Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 17	No. 4	pp. 1147-1160	2018

Original Research Paper Open Access

Evaluation of Agricultural Soil Quality in Khandesh Region of Maharashtra, India

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 25-09-2017
Accepted: 18-12-2017

Key Words:
Khandesh region
Soil fertility
Soil salinity
Statistical analysis

ABSTRACT

Being agronomy as a major profession, soil and water are key resources for the Indian subcontinent. Modern agro practices and anthropogenic human activities are mainly responsible for degradation of agricultural soil. The present investigation deals with the cultivated soil quality in the Khandesh region of Maharashtra state. The study area comprises Jalgaon, Dhule and Nandurbar districts of Khandesh region. The soil quality analysis was conducted over three districts of the region. Total 108 soil samples were collected and processed for physicochemical characterization. The results were processed with linear regression with respect to pre-monsoon and post-monsoon, EC-SAR graphs with 95% CI and PI, ESP-SAR model, Bland-Altman plot and ternary diagrams. The statistical tools viz. one variable statistics, a coefficient of correlation and other ratios were applied for the data analysis. The result shows, calcium, sodium and potassium concentrations are under the prescribed limit. However, magnesium concentration is between 836.77 and 1762.63 mg/kg, which is high as compared to other exchangeable cations. Finally, the results show unbalancing of soil minerals with higher salinity in the area. Regular monitoring and remediation will help to maintain soil quality of the area in the near future.

INTRODUCTION

It is well known that from beginning, India has been an agronomical country, means Indian economy is fully dependent on agriculture. The major crops sown in Khandesh region are such as cereals (e.g. wheat, sorghum, rice, maize and bajra), pulses (e.g. tur, mung and udid), fruits (e.g. banana and sugarcane), cotton, legumes and oilseeds (e.g. groundnut, sesamum, sunflower, soybean, caster seed, safflower, rape and mustard), vegetables and many others. I past few years crop productivity and quality have dropped by excessive use of inorganic or chemical fertilizers, pesticides and insecticides. The continuous sowing of the same crop year by year and reduced manure application in farm causes soil fertility to also decrease (Singh et al. 2007). Usman & Kundiri (2016) clarified the importance of organic fertilizers over chemical fertilizers.

Anthropogenic activities are negatively affecting the environmental factors; these effects may be direct or indirect effects on agricultural soil. From an agricultural point of view, an essential environmental factor is a soil which produces human and animal needed food (Brady & Weil 2007). Hence, there is a requirement to analyse the soil quality in the sense of soil productivity at regular intervals to rectify the problems of soil irrigation. It allows us to focus to increase the farm yield. In this study, we determined and discussed soil quality as well as soil productivity of Khandesh region, which comprises Jalgaon, Dhule and Nandurbar districts.

STUDY AREA

Khandesh region has been selected for the study, including three districts; these are Jalgaon, Dhule and Nandurbar as shown in Fig. 1. These three districts are situated in the northern part of Maharashtra State in India. The Jalgaon district is located at 20°-21° N latitude and 74.55°-76.28° E longitude, Dhule district is located at 20.38°-21.61° N latitude and 73.50°-75.11° E longitude, whereas Nandurbar district is located at 21.00°-22.03° N latitude and 73.31°-74.32° E longitude. All 25 talukas, 15 from Jalgaon, 4 from Dhule and 6 from Nandurbar were covered under the study.

GEOLOGY OF THE STUDY AREA

The study area is covered by Deccan trap rocks of cretaceous to eocene age and alluvium layer is of quaternary age. Tapi river flows through Jalgaon, Dhule and Nandurbar districts of Khandesh region. Thick alluvial deposits are present in Raver, Muktainagar, Yawal, Bhusawal, Chopda, Shirpur, Shahada, Taloda and Navapur talukas. Most part of the study area is covered by Deccan traps except few strips of alluvial land on both sides of the Tapi river (Patil et al. 2015).

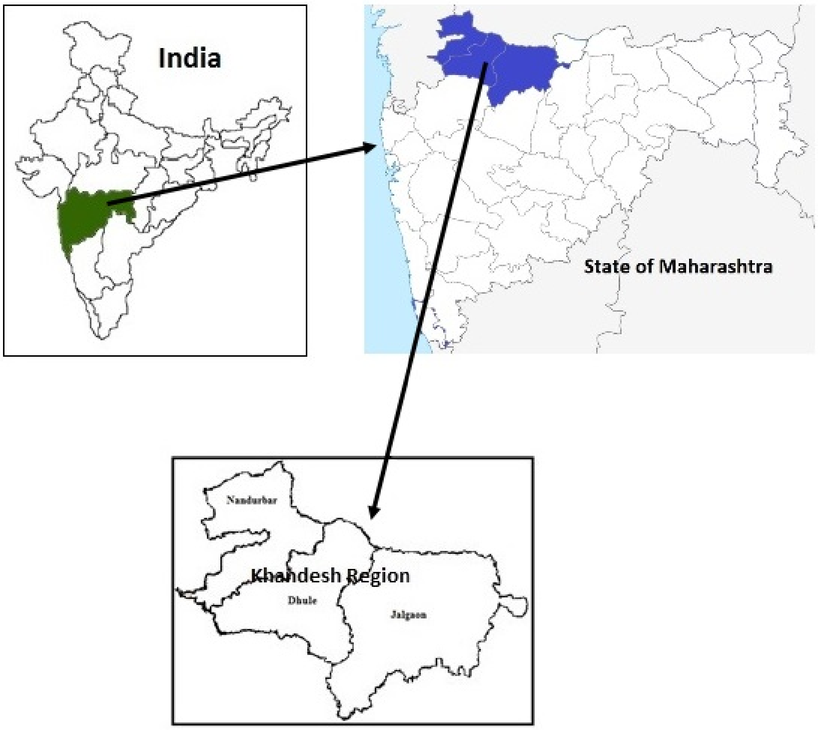


Fig. 1: Location map of study area.

MATERIALS AND METHODS

Collection of soil samples: Pre and post-monsoon sampling was conducted during 2016. The sampling locations were chosen at random basis and determined by using GPS (Global Positioning System) GARMIN (Model No. Montana 650) which are shown in Fig. 2. Total 108 soil samples (0 - 15 cm) were collected from an irrigated field using a hand auger. After sampling, samples were dried, ground and sieved to obtain < 2 mm size soil particles (Zare et al. 2014).

Analytical procedure: The processed soil samples (< 2 mm) were used for analysis of different physicochemical parameters. The physical parameters determined were colour, texture, porosity, bulk density, moisture content and water holding capacity. The chemical parameters analysed included pH, electrical conductivity, available phosphorus, available potassium, sodium, cation exchange capacity (CEC), organic carbon, organic matter, calcium and magnesium by using "Laboratory testing procedure for soil and water sample analysis" (2009).

Colour and texture of soil were determined on the basis of visual diagnosis, while porosity, bulk density, moisture content and water holding capacity were analysed by manual of soil analysis (Margesin 2005) and laboratory manual of the water resources department (2009). Soil pH and electrical conductivity were analysed from 1:2 soil extract by using a pH meter and conductivity meter respectively. Available phosphorus was estimated from the soil by using the Olsen blue colour method, whereas magnesium concentration by EDTA titration method. Sodium, potassium and calcium concentrations were estimated by using a flame photometer. Further, CEC was determined by the ammonium acetate method. Organic carbon was analysed by Walkley and Black method.

