Mapping and characterization of salt affected and waterlogged soils in the Gangetic plain of central Haryana (India) for reclamation and management

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Mapping and characterization of salt affected and waterlogged soils in the Gangetic plain of central Haryana (India) for reclamation and management

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ABSTRACT

IRS LISS III Resource SAT data (2005-07) was integrated with ground truth and soil studies for delineation and characterization of salt affected and waterlogged soils in the Indo-Gangetic plain of central Haryana. The quality appraisal for salty ground water was also conducted prior to its use for irrigation. Such studies are useful for planning reclamation and management of salt affected soils and poor quality ground water. Strongly sodic soils were easily identified based on the white to yellowish white tones, high spectral and low NDVI values. Waterlogged areas (surface ponding) were detected based on higher absorption in infrared range. Sodic soils with poor quality ground water showed higher reflectance from dry salts during June and freshly precipitated moist salts in March and October. Sodic soils irrigated with normal ground water showed higher cropping density and higher NDVI values. Moderately and slightly sodic soils showed mixed spectral signatures for salt crusts, moderate cropping density and surface wetness. Soil profile studies indicated higher moisture content at sub-surface depths. The presence of iron and manganese mottles indicated the incidences of water stagnation. Soils with high pHs, ESP and SAR values and showing the dominance of carbonate and bicarbonates of sodium in the saturation extract indicated sodic nature. Significant presence of $CaCO_3$ concretions at 1 m depth, low organic carbon contents, clay illuviation at sub-surface depth are typical features in sodic soil profiles. Water samples with high pH and SAR values and at places high RSC (Residual Sodium Carbonate) content indicated their sodic nature. Gypsum application is recommended for the reclamation of sodic soils and sodic water. .

Key words Sodic soil, poor quality water, remote sensing, reclamation, management, gypsum

1.0 Introduction

1.1 Global and National Distribution

Salt-affected soils are commonly distributed in arid and semiarid climatic zones and covered 1307 M ha at global scale (FAO, 2008). The largest areas of salt-affected soils are in Australia followed by North and Central Asia, South America and South and West Asia. An estimated area of 6.73 M ha salt-affected soils are in India, of which 2.5 M ha is in the Indo-Gangetic plain (NRSA, 2008; Mandal & Sharma, 2006, Mandal et al., 2011; Saxena et al., 2004). In central Haryana, four districts Karnal, Kurukshetra, Panipat and Sonepat, were worst affected, showing 52% of the geographical area (TGA) under salt-affected soils (Mandal and Sharma, 2005). Interpretation of Landsat images showed old levees, relict flood plain and poorly drained low-lying flats are common topographic zones with salt infestation along the Gangetic alluvial plain (Manchanda & Iyer, 1983). The introduction of canal irrigation from Western Yamuna Canal (WYC) in Haryana during the 1950s accentuated upward movement of salt by rising water table (Singh et al., 2010). Due to the over use of irrigation water in poorly drained areas, waterlogging and secondary salinization appeared and caused losses in productivity for rice (42%), wheat (38%) and sugarcane (61%) crops (Samra et al., 2006). Due to the use of salty ground water (60-70% of TGA) for irrigation, secondary salt enrichment in soil profiles occurred along the Ghaggar and Markanda river plains (Manchanda, 1976; Gupta, 2010; Phogat et al., 2011).

1.2 Modern tools and techniques for diagnosis and assessment of salt affected soils

Because of the large spectral coverage and discreet bands, remote sensing data have been used for mapping and monitoring salt-affected and waterlogged soils in a time and cost effective manner (Saxena, 2003; Rao et al., 1998; Shrestha, 2006; Dwivedi, 2006, Mandal and Sharma

2013). Mougenot et al. (1993) easily identified barren salt-affected soils by high reflectance in the visible range, while studies conducted in thermal, infrared and microwaves ranges were used to characterize hygroscopic characteristics of salts and vegetation-covered soils respectively. Howari (2003) and Howari et al. (2002) used spectro-radiometry as a remote sensing tool in visible and near infrared bands to quantify spectral ranges for salt-affected soils with variable salt composition. Khan et al. (2005) used ratio indices, spectral properties and digital image classification for mapping hydro-saline land degradation in the Indus basin of Pakistan.

1.3 Traditional methods for ground estimation and characterization of degraded soils

Studies conducted by Metternicht and Zinck (1997) showed different approaches for mapping sodium and salt-affected soils, combining digital analysis with field observations and laboratory analysis. They concluded that the main causes of spectral confusions, masking different soil salinity-alkalinity degrees, were the type and abundance of salt tolerant vegetation cover, topsoil texture and other field properties. Joshi and Sahai (1993), Verma et al. (1994) and Sharma et al. (2000) used a similar approach combining remote sensing, ground truth and soil analysis data for mapping coastal salt affected soils in Saurashtra (Gujarat State) and inland salt affected soils of Uttar Pradesh State. Such methods are laborious and need concerted efforts for image analysis, collection of ground truth and laboratory analysis of soil and water to integrate for mapping, but produce results and classified outputs of salt affected soils with higher accuracies. Classification of soils for salinity/alkalinity classes such as slight, moderate and strong, is useful for deciding precise soil reclamation and management options.

1.4 Justification and Objectives

The complexity of soil salinity, alkalinity and waterlogging problems in central Haryana and the Gangetic Plain of India were reported by several authors (Mandal and Sharma, 2005; Raj Kumar et al., 2010; Gupta, 2010; Singh et al., 2010) and is a primary concern for reclamation and management. The complex surface properties of salt-affected and waterlogged soils varied in seasonal imageries causing low mapping accuracies (Sharma et al., 2008; Verma et al., 2007). Field validation is therefore necessary for spatial characterization of salinized areas followed by the chemical characterization of soil samples to assess degrees of limitations required for reclamation and management. Keeping in view the use of poor quality ground water for irrigation and its impact on soil degradation (salt enrichment) and reduced crop production (Gupta 2010), chemical characterization of ground water is also necessary before its use in irrigation. To address these issues, the present study is aimed at the delineation and characterization of degraded (salt-affected and waterlogged) soils, and appraisal of ground water quality in central Haryana useful for planning reclamation and management.

2.0 Methodology

2.1 Study area

The study area (29^{o}52'58.32''N to 30^{o}15'34.42''N latitude and 76^{o}25'31.31'' to 77^{o}21'19.19''E longitude) covered administrative boundary of Kurukshetra district of central Haryana (1530 km^2) and lies 253 m above mean sea level. The average annual rainfall is 608 mm, mean winter temperature is 12.7^0 C and mean summer temperature is 38.5^0 C. The landform is alluvial under the Gangetic alluvium. The area is drained by the Yamuna, Ghaggar and its tributaries Markanda, Saraswati, Chautang, Tangri and other seasonal streams Sahibi, Dohan and Krishnawati that originate from the Aravalli Hills. The primary source of irrigation is the WYC and Bhakra canal. In the absence of canal irrigation supply ground water from tube wells is commonly used for irrigation. Prolonged irrigation altered the moisture regime and chemical characteristics of soils leading to salt infestations, waterlogging and low productivity (Singh, 2009).

