CHAPTER 6

MAPPING AND CHARACTERIZATION OF SALT AFFECTED SOILS FOR RECLAMATION AND MANAGEMENT: A CASE STUDY FROM THE TRANS-GANGETIC PLAIN OF INDIA

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CONTENTS

ABSTRACT

Soil salinity/alkalinity and poor quality groundwater are major constraints causing reduced productivity in the arid and semiarid region of the Trans-Gangetic plain of Central Haryana covering Kaithal district. Visual interpretation of Resourcesat LISS-III data for March, May and October (2009) seasons revealed the presence of salt affected soils spatially distributed as barren patches and intermixed with cropped areas in the irrigated zones. The white to yellowish white tones with high reflectance from salt crusts on barren soil surface prompted the detection of strongly sodic/saline soils. The mixed signatures (yellowish white and red mottling) of salt stress and patchy crop stand indicated the presence of slightly to moderate salt affected soils, which is authenticated by ground truth study. In absence of natural drainage, the waterlogging for stagnated water bodies in irrigated areas was easily identified by the higher energy absorption showing dark blue/black to gray shades in March and November data. Salt affected soils showing low permeability, infiltration and hydraulic conductivity, also showed similar signatures amidst the cropped areas. The prolonged use of poor quality groundwater favored salt build-up in irrigated areas and showed mixed spectral signatures (grayish red to reddish white tones) in the satellite imageries. The sodic (alkali soil dominated by sodium and carbonate salts) and saline (neutral salts dominated by chloride and sulfate) soils are common in the study area. Sodic soils were distributed in northern and central parts of Kaithal district covering Pundri (2.1%), Kaithal (3%), Guhla (1.1%) and Siwan (1.1%) blocks while saline soils were distributed in southern part covering Kalayat (2.6%) and Rajaund (1.3%) blocks. The fine texture (clay to clay loam) sub-surface soils in Ghaggar plain impaired natural drainage thus favored waterlogging and sodicity development. The precipitated calcium carbonates concretions (calcareous layer) are common in strongly sodic soils that impair salt and nutrient movements and root penetration. An area of 26301 ha (11.3%) is salt affected in Kaithal district, of which sodic and saline soils covered 17570 ha (7.3%) and 9388 ha (4%), respectively. The groundwater quality was sodic in north of Kaithal district (Guhla block), at places, showing high Residual Sodium Corbonate (RSC) (12.7 me L^{-1}), saline in the east at Kalayat block (Sodium Adsorption Ratio (SAR) 33.6) and sodic (pH 9.2) in central part of Kaithal block, and also showed high RSC (6.5 me L^{-1}) in selected samples. Based on the soil physico-chemical

characteristics and the quality of groundwater, suitable reclamation and management options were also suggested.

6.1 INTRODUCTION

Overexploitation of land, water and other natural resources during last four decades has set in the process of degradation in soil, water, climate and biodiversity resources. In India unscientific and over use of soil resources led to physical, chemical and biological degradation causing irreversible loss to soil quality. The intensive agriculture, which ushered during green revolution, is now becoming a serious threat to sustainable agriculture due to deteriorating soil quality. Salt affected soils are important degraded soils in the world, which contain excess salts (soluble/exchangeable) that adversely affect plant growth and crop yield. The main causes of salt accumulation include capillary rise from subsoil salt beds or from shallow brackish groundwater, besides other factors include the indiscriminate use of irrigation water of variable qualities, weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials, ingress of sea water along the coast, salt laden sand blown by sea winds, lack of natural leaching due to topographic situation in arid and semiarid regions. Soil characteristics *viz,* soluble salts content and soil reaction (pH) largely influence the changes in physical and chemical properties in a salt affected soil. Besides, soluble salts influence changes in proportion of exchangeable cations and the osmotic and specific ion toxicity for crop production. The presence of excess neutral salt essentially influences solute transport and non-availability of some essential nutrients required for plant growth.

Globally, five categories of salt affected soils were identified based on the nature and composition of salts (Szabolcs, 1989). These soils are saline dominated by natural salts, alkali enriched by salts capable of alkaline hydrolysis (Na_2CO_3 and $NaHCO_3$), gypsiferous with excess gypsum salts, acid sulfate soils with ferric and aluminum sulfates and others including strongly degraded subsoil and potential salinity in irrigated region. In Eastern Europe, these soils were known as Solonchak, Solonetz and Solod. The alkali soils of Europe and erstwhile United Soviet Socialist Republic (USSR) showed a good A horizon and a *natric* (sodic) subsurface B horizon. In India, these soils are known as *Kallar* or *Thur* in Punjab and Haryana, *Usar* or *Reh* in

Uttar Pradesh, *Luni* in Rajasthan, *khar* or *Kshar* in Gujarat and Maharashtra, *Chhouddu* or *Uppu* in Andhra Pradesh, *Choppan* in Karnataka, etc. The United States Soil Salinity Laboratory (Richards, 1954) proposed criteria for distinguishing sodic with saline and saline-sodic soils based on the critical limits of electrical conductivity (EC) of saturation extract, Exchangeable Sodium Percentage (ESP) and soil reaction (pH) of saturated soil paste. Soil Science Society of America (Soil Science Society of America, 1987) used EC and SAR as criteria for classification of salt affected soils. Extensive research conducted at Central Soil Salinity Research Institute (CSSRI) (Agarwal and Yadav, 1956) revealed pH 8.2 as more appropriate limit than pH 8.5 for characterizing sodic soils of the Indo-Gangetic Alluvial Plain (IGP). The adverse effect of sodicity on crop growth (Abrol et al., 1980) showed pH 8.2 as critical limit for alkalinity/sodicity in soils. Similarly, the EC values of 2 dS m^{-1} and ESP value of 5 were found as critical limits for characterizing black sodic vertisols dominated by higher content of clay with smectite mineralogy (Balpande et al., 1996). Australian workers preferred parameters of soil physical conditions and its harmful effects on plant growth for diagnosing commonly occurring sodic soils. It was found that ESP 6 was a limiting value to impairment of physical condition in a swell shrink soil in Australia (Northcote, 1979). To facilitate soil management and the influence of salts on soil properties and plant growth, two broad categories of soils *viz,* saline and sodic were identified in India (Abrol and Bhumbla, 1978; Abrol et al*.,* 1988). The detailed diagnostic characteristics are as follows:

Saline soils are occurring as patches with white salt encrustation on the soil surface located in the lower topographic position. Due to high salt content, high osmotic pressure and ion toxicity these soils do not support normal agriculture. Often, these soils are located in the irrigated region associated with waterlogging condition. The soil salinity is also developed by the presence of saline groundwater used for irrigation purpose in the arid and semiarid region. In the sea coast, large areas are subjected to saline water inundation that is affecting the root zone with high to very high soil salinity. The analytical data of laboratory analysis showed the presence of neutral salts such as chlorides and sulfates of sodium, calcium and magnesium higher than the prescribed limit. The pH of the saturation paste normally lies below 8.2 and the electrical conductivity usually exceeds 4 dS m^{-1} at 25°C. These soils normally have higher (>15) SAR. In the field, alkali soil are usually associated with bleached color, strong blocky structure, presence of mottles of iron and manganese, concretions/nodules of calcium and magnesium, presence of an illuvial fine textures layer dominated by silt/clay at a depth below the surface, and shows moderate to strong/violent effervescence following addition of dilute hydrochloric acid and changes to pink color following application of phenolphthalein indicator. Due to alkaline soil reaction (pH>8.2), these soils adversely affect plant growth and crop yield. The primary limitations are poor (dispersed) soil physical condition and inadequate internal drainage that cause the imbalance of nutrient availability. The laboratory investigations showed high (>15) ESP and dominance of soluble ions such as carbonate, bicarbonate of sodium, calcium and magnesium. Due to high sodium content these soils also showed high SAR.