Ions were converted from mg/L to mg/kg. Ions were also converted from mg/kg to meq/kg to meq/100 g or centimole/kg wherever necessary. The resulted values of each parameter were interpreted and calculated with irrigation indices using the following formulas of sodium adsorption ratio (SAR), exchange sodium percentage (ESP), electrochemical stability index (ESI), sodium percentage (Na%), magnesium percentage (Mg%) and Kelley's ratio (KR) as follows:

***Sodium Adsorption Ratio*:** This was calculated by employing the equation (Raghunath 1987) as:

$$SAR\ (cmol/kg) = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad ...(1)$$

(Concentrations are in cmol/kg)

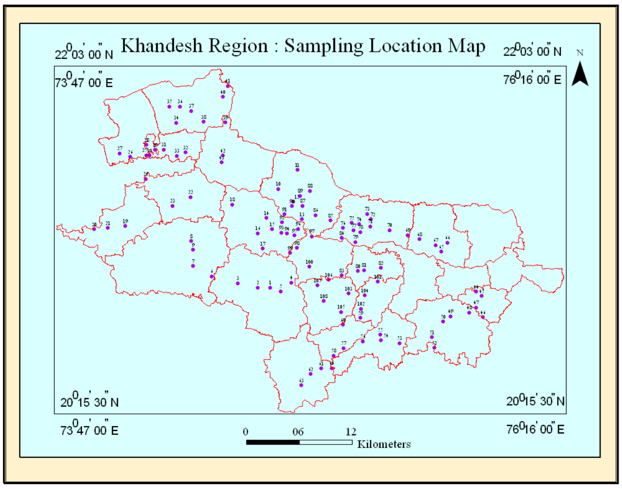


Fig. 2: Sampling sites of the study area.

***Exchangeable sodium percentage*:** This was calculated employing the equation (Seilsepour et al. 2009) as:

$$ESP\ (\%) = \frac{Na^+}{Ca + Mg + Na + K} \times 100 \quad ...(2)$$

(Concentrations are in cmol/kg)

***Electrochemical stability index*:** This was calculated by the formula of (Mckenzie 1998) as:

$$ESI = \frac{EC}{ESP} \quad ...(3)$$

***Sodium percentage*:** This was calculated by the formula of (Patil et al. 2016) as:

$$Sodium\ (\%) = \frac{Na^+}{Ca + Mg + Na + K} \times 100 \quad ...(4)$$

(Concentrations are in cmol/kg)

***Magnesium percentage*:** This was calculated by the formula of (Patil et al. 2016) as:

$$Magnesium\ (\%) = \frac{Mg^{2+}}{Ca + Mg + Na + K} \times 100 \quad ...(5)$$

(Concentrations are in cmol/kg)

***Kelley's ratio*:** This was calculated employing the equation (Kelley 1963) as:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad ...(6)$$

(Concentrations are in cmol/kg)

Statistical Analysis

All the soil samples were analysed using standard chemical methods and the results are presented using one variable statistics. Data used for this study were analysed using graphical and statistical techniques. Firstly, scatter plots of a linear relationship of physical and chemical properties of pre and post-monsoon soil samples were prepared. One of the purposes of this study is to present regression equations for estimating SAR from electrical conductivity for Jalgaon, Dhule and Nandurbar. Initial graphical inspection of the data indicated linear relations between electrical conductivity and SAR for the study area. Linear regression is a tool that can be used to determine the relationship between two constituents. The simple linear regression equation can be expressed as:

$$y_i = mx_i + b, \quad i = 1,2,\ldots\ldots,n \quad ...(7)$$

Where:

y_i is the i^{th} observation of the dependent variable;
m is the slope;
x_i is the i^{th} observation of the independent variable;
b is the y-axis intercept; and
n is the sample size.

The terms 'm' and 'b' are the parameters that need to be estimated from the data. For this study, a relation was determined to be statistically significant at the 95% confidence level. Prediction intervals were determined to evaluate the uncertainty of the estimated values using the regression equation (Helsel & Hirsch 1992). Hence, the 95% prediction intervals were also determined from the regression equation for each district. The mean difference confidence interval approach was used to compare the soil ESP values predicted using the soil ESP-SAR model with the soil ESP values measured by the laboratory tests. The Bland-Altman approach was also used to plot the agreement between the soil ESP values measured by laboratory tests, and the soil ESP values predicted using the soil ESP-SAR model. The ternary diagram shows interrelation between four cations viz., Ca, Mg, Na and K by origin 6.1. Lastly, a tabular coefficient of correlation between all the soil parameters was made. MS-Excel 2007 and 2013 was used to generate the regression equations in this study.

RESULTS AND DISCUSSION

The motive behind examining seasonal variations by comparing this pre and post-monsoon period was to study changes in soil fertility due to use of excess chemical fertilizers and changes in precipitation regimes in the study area.

Physical parameters: Table 1 shows the results of physical parameters, i.e. porosity, bulk density, moisture content and

Table 1: One variable statistical measures for physical parameters.

Physical Parameters	Pre-monsoon Min	Max	Mean	SD	Post-monsoon Min	Max	Mean	SD
PS (%)	28	59	47.32	6.25	31	68	55.48	7.69
BD (g/cm^3)	1.06	2.17	1.65	0.2	0.71	1.54	1.125	0.13
MC (%)	7.5	11.7	9.64	0.83	11.5	24.6	17.47	4.38
WHC (%)	13.8	48.6	29.62	7.37	26.2	60.6	40.42	7.12

Table 2: Pre and post-monsoon correlation analysis results for physical parameters.

Correlation parameters	Pre-monsoon	Post-monsoon
PS-MC	0.55	0.392
PS-WHC	0.38	0.513
MC-WHC	0.564	0.831

Table 3: Criteria for severity classes of salt affected soils (Maharashtra only). (Source: Central Water Commission, TR, 2006)

Level I	Level II	Non Vertisols pH	EC	ESP
Saline	Medium	<8.5	4 to 8	<15
	High	<8.5	8 to 16	<15
	Very high	<8.5	>16	<15
Sodic	Medium	8.5 to 9	<4	15 to 40
	High	9 to 10	<4	40 to 60
	Very high	>10	<4	>60
Saline-Sodic	Medium	8.5 to 9	4 to 8	15 to 40
	High	9 to 10	8 to 16	40 to 60
	Very high	>10	>16	>60

water holding capacity. Most frequently, brown colour soil is found in this region with 52.78% of the total samples followed by black soil with 42.59%, yellow soil with 3.7% and red soil with 0.93 %. The next parameter observed is the texture of soil. It was found that 42.59% of the total soil samples have clay loam texture, 34.26 % sandy loam texture, 12.04 % silt texture, 3.7 % loam texture and 2.78% silt loam texture. Alike but negligible percentage of 0.93 % consists of remaining textures, i.e. clay, sandy, sandy loam, sandy silt and silt clay. Both pre and post-monsoon soil samples did not exhibit any significant difference in colour and texture in the study area. Slight decrease in the BD was observed in post-monsoon soil samples due to semi-arid zone. PS, WHC and MC showed an increasing trend from pre to post-monsoon. Table 1 shows descriptive statistics of PS, BD, MC and WHC for pre and post-monsoon.

The Pearson correlation was used to establish the relationship between two physical variables. The degree of linear relationship between soil quality parameters is measured by the simple correlation coefficient (r). It is presented in Table 2 which shows only efficient relations. A correlation of physical parameters exhibited a very strong positive correlation for MC-WHC in post-monsoon. The moderate positive correlation in PS-MC and MC-WHC existed in pre-monsoon, and in PS-WHC existed in post-monsoon. Similarly, PS-MC and PS-WHC existed a weak positive correlation for post-monsoon and pre-monsoon respectively. Some correlations were not included in the table due to the very weak positive and negative correlations.