2.2 Data, software, tools, and equipment used

1. IRS 1C LISS III (Resource SAT) data (www.nrsc.gov.in) for March 2005 (pre-monsoon), June 2006 (summer) and October 2007 (post-monsoon) seasons. The specifications are shown in Table 1

2. Survey of India topographical maps at 1:50,000 scale (www.surveyofindia.gov.in) showing administrative boundaries, infrastructure (roads/railways), irrigation/drainage (canal/river) and settlements (state/district HQ, villages)

3. Software: ILWIS (ver. 3.3), MS Office- Excel (2007), ERDAS IMAGINE, ARC GIS

4. Legacy data: Salt-affected soil maps at 1:250,000 scale (NRSA 1997), water quality and soil mineralogy data (Manchanda, 1976; Gupta, 2010; Kapoor et al., 1981; Verma et al., 2012) and Soil map of Haryana (Sachdev et al., 1995)

5. Soil sampling tools: color chart, auger, spade, knife etc.

6. GPS (Lawrence global) for collecting location- data for soil profiles and soil sampling sites, water samples and tube wells

2.3 Image processing and spatial analysis

The pre-processed IRS images for atmospheric corrections (by NRSC) were geo-referenced using the Survey of India topographical maps at 1:50,000 scale. The data from different bands were integrated to prepare a digital mosaic for the study area, using ERDAS software. Different band combinations, B321 (NIR, R, G) and B432 (SWIR, NIR, R) with histogram equalized (256 intervals) stretches were used to develop False Color Composites (FCC) for visual analysis of degraded soils (NRSA, 2007). Based on the different manifestations of soil salinity such as tone, texture and patterns, the images (Fig. 1, 2) were visually interpreted to identify degraded soils (Table 2). Spectral reflectance was calculated based on the mean reflectance in bands B2, B3 and B4 (Table 1). A principal component analysis was carried out to prepare homogenous datasets and filters were used to improve sharpness of the images for visual analysis. The spectral response patterns were analyzed for spatial characterization of image elements such as crop, riverine sand, salt-affected and waterlogged soils (Fig. 3). The NDVI values were calculated using the band ratios [(B3-B2) / (B3+B2)] for differentiation of crop and non-crop areas (Fig. 1, 4). A supervised classification of digital data was carried out using a nearest neighborhood operator. An interactive-database was prepared comparing the map units prepared by digital and visual analysis to generate a confusion (error) matrix for accuracy assessment (Table 3). A flow chart showing methodology for mapping salt-affected soils were presented in Fig. 5 for clear understanding.

2.4 Ground truth studies for soil profile and water quality

A ground truth survey was conducted during March (pre-monsoon) and October (post-monsoon) 2005-07 seasons to authenticate interpreted units in the field and locate salt affected and waterlogged areas. The areas showing salinity emergence in different topographic zones and land uses such as crop and non-crop areas were studied and the data on status, condition and types of vegetation tolerant, partially tolerant and non-tolerant crops were also recorded. The salinity status at surface and sub-surface depths were obtained from soil profile studies. The field salinity/alkalinity status of soil samples was measured by portable pH and EC meters. The ground truth observations sites, soil profiles/soil and water sampling sites and topographical data on slope, aspects, contours and related ground control points were collected during the ground truth study and were marked on the topographical maps. Water table depths data were also collected in waterlogged areas under canal irrigation to 1.5 m depth below the surface. Ground water samples were collected from tube wells for detailed chemical analysis. Ground water table depths were also recorded to relate with geology data.

Representative soil profiles (1.5 m depth) were studied to assess status and distribution of soil salinity and alkalinity at 24 sites covering the study area. Soil morphological properties such as soil moisture content, texture, color, structure and drainage were recorded from soil profile studies. Soil samples were collected at representative depths up to 1.2 m and properly stored in polythene and cloth bags to minimize moisture loss and changes in salt composition. These were further air dried, processed to pass through <2mm sieve and stored for physical and chemical properties (Table 4).

2.5. Studies for physical and chemical properties of soil and water samples

In the laboratory, soil samples were analyzed for physical and chemical properties such as soil reaction (pHs) and electrical conductance (ECe, dS m^{-1}); salt composition for soluble Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^- and Cl^-, me L^{-1}; $CaCO_3$ (<2mm size, %) and organic carbon (%); cation exchange capacity (CEC, c mol (p^+) kg^{-1}) and Exchangeable Sodium percentage (ESP, %) and soil separates for sand, silt and clay percentages (Jackson, 1986). Based on soil pHs, electrical conductivity (ECe) and ESP values, soils are classified as saline, sodic and saline-sodic with degrees of soil salinity and sodicity classed as slight, moderate and strong (Richards, 1954). Waterlogged areas were classified as permanent waterlogged for surface ponding and sub-surface waterlogging as a result of high water table depth (<1.5 m) close to the surface (NRSA, 2007).

Fifteen ground water samples were collected from different locations to study water quality for agricultural applications (Table 5). These were analyzed for pH_{iw} and EC_{iw} (dSm^{-1}), soluble cations and anions (Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^- and Cl^-) using the methodology described by Richards (1954). The Sodium Adsorption Ratio (SAR) $[Na^+/ \{(Ca^{2+}+Mg^{2+})/2\}^{1/2}]$ and Residual Sodium Carbonate (RSC) $[(CO_3^{2-}+HCO_3^-)-(Ca^{2+}+Mg^{2+})]$ values were also calculated for classification of saline and sodic water (Richards, 1954).

2.6 Preparation of the thematic layers for base map and degraded soils

The Survey of India topographical maps at 1:50,000 scales, UTM (Universal Transverse Mercator) projections and ILWIS GIS software were used for geo-referencing and digitizing thematic layers for administrative and political boundaries (state/district), infrastructure (roads/railways), irrigation/drainage (canal/river) and settlements (state/district capitals). These layers were overlaid to prepare a base map for the study area. GPS was used to collect geo-referenced data for soil profile locations, soil and water sampling sites, tube wells and were stored in an attribute table that was linked with the base map. The spatial coverage of interpreted units was delineated using on-screen digitizing and were overlaid on the base map. Distinguishing colors were used for representative map units. These were annotated for scale, north direction, legends, title, boundary coordinates and other cartographic elements (Fig. 1, 2, 6).

2.7 Mapping of degraded soils

An integrated approach of image interpretation, ground truth survey and laboratory analysis data for soil physical and chemical properties was used for mapping degraded soils in the Indo-Gangetic plain of Central Haryana (Fig. 5). Legends were developed for mapping degraded soils based on the methodology developed by NRSA (2007). Categories of salt-affected and waterlogged soils were identified based on the soil physical and chemical properties. The area statistics of map (soil) polygons were used to assess spatial extent of salt-affected and waterlogged soils (Mandal and Sharma, 2011; 2012; 2013; Dwivedi, 2006).

