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Delineation and Characterization of Waterlogged Salt Affected Soils in Loonkaransar Area of IGNP for Reclamation and Management

A.K. Mandal* and R.C. Sharma

ICAR-Central Soil Salinity Research Institute, Karnal, Haryana 132 001, India

Abstract: The Indian Remote Sensing (IRS LISS II) data on 1:50,000 scale showed prominent waterlogging as surface ponding in sandy flats and depressions along the Loonkaransar lift canal under the Indira Gandhi Nahar Pariyojona (IGNP). The seasonal data revealed higher extent of waterlogging in February and mixed spectral signatures of high moisture content with poor crop stand in November and permanent waterlogging (close to the lift canal) in June data. Ground truth survey revealed the presence of shallow aquifer (water table depth <1.5 m) condition, patchy crop stand, moist soil profile and soil salinization. The occurrence of fluctuating (1.5-6.0 m) water table depth during dry and wet cycles and poor cop stand in irrigated areas showed the presence of potential waterlogging zones. Moderate to high soil salinity were found at surface soil located in low-lying flats and higher salinity at sub-surface depth (control section, 0.2-0.8 m) of soil profiles indicating initiation of secondary salinization. The layer of calcium carbonate was present at a depth below the surface. The chlorides and sulfates of sodium, calcium and magnesium were dominant salts in the study area. The water quality of drainage effluents was extremely poor and may be used with good quality of water either in cyclic and mixing mode. The quality of ponded and subsurface profile water moderate and are fit for reuse.

Key Words: Waterlogging, soil salinity, remote sensing, GIS, visual interpretation.

The commissioning *Indira Gandhi Nahar Pariyojona* (*IGNP*) introduced canal irrigation for nearly 2.2 Mha of arid lands in the NW part of Rajasthan State (FAO/UNDP 1971). Continuous irrigation in sandy soils and lack of natural drainage resulted in waterlogging and soil salinization in the irrigated areas (Shankarnarayana and Gupta, 1991). The fluctuating water table during wet and dry cycles and arid climate further enhanced soil salinization (Hooja *et al.,* 1995). Indian Remote Sensing data was used for monitoring waterlogging and salt affected soils in the irrigated regions of varied agro-eco-regions of the country (Khan *et al.,* 2005; Dwivedi and Sreenivas, 2002; Dwivedi *et al*., 1999; Dwivedi and Sreenivas, 1998; Mougenot *et al.,* 1993). IRS data was successfully used to delineate salt affected and waterlogged soils in the irrigated areas of Western Yamuna Canal in Haryana, Sharda Sahayak in Uttar Pradesh and Nagarjunsagar in Andhra Pradesh (Sharma *et al.,* 2000; Sharma and Bhargava, 1988; Sujatha *et al*., 2000, Kalra and Joshi, 1996; Mandal and Sharma, 2008). Computerized analysis of digital data was also used for spectral classification and mapping of salt affected and waterlogged areas at the country and global scale (Chaube, 1998; Dwivedi and Sreenivas, 1998, Khan *et al.,* 1999). Permanently and seasonally waterlogged areas were successfully mapped with remote sensing data (Kaluberme *et al*., 1983; Mandal and Sharma, 2001, Mathur *et al.,* 1996) while mapping of areas with high water table is yet to be accomplished. An attempt was therefore made to delineate waterlogged and salt affected soils in the irrigated areas of Loonkaransar lift canal (IGNP) using remote sensing.

Materials and Method

Study area

The study area (66,400 ha) lies between 28°25′N and 28°45′N latitude and 73°35′E and 74°00′E longitude and is situated above 180-200 m above msl (Fig. 1). Currently, it is irrigated by the Loonkaransar lift canal of IGNP (Indira Gandhi Nahar Pariyojona). A significant area was used as pasture land used for grazing purposes. The availability of water for irrigation caused a shift in land uses such as mustard in winter and cotton in summer seasons. The soils moisture and temperature regimes are reported as Ustic and Hyperthermic (FAO/UNDP, 1971). The moderate to severe wind erosion are common soil degradation. Sandy