6.1.1 STATUS OF SALT AFFECTED SOILS: GLOBAL PERSPECTIVE

Salinity related land degradation is important problem in arid and semiarid regions threatening food and nutritional security of the world. According to the FAO/UNESCO soil map of the world, 953 m ha of land (8%) is affected due to soil salinization and alkalization (Szabolcs, 1989). The worst affected areas include Africa, Asia, Australia, Europe, Latin America, Near East and North America (Koohafkan, 2012). A recent survey in Australia indicated about 2 m ha and 20,000 farms across the country is affected as a result of climate changes and 10% of the Western Australia is seriously endangered by soil salinity/alkalinity of primary and secondary origin (Australian Bureau of Statistics, 2002; McFarlane, 2004), Globally, 20% of the irrigated land (450,000 km^2) is salt affected and about 2000–5000 km^2 land lost production every year as a result of salinity (UNEP, 2009). In South Asia, annual economic loss is estimated as US$1,500 million due to salinization (UNEP, 2009). In the tropical countries, soil salinity is a serious problem affecting crop production, plant growth and soil and water quality leading to soil and environmental degradations. In Africa, a serious impact on economy has been reflected on average loss on agriculture from 28% to 76% as a result of land degradation. In India, the average production loss from such degradation varies from 40% in wheat, 45% in rice, 63% in cotton and 48% in sugarcane (Joshi and Agnihotri, 1984). The alkali land reclamation schemes in Haryana, Punjab and Uttar Pradesh (Trans-Gangetic plain) reported changes in cropping intensity by 25% in paddy, 10% in wheat, 21% in pulses and 10% in cotton (CSSRI, 2000). The economic benefit accrued from the sodic land reclamation programs showed the improvements of B:C (benefit-cost) ratio to 1.89 and 1.80 for rice and wheat, respectively (Thimmappa et al., 2013). Soil analytical data of reclaimed sodic soils showed prominent changes in soil pH and concurrent increase of organic carbon that showed improvement in fertility status (CSSRI, 2000; CSSRI, 2007).

6.1.2 STATUS OF SALT AFFECTED SOILS: INDIAN PERSPECTIVE

Current assessment of salt affected soils in India involves spatial measurements, field and laboratory studies and reconciliation to arrive at an estimated area of 6.73 m ha, which is distributed in 15 states and 13 agro-climatic regions (CSSRI, 2007; NBSS & LUP, 2006; NRSA, 1997, 2008). The saline (295 ha) and sodic (377 ha) soils are distributed in 7 physiographic regions, (Mandal et al., 2010). The occurrence of salt affected areas is primarily influenced by rainfall, 29.4% (very high), 26.2% and 19.4% exist in the ranges between 500 to 800 mm, 1000 to 1500 mm and 300 to 500 mm, respectively. These soils are associated with a wide range of parent materials, most importantly, in Pleistocene and Recent origin (38.9%), Archean Schists and Gneisses (9.5%) and Deccan and Rajmahal Traps (7.8%), respectively (Mandal et al., 2011). The irrigation through groundwater is a common practice for growing arable crops in the arid and semiarid regions, the quality of which is primary concern (average poor quality is 25%) for crop productivity. The distribution of saline groundwater, in Rajasthan (41.2%), Haryana (25.9%) and Gujarat (12.4%) states warrants necessary inputs for management (Gupta, 2010, HSMITC, 2001, Manchanda, 1976), while the alkaline groundwater in Punjab (54%), Rajasthan (35%), Haryana (30%) and Gujarat (28%) states showed necessity for promotion for reclamation. The complex saline-alkali water is also prevalent in Gujarat (52%), Rajasthan (49%), Haryana (46%) and Punjab (24%) and need special care for crop production. The expansion of canal irrigation network in arid and semiarid regions caused development of salinity and waterlogging problems in undrained areas.

In India, systematic mapping of soil salinity was originated at the Central Soil Salinity Research Institute at Karnal under the Indian Council of Agricultural Research (ICAR) New Delhi collaborating with National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) Nagpur and National Remote Sensing Centre (NRSC) Hyderabad. A methodology for mapping soil salinity on reconnaissance scale (1:250,000 scale) was developed using remote sensing data in conjunction with ground truth survey, soil and laboratory studies (NRSA, 2008; Mandal and Sharma 2010; Sharma et al., 2011; Sharma and Mandal, 2006). The salt affected soils in coastal areas of Gujarat state (India) were mapped and the integrated approach of image interpretation (Landsat TM) with ground truth was followed (Joshi and Sahai, 1993). The inland soil salinity in Uttar Pradesh state (India) was mapped based on the remote sensing and soil profile studies (Saxena et al., 2004). Digital image classification of soil degradation features was combined with field observations and laboratory determinations (Mitternicht and Zinck, 1997). Singh et al. (2010) found uncertainty in the estimates of complex salt affected soils and suggested reconciliation and harmonization. Currently, Ali et al. (2015), Wu et al. (2014), Scudiero et al. (2014) and Albel and Kumar (2013) studied salt affected soils using high resolution remote sensing data and used ground truth (land use), soil studies and laboratory analysis data for quantification of soil salinity/sodicity. Keeping in view the large scale variability of salt affected soils and scale of mapping FAO (2008) reported harmonized database of salt affected lands for further planning and management.

6.1.3 SIGNIFICANCE OF THE STUDY

The first survey of salt affected soils was initiated by identifying soil alkalinity and salinity problems in the Gangetic alluvium located at Etah district in Uttar Pradesh (Leather, 1914). Further salt affected soils were detected as patches in the lower Ganges canal areas of Uttar Pradesh (Agarwal et al., 1957). Investigations revealed that salts are drained from the Himalayas and Siwalik through rivers/streams and are accumulated at the alluvial plains (Bhargava et al., 1980; Sidhu et al*.,* 1995). The lack of adequate internal drainage in lower topographic regions prompted soil salinization (Bhargava et al., 1980). High evaporation during the dry season and lack of good quality water for leaching caused salt accumulation in soil profiles. The coexistence of salt affected soils and poor quality groundwater in central Haryana are primary constraints for agriculture (Yadav, 2003). The use of poor quality groundwater for irrigation increased salt buildup in soil profiles, which caused reduced productivity. Canal irrigation in undrained areas has also accentuated waterlogging, formation of high water table and secondary salinization in soils. The erratic rainfall and temperature patterns not only threaten agriculture but cause redistribution of salinity affected areas. In the dry regions of central Haryana, the primary dependence on groundwater for irrigation has degraded soils through the deteriorating physical and chemical properties of soils coupled with fine textured Ghaggar alluvium that caused a congenial environment (waterlogging) unfavorable for sustainable agriculture. A thorough investigation of soil and water and spatial distribution of salt affected soils using remote sensing data is required for precise assessment. The variable extents of salt affected soils (4.54 to 2.32 lakh ha) in Haryana (Abrol and Bhumbla, 1971; NRSA 2008) and the complex nature for salts, soil physical properties and drainage (Sharma et al*.,* 2011), have been reported periodically. The complex pedogenic processes due to the anthropogenic activities using poor quality groundwater for irrigation (Jain and Kumar, 2007; Bhalla et al., 2011) were also reported in arid and semiarid areas. For precise assessment of reclamation and management, the physico-chemical characteristics and quality appraisal of irrigation water are of primary importance. This chapter addresses mapping and characterization of salt affected soils and quality appraisal of groundwater in Kaithal district of Central Haryana, India, for reclamation and management.

