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AN INVENTORY OF SALT-AFFECTED SOILS AND WATERLOGGED AREAS IN THE NAGARJUNSAGAR CANAL COMMAND AREA OF SOUTHERN INDIA, USING SPACE-BORNE MULTISPECTRAL DATA

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ABSTRACT

Information is presented on the nature, extent and spatial distribution of waterlogged areas and salt-affected soils, derived through systematic visual interpretation of standard false colour composite (FCC) prints on a 1 : 100 000 scale generated from the Indian Remote Sensing Satellite (IRS-1B) Linear Imaging Self-scanning Sensor (LISS-I) and Landsat–Thematic Mapper (TM) data for the Nagarjunsagar Right Bank Canal Command Area, Andhra Pradesh. A total of 1710 ha of land in the coastal region has been found to be waterlogged. Salt-affected soils cover an area of 42 800 ha, with saline–sodic soils covering 28 480 ha emerging as the dominant category. To make optimal use of these lands and to prevent further degradation both preventive and ameliorative measures have been advocated. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: land degradation; command area monitoring; salt-affected; saline; saline–sodic; sodic; waterlogged areas; seasonal and perennial waterlogged areas; pH; EC; ESP; irrigated areas; remote sensing; multispectral data

INTRODUCTION

In pursuit of improving the agricultural production to meet the growing demand for food, fuel and fodder of an ever-increasing population, several major and minor irrigation projects have been launched in India since Independence under various five-year plans. Though initially, the projects proved to be beneficial to the farmers, waterlogging and subsequent secondary salinization gradually started developing. Extensive seepage from canals, distributaries and channels, and reckless wastage of water in drains, add to groundwater. Improper alignment of canals has obstructed the natural drainage in many cases. Both of these processes have led to the development of waterlogged conditions and subsequent salinization and/or alkalization.

In order to reclaim existing waterlogged areas and salt-affected soils, and to prevent degradation of fertile land, information on their nature, extent, magnitude and spatial distribution is a prerequisite. Until recently this information had been obtained from traditional soil surveys which were tedious and time-consuming, apart from being cost-prohibitive and impractical in the inhospitable terrain. Availability of aerial photographs in the early-1960s improved the pace of mapping of soils and categorization of salt-affected soils (Karale and Venugopal, 1970; Nagar and Singh, 1979), and ushered in a new era in the making of an inventory of natural resources and monitoring environmental hazards. The launch of the Earth Resources Technology Satellite (ERTS-1) in 1972, which provided the synoptic view of a fairly large area at regular intervals, was followed by several satellites of the Landsat, SPOT and IRS series. These cover a large area, in

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regular interval, narrow bands of the electromagnetic spectrum. Such spectral measurements are suitable for analysis by computer, and the space-borne multispectral data enabled scientists to generate information on salt-affected soils. Singh, *et al.* (1977), Venkataratnam (1980), Dwivedi (1992), and Rao, *et al.* (1989, 1995) have utilized Landsat-MSS and TM, SPOT-MLA and IRS LISS-II data for mapping and monitoring salt-affected soils. The information thus generated was adequate for planning regional-level land reclamation programmes.

Realizing the importance of the temporal behaviour of salt-affected soils and waterlogged areas in land reclamation programmes, the National Remote Sensing Agency, Hyderabad, at the insistence of the Indian Ministry of Water Resources, has undertaken the monitoring of waterlogged and salt-affected soils of major command areas in the country using remote sensing techniques. The study reported here was carried out in the Nagarjunsagar Right Bank Canal Command Area to generate base-level information on waterlogged areas and salt-affected soils at a 1 : 100 000 scale using the Indian Remote Sensing Satellite (IRS-1B), IRS-1B LISS-I and Landsat-Thematic Mapper (TM) data.