*E-mail: akmondal@cssri.ernet.in

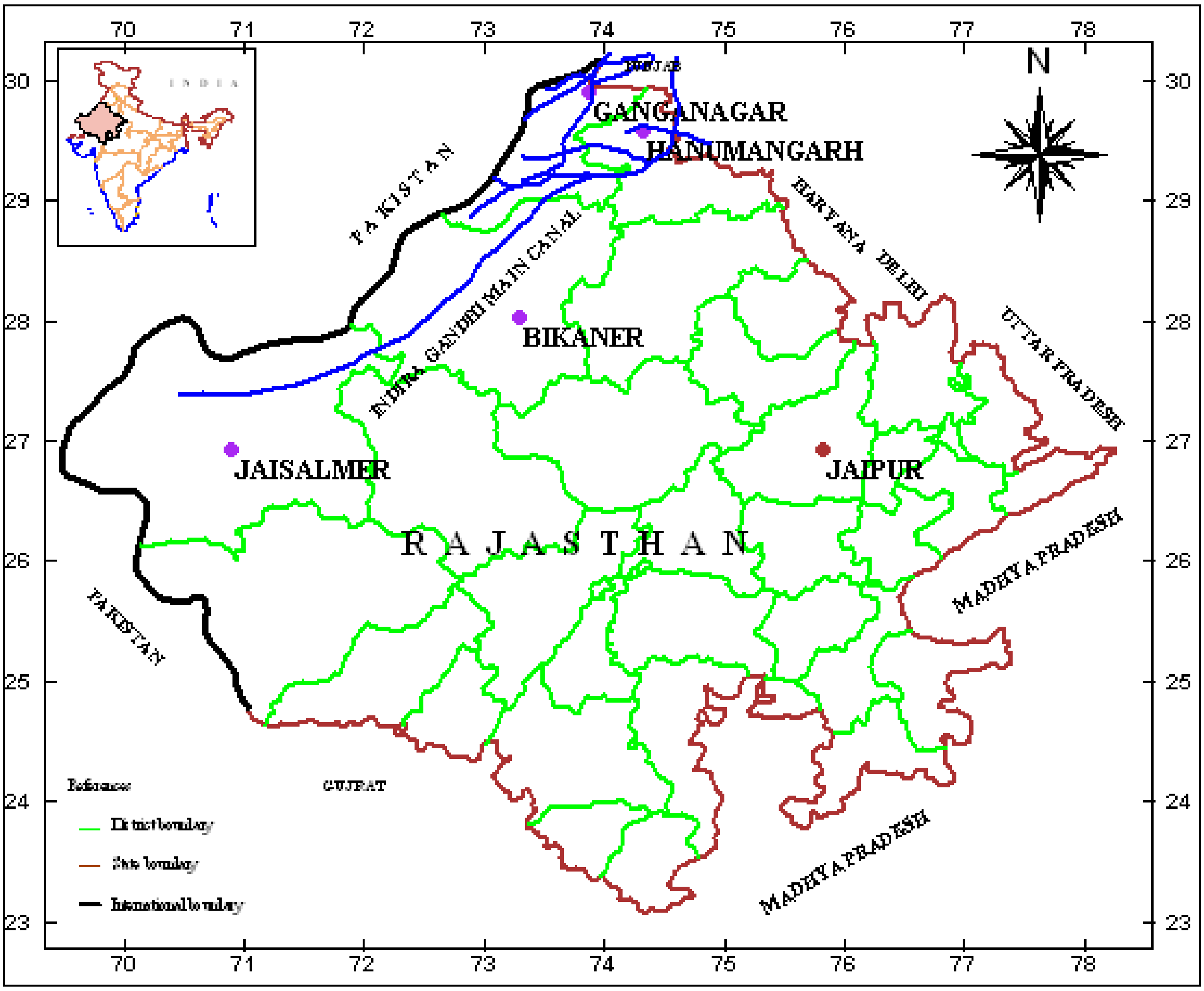


Fig. 1. Location map of Indira Gandhi Canal Command, Rajasthan, India.