6.2 STUDY AREA

The Kaithal district (2317 sq.km) lies between 29°31′27.43″N 76°09′02.99″E, 30°13′07.45″N 76°47′59.44″E, under the old alluvial plain covering D3.3 agro-ecological zone (Yamuna alluvial plain, hot and semiarid region with length of growing period of 90–120 days). It consists of two administrative sub-divisions *viz,* Kaithal & Guhla and six blocks *viz,* Kaithal, Pundri, Rajaund, Guhla, Kalayat and Siwan (Figure 6.1). The climate varies from arid to semiarid. The average rainfall of the district is 500–600 mm. The net cultivable area is 2.02 lakh ha, the area under forest is 3000 ha and barren and uncultivable land covers 2000 ha. The net irrigated area is 1.98 lakh ha mainly by canals and groundwater. The primary source of irrigation is Western Yamuna (Narwana branch and Rajaund distributary) and Bhakra (Saraswati distributary) canals. High (182%) cropping intensity is reported in Kaithal district. The primary crops include paddy in summer (*Kharif*) and wheat in winter (*Rabi*) seasons while cotton, pearl millet, sugarcane, sunflower and pulses (moong) are also practiced. Growing Dhaincha (*Sesbania aculeate*) is common practice in areas under salt affected (alkaline) soils and

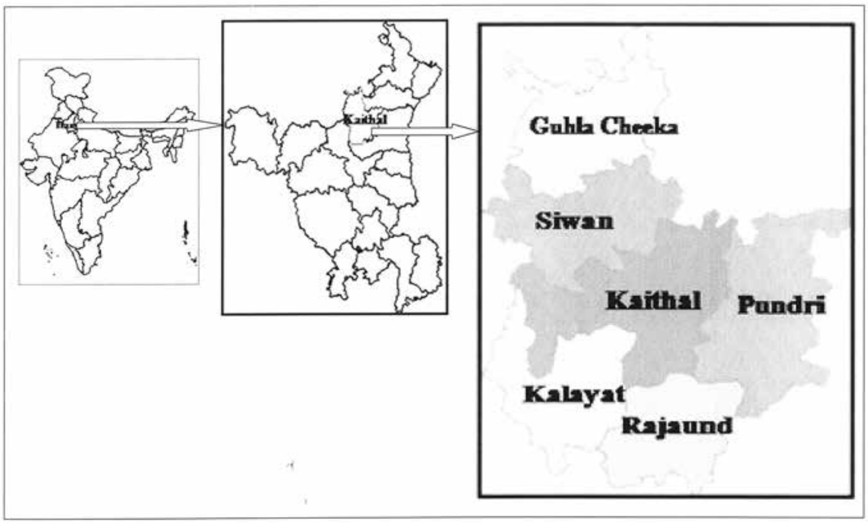

FIGURE 6.1 Location map of the study area.

water to reduce salt injuries and improve soil health (physical properties). The landform is alluvial (Ghaggar alluvium) in general.

6.3 METHODOLOGY

6.3.1 DATA USED IN THE STUDY

Indian Remote Sensing (IRS) (Resourcesat) LISS III data with spatial resolution of 23.5 m and spectral resolution (Green: 0.52–0.59 µm, Red: 0.62–0.68 µm, Near Infra Red: 0.77–0.86 µm and Short-wave Infra Red: 1.55–1.70 µm) for March, May and October 2009 was used in the study (Table 6.1). *The Survey of India Topographical Maps* on 1:50,000 scale (No. 53C/1, 2,

TABLE 6.1 Particulars of Satellite Imageries

Sensor	Spectral Resolution (µm)	Spatial Resolution	Period
IRS - P6 LISS III Resourcesat I	B1 0.52–0.59 (Green)	23.5 m	March 2009
	B2 0.62–0.68 (Red)	Swath 140 km	May 2009
	B3 0.77–0.86 (NIR)		October 2009
	B4 1.55–1.70 (SWIR)		

5, 6, 9 and 10; 53B/4, 8 and 12) were used for preparing the basemap comprising of administrative and political boundaries, irrigation/drainage, infrastructure and settlements. *Software* ERDAS IMAGINE software (*ver 3.3*) was used for digital and spatial data analysis. The software Arc GIS (*ver* 9.3) was used for generation of thematic layers. A Cal Comp (A_0) digitizer, a scanner, a printer attached to a Pentium (PIV) computer equipped with Microsoft Windows XP and Office (2000), was used for entry, editing and analysis of map and attribute data. The ancillary data (State Department of Agriculture Haryana and NBSS & LUP, RC Delhi), water quality data (Gupta, 2010; Manchanda, 1976; HSMITC, 2001), crops and associated land characteristics (District Gazettes Haryana) were also collected for the study area. The salt affected soils map of Haryana (NRSA, 1997) on 1:250,000 scale were also used as legacy data. *Soil Sampling Tools* like color chart, auger, spade and knife, etc., were used. Global Positioning System (GPS) was used for collecting data related to the location of field data.

6.3.2 GEO-REFERENCING AND PREPARATION OF THE BASE MAP

The Survey of India (Government of India) topographical maps on 1:50,000 scale were used for geo-referencing and related with real world coordinates using Universal Transverse Mercator (UTM) projection with projection (ellipsoid WGS 84) and datum WGS 1984) information. The spatial features for state, district and blocks boundaries, roads and railways, canal and river and state, district, block HQ and villages were digitized and the thematic layers were overlaid to develop a base map of the study area.

6.3.3 PROCESSING AND INTERPRETATION OF IRS DATA

The IRS imageries were processed for radiometric and geometric corrections and were geo-referenced. The False Color Composites (FCC) were prepared using combination of bands such as NIR, R and G (B321) and SWIR, NIR and R (B432) (Figure 6.2). The seasonal data were also analyzed to study the dynamics of soil salinity and waterlogging. Visual analysis was done and interpreted units were digitized following standard guidelines (Colwell, 1996). The principal component analysis was done to segregate homogenous data for visual analysis. The ratio indices Normalized Difference Vegetation Index (NDVI) and Vegetation Index (VI) were also carried out to distinguish

FIGURE 6.2 IRS-LISS-III imagery (March 2009) for Kaithal district, Central Haryana.

normal and stressed crops. The seasonal data were analyzed to study and understand the dynamics of salt affected soils and waterlogging. Overlaying thematic layers of base map and ancillary/legacy data, the interpreted units were delineated using on-screen digitization technique.

6.3.4 FIELD SURVEY FOR SOIL PROFILE STUDIES

Ground truth studies were conducted to verify and authenticate interpreted units and establish relationship between image interpretation and field conditions. During field survey important characteristics such as surface salinity and waterlogging status, seasonal behavior, topography, irrigation/drainage and crops/cropping practices were studied. GPS was used to locate sites for ground truth observations, soil profiles/soil and water sampling. The groundwater samples were collected from tube wells (used for irrigation in agriculture). The soil profiles (10 Nos.) were studied to a depth of 1.5 m at representative locations and depth-wise soil samples were collected for laboratory analysis for soil physico-chemical properties (Soil Survey Staff, 1998). These were classified using taxonomic system of soil classification (Soil Survey Division Staff, 2004). The soil samples were also characterized (Richards, 1954) for salinity/alkalinity appraisal (Table 6.2).

6.3.5 PHYSICO-CHEMICAL ANALYSIS, SOIL CLASSIFICATION AND APPRAISAL OF WATER QUALITY

Soil samples were analyzed for physico-chemical properties *viz,* pH, EC (dS m^{-1}), soluble Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^- and Cl^- (me L^{-1}), $CaCO_3$ (<2 mm size, %) and organic carbon (%); CEC (cmol (p^+) kg^{-1}) and

TABLE 6.2 Keys to the Degree of Salinity/Sodicity in Salt Affected Soils (Richards, 1954)

	Saline Soil	Sodic Soil	
Degree	**EC (dS m^{-1})**	**pH**	**ESP**
Slight	4.0–8.0	8.5–9.0	<15
Moderate	8.1–30.0	9.1–9.8	15–40
Strong	>30	>9.8	>40

ESP (%), sand, silt and clay (%) and available N, P and K (Jackson, 1986; Singh et al., 1999). Soils are classified as saline, sodic and saline-sodic and the degrees of classes as slight, moderate and strong (Richards, 1954). The waterlogged areas were classified as permanent waterlogged (surface ponding) and sub-surface waterlogging (water table depth <1.5 m) based on NRSA (2007). Thirteen groundwater samples were collected from different locations to study the water quality for agricultural applications. These were analyzed for pHiw, EC_{iw} (dSm^{-1}), soluble Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^- and Cl^-, SAR = $[Na^+/ \{(Ca^{2+} + Mg^{2+})/2\}^{1/2}]$ and RSC = $[(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})]$.

