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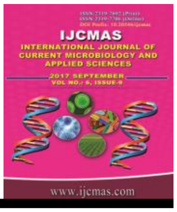

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Geoinformatics for Quantifying Salt Affected Soils in Gohana, Haryana Using Soil Techniques

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ABSTRACT

Geoinformatics is application of information technology for study and management of earth resources. The salt affected soils of Gohana were mapped and evaluated using visual interpretation of IRS-P6 satellite false colour composite (FCC) image with ground survey and laboratory analysis. A total of 72 soil samples across the study area were sampled based on the quality of groundwater used for irrigation at four depths (0-15, 15-30, 30-45 and 45-60 cm). Long-term irrigation with salt affected water results in soil quality decline. The texture in both normal and salt affected soils was loamy sand to sandy clay loam. The cation exchange capacity, exchangeable sodium percentage, organic carbon and calcium carbonate in normal and salt affected soils of block Gohana varied from 6.81-22.19, 3.18-20.93 cmol (p^+) kg^{-1}; 3.42-13.84, 21.61-72.26 percent; 0.12-0.47, 0.06-0.46 percent and 0.10-1.75, 0.10-7.00 percent, respectively. The electrical conductivity, pH and sodium adsorption ratio of soil saturation extract ranged from 1.26-3.79, 1.44-15.82 (dSm^{-1}), 7.06-8.47, 7.39-9.74 and 2.68-9.06, 5.71-36.85 $(mmol\ l^{-1})^{1/2}$, respectively. A strong correlation was observed between EC and pH, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, ESP, SAR_e, CEC and clay and saturation percentage and clay. Available nitrogen, phosphorus and potassium were low to medium in both normal and salt affected soils. From satellite imagery, it was observed that out of 2.41% salt affected area in block, 1.13% and 1.28% is moderately salt affected and strongly salt affected, respectively.

Keywords

Electrical conductivity, False colour composite, Geoinformatics, Satellite imagery, Texture.

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Introduction

In addition to water scarcity, water quality deterioration is anticipated to escalate in arid and semi-arid regions of India due to anthropogenic activities and extreme consequences of climate change. On long-term basis, irrigation with salt affected water results in soil quality decline. The increased accrual of soluble salts at or near surface horizons of soil poses a major threat with serious global economical and social consequences. This accumulation of soluble salts hastens land degradation processes thereby decrease crop yields and agricultural production (FAO, 1988; Farifteh *et al.*, 2007). The irrigated agriculture is beset with the problem of soil salinity and in over 100 countries, 20% of the total irrigated lands and 10% of the total arable land have been struck by various kinds and levels of salinity (Ghassemi *et al.*, 1995; Bilgili, 2013). In India, salt affected soils occupy 2% of the geographical area, mainly present in arid and semi-arid regions and coastal areas (Mandal and Sharma, 2010).

Accumulation of salts in the soil as a result of salinization endangers the sustainability of agricultural and natural soils. So far as soil degradation is concerned, salinization and sodification are the principal processes influencing irrigated lands. The raising development of irrigated farming is indispensable for sustainable production of food needed by the burgeoning global population. However, there is enhancing paucity and low quality of available resources in addition to competitive usage of these resources for other functions thereby impeding the development of irrigated agriculture. Moreover, surface and groundwater resources are contaminated by the drainage effluents of irrigated lands (Ildefonso Pla Sentís, 2014).

With the development of technology, the application of new prospects of information technology and science to soil survey has come into existence (McBratney *et al.*, 2003). Geoinformatics is application of information technology for study and management of earth resources (Bhat *et al.*, 2015). The prime manifestation in soil resource evaluation via geographic information system is the creation of digital property and class maps with the constraint of relatively inadequate expansive fieldwork and subsequent laboratory analysis (McBratney *et al.*, 2003). There has been an increasing need for soil information in recent years. Soil maps are used in many studies such as land evaluation, land suitability analysis, land use planning and GIS applications (Salehi *et al.*, 2003).

Proactive supervising of salt build up is indispensable to limit its negative effects. Salinity monitoring requires the identification of areas where salts accumulate and the detection of temporal and spatial changes in their occurrence (Zinck, 2000; Muller and Niekerk, 2016). Remotely sensed data can play a great role in monitoring these processes on account of its capability to acquire information in both spatial and temporal scales (Abbas *et al.*, 2013; Muller and Niekerk, 2016). Bastiaanssen *et al.*, (2000) reported that remote sensing has the capability to envisage soil salinity, perform diagnosis and evaluate its impact. The combination of remote sensing with field surveys can save labour, time and effort in comparison to sole regular field surveys used for monitoring salt accumulation (Metternicht, 1996; Eldiery *et al.*, 2005; Muller and Niekerk, 2016).

The state of Haryana (India) is one of the most agriculturally productive areas of the country and is of broad agro-ecological significance. Due to the lack of proper drainage in Gohana block, district Sonipat (Haryana), continued agricultural productivity is jeopardised, since limitations have been enforced on the discharge of drainage water to surface water supplies. By and large, the drainage water is disposed to groundwater beneath irrigated lands or to permanent evaporation ponds. Therefore, the study was undertaken by applying geoinformatics to quantify salt affected soils in Gohana using soil techniques.

Materials and Methods

Study area

The study area forms a part of the Indo-Gangetic plains and displays flat terrain with general slope from north to south. The area is devoid of any high topographic features. However, a natural depression exists in north and northwest of block. The maximum elevation of the plain is about 230 m above mean sea level. Gohana is situated at 28º 57' and 29º 12' N latitude to 76º 38' and 76º 52' E longitude. The climate of the area is subtropical, semi-arid with hot dry summer and cold winter. Around 80 percent of the total rainfall occurs during the southwest monsoon (July-September). July is the wettest month of year with 7.5 rainy days and 169 mm rainfall. January is the coldest month with maximum and minimum temperature of 21.3°C and 7.3°C, respectively. Usually there is an increase in temperature in April and *Rabi* (winter) crops ripe a week earlier than *Baisakhi*. The temperature continues to rise until June, which is the hottest month (Central Groundwater Board, 2008).

Soil sampling

A total of 72 soil samples across the study area were sampled based on the quality of groundwater used for irrigation at four different depths (0 to 15, 15 to 30, 30 to 45 and 45 to 60 cm) and subsequently air dried and sieved (2 mm) for laboratory analysis. Soil sampling was carried out before the showers of monsoon when the salt accumulation is generally highest. The geographical locations (UTM coordinates) of the sampling locations were recorded using handheld GPS.

Laboratory analysis

Soil EC and other soil salinity indicators were determined in soil water extractions obtained from saturation pastes that were prepared from 100 g air dried and 2-mm sieved soil. EC (in dS m^{-1}) and pH were measured using EC and pH meter, saturation percentage, soluble cations— Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} and soluble anions— CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} — were determined using standard procedures underlined in USDA Handbook No. 60 (Richards, 1954). Particle size distribution of the soils was determined by International Pipette method (Piper, 1966). Organic carbon was determined by wet-oxidation method (Walkely and Black, 1934), available nitrogen (N) was determined by alkaline permanganate method (Subbaiah and Asija, 1956), available P content was determined by extracting the soil samples using 0.5M $NaHCO_3$ and analysed by spectrophotometer (Olsen *et al.*, 1954) and available potassium was extracted by using neutral normal ammonium acetate and the content was determined by aspirating the extract into flame photometer (Jackson, 1973). Cation exchange capacity (CEC) and exchangeable sodium (Na_{Exc}; meq 100 g^{-1}) were determined by ammonium acetate method (Hesse, 1972). Exchangeable sodium percentage was calculated as follows:

$$ESP = \frac{Na_{Exc}}{CEC} \times 100$$

Methodology for map preparation

The methodology essentially involves geo-referencing of satellite data, delineation of salt affected categories through on screen visual interpretation technique based on legacy data and limited ground truth. Three seasons Resource Sat -1 LISS III satellite data viz. Kharif, Rabi, and Zaid for 2008-2009 were used for delineation of salt affected areas. The satellite data was geo-coded and rectified using ortho-rectified LandSat ETM+ images. The details of the satellite data used for the study are given in table 1.

Image interpretation

Based on the standard image characteristics such as tone, texture, pattern, shape, size, location and association etc. on screen visual interpretation of remotely sensed data was carried out using a hybrid approach. Interpretation "keys" were developed for various salt affected categories. These interpretation "keys" formed the base for delineation of the satellite data. Based on these interpretation keys, satellite data was classified into various salt affected classes based on their occurrence in the block. Different salt affected categories were delineated by following a standard legend prepared by Department of Space. These maps were put in GIS format to create the database. The datum and projection system of the satellite data was taken as WGS 84 and UTM, respectively. Arc GIS Desktop 9.2 and ERDAS Imagine were used for generation of vector layer and geo-referencing, respectively.

Ground verification

Due to variability of salt affected classes and terrain characteristics in the study area, ground truth in the block was collected along with the ground photographs. The doubtful areas in the pre-field interpreted maps were checked during the ground truth and the pre-field maps were modified by incorporating field observations, if any. After due corrections, attributes were attached. The maps were composed in Arc Map 9.2 software to display the different layers of the extracted information in an effective manner for this purpose, the different layers of extracted information in.shp format were loaded in Arc Map and the maps were composed having legend to represent the categories of different classes. The Arc Map was also used to create various thematic maps like EC, ESP and pH maps of the study area.