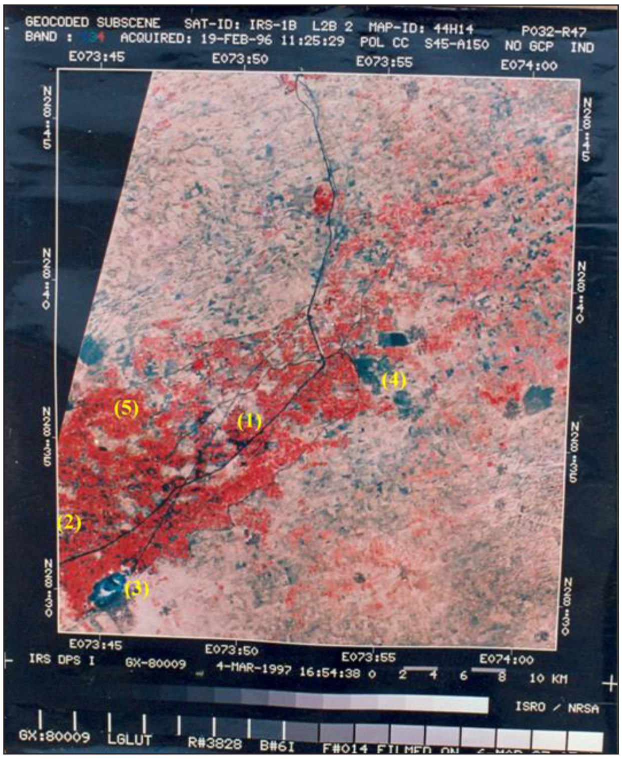
plain, dunes, depressions and flats are common landforms (Singh and Kar, 1991). The water table depth is reported rising @ 1-2 meters per year (Hooja *et al.*, 1995). Flood irrigation practice, canal seepage, sandy soil texture and absence of natural surface drainage are major limitations for irrigated agriculture.

Data and software used

IRS LISS II geo-coded imageries (FCC, bands 432) for February, November and June 1996 seasons, the Survey of India topographical maps on 1:50,000 scale and other ancillary information such as water table depth, water quality, soil survey reports etc. were used for visual image analysis for waterlogged and salt affected areas (Table 1). The digital data for February 1996 was also used for detailed analysis and classification. The software ILWIS (Integrated Land and Water Information System, ver 3.3) was used for image processing, digitization, map calculations and overlaying multiple data layers for image interpretation and output generation.

Table 1 Particulars of satellite imageries

Sensor	Spectral resolution	Spatial resolution	Image/SOI topo map No. and scale	Period
IRS-IB LISS II	B1 0.45-0.52 (Blue) B2 0.52-0.59 (Green) B3 0.62-0.68 (Red) B4 0.77-0.86 (NIR)	36.25 m Swath 148 km No. of Pixel/ha 7.61 Path-Row 32-47	44 H10, 44 H11, 44 H14 FCC: Geo-coded sub-scene Scale 1: 50,000 scale	February 1996, November 1996 June 1998 Digital data: February 1996



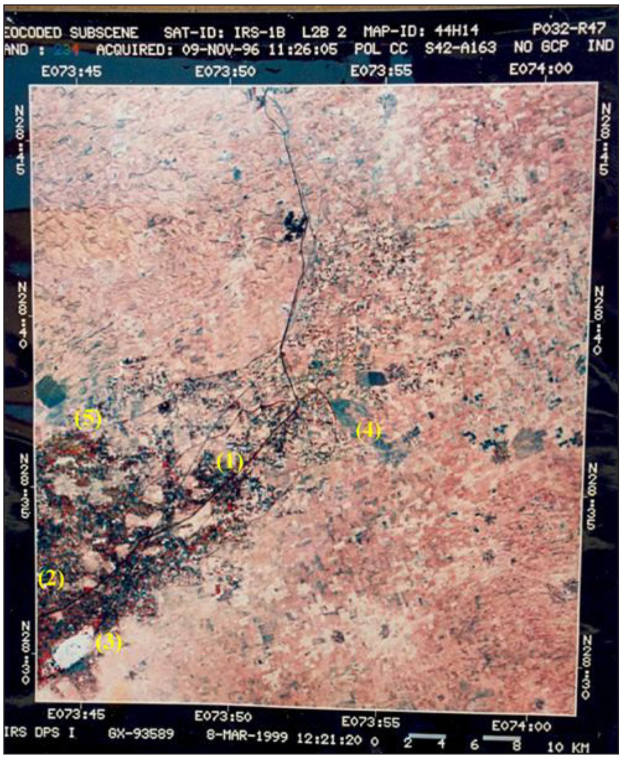


Fig. 2. IRS February imagery showing waterlogged areas in the IGNP (Loonkaransar) command.

Fig. 3. IRS November imagery showing waterlogged and salt affected areas.