6.3.6 MAPPING OF SALT AFFECTED AND WATERLOGGED SOILS

An integrated approach of image interpretation, ground truth survey and laboratory analysis data for soil physico-chemical properties was used for mapping salt affected and waterlogged soils (Dwivedi, 2001; Mandal and Sharma, 2012, 2013; NRSA, 2007). The thematic layers of salt affected and waterlogged soils were linked with the physico-chemical properties of soils to develop a relational database (Mandal and Sharma, 2011). A flow chart showing mapping methodology is presented in Figure 6.3. The area statistics of salt affected and waterlogged soils were generated (Mandal and Sharma, 2011). The thematic maps of salt affected soils and waterlogged areas for Guhla and Kaithal sub-divisions were prepared.

6.4 RESULTS AND DISCUSSION

6.4.1 INTERPRETATION OF IRS DATA

The visual interpretation of IRS LISS III FCC (B321) for March, June and October 2009 seasons identified salt affected soils as white to yellowish

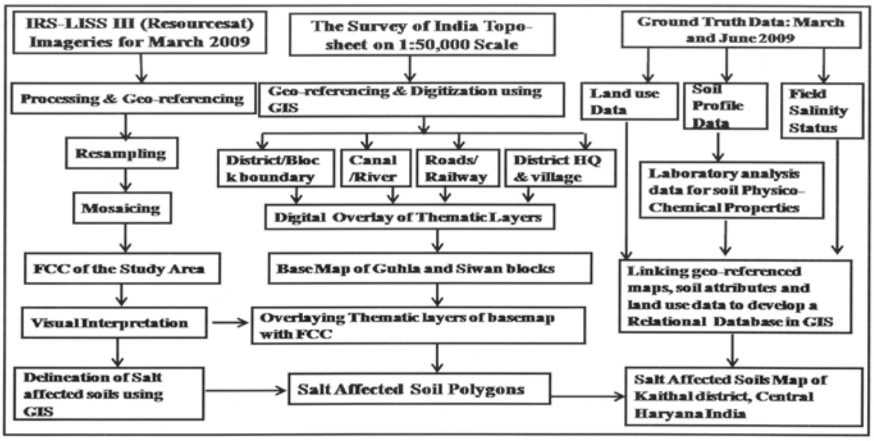

FIGURE 6.3 Methodology for mapping salt affected soils.

white patches in the old alluvial plains of Ghaggar and Saraswati covering Kaithal district. These are associated with waterlogged soils and the cropped areas that appeared as dark blue to black patches and red to dark red tones, respectively. The FCC of bands B432 (SWIR, NIR and R) showed better results due to higher contrast and clear boundaries of waterlogged areas than the FCC of bands B321 (NIR, R and G). Prominent waterlogging and salt infestation were located in the old alluvial plains of Ghaggar covering Guhla block and in the Paleo-channel of Saraswati located in Siwan block. The mixed spectral signatures for light to dark grayish tones with red mottles showed the presence of salt affected and waterlogged soils with scattered cropped areas. The ground truth data indicated prolonged irrigation of arable crops with salty groundwater that caused low permeability, infiltration and poor drainage in moderate to fine texture soils of Ghaggar plain. The post monsoon (October) data showed higher extent of waterlogged and salt affected soils in Guhla block.

Located in the west of Kaithal district, the salt affected and waterlogged soils in Siwan block were distributed as barren patches interspersed with cropped areas showing poor vegetative growth. The ground truth data confirmed the presence of sodic soil and the practice of poor quality groundwater for irrigation in wheat and rice crops. The salt affected soils were also located in the forest-covered areas and are used for growing medicinal and aromatic plants. A large area of salt affected soils were found along the Saraswati drain that flushes excess salts and water during the post-monsoon season. Waterlogging is prominent in the severely salt affected soils showing no natural drainage. Ground truth studies indicated the presence of fine texture layers at sub-surface depth inhibiting percolation of salts, water, nutrient and restricted root growth. At places, salt crusts were detected in the forest-covered areas where the groundwater is sodic in general.

In the canal-irrigated areas, waterlogging and soil salinization were identified in Kalayat block, located in the western part of Kaithal district. The rice, cotton and wheat are major summer and winter crops, respectively. Continuous irrigation in poorly drained areas caused rise of water table resulting in waterlogging. Topographically it is distributed in the low-lying flats/depressions with no or imperfect internal drainage. The waterlogging was higher during the post-monsoon season apparently due to higher irrigation for rice crop. The salt concentration was higher in post-monsoon season due to salt transport with rising water table and repeated wet and dry cycles favored salt precipitation and enriched salt concentration leading to the salt efflorescence during the dry period. Soil profile studies identified impermeable layer of calcium carbonate at a depth below the surface.

The post monsoon (October) imageries showed the patches of waterlogged and salt affected soils in the irrigated areas of Kaithal block located at the southern part of Kaithal district. The cereal crops such as rice and wheat are irrigated with salty groundwater. The ground truth studies indicated good crop growth in coarse texture soils. Waterlogging is more pronounced in the fine texture soils with low permeability and poor internal drainage. The use of salty groundwater caused salt enrichment in soil profiles resulting in low infiltration and movement of water and salts.

The March 2009 data indicated waterlogged and salt affected soils in Rajaund and Pundri blocks located in the south and east of Kaithal district. In the absence of canal irrigation and fresh water supply, the saline groundwater is used for agriculture in Rajaund block. The periodic use of salty groundwater increased salt concentration in soil profile and deteriorated soil physical properties and favored waterlogging. The salt affected soils are found in the localized patches at the low-lying areas of Rajaund block (village Mandwal). The sodic soils were identified along the Paleo-channel of river Chautang (Villages Sakra, Kheri, Sangrauli, Dosain, Buchi) in Pundri block. The IRS data (2009) showed mixed spectral signatures of dry salts and dark tones of residual moisture at the soil surface showing imprints of waterlogging. Besides, the use of sodic groundwater for irrigation in arable crops also favored sodic soil formation.

6.4.2 PHYSICO-CHEMICAL CHARACTERISTICS OF SOILS AND SUGGESTED RECOMMENDATIONS

The physico-chemical properties of soils are presented in Table 6.3. The seasonal imageries indicated barren surface and higher moisture accumulation (seasonal waterlogging) in the pre- and post monsoon seasons. Soil profile studies (March) of Pedon 1 showed salt accumulation, sodic condition (pink color develops on application of phenolphthalein indicator), moist soil strata, deep, fine soil texture, massive to moderate, fine to medium, angular to sub-angular blocky structure and the significant presence of iron and manganese mottles (1–2 mm, 10–20%) at 24–105 cm depth and calcium carbonate concretions (2–4 cm, 20–40%) at 70–135 cm depths, respectively. Based on the data of physico-chemical properties (pH 10.3 to 10.4 and ESP 75.4 to 83.2), the Pedon is classified as strongly sodic (Richards, 1954). The higher contents of CO_3^{2-} + HCO_3^- (14.5 to 16.9 me L^{-1}), Na^+ (15.6 to 44.9 me L^{-1}), Cl^- (8.0 to 14.0 me L^{-1}) and SO_4^{2-} (2.8 to 7.0 me L^{-1}) ions were noted. The soil texture ranges from silty clay loam to loam showing higher clay content (12.2 to 36.6%). CEC varies from 28.7 (at surface) to 13.6 (at 187 cm) cmol (p^+) kg^{-1}. The *Calcrete*s ($CaCO_3$) are present (10.2 to 11.4%) at 1 m depth. The organic carbon, available nitrogen and phosphorus contents are low throughout. These soils can be used for rice-wheat cropping following reclamation with gypsum (4–6 t ha^{-1}).

