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Assessment and Mapping of Salt Affected Soils using Remote Sensing and GIS in Southern Districts of Haryana State

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1.0 Introduction

An estimate of the global distribution of saline and sodic soils indicates that 351.5 mha are saline, 581.0 mha are sodic and together they are present over 932.5 mha across the globe (Szabolcs 1989). More recent estimates indicate the presence of nearly 1.0 billion hectares, which represent about 7% of the earth's continental extent (Ghassemi et al.1995). These salty soils are either naturally occurring/ geogenic in nature and have formed due to natural weathering of salt bearing soil minerals or may alternatively have been human induced. The presence of salt-affected soils and poor quality water may also be influenced by topography, geology, soil texture, drainage, hydrology, irrigation source, groundwater depth and aquifer quality, and irrigation management practices. Managing soil and water resources and conserving them requires intense futuristic research to enhance the ability to predict the future. Since salinization is a dynamic process in space and time, detecting, monitoring and mapping of salt-affected soils are equally complex. A suitable and accurate method is required to urgently identify the salinization threat to normal lands by monitoring and mapping of salinity based on detailed diagnosis for effective management and implementation. Salt affected soils may be saline, alkaline or saline – alkaline in nature and may be of either geogenic origin or a result of secondary salinisation. Inevitably, soil salinity is a problem that generally occurs in the arid, semiarid regions and canal command areas limiting plant growth, resulting in poor yields and drastically affecting food production. Salinity/alkalinity levels in the field are extremely variable and in the absence of standardized criteria, accuracy in identification and inventory has been fraught with difficulty. These variable levels have compounded the ability to map, monitor and inventory salt affected lands. Remotely Sensed data and remote sensing techniques together with Geographical Information Systems (GIS) have provided the much needed tools for managing variables and spatial data. These efficient technologies include image processing and modeling with geo-informatics and ground truth and therefore present a valuable integrated approach for mapping and identification of salt affected soils. Studies based on remote sensing indicate that mapping can be done directly from bare soil in a timely and cost-effective manner for effective management and amelioration of salty lands. Singh *et al.*, 2010, Sethi *et al,* 2001, 2006 and 2012 used a combination of IRS satellite data and ground sensors to determine soil and plant properties for management of salty soils in Uttar Pradesh, Karnataka and in fields and villages of four districts in Haryana, India. They used sensors with GPS and krigging in GIS to define salinity levels within fields A primarily agrarian state, Haryana has 70% of residents engaged in agriculture. The state covers an area of 4.421 million hectares and has a population of 25.3 million. Located between 27°39' to 30°35' N latitude and 74°28' and 77°36' E longitude, the altitude varies between 700 ft to 900 ft above the mean sea level. Widespread salinity and alkalinity are present in the soils of most districts and in particular the south western Districts of Palwal, Mewat, Gurugram and Faridabad.

2.0 Climate

Haryana is extremely hot in summer at around 45 °C (113 °F) and has mild winters. The hottest months are May and June and the coldest December and January. The climate is arid to semi-arid with average rainfall of 354.5 mm. Almost 29% of rainfall is received during the months from July to September, and the remaining rainfall is received during the period from December to February and varies between 160-751 mm.

3.0 Physiography, Geology and Geomorphology

The four main geographical features of the state are the Shivalik Hills, Ghaggar Yamuna Plain, Semi-desert sandy plain and the Aravali hills. The rivers Saraswati, Ghaggar, Tangri and Markanda originate from the Shivalik Hills and flow towards the plains. The Ghaggar Yamuna Plain is made up mainly of sand, clay, silt and hard calcareous balls like gravel known locally as “kankar”. This plain forms the largest part of the state. The semi desert sandy plain and the dry hilly areas share Haryana's borders with Rajasthan. The land is flat, covered with loamy soil which is very suitable for agriculture. The state of Haryana and the adjoining areas are covered to a large extent by Quaternary sediments of alluvial/aeolian origin and made up of the sub-Himalayan system of rocks, mostly of the Siwalik Group. In the south and southwestern corner of Haryana bordering the state of Rajasthan the older rocks present are of the Delhi Supergroup interspersed by Quaternary sediments of alluvial/Aeolian origin. The geomorphic features include 1) High structural hills, 2) Moderate structural cum denudational hills, 3) Low structural-cum-denudational hills, 4) Older and younger piedmont zones, 5) Flood plain, 6) Older Alluvial surface, 7)Aeolian zone, 8) Transitional zone & 9) Upland tract. The river Yamuna flows all along the eastern boundary of the State. The other major river is the Ghaggar which has a well-defined palaeo-channel that is identifiable on satellite images.

4.0 Agriculture

The total geographical area of Haryana is 4.421 million hectare and the area under forest is 45000 hectare. The cultivable area is 3.809 million hectare (86.2%of total geographical area) and the net area sown is 3.566 million hectare (93.6% of cultivable area). The gross cropped area is 6.504 million hectare and the area sown more than once is 2.938 million hectare with the cropping intensity of 182.39%. The net irrigated area is 2.936 million hectare (By canals- 45.3%, by tube wells- 54.2% and by others –

0.5%). The gross irrigated area is 5.446 million hectare and the percentage of net irrigated sown area is 82.3%. The total number of land holdings is 15.28 lakh out of which 7.34 lakh (46.1%) are marginal farmers; average land holding is above 2 hectare. Haryana comes under the Agro Ecological Sub Region (ICAR) North Punjab plain, is a part of the Ganga-Yamuna Doab and Rajasthan upland, hot, dry, semi-arid eco-sub-region (4.1). According to the planning commission it is in Agro-Climatic Region Trans Gangetic Plain region (VI). NARP has put the districts of Panchkula, Ambala, Yamunanagar, Kurukshetra, Karnal, Kaithal, Jind, Panipat, Sonipat, Faridabad, Mewat, Palwal and parts of Rohtak, Jhajjar and Gurugram into Agro Climatic Zone (NARP) Western Zone (HR-2) (Table 1). Out of 4.42 million ha of total geographical area of the state, 0.232 m ha land is affected by salinity/sodicity which about 0.053% of TGA. As salinity is dynamic in nature so its estimation on regular interval is required for its extent and management point of view. In order to identify, assess and characterize salt affected soils in four districts in South of Haryana remote sensing, image processing and ground truth along with physical and chemical analysis were used for mapping salt affected soils and creation of digital maps in GIS. The study area covered 5 blocks and

Table 1. Agro Eco regions of Haryana

Agriculture profile				
1.1	Agro-climatic/Ecological Zone			
	Agro Ecological Sub Region (ICAR)		North Punjab plan, Ganga-Yamuna Doab and Rajasthan upland, hot, dry, semi-arid eco-subregion (4.1)	
	Agro-Climatic Region (Planning Commission)		Trans Gangetic Plain region (VI)	
	Agro Climatic Zone (NARP)		Western Zone (HR-2)	
	List all the districts falling under the NARP Zone		Panchkula, Ambala, Yamunanagar, Kurukshetra, Karnal, Kaithal, Jind, Panipat, Sonipat, Faridabad, Mewat, Palwal and parts of Rohtak, Jhajjar and Gurugram	
1.2	**Rainfall**	**Average (mm)**	**Normal Onset (week and month)**	**Normal Cessation (week and month)**
	SW monsoon (June-Sept)	619.9	I^{st} week of July	3^{rd} week of September
	NE Monsoon (Oct.-Dec.)	24.9	---	---
	Winter (Jan-March)	42.1		
	Summer (Apr-May)	45.6		
	Annual	732.5		

Table 2. Details of the study area

District	TGA	Rainfall	Blocks
Mewat	1860 sq km	577 mm	Nuh, Nagina, Punahna, F. Jirka, Taoru
Palwal	1359 sq km	567 mm	Palwal, Hathin, Hodal
Gurugram	1253 sq km	596 mm	Pataudi, Sohna, Gurugram and Farrukhnagar.
Faridabad	1792 sq km	537.1 mm	Faridabad and Ballabgarh

an area of 1860 sq km in Mewat, 3 blocks and 1359sqkm in Palwal, 4 blocks and 1253 sqkm in Gurugram and 2 blocks and 1792 sqkms in Faridabad (Table 2). A total of 127694 ha area in the 4 districts was not available to agriculture. The net area sown was the maximum in Palwal District in 2013-14 followed by Mewat, Gurugram and Faridabad, respectively (Table 3). The total net area sown in 4 districts was 323579 ha and area sown more than once was 221060 ha. The maximum area sown was in Palwal and least in Gurugram District. The total cropped area was 544624 ha in the districts.

All four districts have limited surface water, and a serious problem of salinization along with a severe shortage of fresh water and water logging. Groundwater is the primary source of fresh water, but available groundwater is limited to a few freshwater pockets and the remainder is saline. Saline groundwater cannot be utilized for domestic or agricultural purposes because of high levels of total dissolved solids (TDS). Despite this, most villagers continue to use saline water for their livelihoods. Many other problems arising from the limited freshwater supply are exacerbated by the mass extraction of fresh water, which is outpacing the rate of natural water recharge.

5.0 Features of Mewat District

The geographical area of the Mewat district (Fig. 1) is 1860 km^2 and consists of alluvial plains with elongated ridges and hillocks. Ridges and hillocks lie to the west, south, and east sides of the region creating a bowl-like shape. The hydrology of the area is characterized by flash runoff events whereby precipitation falling on the ridges and hillocks in the area is quickly conveyed as runoff into ephemeral streams, which settles in the central flats dominated by saline soils and brackish groundwater. The average rainfall varies from 336 mm to 440 mm in the district, with the maximum in July. Since there are no existing rivers in Mewat district, precipitation is the only source of fresh water for recharging the local and regional aquifers. Soils of the district are light in texture (i.e., sandy, sandy- loam and clay-loam) and poor in water and nutrient retention. Almost all the soils of the district are low in organic carbon and phosphorus, with a soil pH in the 7.0 to 8.5 range. During the monsoon season, the water tables have shown to rise by a few meters; however, long term data over ten years has shown a general decrease in water table depth from 0.2 to 4 meters. The quality of ground water that is rising or stagnant is becoming increasingly brackish.

Table 3. Extent and classification of area (ha) in southern district of Haryana (2013-14)

District Name	Reporting Area for land utilization statistics	Forests	Not Available for cultivation			Other uncultivated land excluding fallow land				Fallow land			Net Area sown	Total cropped area	Area sown more than once
			Area under non agriculture uses	Barren and un culturable land	Total	Permanent pastures and other grazing lands	Land under misc tree crops and groves not included in net area	Cultura ble waste land	Total	Fallow lands other than current fallow s	Current Fallow	Total			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Faridabad	72071	323	39293	1442	40735	271	--	--	271	--	665	665	30077	62743	32666
Gurugram	120149	1	24397	58	34336	1078	210	--	1288	--	286	286	80679	110078	29399
Mewat	147650	--	10142	25067	35209	508	--	--	508	--	6773	6773	105160	178198	73038
Palwal	135933	2843	12263	5145	17408	1415			1415		6618	6618	107649	193590	85941
Total	475803	3170	86099	31717	127694	3279	-- 218	--	3492	--	14354	14355	323579	544624	221060

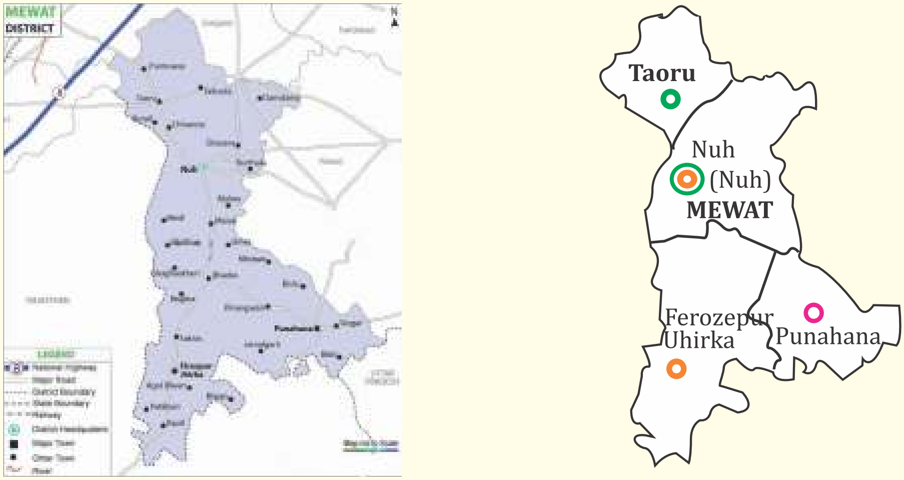

Fig. 1. Location of Mewat district

6.0 Features of Gurugram District

Gurugram district (Fig. 2) has conspicuously flat topography, however, in the north-eastern part small isolated hillocks of pre-cambrian rocks are exposed. The alluvial plain is formed by the Sahibi River which is tributary of River Yamuna. Soils of Gurugram district are classified as tropical and brown soils, existing in the north western extreme, northern and north eastern parts of the district and waterlogged and salt affected soils in the southern parts of the district. The soils are medium textured loamy sand is the average texture in Gurugram and Sohna blocks. In Pataudi and Sohna blocks the organic content of soils is lowest, just up to 0.20 per cent (very low category). In the rest of the district, organic content is 0.2 to 0.40 percent and falls in low category.

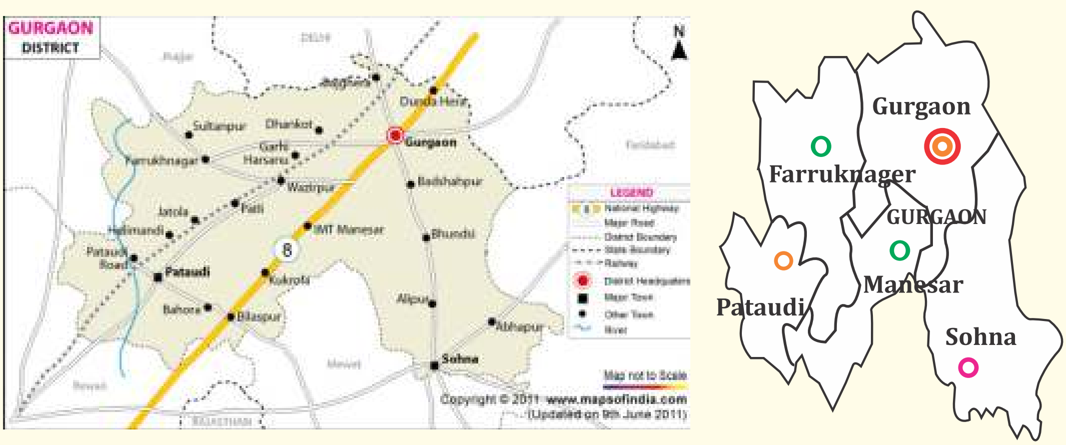

Fig. 2. Location of Gurugram district

7.0 Features of Faridabad District

Faridabad district (Fig. 3) shares its boundaries with the National Capital and Union Territory of Delhi to its north, Gurugram district to the west and Uttar Pradesh to its east and south. The River Yamuna separates the district boundary on eastern side with Uttar Pradesh. Delhi-Agra National Highway No.2 (Shershah Suri Marg) passes through the centre of the district. Faridabad district was carved out from erstwhile Gurugram district. The climate of Faridabad district can be classified as tropical steppe, semiarid and hot. Most of the land area of the district is plain (89%), while the rest of the area is undulated. These plains slope towards south-south east. The soils of the district are light to medium in texture with pH from 7.6 to 10.0.The soils vary from sandy loam, loam to sandy. The soils are alluvial and mostly calcareous, low in nitrogen, and contain low to medium available phosphorus and medium to high in available potassium. The lighter textured soils are marginal and deficient in iron and sulphur while zinc deficiency occurring in most of the soils. The major problems of soils are salinity and alkalinity, impeded drainage, water logging, low fertility and brackish underground water.

Fig. 3.0 Location of Faridabad district

8.0 Features of Palwal District

Palwal district (Fig. 4) is located in the southern part of Haryana and the western part of India, being a part of the National Capital Region. Soils of Palwal district are classified as tropical and brown soils, existing in major parts of the district. In Hathin block the organic content of soils ranging from 0.41 to 0.75 percent which is of medium category. In rest of the area organic contents is 0.2 to 0.4 percent and falls in Low category. The average conductivity of the soil is not more than 0.80 µmhos /cm and the average pH of the soil is between 6.5 and 8.7. The area comprises almost flat plains traversed by one ridge running N-S to NNE-SSW direction, divides the alluvium into two parts. The major River is Yamuna which is a perennial river. Palwal also has an extreme climate. During the summer months of April (latter half), May, June and July, the temperature is 36 deg C on an average. During the rainy months, majorly in August, the rainfall peaks to 184 mm and temperature is 22 deg C on an average. During the winters, the temperature swings at 15 deg C on an average.