Statistical analysis

Descriptive statistical methods were used to analyse the range, mean, standard deviation, variance, coefficient of variation, kurtosis, and skewness of all properties described in laboratory analysis. The correlation analysis was done to determine the relationship among various parameters. These analyses were processed using software SPSS 19.0.

Results and Discussion

Soil is a continuum and its constituents are versatile. The summary of the descriptive statistics of soil properties is given in tables 3 and 4. The coefficient of variation (CV) is an indicator of the general variation or heterogeneity of a given variable. In this study, a soil property is regarded as showing little variation where the CV is <20, moderate variability if the CV is between 20-50 and high variability where the CV is above 50 (Ameyan, 1986).

Soil pH

Statistical analysis indicated that mean pH of both normal and salt affected soils decreased with depth which may be attributed to the high concentration of exchangeable sodium in the surface layer that occurs due to capillary rise as conditioned by high evapotranspiration. Moreover, leaching of salts had not taken place from upper to lower layers as sampling was done prior to monsoon. Standard deviation, variance and coefficient of variation of normal soils increased with depth (Table 3). On the otherhand, in salt affected soils standard deviation, variance and coefficient of variation first decreased and then increased with depth with lowest value observed in 15-30 cm depth (Table 4). Arguably, pH is the single most diagnostic chemical measurement made on soil as it expresses the degree of acidity or alkalinity influencing a wide range of soil properties that is chemical, biological and indirectly even physical. The pH in normal and salt affected soils ranged from 7.06 to 8.42 and 7.39 to 9.74, respectively (Table 3) indicating the neutral to alkaline nature of soil pH. There is a positive and significant correlation between pH and EC ($r = 0.57; p \leq 0.01$) pH and Na^+ ($r = 0.59; p \leq 0.01$) and Cl^- ($r = 0.63$) and SO_4^{2-} ($r = 0.51$) signifying that the pH of the soil is primarily influenced by the Cl^- and SO_4^{2-} content (Table 2). Bai *et al.*, (2016) also reported positive correlation between pH and EC and Na^+ ions in the Wuyu'er-Shuangyang River

Basin, Northeast China. The pH variation in the area is small as indicated by low CV which can be attributed to high buffering capacity of the soils and absence of carbonates in the saturation extract (Sharma and Gupta, 1986). Higher pH values were recorded at various sites across the block which may be attributed to the existence of soluble and exchangeable sodium along with bicarbonate ions which get precipitated as calcium and magnesium carbonates during evaporation (Deshmukh, 2012). Tripathi *et al.*, (2015) also reported low CV for pH while characterizing the spatial variability of soil properties in salt affected area. The high pH in the soils suggests that groundwater was the main source of contamination in the study area. Hence, high pH values are the indication of development of salinity and sodicity in the study area. Similar results were confirmed by Sidhu *et al.*, (1991).

Electrical conductivity (EC_e) of saturation extract

Statistical analysis of electrical conductivity indicated that its mean decreased consistently but standard deviation and variance showed irregular trend down with depth in normal soils (Table 3). However, in salt affected soils, mean, standard deviation and variance decreased constantly with depth (Table 4). This indicates the upward movement of soluble salts in the soil profile and their ultimate deposition in the surface layers which may ultimately result in the development of salt affected soils in the long run. The EC showed medium and medium to high variability in normal and salt affected soils with CV values from 29.01 to 37.10 and 46.06 to 59.46%, respectively (Tables 3 and 4). In salt affected soils, the highest CV was in 0-15cm depth and lowest in 45-60 cm depth. Such trend may be due to more severe wetting and drying cycles in which soluble salts present in the dry beds are transported to the surface soil by upward capillary movement. Corwin and Lesch (2005) reported moderate to high variability in EC_e in saline-sodic soil. Zhaoyong *et al.*, (2014) observed moderate variability in EC_e while assessing the soil salinization risk in Yanqi basin, northwest China. Electrical conductivity is an important diagnostic parameter for evaluation of soil salinity. The EC varied from 1.26 to 3.79 and 1.44 to 15.82 in normal and salt affected soils, respectively. The EC_e showed a decreasing trend with depth which may be due to the capillary rise of brackish groundwater to the soil surface followed by evaporation leaving behind salts. Since, potential evapotranspiration is higher than precipitation as the mercury touches about 45℃ during summers. Other probable explanation is the evaporation of rainwater that accumulates in comparatively lower topographic positions on which the salt affected soils are situated (Sidhu *et al.*, 1991). Qureshi *et al.*, (1996) and Mandal (2014) reported that the higher EC_e at surface may be due to the salt accumulation through run off. There was a significant correlation of 0.96 ($p \leq 0.01$) between EC_e and Na^+ ions as well as and Cl^- (r =0.96) and SO_4^{2-} (r =0.74), ESP (r = 0.68), SAR_e (r = 0.79), pH (r =0.59). Moreover, a significant correlation of 0.63 ($p \leq 0.05$) between EC_e and Ca^{2+} and Mg^{2+} (0.46; $p \leq 0.05$) was observed. Das and Singh (2006) also reported strong linear relationship between EC_e and Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-} ions and evinced that the contribution of Na^+ and Cl^- was more pronounced than other cations and anions. However, there is a negative significant correlation between EC_e and organic carbon. The correlation coefficient between EC and Na^+ was higher than that between pH and Na^+ which implies that other non-alkaline salts also contribute to electrical conductivity.

Cation exchange capacity (CEC)

The mean values of CEC decreased consistently with depth in both normal and salt affected soils. However, standard deviation and variance showed irregular trend with depth in both normal and salt affected soils (Tables 3 and 4). The CEC at all soil depths showed a medium range of variability as indicated by coefficient of variation (CV) values. The CV value was slightly higher for surface soil (0-15 cm) in salt affected soils and for sub soil in normal soils (45-60cm). Hence, the variation differed appreciably among four soil depths studied. The medium CV for CEC was due to medium variation in silt and clay fractions of soil texture (Table 2). Ameyan (1986) has reported relatively high range of variation in CEC with CV values of > 30. Corwin and Lesch (2005) also reported moderate variability in CEC in saline-sodic soil. The cation exchange capacity ranged from 6.81 to 22.19 and 3.18 to 20.93 cmol (p^+) kg^{-1} in normal and sodic soils, respectively. Cation exchange capacity decreased with depth which may be attributed to higher concentration of exchangeable cations in upper layers. Moreover, the sites having higher cation exchange capacity have high clay content and relatively higher organic matter which are responsible for adsorption of exchangeable cations. There is a positive and significant correlation between CEC and OC ($r = 0.31$; $p \leq 0.05$) and clay ($r = 0.44$; $p \leq 0.05$) suggesting that organic matter and clay content determine the cation exchange capacity. However, the higher contribution was shown by clay content. The lower CEC values may be related to coarse soil texture (Mandal, 2014); dominance of illite mineral, other low charge minerals and low organic matter content (Sharma *et al.*, 2011, Dinesh *et al.*, 2017). On the otherhand, negative and significant relationship between CEC and sand content ($r = -0.35$; $p \leq 0.05$) was observed which may be due to dominance of quartz mineral. Wang *et al.*, (2005) also reported negative correlation between soil CEC and sand content ($r = -0.43$) in the calcareous soils with a wide range of $CaCO_3$.

Sodium adsorption ratio (SAR)

Statistical analysis showed that mean, standard deviation and variance of sodium adsorption ratio in both normal and salt affected soils decreased with depth, the highest being observed in the surface layer (0-15 cm). The CV in normal soils was medium to high whereas in salt affected soils CV was high (Tables 3 and 4). Corwin and Lesch (2005) also reported moderate to high variability in SAR in saline-sodic soil. However, Yang et al., (2011) reported high range of variation in SAR with CV values of 119-197%. Zhaoyong *et al.,* (2014) observed high variability in SAR while assessing the soil salinization risk in Yanqi basin, northwest China. The sodium adsorption ratio of the saturated extract of normal and salt affected soils varied from 2.68 to 9.06 and 5.71 to 36.85 $(mmol\ l^{-1})^{1/2}$, respectively. Positive and significant relationship ($p \leq 0.01$) was observed between SAR and Na^+ ($r = 0.90$), Cl^- ($r = 0.72$) and SO_4^{2-} ($r = 0.66$). Significant and positive correlation was observed between ESP and SAR suggesting that higher SAR is accompanied by high ESP. Mohamed *et al.*, (2008) also reported positive and significant relationship between ESP and SAR in Vertisols of Sudan.

Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage determines the percentage of exchangeable sodium adsorbed on soil exchange complex and is used to test soil sodicity. Statistical analysis showed that the mean, standard deviation and variance of exchangeable sodium percentage decreased with depth in both normal and salt affected soils and highest ESP was observed in the surface layer (0-15 cm). Exchangeable sodium percentage showed medium variation as reflected by the coefficient of variation (Tables 3 and 4). The exchangeable sodium percentage in normal and salt affected soils varied from 3.42 to 13.84 and 21.61 to 72.26 percent, respectively. The lower ESP in normal soils could be assigned to the effect of Ca and Mg to offset the effect of Na on cation exchange complex of the soil colloids. Contrarily, the higher ESP in sodic and saline-sodic soils might be due to higher carbonates, bicarbonates and hydroxide ion concentrations in these soils that may engender the calcium to precipitate as $CaCO_3$. There was a significant correlation of 0.73 ($p \leq 0.01$) between ESP and Na^+ ions and pH (r = 0.79) which implies that higher pH is responsible for high ESP as Na^+ was the dominant ion in the saturation extract.