3.0 Results and Discussion

3.1 Results

3.1.1 Image interpretation and ground truth studies of degraded soils

The spatial characteristics of salt affected and waterlogged soil; natural vegetation and field crops were presented with soil chemical properties and ground water data (Table 2). The strongly sodic soils (white to yellowish white tone in B321, irregular shape), normal crops (bright red tone, continuous), waterlogged (surface ponding, dark blue to black tone, irregular shape) soils and riverine sands (yellowish white with definite shape along the river bed) were easily detected based on their strong signatures from the visible and infrared bands in IRS data (Fig. 1, 2) The seasonal data showed higher extents of moist salt affected soils and waterlogged areas (irrigated) during March and October (Fig. 1) and dry salts (salt crust) during June. This may possibly be due to similar reflectance of salt and sand and the absence of vegetative cover during the dry season. The normal cropped areas were identified by the distinct (bright) red tones at different growth stages, while stressed vegetation was identified by lighter red tones, patchy occurrence and patchy white tones for salt crust in the saline and moist surface in waterlogged areas (Mandal and Sharma, 2010). Riverine sands were identified by the yellowish white tone and spotted natural vegetation along the river course (Fig. 1).

Field studies indicated prominent salt crusts, scanty vegetation, scattered salt tolerant natural vegetation, scrub and pastures in strongly sodic soils and in places, intercepted with forestry plantations for biological reclamation. Moderate and slightly sodic soils appeared as mixed red and grey tones in irrigated areas, the ground truth studies showing patchy salts, scattered crop cover, moist soil surface, low permeability and absence of natural drainage. In dry areas, strongly sodic soils appeared as white patches of barren salt crust underlain by sodic ground water. Moderately sodic soils appeared as tiny white patches and red to dark red tones for crops irrigated with good quality ground water (Mandal and Sharma, 2011). Partially reclaimed sodic soils showed moderate crop cover and intermittent salt patches in low lying flats and depressions (Mandal, 2012). Slightly sodic soils showed good to very good crop and vegetative covers (Howari, 2003), though the field study reported low productivity due to crop damages in the maturity stage.

In irrigated areas, permanent waterlogged soils (surface ponding) were in the low-lying flats/depressions and appeared as grey to dark grey tones in all seasons (Fig. 2). Mixed red and reddish gray tones were identified in the irrigated areas supporting vegetation, field studies indicated high water table depth (sub-surface waterlogging, WT <1.5m depth), crop cover and secondary soil salinization during the post-monsoon season (Mandal and Sharma, 2010; Mandal and Sharma, 2001). However, using moderate spatial and spectral resolution of IRS data, the segregation of mixed signatures of water and crop in sub-surface waterlogged areas was difficult (Singh et al., 2010). It was authenticated on the strength of ground truth.

3.1.2 Digital analysis of remote sensing data for spectral properties of degraded soils

Spectral analysis of IRS data identified prominent energy absorption for waterlogged areas (surface ponding, SP_S) during October (B3>B4>B2) and March (B3>B4>B2) (Mandal and Sharma, 2001). The NDVI values were low (0.1 to 0.3) as a result of low crop cover

(Mandal and Sharma, 2011). In irrigated areas, spectral values ranging from 60 to 148 in B3 and 58 to 66 in B4 indicated high water table depth or sub-surface waterlogging SSW (Mandal and Sharma, 2011). The NDVI values (0.24 to 0.34) indicated the presence of stressed vegetation (Dwivedi and Sreenivas, 2002, Joshi et al., 2002).

Strongly sodic soils (SS_SGW) with poor quality ground water showed higher reflectance (80 to 110) of dry salts during June (B2>B3>B4) and the reflectance (40 to 90) of freshly precipitated moist salt surfaces during March (B3>B4>B2) and October (B4>B2>B3). NDVI values (0.28 to 0.37) indicated scattered and poor vegetative cover due to high soil sodicity (Fig.3, 4). Strongly sodic soils with normal ground water showed high reflectance of B3 from salty (carbonate type) surface during October (B3>B4>B2), March (B3>B4>B2) and June (B3>B2>B4) respectively. These areas showed low NDVI values (0.18 to 0.29) due to poor to very poor crop cover (Fig. 3, 4). Moderately sodic soils irrigated with normal (MS_NGW) and poor quality ground water (MS_SGW) showed similar trends of spectral reflectance (B3>B4>B2) during October and March (Mandal and Sharma, 2001). NDVI values (Fig. 4) were low (0.18 to 0.52) for cropped areas irrigated with poor quality ground water and higher (0.48 to 0.52) in normal ground water zone. Slightly sodic soils also showed higher reflectance of B3 followed by B4 and B2 (Fig. 3). Similar data were also reported by Coleman et al. (1991).

Matured winter crops showed higher reflectance of B3 during March (B3>B4>B2) while crops moist soil surface showed higher values of B4 during October. NDVI values showed similar trends during March and October respectively. The spectral reflectance of riverine sand was high (60 to 100) due to bare surface (Fig. 3) and low NDVI values (-0.04 to 0.04) indicated scanty vegetative cover (Fig.4).

Principal component analysis was performed to homogenize digital data and achieve higher accuracy in classification. The principal component coefficients (PC) showed significant relationship between B1 and PC1 (0.524); B2 and PC4 (0.831); B3 and PC1 (0.707) and PC2 (0.683); B4 and PC3 (0.670). PC1 showed 93.5% variance while PC2, 3 and 4 showed 5.91, 0.30 and 0.09% variance, respectively. An average (AVG 3x3) filter was used to enhance sharpness of the images for visual analysis and to reduce noises prior to multi-band image classification. The nearest neighboring nine pixels were calculated to assign the values for central pixel to reduce noises and enhanced interpretation of the images.

Digital classification was performed using a supervised classification based on maximum likelihood classifier. Ground truth, laboratory analysis and land use data (field crop, forestry, urban settlement, road, natural water for pond, river and canal) were included as training sets for digital classification. Legacy data such as digitized maps of salt affected soils, water table depth and quality and other collateral data including topographical maps of the Survey of India were also used as supporting data (Saxena, 2003; Verma et al., 2004). The salt affected soils map at 1:250,000 scale was also consulted as supporting data. Clusters of pixels showing average reflectance for B1 to B4 in March data were assigned a class name and the sample statistics (feature space) of the training set was generated to provide a visual overview of the separation of classes for the training pixels using a scatter plot for two bands. The feature spaces for B1 and B2, B1 and B4 and B2 and B4 indicated positive relation while B1 and B3, B2 and B3, and B3 and B4 showed partial or null relationships. An interactive (cross) database was prepared using maps prepared from visual analysis and digital classification. A confusion (error) matrix was prepared to assess the accuracy of digital classification (Table 3). The data showed an overall accuracy of 25.4%, average accuracy of 18.0% and reliability 10.5% respectively. The highest accuracy was shown for slightly sodic soil (34%, reliability 65%) followed by sub-surface waterlogging (27%, reliability 3%), riverine sand (27%, reliability 21%) and moderately sodic soil (11%, reliability 35%), respectively.

3.1.3 Physical and chemical characteristics of salt affected soils and waters

The field morphological characteristics of four representative soil profiles ranges from deep to very deep, pale brown to dark yellowish brown, sandy loam to sandy clay loam /clay loam texture, medium to strong, coarse to fine angular/sub-angular blocky structure, sticky, plastic to very sticky, very plastic consistence, presence of few to abundant $CaCO_3$ nodules and moist to wet sub-surface horizons. A few iron and manganese mottles were also found in subsurface (50 cm) layers of P3 (Markanda plain) and P4 (Ghaggar plain), due to prolonged saturation with water. $CaCO_3$ concretions (2-5 cm, 10-30%) were found at 1 m depth in P2 and P4. The textural changes occurred from sandy loam to sandy clay loam and sandy clay loam to clay loam at P1, P2 and P4 apparently due to clay illuviation. The silt and clay contents were higher than sand content in P3 and P4 possibly due to lower topographic position.