Fig. 4.0 Location of Palwal district

9.0 Visual Interpretion Technique

For assessing the status of salt affected soils and to estimate their extent IRS P-6 satellite images (Table 4) (Fig. 5), Survey of India topographical sheets and ground truth were used of March 2010 and May 2011. A total of 16 sheets (Table 5) on 1:50,000 scale were used to create the base map of the four districts in ARCGIS.

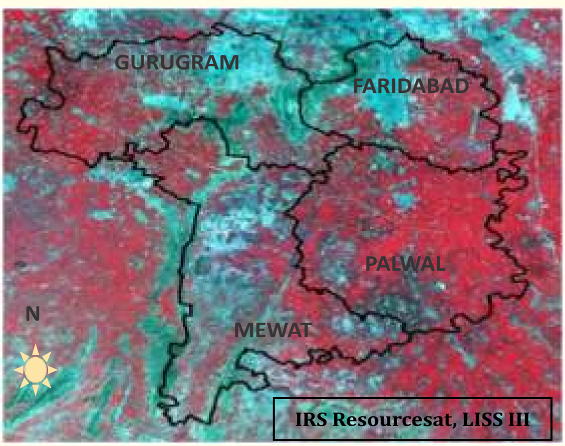

Fig. 5. Satellite Imageries of the study area

Table 4. Details of digital satellite data

Satellite	Sensor	Path/Row	Types	Period	Application
IRS P6	LISS-III	95-51	Digital data	March 2010	Vegetation crop inventory and crop parameters
IRS P6	LISS III	95-52	Digital data	May 2011	Salinity and water logging

Table 5. Details of Survey of India topographical sheets

District	No of toposheets on 1:50,000 scale	Sheet Numbers
Mewat	8	53D/15, 53D/16, 53H/4, 54A/13, 54E/1, 54E/5, 54E/2, 54A/14
Gurugram	6	53D/15, 53H/3 ,53D/11, 53D/16, 53H/4, 53 H/2
Faridabad	5	53H/3, 53H/7, 53H/4, 53H/8, 53 H/6
Palwal	8	53H/3, 53H/7, 53H/4, 53H/8, 53H/12, 54E/1, 54E/5, 54E/9
Total	16	

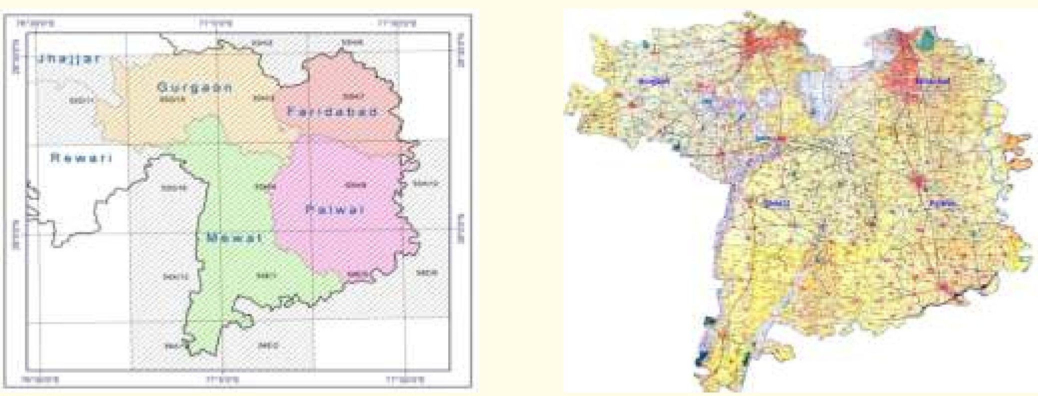

Fig. 6. Topomaps of the study area

The information of contour, administrative boundaries such as sand dunes, canals, important town, villages and roads and highways were digitized using survey of India Topomaps (Fig. 6) to prepare the base map. The IRS P6 Satellite images (Fig. 5) were rectified based on SOI image and GDEM- DEM data using rectification techniques and projective transformation in ERDAS Imagine 9.3. We used 84 ground control points

(GCPs) for rectification and found a root mean square error (RMSE) of 0.6 pixels. It was observed during the interpretation of the SOI map of 1960s that the area marked as scrub land actually represented salt affected areas as interpreted on the 2011 IRS-P-6 images. When the former was overlaid on the latter it was very clear that the two areas merged. The area reclaimed since 1960s could also be accurately identified. To add more information to the database, a vector base map of land use features such as canals, roads, and drainage were composited for the study area based on satellite image and visual interpretation. This was further cross validated with the SOI map (Figure 6). Satellite data was interpreted for demarcation of salt affected patches. The spatial resolution of the data was 23.5 m. and the spectral resolution of the Bands ranged from 520 nm in the green band to 1700 nm in SWIR (Table 6). Salt affected soils were identified on the false colour composite of bands 4 (770-860 nm), 3(620-680 nm), 2(520-590 nm). Barren salt affected soils appear as light blue and white on the images. They also appear mottled with red in areas of moderate salinity and dark blue to grey in areas where water-logging and salinity occur together.

Visual interpretation techniques comprise of (i) Pre-field interpretation (ii) Field work (ground truth) and (iii) Post-field work

9.1 Pre-field interpretation

The enhanced false colour composite (FCC) image of the study area was displayed on 1:50000 scale on monitor. Standard FCC was visually interpreted for salt affected soils and waterlogged areas with the help of image elements like tone, texture, shape, size, pattern and association, etc. The salt affected soils usually appear in tones of bright white to dull white with medium to coarse texture on Standard FCC due to the presence of salts on soil surface. The landforms associated with the occurrence of salt affected soils are also considered during interpretation. The obstruction of natural drainage

Table 6. Key Parameters of IRS-P6 LISS III Sensor

BANDS		
Spatial Resolution	Band 2 (green)	23.5 m
	Band 3 (red)	23.5 m
	Band 4 (NIR)	23.5 m
	Band 5 (SWIR)	23.5 m
Spectral Coverage	Band 2 (green)	520-590 nm
	Band 3 (red)	620-680 nm
	Band 4 (NIR)	770-860 nm
	Band 5 (SWIR)	1550-1700 nm

like roads, railway lines, canal distributaries, etc. can easily be identified on the FCC image. The waterlogged/pond areas appear on the FCC image in dark blue to a black tone with a smooth texture. Additional pre- and post- monsoon images were used to identify permanent waterlogged area. For this an interpretation key was developed. A tentative legend was also prepared. A map showing preliminary interpreted units on FCC with base details was generated before going into the field.

9.2 Field-work (collection of ground truth information)

Initially rapid traverse of the study area was made to identify the sampling points in the area. Detailed field investigations were carried out in various physiographic units to observe the broad physiographic-soil relationship. The study area was surveyed periodically in the year. The ground truth was collected from different villages from different districts and soil samples were taken from salt affected areas and non-salt affected areas. Soil samples were collected with their geographic location using GPS. Also ground water samples from the existing handpump/tube well were collected

Table 7. Location of soil samples in study area (Mewat and Gurugram districts)

Longitude	Latitude	Village Name	No of samples
77°4'27.273"E	28°11'12.529"N	Badelaki	2
77°4'30.694"E	28°11'12.177"N	Badelaki	2
77°4'14.187"E	28°11'7.688"N	Badelaki	2
77°1'41.406"E	28°7'54.474"N	Chandeni	3
77°1'0.635"E	28°8'46.449"N	Chandeni	4
77°0'37.104"E	28°9'2.033"N	Sadain	4
77°2'13.299"E	28°8'18.925"N	Chandeni	1
77°7'13.735"E	28°11'21.793"N	Radka	3
77°7'15.585"E	28°11'39.594"N	Radka	3
77°7'31.096"E	28°12'16.909"N	Hilalpur	3
77°7'59.686"E	28°11'50.289"N	Hilalpur	3
77°6'58.839"E	28°8'54.077"N	Gangoli	3
77°4'51.475"E	28°5'35.638"N	Bajarka	3
77°5'19.8"E	28°2'49.218"N	Ujina	3
77°5'11.361"E	28°1'45.402"N	Ujina	3
77°6'55.837"E	28°1'44.603"N	Chalawali	4
77°5'39.269"E	28°0'11.458"N	Sultanpur	3
77°3'37.012"E	27°56'26.297"N	Patakpur	4
76°57'54.61"E	27°56'5.725"N	Karaira	4
76°59'27.876"E	27°59'3.438"N	Sikandrabad	4
76°59'47.883"E	28°3'18.137"N	Marora	3

from these four districts to know the quality of the ground water in the study area. A reconnaissance survey of the study area was done using satellite images (FCC). Salt affected lands and affected crops were identified on the ground and ascertained on the satellite image by characterising image characteristics. Satellite image of IRS P6 LISS-III of March 2010 and May 2011 were used for the purpose. Soil samples from different locations (Tables 7, 8 and 9) and depths such as 0-5 cm , 0-15, 15-30, and 30-60 cm

Table 8. Ground truth and soil samples from Palwal and Gurugram districts

Longitude	Latitude	Village Name	No of samples
76° 49 24.4	28° 28 03.0	Faruk nagar,	4
76° 49 24.6	28° 28 46.8	Mubarakpur	4
76°49 22.4	28° 28 47.5	Mubarakpur	4
76° 49 22.35	28° 28 45.6	Mubarakpur	4
76° 51 30.03	28° 27 42.14	Sultanpur	4
76° 51 35.48	28° 27 40.82	Sultanpur	4
77°15 45.4	27° 57 42.1	Bahin	5
77° 15 45.8	27° 57 45.3	Bahin	4
77° 16 12.82	27° 57 36.93	Bahin	5
77° 18 27.7	27° 55 38.9	Sundarnagar	5
77° 20 01.2	27° 54 40.9	Soundh	5
77° 20 7.3	27° 52 50.6	Barraka	4
77° 16 46.29	27° 52 25.57	Khaika	4
77° 16 35.615	27° 52 37.99	Khaika	4
77° 14 10.9	27° 56 30.0	Pavsar	4
77° 15 12.3	27° 58 04.5	Pahari	4
77° 14 30.0	27° 58 59.0	Pahari	4
77° 12 18.8	28° 00 20.7	Purrakha	4
77° 13 36.3	28° 01 38.8	Pachanka	4
77° 08 10.8	28° 08 21.6	Gangoli	4
77° 10 40.3	28° 06 33.6	Madnaka	4
77 09 29.5	28° 07 15.3	Riber	3
77 08 14.1	28° 06 05.9	Akbarpur	4
77 09 20.1	28° 05 18.2	Bhagwali	4
77 09 22.4	28° 03 41.8	Matepur	4
77 10 59.5	28° 02 55.0	Khri Brahman	4
77 18 48.1	28° 13 09.1	Baghola	4
77 19 42.3	28° 13 54.5	Devali	4
77 20 16.9	28° 13 35.3	Devali	5
77 20 44.1	28° 13 21.6	Mandkaul	5
77 20 55.1	28° 10 44.0	Janauli	4

Table 9. Ground truth and soil samples from salt affected area of Faridabad district

Longitude	Latitude	Village	No of Samples
77° 18 12.0	28° 16 39.1	Sahapur Khurd	4
77° 19 57.6	28° 15 49.0	Sagarpur	2
77° 20 5.2	28° 15 45.9	Sagarpur	4
77° 15 44.5	28° 15 51.2	Harphalli	4
77° 16 18.9	28° 15 56.9	Harphalla	4
77° 23 42.9	28° 21 4.5	Tigaon	4
77° 22 28.3	28° 19 43.6	Machghar	4
77° 22 28.8	28° 19 25.3	Machghar	4
77° 22 32.7	28° 18 25.6	Dayalpur	4
77° 22 31.7	28° 17 56.5	Dayalpur road	3
77° 22 0.9	28° 17 19.5	Sotai	4
77° 21 28.4	28° 17 11.0	Sahapur kalan	4
77° 22 6.0	28° 16 0.2	Ladhauli	4
77° 20 50.9	28° 16 50.2	Sunped	4
77° 20 3.7	28° 15 22.8	Asaoti	4
77° 18 39.0	28° 13 1.6	Baghola	4
77° 17 46.4	28° 13 36.9	Pirthala	4
77° 15 34.1	28° 19 59.0	Maladpur	4
77° 14 44.4	28° 20 8.2	Qureshipur	4
77° 14 30.2	28° 19 20.8	firozpur kalan	4
77° 15 2.6	28° 18 29.0	Sikrona	4
77° 14 43.3	28° 17 49.9	Kabulpur bangar	4

layer at each sampling site were processed i.e. air dried, grounded using mortar and pestle and passed through a 2-mm brass sieve and stored for analytical purpose. The standard methods used for determination of different properties of these soils are described below. The different physico-chemical properties like pH, EC, organic carbon, calcium carbonate content, ESP, soluble cations and anions were analysed.

9.3 Post field work

Modification of the Post-field work primarily involved preliminary interpreted the mapping units on the FCC of the satellite data in the light of field information and soil physico-chemical data. The tentative legends prepared during the pre-fieldwork were also finalized. A final map showing visual salt affected soils was prepared.

10.0 Field Work, Soil Sampling and Analysis

Field work was executed based on the information which was gathered from visual interpretation and the initial digital rectification of satellite images. Soil samples were collected from bare fields using a soil auger from every 2 km interval from most of the accessible areas in the districts after the harvest of rice from depths of 0-15 and 15-30 cm. Deep core sampling was carried out at a depth of 30-60cms and 60-120 cm from different representative sites. To acquire location details of each sample site, Global Positioning System (GPS) readings were acquired using the hand-set Garmin Etrex GPS units. Even though the GPS was not differentially accurate, the hand-held Garmin GPS instrument is useful in providing a fairly accurate source of ground control points (GCPs) with expected vertical accuracies in the order of ±15m (Racoviteanu et al. 2007) and horizontal accuracies of ±3.9 m .(Ackerman et al. 2001). We estimated a horizontal accuracy of ±6 to 10 m which was displayed on the GPS screen, each time depending on the number of satellite signals received.

10.1 Physico-chemical properties of soils

10.1.1 Soil reaction (pH)

Soil pH was determined using pH Meter in 1:2 soils: water suspension, prepared by taking 20g of soil and 40 mL distilled water in 100 mL beaker. The extract was allowed for 1 h and pH determined (Page et al., 1982).The pH is one of the important characteristics of soil. Based on pH, the soils are categorized as acidic, neutral or alkaline. Plant responds markedly to soil reaction because pH tends to control much of the chemical environment and nutrient availability. The data showed that these soils are neutral to strongly alkaline in reaction and pH ranged from 6.8 to 10.3 with mean value is 7.8 and standard deviation is 0.7. It was also observed from the data that the pH of soils increased with depth.

10.1.2 Electrical Conductivity

Electrical conductivity was measured with the help of a conductivity bridge by putting electrode in the saturation extract and expressed as dS m^{-1} (Page et al., 1982). The electrical conductivity is a measure which shows the presence of soluble salt in the soil environment. Its value directly indicates the presence of soluble salt in the system. The electrical conductivity of soils ranged from as low as 1.23 to as high as 138.9 dS m^{-1} with mean of 28.34 dS m^{-1} and standard deviation is 31.67. In some location of the study area during sampling period soil surface was found encrusted with salt efflorescence and

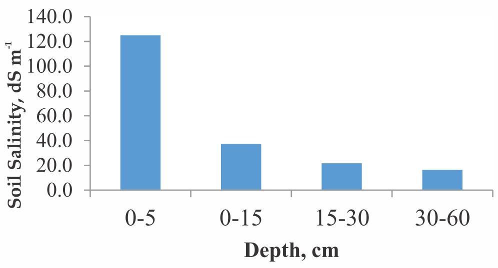

Fig. 7 Distribution of ECe with depth

soil ECe was ranged from 48.1 to 138.9 dS m^{-1}. The electrical conductance data showed that these soils are moderate to highly saline. Soil salinity is higher at surface and decreased with depth (Fig. 7), indicating higher salt accumulation at surface due to higher evaporation during summer months. Lack of agricultural activity and high evaporation enhanced salt concentration at surface. Soil salinity decreased with soil depth in all the locations studied.

10.1.3 Soil organic carbon

Soil organic carbon is oxidized to CO_2 by heat of dilution obtained when a known amount of soil is treated with excess of standard $K_2Cr_2O_7$ in the presence of concentrated H_2SO_4. The excess of $K_2Cr_2O_7$ not reduced by the organic matter is back titrated with standard ferrous ammonium sulphate in the presence of phosphoric acid or sodium fluoride using diphenylamine indicator. The soil organic carbon content was determined by wet oxidation method (Walkley and Black, 1934). 1 gm (0.2 mm) air-dried soil was weighed and transferred in to the Erlenmeyer flask. 10 mL 1*N* $K_2Cr_2O_7$ by a pipette and 20 mL of concentrated H_2SO_4 were added and mixed thoroughly and kept for 30 minutes on asbestos sheet for complete reaction. The suspension was diluted with about 200 mL of distilled water to provide clear suspension for easy detection of end point. 10 mL of 85% H_3PO_4 and then 1mL of diphenylamine indicator were added .Titrated with 0.5*N* ferrous ammonium sulphate until the color changed from dull green though turbid blue to a brilliant green, a end point by adding drop by drop ferrous ammonium sulphate. A blank titration was also performed following above procedure without soil sample.

