RESEARCH ARTICLE

Assessment of Salinity in the Field Soils of Azamgarh and its Relation to their Physico-chemical Properties

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Abstract

Soil salinity generally decreases the plant growth by creating osmotic stress, specific ion toxicity, and imbalance of ions required for the optimal growth. Azamgarh is an agrarian district and is also one of the salinity prone zones of eastern Uttar Pradesh; hence, a detailed study on soil quality analysis was carried out to delineate soil salinity status and its relationship with soil properties. The collected soil samples were moderate to extremely alkaline in reaction and clayey in texture. Soil electrical conductivity (EC) ranged between 0.76 to 48.3 dS/m. The correlation study showed that soil salinity had a significant positive impact on soil pH, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-), however, it was negatively correlated with calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. Our findings revealed that all the soil samples were in general saline-alkaline in nature. Therefore, the awareness on reclamation, drainage, and improved irrigation together with sustainable agricultural practices should be encouraged among farmers to reduce the severity and further spread of salinization in the agricultural lands of Azamgarh district.

Keywords: Food security, Physicochemical properties, Soil fertility, Soil salinity.

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Introduction

Soil salinization, considered as an ecological and economical problem worldwide, is mainly a process of accretion of soluble salts in the soils, often attributed to natural influences (primary salinization) and anthropogenic activities (secondary salinization) (Mandal, 2016; Ennaji *et al.*, 2018; Zhang *et al.*, 2018). The excess soluble salts present in the root zone diminish plant growth due to osmotic stress or specific ion toxicity, and also contribute to the degradation of soil fertility, therefore, constitute a real threat to global food security (Mishra & Mishra, 2007; Daliakopoulos *et al.*, 2016; Mandal, 2016). Soil salinity has also been reported to exert harmful effects on soil physicochemical properties (Singh *et al.*, 2012), biochemical, and enzyme activities (Karlen *et al.*, 2008), and affects soil structure. It often reduces the water permeability (Lee *et al.*, 2014; Daliakopoulos *et al.*, 2016), microbial community, organic matter decomposition, and thus, limiting overall agricultural productivity (Chakraborty *et al.*, 2011; Rady *et al.*, 2011; Guangming *et al.*, 2017; Zhang *et al.*, 2018).

On the basis of salinity, the soil is mainly classified into three types, *viz.*, saline soil (presence of high amount of soluble salt), sodic soil (presence of high amount of sodium cation), and alkaline soil (high pH and high CO_3^{2-} concentration) (Richards, 1954; Van Beek & Toth, 2012; Daliakopoulos *et al.*, 2016). The salt-affected area refers to those soils that are saline or sodic and having electrical conductivity ≥ 4 dS m^{-1} (Richards, 1954) and the major elements contributing to soil salinity are cations, such as, Na^+, K^+, Ca^{2+}, and Mg^{2+}, and anions, i.e., Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-} (Mishra & Mishra, 2007; Van Beek & Toth, 2012; Daliakopoulos *et al.*, 2016; Mandal, 2016; Ennaji *et al.*, 2018). The problem of soil salinity is mainly distributed in arid and semi-arid regions where leaching of salts is restricted because of low precipitation and high evaporation and these regions cover 1,307 Mha on a global scale (Ghassemi *et al.*, 1995; Rengasamy, 2006; Mandal, 2016). In the Indian context, approximately 6.73 Mha areas are affected with the problem of soil salinity, out of which 2.5 Mha is solitary present in the Indo-Gangetic plain (IGP) (National Remote Sensing Agency, 2008; Chakraborty *et al.*, 2011; Mandal, 2016). According to the reports of Central Soil Salinity Research Institute (CSSRI), Karnal (Mandal *et al.*, 2010), approximately 3,770,659 ha of land, which is covering 66% of the total area of the country is occupied by sodic soils. State-wise area and allocation have shown that a significant area is located in Uttar Pradesh (UP), where salt-affected soils are dispersed considerably in the eastern region, which covers mainly Unnao, Raebareli, Sultanpur, Pratapgarh, Jaunpur, Azamgarh, Mainpuri, Etawah, Hardoi, and Etah districts (Mandal, 2016). Azamgarh being an agrarian district is considered as one of the salinity prone zones of eastern UP with quite a variable quality of agricultural soil and low agricultural efficiency.

Therefore, the present study was carried out with two major objectives: (1) to analyze soil salinity status along with some of the key properties and ionic constituents, such as, texture, pH, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, SAR, and ESP in the agricultural soil sample collected from various locations of

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Azamgarh, and (2) to evaluate the relationship between soil salinity and the key salinity parameters (pH, EC, SAR, and ESP) of the soil.

Materials and Methods

Study Area

Azamgarh (26°03′N 83°13′E) one of the agrarian districts of UP (Fig. 1), is located south of the river Ghaghra, and covers 4,234 km^2 area. The district is a level plain without any hills. The main rivers which traverse the district are Ghaghra and Tons. The climate of the district is characterized as a semi-arid to arid with a hot and long summer (March–June), monsoon (end of June to October) post-monsoon (till the end of November), and cold seasons (December–February). The variation in average annual rainfall is between 979 to 1,060 mm. The temperature of the district ranges from 22 to 46°C in the summer, while in winter, it goes down below 5°C. Azamgarh district comes under alluvial plain with some high lying usar plains. The usar soils are classified into two main categories, i.e., saline and alkaline soil or sodic. The irrigation practices followed in the district are mainly through canals and bore wells. The main occupation of the district people is agriculture and the major cultivated crops in the district are rice, wheat, pulses, oilseeds, sugarcane, and potato (district profile-Krishi Vigyan Kendra Azamgarh, azamgarh.kvk4.in/district-profile.html).