Located at the old alluvial plain of Ghaggar (Sachdev et al., 1995; Mandal, 2014) and irrigated by salty groundwater (Block Kaithal), Pedon 2 showed water stagnation and patchy crop stand in March and November satellite data. The soil is characterized by deep, massive to medium sub angular blocky structure, clayey texture and pale yellow to dark yellowish brown color. The moist to wet sub-surface layers and the presence of iron and manganese nodules showed anaerobic condition in soil profile. The physico-chemical analysis data indicated soil sodicity (pH 8.7), soil salinity (EC 6.5 to 8.6 dS m^{-1}) at sub-surface depths. The Na^+ (1.5 to 63.5 me L^{-1}), Ca^{2+} + Mg^{2+} (4 to 38 me L^{-1}), Cl^- (128 to 725 me L^{-1}) and SO_4^{2-} (5.9 to 54.0 me L^{-1}) ions are prevalent. The high clay content (53 to 57%) caused poor internal drainage (Mandal and Sharma, 1997; Mandal, 2014) and higher CEC values (42.6 to 44.1 cmol (p^+) kg^{-1}). The soil is low in organic carbon (0.2 to 0.3 %), available nitrogen (11 to 78 Kg ha^{-1}) and phosphorus (16 to 53 Kg ha^{-1}) contents and showed moderate to high available potassium (466 to 509 Kg ha^{-1}). The treatment with Farm Yard Manure (FYM) or compost is required

TABLE 6.3 Physico-Chemical Properties of Soils from Kaithal District

Horizon	Depth (cm)	pH	EC (dS m^{-1})	Na^+	Ca^{2+}+ Mg^{2+}	CO_3^{2-}+ HCO_3^-	Cl^-	SO_4^{2-}	OC	ESP	$CaCO_3$	CEC cmol (p^+) kg^{-1}	Texture	Clay	Silt	Sand	Av N	Av P	Av. K
				me L^{-1}					(%)					(%)			Kg ha^{-1}		
P1:29°47′38.9″N to 76°39′52.3″E Fine-Loamy Sodic Haplustepts, sodic soil in paleo-channel of the river Chautang, calcareous parent material																			
A1	0–24	10.3	1.6	15.6	4	15.6	8.0	2.8	0.2	76.6	1.9	24.6	sicl	36.6	38.9	24.4	31	17	208
Bw1	24–47	10.4	2.6	27.4	4	15.1	10.0	5.4	0.2	75.4	1.9	28.7	sicl	34.6	37.4	27.9	27	14	208
Bw2	47–72	10.3	2.3	22.9	4	14.5	10.0	4.2	0.2	83.2	1.2	25.4	sicl	28.0	32.1	39.8	23	10	188
B21k	72–105	10.4	3.4	28.7	4	16.7	14.0	5.7	0.2	74.8	2.3	21.1	l	18.3	24.1	57.5	23	10	151
B22k	105–135	10.4	4.0	44.9	4	16.9	13.0	7.0	0.1	80.1	11.4	14.6	l	12.3	17.6	70.0	19	10	88
BC k	135–187	10.4	3.6	39.4	4	15.2	14.0	6.4	0.1	82.4	10.2	13.6	l	12.2	16.8	71.0	19	10	93
P2: 29°46′38.9″N to 76°29′34.9″E Fine Typic Ustochrepts, waterlogged soil, rice basmati (CSR 30) irrigated by sodic water produce moderate yield																			
Ap	0–24	8.7	1.0	1.5	4	4.0	6.0	5.9	0.3	22.5	1.3	42.6	c	53.2	21.5	25.2	11	21	509
Bw1	24–61	8.0	6.5	49.5	20	4.5	9.0	41.8	0.3	27.2	0.7	44.1	c	55.6	23.2	21.1	78	16	488
Bw2	61–92	8.0	8.6	63.5	38	3.5	12.0	54.0	0.2	31.3	1.2	44.1	c	57.3	22.3	20.4	74	53	477
Bw3	92–121	7.9	8.0	44.2	24	4.5	19.0	44.2	0.2	21.8	1.3	42.6	c	57.6	23.6	18.8	70	39	466
P3: 29°46′46.4″N to 76°30′1.9″E Fine-Loamy Typic Ustochrepts, sodic soil & sodic GW, calcareous parent material, rice CSR 30 grown, low yield																			
Ap	0–21	8.6	2.5	22.3	6	4.5	10.0	13.6	0.3	44.6	3.2	13.2	sil	21.4	28.0	50.5	10	38	456
Bw1	21–62	9.2	1.2	12.4	6	4.0	8.0	5.9	0.1	52.3	3.8	19.7	sil	24.8	32.7	42.3	51	34	429
Bw2	62–94	9.2	1.7	19.4	4	4.5	8.0	8.8	0.1	45.8	1.5	22.6	sil	23.6	38.1	38.2	43	23	413
Ck	94–122	9.3	1.9	21.2	6	4.5	8.0	10.9	0.1	54.4	9.9	26.9	sil	19.6	29.3	51.0	31	13	360

P4: 29°49′6.7″N to 76°28′10.6″E, Fine Typic Ustochrepts, sodic soil & sodic GW in the old Ghaggar plain, severely waterlogged & partially barren																		
A1	0–18	8.3	2.3	18.8	8	1.5	10.0	13.7	0.4	32.3	2.3	21.5	c	40.0	24.1	35.8	10	33	392
Bw1	18–56	8.6	2.4	17.7	8	3.0	6.0	11.9	0.2	40.1	1.4	26.8	c	47.0	24.2	28.7	70	22	356
Bw2	56–89	8.4	2.5	19.9	8	4.0	8.0	16.5	0.2	37.3	1.7	31.8	c	49.8	25.4	24.7	70	12	339
Bw3	89–127	8.0	4.1	35.5	10	5.0	10.0	28.3	0.1	29.7	2.1	36.0	c	54.1	25.6	20.3	51	14	332
P5: 30°3′39″N to 76°18′33.9″E, Loamy Sodic Haplustepts, severely sodic soil & GW in the recent Ghaggar plain, barren with sparse vegetation																		
A1	0–22	9.9	6.1	64.5	1.5	6.5	23.0	33.9	0.2	56.0	2.1	16.4	l	14	17.8	68.6	88	28	377
B1	22–56	10.4	8.9	108	1.5	9.0	29.0	52.8	0.2	61.0	1.8	19.5	l	14	22.0	65.8	19	28	470
B2	56–84	10.6	5.8	56.7	1.5	8.5	16.0	38.4	0.1	60.0	3.0	20.0	l	18	22.1	59.3	15	19	203
Ck	84–121	**10.7**	5.0	42.3	2.0	**17.5**	14.0	16.5	0.1	64.0	2.9	19.5	l	21	19.6	59.1	15	25	203
P6: 30°8′56.3″N to 76°24′37.2″E, Fine-Loamy Typic Natrustalf, reclaimed sodic soil, calcareous, rice-wheat grown and produce moderate yield																		
A1	0–20	9.1	1.2	13.3	2	5.0	5.0	4.4	0.6	53.1	4.4	19.2	sil	25	28.1	47.1	86	14	321
Bt1	20–49	9.6	1.4	15.7	1	6.0	4.0	9.6	0.2	66.7	8.1	16.8	sicl	37	24.8	38.5	27	24	349
Bt2	49–88	9.7	1.6	18.5	1	7.0	4.5	9.2	0.1	69.0	5.2	20.0	sicl	29	33.3	38.0	14	27	488
Ck	88–125	9.6	1.7	19.5	3	6.0	3.0	8.4	0.2	58.5	9.5	21.2	sil	25	39.7	35.9	14	26	396
P7: 30°2′36.3″N to 76°14′49.5″E Loamy Typic Ustochrepts, sodic soil in recent alluvial plain, calcareous, rice-wheat crops showed moderate yield																		
Ap	0–22	8.9	4.4	39.2	4	5.3	12.5	22.4	0.4	40.0	2.3	24.5	l	23	21.6	55.0	82	10	243
Bw1	22–61	9.0	4.8	42.3	2	4.0	17.5	28.4	0.2	38.1	2.6	21.1	l	15	17.4	67.4	23	9	286
Bw2	61–93	9.1	3.6	34.1	4	4.8	15.0	17.9	0.2	46.6	2.3	16.3	l	15	18.1	66.6	20	14	340
Bw3	93–121	9.4	2.4	19.2	2	3.5	10.0	8.8	0.1	44.2	4.1	19.0	sil	19	31.6	49.9	16	18	303