Significant negative correlation was observed between ESP and OC (r = -0.31; $p \leq 0.01$) suggesting that organic matter has buffer effect for sodic soils. The decrease in ESP with depth indicates that process of alkalization had started at the surface and proceeded in downward direction. Mitran *et al.,* (2015) reported ESP values of 0.11 to 66% suggesting the impact of sodium hazard in soil which were mostly saline-sodic in nature (40%) while Eldardiry *et al.,* (2013) reported ESP values of 12.78 to 67.27% in saline sodic soils of Egypt.

Major cations and anions

The ionic composition in both normal and salt affected soils showed more or less high variation as revealed by CV values (Tables 3 and 4). The cations Ca^{2+}, Mg^{2+}, Na^+ and K^+ varied from 3.36-11.78, 2.40-9.84, 5.88-29.64, 0.38-2.45 and 1.64-19.34, 1.42-15.28, 7.04-134.92, 0.18-4.13 meq l^{-1} in normal and salt affected soils, respectively. The anions CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-} ranged from traces to 3.08, 2.46-18.10, 5.50-25.32, 0.79-15.91 and traces to 4.80, 2.32-23.96, 6.64-88.93, 0.24-69.12 meq l^{-1} in normal and salt affected soils, respectively. Both cations and anions showed a decreasing trend with depth which may be due to the upward movement of the ions with the capillary water during the summer months as the rise in temperature leads to high evapotranspiration thereby increasing the concentration of these ions in surface layers. Moreover, the sampling was done before the showers of monsoon. Salinity in these soils was the result of chloride and sulphate salts of Na^+ existing in large amount (as the concentration of CO_3^{2-} and HCO_3^- was low) and are the salts of strong acids and bases, therefore, completely dissociate in water (Das and Singh, 2006). Scott and Smith (1987) reported that under irrigated conditions in arid regions the alkali cations may concentrate at the soil surface due to upward capillarity and evaporation. A positive and significant correlation was observed between Na^+ ions and Cl^- (r =0.923; $p \leq 0.01$) and SO_4^{2-} (r =0.818; $p \leq 0.01$) indicating that chloride was the primary salt anion and sulphate was the secondary. Calcium (Ca^{2+}) showed positive relationship with Cl^- (r = 0.494; $p \leq 0.01$). The cations in the saturation extract were significantly correlated with each other except K^+, however, K^+ showed significant correlation with Mg^{2+} (Table 2). In this study, the bicarbonates were observed in all samples but carbonates were only detected in samples having high pH values. This is due to precipitation of calcium and magnesium as carbonates.

Calcium carbonate ($CaCO_3$)

In normal and salt affected soils calcium carbonate ranged from 0.10 to 1.75 and 0.10 to 7.00 percent, respectively (Tables 3 and 4). The calcium carbonate showed highest variation as defined by the coefficient of variation both in normal and salt affected soils, albeit, $CaCO_3$ is a basic property but it is a local phenomenon which may be accountable to its high variability. Moreover, the variation may be ascribed to the nature of parent material and quality of irrigation water used. Saldana *et al.,* (1998) reported high variation in $CaCO_3$ with CV values upto 550% while studying spatial variability of soil properties in chronosequence on terraces of Henares River. Negative but significant correlation was observed between $CaCO_3$ and P (r = -0.29; p≤0.05) which may be assigned to fixation of P as calcium phosphate; $CaCO_3$ and pH (r = -0.24; p≤0.05) because at higher pH, i.e., at 8.3 saturation of calcium carbonate occurs; $CaCO_3$ and K (r = -0.38; p≤0.01), Mg^{2+} (r = -0.29; p≤0.05) and Cl^{-} (r = -0.25; p≤0.05) which may be attributed to the shielding action of water as done by these ions which will make it difficult for Ca^{2+} and CO_3^{2-} ions to find each other and precipitate, moreover, the effect would be greater for divalent ions than univalent ions since the attraction for multiple charged ions should be greater (Krauskopf, 1967). Calcium carbonate showed increasing trend with depth which may be ascribed to poor drainage conditions. Babar and Kaplay (2004) reported that the $CaCO_3$ was higher in salt affected soils as compared to normal soils but increased with depth.

Organic carbon (OC)

The organic carbon varied from 0.12 to 0.47 and 0.06 to 0.46 percent in normal and salt affected soils, respectively (Tables 3 and 4). Organic carbon content decreased consistently with depth. This trend in organic carbon content is expected because in nearly all soils organic carbon in the surface layer is always higher due to addition through farmyard manure and plant residues. The statistical analysis showed a considerable lower range of variability of OC. Soil organic carbon was higher in normal soils compared to salt affected soils which may be ascribed to higher decomposition of organic matter in salt affected soils (sodic) due to dispersion of soil aggregates. The low CV in OC content in the surface layer may be attributed to the rapid oxidation of organic matter and levelling effect of cultivation. Higher CV at lower depths may be caused by root residues left in the sub soil. In terms of magnitude of variation, the variation in OC in the study area was low to medium. Bhatti (2002) observed medium range of variability in organic matter with CV value of 34.66%. Corwin and Lesch (2005) reported moderate variability in total carbon in saline-sodic soil. The OC in the study area was low and showed a decreasing trend with depth which might be ascribed to the prevailing high temperature that is responsible for rapid mineralization of organic matter, as it is not unexpected in subtropical and tropical climates.

Available nitrogen

Statistical analysis of available nitrogen showed that the mean, variance and standard deviation of this parameter decreased more or less with depth in normal soils. However, in salt affected soils these parameters increased with depth except mean (Tables 3 and 4). The mean value of available nitrogen in all locations was low.

Table.1 Details of satellite data

Satellite	Sensor	Date of Acquisition	Spatial Resolution
IRS-P6	LISS-III	May, 2009	23.5 metres
		11 March, 2009	
		13 October, 2008	

Table.2 Correlation coefficient among various parameters of soil

	OC	$CaCO_3$	N	P	K	ESP	EC_e	pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	SAR_e	SP	Sand	Silt	Clay	CEC
OC	1																					
$CaCO_3$	-0.17	1																				
N	0.31^{**}	-0.37^{**}	1																			
P	0.66^{**}	-0.28^{*}	0.35^{**}	1																		
K	0.64^{**}	-0.38^{**}	0.33^{**}	0.49^{**}	1																	
ESP	-0.35^{**}	-0.18	0.14	0.05	-0.15	1																
EC_e	0.05	-0.13	0.25^{*}	0.09	0.22	0.67^{**}	1															
pH	-0.19	-0.24^{*}	0.07	0.04	-0.07	0.86^{**}	0.57^{**}	1														
Ca^{2+}	0.35^{**}	-0.05	0.19	0.31^{**}	0.36^{**}	0.22	0.63^{**}	0.25^{*}	1													
Mg^{2+}	0.25^{*}	-0.29^{*}	0.29^{*}	0.28^{*}	0.44^{**}	0.19	0.46^{**}	0.33^{**}	0.78^{**}	1												
Na^+	-0.01	-0.10	0.24^{*}	0.03	0.15	0.72^{**}	0.96^{**}	$.057^{**}$	0.44^{**}	0.24^{*}	1											
K^+	0.33^{**}	-0.01	-0.18	0.29^{*}	0.23^{*}	-0.09	0.13	-0.03	0.21	0.23^{*}	0.00	1										
CO_3^{2-}	0.37^{**}	0.04	0.00	0.21	0.11	-0.10	0.15	-0.01	0.03	0.03	0.11	0.56^{**}	1									
HCO_3^-	0.24^{*}	-0.01	0.04	0.08	0.23^{*}	-0.04	0.22	0.04	0.09	0.37^{**}	0.14	0.48^{**}	0.69^{**}	1								
Cl^-	0.01	-0.25^{*}	0.32^{**}	0.12	0.27^{*}	0.72^{**}	0.94^{**}	0.61^{**}	0.63^{**}	0.47^{**}	0.91^{**}	0.03	-0.02	0.04	1							
SO_4^{2-}	0.00	0.07	0.13	0.05	0.03	0.54^{**}	0.78^{**}	0.38^{**}	0.46^{**}	0.10	0.82^{**}	-0.14	-0.09	-0.24^{*}	0.72^{**}	1						
SARe	-0.13	-0.04	0.19	-0.06	-0.03	0.74^{**}	0.79^{**}	0.58^{**}	0.08	-0.05	0.90^{**}	-0.06	0.17	0.19	0.72^{**}	0.66^{**}	1					
SP	-0.11	-0.07	-0.26^{*}	0.23^{*}	0.07	0.05	-0.20	0.09	-0.03	0.01	-0.21	-0.12	-0.37^{**}	-0.34^{**}	-0.10	-0.05	-0.24^{*}	1				
Sand	0.00	0.11	0.18	-0.12	-0.01	0.09	0.18	-0.06	-0.01	-0.06	0.21	0.21	0.28^{*}	0.20	0.13	0.08	0.24^{*}	-0.79^{**}	1			
Silt	0.18	-0.14	-0.11	0.16	0.11	-0.20	-0.10	-0.10	-0.03	0.01	-0.11	-0.15	-0.08	0.07	-0.10	-0.13	-0.10	0.45^{**}	-0.81^{**}	1		
Clay	-0.19	-0.04	-0.18	0.03	0.21^{*}	0.04	-0.19	0.11	0.05	0.08	-0.23^{*}	-0.19	-0.45^{**}	-0.41^{**}	-0.11	-0.03	-0.29^{*}	0.84^{**}	-0.81^{**}	0.32^{**}	1	
CEC	0.31^{**}	0.14	-0.04	0.17	0.32^{**}	-0.13	0.20	-0.02	0.66^{**}	0.45^{**}	0.06	0.11	-0.04	-0.10	0.21	0.22	-0.20	0.38^{**}	-0.35^{**}	0.14	0.43^{**}	1

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).