Legends: (1) = Waterlogged (surface ponding), (2) = Waterlogged and salt affected (3) = Salt affected (Selenite deposit), (4) = Pasture land, (5) = Normal cropped.

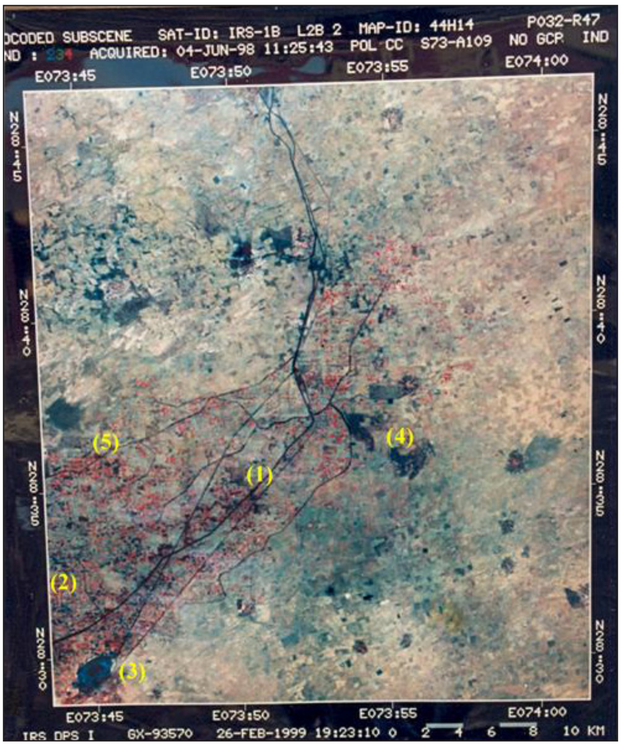


Fig. 4. IRS June imagery showing permanent waterlogged areas.

Geo-referencing, image processing and basemap preparation

The survey of India topomaps on 1:50,000 scale were used for geo-referencing and generate thematic layers of administrative and political boundaries (State/district); irrigation and drainage; infrastructure (roads, railways) and settlements (State/district HQs). These were overlaid to prepare a base map of the study area. IRS (digital) imageries were geo-referenced and geo-coding using UTM coordinate system. IRS imageries were interpreted visually based on the tone, texture pattern, sizes etc. and the seasonal data were used to study the dynamics of waterlogging and soil salinity (Figs. 2, 3 and 4). The interpreted units were delineated using ILWIS software (Fig. 5). The area statistics were prepared to assess spatial extent of soil degradation

Field survey and characterization of soil samples

Ground truth survey was carried out conducted for field validation of the interpreted