Collection of Soil Samples

A random sampling method was applied to the collection of soil samples. Sampling was done during February 2016. A total of seventy-seven (77) soil samples were collected from different locations of the study area from 0 to 20 cm depth. The global positioning system (GPS) was used to record the precise coordinate of every composite sample (Fig. 1). To reduce moisture loss and change in salt composition, polythene bags were used for sample collection. Samples were further dried naturally, processed, and sieved through a 2 mm sieve and stored for the analysis of physicochemical properties and major ions in the laboratory.

Estimation of Soil Physicochemical Properties

The physicochemical properties of soil samples analyzed were soil texture, pH, EC (dS/m), the ionic composition for Na^+, K^+, Ca^{+2}, Mg^{+2}, CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-} in kg ha^{-1}. Soil texture is an assessment of the relative proportion of sand, silt, and clay particles in a soil (Sarkar, 2005; Pawar & Shah, 2009), and was determined by the Bouyoucus hydrometer method (Bouyoucos, 1962). The common textural classes were recognized by using the international equilateral triangles model given by the US Department of Agriculture (Shukla & Chandel, 2000; Hossain *et al.*, 2015). Soil pH and EC were analyzed with the help of a soil and water parameter analysis kit (Systronic), with 1:2.5 ratios of soil and water (Pawar & Shah, 2009). Exchangeable

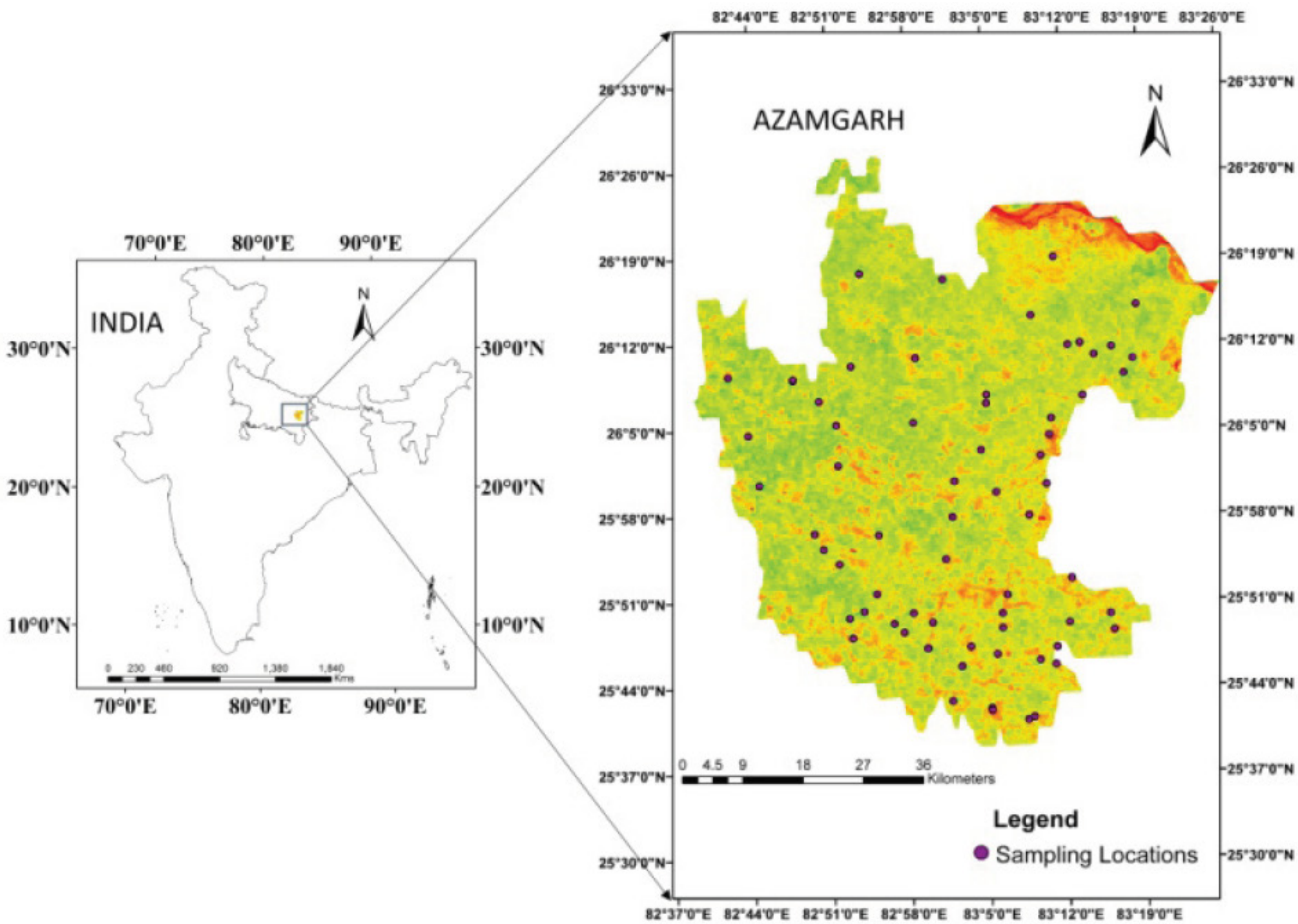

Fig. 1: Study area with sampling locations

basic cations, such as, calcium, magnesium, sodium, and potassium were estimated by saturating the soil samples with 1N ammonium acetate (NH_4OAC) solution at pH 7. Then, Na^+ and K^+ were measured from the extract by using a flame photometer (Systronic). The standard EDTA titrimetric method was used for the estimation of calcium and magnesium (El Mahi *et al.*, 1987). The major anions, such as, chloride (by silver nitrate method), carbonate, and bicarbonate (double indicator method) were measured by titration method. The turbidimetric method was used for sulfur determination (Jackson, 1973; Sarkar, 2005; Pawar & Shah, 2009).