Regression analysis was performed to predict the variations between same soil physical parameter of the two different seasons (Fig. 3). The scatter plots show linear regression lines which specify an association between variables from pre and post-monsoon. The r-square (regression coefficient) indicates the correlation between the predicted and observed values of the dependent variable.

In the study area, physical properties like PS, BD, MC and WHC content of post-monsoon can be predicted with 93.34%, 95.18%, 12.53% and 75.13% variation of these soil properties in the pre-monsoon season respectively. MC pre and post-monsoon has very low variation, which may be due to the pre-monsoon soil samples.

Chemical parameters: Table 4 shows the results of chemical parameters, i.e. pH, EC, P, K, Na, CEC, OC, OM, Ca and Mg. The most suitable pH range is 6.0 to 8.0 for crop production. Marathe et al. (2014) reported a soil pH range of Khandesh region, which is between 6.6 and 8.3. However, in this study, pH range shifts in the range 6.4 to 9.0 and 7.0 to 9.3 for pre and post-monsoon respectively. The pH of both the seasons moves slightly to alkaline scale. It happens because of the frequent use of chemical fertilizers and no use of organic fertilizers such as cow dung on the farmland. Table 3 was used to fix the classification of the soil on the basis of pH and EC.

The electrical conductance of soil resulted in the range of 0.72 mS/cm to 6.38 mS/cm and 1.08 mS/cm to 6.81 mS/cm in pre and post-monsoon respectively. In Jalgaon district, Bodvad taluka fall in saline-medium class. Rest of all soil samples fall in sodic-medium class. Approximately 20 samples may be a saline-very high class or sodic-low class.

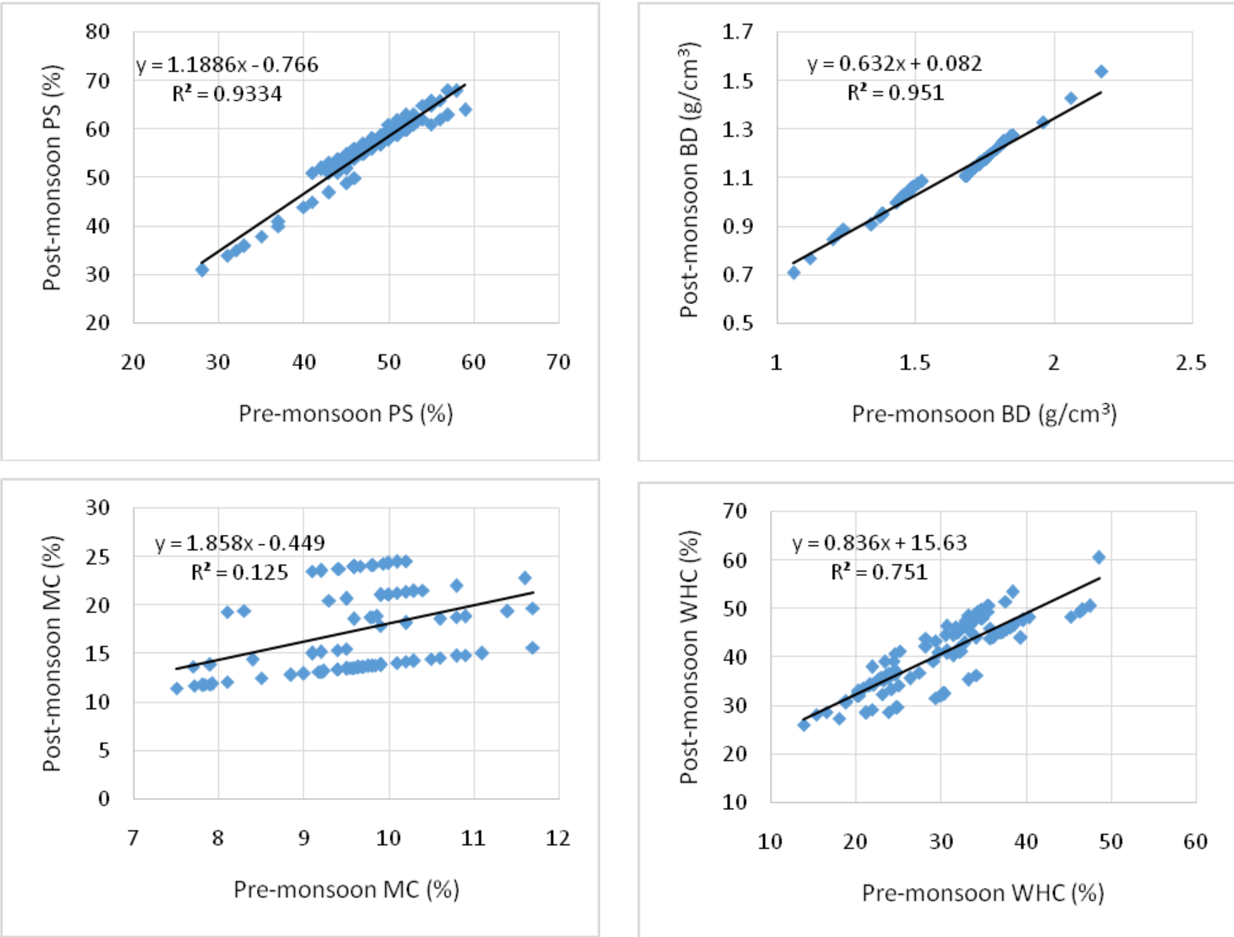
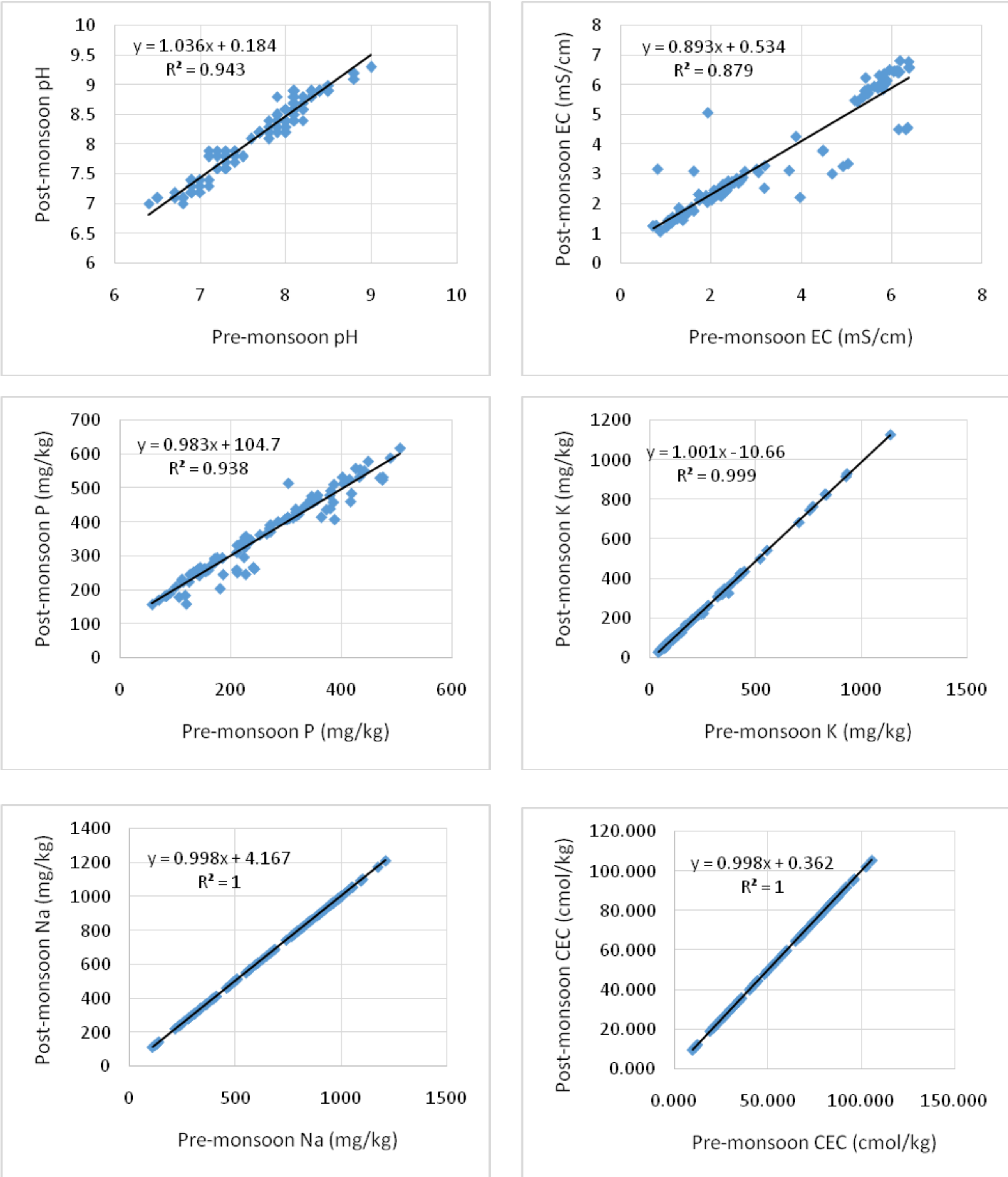


