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Mapping of soil salinity and sodicity using digital image analysis and GIS in irrigated lands of the Indo-Gangetic Plain

R. C. SHARMA AND A. K. MONDAL

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

Abstract: Salt-affected soils in irrigation command of the Western Jamuna Canal were mapped using digital image analysis and GIS. Landsat TM data were assigned sample strip derived training sets for supervised classification using ILWIS software. The final map showed five salinity classes with an over all accuracy level of 85.6 per cent. Moderate and highly saline areas were easier to identify than the slightly saline areas. Combination of red and infrared bands was used for separating saline and sodic soils. A GIS overlay of spatial information was developed to generate base map. Additionally, the non-spatial information such as soil characteristics and salinity parameters were incorporated suitably into the information files as point information to integrate with remotely sensed data. Geo-referenced, digitized, spatial and point data sets were linked to rasterised map. Thus relating of salinity classes to topology and environmental attributes enhanced the use of database in salinity management of irrigated agriculture.

Additional keywords: *Remote sensing, management, salt affected soils*

Introduction

India has created 80 mha irrigation potential mainly through major irrigation projects to raise agricultural productivity in several semi-arid and arid parts of the country. However, long term sustainability of irrigation appears threatened with the development of soil salinity and waterlogging in 15-20% of irrigation command. Lack of accurate information on the extent and impact of problems of waterlogging and soil salinity at the national level handicaps policy formulation and project preparation. For effective salinity control measures, accurate maps that show changes in salinity through time and areas is necessary, which is seldom available from the presently used observation methods of surveys. Several authors (Sharma and Bhargava 1988; Abdel and Shrestha 1992; Kalra and Joshi 1996; Sharma *et al.* 2000) have used visual interpretation of satellite images to map soil salinity. Similarly, Singh and Dwivedi (1989), Saha *et al.* (1990) and Metternicht and Zinck (1997) have attempted to detect saline soils through digital analysis of satellite images. In most of the surveys, collection, storage, retrieval, transformation, display and analysis of large volume of spatial and attribute data from real world always remain a problem. But this problem now can be overcome by the use of a set of tools called Geographical Information System (GIS).

Thus, employing modern survey tools of remote sensing and GIS, a study was undertaken to apply digital image analysis of satellite data to map saline soils and integrate remotely sensed and field data with GIS for better management of salinity related issues in irrigated agriculture.

Study area

The study area is located in the Western Jamuna Canal Command in Haryana state, India between 29^0 to 29^0 15^0 N latitudes and $76^0 30^0$ to 77^0E longitudes. The area is a part of the low-lying flat Indo-Gangetic basin resulting in restricted surface drainage. Good network of roads and canals further aggravates the problem of surface drainage.

The average annual rainfall is 425 mm and the annual evapotranspiration is 1400 mm. Poor surface drainage, high water table and poor quality ground water are mainly responsible for regional problems of secondary salinisation in agricultural fields. The soil solution gets constant release of salts from mineral weathering under alternate dry and wet conditions (Bhargava *et al.* 1981). The main source of irrigation water is surface water, distributed to farmers through an extensive network of canals. Canal water is compensated by more than 1700 private tubewells installed by farmers to compensate for canal water inadequacy and unreliability. However, the poor quality groundwater in some area contributes to an increase in soil salinity (Manchanda and Sharma 1993). Wheat, rice and mustard are the main crops whereas maize, sugarcane and forages are the minor crops of the area.

Materials and Methods

Seven bands of Landsat TM, cloud free data of 22nd November 1995, were used in the study. Ancillary data on ground water quality, water table depth, crop growth stages and prevailing farming practices was reviewed and used during image analysis and the selection of training sets. Integrated Land and Water Information System (ILWIS) was used for image processing and geo-information handling. The GIS database was based on the Survey of India topographic map base at 1:50,000 scale.

Fieldwork for salinity assessment

Fieldwork was done in the month of November. Initial field traverse was made to select sample strips covering various degrees of salinised and waterlogged areas. In two sample strips, seventeen soil profiles were studied for morphological characteristics and horizon-wise soil samples were collected for laboratory analysis. Random auger bores and surface sampling outside the sample strips was done to validate and correlate ground conditions with corresponding image characteristics. The soil samples were analysed for soil pHs, ECe, soluble ions, soil texture, organic matter and $CaCO_3$ using standard procedures. Based on morphological and analytical data, the soil profiles were assigned to five different soil salinity classes.