Organic carbon (g/kg) = 10[(B-S)/B] × 0.003 × [1000/weight of sample (g)]

Where, B is mL of ferrous ammonium sulphate solution consumed in blank titration and S is mL of ferrous ammonium sulphate solution consumed in sample titration.Soils under arid and semi-arid part of the IGP lack in organic carbon due to decomposition. While the organic-matter content of soils of arid regions is usually low under virgin conditions, it commonly increases with the application of irrigation water and cultivation, especially when crop management is good. Aside from its value as a source of plant nutrients, organic matter has a favorable effect upon soil physical properties. There is considerable evidence that organic matter tends to counteract the unfavorable effects of exchangeable sodium on soils. In general organic carbon content of saline soils is low. The value of organic carbon ranged from 0.15 to 0.62% with mean of 0.29% and standard deviation was 0.1.

10.1.4 Saturation extract analysis:

Salt composition showed dominance of Na followed by calcium + magnesium and potassium and among anions chloride was dominant followed by sulphate and bicarbonate, Carbonate was found to be absent in these soils. High salinity was developed in all studied soils due to high salt content. From the data it is observed that all cations showed a decreasing trend with increase in soil depth (Fig. 8)

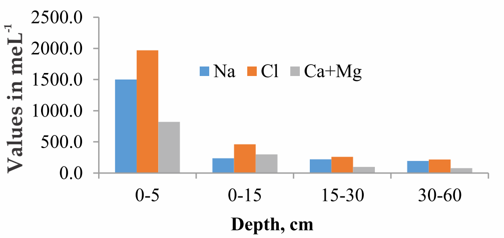

Fig. 8 Distribution of ions with depth

10.1.4.1 Sodium:

Sodium was determined in soil water extract using flame photometer (FPM) (Richard,1954). The concentration of soluble sodium was estimated using the equation.

Na^+ (me L^{-1}) = (Reading of FPM, ppm x dilution factor)/23

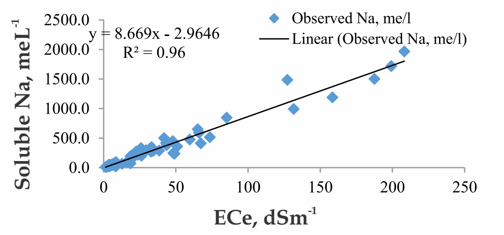

Fig. 9. Correlation between Soluble Na and ECe

Sodium was the most dominant cation among all the cations present in the soil solution. The value ranged from 9.23 to 1964.34 me L^{-1} with mean value of 329.25 me L^{-1} and standard deviation was 424.29. Soluble sodium showed a positive and significant correlation with electrical conductivity (R^2=0.96) (Fig. 9).

10.1.4.2 Potassium

Potassium was determined by the same method using flame photometer. The concentration of soluble potassium was estimated using following equation.

K^+ (me L^{-1}) = (Reading from FPM, ppm x dilution factor)/39

Soluble potassium content of these soils ranged from 0.1 to 0.9 me L^{-1} with mean value was 0.31 me L^{-1}. The standard deviation was 0.23 and coefficient of variation was 0.74.

10.1.4.3 Calcium and Magnesium

It was determined by Versanate titration method (Cheng and Bray, 1951). 5 mL aliquot was pipette out from soil water extract in 100 mL conical flask and 5 mL of ammonium chloride-ammonium hydroxide buffer was added. The colour of the solution became wine red after adding 4 drops of EBT indicator. The content in the conical flask was mixed thoroughly and titrated with 0.01 *N* EDTA solution till the colour change from wine red to blue. Precaution was taken that any tinge of wine red colour should not be remained in the solution.

$$Ca^{2} + Mg^{2+} (meL^{-1}) = \left(\frac{\text{Volume of EDTA used mL x normality EDTA x 1000}}{\text{Volume of aliquot taken in mL}}\right)$$

Calcium and magnesium were the dominant cations after sodium present in these soils. Presence of these cations in the soils is very important because they govern the structural stability of the soil particles and maintain favourable condition for plant growth. The content of calcium and magnesium together ranged from 5 to 820 me L^{-1} with mean 131.7 me L^{-1} showing wide variation in soils of the area. These cations showed very high correlation (R^2=0.79) with electrical conductivity of soils (Fig. 10).

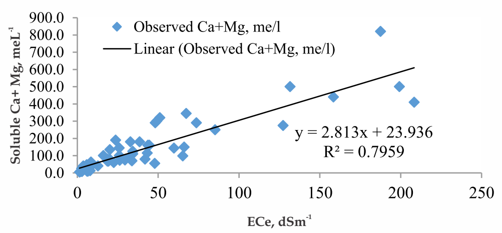

Fig. 10 Correlation between Ca+Mg and ECe

10.1.4.4 Chloride

In the same extract which has already been titrated for HCO_3^-, 4 drops of potassium chromate indicator was added and then titrated with 0.005 *N* $AgNO_3$ till the first brick red colour appeared and burette reading was noted down. (Richards, 1954)

$$Cl^- (meL^{-1}) = \left(\frac{\text{mL of AgNo}_3 \text{ consumed x 0.05 x 1000}}{\text{mL of soil extract main}}\right)$$

Among anions present in these soils, chloride was the dominant anion in the saturation extract. It determines the type of salt present in soils. Wide variation was observed in the content of soluble chloride which varied from 10 to 2320 me L^{-1} with mean of 420.75 me L^{-1}. The chloride content of these soils is relatively higher in surface horizons compared with the lower horizons. Soluble chloride content in these soils showed very strong correlation with electrolytic concentration of soils (R^2 = 0.98) (Fig. 11).

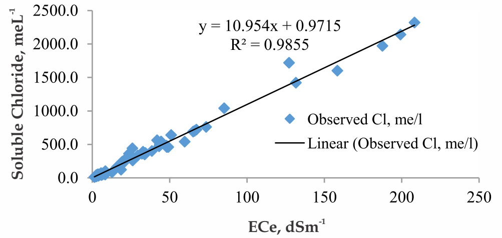

Fig. 11. Correlation between soluble chloride and ECe

10.1.4.5 Sulphate

Sulphate in soil saturation extracts is conventionally determined gravimetrically as

$BaSO_4$ which is a tedious process. Sulphate was estimated with 0.25 % HNO_3, acetic acid-phosphoric acid, barium chloride and gum-acacia using spectrophotometer (Chesmin and Yion, 1950). Sulphate was the second dominant anion present in the extract of these soil samples which ranged from 1.9 to 74.5 me L^{-1} l. Soluble sulphate also showed a positive correlation with soil salinity (R^2 = 0.46) (Fig. 12).

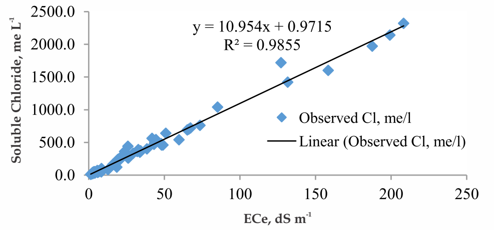

Fig. 12 Correlation between Soluble SO_4 and EC_e

10.1.4.6 Carbonate and Bicarbonate

5 mL of soil water extract in 100 mL conical flask was pipette out and 1 drop of Phenolphthalein indicator was added. No pink colour was appeared after addition of Phenolphthalein indicator means no carbonate was present. In the same flask 2 - 3 drops of methyl red indicator were added till yellow colour appears and titrated against 0.01 N H_2SO_4 till rose red colour appears. The burette reading was noted (Richards, 1954).

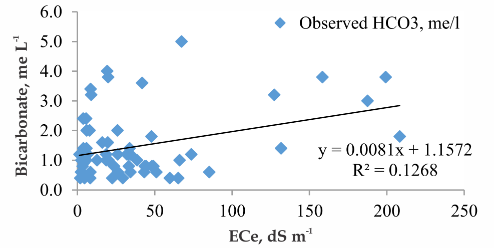

Fig. 13. Correlation between bicarbonate and ECe

$$HCO_3^- \left(meL^{-1}\right) = \frac{\text{B-2A x Normality of } H_2SO_4 \text{ x } 1000}{\text{Volume of aliquot taken in mL}}$$

A small amount of bicarbonate content was observed in these soils which ranged from 0.4 to 5 me/l and another anion carbonate was completely absent which is responsible for development of sodicity in soils and its presence in soil solution not so much correlated with soil salinity as observed from figure 13.

10.2 Sodium adsorption ratio (SAR)

It is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. It is also a measure of the sodicity of soil, as determined from analysis of water extracted from the soil. It is a ratio of the sodium (detrimental element) to the combination of calcium and magnesium (beneficial elements) in relation to known effects on soil dispersibility. It is accepted that the SAR and the electrical conductivity of irrigation water can be assessed for the potential to cause dispersion in a soil. Sandy soils are not affected by the sodium (because of the low clay content), but the plants growing on them may be affected. SAR is a mathematical relationship shown in following equation, the concentration of sodium in relation to calcium and magnesium.

$$SAR = \frac{[Na+]}{\sqrt{\frac{([Ca^{2+}] + [Mg^{2+}])}{2}}}$$

where [ ] represents the concentration of cation in me L^{-1}

10.3 Calcium carbonate

The calcium carbonate in soil was determined by titrimetric method (Richard, 1954). 5 gm (0.2 mm) air-dried soil was weighed and transferred in to the Erlenmeyer flask. 50 mL 1*N* HCl was added by a pipette. The content was swirled and left for 30 minutes. The content in the flask was boiled for 5 minutes and allowed to cool and filtered the content. 10 mL of filtrate was taken and 2 drops of phenolphthalein indicator was added. Titrated with 1N sodium hydroxide until the color changed from faint pink colour develops (end point). Then the reading was taken.

$$CaCO_3\,(\%) = \left(\frac{(N_1V_1 - N_2V_2) \times 50 \times 100}{1000 \times \text{wt of soil}}\right)$$

The alkaline-earth carbonates that occur in significant amounts in soils consist of calcite, dolomite, and possibly magnesite. Owing to low rainfall and limited leaching, alkaline-earth carbonates are usually a constituent of soils of arid and semiarid regions. The amounts present vary from traces to more than 50 percent of the soil mass. Alkaline-earth carbonates influence the texture of the soil when present in appreciable amounts, for the particles commonly occur in the silt-size fraction. The presence of fine alkaline-earth carbonate particles is thought to improve the physical condition of soils. Conversely, when alkaline-earth carbonates occur as caliche or as cementing agents in indurated layers, the movement of water and the development of root systems are impeded. Alkaline-earth carbonates are important constituents of alkali soils, for they constitute a potential source of soluble calcium and magnesium for the replacement of exchangeable sodium.In present soils the $CaCO_3$ content varied from 0.15 to 2.3 per cent with mean value of 0.41 per cent and standard deviation 0.44. It is observed that the $CaCO_3$ content increased with depth of soils.

11.0 Soils of Mewat and Gurugram districts

Though the soils of the villages namely Badelaki 1, Badelaki 2, Badelaki 3 were neutral to slightly alkaline in soil reaction and pH ranged from 7.2 to 7.5, but strongly saline as the electrical conductivity of saturation extract ranged from 23.7 to 131.6 dS m^{-1} (Table 10). It is observed that the EC values decreased with increase in depth. It means more salt accumulation was at surface as compared to lower layer which may be due to high evapo-transpiration during summer months. Among the soluble cations, sodium is dominant, value ranged from 244.0 to 991.3 me L^{-1} followed by calcium and magnesium, value ranged from 180 to 500 me L^{-1}. Similarly among soluble anions chloride was dominant followed by sulphate and bicarbonate. The sodium adsorption ratio ranged from 20.3 to 62.7 $mmol^{1/2}L^{-1/2}$. Salt affected soils are generally very low in organic matter content and the organic carbon content in these soils ranged from 0.2 to 0.4%. These soils were very low in free calcium carbonate content which varied from 0.3 to 2.0%. Soil of the villages Chandeni1 and Chandeni 3 were almost neutral in soil reaction with pH ranged from 6.8 to 7.8 and moderately saline with ECe value ranged from 5.8 to 20.1 dS/m (Table 11), whereas the soils at Chandeni 2 locations were strongly saline and moderately alkaline in soil reaction. The soil salinity was more at surface and decreased with increase in soil depth (Fig. 14). The nature of salt present was of sodium chloride type as the dominant cation in saturation extract was sodium and anion was chloride. The others in the order of predominance were calcium, magnesium and potassium. Among anions chloride was dominant followed by sulphate and bicarbonate. The carbonate anion was found to be absent in these soils. Organic carbon content in these soils ranged from 0.2 to 0.4%. These soils were having very low amount of free calcium carbonate content and categorized as non calcareous soils. Soils of Chandeni 1 and 3 were slightly saline and these soils can be put under cultivation because the soluble salt content in these soils might be leached out by the rain water. The dominant cation in saturation extract of soils of Radka village was

Table 10. Physico-chemical properties of soils of Badelaki

Properties	Badelaki 1		Badelaki 2		Badelaki 3	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH	7.2	7.5	7.0	7.3	7.0	7.2
ECe dS m^{-1}	131.6	38.5	32.8	23.7	51.0	48.2
OC (%)	0.4	0.2	0.4	0.2	0.4	0.3
$CaCO_3$ (%)	0.3	2.0	0.4	0.4	0.5	0.4
Na (me L^{-1})	991.3	289.1	270.4	218.0	358.6	244.0
K (me L^{-1})	0.7	0.2	0.5	0.4	0.7	0.4
Ca+Mg (me L^{-1})	500.0	180.0	180.0	190.0	320.0	290.0
HCO_3 (me L^{-1})	1.4	1.0	1.2	0.8	0.6	0.5
Cl (me L^{-1})	1420.0	400.0	390.0	360.0	640.0	460.0
SO_4 (me L^{-1})	55.2	27.5	23.8	16.5	33.2	19.9
SAR ($mmol^{1/2}L^{-1/2}$)	62.7	30.5	28.5	22.4	28.4	20.3

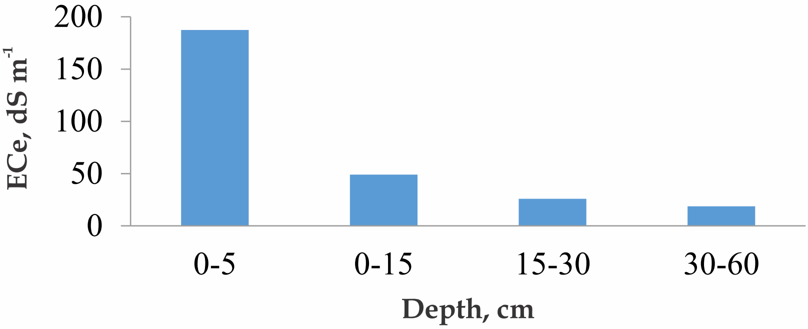

Fig. 14 Distribution of ECe with depth (Chandeni 2 village)

sodium and anion was chloride. The other cations in the order of predominance were calcium, magnesium and potassium. Among anions chloride was dominant followed by sulphate and bicarbonate. The chloride content was high in village Radka2 as compared to village Radka1. The carbonate anion was found to be absent in these soils. Very low organic matter content was observed in these soils that ranged from 0.2 to 0.3%. These soils were found to be non calcareous and free calcium carbonate content varied from 0.2% and 0.3% (Table 12). Soils of Radka-1 can easily be reclaimed through leaching of salt by rain water because of very low amount of electrolyte concentration as compared to Radka-2 soils. The soils of Hilalpur village were neutral to slightly alkaline in nature and pH ranged from 7.1 to 8.3. Similarly these soils were highly saline as the electrical conductivity of saturation extract ranged from 22.5 to 66.1 dS m^{-1} (Table 13). The salt accumulation was observed more at surface as compared to lower horizons.