Fig. 3: Scatter plots representing linear relationship for physical properties of soil w.r.t. pre and post-monsoon.

Dhule district has most of the samples falling in the saline-medium category. Sodic-medium soil is found only in Vikharan of Shirpur taluka. The soil samples of Navalnagar and Fagane of Dhule taluka, Boradi of Shirpur taluka and Chimthane of Shindkheda taluka are saline-very high class or sodic-low category. Remaining soil samples of Dhule district surely drop down to saline-medium class. In Nandurbar area all the soil samples were characterized as saline-medium class, except only one sample having a sodic-medium class in Bebadadapada of Dhadgaon taluka. Ac-

Table 4: One variable statistical measures for chemical parameters.

Chemical Parameters	Pre-monsoon Min	Max	Mean	SD	Post-monsoon Min	Max	Mean	SD
pH	6.4	9	7.71	0.56	7	9.3	8.18	0.59
EC (mS/cm)	0.72	6.38	3.25	1.89	1.08	6.81	3.44	1.8
P (mg/kg)	58.57	506.14	258.59	115.98	158.57	617.14	359.13	117.76
K (mg/kg)	39.54	1136.4	218.97	221.94	29.54	1126.4	208.54	222.24
Na (mg/kg)	110.34	1211	696.02	300.93	114.34	1214	699.46	300.62
CEC (cmol/kg)	9.6	105.31	60.53	26.17	9.94	105.57	60.82	26.14
OC (%)	0.09	0.9	0.42	0.22	0.15	1.4	0.77	0.29
OM (%)	0.16	1.55	0.73	0.38	0.259	2.41	1.34	0.5
Ca (mg/kg)	39.21	938	254.89	217.07	39.21	1238	300.95	267.95
Mg (mg/kg)	836.77	1762.63	1307.41	218.25	968.5	1912.63	1370.23	246.27
Na%	3.57	34.88	19.22	7.88	3.49	34.07	18.55	7.91
Mg%	49.59	92.56	69.53	8.18	47.98	93.03	69.75	8.47


y = 1.036x + 0.184
R² = 0.943
Post-monsoon pH
Pre-monsoon pH
y = 0.893x + 0.534
R² = 0.879
Post-monsoon EC (mS/cm)
Pre-monsoon EC (mS/cm)
y = 0.983x + 104.7
R² = 0.938
Post-monsoon P (mg/kg)
Pre-monsoon P (mg/kg)
y = 1.001x - 10.66
R² = 0.999
Post-monsoon K (mg/kg)
Pre-monsoon K (mg/kg)
y = 0.998x + 4.167
R² = 1
Post-monsoon Na (mg/kg)
Pre-monsoon Na (mg/kg)
y = 0.998x + 0.362
R² = 1
Post-monsoon CEC (cmol/kg)
Pre-monsoon CEC (cmol/kg)

cont....

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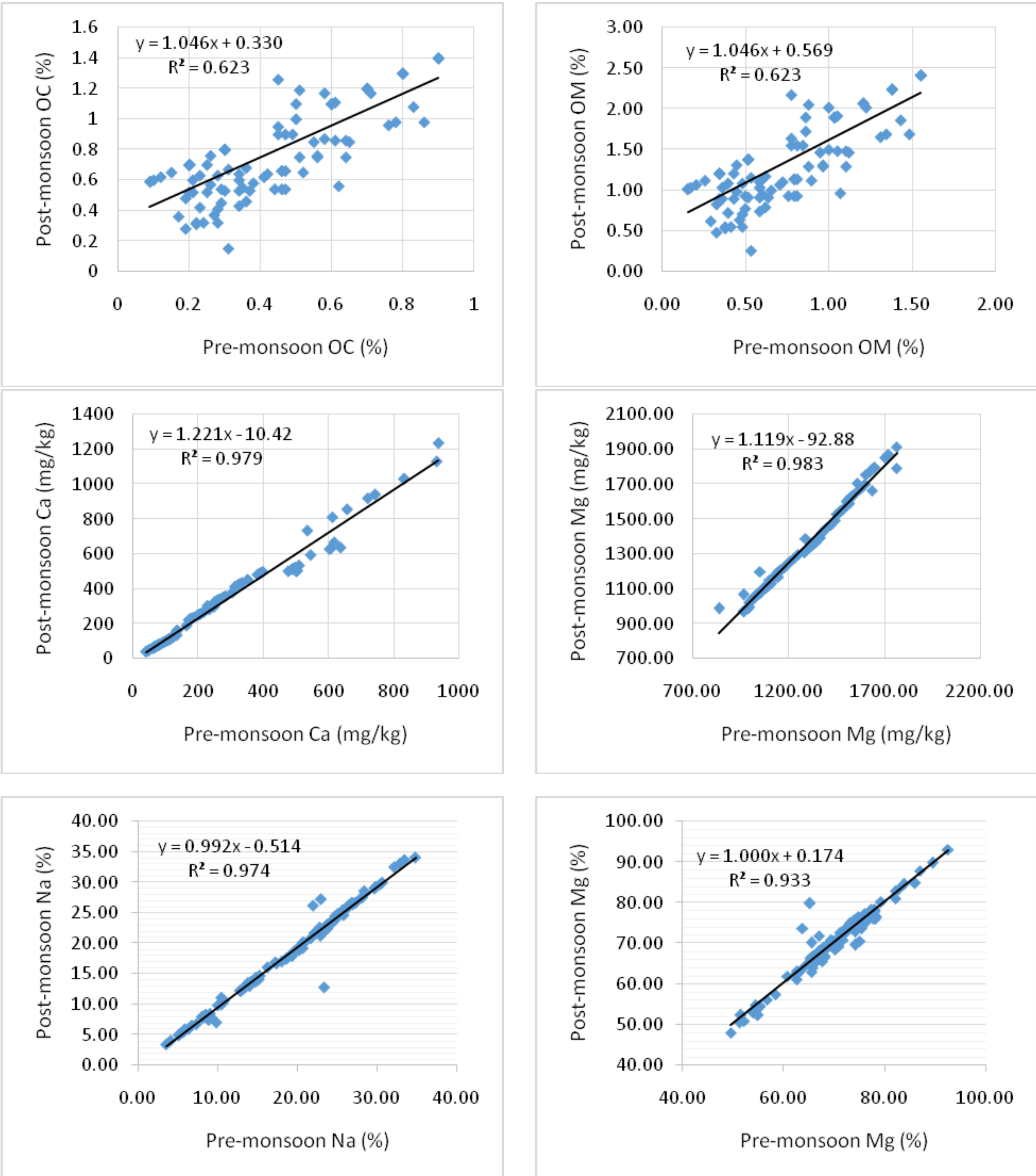