STUDY AREA

Lying between the geocoordinates 15°21′–16°41′24″ and 70°18′44′–80°25′50″E, the Command Area has a geographical area of 43 5285 ha, and covers the Guntur and Prakasam Districts of Andhra Pradesh State, India (see Figure 1). It is bound on the north by the river Krishna and on the south by the river Musi. The Canal, with a total length of 2617 km including its minors and subminors, has been divided by the Command Area Development Authority into 22 blocks for the sake of management. Lithologically, the area consists of quartzites, limestones and shales. Coastal and peninsular plains comprise the broad physiographic unit. Inselbergs, hills, pediplain and occasional flood plains of streams and rivers comprise the major physiographic units within the peninsular plain. Different subgroups of Haplustalfs, Rhodustalfs, Ustochrepts, Ustorthents, Ustifluvents and Haplusterts soils (US Department of Agriculture, 1975) are encountered in the area. The river Krishna with its tributary the Musi drain the area and discharge into the Bay of Bengal. The drainage network, slopes northwest to southeast. The broad drainage pattern could be categorized as subparallel and dendritic (Thonbury, 1986).

DATABASE

IRS-1B LISS-I and Landsat-TM data were used to delineate various categories of waterlogged areas and salt-affected soils (Table I). The satellite data of February/March period has been found to be appropriate for detection and delineation of salt-affected soils, while the post-monsoon season (December) data is well-suited for detection and mapping of waterlogged areas. For delineating salt-affected soils the IRS-1B LISS-II data acquired during the dry season was used. Because there was no good quality cloud-free IRS-IB data available during the post-monsoon season, Landsat-TM data was utilized. The details of the data used are given in Table I. Survey of India topographical maps of 1 : 250 000 and 1 : 50 000 scales were also used. Meteorological data from the network of Agromet observatories of the Agricultural University,

Table I. Details of remote sensing data used

S. no.	Sensor	Path-row nos.	Date of acquisition	Data product
1	Landsat-TM	142–049	09.02.1995	CCT and FCC prints
		143–049	20.03.1995	CCT and FCC prints
			30.12.1995	CCT and FCC prints
2	IRS-1B LISS-I	24–56	18.03.1995	CCT and FCC prints
			28.12.1994	CCT and FCC prints