Estimation of SAR and ESP

SAR is the relative amount of sodium to calcium and magnesium ions, and it takes into consideration that the negative effect of sodium is overcome by calcium and magnesium (Chun-Ming *et al.*, 2011; Daliakopoulos *et al.*, 2016). The following formula was used for the estimation of SAR value and expressed as [mmoles $L^{-1}]^{0.5}$.

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

ESP is defined as the concentration of adsorbed Na^+ on the soil exchange complex and calculated by using the following formula.

$$ESP\ (\%) = Exchangeable\ [(Na)/(Ca + Mg + K + Na)] \times 100 \quad (2)$$

Data Analysis

The data obtained from collected soil samples were calculated and illustrated in graphs by using Microsoft Office Excel. Arc GIS 10.3 software was used for preparing the map of the study area. The correlation analysis was evaluated by the correlation matrix plot performed in R programming language software.

Results

Soil Physicochemical Properties

The tested physicochemical characteristics of the collected soil samples are depicted in Figs 2 and 3, and Tables 1 and 2.

Soil Texture

The soil samples of Azamgarh district were observed to comprise different textural groups, *viz.*, sandy loam, clay loam, sandy clay, clay, and sandy clay loam (Fig. 2). Out of 77 soil samples analyzed, clay soil was found in 28 samples, sandy clay loam in 16, sandy loam in 14, clay loam in 8, sandy clay in 5, loam in 2, silt clay loam in 2, silt clay in 1, and silt loam in 1-sample.

Soil pH

The analysis of soil samples revealed that the pH values ranged from 7.6 to 10.1 indicating that the soils were slightly alkaline to extremely alkaline (Table 1). An assessment of soil data showed that 46% of soil samples were having a pH range of 7.6

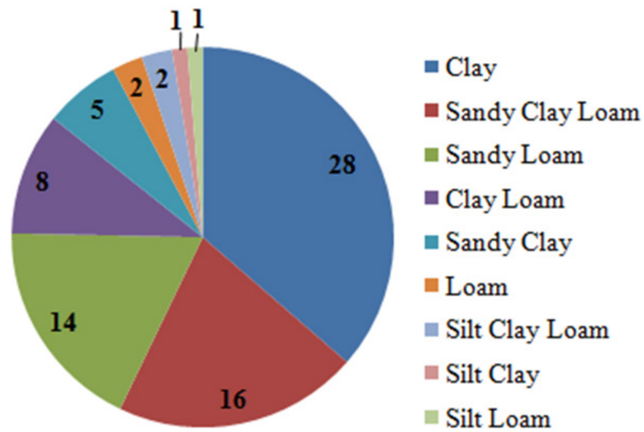

Fig. 2: Different textural groups of soil samples and their distribution count

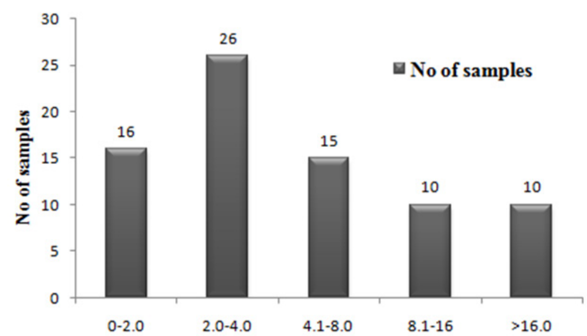

Fig. 3: Electrical conductivity of soil samples; samples were grouped on the basis of EC range (according to the classification of Richards, 1954)

Table 1: Descriptive statistics of physicochemical characteristics of soil samples collected from Azamgarh district

Parameters	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
pH	7.6	10.1	8.5	0.67
EC (dS/m)	0.76	48.3	6.9	8.5
Ca^{2+} (kg/h)	98.6	1,254	523.1	323.1
Mg^{2+} (kg/h)	83.6	1,248	477.1	237.3
Na^+ (kg/h)	24.8	1,103.9	312.2	251.4
K^+ (kg/h)	151	682	188.8	64.5
Cl^- (kg/h)	305	2,086	893.9	289.8
SO_4^{2-} (kg/h)	0.24	90.1	23.4	19.8
CO_3^{2-} (kg/h)	67	1,411	702.4	350.9
HCO_3^- (kg/h)	1.12	1,632	968.7	299.8
SAR (mmoles $L^{-1})^{0.5}$	0.64	89	14.9	13.7
ESP (%)	0.89	67	18.3	15.4

Table 2: Physicochemical characteristics of various soil samples collected from different locations of Azamgarh district [all values are in kg/ha, except pH, EC (dS/m), ESP (%), and SAR]