Table 11. Physico-chemical properties of soils of Chandeni

Properties	Chandeni 1			Chandeni 2		Chandeni 3		
	0-15 cm	15-30 cm	30-60 cm	0-5 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm
pH	7.8	7.1	7.1	8.4	8.2	8.20	8.5	6.8
ECe (dSm^{-1})	6.6	5.8	20.1	187.5	49.1	26.0	18.6	8.4
Na (me L^{-1})	53.8	40.4	167.3	1500.0	235.6	220.8	193.4	69.7
K (me L^{-1})	0.20	0.2	0.6	0.8	0.3	0.2	0.2	0.7
Ca+Mg (me L^{-1})	40.0	47.5	135.0	820.0	300.0	100.0	80.0	62.5
HCO_3 (me L^{-1})	1.20	1.0	1.0	3.0	0.8	1.20	1.0	0.6
Cl (me L^{-1})	64.0	60.0	250.0	1970	460.0	260.0	218.0	100.0
SO_4 (me L^{-1})	16.3	14.5	28.3	74.5	60.0	38.4	34.1	30.2
SAR ($mmol^{1/2}L^{-1/2}$)	12.0	8.30	20.4	74.1	19.2	31.2	30.6	12.5
OC (%)	0.40	0.20	0.20	0.4	0.3	0.2	0.2	0.3
$CaCO_3$ (%)	0.30	0.30	0.40	0.5	0.4	0.3	2.3	0.2

Table 12. Physico-chemical properties of soils of Radka

Properties	Radka 1			Radka 2		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
pH	7.1	7.6	7.8	6.9	7.3	7.6
ECe (dS m^{-1})	4.5	3.4	2.6	85.2	44.5	34.3
Na (me L^{-1})	46.3	44.2	19.4	845.6	426.0	280.4
K (me L^{-1})	0.2	0.1	0.1	0.3	0.5	0.4
Ca+Mg (me L^{-1})	30.0	25.0	12.5	250.0	160.0	125.0
HCO_3 (me L^{-1})	1.0	0.8	1.0	0.6	0.8	0.6
Cl (me L^{-1})	50.0	50.0	20.0	1040.0	542.0	370.0
SO_4 (me L^{-1})	18.9	16.4	11.7	41.3	31.9	28.7
SAR ($mmol^{1/2}$ $L^{-1/2}$)	12.0	12.5	7.8	75.6	47.6	35.5
OC (%)	0.2	0.2	0.2	0.3	0.2	0.2
$CaCO_3$ (%)	0.3	0.3	0.3	0.2	0.2	0.2

The soluble salts mainly sodium chloride type was observed as dominant cation and anion in these soil were sodium and chloride, respectively followed by calcium-magnesium, potassium as cations and suplphate and bicarbonate as anions. The carbonate anion was found to be absent in these soils. The SAR ranged from 47.3 to 92.5. Salt affected soils are generally very low in organic matter content and the organic carbon content in these soils ranged from 0.2 to 0.4%. These soils are having very low amount of free calcium carbonate content which varied from 0.2 to 1.5%. The soils of the village Ujina1 were slightly alkaline in nature and pH ranged from 8.0 to 8.1, but the soils of village Ujina2 were sodic in nature with pH ranged from 10.1 to 10.3 (Table 14). The soils of Ujina1 were saline as the electrical conductivity of saturation extract of surface soil was 20.0 dS m^{-1} and subsurface layers ranged from 6.6 to 7.9 dS m^{-1}. The soils of Ujina 2 were highly saline as the electrical conductivity of saturation extract of surface soil was 41.9 dS m^{-1} and subsurface layers varied from 3.7 to 8.5 dS m^{-1}. The salt accumulation was more at surface as compared to lower layer which might be because of high evaporation during summer months. The dominant cation in saturation extract was sodium. The other cations in the order of predominance were calcium, magnesium and potassium. Among anion chloride was dominant followed by sulphate and bicarbonate. The carbonate anion was found to be absent in these soils. The SAR ranged from 10.3 to 78.7. Organic carbon content in these soils ranged from 0.2 to 0.5%. These soils were having very low amount of free calcium carbonate content which varied from 0.3 to 0.4% and were categorized in to non calcareous soils. The soils of Ujina 1 were grouped as moderately saline soils whereas the soils of Ujina 2 were grouped as saline-sodic soils. Different techniques/technologies are required to reclaim/manage these two soils for putting under cultivation. The soils of the village

Table 13. Physico-chemical properties of soils of Hilalpur

Properties	Hilalpur 1			Hilalpur 2		
	0-15 cm	15-30 cm	30-60cm	0-15 cm	15-30 cm	30-60cm
pH	8.0	8.3	8.0	7.1	7.2	7.2
ECe (dS m^{-1})	65.2	33.2	33.8	66.1	32.0	22.5
Na (me L^{-1})	647.8	345.6	323.9	589.1	317.3	271.7
K (me L^{-1})	0.7	0.4	0.3	0.5	0.4	0.2
Ca+Mg (me L^{-1})	98.0	75.0	70.0	150.0	90.0	60.0
HCO_3 (me L^{-1})	0.4	0.8	1.4	1.0	1.2	0.4
Cl (me L^{-1})	690.0	372.0	350.0	700.0	360.0	300.0
SO_4 (me L^{-1})	43.3	38.3	34.4	38.1	33.2	26.0
SAR($mmol^{1/2}L-^{1/2}$)	92.5	56.4	54.8	68.0	47.3	49.6
OC (%)	0.3	0.2	0.2	0.4	0.3	0.2
$CaCO_3$ (%)	0.5	1.0	1.5	0.2	0.3	0.3

Gangoli and Bajarka were neutral to slightly alkaline in nature and pH ranged from 7.1 to 8.5. The electrical conductivity of saturation extract of soils of Gangoli was less that 4.0 dS m^{-1} which indicated that these soils are non saline in nature. The soils of Bajarka were slightly saline as the electrical conductivity of saturation extract ranged from 2.4 to 6.0 dS m^{-1} (Table 15). Organic carbon content in these soils ranged from 0.2 to 0.3%. These soils were having very low amount of free calcium carbonate content which varied from 0.2% to 0.4% and categorized as non calcareous soils. The soils of Gangoli were grouped in to non saline soils and that of Bajarka into slightly saline soils. Soils of village Sultanpur were slightly alkaline in nature and pH ranged from 8.0 to 8.2 and that of Marora village were neutral in soil reaction and pH ranged 7.0 to 7.8. Soils of village

Table 14. Physico-chemical properties of soils of Ujina

Properties	Ujina1			Ujina 2		
	0-15 cm	15-30 cm	30-60cm	0-15 cm	15-30 cm	30-60cm
pH	8.0	8.1	8.0	10.3	10.2	10.1
ECe (dS m^{-1})	20.0	7.9	6.6	41.9	8.5	3.7
Na (me L^{-1})	155.9	67.3	63.2	497.8	95.9	45.8
K (me L^{-1})	0.6	0.2	0.1	0.2	0.1	0.1
Ca+Mg (me L^{-1})	80.0	12.5	10.0	80.0	50.0	40.0
HCO_3 (me L^{-1})	3.8	2.0	1.2	3.6	3.4	2.4
Cl (me L^{-1})	220.0	55.0	48.0	560.0	90.0	40.0
SO_4 (me L^{-1})	14.8	20.6	18.0	15.6	39.9	35.0
SAR($mmol^{1/2}L-^{1/2}$)	24.7	27.0	28.3	78.7	19.2	10.3
OC (%)	0.5	0.4	0.3	0.3	0.2	0.2
$CaCO_3$ (%)	0.3	0.4	0.3	0.3	0.3	0.3

Table 15. Physico-chemical properties of soils of Gangoli and Bajarka

Properties	Gangoli			Bajarka		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
pH	7.1	7.1	7.6	7.6	8.0	8.5
ECe (dS m^{-1})	2.9	1.9	1.4	4.1	2.4	6.0
Na (me L^{-1})	21.1	14.6	9.2	20.0	14.6	55.8
K (me L^{-1})	0.2	0.02	0.01	0.05	0.02	0.04
Ca+Mg (me L^{-1})	7.5	7.5	5.0	22.5	12.5	10.0
HCO_3 (me L^{-1})	0.6	0.4	1.2	0.9	0.6	2.0
Cl (me L^{-1})	25.0	19.0	10.0	30.0	23.0	50.0
SO_4 (me L^{-1})	2.3	2.0	1.9	21.2	18.0	15.6
SAR($mmol^{1/2}L^{-1/2}$)	10.9	7.5	5.8	6.0	5.9	25.0
OC (%)	0.3	0.3	0.2	0.3	0.2	0.2
$CaCO_3$ (%)	0.2	0.2	0.2	0.3	0.3	0.4

Sultanpur were salightly saline as the electrical conductivity of saturation extract ranged from 2.7 to 5.7 dS m^{-1} and that of Marora village were moderately saline and ECe ranged from 4.6 to 26.2 dS m^{-1}. Among the soluble cations sodium was dominant followed by calcium-magnesium and potassium and among anions chloride was dominant followed by suphate and bicarbonate. The SAR value ranged from 6.1 to 32.8 (Table 16). These soils were very low in organic matter content and calcium carnonate and the organic carbon content ranged from 0.2 to 0.4%. The soils of the villages Sadain

Table 16. Physico-chemical properties of soils of Sultanpur and Marora

Properties	Sultanpur			Marora		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
pH	8.2	8.1	8.0	7.0	7.2	7.8
ECe (dS m^{-1})	5.7	3.9	2.7	26.2	8.3	4.6
Na (me L^{-1})	47.0	31.9	21.4	198.3	19.1	29.5
K (me L^{-1})	0.2	0.2	0.1	0.3	0.1	0.0
Ca+Mg (me L^{-1})	35.0	24.0	25.0	73.0	45.0	25.0
HCO_3 (me L^{-1})	2.4	1.4	1.0	0.6	0.4	0.4
Cl (me L^{-1})	70.0	50.0	40.0	260.0	48.0	44.0
SO_4 (me L^{-1})	7.8	4.1	3.4	16.4	14.4	9.2
SAR($mmol^{1/2}L$-$^{1/2}$)	11.2	9.2	6.1	32.8	4.0	8.4
OC (%)	0.3	0.2	0.2	0.4	0.2	0.2
$CaCO_3$ (%)	1.3	0.4	0.4	0.2	0.2	0.2

and Chalawali were alkaline in soil reaction and pH ranged from 7.9 to 8.4. The electrical conductivity of saturation extract of these soils ranged from 12.7 to 199.2 dS m^{-1}. Among the soluble cations sodium was dominant, value ranged from 64.7 to 1717.3 me L^{-1} followed by calcium-magnesium (40.0 to 500.0 me L^{-1}) and potassium (0.2 to 0.9 me L^{-1}). Among anions chloride was dominant and value ranged from 84.0 to 2140 me L^{-1} followed by sulphate (18.7 to 65.0 me L^{-1} and bicarbonate (0.4 0 to 3.8 me L^{-1}). SAR ranged from 13.5 to 126.7 (Table 17). It is observed that the salt accumulation was more at surface as compared to lower layer which may be due to high evapo-transpiration during summer months and highly saline ground water. These salt affected soils were very low in organic matter content and the organic carbon content ranged from 0.2 to 0.5%. These soils were very low in free calcium carbonate content which varied from 0.3 to 2% and categorized as non calcareous soils. The soils of the village Karaira were relatively more saline as compared to that of village Patakpur as evident from ECe values and slightly alkaline in soil reaction for both villages. The pH values were nearly uniform throughout the soil profile. Soluble sodium content of Patakpur soils ranged from 42.5 to 410.6 me L^{-1} and that of Karaira ranged from 69.7 to 1186.9 me L^{-1}. Soluble calcium and magnesium content of these soils ranged from 18 to 440 me L^{-1} and sulphate content ranged from 15.9 to 29.6 me L^{-1}. SAR values of soils of Patakpur village ranged from 13.5 to 31.3 and that of village Karaira ranged from 12.0 to 80.0 (Table 18). Organic carbon content of these soils ranged from 0.15 to 0.52 per cent and decreased with increase in soil depth. These soils were non calcareous. The soils of the village Sikandrabad were neutral in soil reaction and pH ranged from 7.5 to 7.7 (Table 19) and

Table 17. Physico-chemical properties of soils of Sadain and Chalawali

Properties	Sadain				Chalawali			
	0-5 cm	0-15 cm	15-30 cm	30-60 cm	0-5 cm	0-15 cm	15-30 cm	30-60 cm
pH	8.1	8.2	7.9	8.0	8.4	8.4	8.3	8.2
ECe (dS m^{-1})	127.2	25.9	16.1	12.7	199.2	59.7	43.2	34.3
Na (me L^{-1})	1485.6	330.9	95.3	64.7	1717.3	473.9	416.9	306.9
K (me L^{-1})	0.7	0.3	0.2	0.2	0.4	0.9	0.9	0.8
Ca+Mg (me L^{-1})	275.0	145.0	100.0	40.0	500.0	144.0	115.0	110.0
HCO_3 (me L^{-1})	3.2	2.0	1.6	1.0	3.8	0.4	0.6	1.2
Cl (me L^{-1})	1720.0	440.0	164.0	84.0	2140.0	540.0	470.0	360.0
SO_4 (me L^{-1})	34.1	30.4	22.9	18.7	65.0	48.2	46.3	44.4
SAR ($mmol^{1/2}L^{-1/2}$)	108.6	55.9	55.0	41.4	126.7	38.9	13.5	14.5
OC (%)	0.4	0.3	0.3	0.2	0.5	0.3	0.2	0.2
$CaCO_3$ (%)	0.3	0.3	0.3	0.3	0.5	2.0	1.0	0.8

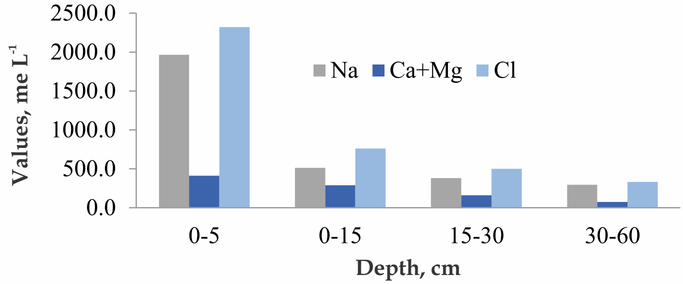

Fig. 15 Distribution of ions with soil depth

strongly saline with salt efflorescence as soil salinity of upper 0-5 cm depth is 208.3 dS/m and ECe value decrease with increase in soil depth. Similar pattern was observed with soluble sodium, calcium and magnesium, chloride and sulphate ions (Fig. 15) and also with organic carbon content of these soils. This showed the salt accumulation was more at surface as compared to lower layers. The salt present in these soils were of soluble in nature and during rainy season leaching of salts takes place with rain water and soil salinity may reduce to some extent. The dominant cation and anion in saturation extract was sodium and chloride, respectively. The other cations present were calcium, magnesium and potassium and anions were sulphate and bicarbonate. The carbonate anion was found to be absent in these soils. These soils were non calcareous in nature as free calcium carbonate content was less than 1%

12.0 Soils of Palwal district

Salt encrustation/ efflorescence and waterlogging was higher in post-*rabi* (March) season apparently due to intensive agriculture. Prominent areas of salt affected soils

Table 18. Physico-chemical properties of soils of patakpur and karaira

Properties	Patakpur				Karaira			
	0-5 cm	0-15 cm	15-30 cm	30-60 cm	0-5 cm	0-15 cm	15-30 cm	30-60 cm
pH	7.7	7.9	8.0	8.0	8.1	7.7	7.9	8.1
ECe (dS m^{-1})	67.3	19.3	9.0	5.8	158.4	47.9	19.6	18.6
Na (me L^{-1})	410.6	201.7	62.3	42.5	1186.9	445.6	187.8	69.7
K (me L^{-1})	0.4	0.1	0.2	0.1	0.6	0.3	0.1	0.1
Ca+Mg (me L^{-1})	345.0	68.0	43.0	18.0	440.0	55.0	75.0	68.0
HCO_3 (me L^{-1})	5.0	4.0	3.2	1.4	3.8	1.8	1.6	1.2
Cl (me L^{-1})	720.0	240.0	80.0	40.0	1600.0	480.0	240.0	120.0
SO_4 (me L^{-1})	29.6	20.9	17.5	18.0	21.7	17.5	18.8	15.9
SAR($mmol^{1/2}L^{-1/2}$)	31.3	34.6	13.5	14.2	80.0	85.0	30.7	12.0
OC (%)	0.5	0.5	0.3	0.2	0.6	0.4	0.3	0.2
$CaCO_3$ (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3

Table 19. Physico-chemical properties of soils of Sikandrabad

Properties	Sikandrabad			
	0-5 cm	0-15 cm	15-30 cm	30-60 cm
pH	7.6	7.5	7.6	7.7
ECe (dS m^{-1})	208.3	73.6	43.6	29.4
Na (me L^{-1})	1964.3	513.0	380.8	293.4
K (me L^{-1})	0.5	0.4	0.3	0.2
Ca+Mg (me L^{-1})	410.0	290.0	160.0	75.0
HCO_3 (me L^{-1})	1.8	1.2	0.8	0.4
Cl (me L^{-1})	2320.0	760.0	500.0	332.0
SO_4 (me L^{-1})	45.5	35.1	31.9	29.4
SAR ($mmol^{1/2}L^{-1/2}$)	137.0	42.6	42.6	47.9
OC (%)	0.6	0.4	0.3	0.2
$CaCO_3$ (%)	0.2	0.2	0.2	0.2

and associated waterlogging were identified in Soundh, Madnaka, Riber, Akbarpur Natol, Bhigawali and matepur and adjoining villages located in the alluvial plain. IRS imageries also showed strong reflectance of barren salt affected soils and higher water absorption in cropped areas irrigated with saline ground water. Ground truth was collected to characterize interpreted units for land uses, topography, drainage, irrigation, waterlogging, salt affected soils and the presence of sub-surface salinity/alkalinity, concretions and textural grades etc. Depth-wise soil samples were collected from soil profiles (upto 90 cm depth) for determination of physico-chemical properties. Analytical data showed that these soils were saline in nature with ECe ranging from as low as 0.26 to as high as 59.9 dS/m. Among soluble cations sodium was dominant followed by magnesium and calcium. Soluble sodium and chloride ions were significantly correlated with electrical conductivity (ECe). The mean concentration of soluble sodium was 2.0 times more than the concentration of calcium + magnesium in these soils. Similarly chloride content was as high as 500 me/L and sulphate as high as 74.5 me/L. Soil at Mandkaul and Devali villages were highly sodic soils with pHs ranged from 9.2 to 10.0 with presence of carbonate and bicarbonate ions (Table 20).The soils of the study area were sandy loam to loamy sand in texture. These soils were low in available nitrogen content (35 to 129 Kg ha^{-1}) and poor in soil organic carbon content (0.04 to 0.65%) (Table 21). Satellite imageries were interpreted and subjected to supervised classification for estimation of area under different categories. Laboratory analysis of ground water samples from Palwal district revealed that pH_w ranged from 6.8 to 7.8 and EC_w ranged from 1.3 to 15.4 dS/m. The predominant cation and anion in the ground water was sodium and chloride, respectively. The groundwater was also influenced by the fluoride content which ranged from 0.3 to 9.0 ppm (Table 22).