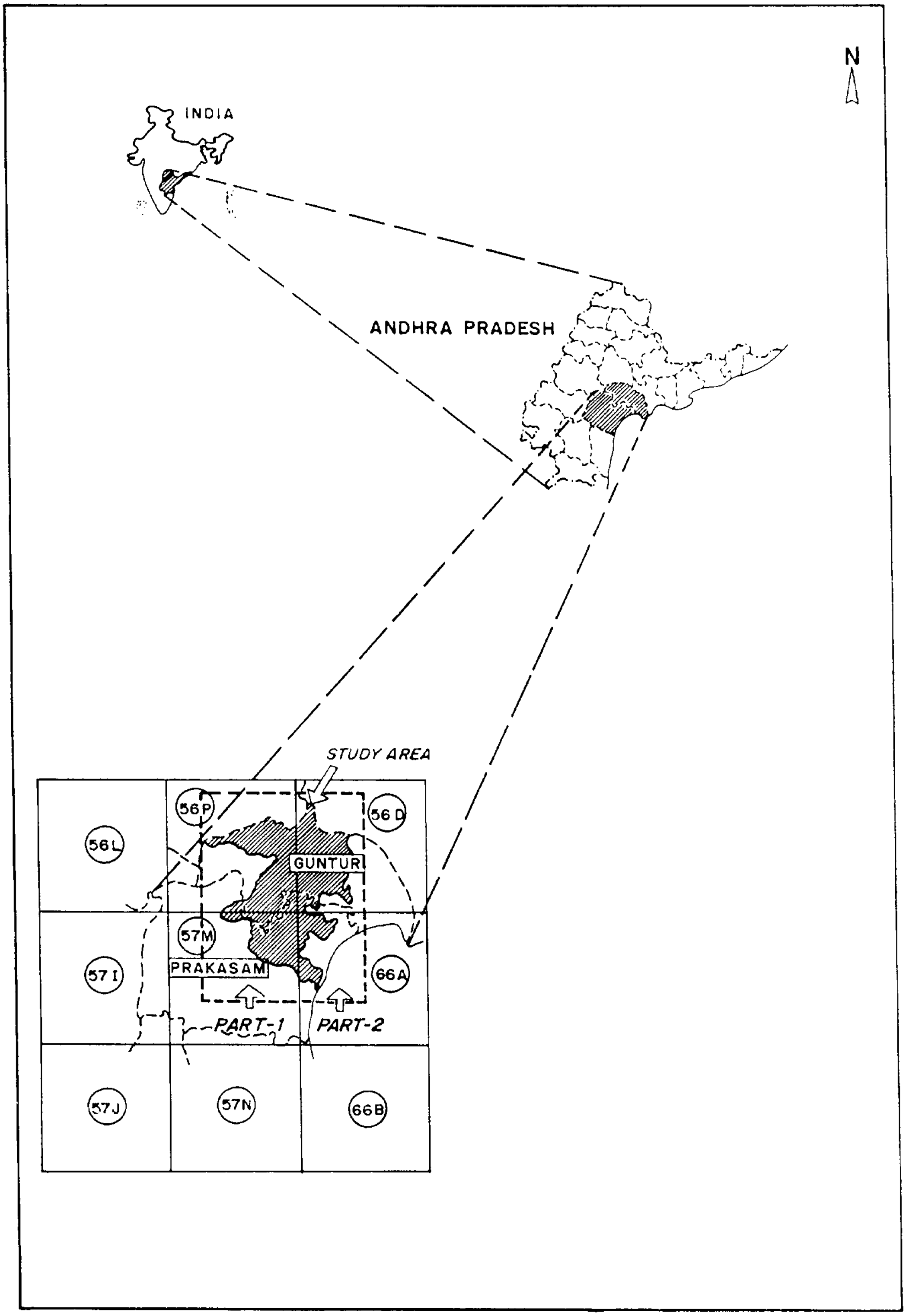

Figure 1. Location map of the study area.

and of the Indian Meteorological Department located within the command area, were used as ancillary information.

APPROACH

The approach essentially involves the following steps.

Preparation of Database

In order to bring the satellite data to a reference map scale, the Landsat-TM and IRS-1B LISS-I data were registered digitally on a corresponding Survey of India topographical sheet at a 1 : 50 000 scale using an IBM RS 6000 system. To begin with, the topographical sheets were scanned on a Contex colour scanner and were projected onto a database at 30 m resolution using an IBM system. The geocoded database has been used as a master data set for a subsequent image registration process. The digital registration was accomplished by selecting 15 ground control points (GCPs) which were common to both Landsat-TM digital data and scanned topographical sheet. Subsequently, both the data sets were registered using these GCPs using a third-order polynomial transform to get a subpixel accuracy. The IRS-1B digital data were also registered to Landsat-TM data following the same procedure. Subsequently, the IRS-1B LISS-I data were resampled to a 30 m pixel dimension – the same as that of the Landsat-TM pixel – using the cubic convolution approach, and the output was filmed in an optronics system (FIRE-240). The standard false colour composite (FCC) prints, from digitally registered Landsat-TM and IRS-1B LISS-I data, were generated using green, red and near-infrared spectral bands.

Visual Interpretation

The broad delineation of different categories of salt-affected soils, namely, saline, saline–sodic and sodic, was made on 1 : 100 000-scale FCC prints of Landsat-TM and IRS-1B LISS-I data collected during February and March 1995. The delineations were made based on image elements, namely colour, texture, shape, pattern, association, etc., and published soil survey reports/maps. For delineating waterlogged areas both pre-monsoon, i.e. February and March, as well as post-monsoon, i.e. December, data were utilized. Salt-affected soils could be identified by their dull- to bright-white colour in the FCC prints and their association with the flood plains and stream courses. Waterlogged areas appear as cyan and various shades of blue colour and are confined to local depressions on either side of canal courses and lower slopes.

Sample strips for field verification were selected in the FCC prints based on nature and magnitude of salt-affected soils and trafficability. During the field visit, a reconnaissance traverse of the area was made to establish the relationship between image features and different categories of salt-affected soils; and at the observation sites within the sample strips, terrain conditions, namely, physiography, landuse and/or land-cover, surface drainage, groundwater-table, etc., were noted. Soil profiles were excavated at representative sites, morphological features studied and soil samples from different horizons were collected for analysis in the laboratory. Auger samples were collected to a depth up to 1 m were also studied within a given salt-affected patch to account for within-the-class variations. Further, observations were made randomly outside the sample strips to account for variations in salt-affected soils, if any. Soil samples, thus collected, were analysed for pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), $CaCO_3$, organic carbon, cation exchange capacity (CEC), exchangeable cations and anions; and particle size distribution, following the procedure advocated by Jackson (1973) and the US Department of Agriculture (1954). Salt-affected soils were categorized as saline, sodic and saline–sodic and the magnitude of salinity and/or alkalinity was assessed based on pH, EC and ESP values (see Tables IIa and b). The boundaries of salt-affected soils and waterlogged areas were subsequently modified *vis-à-vis* field observations. The areal extent of various categories of salt-affected soils and waterlogged areas was estimated using a digital planimeter (model KP-90N).