Fig. 4: Scatter plots representing linear relationship for chemical properties of soil w.r.t. pre and post-monsoon.

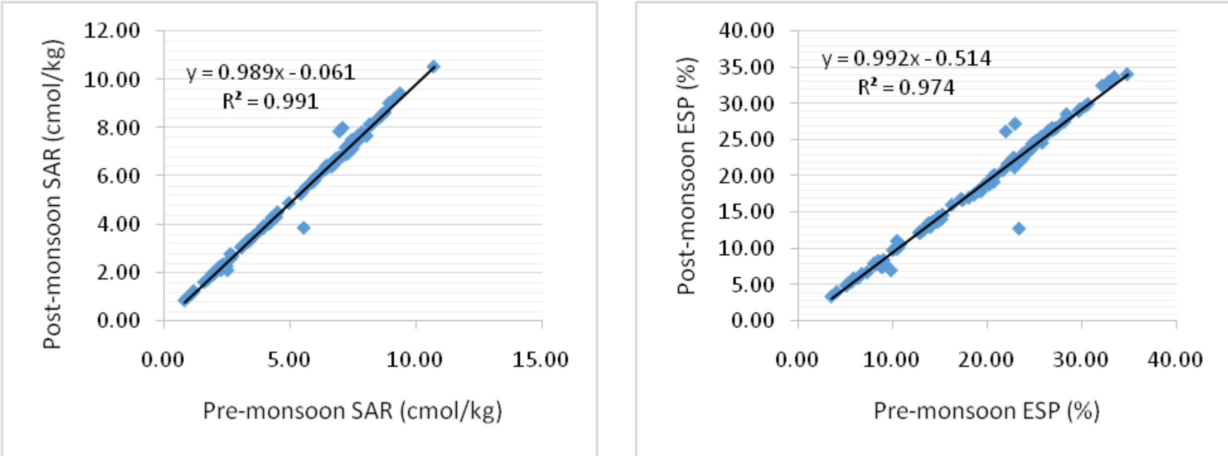

Fig. 5: Scatter plots representing linear relationship for SAR and ESP of soil w.r.t. pre and post-monsoon.

Table 5: Pre and post-monsoon correlation analysis results for chemical parameters.

Correlation parameters	Pre-monsoon	Post-monsoon
pH-EC	-0.7494	-0.6182
pH-Na	0.7657	0.7785
pH-Ca	-0.3055	-0.2414
EC-Na	-0.7273	-0.6891
EC-Ca	0.2461	0.2653
K-Ca	0.9261	0.9446

cording to the electrical conductivity, it is evident that more than 50% sodic soil was found in Jalgaon district, while about 60% and 96% saline soil was found in Dhule and Nandurbar districts respectively (Kaul et al. 2010).

An increasing trend in available P, Ca and Mg was noticed from pre to post-monsoon. Similarly, a slight increase in Na, CEC, OC and OM was observed from pre to post-monsoon. But a decreasing trend in available K has been seen in pre to post-monsoon. Mg concentration is high as compared to other cations; hence, it is evident that the soil exhibits saline properties. This condition will remain for many years, as this soil has been converted from neutral to saline soil and further conversion process into a saline-sodic and next sodic soil may be possible. Table 4 shows descriptive statistics of all chemical parameters which include minimum, maximum, average and standard deviation for pre and post-monsoon.

The Pearson correlation was used to establish the relationship between two chemical variables. The degree of linear relationship between soil quality parameters is measured by the simple correlation coefficient (r). It is presented in Table 5 which shows only efficient relations. Both season results exhibited a very strong positive correlation for K-Ca. A strong positive correlation for pH-Na existed in both the seasons while a strong negative correlation for pH-EC and EC-Na existed in both the seasons. Lastly, a weak positive correlation exhibited for EC-Ca in both the seasons, while a weak negative correlation exhibited for pH-Ca in both the seasons.

Regression analysis was performed to predict the variations between same soil chemical parameters of two different seasons in Fig. 4. The scatter plots show linear regression lines which specify an association between variables from pre and post-monsoon. The r^2 (regression coefficient) indicates the correlation between the predicted and observed values of the dependent variable.

In the study area, chemical parameters like pH, EC, P, K, Na, CEC, OC, OM, Ca, Mg, %Na and %Mg content of post-monsoon can be predicted with 94.37%, 87.96%, 93.86%, 99.93%, 100%, 100%, 62.33%, 62.33%, 97.95%, 98.36%, 97.47% and 93.39% variation of these soil properties in the pre-monsoon season respectively.

Irrigational quality parameters: Table 6 shows the results of irrigational quality parameters, i.e. SAR, ESP, ESI and KR. The SAR values are seen almost same in both the seasons. The ESP values slightly decrease from pre to post-monsoon. The ESI values increase from pre to post-monsoon. The KR values somewhere increase and somewhere decrease from pre to post-monsoon, but it is not important, the important thing is that all values were below 1.

Regression analysis was performed to predict the variations between same soil irrigational quality parameters of two different seasons (Fig. 5). The scatter plots show linear regression lines which specify an association between vari-