TABLE 6.3 (Continued)

Hori-zon	Depth (cm)	pH	EC (dS m^{-1})	Na^+	Ca^{2+}+ Mg^{2+}	CO_3^{2-}+ HCO_3^-	Cl^-	SO_4^{2-}	OC	ESP	Ca-CO_3	CEC cmol (p^+) kg^{-1}	Tex-ture	Clay	Silt	Sand	Av N	Av P	Av. K
				me L^{-1}					(%)					(%)			Kg ha^{-1}		
P8: 29°59′54.3″N to 76°25′41.3″E Fine-Loamy Typic Natrustalf, strongly sodic soil in old alluvial plain, natural vegetation and forestry plantations																			
A1	0–22	10.6	7.4	98.7	4	15.0	31.0	10.9	0.1	99.5	2.4	14.3	l	15.2	14.7	69.9	79	56	543
Bt1	22–56	11.0	5.5	80.0	4	15.0	18.0	12.8	0.1	91.8	2.4	20.6	cl	24.9	19.4	55.5	73	43	490
Bt2	56–91	11.1	4.6	70.4	3	20.0	15.0	9.1	0.1	96.9	0.9	25.7	cl	25.8	18.8	55.2	67	24	463
BC	91–118	11.2	5.3	83.9	3	27.0	12.0	6.2	0.1	94.1	1.4	24.6	cl	23.3	18.5	58.1	56	15	390
P9: 29°40′35.9″N to 76°13′8.5″E Coarse-Loamy Typic Ustochrepts (Saline phase), waterlogged (WT <0.5m) soil under canal irrigation, cotton crop																			
A1	0–18	7.9	21.7	168	78	3.0	112	131	0.3	51.5	0.6	14.6	sl	14.7	16.5	68.6	121	25.	437
Bw1	18–53	7.8	19.3	144	74	3.5	104	111	0.2	32.6	0.2	13.6	sl	15.8	15.6	68.5	109	15	389
Bw2	53–94	7.9	16.7	123	60	3.0	90	90	0.1	43.8	0.5	17.1	sl	19.1	18.7	62.0	90	13	320
B k	94–128	7.9	12.5	88	48	2.5	80	53	0.1	37.3	10.0	14.1	sl	11.8	23.3	64.8	82	10	277
P10: 29°52′25.3″N to 76°19′49.9″E Loamy Sodic Haplustepts, reclaimed sodic soil in the old alluvial plain, medicinal & aromatic plants growing																			
A1	0–26	9.6	9.2	117	4.0	20.0	33.0	0.6	0.1	75.9	0.1	13.6	l	13.8	21.8	64.7	115	10	425
B1k	26–58	10.4	13.7	193	4.0	44.5	32.0	4.6	0.1	91.2	0.6	14.3	l	14.1	24.7	61.1	105	6	358
B2k	58–94	10.8	13.4	193	3.0	33.0	35.0	8.1	0.1	92.3	0.7	16.6	sil	12.2	26.5	61.2	25	7	268
B3k	94–129	10.8	11.5	151	3.0	30.0	31.0	7.1	0.1	96.7	0.8	15.0	sil	11.7	25.1	63.1	20	15	186

P = Pedon, The mixed parent materials & hyperthermic temperature regimes are common in all Pedon, GW = Groundwater. AV = Available.

to improve soil physical properties and internal drainage. The alkali groundwater may be treated suitably with gypsum while the saline groundwater may be used in mixing or cyclic mode for irrigation purpose (Gupta, 2010; Singh, 2009).

The sub-angular blocky structure, silty loam texture and pale yellow to yellowish red color and sodic groundwater were characteristic features of Pedon 3 (Jain and Kumar, 2007). The scattered crop and higher water absorption (dark gray tone) for waterlogging are typical surface features in the satellite imageries. The pH (8.6 to 9.3) and ESP (44.6 to 54.4) values indicated slight to moderate sodicity and is used for rice-wheat cropping following reclamation (0–30 cm). Prominent waterlogging appeared due to fine soil texture (silt loam) and stratification caused due to irrigation by poor quality groundwater. The Na^+ (12.4 to 22.3 me L^{-1}), CO_3^{2-} and HCO_3^- (4.0 to 4.5 me L^{-1}) ions are dominating and caused sodicity development. The presence of Cl^- (8.0 to 10.0 me L^{-1}) and SO_4^{2-} (5.9 to 13.6 me L^{-1}) ions showed the presence of mixed parent materials (Sachdev et al*.,* 1995). The $CaCO_3$ content (1.5 to 9.9%) indicated calcareous parent materials. The high CEC values (13.2 to 26.9 cmol (p^+) kg^{-1}) appeared due to higher clay contents (19.6 to 24.8%). The organic carbon (0.1 to 0.3%), available nitrogen (10 to 51 Kg ha^{-1}) and phosphorus (13 to 38 Kg ha^{-1}) contents are low. The gypsum and FYM application is suggested prior to arable cropping.

The pH (8.0 to 8.6) and ESP values (29.7 to 40.1) of Pedon 4 indicated the initiation of sodicity development. The $CaCO_3$ (<2 mm) is evenly distributed (1.4 to 2.3%) in the soil profile and higher values may be attributed to the carbonate containing irrigation water. The increase of EC values (2.3 to 4.1 dS m^{-1}) at sub-surface depths indicated the presence of salty groundwater. The Na^+ (17.7 to 35.5 me L^{-1}), $Ca^{2+} + Mg^{2+}$ (8.0 to 10.0 me L^{-1}), CO_3^{2-} + HCO_3^- (1.5 to 5.0 me L^{-1}), Cl^- (6.0 to 10.0 me L^{-1}) and SO_4^{2-} (11.9 to 28.3 me L^{-1}) ions indicated dominance of alkaline parent materials. The higher CEC values (21.5 to 36.0 cmol (p^+) kg^{-1}) are attributed to high clay content (40.0 to 54.1%). The increasing ESP values (29.7 to 40.1) indicated the influence of alkali water irrigation. The sprinkler and drip methods of irrigation are suggested for irrigation with salty groundwater. The soil is suitable for growing low water requiring crops, fruits (horticulture) and forestry plantations to sustain in waterlogged soil affected soils and poor quality waters.

The pH values (9.9 to 10.6) of Pedon 5 indicated strongly sodic soil characterized by sparse vegetation in the Ghaggar plain (Block Guhla). The EC values (8.9 to 5.0 dS m^{-1}) indicated salt accumulation due to irrigation with salty groundwater (Qureshi et al., 1996). The high Na^+ (42.3 to 108.0 me L^{-1}) and CO_3^{2-} and HCO_3^- (6.5 to 17.5 me L^{-1}) contents cause increased soil pH and low contents of Ca^{2+}+ Mg^{2+} (1.5 to 2.0 me L^{-1}), Cl^- (14.0 to 29.0 me L^{-1}) and SO_4^{2-} (16.5 to 52.8 me L^{-1}) result in high SAR. The higher ESP (56.0 to 64.0) appeared due to the saturation with Na^+ ions. The low organic carbon (0.1 to 0.2%), available nitrogen (15 to 88 Kg ha^{-1}) and phosphorous (19 to 28 Kg ha^{-1}) contents indicated low fertility status. For reclamation, gypsum (@ 8–10 t ha^{-1}) application is necessary prior to growing arable crop such as rice and wheat.