Table II. (a) Legend for mapping salt-affected soils and waterlogged areas

Physiography	Kind of salinity/sodicity	Degree of salinity/sodicity
D – Coastal plains	S – Saline	1 – Slight
	N – Sodic	2 – Moderate
F – Peninsular plains	SN – Saline sodic	3 – Strong
W – Waterlogging	W1 – Seasonal waterlogging	
	W2 – Permanent waterlogging	

(b) Key to degree of salinity/sodicity

Magnitude of the problem	Salinity ECe dS m^{-1}	Sodicity	
		pH	ESP
Slight	4–8	8·5–9·0	< 15
Moderate	8–30	9·0–9·8	15–40
Strong	> 30	> 9·8	> 40

RESULTS AND DISCUSSION

Salt-affected Soils

The salt-affected soils observed in the Command Area are derived from the sodium salts brought down from upper reaches. The sodium salts are liberated from sodium-bearing minerals (plagioclase feldspars) which are constituents of the granite–gneissic complex. Since the salts are transported from the source rock to the Command Area by fluvial activity, they are concentrated on in the flood plains along the streams. This process is referred to as primary salinization. In addition, at places, there are small pockets of salt-affected soils which have developed on account of rising ground water, owing to the introduction of canal irrigation since the 1960s. This process is called secondary salinization.

The space-borne multispectral data have been found very useful for separating-out different levels of salinity and/or alkalinity in the USA (Wiersma and Horton, 1976), Canada (Sommerfeldt, *et al*., 1985) and Iraq (Al Majawili, 1983). Since most of the soils are dark-grey in colour with fine texture, the colour of the salt efflorescence in these soils is the same as that of normal cultivated soil. Consequently, in the standard FCC prints salt-affected soils and non-salt-affected soils look alike. However, patches with severe salinity and alkalinity problems do show a characteristic spectral response pattern, hence, they could be delineated using space-borne multispectral data. For delineating slight and moderate categories of such soils, the approach advocated by Wiegand, *et al*. (1994), which uses the vegetative condition as a surrogate measure of soil salinity, could be attempted.

Apart from salt-affected soils in the inland area, the salinity problem is also observed along the sea coast. Here the salinity has developed due to the continuous ingression of seawater on to the land. These soils do not exhibit any characteristic features such as salt efflorescence on the surface due to prevailing hydrologic conditions. Hence, their delineation based on the image elements alone may not be reliable. However, physiographic condition, vegetation pattern and moisture status as revealed from temporal multispectral data may provide clues for the detection of salt-affected soils.

Waterlogged Areas

Waterlogging, which has been defined in the strict sense as ‘the saturation of the root-zone for a very long period affecting the growth of most of the mesophytic plants’, does not seem feasible to detect using space-borne multispectral data since the spectral response pattern of non-waterlogged areas and those with subsurface drainage congestion is almost similar. However, the waterlogging in the form of surface ponding, the presence of a thin film of water at the surface, and surface wetness are amenable to resolution using space-borne multispectral data.

Two categories of waterlogged areas, i.e. seasonal and perennial waterlogging, have been mapped using pre- and post-monsoon period space-borne multispectral data. The areas which experience waterlogging during the post-monsoon season represent seasonally waterlogged areas, whereas those which continue to remain waterlogged even during the dry period (summer) season have been mapped as perennially water-logged areas. Such areas could be noticed as isolated pockets along the coast in block 22 of the command area (see Table III). Of the total waterlogged area of 1710 ha, the seasonally waterlogged areas constitute 1650 ha, whereas 60 ha have been found to be perennially waterlogged (see Figures 2 and 3).