Table.3 Descriptive statistics of soil characteristics (0-60cm depth) of normal soils

Characteristics	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis	CV
0-15 cm depth								
SP	31.52	41.02	35.14	3.19	10.19	1.05	1.00	9.08
Sand	60.22	77.80	70.55	7.81	60.96	-0.46	-2.08	11.07
Silt	9.65	20.60	14.40	4.54	20.63	0.43	-2.21	31.53
Clay	10.90	20.65	15.05	3.66	13.39	0.30	-1.11	24.31
Silt+Clay	22.20	39.78	29.45	7.81	60.96	0.46	-2.08	26.51
CEC	8.12	22.19	15.97	4.32	18.65	-0.69	1.76	27.05
OC	0.41	0.57	0.49	0.06	0.00	0.04	-1.01	11.66
$CaCO_3$	0.10	1.12	0.34	0.37	0.14	1.80	1.80	108.78
Available N	104.37	220.40	156.17	36.17	1308.00	0.59	1.28	23.16
Available P	16.52	28.77	20.35	4.36	19.04	1.37	1.66	21.44
Available K	245.17	323.32	274.59	26.20	686.28	1.12	1.24	9.54
ESP	3.96	13.84	9.66	3.85	14.85	-0.16	-1.62	39.89
ECe	1.83	3.79	2.84	0.90	0.81	0.03	-0.89	29.01
pH	7.39	8.47	7.82	0.39	0.15	1.55	3.32	4.93
SARe	3.11	9.06	5.85	3.00	9.01	1.21	-0.06	51.35
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	5.62	11.78	8.55	2.39	5.71	0.05	-1.82	27.96
Mg^{2+}	3.52	9.84	5.54	2.36	5.58	1.22	0.56	42.60
Na^{+}	7.02	29.64	15.25	7.76	60.26	1.27	1.02	50.90
K^{+}	0.69	2.45	1.47	0.58	0.34	0.59	0.13	39.58
Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	3.08	1.83	1.33	1.76	-0.78	-1.27	72.57
HCO_3^{-}	4.20	18.10	9.68	4.88	23.83	0.78	-0.18	50.41
Cl^{-}	7.96	25.32	14.80	5.62	31.57	1.04	1.49	37.96
SO_4^{2-}	1.21	15.91	5.72	4.86	23.58	1.88	4.13	84.93
15-30 cm depth								
SP	30.86	40.36	34.18	3.09	9.54	1.48	2.86	9.03
Sand	61.78	78.90	72.20	7.52	56.53	-0.70	-1.69	10.41
Silt	9.70	19.40	13.62	3.98	15.85	0.70	-1.57	29.24
Clay	10.10	19.78	14.18	3.78	14.29	0.43	-1.46	26.66
Silt+Clay	21.10	38.22	27.80	7.52	56.53	0.70	-1.69	27.05
CEC	7.63	20.52	14.85	4.05	16.40	-0.69	1.24	27.27
OC	0.34	0.47	0.40	0.06	0.00	0.23	-2.47	14.94
$CaCO_3$	0.14	1.18	0.43	0.37	0.13	1.67	1.43	84.17
Available N	98.22	211.60	141.81	34.81	1211.00	1.41	3.31	24.54
Available P	10.20	22.69	15.27	4.19	17.60	0.86	0.46	27.46
Available K	210.33	284.44	248.06	24.66	608.05	-0.35	-0.01	9.94
ESP	3.85	12.81	9.31	3.52	12.38	-0.30	-1.31	37.80
ECe	1.55	3.25	2.29	0.93	0.87	0.02	-0.72	32.23
pH	7.27	8.45	7.65	0.42	0.18	1.81	3.74	5.55
SARe	3.00	8.77	5.55	2.65	7.02	1.08	-0.70	47.73
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	4.30	10.76	7.90	2.44	5.97	-0.32	-1.53	30.93
Mg^{2+}	2.68	9.66	4.98	2.42	5.87	1.50	1.74	48.67
Na^{+}	6.35	26.09	13.89	6.78	45.96	1.11	0.60	48.81
K^{+}	0.53	2.36	1.30	0.61	0.37	0.91	0.45	46.87
Soluble anions in saturation extract (meq l^{-1})								

CO_3^{2-}	0.00	2.82	1.61	1.18	1.40	-0.70	-1.37	73.68
HCO_3^{-}	3.82	15.12	8.79	4.37	19.06	0.38	-1.82	49.65
Cl^{-}	6.84	24.04	13.43	5.65	31.96	1.11	1.38	42.09
SO_4^{2-}	1.12	15.42	5.22	4.83	23.35	1.96	4.25	92.61
30-45 cm depth								
SP	30.20	42.05	34.94	3.93	15.47	0.83	0.90	11.26
Sand	58.91	81.20	71.36	9.37	87.86	-0.56	-1.82	13.14
Silt	10.00	21.00	13.91	4.77	22.77	0.79	-1.49	34.31
Clay	8.80	21.39	14.73	4.79	22.91	0.25	-1.68	32.49
Silt+Clay	18.80	41.09	28.64	9.37	87.86	0.56	-1.82	32.73
CEC	7.37	17.81	14.16	3.50	12.25	-1.28	2.03	24.73
OC	0.21	0.38	0.30	0.06	0.00	-0.19	-0.13	18.86
$CaCO_3$	0.18	1.54	0.64	0.50	0.25	1.10	-0.56	77.54
Available N	84.51	202.20	129.13	35.81	1282.00	1.51	3.84	27.73
Available P	8.37	18.47	11.60	3.45	11.87	1.53	2.54	29.70
Available K	141.21	269.98	214.93	43.16	1863.00	-0.60	0.11	20.08
ESP	3.61	12.59	8.93	3.36	11.31	-0.34	-1.05	37.68
ECe	1.41	2.61	2.15	0.84	0.70	-0.27	-1.21	32.86
pH	7.18	8.42	7.56	0.45	0.20	2.02	4.62	5.95
SARe	3.04	8.01	5.18	2.44	5.97	1.09	-0.79	47.19
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	4.25	9.94	7.00	2.28	5.20	0.29	-1.49	32.58
Mg^{2+}	2.54	9.56	4.54	2.39	5.71	1.96	4.00	52.62
Na^{+}	6.17	21.21	12.13	5.59	31.19	0.98	-0.54	46.03
K^{+}	0.49	2.24	1.18	0.62	0.39	1.00	-0.06	52.86
Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	2.78	1.22	1.02	1.05	0.14	-0.88	83.81
HCO_3^{-}	2.74	14.36	7.63	4.20	17.66	0.65	-0.76	55.10
Cl^{-}	5.72	21.70	11.47	5.23	27.32	1.39	2.26	45.55
SO_4^{2-}	0.92	13.67	4.47	4.36	19.05	1.92	4.21	97.55
45-60 cm depth								
SP	31.26	41.42	34.95	3.87	14.96	0.87	-0.50	11.07
Sand	57.86	79.40	70.30	9.78	95.58	-0.40	-2.57	13.91
Silt	9.60	21.20	14.42	5.29	28.01	0.40	-2.48	36.70
Clay	10.80	21.99	15.28	4.68	21.90	0.43	-2.00	30.62
Silt+Clay	20.60	42.14	29.70	9.78	95.58	0.40	-2.57	32.91
CEC	6.81	18.98	13.45	3.93	15.42	-0.40	0.46	29.21
OC	0.12	0.33	0.22	0.08	0.01	0.17	-0.95	34.81
$CaCO_3$	0.25	1.75	0.81	0.57	0.33	1.09	-0.66	71.03
Available N	79.26	192.40	116.93	35.59	1267.00	1.92	4.65	30.44
Available P	5.24	12.81	8.79	2.41	5.79	0.26	0.69	27.37
Available K	107.92	251.90	182.85	46.18	2132.00	-0.27	0.38	25.25
ESP	3.42	12.38	8.76	3.29	10.84	-0.41	-0.78	37.60
ECe	1.26	2.45	1.85	0.87	0.76	-0.02	-1.04	37.10
pH	7.06	8.40	7.46	0.49	0.24	2.07	4.78	6.50
SARe	2.68	7.31	4.87	2.31	5.34	0.95	-1.02	47.41
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	3.36	9.40	6.45	2.44	5.97	0.03	-1.63	37.90
Mg^{2+}	2.40	9.22	4.11	2.32	5.40	2.33	5.73	56.54
Na^{+}	5.88	19.84	10.81	5.03	25.28	1.14	0.39	46.50
K^{+}	0.38	2.17	1.09	0.65	0.42	0.91	-0.41	59.95

Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	2.70	1.06	0.96	0.92	0.63	0.16	90.55
HCO_3^-	2.46	13.82	6.83	3.91	15.30	0.86	0.45	57.23
Cl^-	5.50	16.16	10.02	3.47	12.05	0.71	0.75	34.66
SO_4^{2-}	0.79	12.94	4.02	4.20	17.64	2.02	4.44	104.54

Table.4 Descriptive statistics of soil characteristics (0-60 cm depth) of salt affected soil