The Pedon 6 soil is characterized by silt loam to silty clay loam texture, moderate medium to massive sub-angular blocky structure, fine consistency and yellowish brown color. Poor to imperfect drainage and the presence of lime, iron, manganese nodules and concretions of $CaCO_3$ (calcareous layer) were found at a depth below the surface. The silty clay loam soil texture at sub-surface depth with clay content ranging from 29 to 37% and ESP (66.7 to 69.0%) favored the formation of natric horizon. The pH (9.1 to 9.7) and EC (1.2 to 1.7 dS m^{-1}) values indicated strong sodicity except the surface soil which is reclaimed. Higher contents of Na^+ (13.3 to 19.5 me L^{-1}), CO_3^{2-} and HCO_3^- (5.0 to 7.0 me L^{-1}), as compared to Ca^{2+}+ Mg^{2+} (1.0 to 3.0 me L^{-1}), Cl^- (3.0 to 5.0 me L^{-1}) and SO_4^{2-} (4.4 to 9.6 me L^{-1}) indicated strong alkaline ions causing sodicity development. The higher ESP values (53.1 to 69.0) supplemented soil alkalization. The $CaCO_3$ (<2 mm) content (4.4 to 9.5%) showed precipitated calcareous parent materials at high soil pH and ESP. The Pedon can be used for arable crops following reclamation using gypsum (@6–8 t ha^{-1}). Due to the presence of *natric* horizon and poor quality groundwater, plantations of forestry, medicinal and aromatic plants and low water requiring food crops are more suitable.

The range of pH and ESP values (8.9 to 9.4 and 38.1 to 44.2) of Pedon 7 indicated moderately sodic soil and higher salt concentration (2.4 to 4.8 dS m^{-1}) at surface resulting from the irrigation with salty groundwater. The dominance of Na^+ (19.2 to 42.3 me L^{-1}) and CO_3^{2-} + HCO_3^- (3.5 to 5.3 me L^{-1}) increased soil pH. The CEC values (16.3 to 24.5 cmol (p^+) kg^{-1}) are related to clay content (15 to 23%). The $CaCO_3$ content is increased with depth (2.3 to 4.1%). The available nitrogen (16 to 83 Kg ha^{-1}) and phosphorus (9 to 18 Kg ha^{-1}) contents are low. The use of salt resistant varieties of rice and wheat is suggested to improve productivity.

In the old alluvial plain of Ghaggar (Block Siwan), the soils (Pedon 8) showed finer soil texture (loam to clay loam), massive to moderate medium sub-angular to angular blocky structure, yellowish brown to pale yellow color and poor to imperfect drainage. The pH values (10.6 to 11.2) showed strongly sodic soil. The high ESP values indicated saturation with sodium favoring hydrolysis and soil alkalinity. The Na^+ (70.4 to 98.7 me L^{-1}) and CO_3^{2-}+HCO_3^- (15.0 to 27.0 me L^{-1}) ions are dominating and favored sodicity development (Sharma et al., 2011) The CEC values (14.3 to 25.7 cmol (p^+) kg^{-1}) showed dominance of mixed clay minerals. The increasing clay content (24.9 to 25.8%) and higher ESP (91.8 to 96.9) showed *natric* horizon formation. The gypsum application @ 8 to 10 t ha^{-1} is required for reclamation and the soil can be used for arable (rice-wheat) cropping.

Located in the arid sandy alluvial plain of Ghaggar (Block Kalayat) and irrigated with Narwana branch of Western Yamuna canal Pedon 9 showed waterlogging (water table depth 0.5 m) and poor productivity. A thick layer of $CaCO_3$ concretions (2–5 mm, 50 to 60%) is found at a depth (120 cm) below the surface. The neutral soil pH (7.8 to 7.9) and higher salinity (12.5 to 21.7 dS m^{-1}) is found throughout the soil profile. The higher contents of Na^+ (88 to 168.0 me L^{-1}), Ca^{2+}+Mg^{2+} (48 to 78 me L^{-1}), Cl^- (80 to 112 me L^{-1}) and SO_4^{2-} (53 to 131 me L^{-1}) are noted. The $CaCO_3$ (<2 mm) content increased from 0.6 at surface to 10.0% below. The CEC values are low (13.6 to 17.1 cmol (p^+) kg^{-1}) due to coarse soil texture (sand 62.0 to 68.8%). The ESP values and the presence of carbonate and bicarbonate salts showed complex saline-alkaline nature. The soil needs installation of sub-surface drainage (SSD) to lower the water table depth below the root zone and reduce soil salinity. Alternately it can also be used for aquaculture

Strongly sodic soil (Pedon 10) is located at the old alluvial plain of Ghaggar in Central Haryana (Block Siwan) and is currently used for forestry, medicinal and aromatic plantations. The soil texture varies from loam to silty loam while strong to medium soil structure and pale yellow to dark yellowish brown color at surface and sub-surface depths resulted due to high soil sodicity and impaired drainage. The pH and ESP values range from 9.6 to 10.8 and 75.9 to 96.7 at surface and subsurface depths, respectively. The high Na^+ (117.0 to 193.0 me L^{-1}) and CO_3^{2-}+HCO_3^- (20.0 to 44.5 me L^{-1}) contents favored strong sodicity development. The higher soil salinity (9.2 to 13.7 dS m^{-1}) has resulted from irrigation of salty (high RSC) groundwater. The CEC values are low due to loamy soil texture (sand 61.1 to 64.7%). The soil needs suitable dosage @10 to 12 t ha^{-1} of gypsum application to neutralize CO_3^{2-}+HCO_3^- and reduce ESP. The arable cropping (rice-wheat) is suggested after reclamation.

6.5 WATER QUALITY STUDY

The physico-chemical properties of groundwater samples are presented in Table 6.4. The depth of groundwater table ranges from 76–83 m in Kaithal block, 19–21 m in Kalayat, 76–91 m in Guhla and Siwan blocks, respectively. The water samples of Kaithal block (PW 1 to 4) showed neutral to sodic pHiw (7.6 to 8.3) and dominance of carbonate and bicarbonate (8.5 to 10.5 me L^{-1}) of sodium (9.9 to 17.7 me L^{-1}), calcium and magnesium (8.0 to 10.0 me L^{-1}). PW 5 is saline (EC 12.7 dS m^{-1}), high SAR (33.6) and showed the dominance of Na^+ (164.8 me L^{-1}), $Ca^{2+} + Mg^{2+}$ (48.0 me L^{-1}), Cl^- (80.0 me L^{-1}) and SO_4^{2-} (54.8 me L^{-1}). PW 6 is sodic (pH 9.3) and high RSC (6.5) appeared due to higher $CO_3^{2-} + HCO_3^-$ (8.5 me L^{-1}) and Na^+ (9.9 me L^{-1}). The PW 7 to 13 showed sodic pH (8.6 to 9.3), high SAR (5.5 to 23.4), at places high RSC (1.0 to 12.7 me L^{-1}) and is dominated by the Na^+ (6.8 to 14.1 me L-1) and $CO_3^{2-} + HCO_3^-$ (2.5 to 15.7 me L^{-1}), Cl^- (1.7 to 20.0 me L^{-1}) and SO_4^{2-} (0.4 to 8.8 me L^{-1}) ions. The water samples (PW 7–12) showing low contents of $CO_3^{2-} + HCO_3^-$ and high SAR, can be used mixing with good quality water. PW 6 and 13 should be treated with gypsum for neutralizing residual $NaHCO_3$. PW 5 showing high SAR may be used alternately with good quality water. PW 1–4 is suitable for irrigation of salt resistant varieties.