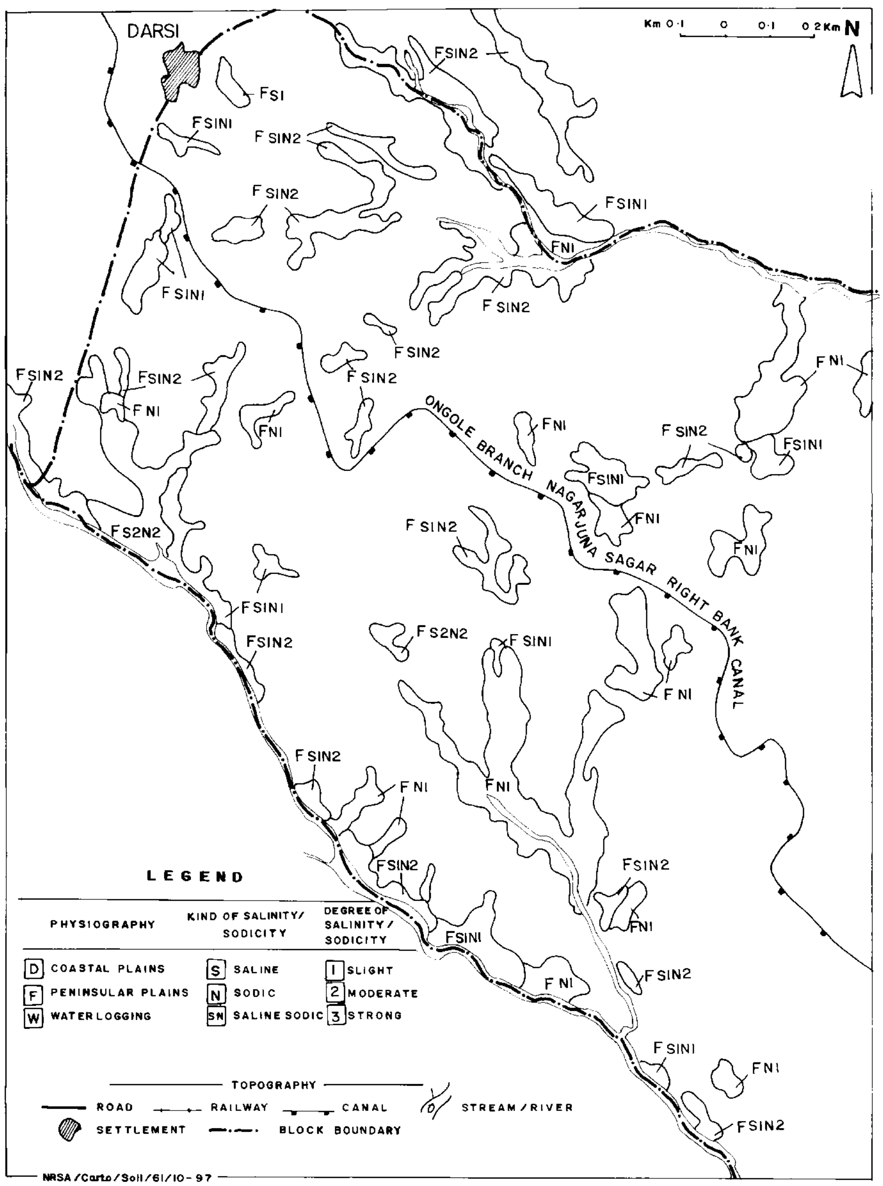

Figure 2. Inland salt-affected soils in part of the study area.

Table III. Spatial distribution of various categories of salt-affected soils

S No.	Block No.	Spatial extent (ha)													Total
		S1	S2	S3	N1	N2	S1N1	S1N2	S1N3	S2N1	S2N2	S2N3	S3N2	S3N3	
1	6	–	–	–	–	–	20	–	–	–	80	–	–	–	100
2	8	40	60	240	60	20	330	250	–	–	620	90	–	–	1710
3	9	–	–	–	–	–	–	40	–	–	–	–	–	–	40
4	10	–	–	–	–	–	80	180	–	90	20	–	30	–	400
5	11	570	1370	970	350	–	2040	3190	280	160	2210	890	–	–	12 030
6	12	–	–	–	–	–	10	–	–	260	–	–	–	–	270
7	13	40	–	–	20	–	80	–	–	–	660	120	–	–	920
8	14	–	–	–	–	–	–	–	–	–	100	300	–	–	400
9	15	–	–	–	2300	–	390	110	–	–	80	–	–	–	2880
10	16	–	–	–	–	–	20	50	–	–	190	80	–	–	340
11	17	–	–	–	10	–	540	90	–	–	150	–	–	–	790
12	18	–	–	–	60	–	520	90	20	–	390	–	–	–	1080
13	19	–	–	–	–	–	860	750	240	–	1560	180	–	–	3590
14	20	–	–	–	40	–	350	350	–	–	310	–	–	–	1050
15	21	–	–	–	310	–	380	1170	–	–	20	30	–	–	1910
16	22	810	770	3260	3020	–	2310	2850	–	130	1320	800	–	20	15 290
Total		1460	2200	4470	6170	20	7930	9120	540	640	7710	2490	30	20	42 800

