlogged and 6 (9.23%) wells are potentially waterlogged from the area. This indicates that nearly 43% area is under threat of waterlogging. In general, the downstream part and backwater area of Ojhar weir (Figure 1) showed more potential of waterlogging which further leads to intensive salinisation and/or alkalization problem.

Boron toxicity

Plant species differ markedly in their tolerance to excessive concentration of boron. Richards (1968) has categorized the boron concentration relative to tolerance of crop/plants. In this classification, boron concentrations

Table 5. Classification of soils based on boron concentrations from study area.

Class	Boron conc. (ppm)	No. of samples and locations
Safe	< 0.7	S18, S21, S23, S24, S28, S29, S31, S32, S33, S34, S35, S36, S37, S38, S39, S40, S41, S42, S43, S44, S45, S46, S47, S48, S49, S50, S51, S53, S54, S55, S58, S59, S60, S61, S62 **= 35 (56.45%)**
Marginal	0.7 to 1.5	S19, S22, S30, S52, S56, S57 **= 6 (9.67%)**
Unsafe	> 1.5	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S20, S25, S26, S27 **= 21 (33.81%)**

in the soil extract below 0.7 ppm are considered safe for sensitive plant, from 0.7 to 1.5 ppm as marginal and greater than 1.5 ppm as unsafe. Based on these limits, the soils in the area are classified (Table 5).

It is observed from the table that 35 (56.45%) samples were safe in boron concentration, 6 (9.67%) samples are marginal and 21 (33.81%) samples reflect unsafe class. This indicates that 27 (43.88%) samples have exceeded safe limit of boron. Therefore, it is inferred that these soils have boron concentration in toxic quantities. Critical look on the data in Table 5 and Figure 1 indicates that these samples are located in the problem area and in the back-waters of Ojhar weir. This is possibly due to high soil pH, high EC leading to salinisation, impeded drainage and limited leaching, high and fluctuating water table and clayey soil texture in the area. However, the remaining 35 (56.45%) samples are in the safe limit. Since, non-irrigated area shows occurrence of calcareous soils, the high concentration of boron are not expected to cause any toxicity. This is due to the fact that in these soils, B precipitates as calcium borate (Gupta, 1974).

Conclusions

In order to understand the impact of irrigation on the chemistry of soils from Sangamner area, the chemical properties like pH, EC, soluble cations and anions, exchangeable cations and boron were estimated by analyzing 62 soil samples. pH of the soils ranges from 8 to 9.7 reflecting alkaline nature. The higher values of pH are observed in the central and downstream part of the area which is indicative of development of salinity/sodicity in the area. The higher values of EC have been observed from downstream part indicating low flushing rate and sluggish groundwater movement where intensive irrigation is practiced. The normal soils lie in the upper part of Pravara River basin which is predominantly non-irrigated. The saline soils are developed due to climate, topography, geology, over-irrigation, water quality, use of chemical fertilizers and land use pattern in the area. The origin of sodiumization is more or less similar to salinisation. However, predominance of Na over other cations, high Mg/Ca ratio, relatively high ESP and SAR and semi-arid climatic conditions have favored the sodiumization in the majority part of the area. Nearly 43% of the area is under the threat of waterlogging. The excess recharge at higher latitude, less withdrawal of saline groundwater, inadequate drainage, monoculture type of cropping pattern, unique climatic conditions and silting up at river bed are some of the causes of waterlogging identified in the area. As far as boron toxicity is concerned, 32% soil samples are unsafe for crop development. These soils are located in the downstream part of the river and in the backwater areas of Ojhar weir. However, high levels of boron can be reduced from saline/sodic soils by leaching, using gypsum as amendment and by selection of boron tolerant crops. Adequate drainage and leaching, selection of salt tolerant crops, blending of saline water with good quality of water, use of manures and mulching can be adopted to improve the problematic soils in the area. Frequent awareness and training programs for farmers can be arranged to avoid further degradation of soils.

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