6.6 DISTRIBUTION OF SALT AFFECTED SOILS

The area under different categories of salt affected soils was computed based on the statistics derived in Geographic Information System (GIS) (Table 6.5). Six categories of salt affected soils were identified and these are distributed in four blocks (Kaithal, Kalayat, Pundri and Rajound) of Kaithal subdivision. In Kaithal block, sodic soils (6122 ha) are dominating where sodic groundwater is used for irrigation. These are slight (4313 ha) and moderately (1809 ha) sodic in nature. Saline soils (804 ha, 0.3%) are also located at selected places only in the lower topographic zone (Figure 6.4). Saline soil is dominant (4620 ha, 2%) in the irrigated areas of Kalayat block. The patches of sodic soils (1452 ha, 0.6%) are also found in the adjoining areas. Saline soils (3063 ha, 1.3%) were dominant in irrigated areas of Rajaund block. Salt affected soils covered 4891 ha (2.1%) in Pundri block, these are primarily sodic (4723 ha, 2%) and saline (168 ha, 0.07%). Saline (1415 ha, 0.61%) and

TABLE 6.4 Quality of Groundwater Samples from Kaithal District

S. No	Location, source and depth of groundwater	pHiw	ECiw dS m^{-1}	Na^+ (me L^{-1})	K^+	Ca^{2+}+ Mg^{2+}	CO_3^{2-} + HCO_3^-	Cl^-	SO_4^{2-}	RSC	SAR
Water samples from Kaithal sub-division											
1	Vill.Mundri Block Kaithal (76 m)	8.3	1.1	10.3	0.06	10.0	9.0	10.0	tr	tr	4.8
2	Vill. Mundri Block Kaithal (83 m)	8.3	1.1	10.3	0.05	10.0	9.5	15.0	tr	tr	4.7
3	Vill.Sampli Kheri Block Kaithal (76 m)	7.6	1.1	9.9	0.08	8.0	10.5	12.0	tr	tr	4.9
4	Devigarh farm (HAU) Kaithal Seepage water	7.2	2.3	17.7	0.01	10.0	8.5	16.0	7.1	tr	7.9
5	Vill. Kolekha Block Kalayat (19–21 m)	7.6	12.7	164.8	0.05	48.0	5.0	80.0	54.8	tr	33.6
6.	Vill. Bhaini Majra Block Kaithal (83 m)	9.3	1.2	9.9	0.07	2.0	8.5	3.0	tr	6.5	9.9
Water samples from Guhla and Siwan blocks											
7	Vill. Sehun Majra, Block Guhla, 76 m	8.6	1.3	10.6	0.1	3.0	2.5	10.0	8.8	tr	8.6
8	Vill. Kheri Daban, Block Guhla, 76 m	9.1	1.3	12.6	0.1	1.5	2.5	10.0	6.4	1.0	14.5
9	Vill. Hansu Majra, Block Guhla, 76 m	9.3	1.4	14.1	0.1	1.0	3.0	6.0	4.7	2.0	19.9
10	Vill. Majri, Block Guhla, 91 m	9.1	1.2	12.1	0.1	2.0	4.0	20.0	2.9	2.0	12.1
11	Vill. Tatiana, Block Guhla, 91 m	9.1	1.6	16.6	0.1	1.0	3.0	5.0	7.7	2.0	23.4
12	Vill. Kamheri Block Guhla, 91 m	8.8	0.8	6.8	0.1	3.0	2.5	3.0	0.4	tr	5.5
13	Vill. Bichian, Block Siwan, 83 m	8.8	1.1	13.9	0.1	2.9	15.7	1.7	tr	12.7	11.5

TABLE 6.5 Distribution and Extent (ha) of Salt Affected Soils in Kaithal District

Name of the block	Categories of Salt Affected Soils						Total area	% of TGA
	Modera-tely saline	Mode-rately sodic	Slight-ly saline	Slight-ly sodic	Strong-ly saline	Strong-ly sodic		
Kaithal sub-division								
Kaithal	148	1809	50	4313	606	tr	6926	3.0
Kalayat	935	1306	1335	146	2350	tr	6072	2.6
Pundri	tr	1682	168	3041	tr	tr	4891	2.1
Rajaund	tr	09	2028	51	1026	tr	3114	1.3
Sub-total	1083	4806	3581	7551	3982	tr	21002	9.0
Guhla and Siwan blocks								
Guhla	tr	73	1415	1015	tr	143	2646	1.1
Siwan	tr	tr	255	143	tr	2255	2653	1.1
Sub-total	tr	73	1670	1158	tr	2398	5299	2.3
Grand total	1083	4879	5251	8709	3982	2398	26301	11.3

TGA = Total Geographical Area of Kaithal district.

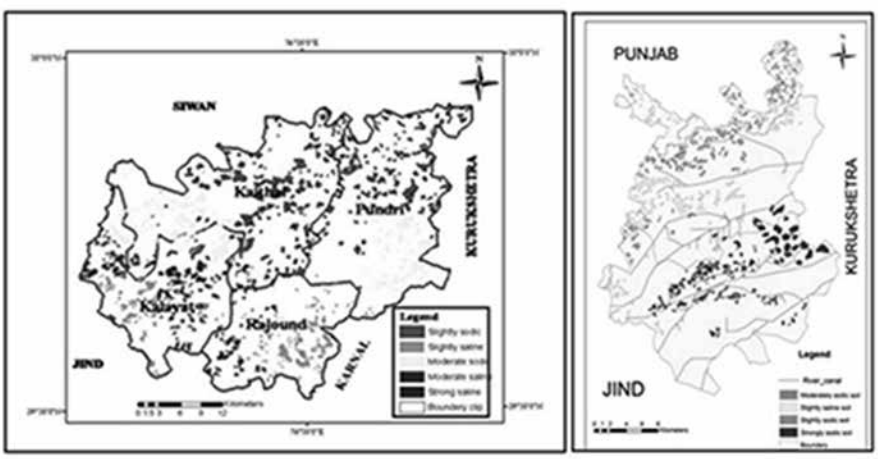

FIGURE 6.4 Distribution of salt affected soils in Guhla and Kaithal sub-divisions (Kaithal district).

sodic (1015 ha, 0.44%), soils are distributed in Guhla sub-division (Figure 6.4) covering Guhla and Siwan blocks of Kaithal district. Slightly saline and sodic soils are distributed in the irrigated areas and covered 1415 ha (0.61%) and 1015 ha, (0.44%), respectively. Strongly (143 ha, 0.06%) and moderately sodic (73 ha, 0.03%) are located along the Ghaggar plain. Salt affected soils covered 2653 ha (1.1%) in Siwan block, strongly sodic (2255 ha, 0.97%) soils are distributed along the Paleo-channel of the Saraswati river while slightly saline (255 ha, 0.1%) and slightly sodic (143 ha, 0.06%) soils are also found in the irrigated areas. Thus, 26301 ha (11.3%) is salt affected in Kaithal district, in which 6.8% (15,986 ha) and 4.4% (10,315 ha) areas are sodic and saline in nature.

6.7 CONCLUSIONS

The integrated approach of Indian Remote Sensing data interpretation with ground truth and laboratory studies facilitated the mapping and characterization of salt affected soils in Kaithal district of Central Haryana. Strongly salt affected soils were identified due to high reflectance of salty surfaces while moderate and slightly salt affected soils with mixed spectral signatures were detected in combination with ground truth and soil characteristics. The physico-chemical characteristics of salt affected soils showed complex saline and sodic nature. The dominance of carbonates and bicarbonates of sodium and higher ESP favored alkalization of soils in the Ghaggar plain. The concretionary calcium carbonate layer at sub-surface depths indicated precipitation and deposition under alkaline condition. The sodic soils are detected in the Ghaggar plain and along the paleo-channel of river Saraswati, while the saline soils are found in the irrigated region. Coarse soil texture and poor internal drainage in Kalayat block caused waterlogging and soil salinization in the irrigated region. The use of poor quality groundwater for irrigation caused salt enrichment in Kaithal block. The water samples of Kaithal and Siwan blocks are sodic and at places with high RSC, the quality of water samples in Guhla block is sodic with high SAR. Suitable management and land uses options are suggested for growing salt resistant crops, horticulture and forestry plantations with proper water management practices. The poor quality groundwater needs prior treatment for removal of salts injurious to plants.

KEYWORDS

- **Alkalinity**
- **GIS**
- **Reclamation**
- **Remote Sensing**
- **Salt Affected Soils**
- **Soil Salinity**
- **Trans-Gangetic Plain**
- **Water Quality**

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