Note: S1: Slightly saline; S2: Moderately saline; S3: Strongly saline; N1: Slightly sodic; N2: Moderately sodic; N3: Strongly sodic.

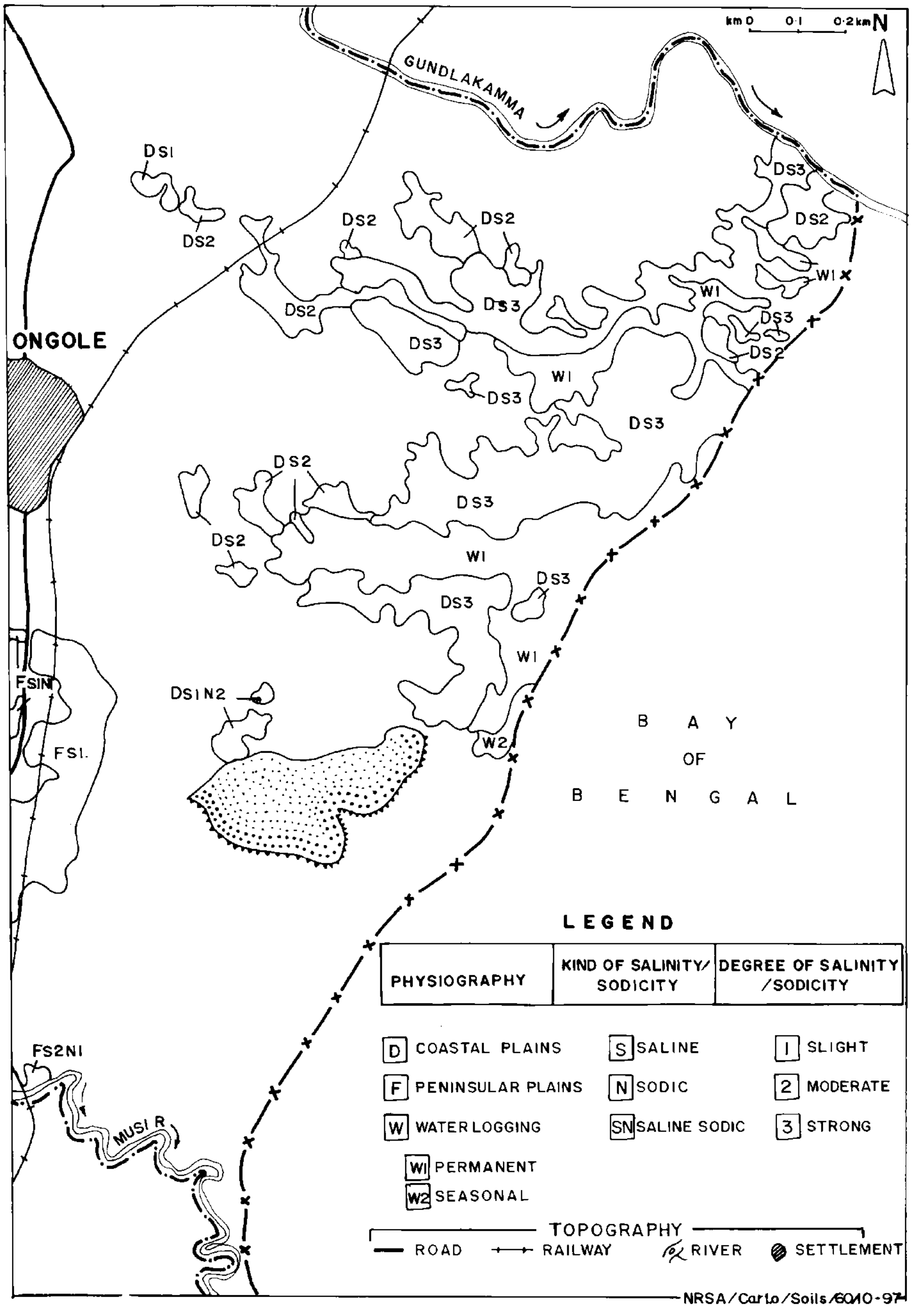

Figure 3. Coastal salt-affected soils and waterlogged areas in part of test site.

The following categories of salt-affected soils are encountered in the command area:

- Saline soils – Slightly saline (S1); moderately saline (S2); strongly saline (S3)
- Sodic soils – Slightly sodic (N1); moderately sodic (N2)
- Saline–sodic soils – Slightly saline–sodic (S1N1); slightly saline and moderately sodic (S1N2); slightly saline and strongly sodic (S1N3); moderately saline and slightly sodic (S2N1); moderately saline–sodic

Table IV. Chemical analysis data for different categories of salt-affected soils

S no.	Category	pH	EC (1 : 2) ($dS\ m^{-1}$)	ESP
Saline soils				
1	S1	8·3–8·4	5·6–8·0	6·9–11·6
2	S2	8·0	17·2	5·5
3	S3	8·1–8·2	32·0–38·0	4·0–12·0
Sodic soils				
4	N1	8·6	2·4	14·8
5	N2	9·1	3·2	31·9
Saline sodic soils				
6	S1N1	8·2	4·0	16·2
7	S1N2	9·0	7·2–7·6	31·4–39·3
8	S1N3	9·4–9·8	5·6–6·0	48·2–50·4
9	S2N1	9·0	5·0	15·30
10	S2N2	8·8–9·5	8·8–15·6	25·3–39·5
11	S2N3	9·5–9·8	9·6–24·4	44·2–61·5
12	S3N2	9·4	37·6	19·2
13	S3N3	9·5	57·2	55·8

Notes: S1: Slightly saline; S2: Moderately saline; S3: Strongly saline.
N1: Slightly sodic; N2: Moderately sodic; N3: Strongly sodic.

(S2N2); moderately saline and strongly sodic (S2N3); strongly saline and moderately sodic (S3N2); strongly saline–sodic (S3N3)

The pH and EC values of saline soils have been found to be in the range of 7·8–8·3 and 5·6–38·0 $dS\ m^{-1}$ respectively (see Table IV). The range of pH, EC and ESP values for saline–sodic soils has been observed as 8·2–9·8, 4·0–57·2 $dS\ m^{-1}$ and 16·2–68·8 $dS\ m^{-1}$, respectively. The non-saline–sodic soils have the pH, EC and ESP values in the range of 8·6–9·1, 2·4–3·2 $dS\ m^{-1}$, and 15·8–31·9, respectively.