Characteristics	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis	CV
0-15 cm depth								
SP	29.94	43.45	36.01	4.85	23.52	0.36	-1.51	13.47
Sand	59.44	86.64	72.85	8.08	65.22	-0.39	0.21	11.09
Silt	7.60	26.53	12.57	5.63	31.74	1.89	3.36	44.80
Clay	5.76	23.30	14.57	5.02	25.18	0.13	0.06	34.44
Silt+Clay	13.36	40.56	27.15	8.08	65.22	0.39	0.21	29.75
CEC	3.18	19.60	12.77	5.22	27.24	-0.42	-0.74	40.88
OC	0.28	0.46	0.35	0.07	0.00	0.44	-1.30	18.47
$CaCO_3$	0.10	1.25	0.39	0.60	0.36	2.59	6.75	154.64
Available N	92.04	195.30	153.95	29.18	851.69	-0.79	0.63	18.96
Available P	10.12	28.05	20.04	5.05	25.53	-0.42	0.07	25.22
Available K	196.68	304.15	262.40	33.80	1142.00	-0.97	0.14	12.88
ESP	25.00	72.26	43.79	15.04	226.18	0.55	-0.59	34.34
ECe	2.75	15.82	6.07	3.61	13.01	2.22	5.94	59.46
pH	8.43	9.74	9.05	0.46	0.21	0.44	-1.48	5.11
SARe	5.71	36.85	15.18	9.39	88.09	1.33	1.86	61.83
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	2.72	19.34	9.35	5.40	29.13	0.66	-0.39	57.72
Mg^{2+}	2.67	15.28	7.87	4.15	17.23	0.60	-0.50	52.71
Na^+	14.20	134.92	42.66	33.14	1098.00	2.45	7.07	77.69
K^+	0.71	4.13	2.04	1.04	1.09	0.58	0.10	51.09
Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	4.80	2.04	1.52	2.32	0.33	-0.93	74.59
HCO_3^-	2.87	23.96	12.83	7.35	54.07	-0.08	-1.41	57.32
Cl^-	12.42	88.93	34.07	22.18	492.08	1.74	3.29	65.11
SO_4^{2-}	0.62	69.12	12.74	19.02	361.62	3.11	10.06	149.31
15-30 cm depth								
SP	30.25	44.28	35.97	4.78	22.89	0.73	-0.83	13.30
Sand	58.58	82.34	72.84	6.70	44.91	-1.04	0.99	9.20
Silt	7.10	27.96	12.53	5.90	34.78	2.06	4.78	47.07
Clay	8.18	23.20	14.63	3.89	15.16	0.83	1.78	26.61
Silt+Clay	17.66	41.42	27.16	6.70	44.91	1.04	0.99	24.67
CEC	7.64	19.04	12.57	3.34	11.13	0.10	0.33	26.54
OC	0.21	0.38	0.28	0.06	0.00	0.46	-1.23	20.14
$CaCO_3$	0.15	1.42	0.49	0.67	0.45	2.58	6.75	135.62
Available N	76.56	185.33	138.80	31.57	996.89	-0.46	-0.06	22.75
Available P	9.32	19.18	14.85	3.42	11.72	-0.48	-0.67	23.05
Available K	124.11	286.23	218.52	60.04	3605.00	-0.56	-1.41	27.48
ESP	22.76	69.31	40.14	14.29	204.30	0.76	0.08	35.61
ECe	1.84	11.43	5.13	2.72	7.39	1.24	1.93	52.93
pH	8.36	9.63	8.91	0.43	0.19	0.54	-1.38	4.87
SARe	4.84	34.39	14.35	9.12	83.12	1.13	1.12	63.53
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	2.46	17.26	7.80	4.47	20.02	0.77	0.51	57.38
Mg^{2+}	2.42	12.08	6.17	3.38	11.41	0.82	-0.37	54.76
Na^+	9.62	98.02	35.69	24.41	595.71	1.73	4.12	68.39
K^+	0.55	3.85	1.60	0.99	0.99	1.16	1.48	62.10
Soluble anions in saturation extract (meq l^{-1})								

CO_3^{2-}	0.00	4.86	1.70	1.51	2.28	0.87	0.21	88.80
HCO_3^-	2.96	22.10	11.38	6.92	47.95	0.04	-1.51	60.84
Cl^-	9.64	67.58	28.59	17.78	316.08	1.43	1.46	62.19
SO_4^{2-}	0.43	40.18	8.70	10.76	115.80	2.96	9.36	123.68
30-45 cm depth								
SP	30.28	44.21	36.46	5.46	29.77	0.21	-1.96	14.96
Sand	57.66	79.95	71.64	7.30	53.27	-0.62	-0.67	10.19
Silt	6.10	20.24	12.19	4.15	17.24	0.83	0.06	34.07
Clay	9.53	27.40	16.17	5.63	31.65	0.62	-0.18	34.79
Silt+Clay	20.05	42.34	28.36	7.30	53.27	0.62	-0.67	25.74
CEC	7.15	20.93	12.54	4.18	17.50	0.64	0.36	33.37
OC	0.13	0.25	0.20	0.04	0.00	-0.11	-0.54	19.25
$CaCO_3$	0.18	1.96	1.18	1.70	2.90	2.41	5.97	144.47
Available N	64.13	166.75	121.88	35.44	1256.00	-0.41	-0.88	29.08
Available P	8.02	13.76	10.98	2.20	4.84	0.00	-1.77	20.04
Available K	112.32	263.76	188.98	52.16	2721.00	-0.10	-1.32	27.60
ESP	22.65	65.07	37.78	12.69	160.98	0.94	0.73	33.58
ECe	1.50	9.69	4.58	2.28	5.20	0.97	1.40	49.82
pH	7.84	9.41	8.74	0.45	0.21	-0.23	0.13	5.20
SARe	3.96	31.29	13.33	8.15	66.35	0.97	1.08	61.10
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	2.23	14.30	6.87	3.72	13.82	0.55	-0.08	54.14
Mg^{2+}	2.21	10.86	5.31	3.00	9.01	0.90	-0.40	56.52
Na^+	7.12	84.36	31.18	20.87	435.57	1.67	4.14	66.93
K^+	0.24	3.78	1.30	1.03	1.07	1.49	2.52	79.81
Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	4.74	1.29	1.45	2.11	1.64	2.34	112.81
HCO_3^-	2.44	21.68	10.42	6.92	47.82	0.14	-1.43	66.34
Cl^-	8.30	61.04	24.67	15.77	248.72	1.43	1.87	63.92
SO_4^{2-}	0.32	33.85	7.17	9.12	83.20	2.96	9.34	127.20
45-60 cm depth								
SP	31.10	44.75	36.73	5.25	27.58	0.55	-1.40	14.30
Sand	54.40	78.48	70.10	8.06	64.91	-0.99	-0.13	11.49
Silt	8.70	21.66	12.67	4.36	18.99	1.45	0.91	34.39
Clay	10.36	26.80	17.23	5.64	31.86	0.49	-1.26	32.76
Silt+Clay	21.52	45.60	29.90	8.06	64.91	0.99	-0.13	26.94
CEC	6.43	19.75	12.22	4.67	21.82	0.28	-1.38	38.22
OC	0.06	0.20	0.12	0.04	0.00	0.95	0.42	36.46
$CaCO_3$	0.28	2.52	1.73	2.45	6.00	2.18	4.81	141.93
Available N	55.68	156.97	109.23	37.13	1378.00	0.03	-1.66	33.99
Available P	6.21	12.43	8.64	2.14	4.60	0.86	-0.09	24.83
Available K	92.15	251.30	164.97	48.98	2399.00	0.07	-0.77	29.69
ESP	21.61	56.79	33.63	10.66	113.64	0.93	0.72	31.70
ECe	1.44	7.21	3.83	1.76	3.11	0.29	-0.37	46.07
pH	7.39	9.32	8.60	0.51	0.26	-1.04	2.79	5.93
SARe	3.94	21.79	11.24	5.80	33.61	0.39	-0.54	51.60
Soluble cations in saturation extract (meq l^{-1})								
Ca^{2+}	1.64	9.34	5.60	2.76	7.61	-0.11	-1.64	49.28
Mg^{2+}	1.42	8.62	4.60	2.45	6.01	0.48	-1.09	53.29
Na^+	7.04	56.88	24.40	14.54	211.41	0.99	1.20	59.59
K^+	0.18	3.40	1.01	0.92	0.85	1.90	4.50	90.89
Soluble anions in saturation extract (meq l^{-1})								
CO_3^{2-}	0.00	4.58	1.09	1.44	2.06	1.82	2.88	131.54
HCO_3^-	2.32	19.52	9.06	6.36	40.48	0.46	-1.37	70.23
Cl^-	6.64	55.00	20.89	14.00	195.98	1.53	2.86	67.03
SO_4^{2-}	0.24	20.21	5.10	5.41	29.31	2.49	7.15	106.09

Table.5 Estimation of the salt affected area of block Gohana, Sonipat

Area and Soil Type	Area in Hectares
Total area of the block	36448
Total salt affected area	880 (2.41)*
Moderately salt affected	412 (1.13)*
Strongly salt affected	468 (1.28)*

*Bracket values indicate percentage

Table.6 Keys for identification of salt affected area

Class	EC_e (dSm^{-1})	pH	ESP
Saline	>4	<8.5	<15
Saline-sodic	>4	8.5	>15
Sodic	<4	>8.5	>15
Normal	<4	<8.5	<15