Sample	*Location*	*pH*	*EC*	*Na^+*	*K^+*	*Ca^{2+}*	*Mg^{2+}*	*SO_4^{2-}*	*CO_3^{2-}*	*HCO_3^-*	*Cl^-*	*SAR*	*ESP*
1	Rampur	7.89	3.22	86.8	205	1,093	699	10.1	67.2	1.12	458	2.3	3.6
2	Katharwa	8.43	1.66	229	366	1,138	785	7.63	67	804.16	560	5.9	6.4
3	Kapsetha	8.54	2.81	97.8	165	797	708	37.7	604.8	719.04	967	2.9	2.7
4	Devgaon	8.56	3.54	63.6	460	394	209	48.5	336	728	407	2.8	5.6
5	Godhara	8.23	1.11	181	505	1,147	1,248	13.1	470.4	992.32	916	4.3	5.1
6	Bardah	9.92	22.2	905	340	556	340	12.4	1,277	1,301.4	1,985	34	42
7	Bhagmalpur	8.65	1.89	221	479	564	337	18.3	940.8	707.84	509	8.2	14
8	Sarawa	8.41	1.94	187	398	439	349	15.1	598.1	786.46	590	7.6	14
9	Sofipur	9.98	29.7	785	454	108	83.6	90.1	1277	1167	2,026	64	55
10	Retwa	9.71	13.8	460	457	197	125	25.8	1411	1,095.4	1,761	29	37
11	Baridieh	8.33	2.06	403	453	170	905	24.5	134.4	62.72	845	16	21
12	Lahuakalan	9	5.43	102	442	152	170	21.5	806.4	981.12	1,542	6.6	12
13	Gangwal	9.75	8.04	41.7	345	278	206	9.7	604.8	866.88	1,532	2.1	4.8
14	Ramnagar	8.67	8.14	40.9	346	493	332	28.1	336	586.88	1,171	1.6	3.4
15	Mauparase	7.77	2.45	63.1	170	573	866	23.4	134.4	331.52	473	2	3.8
16	Katholi	9.6	16.0	374	294	161	143	19.3	1,008	1,176	967	24	38
17	Kabutara	8.79	2.68	428	163	1,093	311	17.3	739.2	983.36	641	12	14
18	Karta	8.26	5.63	103	383	1,167	1,193	57.4	67.2	669.76	967	2.4	3
19	Bongaria	8.21	1.4	175	343	98.6	803	15.3	604.8	987.84	947	7.8	12
20	Jua	7.93	8.81	400	682	887	660	8.6	1,277	1,301.4	1,934	11	9.5
21	Gatwa	9.65	15.2	785	499	134	170	12.8	940.8	1,043.8	1,730	53	49
22	Tarwa	8.97	4.3	460	496	188	499	49.4	1,142	1,305.9	575	22	28
23	Dharara	8.13	9.52	373	389	215	747	87.9	1,075	1,241	1,883	15	22
24	Madaiya	9.49	4.44	441	464	708	917	22.5	201.6	799.68	1,323	13	17
25	Kaithishankarpur	9.18	12.6	467	421	251	179	62.2	1,008	1,646.4	1,221	25	35
26	Shankarpur	9.03	4.68	457	321	332	296	17.7	604.8	1,122.2	1,171	21	33
27	Ishaqpur	8.6	7.32	220	654	278	337	13.5	1,008	1,108.8	865	10	15
28	Martinganj	10	17.4	261	378	161	203	19.4	604.8	987.84	865	16	26
29	Martinganj 2	9.7	30.2	229	619	188	116	13.6	336	1,332.8	1,018	15	20
30	Surhan	10.18	48.3	1,104	415	106	95.3	27.9	1,008	1,243.2	2,086	89	67
31	Shabari	8.53	1.17	165	158	493	403	40.2	537.6	654.08	1,069	6.2	14
32	Aspatpur	8.45	2.84	370	424	349	278	25.8	604.8	786.24	560	17	26
33	Hiyya	7.75	1.22	130	361	753	615	7.63	1,008	1,243.2	840	4	7
34	Dostpur	9.86	33.3	142	457	125	179	65.6	940.8	1,178.2	356	9.7	16
35	Pakadpur	7.92	2.4	132	176	224	296	2.79	806.4	1,048.3	763	6.9	13
36	Hasapurkhurd	8.56	1.75	761	315	439	349	25.7	1,048	1,295.6	763	31	41
37	Shahpur	8.21	2.54	230	369	582	642	44.1	1,277	1,368.6	916	7.7	13
38	Koyalsa	7.73	2.35	151	309	421	397	2.3	336	862.4	916	6.1	12
39	Kaptanganj	7.97	3.52	385	528	349	337	15.6	1,008	1,317.1	763	17	24
40	Khutauli	8.11	2.32	150	383	645	281	10.9	672	985.6	611	5.3	10
41	Jamalpur	9.92	19.5	731	369	134	320	8.24	1,277	1,308.2	1,069	43	47
42	Fariha	9.74	23.9	575	542	287	143	29	806.4	1,048.3	1,008	30	37
43	Makharakpur	8.52	2.48	153	662	636	1,072	18.9	1,008	1,243.2	1,125	4.5	6

Cont...