In the command area all the three categories of salt-affected soils, saline, saline–sodic, and sodic, are encountered (see Figure 2). Among various categories of salt-affected soils, saline–sodic soils with a geographical area of 28 480 ha (see Table III) are more prevalent, followed by saline soils (8130 ha) and sodic soils (6190 ha). The physical and chemical properties of a typical inland saline–sodic soil are given in Table V. It is evident from the table that both high salt content as well as high exchangeable sodium contribute to the poor physical condition and chemical degradations.

In addition, saline soils, which have developed due to impregnation of the soil profile with salts owing to the ingress of seawater, are confined mostly to coastal plains. A close look at Table III shows that more than 60 per cent of salt-affected soils are encountered in blocks 11 and 22, followed by 15 and 19, which accounts for about 15 per cent of the geographical area of the irrigated command. The physical and chemical characteristics of a typical profile of coastal saline soils is given in Table VI. An exceptionally high EC value is a common feature of these soils. The waterlogged and salt-affected soils, thus identified, through remote sensing constitute 9·8 per cent of the total command area.

In order to make optimal use of these lands and to prevent further degradation, both ameliorative as well as preventive measures need to be employed:

- Drains should be desilted regularly and kept free from aquatic vegetation.
- Farm-level-drainage measures need to be planned, especially in the heavy-textured soils.
- Use of optimal quantity of irrigation water should be practised.
- There should be conjunctive use of groundwater and canal water in areas where the quality of water is poor.