Soil physical and chemical properties of four representative soil profiles are presented in Table 4. The pHs value ranges from 9.1 to 10.7 indicating alkaline reaction. The depth distribution of ECe values of P1 (4.5 to 7.4 dS m^{-1}) and P3 (2.4 to 6.6 dS m^{-1}) indicated moderate soil salinity while P2 (1.2 to 8.5 dS m^{-1}) showed higher salinity at sub-surface depth and soil salinity in P4 (1.2 to 1.8 dS m^{-1}) is low in general. The carbonate plus bicarbonate content is high in P1 (17.0 to 28.5 me L^{-1}) and P2 (15.7 to 35.5 me L^{-1}) and low in P3 (5.0 to 15.5 me L^{-1}) and P4 (5.0 to 10.0 me L^{-1}). A significant content of $CaCO_3$ (calcretes) was noted at 99 cm and 105 cm depths in P2 (1.3 to 4.9%) and P4 (4.4 to 14.5%) which caused restricted drainage and caused low permeability. CEC values were low in P1 (8.8 to 13.1 c mol (p+) kg^{-1}) and P3 (13.2 to 18.4 c mol (p+) kg^{-1}) due to coarse texture. The higher ESP values in P1 (49.6 to 76.9), P3 (50.0 to 94.6), P2 (46.8 to 56.5) and P4 (53.1 to 69.0) favored higher alkalinity.

Chemical properties such as pH (8.7 to 9.5), RSC (9.0 to 12.7 me L^{-1}), and SAR (12.4 to 23.4) water samples are presented in Table 5. Among the anions CO_3^{2-} (1.5 to 3.0 me L^{-1}), and HCO_3^-(2.5 to 13.2 me L^{-1}) and cations Na^+ (9.9 to 16.6 me L^{-1}) and Ca^{2+}+Mg^{2+} (1.0 to 2.5 me L^{-1}) and Cl^- (1.7 to 10.0 me L^{-1}) were dominant. RSC values range from 2.0 to 12.7 me L^{-1} and are critical in T1 (12.7 me L^{-1}), T3 (12.0 me L^{-1}), T2 (9.0 me L^{-1}) and T4 (6.0 me L^{-1}) respectively (Richards, 1954). SAR values are higher (>10) in general.

3.1.4 Distribution of salt affected and waterlogged soils

The spatial distribution of salt affected and waterlogged soils is shown in Fig. 6 and the extents were presented in Table 6. Slightly sodic soils have the largest area (10409 ha) covering 61% of the total degraded soil in Kurukshetra district. It is followed by moderately sodic soils 5697 ha covering 33.6% area and strongly sodic soils that occur in 0.2% of the area. Surface ponding occupies 363 ha (2.1%) while sub-surface waterlogging (203 ha) covers 1.2% area. Riverine sand covers 210 ha (2.1%) along the flood plain of the Markanda River.

3.2 Discussion

3.2.1 Remote sensing studies

The digital analysis of remote sensing data revealed mixed surface properties for salts, soil particles during dry (June) season and complex spectral signatures of moist soil surface and moderate crop cover in salt affected soils (Khan et al., 2005). The similarity of spectral signatures for village settlements (muddy roof top) and barren salt affected soils caused spectral confusion during digital analysis. Visual analysis revealed definite shape and sizes of rural settlements that differs from irregular pattern in salt affected soils (Khan et al., 2005). Mixed grey to reddish grey and mottled red tones indicated waterlogging in cropped areas (Mandal and Sharma, 2013), which was authenticated during field studies. The linear shape of canals and typical curvilinear meandering rivers differs from stagnant water bodies (waterlogged surface) though these elements showed similar spectral reflectance. Irrigated areas with poor quality ground water showed mixed spectral signatures for poor crop stand (light to red tone) and moist soil surface (light to grey tones). Ground truth studies showed salt enrichment, unfavorable physical properties and poor drainages in soil profiles (Sharma and Mandal, 2006; Mandal et al., 2013). The low reflectance values of irrigated sodic soils in March data (40 to 60) appeared to be due to surface moisture. Similar results were reported for carbonate rich salts in visible (0.55 - 0.77 um) and infrared (0.9-1.3 um) ranges (Csillag et al. 1993, Rao et al., 1995; Khan et al., 2005). The higher NDVI values of moderately sodic soils (0.29 to 0.52) may be ascribed to higher vegetative cover and also management interventions at selected locations (Mandal and Sharma, 2011, Raghuwansi et al., 2010). The mixed reddish grey to dark grey tone for sub-surface waterlogged areas indicated scattered crop cover, and higher moisture content at soil surface.

3.2.2 Soil studies

Slight to strong soil alkalinity/sodicity indicated variable and complex chemical properties of sodic soils in the Kurukshetra district. The higher soil pHs (P3) at 40 cm depth indicated unfavorable soil physical properties and development of waterlogging. The high soil pHs of P1 (9.6 to 10.2) and P2 (9.8 to 10.7) at surface depth also limited its use for arable cropping. The dominance of CO_3^{2-}+ HCO_3^- anions and high Na^+ content in P1, P3, P2 and P4 indicated the sodium carbonate and bicarbonate parent materials that favored sodicity development in soils (Bhargava et al., 1980; Sharma et al., 2011). The low contents of Ca^{2+}+Mg^{2+} is due to precipitation of calcium carbonates in an alkaline medium (Bhargava and Bhattacharjee, 1982). The texture analysis of P4, P3, P1 and P2 indicated higher clay contents in sub-surface layers that caused restricted drainage and favored waterlogging. Higher CEC values in P2 and P4 is attributed due to higher clay content. The high ESP values showed significant saturation with exchangeable Na^+ that favored alkali soil formation. The high $CaCO_3$ contents caused drainage congestion. The soil physical and chemical properties indicated variable alkalinity dominated by alkaline earth metals and poor drainage caused low permeability (Raghuwanshi et al., 2010).

The high pH, RSC and SAR values of water samples indicated their sodic nature dominated by the presence of CO_3^{2-}, $HCO_3^-$and Na^+ while the presence of Ca^{2+}+Mg^{2+} and Cl^- is also noted. Higher SAR values indicated dominance of Na^+ ion, causing soils unsuitable for agriculture (Richards, 1954). The critical limits of RSC in T1, T3, T2 and T4 indicated the need for treatment with amendments for irrigation in field crops. Treatment with gypsum is required for water samples with high RSC (T1 to T4). Samples with moderate alkalinity (T5 and T6) may be used for the growing salt resistant varieties.