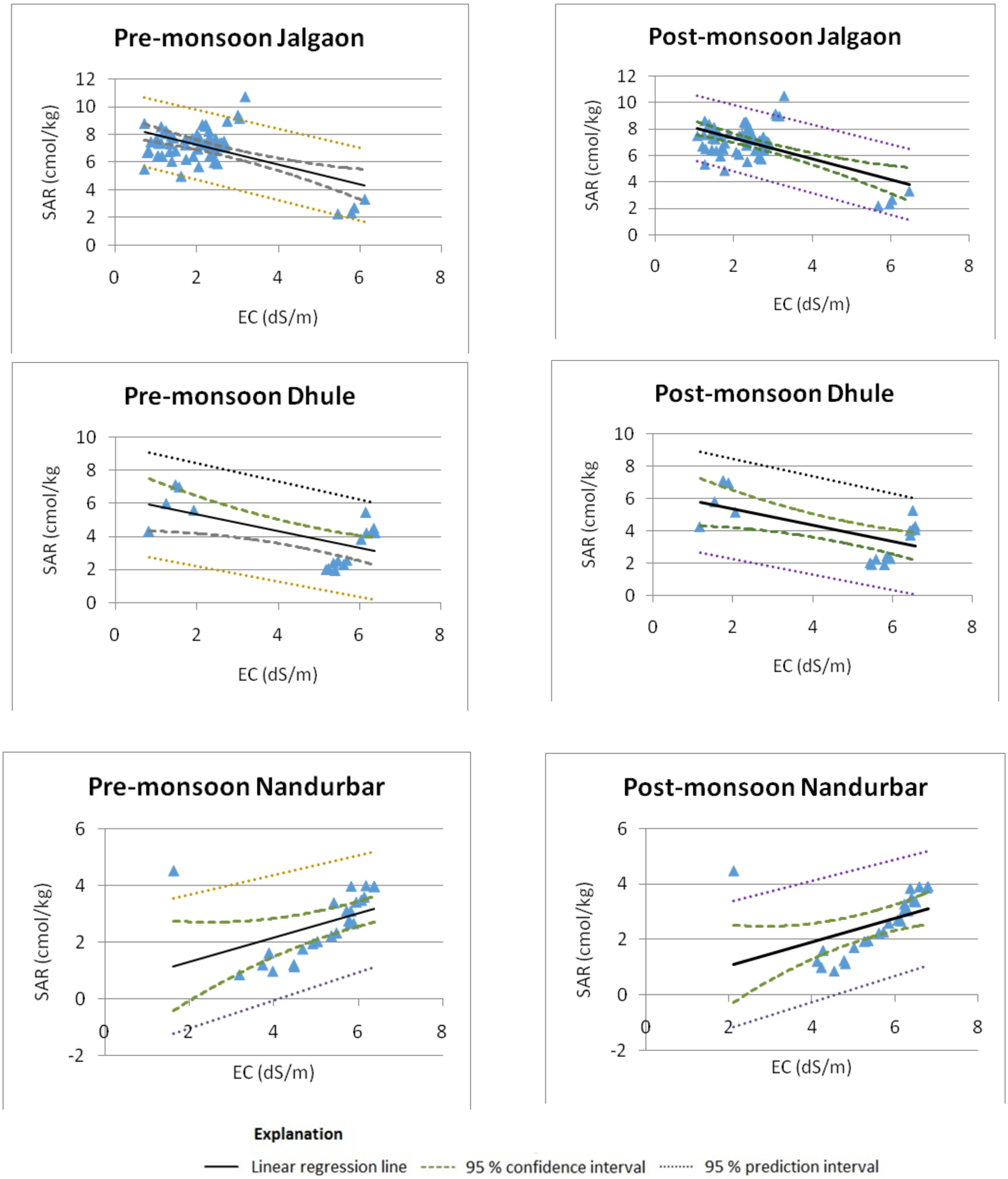

Fig. 6: SAR in relation to electrical conductivity in soil quality samples collected from districts in Jalgaon, Dhule and Nandurbar.

ables from pre and post-monsoon. The r^2 (regression coefficient) indicates the correlation between the predicted and observed values of the dependent variable. In the study area, SAR and ESP of post-monsoon can be predicted with 99.13% and 97.47% variation of these soil properties in the pre-monsoon season, respectively.

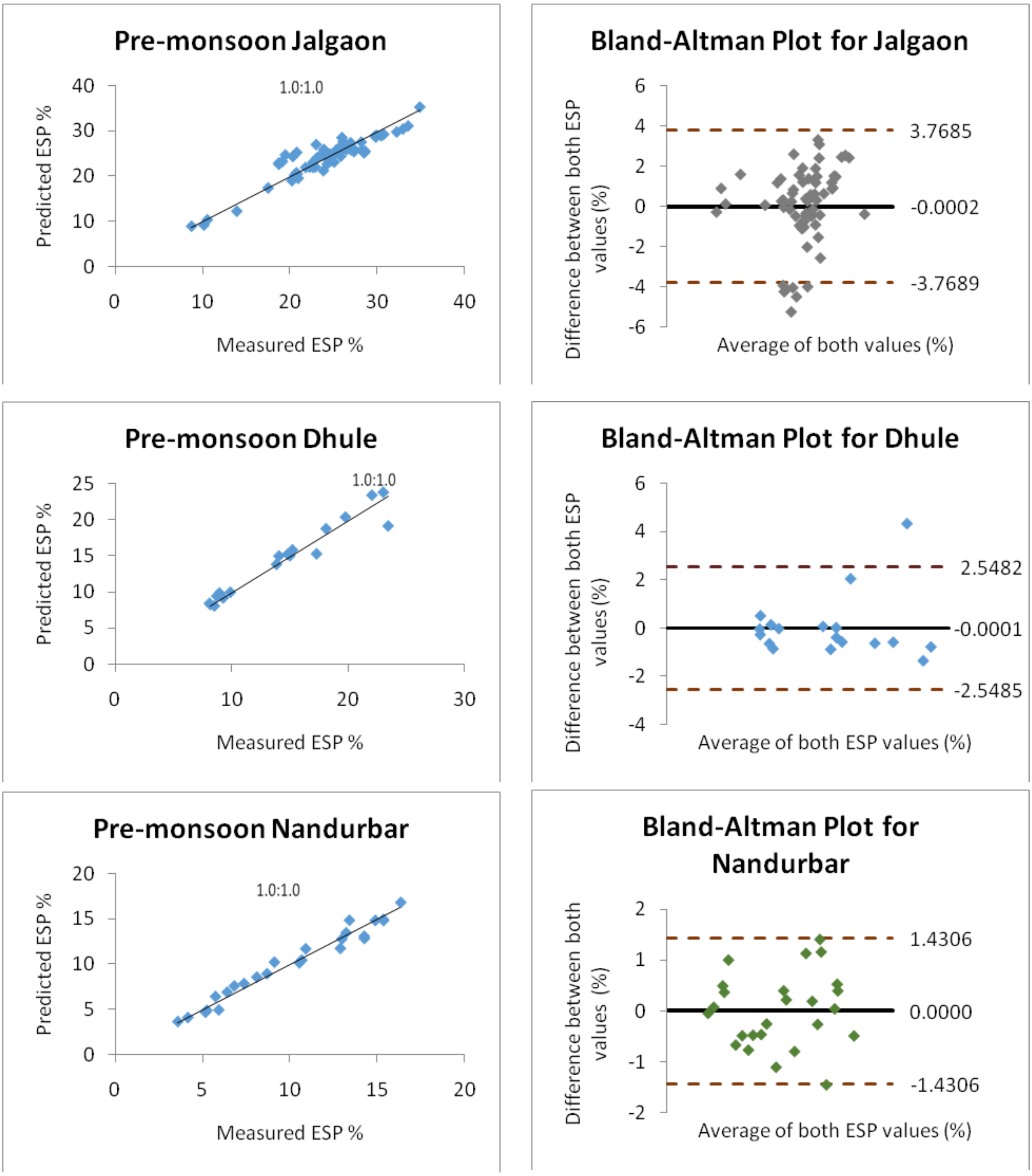

Fig. 7: The left side column of the graph indicates measured ESP and predicted ESP, using the soil ESP-SAR model with the line of equality (1.0:1.0) and right side column of the graph indicates Bland-Altman plot for the comparison of measured ESP and predicted ESP, using the ESP-SAR model; the outer dash lines indicate the 95% limits of agreement and the center continuous line shows the average difference for pre-monsoon.