GIS database creation and management

For study area, Survey of India map sheet nos. 53C/12 and 53C/16 (1:50,000 scale) were used as base reference. Before digitizing, a relationship between map and digitizer coordinate was established through map reference. All spatial data consisting of remotely sensed one, maps from conventional sources and observation points were standardized to a single reference. Different map layers in the form of canals, drains, road network, soil map, villages and soil profile location were digitized and combined to form the base map. The base map was further annotated with grids, legends, scale and north direction. Data of soil mapping units, salinity classes and soil profile characteristics was entered through keyboard in the form of attribute tables that in turn were linked to spatial maps.

Satellite image processing

The image (raster map) was georeferenced to relate the geometry of rows and columns with the real world coordinates. For this, X-Y coordinate of eleven well identified tie-points present both in the image and topomaps were specified. The assignment of points achieved a satisfactory sigma value of 1.1. The map used Lambert Conical Conformal Map Projection. The image was resampled by nearest neighbour interpolation method. The spectral information stored in the separate bands was integrated into a false colour composite (FCC) by assigning red colour to TM band 4, green colour to TM band 3 and blue colour to TM band 2. The FCC, thus generated with enhanced readable details was used in further analysis. Selected window areas of FCC image were visually interpretated to identify and correlate with classes derived through digital analysis. Schematic diagram of methodology is shown in figure 1.

Results and Discussion

Salt-affected soils

Based on the nature of salts present, the salt affected soils of the study area qualify for saline and sodic soils. Morphologically, all the soils are similar in colour, texture, structure and distribution of roots. In saline soils,