Fig.1 False colour composite image of block Gohana on 1:50,000 scale

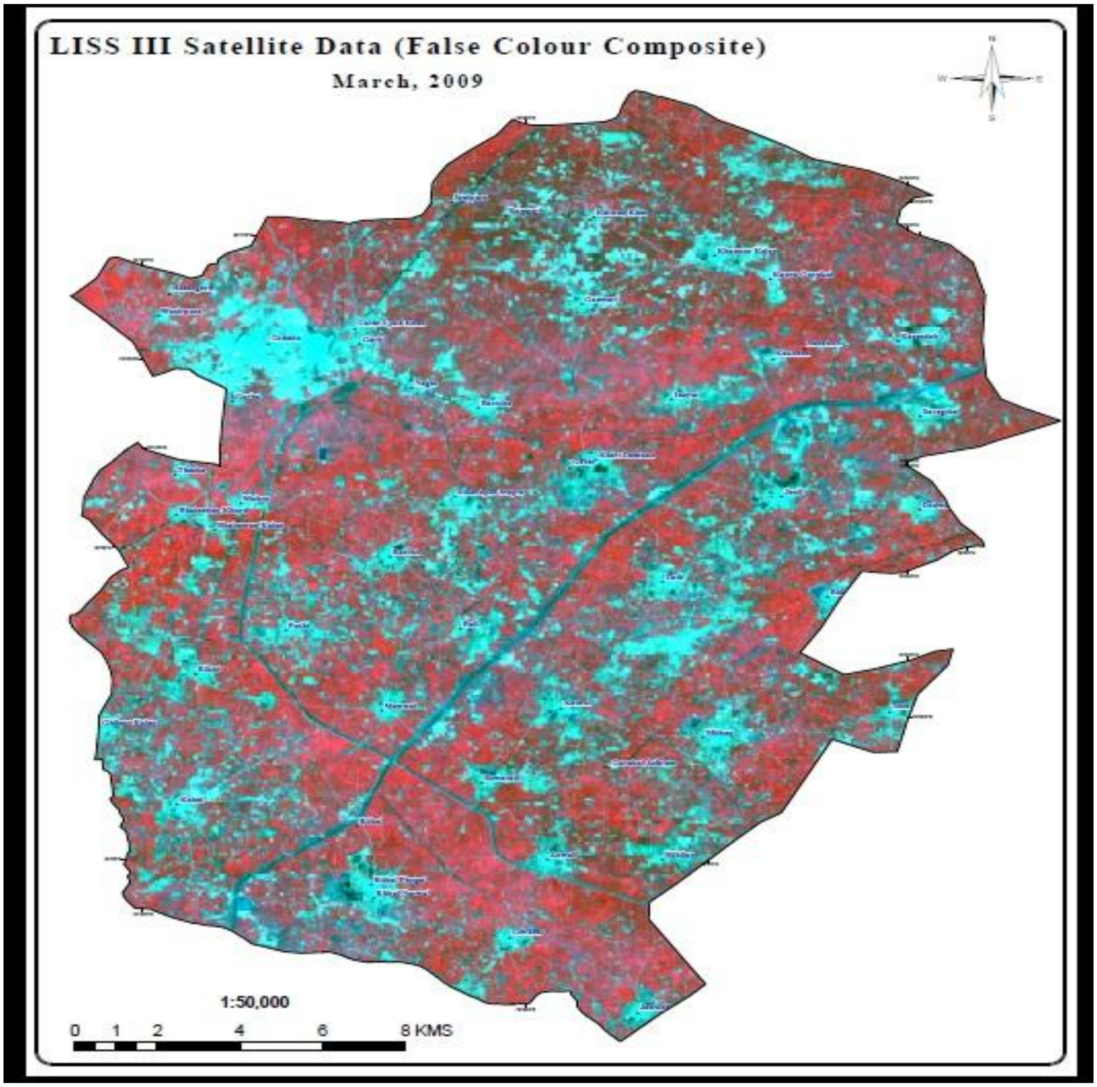


Fig.2 Spatial variability of soil pH at depth of 0-60 cm

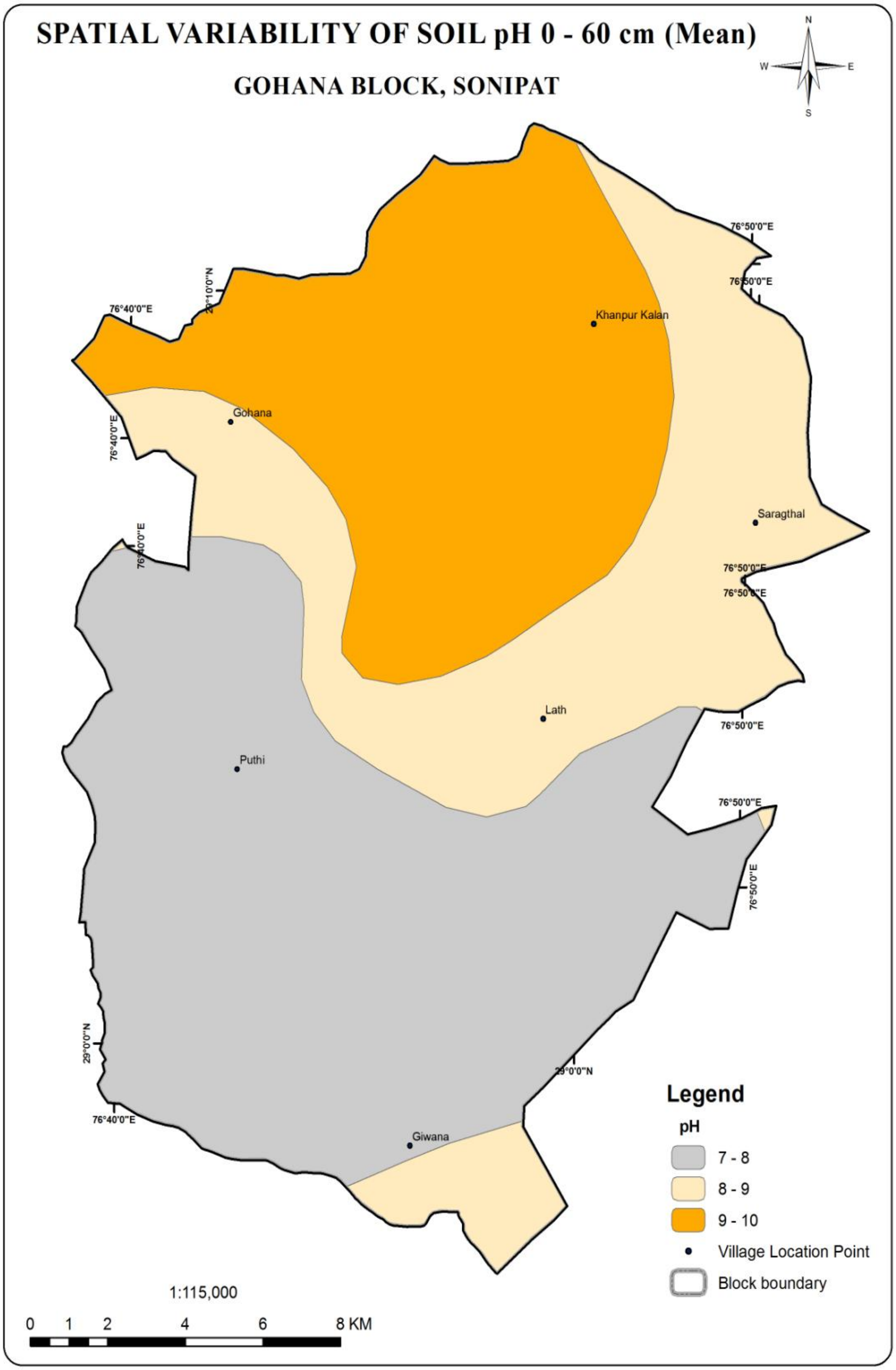


Fig.3 Spatial variability of soil EC_e at depth 0-60 cm of block Gohana

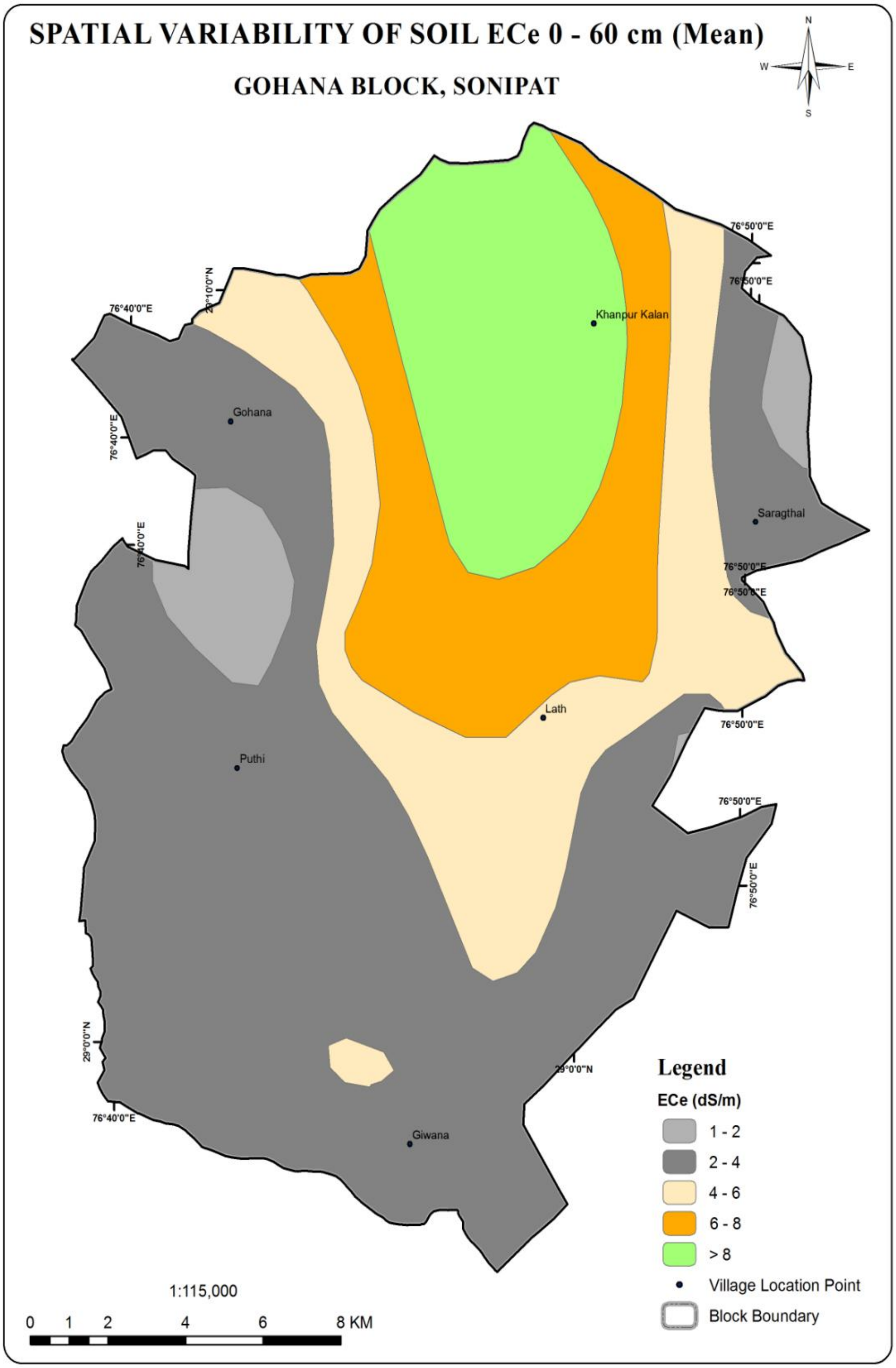


Fig.4 Spatial variability of soil ESP at depth 0-60 cm of block Gohana

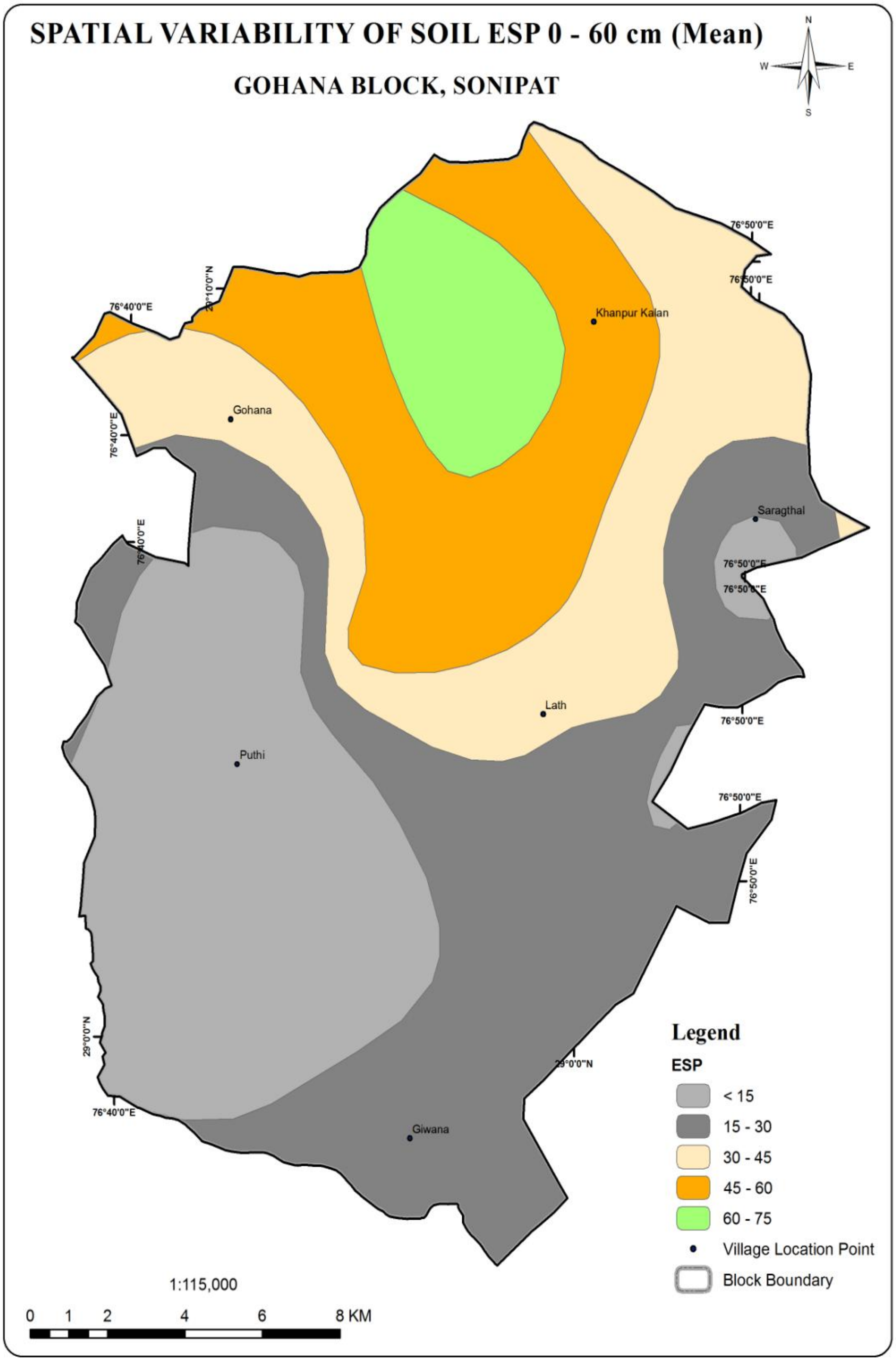
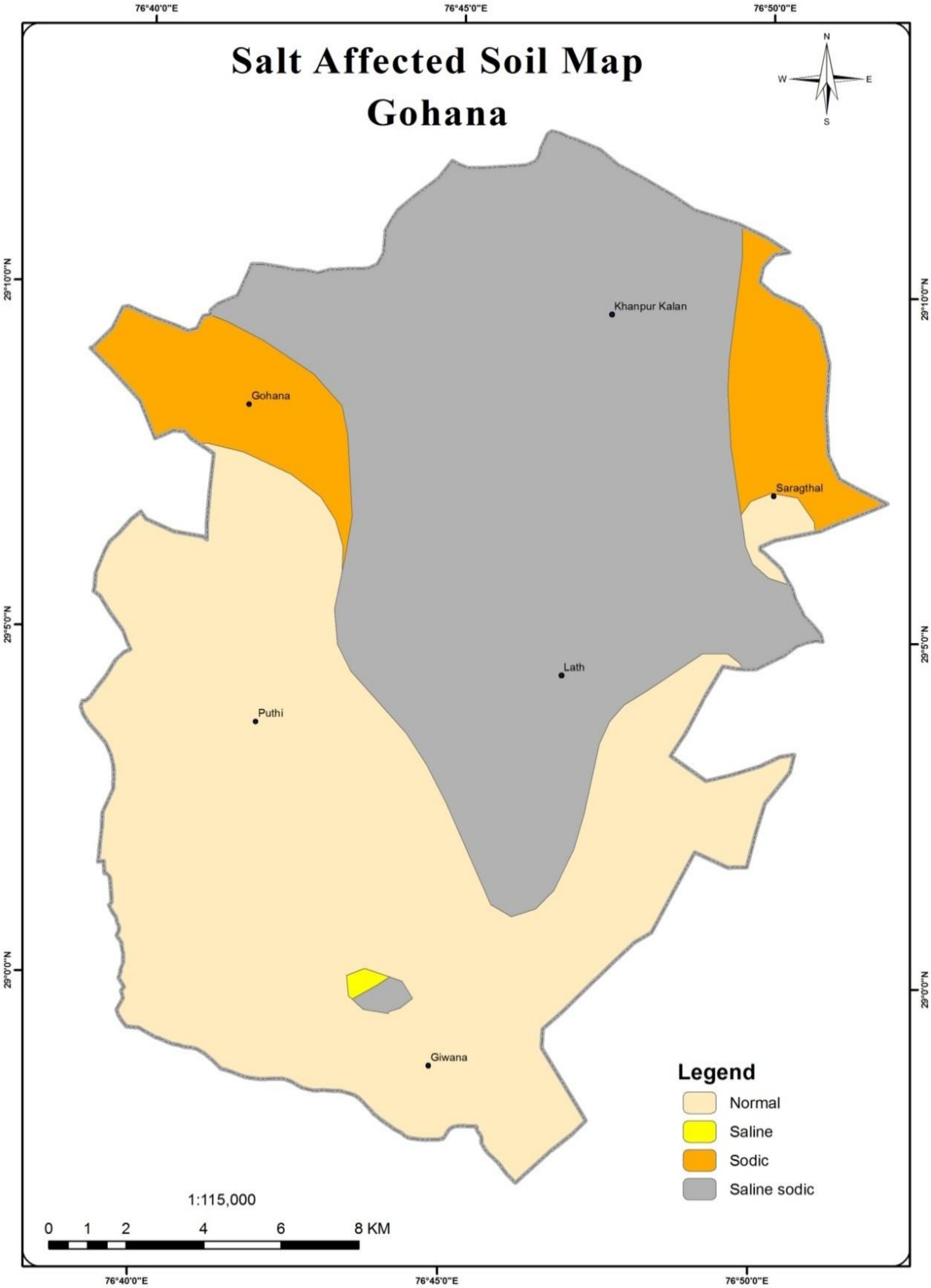


Fig.5 Soil quality map of block Gohana



Due to low organic matter in the soil, the nitrogen is likely to be low because mineralization of organic matter is known to significantly contribute to the concentrations of nitrogen. Nitrogen showed medium variation in normal soils and low to medium in salt affected soils as indicated by CV values. Tripathi *et al.*, (2015) have reported medium range of variation in available N with CV value of 37.24%. There is a significant correlation of 0.56 ($p \leq 0.05$) between OC and N suggesting that organic matter has influence on availability of N. As organic carbon and nitrogen exhibited significantly positive correlation (Table 2) the reduction in nitrogen with depth might be due to corresponding decrease in organic carbon with soil depth. Hailu *et al.*, (2015) also reported strong relationship between OM and total N ($r = 0.85$; $p < 0.01$).