3.3 Reclamation and use potential of salt affected and waterlogged soils

Sodic soils of the Gangetic plain in Central Haryana are rich in sodium carbonate and bicarbonate salts and showed high ESP and variable soil texture. Strongly sodic soils (P1 and P2) containing high Na_2CO_3 and $NaHCO_3$ salts, coarse soil texture and sodic ground water needs gypsum application @ 8-10 t ha^{-1} to reduce alkalinity in soil and water followed by leaching of excess soluble salts. Moderately sodic soil (P3) containing soluble Na_2CO_3 and $NaHCO_3$ salts and fine soil texture can be reclaimed by addition of 4-6 t ha^{-1}gypsum. Due to high clay content and presence of $CaCO_3$ concretions, P4 (slightly sodic soil) showed drainage restrictions and waterlogging. It may be used for growing salt tolerant rice and wheat crops. The addition of FYM in soils and cultivation of Dhaincha (*Sesbania sp.*) is suggested to improve physical properties, drainage conditions and reduce waterlogging.

4.0 Conclusions

Visual and digital analysis of IRS LISS III multi-temporal data was used for identification and delineation of sodic soils and waterlogged areas in the Gangetic plain of Central Haryana. Field validation and laboratory analysis for physical and chemical properties facilitated development of map legends. High values for spectral reflectance were observed from salty surfaces, and higher energy absorption in visible and infrared bands suggested the identification of strongly sodic soils and surface waterlogging. The mixed spectral signatures for salt, scattered crop covers and waterlogging were authenticated by field investigation. Saturation of Na_2CO_3 and $NaHCO_3$ salts in soil and ground water caused alkalization and low soil productivity. Fine soil texture and the presence of concretionary calcium carbonate layer at sub-surface depths tended to produce waterlogging. Sodic soils and sodic water can be reclaimed with suitable amendments such as gypsum or pyrite.

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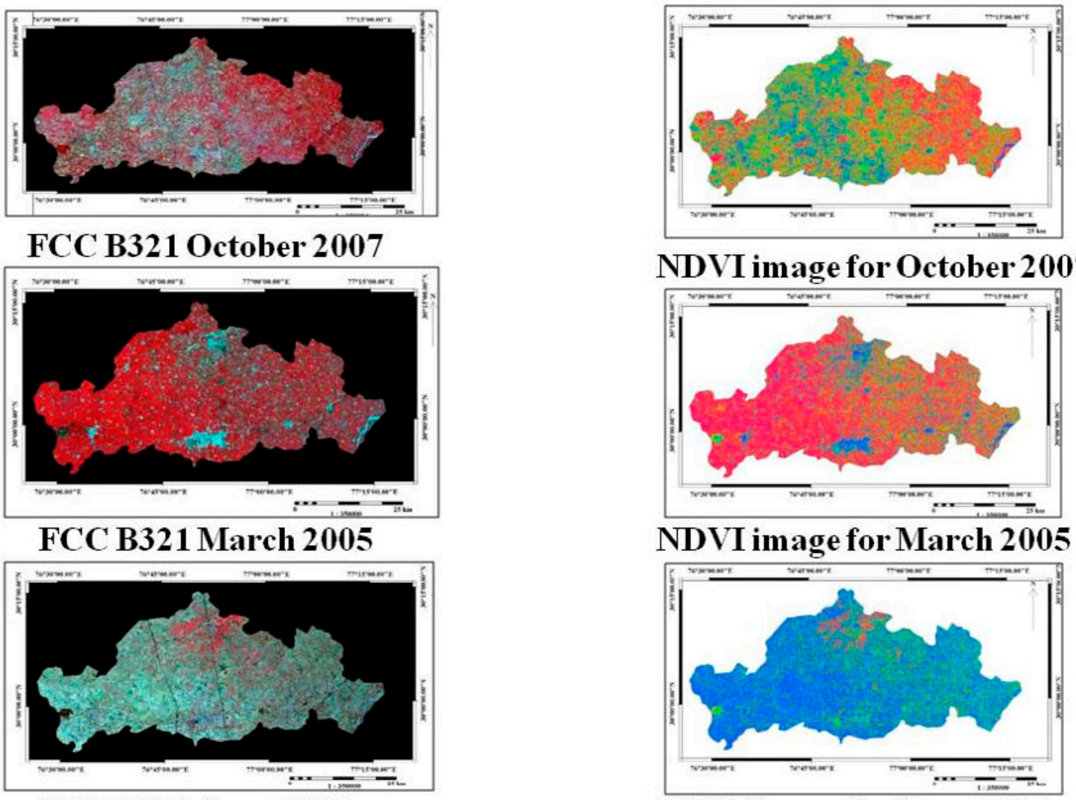
List of Figures:



FCC B321 October 2007

NDVI image for October 2007

FCC B321 March 2005

NDVI image for March 2005

FCC B321 June 2006

NDVI image for June 2006

Figure 1 IRS FCC and NDVI images for the study area

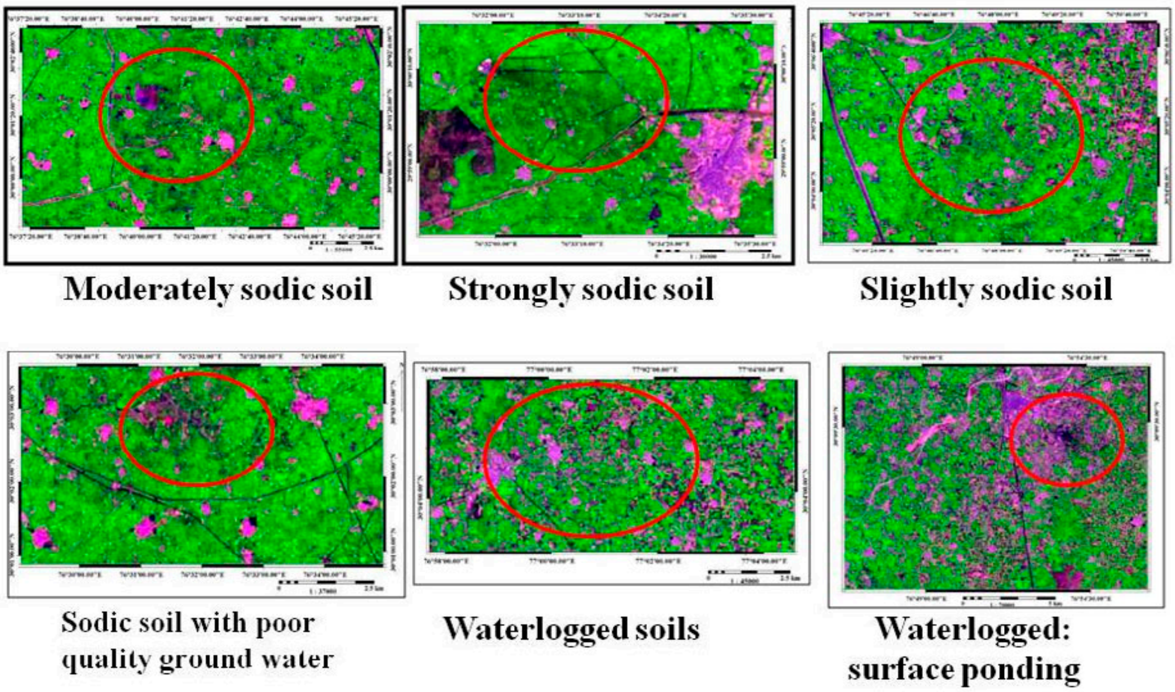
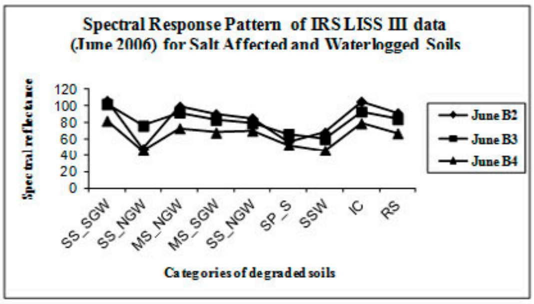
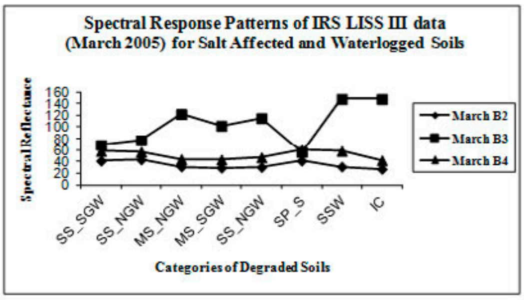
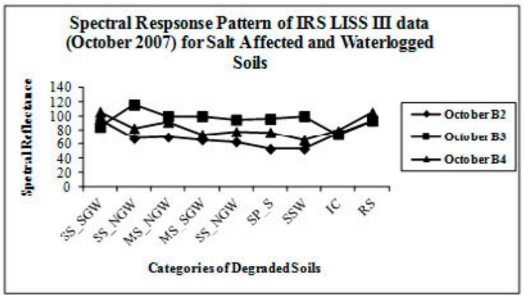