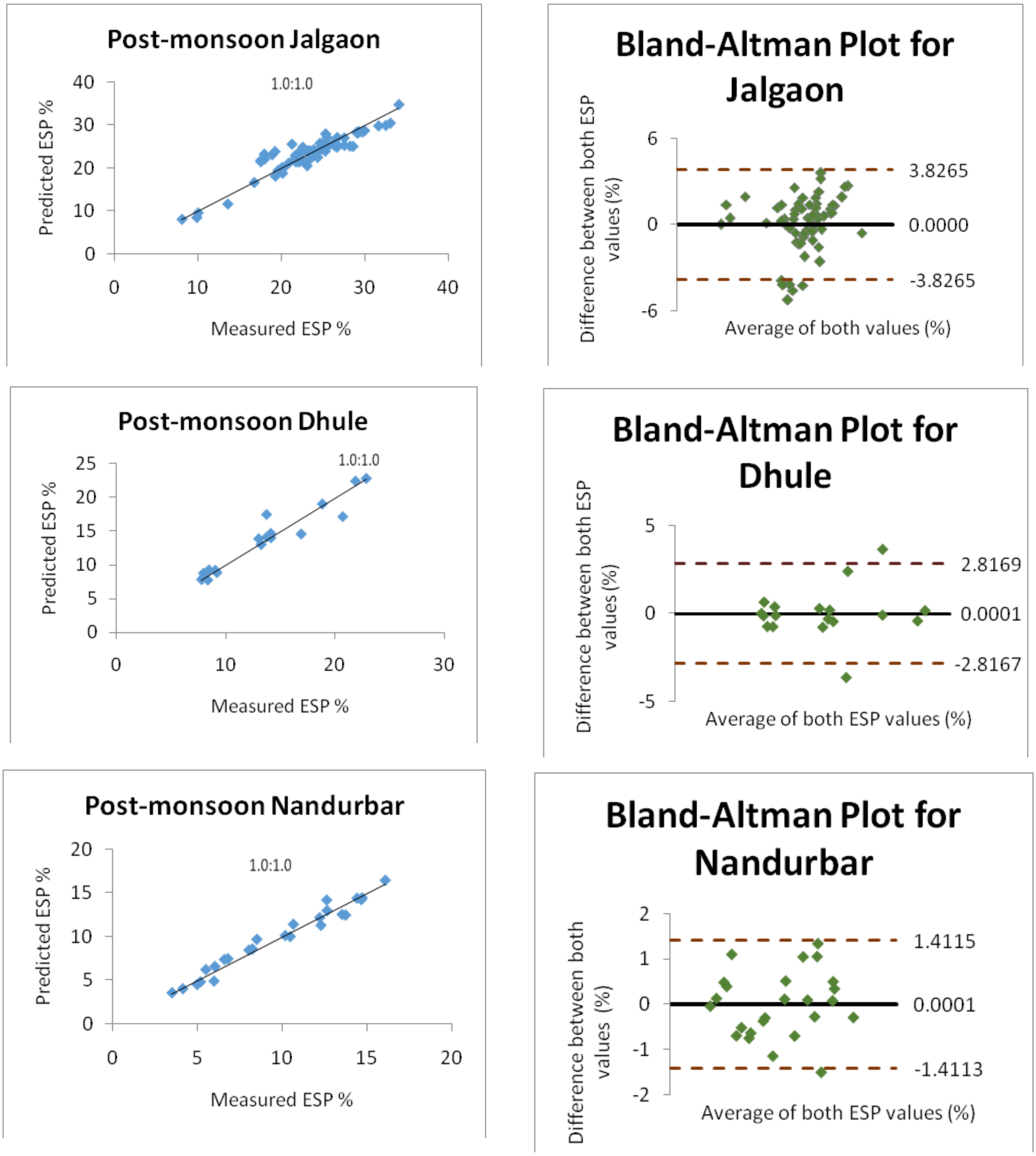

Fig. 8: A left side column of the graph indicates measured ESP and predicted ESP, using the soil ESP-SAR model with the line of equality (1.0:1.0) and right side column of the graph indicates Bland-Altman plot for the comparison of measured ESP and predicted ESP, using the ESP-SAR model; the outer dash lines indicate the 95% limits of agreement and the center continuous line shows the average difference for post-monsoon.

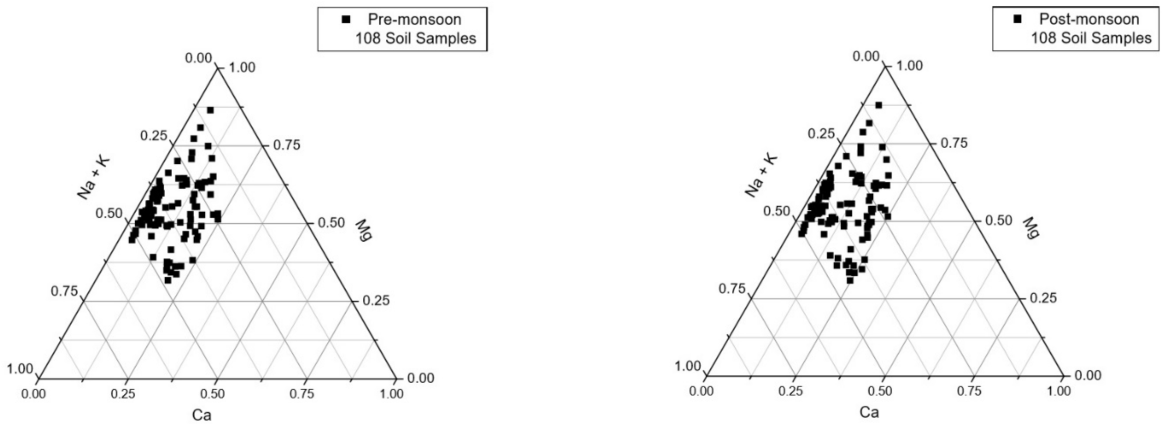

Fig. 9: Relation of Ca, Mg and Na + K for pre and post-monsoon.

Table 6: One variable statistical measures for irrigational quality parameters.

Chemical Parameters	Pre-monsoon Min	Max	Mean	SD	Post-monsoon Min	Max	Mean	SD
SAR (cmol/kg)	0.85	10.73	5.58	2.46	0.85	10.53	5.46	2.44
ESP %	3.57	34.88	19.22	7.88	3.49	34.07	18.55	7.91
ESI	0.02	0.96	0.27	0.26	0.04	0.83	0.28	0.25
KR	0.04	0.55	0.26	0.12	0.04	0.52	0.25	0.12

Table 7: Regression equations of EC and SAR for the districts of Jalgaon, Dhule and Nandurbar.

Season	District name	Equation	R^2	*p*-value
Pre-monsoon	Jalgaon	SAR = -0.7156(EC) + 8.6863	0.2828	<0.001
	Dhule	SAR = -0.5047(EC) + 6.3179	0.3719	<0.001
	Nandurbar	SAR = 0.4215(EC) + 0.4774	0.1925	<0.001
Post-monsoon	Jalgaon	SAR = -0.7797(EC) + 8.8829	0.3204	<0.001
	Dhule	SAR = -0.5066(EC) + 6.3595	0.3887	<0.001
	Nandurbar	SAR = 0.4278(EC) + 0.2161	0.1943	<0.001

Miscellaneous Ratios

***Relationship between SAR and EC*:** An important chemical parameter for judging the suitability of the soil for irrigation salinity hazard which is SAR (Alagbe et al. 2006). It measures the potential dangers posed by excessive sodium in irrigated soil (Rahman et al. 2012). SAR is determined by the Eq. 1 which is mentioned earlier in this study. The cation concentrations are expressed in centimole per kilogram. EC is determined by conductivity meter and expressed in milli Siemens per centimetre. The electrical conductivity and SAR relations were determined to be statistically significant (p-value < 0.001) at each district and the linear regression equations are presented for the three districts in Table 7. The relation between EC and SAR was stronger (pre 0.03719, post 0.3887) at Dhule than Nandurbar (pre 0.1925, post 0.1943). The coefficient of determination for the Jalgaon area (pre 0.2828, post 0.3204) was near to the values for Dhule district. Fig. 6 also shows 95% confidence interval and 95% prediction interval.