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44	Rohua	8.87	2.73	660	532	941	582	32.6	1,411	1,632	1,069	19	24
45	Kisunpur	8.72	3.86	304	450	529	714	16.2	1,277	965.44	967	10	15
46	Rani Kisaragi	8.25	2.58	181	467	1,093	747	7.76	604.8	806.4	611	4.7	6
47	Narauli	8.13	2.41	131	455	439	905	9.94	201.6	732.48	509	4.4	6.8
48	Sarahmanraj	8.38	1.55	138	318	1,254	806	11.1	1210	1,303.7	763	3.4	5.5
49	Namdarpur	7.95	0.76	81.4	342	493	791	17.5	672	985.6	662	2.7	4.8
50	Langadpur	7.94	2.27	149	633	1,236	1,183	13.6	604.8	719.04	611	3.5	3.9
51	Kollmodipur	8.37	3.64	229	179	977	666	34.4	470.4	891.52	814	6.3	11
52	Khaziaber	7.96	1.58	29.2	308	1,129	1,792	35.1	336	459.2	865	0.6	0.9
53	Madhanapur	7.61	4.06	96.5	580	1,254	269	56.7	604.8	954.24	1,023	2.6	4.4
54	Padre	8.16	2.74	72.6	153	1,165	615	19.6	665.3	851.42	611	1.9	3.6
55	Ramnagar	8.38	1.04	36	151	1,175	671	13.7	739.2	1,252.2	687	0.9	1.8
56	Ramnagar	8.61	6.69	24.9	193	134	236	6.91	268.8	595.84	611	1.6	4.2
57	Mirzapur	8.12	2.74	89.4	345	1,093	1,009	4.61	739.2	983.36	916	2.2	3.3
58	Anjaanshahid	8.58	2.89	736	353	1,030	768	62.7	665.3	1,086.6	763	20	25
59	Gulaur Bazaar	7.97	5.13	640	477	224	367	26.1	470.4	723.52	1,069	32	37
60	Lohanpur	9.5	10.6	504	462	134	194	76.7	806.4	981.12	1,120	33	39
61	Nerrehta	9.51	6.84	905	371	251	233	25.1	470.4	790.72	1,181	47	51
62	Jalalpur	8.68	6.09	441	202	314	140	8.24	604.8	719.04	763	23	40
63	Dayalapur	8.62	2.95	598	387	1,156	564	14.1	336	593.6	865	16	22
64	Chaukhat	8.47	2.04	218	361	1,156	684	44.8	940.8	1,238.7	916	5.6	9
65	Godhaura	8.13	6.22	97.2	423	116	433	34.1	537.6	1,191.7	967	5.3	9.1
66	Bajaha	9.46	2.24	304	394	170	415	2.67	470.4	589.12	1,069	16	24
67	Nassirudinpur	7.68	2.66	163	177	1,120	726	1.58	672	1,254.4	458	4.2	7.5
68	Tashipur	8.01	1.7	132	248	376	1,231	2.79	806.4	1,115.5	967	4.2	6.7
69	Belahara	8.41	1.57	215	434	1,174	1,150	2.67	268.8	1,267.8	967	5.1	7.2
70	Chatwara	8.55	1.61	195	174	1,228	1,072	0.24	1,142	1,238.7	305	4.6	7.3
71	Kajibhiti	9.63	15.6	841	378	134	260	3.27	470.4	1,261.1	1,629	52	52
72	Ahiyayi	7.87	4.31	157	378	457	684	38.2	604.8	880.32	1,069	5.6	9.4
73	Karauti	8.16	4.63	324	210	296	618	23.8	336	996.8	967	13	22
74	Pawnikalan	7.6	13.8	374	408	1,165	358	8.73	739.2	983.36	1,221	10	16
75	Sarai	7.73	1.93	94.5	447	493	887	17.3	1,210	1,303.7	763	3.1	4.9
76	Bhadaiya	7.91	2.65	167	442	869	439	1.58	336	680.96	662	5.1	8.7
77	Lafiya	8.71	8.24	496	434	224	678	14.8	604.8	987.84	1,272	21	27

to 8.5; however, 54% of soil samples showed a pH greater than 8.5.

Soil Electrical Conductivity

The EC value of soil was observed in the range of 0.76 to 48.3 dS/m (Table 1). Out of the samples collected, it was observed that 16 samples were not affected by salinity (EC < 2 dS/m), whereas 26 samples were classified as slightly saline (EC 2–4 dS/m), 15 samples as moderately saline (EC 4–8 dS/m), and 10 samples as strongly saline while remaining 10 samples exhibited extreme salinity (> 16 dS/m).

SAR and ESP

The soil analysis showed that the values of SAR ranged from 0.64 to 89 (mmoles $L^{-1})^{0.5}$ (Table 1). The maximum SAR value 89 (mmoles $L^{-1})^{0.5}$ was observed in the location Surhan (S30), however, location Khaziaber (S52) showed the minimum value of 0.64 (mmoles $L^{-1})^{0.5}$. The estimated soil data revealed that 30 samples were having SAR greater than the higher value (SAR = 13), whereas 47 samples showed a value of SAR less than 13. The soil ESP values ranged from 0.89 to 67% (Table 1). The maximum value of ESP (67%) was estimated in the sample collected from location Surhan (S30), while the minimum (0.89%) in the location Khaziaber (S52).

Soil Cation and Anions

Sodium

The amount of Na^+ present in the soils ranged from 24.8 to 1, 103.9 kg/ha (Table 1), which clearly indicates the high accumulation of Na^+ within the soil samples. The minimum value of Na^+ (24.8 kg/ha) was observed in soil samples belonging to Ramnagar (S56), while the maximum (1,103.9 kg/ha) was observed in the location Surhan (S30).

Potassium

The results obtained for potassium showed that 62% of soil samples were having a very high concentration of K^+ (> 360 kg/ha), 17% exhibited high K^+ amount (between 300 to 360 kg/ha), 12% showed a moderate range of K^+ (between 181 to 240 kg/ha), and remaining 9% showed low K^+ (between 121 to 180 kg/ha). The minimum K^+ value (151 kg/ha) was observed in Ramnagar location (S54), while the maximum K^+ value (682 kg/ha) was observed in Jua location (S20).

Calcium

The results obtained for calcium revealed that the concentration of Ca^{2+} ranged from 98.6 to 1,254 kg/ha (Table 1). The sample of location Madhanapur (S53) showed the highest concentration of Ca^{2+} (1,254 kg/ha), while location Bongaria (S19) was marked for the lowest concentration of Ca^{2+} (98.6 kg/ha).