Figure 2 FCC (B432) showing salt affected soils and waterlogged areas

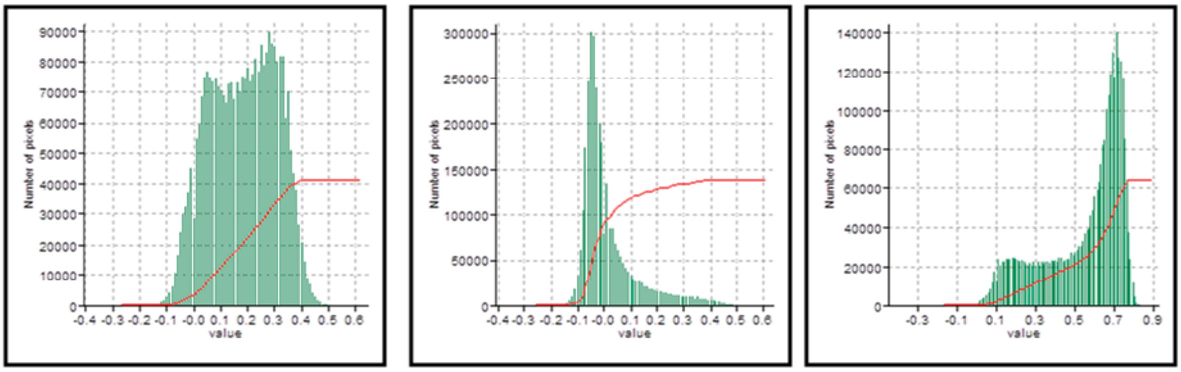






References

SS_SGW= Strongly sodic soil & sodic GW
SS_NGW = Strongly sodic soil & normal GW
MS_NGW= Moderately sodic soil & normal GW
MS_SGW= Moderately sodic soil & sodic GW
SS_NGW= Slightly sodic soil & normal GW
SP_S= Surface Ponding –slight
SSW= Sub-surface waterlogging
IC=Irrigated crops RS= Riverine sand
GW= Ground water



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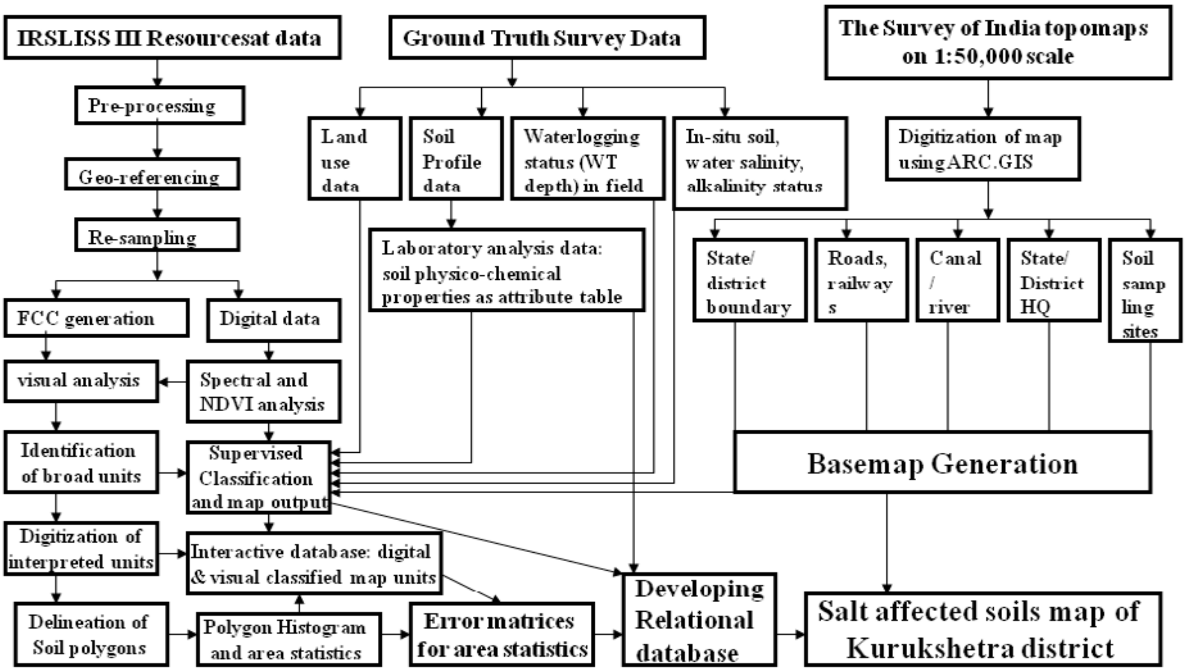
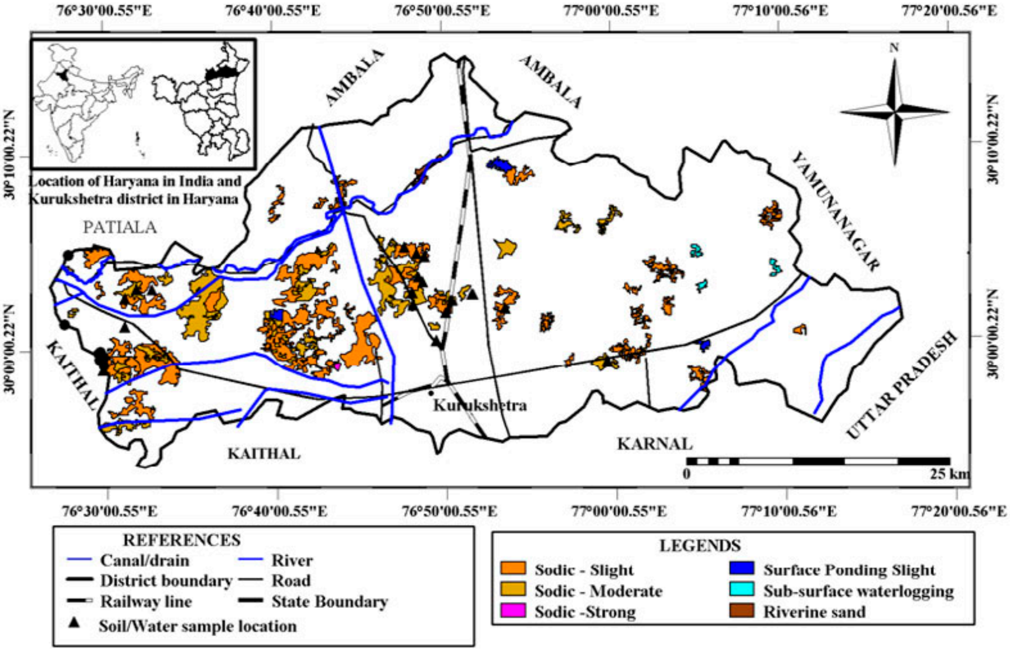