Table 20. Physico-chemical properties of salt affected soils in Palwal district

Village Name	Depth, cm	ECe dS m^{-1}	pHs	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	CO_3	HCO_3^-
				me L^{-1}						
Faruk nagar	0-15	3.8	7.0	3.7	0.0	0.8	2.8	2.0	0.0	1.6
	15-30	2.0	7.2	3.0	0.0	0.8	2.2	1.8	0.0	1.2
	30-60	1.7	7.9	2.2	0.0	0.6	2.4	1.4	0.0	1.0
	60-90	2.0	8.1	1.4	0.0	0.6	2.0	1.0	0.0	0.6
Faruk nagar	0-15	1.6	7.9	0.9	0.1	1.6	1.4	3.0	0.0	1.6
	15-30	0.5	7.9	2.5	0.0	0.8	1.6	2.0	0.0	1.4
	30-60	1.4	8.0	2.3	0.0	0.6	1.2	2.4	0.0	1.2
	60-90	0.8	8.4	1.9	0.0	0.4	1.4	1.4	0.0	1.2
Mubarakpur	0-15	0.5	8.1	0.3	0.6	2.8	1.4	2.2	0.0	2.2
	15-30	1.9	8.2	2.1	0.1	1.6	1.0	2.0	0.0	1.4
	30-60	1.6	8.2	1.8	0.0	1.2	1.2	1.8	0.0	1.4
	60-90	0.9	7.9	0.5	0.0	0.8	1.6	1.4	0.0	1.4
Mubarakpur	0-15	1.8	7.9	0.5	0.6	2.2	0.8	1.4	0.0	1.4
Mubarakpur	0-15	2.2	7.5	8.4	1.3	16.4	15.0	1.6	0.0	1.0
	15-30	23.9	7.5	21.5	1.6	13.2	18.0	97.4	0.0	0.8
	30-60	43.1	7.2	26.5	1.0	12.0	18.0	105.0	0.0	1.0
	60-90	31.1	7.2	23.4	0.5	11.8	18.2	99.4	0.0	1.4
Sultanpur	0-15	2.6	8.1	2.2	1.0	3.8	2.6	3.8	0.0	1.4
	15-30	1.4	8.2	1.9	0.5	2.4	3.2	3.8	0.0	1.2
	30-60	1.0	8.2	1.5	0.3	2.2	3.4	3.0	0.0	1.2
	60-90	0.9	8.2	0.9	0.1	1.8	2.4	2.6	0.0	0.8
Sultanpur	0-15	0.5	8.6	2.2	0.3	2.2	1.8	3.8	0.0	2.2
	15-30	1.4	8.9	1.9	0.1	0.6	1.2	2.8	0.0	1.6
	30-60	1.0	9.1	1.4	0.1	0.6	1.2	2.8	0.0	1.4
	60-90	1.2	9.2	0.9	0.1	0.6	0.4	2.8	0.0	1.4
Bahin	0-5	35.9	8.0	15.0	1.3	22.0	3.0	134.4	0.0	1.2
	0-15	9.7	8.1	14.3	0.5	11.2	16.0	58.2	0.0	1.0
	15-30	6.6	8.3	13.6	0.4	10.0	17.0	32.2	0.0	1.0
	30-60	5.4	8.5	9.4	0.3	6.2	19.8	24.8	0.0	0.8
	60-90	3.9	7.9	0.7	0.2	1.8	16.4	15.4	0.0	0.8
Bahin	0-15	2.1	7.5	12.0	0.4	12.2	8.8	3.8	0.0	2.0
	15-30	1.7	7.4	12.0	0.3	11.0	10.8	3.0	0.0	1.4
	30-60	1.7	7.5	2.2	0.3	6.6	15.2	2.8	0.0	1.2
	60-90	1.6	7.9	1.9	0.2	6.0	15.6	2.8	0.0	1.2
Bahin	0-5	20.9	7.0	18.8	3.1	38.4	60.6	97.8	0.0	3.0
	0-15	11.0	7.2	18.0	2.9	30.4	47.8	88.4	0.0	1.8

	15-30	5.8	7.8	12.0	0.5	26.2	50.0	44.2	0.0	1.6
	30-60	4.7	8.0	9.4	1.0	20.0	40.2	24.0	0.0	1.4
	60-90	5.1	8.0	10.5	0.7	14.2	25.8	26.2	0.0	1.4
Sundarnagar	0-5	3.8	7.7	4.7	0.8	14.8	20.2	7.0	0.0	1.8
	0-15	17.0	7.2	4.3	0.3	14.8	67.4	72.0	0.0	1.0
	15-30	11.0	7.2	4.5	0.2	13.8	66.2	48.2	0.0	1.0
	30-60	5.4	7.9	3.7	0.2	11.0	59.2	28.0	0.0	0.8
	60-90	5.1	7.9	3.5	0.1	9.8	32.0	19.4	0.0	1.0
Soundh	0-5	4.5	7.0	3.7	0.5	5.8	24.8	13.8	0.0	2.0
	0-15	0.6	7.5	3.5	0.0	2.0	2.4	3.8	0.0	2.0
	15-30	0.7	7.9	3.0	0.0	1.8	2.0	4.0	0.0	2.0
	30-60	0.7	8.3	2.6	0.0	1.4	2.2	3.2	0.0	1.6
	60-90	0.4	8.2	1.5	0.0	1.0	1.0	1.4	0.0	1.6
Barraka	0-15	1.8	8.0	4.7	0.0	1.8	4.6	6.4	0.0	1.2
	15-30	2.1	8.0	4.5	0.0	1.4	4.4	6.4	0.0	2.8
	30-60	2.4	7.5	4.5	0.0	1.4	3.6	6.6	0.0	1.8
	60-90	2.0	7.7	3.7	0.0	0.8	3.2	5.8	0.0	1.8
Khaika	0-15	2.4	8.0	5.8	0.0	1.8	6.0	8.4	0.0	1.6
	15-30	1.5	9.0	3.7	0.0	1.4	0.4	2.4	0.0	1.4
	30-60	1.2	8.1	3.7	0.0	0.8	0.8	2.4	0.0	1.8
	60-90	1.1	8.5	4.3	0.0	0.8	0.6	2.2	0.0	1.8
Khaika	0-15	8.4	7.3	23.4	0.2	25.0	23.4	29.6	0.0	1.4
	15-30	4.9	7.5	21.5	0.2	11.8	16.6	31.0	0.0	1.4
	30-60	6.5	7.6	22.4	0.1	8.0	22.0	32.8	0.0	1.6
	60-90	5.1	7.2	18.8	0.0	7.8	21.4	28.2	0.0	1.6
Pavsar	0-15	13.6	7.5	28.8	0.0	11.8	53.0	55.8	0.0	1.0
	15-30	3.7	8.2	7.2	0.0	9.6	7.2	19.8	0.0	0.8
	30-60	3.8	8.1	5.8	0.0	6.2	10.2	20.0	0.0	1.0
	60-90	3.9	7.9	4.7	0.0	2.2	13.8	17.8	0.0	0.8
Pahari	0-15	0.9	9.0	5.8	0.0	0.6	1.2	5.8	0.0	1.6
	15-30	4.9	9.2	7.2	0.0	0.6	0.6	5.2	0.0	1.2
	30-60	1.5	9.4	4.7	0.0	0.6	0.6	5.0	0.0	1.0
	60-90	1.1	9.6	2.6	0.0	0.6	0.2	5.2	0.0	1.0
Pahari	0-15	1.2	8.5	3.7	0.0	0.4	2.4	2.9	0.0	1.2
	15-30	0.8	8.2	3.0	0.0	0.4	1.6	2.6	0.0	1.0
	30-60	0.5	8.3	2.3	0.0	0.4	1.4	2.4	0.0	1.0
	60-90	0.8	8.4	2.6	0.0	0.4	1.4	2.6	0.0	1.2
Purrakha	0-15	1.9	8.4	3.7	0.0	0.4	1.2	2.2	0.0	1.4
	15-30	0.9	8.6	2.2	0.0	0.4	0.6	2.0	0.0	1.2

	30-60	0.9	8.6	1.9	0.0	0.4	1.0	2.0	0.0	1.2
	15-30	4.1	8.0	4.5	0.3	0.9	16.5	12.8	0.0	1.0
	30-60	6.0	8.6	4.9	0.2	1.1	14.3	13.0	0.0	1.0
	60-90	5.3	7.6	2.2	0.1	1.0	12.8	13.0	0.0	0.8
Gangoli	0-15	17.2	7.0	12.0	0.5	10.0	2.4	82.0	0.0	1.0
	15-30	4.6	7.1	40.2	0.1	18.2	14.2	28.4	0.0	0.6
	30-60	2.8	7.2	3.1	0.1	4.4	19.8	18.2	0.0	0.8
	60-90	1.3	7.2	1.9	0.1	1.8	13.6	10.0	0.0	0.6
Madnaka	0-15	9.0	7.5	8.8	0.2	17.0	39.4	33.0	0.0	1.0
	15-30	3.2	8.0	6.3	0.1	7.4	21.2	10.0	0.0	1.0
	30-60	3.5	7.9	5.8	0.1	7.2	19.0	10.0	0.0	1.0
	60-90	2.7	7.9	2.7	0.0	2.2	20.0	8.2	0.0	0.6
Riber	0-5	27.1	7.5	23.4	1.2	40.4	106.0	137.6	0.0	2.0
	0-15	6.3	7.6	2.7	0.2	21.8	26.6	39.0	0.0	1.2
	15-30	4.1	7.7	3.7	0.2	7.8	26.4	22.2	0.0	1.2
Akbarpur	0-15	9.4	8.2	18.8	0.2	9.0	59.4	35.8	0.0	2.2
	15-30	2.1	9.1	8.8	0.0	6.2	10.0	10.0	0.0	1.4
	30-60	3.0	9.0	9.4	0.0	2.2	12.2	10.2	0.0	1.2
	60-90	2.5	7.9	2.7	0.0	1.0	9.20	8.2	0.0	1.2
Bhagwali	0-15	4.9	7.9	17.2	0.8	13.0	22.6	37.0	0.0	1.2
	15-30	3.9	7.8	12.3	0.4	13.8	15.4	24.0	0.0	0.8
	30-60	4.7	7.6	13.6	0.3	8.20	20.0	24.4	0.0	0.8
Matepur	0-5	14.4	7.9	23.4	0.3	20.6	76.2	105.0	0.0	2.8
	0-15	8.5	7.9	18.8	0.1	15.8	26.6	35.8	0.0	1.2
	15-30	2.6	8.2	8.8	0.1	8.0	10.2	12.2	0.0	1.0
	30-60	1.6	7.9	0.5	0.1	2.2	12.0	8.6	0.0	0.8
Khri Brahman	0-15	0.9	8.2	3.7	0.0	0.8	3.0	3.8	0.0	1.6
	15-30	0.9	8.3	2.2	0.0	0.8	0.8	2.0	0.0	1.0
	30-60	3.9	7.2	2.6	0.0	0.6	1.4	1.4	0.0	1.0
	60-90	5.3	7.5	3.0	0.0	0.6	2.4	2.2	0.0	0.8
Baghola	0-15	7.4	7.9	6.1	0.0	6.4	18.4	21.6	0.0	1.4
	15-30	8.1	8.0	6.6	0.0	6.4	20.6	22.0	0.0	0.8
	30-60	10.3	7.5	6.9	0.0	4.2	22.6	23.4	0.0	1.0
	60-90	10.6	7.9	7.2	0.0	2.2	24.4	23.8	0.0	1.0
Devali	0-15	0.6	8.0	3.7	0.0	0.6	1.6	2.0	0.0	1.0
	15-30	0.2	8.3	0.4	0.0	0.6	1.2	2.0	0.0	1.0
	30-60	0.9	8.2	0.5	0.0	0.4	1.0	2.0	0.0	0.8
	60-90	1.2	8.0	0.7	0.0	0.4	1.0	2.2	0.0	0.6
Devali	0-5	59.9	9.8	60.1	1.9	21.	280.8	100.0	48.5	60.0

	0-15	25.7	10.0	60.1	0.5	3.0	4.0	18.3	13.8	17.5
	30-60	0.9	9.8	0.5	0.3	1.0	0.8	2.0	0.4	1.2
	60-90	3.2	9.7	0.7	0.3	0.6	2.8	1.8	0.4	0.8
Mandkaula	0-5	33.5	10.0	58.8	4.1	0.6	1.8	45.0	28.0	34.0
	0-15	1.9	9.9	35.5	0.1	0.6	1.2	4.2	0.8	1.2
	15-30	0.9	9.2	9.3	0.1	0.8	0.8	2.4	0.0	0.8
	30-60	1.0	9.5	10.9	0.1	0.4	1.4	2.8	0.0	1.8
	60-90	1.3	8.7	12.6	0.1	0.4	1.6	2.6	0.0	0.6
Janauli	0-15	20.3	8.2	60.1	0.5	2.2	10.8	66.0	0.0	1.0
	15-30	9.4	8.2	54.6	0.3	1.8	8.6	36.0	0.0	0.8
	30-60	5.1	8.2	37.7	0.3	1.8	6.4	24.2	0.0	0.8
	60-90	4.4	8.2	27.3	0.3	0.8	7.6	11.8	0.0	1.0
Max		59.9	10.0	60.1	4.1	40.4	280.8	137.6	48.5	60.0
Min		0.2	7.0	0.3	0.0	0.4	0.2	1.0	0.0	0.6
Mean		5.8	8.1	9.9	0.3	6.0	15.4	20.2	0.7	2.0
SD		8.9	0.6	13.0	0.5	7.8	29.6	28.9	5.0	6.7

Table 21. Organic carbon, macro and micronutrients status of soils from Palwal district

Soil depth, cm	Village Name	OC, %	Av. N_2, Kg ha^{-1}	Av. K kg ha^{-1}	Zn, ppm	Cu, ppm	Fe, ppm	Mn, ppm
0-15	Faruknagar	0.2	91.0	101.2	1.1	0.3	4.3	6.8
15-30		0.2	91.0	93.4	0.8	0.3	4.1	2.8
30-60		0.1	70.0	70.2	0.5	0.3	3.6	3.9
60-90		0.2	52.5	62.7	0.6	0.2	2.4	2.6
0-15	Faruknagar	0.4	101.5	346.5	0.5	0.9	2.1	1.9
15-30		0.4	98.0	307.5	0.5	0.8	1.6	2.9
30-60		0.3	70.0	238.7	0.5	0.6	1.1	2.6
60-90		0.3	66.5	142.9	1.1	0.6	1.3	4.0
0-15	Mubarakpur	0.3	129.5	38.8	0.8	0.5	1.4	1.6
15-30		0.3	105.0	320.1	0.6	0.4	1.3	2.8
30-60		0.4	108.5	283.3	0.4	0.6	1.7	2.1
60-90		0.4	42.0	188.4	0.4	0.2	1.0	1.3
0-15	Mubarakpur	0.4	101.5	606.9	0.8	0.1	2.3	1.2
0-15	Mubarakpur	0.4	115.5	537.5	0.5	0.2	1.1	1.0
15-30		0.4	115.5	373.6	1.0	0.3	0.8	1.9
30-60		0.4	105.0	295.2	0.9	0.2	0.9	1.8
60-90		0.3	70.0	249.4	1.0	0.2	0.7	2.5
0-15	Sultanpur	0.7	129.5	470.3	3.3	1.9	1.4	2.1
15-30		0.7	126.0	470.3	0.8	0.4	1.2	2.5