Magnesium

The concentration of Mg^{2+} in studied soil samples ranged from 83.6 to 1,248 kg/ha (Table 1). The maximum concentration of Mg^{2+} was observed in location Godhara (S5), while the soil samples belonging to Sofipur (S9) showed a minimum concentration of magnesium.

Carbonate

The analysis of the soil samples revealed that the value for the CO_3^{2-} ion ranged from 67 to 1,411 kg/ha (Table 1). The sample of location Rohua (S44) showed a maximum concentration of carbonate (1,411 kg/ha), while that of Katharwa (S2) exhibited a minimum concentration of carbonate (67 kg/ha).

Bicarbonate

The value for the HCO_3^- ranged from 1.12 to 1,632 kg/ha (Table 1). The location Rohua (S44) was observed for maximum concentration of bicarbonate (1,632 kg/ha), while location Rampur (S1) showed a minimum concentration of bicarbonate (1.12 kg/ha).

Chlorides

The concentration of Cl^- in the soil samples was found in the range of 305 to 2,086 kg/ha (Table 1). The location Surhan (S30) showed a maximum concentration of chloride (2,086 kg/ha), while that of Chatwara (S70) showed a minimum Cl^- concentration (305 kg/ha).

Sulfate

The values for the SO_4^{2-} in the collected soil samples ranged from 0.24 to 90.11 kg/ha (Table 1). The sample of location Sofipur (S9) showed a maximum concentration of sulfate (90.1 kg/ha), while that of Chatwara (S70) revealed a minimum concentration of sulfate (0.24 kg/ha).

Relation between Soil Salinity and Soil Physicochemical Characteristics

A slightly higher linear relationship was observed than the monotonic relationship among all the variables (Figs. 4 to 6).

Relation between Soil Salinity, pH, SAR, and ESP

Correlation between soil salinity, pH, SAR, and ESP is shown in Fig. 4, which clearly showed the positive correlation between soil salinity (EC) and soil pH (r = 0.73), SAR (r = 0.72), and ESP (r = 0.65).

Relation between Soil Salinity and Exchangeable Cations

Correlation between soil salinity and exchangeable cations Na^+, K^+, Ca^{+2}, and Mg^{+2} as shown in Fig. 5, exhibited that soil salinity was significantly and positively correlated with exchangeable

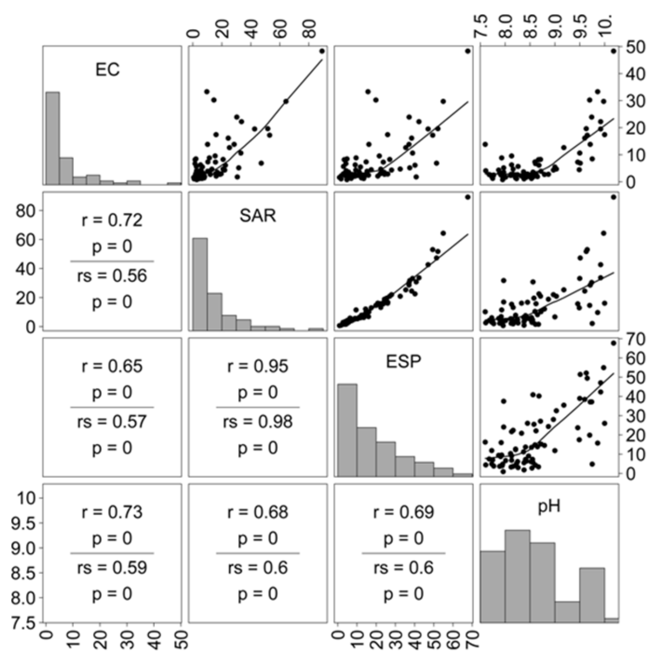

Fig. 4: Correlation matrix plot between soil salinity (EC) and pH, SAR, and ESP (significance level p < 0.05)

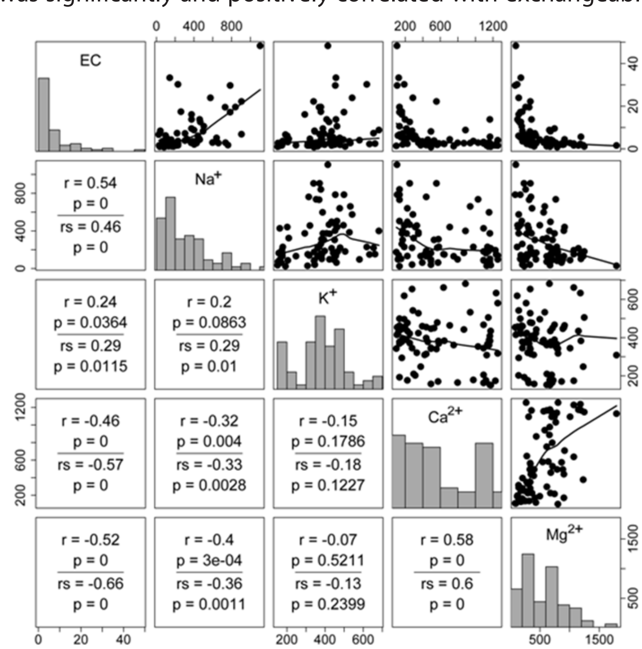

Fig. 5: Correlation matrix plots between soil salinity and soil exchangeable cations (Na^+, K^+, Ca^{+2}, and Mg^{+2}) (significance level p < 0.05)