Table V. Physicochemical properties of a typical inland saline–sodic soil (fine-loamy Aquic Natrustalfs)

Horizon	Depth	Colour	Texture	Structure	Cutan	Effervescence	Mottles
A	0–6	2·5Y5/2	Sl	Weak, fine, subangular blocky	–	Strong	–
Bk	6–12	2·5Y4/4	Scl	Moderate, medium, subangular blocky	–	Strong	–
Btk	12–28	10YR3/2	C	Strong, medium, subangular blocky	Patchy and thin	Strong	–
Bgk	28–55	10YR4/2	C	Strong, medium, coloumnar	–	Strong	Few, fine, faint (10YR3/2)
BCk	55–84	10YR4/3	SCl	Moderate, medium, subangular blocky	–	Slight	–

Note: Sl: Sandy-loam; SCl: sandy-clay loam; C: Clay.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	ECe (dS m^{-1})	OC (%)	$CaCO_3$ (%)	Ex. Na	CEC	ESP
								cmol(+)/kg		
0–6	75	11	14	10·76	44·40	0·23	2·1	3·77	12·40	30·42
6–12	62	15	23	9·79	24·40	0·32	2·4	8·72	21·60	40·41
12–28	43	16	41	10·19	5·60	0·46	2·6	13·99	31·71	44·12
28–55	34	23	43	9·31	0·56	0·47	2·6	16·38	33·70	48·61
55–84	70	3	27	9·39	1·12	0·28	1·3	5·08	13·71	37·10
Weighted average of upper 30 cm	–	–	–	10·16	16·78	–	–	–	–	40·93

Table VI. Physico-chemical properties of a typical coastal saline soil (Typic Ustifluvent)

Horizon	Depth	Colour	Texture	Structure	Effervescence
Ak	0–24	10YR5/3	Sl	Weak, fine, subangular blocky	Slight
Ck1	24–54	10YR5/4	Sl	Weak, fine, subangular blocky	Slight
2Ck2	54–83	7·5YR3/4	LS	Weak, fine, subangular blocky	Slight
3Ck3	83–125	10YR5/4	Sl	Weak, fine, subangular blocky	Slight

Note: Sl: Sandy-loam; LS: Loamy-sand.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	ECe (dS m^{-1})	OC (%)	$CaCO_3$ (%)	Ex. Na	CEC	ESP
								cmol(+)/kg		
0–24	72	12	16	7·5	126·00	0·81	1·20	1·47	14·2	4·6
24–54	75	6	19	7·7	62·88	0·92	1·09	1·16	16·0	7·3
54–83	83	6	11	8·3	75·00	0·38	1·10	1·69	9·0	1·8
83–125	79	6	15	8·1	70·00	0·40	0·56	1·50	13·0	8·6
Weighted average of upper 30 cm	–	–	–	7·5	113·37	–	–	–	–	5·1

- Lining of canals and distributaries should be undertaken up to reduce seepage losses.
- Reclamation of already affected soils through appropriate use of amendments – gypsum/pyrite and leaching, should be undertaken, both by the farmers as well as by the government.
- Salt-resistant crop and/or horticultural plantation varieties should be raised.

CONCLUSIONS

It is clear from the foregoing that the IRS-1B LISS-I and Landsat-TM data, in conjunction with ground truth and other collateral data, enable delineation of waterlogged areas and salt-affected soils. In order to be detected using remote sensing data, the salt-affected soils and waterlogged areas need to have some diagnostic surface manifestation in the form of a salt-efflorescence of contrasting colour, a surface wetness, a thin film of water, etc. In the absence of such features, temporal multitemporal data portraying vegetation density and condition as a surrogate measure of such a problem could be utilized. The information, thus generated, is useful for planning land reclamation programmes, and for monitoring their progress and success. Though mapping of salt-affected soils and waterlogged areas is attempted at a 1 : 100 000 scale, with the availability of higher spatial resolution data from the IRS-1C Linear Imaging Self-scanning Sensor (LISS-III) and Panchromatic sensor data, the generation of such maps up to a 1 : 12 500 scale seems feasible.

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