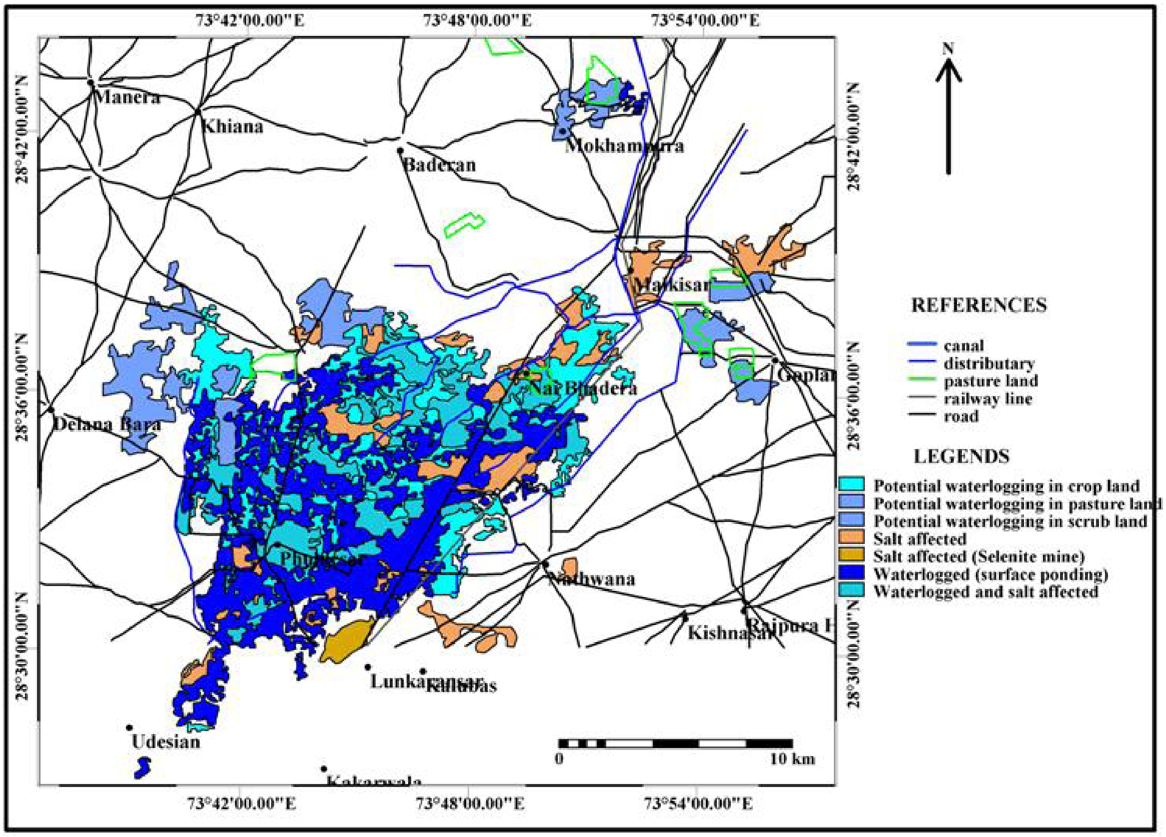


Fig. 5. Distribution of waterlogged and salt affected soils in Loonkaransar (IGNP) canal command.

units during March and November seasons. The auger bores and soil profiles were studied to assess surface and sub-surface soil salinity and waterlogging status. The water table depths data were also recorded from the piezometer, tube wells and open dug wells (Table 2). The soil morphological characteristics were studied to assess soil salinity, moisture content, drainage etc using standard procedure (Soil Survey Division Staff, 2004). The depth-wise soil samples were collected from the master horizons for laboratory determination of physico-chemical characteristics (Table 4). The water samples were collected from the accumulated (ponded) seepage lakes (*Tal*), auger bore and drainage sump/pits (Table 5). The water table depths were also recorded during the auger bore and profile studies. Standard methods

Table 2 Spatial characteristic of interpreted units in Loonkaransar canal command area

Interpreted units	Land use/ land cover	Image tone	Range of soil properties		
			pHs	ECe (dS m^{-1})	Depth of water table (m)
Waterlogged (surface ponding)	Stagnant water and scattered growth of aquatic grasses	Dark blue/blue-black	7.9-8.4	8-21	Surface water
Waterlogged and salt affected soils	Partially cropped with low vegetative growth	Dark grayish red	7.5-8.5	5-15	<1.5 m
Potential waterlogging zone	Moderately dense crop	Reddish gray	7.5-8.2	5-10	1.5-6.0 m
Salt affected soil	Presence of salt crust, grasses, bushes, shrubs	Grayish white/ yellowish white	8.5-9.2	5-15	<3.0 m
Irrigated crop	Normal vegetation	Red to dark red	7.0-7.5	2-5	>3.0 m
Pasture and scrub land	Grasses, shrubs, bushes with clear boundary	Red mottling with green tinges	6.5-7.5	2-4	>2.5 m

Table 3. Extent of area in waterlogged and salt affected soils in Loonkaransar

Land use classes	Area (ha)	% TGA*
Ponded water	7281	11
Waterlogged and salt affected	3450	5
Potential waterlogging zone	7559	11
Salt affected + selenite deposits	2894	4
Total	21184	31

*TGA= Total geographical area.

were followed for determining mechanical composition, calcium carbonate, and cation exchange capacity (Jackson, 1967). Saturation extract of soils samples were analyzed for pHs, ECe, soluble cations and anions (Richards, 1954). Water samples were analyzed for pH, EC_{iw}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^- and SAR [Sodium Adsorption Ratio = $Na^+/(Ca^{2+}+ Mg^{2+}/2)^{1/2}$] for quality appraisal (Table 4) using standard methodology (Richards, 1954).