IRSLISS III Resourcesat data
Pre-processing
Geo-referencing
Re-sampling
FCC generation
Digital data
visual analysis
Spectral and NDVI analysis
Identification of broad units
Supervised Classification and map output
Digitization of interpreted units
Interactive database: digital & visual classified map units
Delineation of Soil polygons
Polygon Histogram and area statistics
Error matrices for area statistics
Ground Truth Survey Data
Land use data
Soil Profile data
Waterlogging status (WT depth) in field
In-situ soil, water salinity, alkalinity status
Laboratory analysis data: soil physico-chemical properties as attribute table
Developing Relational database
The Survey of India topomaps on 1:50,000 scale
Digitization of map using ARC.GIS
State/ district boundary
Roads, railway s
Canal / river
State/ District HQ
Soil samp ling sites
Basemap Generation
Salt affected soils map of Kurukshetra district



76°30'00.55"E
76°40'00.55"E
76°50'00.55"E
77°00'00.55"E
77°10'00.56"E
77°20'00.56"E
30°10'00.22"N
30°00'00.22"N
Location of Haryana in India and Kurukshetra district in Haryana
PATIALA
AMBALA
AMBALA
YAMUNANAGAR
UTTAR PRADESH
KAITHAL
KAITHAL
Kurukshetra
KARNAL
N
0
25 km
REFERENCES
Canal/drain
River
District boundary
Road
Railway line
State Boundary
Soil/Water sample location
LEGENDS
Sodic - Slight
Sodic - Moderate
Sodic -Strong
Surface Ponding Slight
Sub-surface waterlogging
Riverine sand

Table 1 Particulars of satellite imageries in Kurukshetra district, Central Haryana, India

Sensor	Spectral Resolution	Spatial Resolution	Image No. and scale	Period
IRS- IB LISS III	B1 0.52-0.59 nm (Green)	23.5 m	53 C/ 01, 05, 09, 13	FCC:
	B2 0.62-0.68 nm (Red)	Swath 140 km	53 B/ 04, 08, 12, 16,	March 2005
	B3 0.77-0.86 nm (NIR)	No. of Pixel/ha 18.11	43 F/4, 53 G/1	June 2006
	B4 1.55-1.70 nm (SWIR)		Scale 1: 50,000 scale	October 2007

Table 2 Spatial characteristic of interpreted units in Kurukshetra district

	Interpreted units	Land use / Land cover/ surface soil moisture/wetness and other visible/in-situ local observations	Image tone	Ranges of soil properties		
				pHs	ECe dS m^{-1}	Depth (m) of WT
1.	Strongly sodic soil and sodic GW	Barren salt crust and associated with salt grasses/bushes/pasture/ scrub lands, forest covered and higher moisture content at surface	Dark grayish white, spotted red to dark red scattered surface	9.6-10.2	4.5-7.4	100-120
2.	Strongly sodic soil and normal (good quality) GW	Barren, surface salt crust, sparse vegetation, forest cover*, higher moisture accumulation at surface during October and March season	Grayish white, red to dark red cover, defined boundary*	9.8-10.7	1.2-8.5	100-120
3	Moderately sodic soil and normal GW	Tiny salt patches with patchy crop stand showing poor germination, cropped areas around the patches showed moderate crop growth	Red to grayish red with white or yellow mottles	9.3-10.2	2.4-6.6	60-100
4.	Moderately sodic soil and sodic GW	Scattered cropped areas with very poor vegetative growth, prolonged water stagnation after irrigation with poor quality ground water	Irregular grayish to dark grayish mixed with red to light red color	9.1-9.6	1.2- 1.8	100-120
5.	Slightly sodic soil and crop covered	Vegetative growth of crops are comparable to normal soils, yield is relatively low	Red to dark red gray patches at some locations	8.5-9.0	<4.0	100-120
6.	Surface ponding-slight	Stagnant water, scattered growth of aquatic grasses, canal irrigated, excess irrigation water from the cropped areas accumulated at low-	Dark gray/ black patches, higher water absorption in post-monsoon	8.4-8.9	8-12	Surface water

		lying flats /depressions	(October) data			
7.	Sub-surface waterlogging	Partially cropped, low vegetative growth, high moisture content in soil profile, high water table depth	Dark blue/ blue-black tone	7.8-8.2	6-10	<1.5
8	Irrigated crop	Normal vegetation	Red to dark red	7.5-8.0	<4	100-120
9	Riverine sand	Barren sandy soil at surface along the river course and often found with natural vegetation viz, grasses, shrubs, bushes	yellowish white/ white with red mottles	7.0-7.5	2-5	40-80

WT= water table GW = Ground water

Table 3 Confusion matrix and accuracy estimates of classified image

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Accuracy
A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	927	559	0	1117	103	41	715	7	633	277	577	873	0	45	691	0.09
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	137	79	0	1019	64	277	248	0	548	106	307	838	0	46	42	0.27
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	3975	2500	0	18889	56153	2575	4365	76	63603	3146	18286	8294	0	1948	4394	0.34
J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	1824	1275	0	9748	28589	1096	1866	26	33147	1648	11411	7976	0	1762	2711	0.11
L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	3	9	0	4	0	15	0	13	73	0	430	5	0	56	49	0
N	224	94	0	134	20	109	10	13	318	4	1162	288	0	1033	402	0.27
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reliability	0	0.12	0	0.03	0	0	0	0	0.65	0	0.35	0	0	0.21	0	

A=Canal, B= Surface ponding -slight, C= Surface ponding- moderate, D= Sub-surface waterlogging, E= Normal field crop, F= Reserve forest, G= Road, H= River, I= Sodic – slight, J= Sodic- slight under forest, K= Sodic–moderate, L= Sodic– moderate under forest, M= Sodic –strong, N= Riverine sand, O= Urban settlements