***ESP-SAR model*:** Another simple and cheap method of measuring soil salinity is ESP-SAR model. It explains the relationship between them and further analysis completed with Bland-Altman plot. ESP is calculated by Eq. 2. Here also, cation concentrations are expressed in centimole per kilogram. The linear regression, R^2 value and p-value of the pre and post-monsoon soil of the ESP-SAR model for all three districts are presented in Table 8.

Plots of the soil ESP values determined by the soil ESP-SAR model and laboratory tests with the line of equality (1.0:1.0) for all the three districts are shown in Figs. 7 and 8 for both the seasons. The average soil ESP difference between two methods was zero for all districts, while 95% CI and p-value are shown in Table 9 for both the seasons. The

Table 8: The coefficient of determinationof independent variable and p-value of the ESP-SAR model for the districts of Jalgaon, Dhule and Nandurbar.

Season	District name	Equation	R^2	*p*-value
Pre-monsoon	Jalgaon	ESP = 3.1163(SAR) + 1.8389	0.8587	<0.001
	Dhule	ESP = 3.0393(SAR) + 2.1726	0.9411	<0.001
	Nandurbar	ESP = 3.5782(SAR) + 0.5928	0.9672	<0.001
Post-monsoon	Jalgaon	ESP = 3.21(SAR) + 0.923	0.8594	<0.001
	Dhule	ESP = 2.9859(SAR) + 2.002	0.9533	<0.001
	Nandurbar	ESP = 3.5356(SAR) + 0.5254	0.9643	<0.001

Table 9: Paired samples t-test analyses on comparing soil ESP determination methods (Laboratory test vs. ESP-SAR model).

Season	District name	Standard deviation of difference (%)	*p*-value	95 % confidence intervals for the difference in means (%)
Pre-monsoon	Jalgaon	1.964	0.9991	-0.4863, 0.4869
	Dhule	1.107	0.9999	-0.5507, 0.5508
	Nandurbar	0.732	0.9999	-0.3022, 0.3022
Post-monsoon	Jalgaon	1.952	1.00	-0.4837, 0.4838
	Dhule	1.437	0.9997	-0.7146, 0.7148
	Nandurbar	0.720	0.9994	-0.2971, 0.2974

paired samples *t*-test results showed that the soil ESP values of both the methods were not significantly different (Table 9). The soil ESP differences between these two methods were normally distributed and 95% of the soil ESP differences were expected to lie between μ-1.96σ and μ+1.96σ, known as 95% limit of agreement (Bland & Altman 1999). The 95% limit of agreement for comparison of soil ESP determined with laboratory test and the soil ESP-SAR model was calculated at -3.8265 and 3.8265 for Jalgaon, -2.8167 and 2.8169 for Dhule and -1.4113 and 1.4115 for Nandurbar. Thus, soil ESP predicted by the soil ESP-SAR model may be -3.8265% lower or 3.8265% higher in Jalgaon, -2.8167% lower or 2.8169% higher in Dhule and -1.4113% lower or 1.4115% higher than soil ESP measured by the laboratory test.

***Electrochemical stability index*:** ESI is a term calculated by the Eq. 3 and expresses the relationship between sodicity and salinity of the soil. The index range is 0.02 to 0.96 with 0.27 mean and 0.26 SD for pre-monsoon while 0.04 to 0.83 with 0.28 mean and 0.25 SD for post-monsoon. This relation expounded the soil structural stability or in other hand soil degradation potential. All the values are above 0.05, which proved that significantly 30% of the study area is in good structural stability and 35% of the study area is in the process of degrading soil structure (Mckenzie 1998). The remaining study area is in moderate condition.

***Triangular relationship of Ca, Ma, Na and K*:** The ternary diagram indicates the triangular relationship between calcium, magnesium and sum of sodium and potassium (Fig. 6). The sum of total exchangeable cations is considered as 100% for this triangular study. All soil samples having a maximum concentration of magnesium in the range of 49.59% to 92.56% of 69.53% mean and 8.18 SD for pre-monsoon, while 47.984% to 93.03% of 69.57% mean and 8.44 SD for post-monsoon. Calcium has a much less concentration in the range of 1.35% and 20.98% of 7.88% average and 5.77 SD for pre-monsoon, while 1.28% and 24.11% of 8.81% average and 6.6 SD for post-monsoon as compared to magnesium. The sum of sodium and potassium also has a less percentage between 4.39% and 36.12% with 22.59% mean and 7.24 SD for pre-monsoon, while 4.1% and 35.11% with 21.62% mean and 7.13 SD for post-monsoon out of the sum of total exchangeable cations. Hence, it is proved that the magnesium content in the soil is more than the other exchangeable cations. Therefore, by this observation the soil exhibits alkaline properties.

***Kelley's ratio*:** Kelley's ratio was estimated by Eq. 6 and expresses the ratio of the sodium concentration to the sum of calcium and magnesium concentration. KR values lie in the range of 0.04 to 0.52 of 0.26 mean and 0.12 SD for pre-monsoon, while 0.04 to 0.52 of 0.25 mean and 0.12 SD for post-monsoon. Both season values were same, but all values were less than 1 and this indicated that all the soil samples are suitable for irrigation. On the other hand, if KR values are beyond 1, then that soil is not suitable for irrigation (Patil et al. 2014).

CONCLUSION

All the soil samples were analysed and correlated with each other wherever necessary. The pH of the samples is in the permissible range which is suitable for crop production. In Jalgaon district pH is greater than 8.0 in all talukas except Bodvad taluka. In Dhule and Nandurbar districts saline soil is found. Regression equations for SAR and EC were statistically significant (p-value < 0.001) in the whole study area for both pre and post-monsoon, but no strong relation was seen between them.

However, a linear regression model based on soil SAR was used to predict soil ESP. The soil ESP values predicted using the model were compared with the soil ESP values measured by laboratory tests. The paired samples *t*-test results indicated that the difference between the soil ESP values predicted by the model and measured by laboratory tests was not statistically significant ($P > 0.05$). Therefore, the soil ESP-SAR model can provide a short, easy and economical method to estimate ESP for both the seasons.

Triangular relation shows that the percentage of Mg content in the soil is more than Ca and Na+K, which shows alkaline properties. It is a process in which conversion of neutral to saline soil takes place. It happens because of continuous overloading of chemical fertilizers in the soil. This situation makes severe problems in the future, such as conversion of soil properties from saline to saline-sodic, and further fully sodic soil may be possible. The process of degrading soil structure has been found in 35% of the study area, while the remaining study area is in moderation and good condition. On the other hand, average Kelley's ratio is less than 1 and useful for irrigation. According to the above study, medium sodic soil quality has been found in Jalgaon district, and medium saline soil quality in Dhule and Nandurbar districts.

The unbalancing of soil minerals or inter-elemental ratios create crisis conditions for human beings due to the lack of food and fodder. There is need of a proper action now to remove future problems. This region requires remediation and regular monitoring. The preventive measures are necessary.

ACKNOWLEDGEMENT

The authors sincerely acknowledge for financial support in the form of SAP-DRS (Phase-II) major research project [F.4 - 26/2015/DRS-II (SAP-II)] by the University Grant Commission (UGC), New Delhi, India.

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