Results and Discussion

Image interpretation and ground truth

Visual interpretation of IRS data (FCC) identified waterlogged areas (surface ponding) appearing as irregular shape with dark blue to black tone commonly confined in the low-lying flats and depressions (Table 2). The Band 4 (NIR) data confirmed waterlogging appearing in dark gray to black tones for higher absorption against surface water stagnation. The pre-(February), post-monsoon (November) and summer (June) data showed dynamics of waterlogging, higher during February and November seasons (Figs. 2, 3 and 4). The bright red tones indicated normal cropped area with moderate vigor during February, scattered during November and scanty in June data. The extent of waterlogging was higher in February due to less evaporation and higher irrigation applications for agricultural operations (Mandal and Sharma, 2001). The mixed spectral signatures ranging from grayish to dark grey tones with red mottles due to poor crop stand and low vegetative growth indicated areas with potential waterlogging. Ground truth study indicated the high (<1.5 m) and fluctuating (1.5 to 6.0 m) water table depth and poor crop growth. These were classified as potential waterlogging zone.

Salt efflorescence was identified as grey to yellowish white tone in irregular patches around the waterlogged areas (Table 2). Ground truth study revealed higher salt accumulation in November due to freshly precipitated salts and higher evapotranspiration (Mandal and Sharma, 1997). Salt crust was also found as barren areas, discontinued from agricultural operations. High soil salinity was found in basin land due to prolonged salt accumulation through surface runoff. Strong spectral signature for patchy selenite deposit (239 ha) was shown close to the command area. At places, the in-situ mixture of sand and salt resulted due to strong aeolian activity. The moist soil surface in the irrigated areas rendered identification of salt affected soils in the satellite imageries (Mandal and Sharma, 2010). The area statistics showed that permanent waterlogged (surface ponding) and waterlogged salt affected soils covered 10731 ha (16%). The salt crust and selenite deposits covered 2894 ha (4%) and the potential waterlogging areas with high water table depth covered 7559 ha (11%). Thus a total area of 21184 ha (31%) of the command area is degraded due to waterlogging and soil salinization (Table 3).

Soil characteristics

The salient characteristics of five pedons were presented to show salt content and its composition and also the pedogenic nature of soils (Table 4). Morphological characteristics showed coarse texture ranging from loamy sand to sandy loam, weak (single grained) to moderately strong (sub-angular blocky) structure, weak consistence (loose to friable) and few to abundant $CaCO_3$ nodules. A few iron and manganese mottlings were also found around the micro-pores in subsoil horizons due to waterlogging. Presence of *kankar* layer ($CaCO_3$ concretion) was observed at a depth of 1 m below the surface. It has restricted percolation, internal drainage and infiltration and thereby facilitated the formation of a perched water table close to the surface. In the irrigated areas, soil profiles were generally moist at surface and wet within the control section. A poor horizon development and mixing of soil particles by strong aeolian activity showed the presence of alluvial parent material. The accumulation of finer soil particles below the surface layer also caused low permeability. The sandy soil texture facilitated upward movement of water table and capillary rise of salts to develop secondary soil salinity within the root zone. Such process,