Table 4 Physico-chemical characteristics of soils in Kurukshetra district

Horizon	Depth (cm)	pHs	ECe (dS m^{-1})	Na^+	K^+	Ca^{2+}+Mg^{2+}	CO_3^{--}+ HCO_3^-	Cl^-	SAR	OC	$CaCO_3$	ESP	CEC (cmol kg^{-1})	Sand	Silt	Clay	Texture
				---------------(me L^{-1})-----------------------						------------(%)-----------				------------(%)--------			
P1	29°59′54.3″N 76°25′41.3″E Strongly sodic soils (Sodic Haplustept) and sodic GW, Ghaggar plain, Kikar, *Prosopis juliflora* plantation																
A1	0-14	9.6	7.4	98.7	0.9	4.0	17.0	31.0	49.3	0.08	2.45	49.6	13.1	71.2	14.9	13.7	sl
AB	14-40	10.0	5.5	80.0	0.2	4.0	21.0	18.0	40.0	0.06	2.45	51.8	8.8	61.9	21.6	16.3	sl
B21t	40-82	10.1	4.6	70.4	0.1	3.0	28.5	15.0	40.6	0.03	0.98	76.9	11.1	58.8	20.0	21.0	scl
B22t	82-109	10.2	5.3	83.9	0.1	3.0	27.5	12.0	48.4	0.02	1.47	54.1	13.9	58.6	18.6	22.6	scl
C	109-139	9.8	4.5	75.8	0.1	3.0	18.5	11.5	43.8	0.02	2.85	43.2	9.5	63.2	20.1	16.7	sl
P2	29°59′02.7″N 76°59′37.6″E Strongly sodic (Sodic Haplustept), good quality (normal) GW, Yamuna plain, forestry plantations																
A1	0-12	9.8	1.2	11.5	0.1	1.0	15.7	3.5	11.5	0.17	1.3	46.8	21.6	59.0	23.0	18.0	sl
B21t	12-28	10.7	5.3	54.0	0.1	1.5	30.2	12.5	44.1	0.11	1.0	56.5	26.3	53.0	22.0	25.0	scl
B22t	28-58	10.6	6.2	60.6	0.1	1.0	27.5	10.5	60.6	0.17	2.0	51.8	22.0	52.0	24.0	24.0	scl
B23t	58-99	10.7	7.6	67.1	0.1	1.0	31.5	12.0	67.1	0.11	3.3	50.0	21.2	52.0	27.0	21.0	scl

Ck	99-142	10.5	8.5	75.4	0.1	1.0	35.5	12.5	75.4	0.11	4.9	55.0	21.0	53.0	28.5	18.5	sl
P3 30°02′33.6″N 76°51′40.7″E Moderately sodic soil (Sodic Haplustept) , cropped (rice), good quality (normal) GW, Markanda plain																	
Ap	0-15	9.3	2.4	28.6	0.2	3.0	5.0	25.0	16.5	0.18	5.3	50.0	13.2	51.3	25.1	23.4	scl
AB	15-39	9.7	2.6	33.0	0.1	2.0	4.0	20.0	23.3	0.08	1.7	94.6	15.5	43.9	31.1	24.8	l
Bw1	39-76	10.1	4.0	53.9	0.1	2.0	10.0	25.0	38.1	0.08	1.3	94.2	15.9	47.3	26.8	25.8	scl
Bw2	76-105	10.2	5.9	96.7	0.2	2.0	12.5	30.0	68.3	0.08	1.7	83.1	18.4	48.1	24.7	27.0	scl
Bw3	105-149	10.0	6.6	99.5	0.2	2.0	15.5	32.0	70.3	0.05	1.9	89.7	16.8	46.2	25.8	28.0	scl
P4 30°08′56.3″N 76°25′37.2″E Strongly sodic soil (Typic Natrustalf), reclaimed at surface, partially cropped, sodic GW, Ghaggar plain																	
Ap	0-18	9.1	1.2	13.3	0.1	1.5	5.0	5.0	10.8	0.6	4.4	53.1	19.2	47.1	28.1	24.8	scl
AB	18-41	9.6	1.4	15.7	0.1	1.0	6.0	4.0	15.7	0.2	8.1	66.7	16.8	48.5	24.8	26.7	scl
B21t	41-68	9.7	1.6	18.5	0.1	1.0	7.0	4.5	18.5	0.1	5.2	69.0	20.0	38.0	23.3	38.8	cl
B22t	68-105	9.6	1.7	19.5	0.1	2.5	6.0	3.0	12.3	0.2	9.5	58.5	21.2	35.9	29.7	34.5	cl
B23k	105-156	9.8	1.8	22.0	0.1	4.5	10.0	8.5	10.3	0.1	14.5	65.8	22.0	36.8	35.5	27.7	l

GW= Ground water

Table 5 Quality of ground water samples in Kurukshetra district

SN	Water sample- Location and latitude-longitude, depth (m)	pH_{iw}	EC_{iw} (dS m^{-1})	Na^+	K^+	Ca^{2+}+ Mg^{2+}	CO_3^{--}	HCO_3^-	Cl^-	RSC	SAR
				----(me L^{-1})----							
T1	Village Macheri (108m) 29°59′08.4″N76°25′55.0″E	8.8	1.4	13.9	0.1	2.5	2.0	13.2	1.7	12.7	12.4
T2	Village Macheri, (60m) 29°59′54.3″N76°29′41.3″E	8.7	1.1	9.9	0.2	2.5	1.5	10.0	1.7	9.0	8.9
T3	Village Seonsar (108m) 29°59′29.9″N76°29′39.4″E	9.5	1.4	13.3	0.1	2.0	3.0	11.0	1.7	12.0	13.3
T4	Village Kheri Daban (100m) 30º01′19.9″N76°27′36.6″E	9.1	1.3	12.6	0.1	1.5	Tr.	2.5	10.0	6.4	14.5
T5	Village Hansu Majra (100m) 29°59′36.4″N76°29′55. 5″E	9.3	1.4	14.0	0.1	1.0	Tr.	3.0	6.0	2.0	19.7
T6	Village Tatiana (120 m) 30º04′57.5″N76°27′35.8″E	9.1	1.6	16.6	0.1	1.0	0.0	3.0	5.0	2.0	23.4

Where, RSC= (CO_3^{--}+ HCO_3^-)-(Ca^{2+}+Mg^{2+}), SAR= [Na^+/ (Ca^{2+}+Mg^{2+})]$^{1/2}$, T=Tube well

Table 6 Spatial extent of salt affected soils and associated land degradations

Sl No.	Categories of salt affected soils and associated degradations	Area (ha)	%
1.	Slightly sodic soil	10409	61.0
2.	Moderately sodic soil	5697	33.6
3.	Strongly sodic soil	34	0.2
4.	Surface ponding-slight	363	2.1
5.	Sub-surface waterlogging	203	1.2
6.	Riverine sand	210	1.2
Total		16916	

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Public interest statement:

The submitted paper highlighted the potential of remote sensing data for natural resource inventory for salt affected soils and poor quality ground water in the arid and semiarid regions and also used geo-informatics for decision making and planning in the land reclamation, soil and water management and sustainable land use planning in the Gangetic plain of India