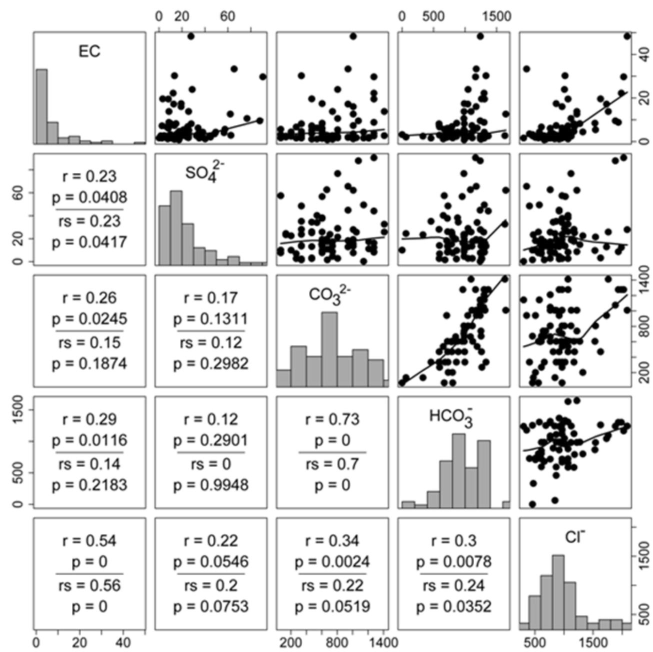

Fig. 6: Correlation matrix plots between soil salinity and soil anions (Cl^-, SO_4^{2-}, CO_3^{2-}, and HCO_3^-) (significance level $p < 0.05$)

Na^+ (r = 0.54) and K^+ (r = 0.24), however, it was negatively correlated with exchangeable Ca^{+2} (r = -0.46) and Mg^{+2} (r = -0.52). The positive correlation between Na^+ and K^+ were found non-significant (r = 0.2, $p < 0.08$), while Ca^{2+} and Mg^{2+} ions were negatively correlated with Na^+ ion. The correlation between K^+ ion and Ca^{2+} and Mg^{2+} ions were also negatively correlated. The correlation coefficient between Ca^{2+} and Mg^{2+} ions was found to be 0.58, which was the highest amongst the reciprocal of all cations. These results indicate that out of all four soluble exchangeable cations, Na^+ ion has the most influencing effect on soil salinity.

Relation between Soil Salinity and Soil Anions

The correlation between soil salinity and soil anions Cl^-, SO_4^{2-}, CO_3^{2-}, and HCO_3^- is shown in Fig. 6, which clearly indicates that soil salinity was significantly correlated with Cl^- (r = 0.54), however, the positive correlation with SO_4^{2-} (r = 0.23), CO_3^{2-} (r = 0.26), and HCO_3^- (r = 0.29), were found very low.

Discussion

Soil Physicochemical Properties

Salinity is a dynamic process that has been considered as a major limiting factor for agricultural soils (Singh *et al.*, 2012a). In our study, the dominating soil types of the study area were represented by clay, sandy clay loam, and sandy loam texture, respectively. The results observed were in accordance with the report of Comprehensive District Agriculture Plan Azamgarh (2008), which stated that the majority of the agricultural soils of the district are clay textured types. Although the studied area is dominated by clay textured soil in spite of that most of the soil samples that showed higher soil salinity were dominated by sandy loam and sandy clay loam texture soil probably due to clay illuviation and profound effects of changing soil salinity (Hossain *et al.*, 2015; Daliakopoulos *et al.*, 2016; Mandal, 2016; Bunemann *et al.*, 2018).

The pH value of the studied area ranged from moderate alkaline to extremely alkaline might be due to the hydrolysis of sodium carbonate (Pan *et al.*, 2013; Hossain *et al.*, 2015; Daliakopoulos *et al.*, 2016). Approximately 45% of the total soil samples showed EC greater than 4 dS/m. The reason for excess salinity at some locations might be due to clay textured soils that have more empty pores that can hold salt and moisture (Daliakopoulos *et al.*, 2016). SAR and ESP are generally acknowledged as the index for describing soil sodicity, which defines the fraction of sodium with respect to calcium and magnesium present in soil solution (Mandal, 2016). The high SAR (> 13) and ESP (> 15) values at some locations indicate the dominance of Na^+ ion which may favor alkali soil formation and makes soil unsuitable for agricultural practices (Chun-Ming *et al.*, 2011). In the study area, it was observed that most of the salt-affected soils were saline-sodic types, which indicated the presence of soluble salts in the soil solution (salinity) and presence of excess Na^+ attached to clay surface (sodicity). This type of salinity is presumed to be more dangerous, and might be responsible for a decrease in plant growth by reducing the plant's potential to extract soil water, causing specific ion toxicity, slowing root growth, and imbalance in ions, which are required for optimal plant function (Daliakopoulos *et al.*, 2016; Zhang *et al.*, 2018).