30-60		0.6	105.0	438.3	0.9	0.3	1.3	1.1
60-90		0.6	87.5	307.5	0.5	0.3	1.2	1.1
0-15	Sultanpur	0.3	98.0	360.4	0.7	0.8	2.6	1.9
15-30		0.3	98.0	295.2	0.5	1.3	0.9	1.1
30-60		0.2	87.5	249.4	0.6	1.3	1.4	2.4
60-90		0.1	87.5	160.6	0.6	1.3	1.6	2.1
0-5	Bahin	0.2	87.5	1181.0	1.1	1.1	0.8	2.4
0-15		0.4	91.0	715.9	0.5	0.8	0.8	1.5
15-30		0.5	87.5	198.0	0.6	0.6	0.8	1.5
30-60		0.5	70.0	151.7	0.6	0.4	0.8	1.2
60-90		0.5	66.5	134.3	0.4	0.3	0.7	2.3
0-15	Bahin	0.6	105.0	438.3	0.8	1.5	2.5	2.9
15-30		0.64	108.5	360.4	0.8	1.1	0.8	7.8
30-60		0.62	105.0	307.5	0.3	0.5	0.8	2.3
60-90		0.61	98.0	260.4	0.4	0.3	0.6	0.8
0-5	Bahin	0.41	108.5	997.8	3.1	1.6	2.3	5.1
0-15		0.42	105.0	792.2	1.1	1.1	0.9	3.7
15-30		0.54	101.5	438.3	0.4	0.5	0.7	1.1
30-60		0.47	73.5	360.4	0.3	0.5	0.6	1.2
60-90		0.42	70.0	360.4	0.4	0.3	0.4	1.5
0-15	Faruknagar	0.27	91.0	101.2	1.1	0.3	4.3	6.8
15-30		0.25	91.0	93.4	0.8	0.3	4.1	2.8
30-60		0.19	70.0	70.2	0.5	0.3	3.6	3.9
60-90		0.2	52.5	62.7	0.6	0.2	2.4	2.6
0-15	Faruknagar	0.4	101.5	346.5	0.5	0.9	2.1	1.9
15-30		0.4	98.0	307.5	0.5	0.8	1.6	2.9
30-60		0.3	70.0	238.7	0.5	0.6	1.1	2.6
60-90		0.3	66.5	142.9	1.1	0.6	1.3	4.0
0-15	Mubarakpur	0.3	129.5	38.8	0.8	0.5	1.4	1.6
15-30		0.3	105.0	320.1	0.6	0.4	1.3	2.8
30-60		0.4	108.5	283.3	0.4	0.6	1.7	2.1
60-90		0.4	42.0	188.4	0.4	0.2	1.0	1.3
0-15	Mubarakpur	0.4	101.5	606.9	0.8	0.1	2.3	1.2
0-15	Mubarakpur	0.4	115.5	537.5	0.5	0.2	1.1	1.0
15-30		0.4	115.5	373.6	1.0	0.3	0.8	1.9
30-60		0.4	105.0	295.2	0.9	0.2	0.9	1.8
60-90		0.3	70.0	249.4	1.0	0.2	0.7	2.5
0-15	Sultanpur	0.7	129.5	470.3	3.3	1.9	1.4	2.1
15-30		0.7	126.0	470.3	0.8	0.4	1.2	2.5

30-60		0.6	105.0	438.3	0.9	0.3	1.3	1.1
60-90		0.6	87.5	307.5	0.5	0.3	1.2	1.1
0-15	Sultanpur	0.3	98.0	360.4	0.7	0.8	2.6	1.9
15-30		0.3	98.0	295.2	0.5	1.3	0.9	1.1
30-60		0.2	87.5	249.4	0.6	1.3	1.4	2.4
60-90		0.1	87.5	160.6	0.6	1.3	1.6	2.1
0-5	Bahin	0.2	87.5	1181.0	1.1	1.1	0.8	2.4
0-15		0.4	91.0	715.9	0.5	0.8	0.8	1.5
15-30		0.5	87.5	198.0	0.6	0.6	0.8	1.5
30-60		0.5	70.0	151.7	0.6	0.4	0.8	1.2
60-90		0.5	66.5	134.3	0.4	0.3	0.7	2.3
0-15	Bahin	0.6	105.0	438.3	0.8	1.5	2.5	2.9
15-30		0.6	108.5	360.4	0.8	1.1	0.8	7.8
30-60		0.6	105.0	307.5	0.3	0.5	0.8	2.3
60-90		0.6	98.0	260.4	0.4	0.3	0.6	0.8
0-5	Bahin	0.4	108.5	997.8	3.1	1.6	2.3	5.1
0-15		0.4	105.0	792.2	1.1	1.1	0.9	3.7
15-30		0.5	101.5	438.3	0.4	0.5	0.7	1.1
30-60		0.4	73.5	360.4	0.3	0.5	0.6	1.2
60-90		0.4	70.0	360.4	0.4	0.3	0.4	1.5
0-5	Sundarnagar	0.4	105.0	360.4	0.8	0.3	0.5	4.3
0-15		0.4	105.0	360.4	0.5	0.6	0.4	3.9
15-30		0.5	108.5	346.5	0.3	0.6	0.3	1.9
30-60		0.4	105.0	320.1	0.5	0.7	00.3	1.3
60-90		0.3	94.5	295.2	0.4	0.6	00.3	8.6
0-5	Soundh	0.6	105.0	997.8	1.2	2.3	30.7	13.6
0-15		0.6	94.5	954.8	0.5	2.1	15.6	9.9
15-30		0.6	98.0	474.6	0.3	1.2	5.5	5.5
30-60		0.6	87.5	307.5	0.4	1.3	19.3	19.3
60-90		0.4	84.0	207.9	0.3	1.3	5.0	5.0
0-15	Barraka	0.4	101.5	179.0	1.9	0.7	5.0	5.0
15-30		0.4	105.0	188.4	0.7	0.8	3.4	3.4
30-60		0.4	87.5	151.7	0.6	1.0	5.7	5.7
60-90		0.3	38.5	117.5	0.5	0.9	4.3	4.3
0-15	Khaika	0.1	59.5	101.3	0.3	0.2	3.7	3.7
15-30		0.1	63.0	101.3	0.3	0.5	4.9	4.9
30-60		0.1	59.5	93.4	0.2	0.1	2.5	2.5
60-90		0.1	52.5	62.8	0.2	0.0	1.9	1.9
0-15	Khaika	0.1	94.5	320.1	0.5	0.7	3.7	3.7

15-30		0.2	98.0	307.5	0.3	0.8	4.9	4.9
30-60		0.1	87.5	238.7	0.2	0.5	4.0	4.0
60-90		0.1	66.5	179.0	0.2	0.4	3.1	3.1
0-15	Pavsar	0.2	73.5	188.4	0.3	0.5	2.8	2.8
15-30		0.2	70.0	179.0	0.3	0.6	3.8	3.8
30-60		0.2	73.5	160.6	0.2	0.5	2.6	2.6
60-90		0.1	52.5	134.3	0.3	0.4	1.9	1.9
0-15	Pahari	0.1	70.0	260.4	0.3	0.8	4.1	4.1
15-30		0.1	66.5	249.4	0.2	0.5	2.0	2.8
30-60		0.0	66.5	179.0	0.2	0.4	2.3	3.8
60-90		0.0	35.0	151.7	0.1	0.4	3.0	3.6
0-15	Pahari	0.4	112.0	249.4	0.5	1.4	3.5	3.5
15-30		0.4	105.0	260.4	0.3	1.4	1.9	3.6
30-60		0.4	108.5	234.9	0.3	1.2	2.2	3.1
60-90		0.0	98.0	160.6	0.3	1.0	1.6	4.1
0-15	Purrakha	0.2	101.5	125.9	0.3	0.5	3.0	2.3
15-30		0.2	101.5	125.9	0.3	0.6	2.4	3.0
30-60		0.2	52.5	101.3	0.2	0.5	1.4	2.7
60-90		0.2	35.0	77.9	0.2	0.3	1.5	2.6
0-15	Pachanka	0.1	87.5	307.5	0.4	0.6	1.1	8.0
15-30		0.1	87.5	283.3	0.3	0.5	0.6	1.7
30-60		0.1	70.0	260.4	0.4	0.3	0.6	1.3
60-90		0.1	52.5	160.6	0.4	0.2	0.8	1.5
0-15	Gangoli	0.4	119.0	283.3	0.9	1.5	10.1	8.7
15-30		0.4	119.0	249.4	0.3	1.0	4.1	10.4
30-60		0.4	105.0	207.9	0.5	1.0	3.4	9.6
60-90		0.3	66.5	142.9	0.3	0.9	3.6	5.9
0-15	Madnaka	0.1	84.0	125.9	0.5	0.7	5.3	3.7
15-30		0.1	84.0	134.3	0.3	0.4	2.9	2.2
30-60		0.1	70.0	117.5	0.3	0.3	1.7	3.3
60-90		0.0	52.5	93.4	0.3	0.2	1.3	2.7
0-5	Riber	0.3	126.0	421.4	2.6	1.1	12.6	22.6
0-15		0.4	126.0	405.2	1.9	1.2	12.0	11.4
15-30		0.5	108.5	320.1	0.6	0.7	4.7	7.2
0-15	Akbarpur	0.1	105.0	125.9	0.5	0.6	5.9	3.0
15-30		0.1	101.5	134.3	0.3	0.3	2.3	3.0
30-60		0.1	87.5	109.4	0.3	0.3	1.9	3.4
60-90		0.1	49.0	93.4	0.3	0.3	1.9	2.1
0-15	Bhagwali	0.21	98.0	421.4	0.71	1.5	2.9	8.7

15-30		0.2	98.0	374.8	0.3	0.7	0.9	4.2
30-60		0.1	63.0	333.1	0.3	0.4	0.5	2.8
0-5	Matepur	0.1	108.5	160.6	0.6	1.3	3.3	4.1
0-15		0.1	108.5	140.5	0.6	0.8	3.3	4.2
15-30		0.1	87.5	125.9	0.3	0.6	1.6	3.9
30-60		0.1	87.5	93.4	0.3	0.3	1.1	2.1
0-15	Khri Brahman	0.3	129.5	249.4	0.4	0.8	4.4	4.8
15-30		0.3	126.0	238.7	0.3	0.9	3	5.2
30-60		0.3	105.0	207.9	0.3	1.0	1.3	4.3
60-90		0.3	73.5	93.4	0.3	0.9	1.3	4.1
0-15	Baghola	0.0	87.5	117.5	0.5	0.5	2.9	4.3
15-30		0.1	87.5	117.5	0.4	0.4	2.1	3.5
30-60		0.0	70.0	101.3	0.3	0.3	1.5	4.1
60-90		0.1	59.5	70.3	0.3	0.3	1.4	4.0
0-15	Devali	0.2	98.0	307.5	0.7	1.5	29.8	6.7
15-30		0.3	94.5	320.1	0.4	0.7	8.0	5
30-60		0.2	73.5	283.3	0.3	0.5	3.6	5.5
60-90		0.2	70.0	151.6	0.3	0.4	2.2	4.9
0-5	Devali	0.3	87.5	405.2	0.8	1.3	70.5	7.2
0-15		0.3	87.5	421.4	0.5	1.3	22.2	7.3
15-30		0.3	73.5	389.7	0.3	0.9	8.3	8.4
30-60		0.3	70.0	307.5	0.3	0.8	6.4	8.3
60-90		0.3	59.5	198.0	0.3	8.3	6.4	7.9
0-5	Mandkaula	0.0	91.0	537.5	1.3	2	10.6	4.4
0-15		0.1	91.0	438.3	1.3	1.4	7.7	4.1
15-30		0.0	87.5	421.4	0.4	0.7	3.4	3.5
30-60		0.1	70.0	346.5	0.3	0.7	3.0	3.7
60-90		0.0	73.5	160.6	0.2	0.2	1.5	3.6
0-15	Janauli	0.0	59.5	470.3	0.4	0.7	2.1	3.8
15-30		0.0	56.0	503.6	0.7	0.9	4.4	3.6
30-60		0.0	52.5	320.1	0.3	0.9	5.6	4.2
60-90		0.0	38.5	179.0	0.6	0.7	3	3.9
Max		0.7	129.5	1181.0	3.3	8.3	70.5	22.6
Min		0.0	35.0	38.8	0.1	0.0	0.3	0.8
Average		0.3	86.6	280.6	0.6	0.8	4.1	4.2
Std Deviation		0.1	22.1	193.9	0.4	0.8	7.5	3.1

Table 22. Composition of groundwater samples from Palwal district

Name of village	ECw, dS m^{-1}	pHw	Na, me L^{-1}	K, me L^{-1}	Ca+Mg, me L^{-1}	Cl, me L^{-1}	HCO3, me L^{-1}	NO3, ppm	F, ppm
Yakubpur	1.4	7.2	1.9	0.09	15.0	19.0	0.6	198.6	0.3
Malai	1.8	7.2	8.3	0.0	12.0	17.0	0.7	4.0	0.3
Kot	15.4	6.8	129.5	0.3	49.0	159.0	0.8	0.5	8.5
Sundarnagar	3.9	7.2	48.2	0.3	14.0	31.0	1.1	114.1	3.8
Nimka	3.4	7.3	31.1	0.0	12.0	25.0	1.0	327.1	3.4
Madnaka	3.0	7.0	12.3	0.2	22.0	32.0	0.5	129.3	2.4
Akbarpur Natol	1.6	7.8	15.7	0.0	2.0	15.0	0.6	20.7	4.4
Bhigawali	1.3	7.2	7.3	0.0	9.0	18.0	0.5	24.1	0.0
Mathepur	4.4	7.5	37.7	0.7	10.0	45.0	0.9	0.5	4.1
Devali	8.5	7.2	60.1	0.4	23.0	85.0	1.0	9.0	7.9
Devali	5.7	7.1	44.5	0.8	14.0	57.0	0.8	29.3	9.0
Janauli	2.8	7.5	31.2	0.1	4.0	26.0	1.3	3.0	8.8
Maheshpur	2.5	7.0	18.0	0.0	9.0	24.0	0.8	56.1	0.3

13.0 Soils of Faridabad district

Interpretation of satellite images of IRS P-6 LISS-III was done to identify salt affected soils over Faridabad district of Southern Haryana, the prominent areas in Sahapur Khurd, Machhghar, Baghola, Prithla, Sikrana, Kabulpur Bangar villages of the Faridabad district and adjoining villages in the alluvial plain affected by the salinity/sodicity were identified and marked. IRS imageries showed strong reflectance of barren salt affected soils and higher water absorption in cropped areas irrigated with saline ground water. Ground truth was done to characterize the interpreted units for land uses, topography, drainage, irrigation, water logging, salt affected areas and presence of sub-surface salinity/alkalinity, concretions and textural grades etc. Depth-wise (0-15, 15-30, 30-60 and 60-90 cm) soil samples were collected using auger for determination of physico-chemical properties. Analytical data showed that soil salinity was found to be as high as 54.7 dS m^{-1} with mean of 7.8 dS m^{-1} and standard deviation 11.8. Soil pH was ranged from 7.1 to 10.0 with mean 8.6 and std. deviation of 0.57. These soils are saline as well as sodic in nature. Soluble sodium and chloride ions are significantly correlated with electrical conductivity (EC_e). The mean concentration of soluble sodium is 3.0 times more than the concentration of calcium + magnesium in these soils. Similarly chloride content was as high as 492.0 me L^{-1}. Soils at Machghar, Sotai, Sagarpur and Harphalli villages were highly sodic soils with pHs ranged from 9.2 to 10.0 (Table 23). Soils of the study area are sandy loam to loamy sand in texture. These soils are low in available nitrogen content and soil organic carbon content ranged from 0.21 to 0.62%. The groundwater samples from handpump/tubewell at different villages namely Piyala, Sagarpur, Deegh, Harphalli, Mirzapur, Tigaon, Nawada, Dayalpur, Sahapur Kalan, and Sunped were collected for knowing status of water quality. Laboratory analysis of ground water samples from Faridabad district revealed that pH_w ranged from 6.8 to 9.2 and EC_w ranged from 0.8 to 4.5 dS m^{-1} with SAR ranged from 1.9 to 17.1. At some places the high RSC water was also found with value as high as 19.0 (Table 24).