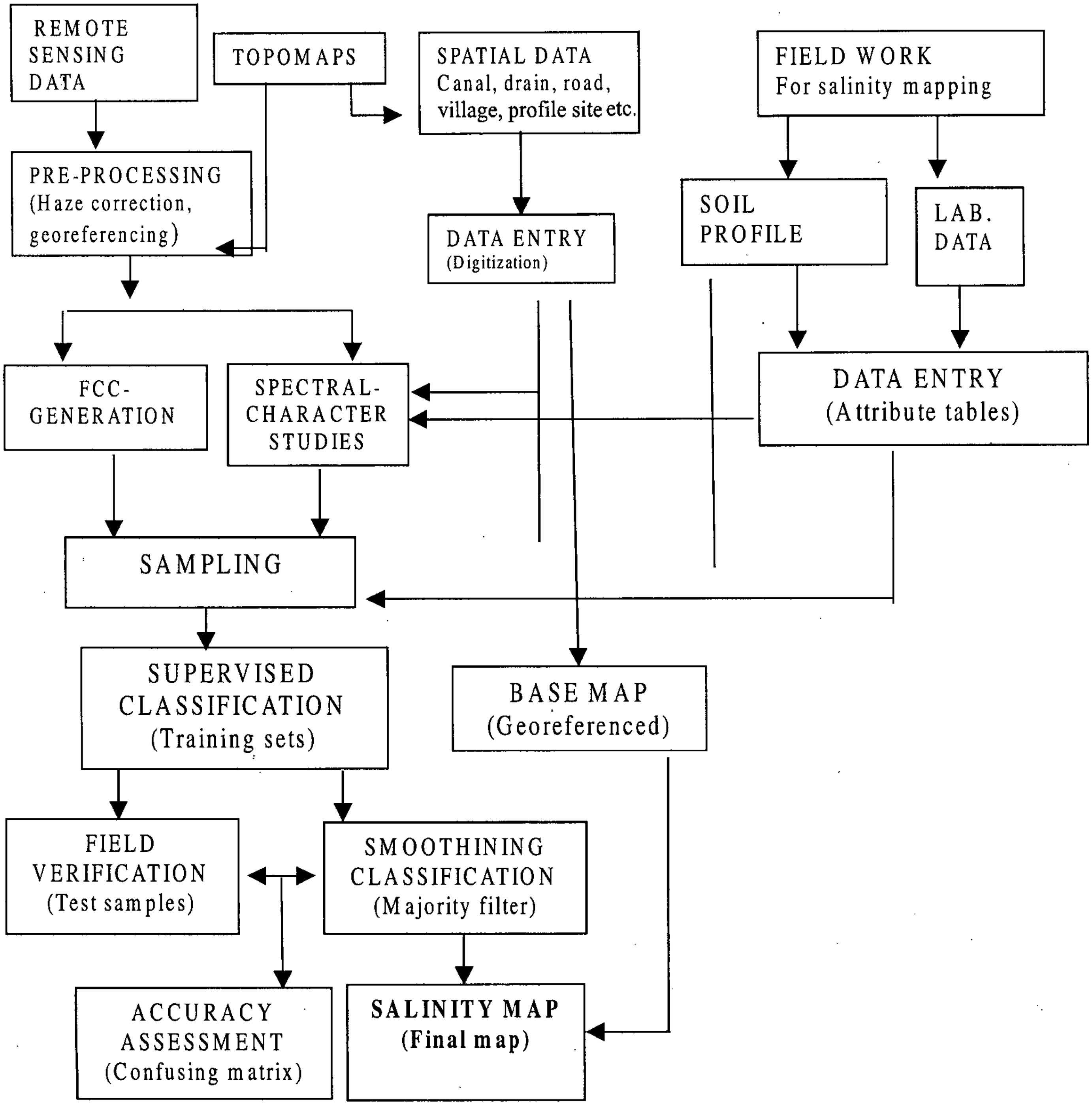

Fig. 1. Schematic diagram for salinity mapping using digital image analysis and GIS

shallow water table and capillary rise of water is common leading to a moistened appearance of soil surface with presence of salt crusts. However, the saline soils from village Lath have a compact and dense petrocalcic layer at 80-90 cm depth which restricts free capillary rise of ground water to keep the salt layer and soil surface in a relatively dry state. The soils with higher degree of salinity have predominance of neutral salts (chlorides and sulphates of sodium, calcium and magnesium). The sodic soils have 2-5 mm thick platy soil structure on the surface, dense and compact solum, poor permeability, high pHs values (between 9.9 to 10.2) and prominence of carbonates and bicarbonates of sodium. The total salt content in saline soils is much larger than in sodic soils.

Supervised image classification

The poor vegetative growth of wheat due to salinity stress in its early growth stages has been reflected in the satellite image of November. Nine classes, 5 representing different degrees of saline and sodic conditions of the soils and 4 representing normal cropped area, sand dune, submerged soil and waterlogged soils were identified. Spatial, spectral, field and laboratory data were used in the selection of training sets for each of the classes. Subsequent classification was done using maximum likelihood classifier. Different threshold values were iterated based on the variance and covariance of clusters. A threshold value of 30 gave the most satisfactory results. A majority filter was applied to remove some possible noises and to reduce salt and pepper appearance from the classification result (Townshend 1984). The supervised classification resulted into the output salinity map, which was geometrically corrected to fit a digitized and rasterised topographic base map of scale 1:50,000.

Classification accuracy

More than 150 test pixels selected outside the sample strips for each class were used to assess the classification accuracy through a confusion matrix. An overall classification accuracy of 87.1 per cent and average reliability of 85.2 per cent was achieved (Table 1). Highly saline and sodic soils, waterlogged and submerged soils and normal cropped areas could be identified with a high degree of confidence (>87%). The nil to slightly saline and moderately saline soils were partly intermixed possibly due to lower salt concentrations that could not exert much salt stress on wheat, which is a salt tolerant crop. The S3 class (highly saline soils with dry salts) was tending to mix with S6 class (sand dunes) owing to their similarity of doughtiness. Using SPOT satellite image, Vidal *et al.* (1996) identified high salinity class with an accuracy of 66 per cent in irrigation system of Punjab in Pakistan.

Extent of salt affected and other land cover classes

The area statistics (Table 2) show that 11 per cent area fall under the classes of highly saline, sodic, waterlogged, submerged and sand dunes. Twenty five percent area falling under moderate salinity can allow to grow only one average crop during *kharif* only. Thirty two percent area covered under nil to slightly saline class appeared most vulnerable to degradation due to rising water tables. Thus, the study area, which is a part of high irrigation network of canal command, is left with only 32 per cent area without any problem.