Soil Exchangeable Cations and Anions

The higher concentration of Ca^{2+} and Mg^{2+} in the soil might be due to alkaline earth carbonate because calcareous soils are accumulated with carbonates of calcium and magnesium ions in different ratios throughout the soil profile (Richards, 1954; Sarkar, 2005). Although it is considered that Ca^{2+} and Mg^{2+} are rarely found deficient in alkaline soils (Horneck *et al.*, 2011). The higher concentration of Ca^{2+} at some location might also be due to the use of gypsum (a calcium salt), which has been reported to be used at some places in the study area for reclamation of usar soil (Dhar, 2004). Even though, their excess in calcareous soils can slow down the uptake of important **min**eral nutrients, such as, phosphorus and nitrogen **(**Swanti *et al.*, 2014; Daliakopoulos *et al.*, 2016). Regarding the concentration of sodium an excessive amount was found at some locations in the study area. These findings indicate that some locations are severely affected by sodicity problems, which might be toxic to crops being sensitive to sodium. Because soil sodicity encloses adequate exchangeable sodium causing dispersion of soil and increasing the pH, thus, negatively affects both the physicochemical and nutritional characteristics of the soil resulting in decreased growth of plants (Chun-Ming *et al.*, 2011; Rasel *et al.*, 2013). Regarding K^+, the analyzed samples represented a very high concentration of K^+ in the soil, which might be due to the soil parent material (which has very high K^+ rich clay content) and excess use of K^+ rich fertilizers (Islam *et al.*, 1985; Bao, 2000; Zhang *et al.*, 2018).

The dominance of CO_3^{2-} and HCO_3^- in the soil might be due to parent material that favored the alkalinity of the study area (Pawar & Shah, 2009; Mandal, 2016). Their presence in significant amounts indicated that they influenced the soil texture and might be responsible for drainage restrictions and water logging problem in the study area (Richards, 1954; Sarkar, 2005). The derivation of saline soil directly or indirectly comes from water logging problem, which contains mainly chlorides of sodium, magnesium, and calcium in the quantities that is enough to hamper plant growth. Cl^- concentration greater than 50 ppm is considered as harmful to crop plants (Horneck *et al.*, 2011). In this study, it was observed that a high amount of Cl^- (an average ~399 ppm) in the soil might be injurious to many crops by contributing to overall salinity. The reason behind accumulation of chloride in soils might be due to excessive application of potassium fertilizers, such as, muriate of potash (KCl), which constitutes 47% of chloride and 53% of potassium. Another reason may be the quality of irrigation water and failure to use enough water to leach Cl^- ion from the root zone (Daliakopoulos *et al.*, 2016; Zhang *et al.*, 2016). The concentration of 3 to 5 mg/kg of SO_4^{2-} in the soil is found to be sufficient for the growth of most crop plants. It is considered that a good amount of SO_4^{2-} is associated with calcium carbonate in calcareous soil, but its availability to plants is relatively low due to the presence of calcium carbonate and few other factors, such as, moisture content, common ion effects, etc. In this study, a heterogeneous distribution of SO_4^{2-} was observed. Its low concentration at most of the places might be due to the presence of negative charge on SO_4^{2-} ion making it not tightly held by clay particles, which are also negatively charged and therefore, sulfate can move downward through the soil, while its excess at some places might be due to gypsiferous soil (Sarkar, 2005; Horneck *et al.*, 2011).

Thus, on the basis of the above findings, the dominance of HCO_3^- and Cl^- anions, and high content of Ca^{2+}, Mg^{2+} cations at some places indicated the presence of $CaCO_3$ and $NaHCO_3$ type of parent material which might be responsible for the development of saline-sodic nature of the soil, however, excess amount of Na^+, K^+, and Cl^- ions might be due to inappropriate use of chemical fertilizers and undisciplined irrigation practices (Mandal, 2016; Zhang *et al.*, 2016). Apart from this, seasonal fluctuations, hydrological conditions, and shallow saline groundwater table might be the other main reasons behind the accumulation of these ions at the plough layer of agricultural soil.

Relation between Soil Salinity and Soil Physicochemical Properties

Soil electrical conductivity is influenced by various soil physicochemical properties (Daliakopoulos *et al.*, 2016; Zhang *et al.*, 2018). The relation between soil salinity (EC) and key salinity parameters was evaluated by correlation matrix plot, comparing the values of the Pearson correlation coefficient (r), which shows the strength of the linear relationship between two variables and the Spearman correlation coefficient (rs), which shows the strength of the monotonic relationship between two variables (Srivastava *et al.*, 2014). p values are considered significant at < 0.05. The correlation analysis indicated higher linearity of EC with pH, SAR, and ESP. Among these four parameters, a highly significant correlation was found in SAR and ESP ($r = 0.95$). The correlation coefficient of SAR, ESP, and pH with respect to soil salinity showed a similar pattern, and it may be due to the associated relationship with soil intrinsic properties (Lee *et al.*, 2014; Zhang *et al.*, 2018). Out of the four cations, Na^+ ion had shown a maximum correlation with soil salinity. This result conforms with other worker's results that Na^+ exerts a major influence on soil EC than other cations (Hernandez Bastida *et al.*, 2004; Lee *et al.*, 2014). Ca^{2+} was negatively correlated with all cation, except Mg^{2+}; it is because Ca^{2+} competes with Na^+ to occupy the exchange site (Johnston, 2011), and therefore, an increase in Ca^{2+} concentration reduces the concentration of Na^+ (Hanson, 1999; Lee *et al.*, 2014). Thus, the supplementation of Ca^{2+} can be used as a tool to reclaim soil salinity. Apart from Na^+, Cl^- also showed maximum correlation with soil salinity out of all anions which can be assumed that Cl^- has much influence on soil salinity (EC) in comparison to other anions. Although a very high concentration of CO_3^{2-} and HCO_3^- were observed in soil, but their low correlation with soil salinity shows that their high concentration might be due to the parent material so can be considered less toxic than other anions (Daliakopoulos *et al.*, 2016).

Soil salinity is caused by numerous factors. In the present study, soil salinity in the field soils was explored. The concentration of ions causing salinity and a relationship of these with respect to soil salinity (EC) was investigated. The results of the current study revealed that the field soils of Azamgarh district were saline-alkaline type in general, and suitable measures should be taken to prevent crop losses in such soils due to salinity.

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