Table 23. Physico-chemical properties of soil samples from Faridabad district

Village	Depth, cm	pHs	ECe, dS m^{-1}	OC, %	$CaCO_3$,	Na, me l^{-1}	K, me l^{-1}	Ca+Mg, me l^{-1}	CO_3, me l^{-1}	HCO_3, mel^{-1}	Cl, mel^{-1}
Sahapur	0-15	7.9	28.3	0.5	1.3	51	0.2	79.0	0	0	245.0
Khurd											
	15-30	8.1	18.3	0.4	1.4	110	0.1	45.0	0	0	154.0
	30-60	8.1	14.7	0.4	1.6	88.3	0.0	39.0	0	0	95.0
	60-90	8.3	11.1	0.3	2.0	84	0.0	32.0	0	0	64.0
Sagarpur	0-15	8.7	1.2	0.4	4.7	9.7	0.0	8.0	0	0	8.0
	15-30	8.7	2.0	0.4	9.9	9.6	0.0	7.0	0	0	9.0
Sagarpur	0-15	8.7	0.9	0.4	4.5	9.0	0.1	6.0	0	0	7.0
	15-30	8.7	1.0	0.4	5.8	9.2	0.0	5.0	0	0	7.0
	30-60	8.7	1.4	0.3	1.1	13.3	0.0	5.0	0	0	7.0
	60-90	8.8	1.4	0.3	1.1	13.8	0.0	5.0	0	0	7.0
Harphalli	0-15	8.6	1.4	0.4	0.6	16.7	0.1	5.0	0	0	10.0
	15-30	8.4	1.2	0.4	0.5	20.6	0.0	4.0	0	0	10.0
	30.6	8.1	3.7	0.3	0.5	40.9	0.0	8.0	0	0	16.0
	60-90	7.6	4.2	0.3	0.4	39.8	0.0	9.0	0	0	23.0
Harphalla	0-15	8.6	1.4	0.4	0.4	10.3	0.0	5.0	0	0	10.0
	15-30	8.2	4.0	0.4	0.4	51.0	0.0	7.0	0	0	21.0
	30-60	8.2	5.6	0.4	0.5	82.9	0.0	8.0	0	0	35.0
	60-90	8.2	5.2	0.4	0.6	37.7	0.0	8.0	0	0	33.0
Tigaon	0-15	8.3	4.2	0.4	0.7	35.7	0.4	7.0	0	0	26.0
	15-30	8.5	2.5	0.4	0.6	21.1	0.2	7.0	0	0	18.0
	30-60	8.5	2.0	0.3	1	17.0	0.1	6.0	0	0	15.0
	60-90	8.6	1.9	0.3	0.6	12.8	0.0	6.0	0	0	15.0
Machghar	0-15	10.1	7.2	0.4	7.4	63.7	0.0	7.0	0	0	27.0
	15-30	10.2	8.7	0.3	5	101.8	0.1	5.0	0	0	29.0
	30-60	10.2	11.9	0.3	2	128.4	0.0	5.0	3	2	36.0
	60-90	10.1	11.6	0.3	2	120.2	0.0	5.0	2	2	38.0
Machghar	0-15	10.0	2.6	0.4	4.7	18.3	0.0	6.0	0	2	14.0
	15-30	9.2	6.9	0.3	2.5	40.2	0.0	6.0	0	0	20.0
	30-60	10.1	10.5	0.3	2	96.6	0.0	6.0	0	0	20.0
	60-90	10.2	8.9	0.2	3.1	84.0	0.0	5.0	0	0	16.0

Dayalpur	0-15	8.2	2.9	0.4	0.5	17.1	0.2	9.0	0	0	15.0
	15-30	8.2	1.1	0.4	0.6	6.8	0.1	6.0	0	0	12.0
	30-60	8.3	0.7	0.3	0.5	4.6	0.0	6.0	0	0	8.0
	60-90	8.4	0.7	0.2	6.3	5.1	0.0	6.0	0	0	6.0
Dayalpur road	0-15	7.7	1.0	0.6	0.5	4.4	0.2	6.0	0	0	8.0
	15-30	7.9	1.1	0.5	0.4	5.2	0.0	6.0	0	0	7.0
	30-60	8.2	0.8	0.4	0.5	2.8	0.0	5.0	0	0	6.0
Sotai	0-15	8.5	1.1	0.5	0.7	9.4	0.0	5.0	0	0	11.0
	0-30	8.5	1.3	0.4	0.8	10.2	0.0	5.0	0	0	8.0
	30-60	8.3	1.2	0.4	0.5	8.4	0.0	5.0	0	0	7.0
	60-90	8.3	1.0	0.2	0.5	5.7	0.3	5.0	0	0	6.0
Sahapur kalan	0-15	8.1	0.8	0.6	0.8	5.6	0.0	6.0	0	0	7.0
	15-30	8.5	0.7	0.5	0.2	4.6	0.0	5.0	0	0	6.0
	30-60	8.2	0.7	0.3	0.3	5.2	0.0	5.0	0	0	6.0
	60-90	8.1	0.7	0.2	0.8	4.3	0	5.0	0	0	6.0
Ladhauli	0-15	8.3	0.4	0.4	0.8	1.9	0.0	6	0	0	10.0
	15-30	8.3	0.4	0.3	0.5	2.2	0.0	6	0	0	6.0
	30-60	8.1	0.5	0.3	0.8	4.1	0.0	5	0	0	5.0
	60-90	8.1	0.5	0.3	0.6	3.3	0.0	5	0	0	5.0
Sunped	0-15	7.9	0.7	0.3	0.4	2.2	0.1	7	0	0	5.0
	15-30	8.1	0.7	0.5	0.5	2.1	0.0	7	0	0	5.0
	30-60	8.1	0.7	0.4	0.5	3.7	0.0	5	0	0	10.0
	60-90	8.1	0.8	0.4	0.5	6.7	0	5	0	0	10.0
Asaoti	0-15	8.1	2.2	0.3	0.6	15.3	0.0	5	0	0	15.0
	15-30	8.2	1.4	0.2	0.4	10.9	0.0	5	0	0	8.0
	30-60	8.0	1.4	0.5	0.5	9.1	0.1	5	0	0	7.0
	60-90	8.3	1.4	0.3	0.5	13.1	0.6	5	0	0	8.0
Baghola	0-15	6.4	50.3	0.4	0.4	276	1.2	164	0	0	441.0
	15-30	7.5	26.8	0.3	0.5	31.3	0.1	59	0	0	190.0
	30-60	7.2	29.9	0.3	0.5	207	0.1	55	0	0	178.0
	60-90	8.2	25.4	0.3	1.1	178.7	0.1	40	0	0	157.0
Pirthala	0-15	7.6	18.7	0.6	0.5	106.8	2.4	71	0	0	126.0
	15-30	7.7	14.1	0.4	0.4	90.9	0.8	54	0	0	92.0
	30-60	8.0	12.9	0.3	0.5	62.7	0.5	48	0	0	88.0
	60-90	7.8	13.6	0.3	0.6	50.7	0.5	55	0	0	96.0
Maladpur	0-15	8.0	1.1	0.6	0.3	4.9	0.0	10	0	0	11.0
	15-30	8.0	1.1	0.4	0.2	6.8	0.0	8	0	0	10.0

	30-60	8.1	1.2	0.3	0.3	7.6	0.0	7	0	0	10.0
	60-90	8.3	1.0	0.3	0.4	7	0	7	0	0	10.0
Qureshipur	0-15	8.2	0.3	0.2	0.4	0.6	0.0	8	0	0	10.0
	15-30	8.7	0.3	0.2	0.3	1.6	0.0	8	0	0	10.0
	30-60	8.4	0.2	0.2	0.7	1	0.1	7	0	0	7.0
	60-90	8.3	1.1	0.2	0.5	1.4	0.0	7	0	0	8.0
firozpur kalan	0-15	8.3	0.8	0.5	0.5	4.3	0.0	8	0	0	10.0
	15-30	8.3	0.9	0.3	0.5	7.6	0.0	6	0	0	8.0
	30-60	8.2	3.0	0.3	1	16.1	0.0	7	0	0	16.0
	60-90	8.1	3.1	0.3	1.1	18.1	0.0	8	0	0	16.0
Sikrona	0-15	7.4	51.5	0.5	0.5	652.1	0.4	105	0	0	405.0
	15-30	7.3	27.5	0.4	0.5	207	0.1	60	0	0	186.0
	30-60	7.4	20.2	0.4	0.4	197.1	0.1	52	0	0	111.0
	60-90	7.5	17.4	0.4	0.3	198.2	0.1	50	0	0	102.0
Kabulpur bangar	0-15	7.2	54.7	0.3	0.4	345.7	0.3	220	0	0	492.0
	15-30	7.3	32.1	0.3	0.4	137.1	0.2	125	0	0	245.0
	30-60	7.4	21.5	0.3	0.5	141.8	0.1	86	0	0	156.0
	60-90	7.5	18.5	0.2	0.5	172.1	0.1	80	0	0	132.0
Min		6.4	0.2	0.2	0.2	0.6	0	4	0	0	5.0
Max		10.2	54.7	0.6	9.9	652.1	2.4	220	3	2	492.0
Mean		8.3	7.8	0.4	1.2	61.2	0.1	22.6	0.0	0.0	53.7
SD		0.7	11.8	0.0	1.7	107.3	0.3	37.1	0.3	0.3	95.0

Table 24. Composition of groundwater samples from villages in Faridabad district

Village	ECw (dS m^{-1})	pHw	Na (me l^{-1})	K (me l^{-1})	Ca+Mg (me l^{-1})	Cl (me l^{-1})	HCO_3 (me l^{-1})	SAR	RSC
Piyala	2.8	7.4	31.6	3.4	10.0	24.0	13.0	14.1	3.0
Sagarpur	3.9	7.0	35.9	0.6	19.0	34.0	9.0	11.6	0
Deegh	3.9	6.7	39.4	0.6	15.0	37.0	8.0	14.3	0
Deegh	1.0	6.9	4.2	0.1	10.0	10.0	6.0	1.8	0
Deegh	4.5	7.2	37.6	0.7	20.0	38.0	9.0	11.8	0
Harphalli	2.2	9.1	27.1	1.7	5.0	12.0	10.0	17.1	5.0
Tigaon	2.2	7.2	26.3	1.1	6.0	34.0	25.0	15.1	19.0
Tigaon	2.3	7.1	24.7	0.8	6.0	20.0	13.0	14.2	7.0
Tigaon	2.2	7.1	26.1	0.7	6.0	19.0	12.0	15.0	6.0
Nawada	2.6	6.8	25.6	0.6	10.0	22.0	15.0	11.4	5.0
Dayapur	1.1	7.2	10.5	0.4	9.0	8.0	9.0	4.9	0.0

Sahapur kalan	0.8	7.3	5.3	0.1	5.0	9.0	8.0	3.3	3.0
Sunped	0.8	7.4	3.3	0.2	5.0	9.0	7.0	2.0	2.0
Max	4.5	9.2	39.4	3.4	20.0	38	25	17.1	19.0
Min	0.8	6.8	3.3	0.1	5.0	8.0	6.0	1.8	0
Mean	2.3	7.3	22.8	0.8	9.6	21.2	11.0	10.5	

14.0 Image classification

Initially an unsupervised classification was carried out using ISODATA in ERDAS IMAGINE on the complete image encompassing all the districts. The first iterations were run to create clusters. Subsequently the number of iterations was reduced and the classes identified for input in the creation of the supervised classification. Individual samples for each class were identified and analyzed for reflectance values and spectral profiles of major soil types were generated using ERDAS Imagine 9.3. Ground sample analysis of soil samples from all the districts formed the integral basis for classification and creation of the spectral profile and classification. A spectral profile was created to represent various types of salt affected soils, moderately salt affected soils, waterlogged and saline soils and vegetation using the IRS P6 LISS III image. The averages DN values of spectral profiles of each class were calculated separately for clarity. It was observed that all soils had higher reflectance in the Green band (0.555µm) with salt affected soils reflecting the maximum (Fig. 16) followed by moderately salt affected soils. The lower reflectance of moderately salt affected soil in the red and SWIR region is where the soils have a vegetative cover. Waterlogged saline soils also had a lower reflectance because of the presence of moisture in the Red, NIR and the SWIR region. Vegetation peaked in the NIR region due to the green colour of vegetation. Reflectance of vegetation was low in the red, green and SWIR regions of the spectrum because of the absorption of chlorophyll for photosynthesis. It is noticeable that the reflectance from healthy green vegetation increases dramatically as we reach the near infrared portion of the spectrum. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves (www.crisp.nus.edu.sg.).

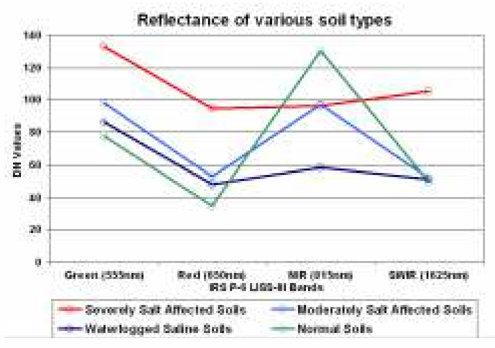

Figure 16: Spectral signatures of soils in different bands

It was found that reflectance of all soils was considerably lower in the red band (0.65µm) however severely salt affected soils had a high reflectance in all the

Table 25. Average Spectral Profile of different soils in different bands

	Green (0.555µm)	Red (0.65µm)	NIR (0.815µm)	SWIR (1.625µm)
Severely Salt Affected Soils	133	95	96	106
Moderately Salt Affected Soils	98	53	97	52
Waterlogged Saline Soils	86	48	58	51
Normal Soils	78	35	130	50

bands equally because of poor or no vegetation cover. Moderately salt affected soils had a lower reflectance along with green vegetation in the red band of the spectrum. The reflectance on the near-infrared plateau varied with vegetation type, water content, and canopy architecture. In contrast, bare salt affected soil had approximately the same reflectance in both the visible and near-infrared portion of the spectrum. The reflectance characteristics in the visible and the near infrared bands had been used to monitor vegetation in the multispectral remote sensing images. Based on the spectral signatures and the established range, training sites were decided for different classes for supervised classification using the Maximum likelihood classification. The maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Richards, 1999). All pixels were classified and each pixel was assigned to the class that had the highest probability hence the clusters created had maximum separability for assigning class names. These classes included normal soils with agriculture, severely salt affected barren, moderately salt affected soils with agriculture, sand, waterbody, settlements, waterlogged and saline soils with agriculture. Supervised classification with maximum likelihood was performed based on these training sites. We found that roads were misclassified as saline soils therefore assuming that the roads had a width of 10 m, buffers were generated along the roads. The classified image was then converted into vector (polygon) database. Misclassified roads were clipped from classified vector database using clip algorithm of GIS overlay operation based on ArcGIS to eliminate the misclassification and subsequently remove the error.

15.0 Accuracy assessment

To study the accuracy of the classification an accuracy assessment of the classified maps was carried out using an error matrix based on accuracy measures (Congalton, 1991). The digital image of Febuary 2007 of LISS III was selected as a reference image for assessing the accuracy of the image classification which was used in previous study by Sethi et al. (2004). Ground soil sample details as before were the basis of the final classification process, selection of pixels and accuracy assessment.The 50 testing pixels were collected in equalized random fashion from the classified LISS III image per class. The error matrix generated could be utilized to determine the over-all accuracy of the map and individual class accuracies in the form of user's and producer's accuracies (Congalton, 1991). The overall accuracy was then used to indicate the accuracy of the whole classification (i.e. the number of correctly classified pixels divided by the total number of testing pixels). The producer's accuracy relates to the probability that a reference sample was correctly mapped, and measures the omission error. The user's accuracy indicates the probability that a sample from the classified map actually matches what it was in the reference data, and measures the commission error. The error-matrix based accuracy assessment reveals that the methodology applied here has been quite successful in mapping and isolating salt affected soils and other land-cover classes. The *Kappa* statistic applied reflects the difference between actual agreement and the agreement expected by chance Kappa of 0.85 means there is 85% better agreement than by chance alone. Kappa is computed as

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

Where N is the total number of sites in the matrix, r is the number of rows in the matrix, xii is the number in row *i* and column *i*, x_{+i} is the total for row *i*, and x_{i+} is the total for column I(Jensen 1996). The producer's accuracies for all classes in table 26 were above 80% except in moderately salt affected soils with agriculture where it was 73.21%. In the users accuracy again the accuracy levels were more than 80% but was only 76% in severely salt affected barren soils. These errors occurred due to misclassification of the

Table 26. Accuracy assessment for land use classes in Mewat district .