Table 4. Physico-chemical properties of soils in Loonkaransar canal command area

Depth (Horizon) (cm)	pHs	ECe (dS m^{-1})	Na^+	Ca^{2+}+ Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3	$CaCO_3$	O.M.	ESP	Sand	Silt	Clay	CEC c. mol. (p^+) kg^{-1}
			me L^{-1}					%						
Pedon 1: Vil. Loonkaransar (28°31′05″N, 73°45′22″E), barren, water table depth 1.5 m, Typic Torripsamments*														
0-19 (A1)	8.0	3.9	21.8	20.0	8.5	5.6	1.0	2.18	0.68	19	85.4	8.32	6.24	5.61
19-66 (C1)	8.1	1.4	7.4	9.0	10.0	1.0	2.5	3.03	0.42	21	86.2	5.91	7.88	4.89
66-96 (C2)	8.0	1.1	3.3	11.0	10.0	0.2	1.5	5.06	0.16	17	91.1	4.43	4.43	8.51
96-125+(C3)	8.3	0.9	4.4	8.0	5.0	0.4	3.0	6.05	0.16	17	91.2	4.35	4.35	4.20
Pedon 2: Vil. Loonkaransar (28°31′49″N, 73 °45′26″E), barren, water table depth 1.2 m, Typic Torripsamments*														
0-22 (A1)	8.5	0.4	1.0	4.0	1.5	trace	0.5	1.00	0.36	11	95.9	2.1	4.0	3.60
22-76 (C1)	8.2	0.6	0.9	8.0	2.5	trace	0.5	0.55	0.29	12	94.0	2.0	4.3	7.80
76-105 (C2)	8.8	6.2	38	8.0	12.0	7.6	1.5	4.00	0.29	10	91.5	2.2	4.9	8.90
105-147 (C3)	8.4	10.2	62.4	10.0	65.0	8.4	1.5	8.00	0.22	15	93.0	4.3	4.5	6.40
147-160+(C4)	9.9	1.6	10.5	4.0	5.0	7.4	1.5	11.30	0.68	14	90.9	4.5	4.6	4.20
Pedon 1: Pedon 3: Vil. Badhera (28°36′10″N, 73°49′14″E), barren, water table depth 0.75 m, Typic Torripsamments*														
0-7 (A1)	7.4	142.0	1150.9	400	1919	363.2	Nil	1.8	0.68	17	93.1	2.3	4.7	4.20
7-43 (C1)	7.8	24.5	109.9	139	255.0	30.0	Nil	3.4	0.55	21	91.5	2.1	6.3	6.70
43-65 (C2)	7.9	23.0	120.2	128	223.5	19.6	1.0	4.7	0.55	17	93.5	2.2	4.3	4.70
65-115+(C3)	7.9	18.7	89.5	100	187.0	12.0	1.0	5.1	0.55	15	91.5	4.2	4.3	4.60
Pedon 4: The. Loonkaransar (28°31′03″N, 73°45′20″E), water table depth 1.5 m, patchy growth of mustard crop, Typic Torripsamments*														
0-15 (Ap)	7.9	7.5	24.4	43	46.5	4.6	1.0	1.4	1.74	19	91.4	2.13	5.53	4.23
15-30 (C1)	8.3	3.6	19.0	12	17.5	6.6	2.0	0.5	2.58	21	87.1	4.27	5.98	6.98
30-60 (C2)	8.2	8.7	47.2	48	20.5	11.6	1.0	6.6	0.48	15	91.3	4.32	4.32	4.62
60-90 (C3)	8.2	11.5	77.5	21	86.0	3.4	1.0	7.6	0.36	16	91.2	4.35	4.35	4.34
Pedon 5: Vil. Badhera (28°36′09″N, 73°49′11″E), water table depth 0.5 m, Eucalyptus plantation, Typic Torripsamments*														
0-30 (A1)	9.3	6.13	35.4	10.0	36.0	---	12.5	2.6	0.62	8	95.6	2.17	2.17	3.33
30-60 (C1)	8.4	2.29	14.4	8.0	15.0	1.6	1.5	7.1	0.62	5	95.3	2.32	2.32	3.91
60-90 (C2)	8.6	1.38	5.1	16.0	7.0	4.4	2.0	8.6	0.62	6	95.6	2.17	2.17	3.33

(*Shyampura *et al.*, 2002)

when occurring continuously for longer period, caused severe salinization as surface salt efflorescence and salt crust, restricting all agricultural operations. The physico-chemical characteristics data showed that pHs values were in general ranging between near neutral to moderate alkalinity (7.4 to 9.3) at surface but strong alkalinity (pHs 9.9) at lower depth (Pedon 2). The ECe values were low (0.4 to 2.3 dS m^{-1}) at surface soil of Pedon 2 and at subsurface depths in Pedon 1 and Pedon 5; moderate (3.6 to 10.2 dS m^{-1}) at surface soil in Pedon 1 and 5 and in the control section (15-60 cm) of Pedon 2 and 4; high (11.5 to 24.5 dS m^{-1}) at sub-surface depths (7-115 cm) of Pedon 3 and 4; and very high (142.0 dS m^{-1}) at surface soil (0-7 cm) in Pedon 3, indicating abrupt changes occurred due to interventions of irrigation. The ECe values decreased from surface to sub-surface depths in Pedon 1 (3.9 to 0.9 dS m^{-1}), Pedon 3 (142.0 to 18.7 dS m^{-1}) and Pedon 5 (6.13 to 1.38 dS m^{-1}). Contrarily, the ECe values increased in Pedon 2 (0.4 to 10.2 dS m^{-1}) and Pedon 4 (3.6 to 11.5 dS m^{-1}) apparently showing transportations of salts from the parent materials. The higher contents of Cl^- (187.0 to 1919.0 me L^{-1}), SO_4^{2-} (12.0 to 363.2 me L^{-1}), Na^+ (89.5 to 1150.9 me L^{-1}) and Ca^{2+}+ Mg^{2+} (100 to 400 me L^{-1}) in Pedon 3 indicated the possibility of salt transport from the nearby selenite deposit. The Na^+ (24.4 to 77.5 me L^{-1}) and Cl^- (46.5 to 86.0 me L^{-1}) contents at sub-surface depths and variable Ca^{2+}+ Mg^{2+} (12 to 48 me L^{-1}) and SO_4^{2-} (3.4 to 11.6 me L^{-1}) contents in Pedon 4 indicated the presence of sodium bearing parent materials. Pedon 2 showed similar results of Na^+ (0.9 to 62.4 me L^{-1}), Ca^{2+}+ Mg^{2+} (4.0 to 10.0 me L^{-1}), Cl^- (1.5 to 65.0 me L^{-1}) and HCO^- (0.5 to 1.5 me L^{-1}) contents. The soil texture ranges from loamy sand to sandy loam in all Pedon and the organic matter content was low in general. The CEC values were low due to coarse soil texture and also indicated the presence of non-expanding minerals or mixed mineralogy. The low ESP values ranging from 5 to 21 indicated low alkalinity.