Available phosphorus

The available phosphorus ranged from 5.24 to 28.77 and 6.21 to 28.05 kg ha^{-1} in normal and salt affected soils, respectively (Tables 3 and 4). Phosphorus showed a decreasing trend with depth which might be due to the confinement of crop cultivation to this layer and supplementation of the depleted phosphorus through external sources i.e. fertilizers. However, the reduction in available phosphorus at lower depths may be ascribed to decrease in organic carbon from surface to subsurface soil. A significant positive correlation was observed between phosphorus and organic carbon ($r = 0.66$; $p \leq 0.01$) suggesting that higher available P is associated with higher organic matter. Havlin *et al.*, (2005) reported that organic matter increases P by anion replacement of $H_2PO_4^-$ ion on adsorption sites and increasing the quantity of organic P mineralized to inorganic P. Phosphorus showed moderate variation in both normal and salt affected soils as indicated by CV values. Tripathi *et al.*, (2015) have reported medium range of variation in available P with CV value of 25.95%.

Available potassium (K)

The available potassium ranged from 107.92 to 323.32 and 92.15 to 304.15 kg ha^{-1} in normal and salt affected soils, respectively. Potassium at all locations was medium in range and showed a decreasing trend with depth. The reason can be attributed to predominance of K rich micaceous and feldspar minerals in parent materials. One more reason can be ascribed to potassium fertilization to the surface layer. The correlation analysis shows that K had positive and significant correlation with organic carbon ($r = 0.65$; $p \leq 0.01$) and clay ($r = 0.21$; $p \leq 0.05$) owing to presence of enough cation exchange sites and higher specific surface thereby retaining enough K on the exchange complex. Vadivelu *et al.*, (2001) also reported positive significant correlation between available K and organic carbon and clay. Under saline and sodic soils, K fertilization management may need to be altered because of potassium competition with other cations especially Na^+ in the plant and to the effects of salinity in K reactions in soil (Bar-Tal *et al.*, 1991). The coefficient of variation varied sharply with depth indicating lateral and vertical variation. Tripathi *et al.*, (2015) have reported medium range of variation in available K with CV value of 36.67%.

Saturation percentage (SP)

Saturation percentage is useful for characterizing soil texture. Saturation percentage varied from 30.20 to 42.05 and 29.94 to 44.75 percent with the greatest range occurring at lower depths in both normal and salt affected soils depending upon the texture of the soil. Saturation percentage showed an irregular trend with depth which may be ascribed to the difference in texture at different depths. Saturation percentage showed little variation as shown by the CV values (Tables 3 and 4). Corwin and Lesch (2005) also reported low variability in SP in saline-sodic soil. A positive and significant correlation was observed between saturation percentage and clay ($r = 0.83$; $p \leq 0.01$) and silt ($r = 0.45$; $p \leq 0.01$) thereby showing the dependence of saturation percentage on finer fractions. However, the sand fraction showed highly negative and significant relationship with saturation percentage ($r = -0.79$; $p \leq 0.01$). Stiven and Khan (1966) also reported positive and significant correlation between clay and saturation percentage and negative correlation between sand and saturation percentage.

Soil texture

The texture of the study area varied from loamy sand to sandy clay loam. Majority of the samples were coarse in texture. Clay content varied from 8.80 to 21.99% and 5.76 to 27.40% in normal and salt affected soils, respectively. The proportions of silt and sand varied from 9.60-21.20, 6.10-27.96 and 57.86-81.20, 54.40-86.64%, respectively in normal and salt affected soils (Tables 3 and 4). The variation in texture may be attributed to the difference in parent material and influence of pedogenesis. The coefficient of variation for sand was low as the variation in texture with depth was, by and large, small. The silt and clay proportions showed moderate variation which may be attributed to illuviation process. The mean value of silt+ clay did not show any well-defined trend with depth in normal soils, however, this parameter showed increased trend with depth in salt affected soils which may be attributed to the illuviation process. Bhatti (2002) reported low, moderate and high variability with CV values of 12.43, 34.12 and 55.79 for sand, silt and clay, respectively. Ameyan (1986) indicated that silt and clay had medium to high variation with CV values 18-88.

Image interpretation

The area of salt affected soils in block Gohana is presented in table 5. Taking advantage of good contrast of surface salt encrustation and soil bareness, the satellite image was visually interpreted. Figure 1 shows the false colour composite (FCC) generated by band combination of 2, 3 and 4 in blue, green and red filters. Based on visual interpretation, the FCC demonstrates white patches followed by light bluish tone of different dimensions indicating salt efflorescence of salt-affected soils. According to spectral signatures, salt affected soils were classified into two groups, moderately salt affected and strongly salt affected. Out of 2.41% salt affected area of the block, 1.13% was moderately and 1.28% strongly salt affected. It revealed that salt-affected areas are clearly delineated. Normal and salt-affected soils exhibit differences in ground surface conditions. Salt-affected soils are characterised by the presence of various accumulated salts in the soil profile. This distinctive feature can be identified using satellite data. It is noteworthy that spectral response of salt-affected soils is higher than those of normal soils. The area under salt affected soils is mainly confined to north and northwest region of the block. The reason may be ascribed to presence of natural depression in that region which is poorly drained topographically, as a result of which water accumulates in that region and in summer due to high evapotranspiration as mercury touches almost 45℃, the salt concentration increases which is responsible for development of salt affected soils in that region. This suggests, in agreement with Shrama (2002), that geoinformatics can be used as tool for estimating and delineation of salt affected soils. Guler *et al.,* (2014) reported that those areas had no salinity which were higher in elevation than the areas having lower elevation, and this resulted in high groundwater levels that caused more severe soil salinity in low areas.

Soil pH maps

The maps of alkalinity for 0-15, 15-30, 30-45 and 45-60 cm were overlayered and combined to construct a single map depicting the spatial distribution of soil pH over the soil depth i.e. 0-60 cm as shown in figure 2. The pH values were divided into three classes 7-8, 8-9 and 9-10. Maximum area was falling under the pH range of 7-8.

Soil ESP maps

The maps of sodicity (ESP) for 0-15, 15-30, 30-45 and 45-60 cm were overlayered and combined to construct a single map depicting the spatial distribution of ESP for the soil depth i.e. 0-60 cm as shown in figure 3. The ESP values were divided into five classes i.e. < 15, 15-30, 30- 45, 45-60 and 60-75 percent. Maximum area was falling under ESP value of 15-30.

Soil EC_e maps

The maps of electrical conductivity (EC_e) for 0-15, 15-30, 30-45 and 45-60 cm were overlayered and combined to construct a single map depicting the spatial distribution of EC_e for the soil depth i.e. 0-60 cm as shown in figure 4. The EC_e values were divided into five classes i.e. 1-2, 2-4, 4-6, 6-8 and > 8 dSm^{-1}. Maximum area was falling under EC_e value of 2-4 dSm^{-1}.

Soil quality map

The soil quality map of block Gohana was constructed to illustrate the spatial distribution of salt affected areas and is represented in figure 5. Since, the soil quality is a function of EC_e, pH and ESP; the soil quality maps were prepared by combining the EC_e, pH and ESP maps in a mathematical manipulation to assess various levels of salinity and sodicity of block Gohana. By combining and overlapping the thematic maps of study area, the soil quality map was prepared. The classification algorithm for salt affected soils was developed as per the guidelines of US Salinity Laboratory which is given in table 6. Finally the classification algorithm was run to produce the final soil quality map of saline, saline-sodic, sodic and normal areas. Figure 5 demonstrate the soil quality map of the study area. These three maps based on EC, pH and ESP were then overlapped and combined to classify the entire area of the block. All soil quality classes, i.e. saline, saline-sodic, sodic and normal were identified in the study area. Most of the study area was having saline-sodic soil.

From the results of the study, it is concluded that the physicochemical characteristics of salt affected soils of Gohana block showed complex saline and sodic nature. Within the analysis of soil samples, a large amount of variation occurred signifying that the sources and factors influencing soil properties were complex. The use of poor quality waters resulted in salt accumulation in the soil. At most of the sites, highest EC_e and SAR_e were observed in surface layer (0-15 cm) which gradually decreased with soil depth. However, in some sites maximum SAR_e was found in lower layers depending upon the texture of soil, quality of irrigation water, management practices and rainfall pattern of particular locality. The application of geoinformatics provides a promising solution in classifying and delineating soils and is cost-effective, time-effective technology which plays pivotal role in study and management of earth resources.

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