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	52	50	50	---	--
Sand	45	50	43	95.56%	86.00%
Severely salt affected/barren	43	50	38	88.37%	76.00%
Settlement	52	50	45	86.54%	90.00%
Normal soils/Agriculture	51	50	43	84.31%	86.00%
Waterbody	47	50	45	95.74%	90.00%
Moderately salt affected	56	50	41	73.21%	82.00%
Waterlogged and saline soils	54	50	44	81.48%	88.00%
Totals	400	400	349		
Overall Classification Accuracy = 87.25%					

pixels. The overall accuracy of the maximum liklihood classfication using the accuracy assessemnt matrix was 87.25 percent using the KHAT coefficient in four districts. Ancillary data like published soil survey reports, atlas of Haryana, census report for the study area were collected and utilized during interpretation and field work.

16.0 Mapping and reports

For the purpose, multi-spectral and multi-date IRS P6, LISS III, March 2010 and May 2011 images of the study area were procured from the National Data Center (NDC), Balanagar, National Remote Sensing Agency (NRSA), Hyderabad.

(I) Ancillary data : Survey of India (SOI) Toposheet Maps in the scale of 1:50,000, district maps, their village maps, cadastral map of study area, published soil survey reports, soil maps, atlas, census report, water quality reports for the study area were collected and utilised during interpretation and field work.

(ii) Preparation of base map: The base maps indicating permanent cultural features such as major canals, highways, roads, railways, villages and sand dunes were prepared in Arc View 3.1 and ARC GIS 8.0 software. For this, Survey of India toposheets were used as reference. The Survey of India toposheet was geo-referenced using the geographic latitude/ longitude WGS 84 coordinate system. The coordinate of the toposheet was converted into the geographic latitude/ longitude values in meters using ERDAS IMAGINE–8.1software. Finally toposheet on 1:50,000 scale covering the study area was digitised to prepare the base map. A part of this irrigation network was digitised and added to the base map from satellite data to facilitate mapping of salt affected soils and secondary salinity.

(iii)Generation of False Colour Composite (FCC) : IRS P6 LISS III data has four bands: blue (0.45- 0.52nm), green (0.52-0.59nm), red (0.62- 0.68nm) and near infrared (0.77-0.86nm). The FCC was generated by combination of three bands: infrared, red and green bands projecting as red, green and blue image planes. The standard false colour composite was used. The vegetation was represented by red colour instead of green colour in the false colour composite. Methodologies comprises of pre-field interpretation, field work (Ground truth) and post-field work (Analysis). The enhanced false colour composite image of the study area (1:50,000 scale) was displayed on monitor. Standard FCC was visually interpreted for salt affected soils and waterlogged areas with the help of image elements like tone, texture, shape, size, pattern and association, etc. The salt-affected soils were depicted in tones of bright white to dull white with medium to coarse texture on Standard FCC as per the presence of salts on soil surface. The landforms associated with the occurrence of salt-affected soils were also considered during interpretation. The obstructions to natural drainage like roads, railway lines, distributaries, etc. could easily be identified on FCC images. The waterlogged areas appeared on the FCC image in tones of dark blue to black with a smooth texture. Additional pre- and post-monsoon images were used to permanently identify waterlogged area. Initially rapid traverse of the study area was made to identify the sampling points in the area. Detailed field investigations were carried out in various physiographic units to observe the broad physiographic-soil relationship. A reconnaissance survey of the study area was done using satellite images (FCC). Salt affected lands were identified on the ground and ascertained on the satellite image by characterising their images. Satellite image of IRS P6 LISS III of March 2010 was used for the purpose. Modification of the post-field work primarily involved interpreting the mapping units on the FCC of the satellite data in the light of field information and soil physico-chemical data. On the basis of this information, a final map showing salt-affected soils was prepared. Image classification, that is, categorisation of pixels based on their spectral characteristics is one of the fundamental analysis techniques for remotely sensed data. The two common methods of digital classification, that is, unsupervised and supervised methods were utilised to prepare the land use/ land cover from IRS P6 LISS III satellite data of March 2010. During March, in the study area, wheat and other vegetation cover are at an optimum growth condition. Therefore, various land cover types can be distinctly separated during classification. The application of unsupervised classification has had a significant advantage for the area under study because similar results were obtained for the same data set. The unsupervised classification was carried out for understanding the pixel separability of classes based on the clustering of DN values and respective cover type on the ground. Supervised classification procedures are the most important analytical tools used for the extraction of more information from remotely sensed digital image data. The classification was carried out using the maximum likelihood classifier. Before starting this procedure, the possibility of separation of each class was determined from various enhancement techniques and the unsupervised classification techniques. The supervised classification using maximum likelihood algorithm quantitatively evaluated both the variance and co-variance categories of spectral responses. The training samples were assigned based on the ground truth information collected from each of the variable crop cover types in order to ensure the planimetric accuracy of the samples. The GPS points indicating geographical coordinates of each cover type were also considered. IRS.P6 USS III Image data have been used to detect and assess the salt-affected land and waterlogged land and crop through a combination of visual and digital techniques. Methods commonly applied for the classification of digital remote sensing data are based on the radiometric information contained in the image bands. Ideally, pixels are expected to be, to a degree, more or less grouped in the multispectral space in clusters corresponding to different land cover types (Price 1994). The maximum likelihood classification algorithm was applied in this study. Both the unsupervised classification procedure and the supervised classification processes are discussed below. The unsupervised classification is computer automated. The computer algorithm (unsupervised) identifies statistical part in the data without using any ground truth data. Therefore, the unsupervised ISODATA algorithm was used to perform this classification. Initially the land use/ land cover was classified with unsupervised classification into 16 clusters (spectral classes). The maximum number of iterations was kept at six. 16 clusters (classes) were enlarged after the iteration. These clusters were specified to classify the spectral variability representing the land use/ land cover in the study area. These classes represented wheat crop conditions influenced by salinity and normal conditions and were identified based on the field observations for the major land use /land cover classes. Subsequently, these clusters were studied to identify the land use/ land cover classes based on field data collected with GPS. The spectral groupings were assigned to land use/ land cover classes. Eventually seven land use/ land cover classes (clusters) were classified in the area. Spectral clusters of crops affected by moderate salinity were not distinguished by the unsupervised classification and merged with the normal crop. The crop affected by severe salinity could be separated into a cluster. Areas under fallow (sand dunes) were also distinguished clearly as a separate cluster. There were three basic stages involved in the supervised classification method, viz training stage, classification stage and accuracy assessment stage. In the training stage, pixels in the image that represented the typical spectral information about severe and moderate salinity were examined for studying the classification. The maximum likelihood decision rule is based on a normalized (Gaussian) estimate of the probability density function of each class. The maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel. These classes appeared distinctly on the standard FCC and their GPS locations were recorded to generate training sets. Crops affected by salinity were divided in two classes-crops affected by severe salinity and crops affected by moderate salinity. After generation of training sets, supervised classification was performed using the maximum likelihood classifier algorithm by ERDAS imagine software. Training sets were collected from the field survey by recording the geographic coordinates of homogeneous land-cover area with GPS.

In the supervised classification, classes were identified and training sets were generated. These training sets were generated with the help of ground truth data. The land use land cover classes classified in the area. The area under crops affected by severe salinity was identified. The crops of this category have a distinct spectral signature and were easily marked in the training set generation. The area under crops affected by moderate salinity was also mapped. The spectral signature was not very distinct and training sets were provided with GPS locations. The resulting spectra and locations were accurate and crops affected by moderate salinity were classified. Normal crops were depicted on the image (Std. FCC) with a red and bright red tonal variation. Training sets of this class were very well identified on the image. The crops with normal spectra were also growing on normal soils. The crop growth was observed to be in very good condition and a high crop yield was predicted. Waterlogged/ canal areas where water accumulation was found on the surface was classified. The training set was easily generated for this class. Settlement area was also classified. Table 27 depicts the extent of area of various Land use / and land cover based on supervised classification (IRS P6, LISS III, March 2010) An accuracy assessment determines the quality of information derived from remotely sensed data. Seven land cover classes were classified in the area. The accuracy of each class was assessed with reference pixels. Reference pixels were identified based on the ground truth survey. The crops affected by severe and moderate salinity were classified with an accuracy of 81.65 per cent and 82.41 per cent, respectively. The normal crop class was classified with maximum accuracy of 91.71 per cent. Waterlogged area, and settlement were classified with an accuracy of 88.69 per cent, and 86.06 per cent, respectively. The overall accuracy for the salt affected/ waterlogging land use/ land cover map was found to be 85.47 per cent. The accuracy assessments of the supervised classification of March data indicate the high level of accuracy that was achieved by correctly providing data and ground information. The supervised classification (maximum likelihood algorithm) provided vastly improved results over the unsupervised classification. However, the unsupervised classification was found to be an important tool in the initial analysis. Satellite imageries were interpreted and subjected to supervised classification (Fig. 17) for estimation of area under different categories. Mapping of salt affected soils of four districts of southern Haryana using topomap of 1:50000 completed and extent of salt affected area in districts of Mewat, Palwal, Gurugram and Faridabad was found to be 399.6, 336.83, 161.67 and 91.15 sq km, respectively (Table 27).

Table 27. Extent of salt affected area (sq. km) in four districts of Southern Haryana

Class Name	Faridabad	Palwal	Gurugram	Mewat
Built-up Land/Settlements	161.41	119.71	281.71	215.42
Hill Area	132.32	28.61	282.55	257.35
Normal Soils	344.67	843.04	502.30	636.91
Moderately salt affected soils	44.22	105.89	53.19	142.07
Severely salt affected soils	22.11	40.12	23.16	157.28
Waterlogged Saline Soil	24.82	190.82	85.32	100.25
Waterbody	9.59	26.38	6.93	9.03
Total	739.14	1354.58	1235.16	1518.31

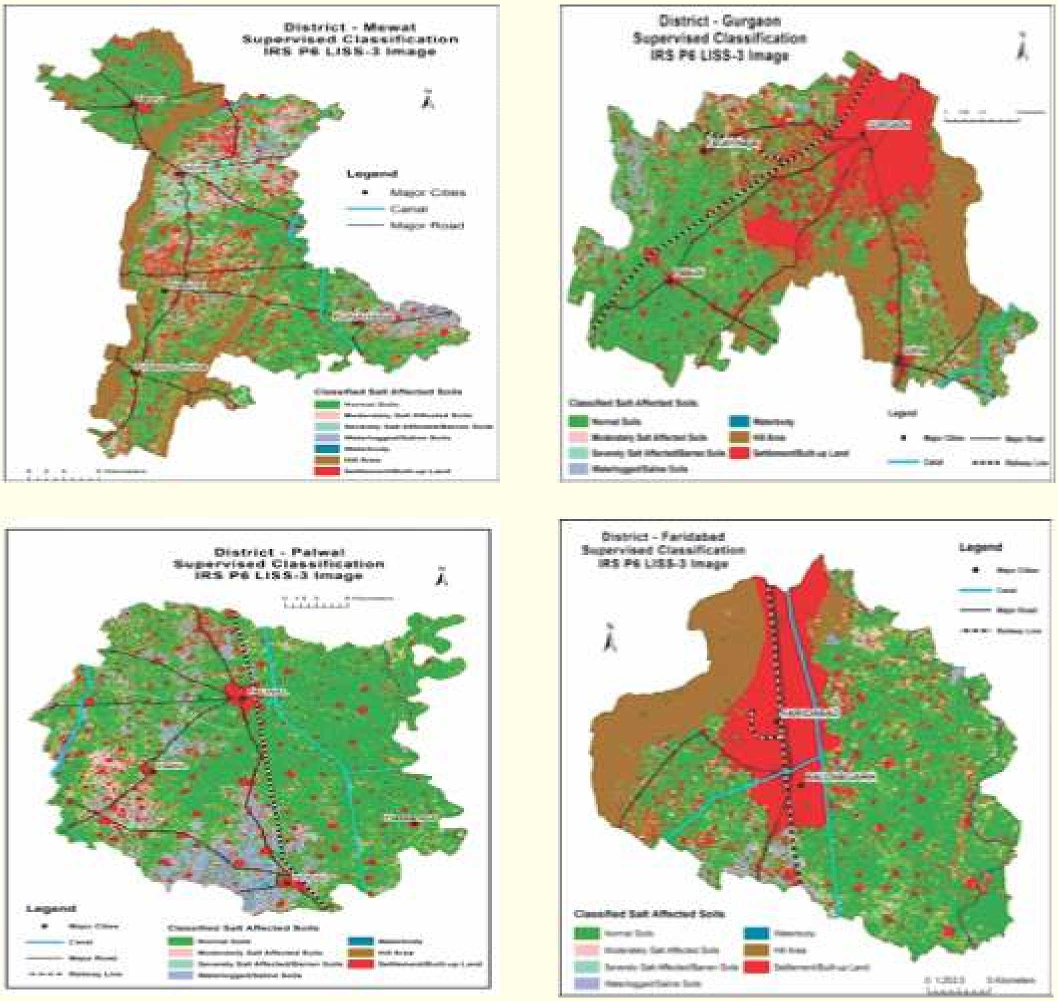

Fig. 17. Supervised classification of IRS P6 LISS-III images of different districts

17.0 References

Ackerman, T., Erickson , T. and Williams, M.W., 2001, Combining GIS and GPS to Improve Our Understanding of the Spatial Distribution of Snow Water Equivalence (SWE). *ESRI Users Conference*. San Diego, California.

Cheng, K.I. and Bray, R.H. 1951. Determination of calcium and magnesium in soil and plant material. *Soil Sci. Vol.* **72:** 449-458.

Chesnin, L. and Yion, C.H. 1950. Turbidimetric determination of available sulphates. *Soil Sci. Soc Proc Amer,* **15:**149-151.

Congalton R. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Enviroment.* **37**,35-46. DOI: 10.1016/0034-4257(91)90048-B

Ghassemi F., Jakeman A. J., and Nix H. A. 1995. Salinisation of land and water resources: human causes, extent, management and case studies. Canberra, Australia: The Australian National University, Wallingford, Oxon, UK, CAB International.

Jensen JR. 1996. Introductory Digital Image Processing: *A Remote Sensing Perspective* (Second edition). Prentice Hall, Inc., Upper Saddle River, New Jersey.

Page, A.L., Miller, Keeney, R.H., D.R. 1982. *Methods of soil analysis II. Chemical and Microbiological properties*. 2 Edition. ASA-SSSA, Madison, USA.

Price, J.C. 1994. B*and selection procedure for multispectral scanners. Applied Optics,* 33(15):3281-8. doi: 10.1364/AO.33.003281.

Racoviteanu AE, Manley WF, Arnaud Y, Williams M. 2007. Evaluating digital elevation models for glaciologic applications: An example from Nevado Coropuna , Peruvian Andes. Global Planet Change **59**,pp. 110-125. DOI: 10.1016/j.gloplacha. 2006.11.036

Richards JA. 1999, *Remote Sensing Digital Image Analysis*: An Introduction, Springer-Verlag Berlin, Germany, 240p.

Richards, L.A. 1954. *Diagnosis and improvement of saline and alkali Soils*. Agric. Hand Book No.**60,** USDA, U.S. Govt. Printing Of_ice, Washington D.C. p160.

Sethi M., Dasog G.S., Van Lieshout A. and Salimath S.B. 2006. Salinity appraisal using IRS images in Shorapur Taluka, Upper Krishna Irrigation Project-Phase I, Gulbarga District, Karnataka, India. *Int. J. Remote Sens.***27**:2917–2926

Sethi M., Ghosh D.K., Kudrat M. 2001. Inventorying salt-affected soils: A case study of Kanpur District Uttar Pradesh, India. *In*: Spatial Information Technology, Remote Sensing and Geographical Information Systems, Vol. II, I. V. Muralikrishnan (Ed.) pp, 417-422 (Hyderabad, India: ICORG, BS Publications).

Sethi M., Khurana, M.L., Bhambri, Rakesh, Bundela, D.S., Gupta, S.K., Sita Ram, Chinchmalatpure, Anil R., Chaudhari, S.K. and Sharma, D.K. 2012. Appraisal of salt-affected and waterlogged soils in Rohtak, Bhiwani, Jind and Jhajjar districts of Haryana using Remote Sensing and GIS. Technical Bulletin no. 2012/02, Central Soil Salinity Research Institute, Karnal, p 28.

Sethi M., Sharma, B.D., Kumar, R, Lal, K., Gupta, S.K. 2004. Prognosing Secondary Salinization in a part of an irrigated command area of south west Punjab, India. NATP Final report (World Bank).

Singh, G, Bundela, D.S., Sethi, M., Lal, K. and Kamra, S.K. 2010. Remote sensing and GIS for appraisal of salt-affected soils in India. *Journal of Environmental Quality* **39** (1)**:** 5-15

Szabolcs I. 1989. *Salt affected soils*. Boca Raton, CRC Pres

Walkley, A.J. and Black, I. A. 1934. Estimation of soil organic carbon by the chromic acid titration methods. *Soil Sci*. **37:**29-38