Water quality

As result of surface irrigation, considerable amount of seepage occurred in the irrigated areas which resulted formation of lakes (*Tal*) inundating good agricultural lands. The chemical characteristics of water samples collected from various source were presented to show the salt content and composition for quality appraisal (Table 5). The drainage water (Agriculture Research Farm at Loonkaransar) showed high EC (30.66 dS m^{-1}) and SAR (90.2) due to salt enrichment with Na^+ (285.2 me L^{-1}), Cl^- (286.0 me L^{-1}) and SO_4^{2-} (35.0 me L^{-1}) ions. The ponded water (seepage *Tal* showed moderate EC (3.96 dS m^{-1}) and SAR (13.1). These samples also showed alkaline reaction (pH 8.5 to 8.8) possibly due to the presence of bicarbonate ions (11-12 me L^{-1}). These can be reused with good quality of water either in cyclic or mixing mode for crop production. The auger bore water showed moderate EC (3.06 dS m^{-1}) and SAR (6.78) and can be used safely for irrigation purposes.

Soil reclamation and management options

Based on the physico-chemical characteristics data, the pedons 4 and 5 with moderate salinity could be used for salt tolerant crops following salt leaching. Pedon 1 and 2 were characterized as low to moderately saline and loamy sand texture. These may be used for arable cropping with proper soil and limited water application practices. Pedon 3 showing high to very high salinity should be drained through the installation of subsurface drainage and salt leaching before using for agricultural purposes.

Table 5. Water quality in Loonkaransar canal command area

EC (dS m^{-1})	pH	Na^+	K^+	Ca^{2+}+Mg^{2+}	CO_3^{2-}+HCO_3^-	Cl^-	SO_4^{2-}	SAR
		me L^{-1}						
Drainage water: Loonkaransar, Dist. Bikaner 28°31′05″N, 73°45′22″E								
30.66	8.5	285.2	0.52	20.0	11.0	286.0	35.0	90.2
Auger bore (150 cm): Teh. Loonkaransar, Dist. Bikaner (28°36′09″N, 73°49′11″E)								
3.06	7.33	16.4	0.06	12.0	4.0	18.0	8.0	6.78
Ponded water: Vill. Badhera, Teh. Loonkaransar, Dist. Bikaner (28°36′10″N, 73°49′14″E)								
3.96	8.8	29.3	0.39	10.0	12.0	17.5	10.0	13.1

Conclusion

The waterlogged and salt affected soils in the irrigated areas of Loonkaransar lift canal (IGNP) were detected and mapped using visual analysis of temporal IRS LISS II data integrated with ground truth and soil studies. The permanent waterlogged, highly salinized and normal cropped areas were detected from the satellite imageries due to higher reflectance. The areas showing mixed pixel composition were characterized on the strength of ground truth. Field soil studies revealed high and fluctuating water table depth and moderate to severe soil salinization, coarse soil texture and the presence of sub-surface $CaCO_3$ layer. The salt composition indicated dominance of Na^+, Ca^{2+} and Mg^{2+}, Cl^- and SO_4^{2-} ions. The areas showing high and fluctuating water table depth were characterized as potential waterlogging zone. The reclamation and management options for waterlogged and salinized soils were also discussed

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