Table 1. Error matrix for assessing supervised image classification accuracy in Gohana study area

Clsm/Tstms	S1	S2	S3	S4	S5	S6	S7	S8	S9	Total
S1	311 (71)	80 (17)	0	2	1	0	15	27 (6)	0	436
S2	39 (18)	167 (77)	0	10	0	0	0	1	0	217
S3	4	5	123 (80)	6	4	11	0	1	0	154
S4	0	1	14	164 (80)	2	12	0	0	0	193
S5	5	5	0	0	150 (90)	0	0	0	0	160
S6	0	0	24	0	0	149 (86)	0	0	0	173
S7	3	0	0	0	0	0	296 (90)	4	13	316
S8	42 (10)	0	0	0	0	0	20	351 (85)	0	413
S9	0	0	0	0	0	0	9	0	738 (99)	747
Rel.	0.77	0.65	0.76	0.90	0.96	0.87	0.87	0.91	0.98	

Clsm = Classified map; Tstm = Test map
Figures in parenthesis indicates "percentages"
Average accuracy: 85.6 (%); Average reliability: 85.2 (%); Over all accuracy: 87.1 (%)
S1, S2,...S9 are classes depicted in table2

Table 2. Spatial extent of cover classes with ECe and pHs of representative soils

Class Symbol	Class name	ECe (dS/m)	pHs	Area (ha)	Area (%)
S1	Nil to slightly saline soils	4-10	8.0-8.4	47,772	32
S2	Moderately saline soils	10-25	8.2-8.4	38,162	25
S3	Highly saline soils (Dry Salts)	25-40	8.5-8.8	4,559	3
S4	Highly saline soils	25-55	8.7-8.9	2,085	1
S5	Sodic soils	10-20	9.9-10.2	2,206	1
S6	Sand dunes (>5 m)	<1.00	<8.5	271	<1
S7	Normal Cropped area			47,851	32
S8	Waterlogged soils	—	—	4,952	3
S9	Submerged soils	—	—	3,128	2
	Total area			1,50,986	100

Differentiation between saline and sodic soils

In the present study, the area was homogenous in terms of topography, surface soil colour, texture, mineralogy and agricultural practices. The only major differences were in term of surface accumulated salts. Rao *et al.* (1995) observed that saline soils reflected higher in the visible and near infrared region when compared to normal cultivated soils. Due to high reflection in the FCC, saline, sodic and sand dune conditions were difficult to differentiate. The inherent differences in the chemical, hydrological and physical attributes of these soils have clearly been depicted in the spectral characteristics recorded in near and middle infrared and thermal bands. Based on these subtle variations, it was possible to differentiate between saline and sodic soils and also between sand dunes and salt- affected soils. Both the saline and sodic soils have similar reflectance (DN value 45-46) in TM band 3 (0.63-0.69 μm) but the saline soil shows significantly higher reflectance (DN value 86) than sodic soil (DN value 74) in TM band 4 (0.76-0.90 μm). This observation is extremely useful as it helps the segregation of saline soils from sodic soils, which is most important from the reclamation point of view.

Conclusions

Digital image processing techniques supported by visual interpretation and ground truth based training sets identified and mapped 5 classes of saline and sodic soils with an average accuracy level of 85.6 per cent. The study showed that surface accumulated white salt crystals are a good indicator for the detection and correlation of salinity during the dry season. Based on their spectral characteristics, sodic soils were separated from saline soils. While the saline and sodic soils reflect similar in TM band 3 (0.63-0.69 μm), the saline soils reflect significantly higher than sodic soils in TM band 4 (0.76-0.90 μm). The image processing and GIS capability of ILWIS was demonstrated in integrating image features with a geo-referenced base map.

References

Abdel-Hamid, M. A. and Shrestha, D.P. (1992). Soil salinity mapping in the Nile Delta, Egypt using remote sensing techniques. *International Archives of Photogrammetry and Remote Sensing*, vol. XXIX, part B7, 783-787. ISPRS Commission VII/4, Washington D.C., U S A. August 1992.

Bhargava,G.P., Pal, D.K., Kapoor, B.S. and Goswami, S.C. (1981). Characteristics and genisis of some sodic soils in the Indo-Gangetic Alluvial Plain of Haryana and U.P. *Journal of the Indian Society of Soil Science* **29** : 61-70.

Kalra, N.K. and Joshi, D.C. (1996). Potentiality of LANDSAT, SPOT and IRS satellite imagery for recognition of salt affected soils in Indian arid Zone. *International Journal of Remote Sensing* **17** : 3001-3014.

Manchanda, H.R. and Sharma, S.K. (1993). Saline water, soil salinity and crop growth. *Salinity Research,* Haryana Agricultural University, Hisar, India, 1-43.

Metternicht, G. and Zinck, J.A. (1997). Spatial discrimination of salt and sodium-affected soil surfaces. *International Journal of Remote Sensing* **18** : 2571-2586.

Rao, B.R.M., Sankar, T.R., Dwivedi, R.S., Thammappa, S.S., Venkataratnam, L., Sharma, R.C. and Das, S.N. (1995). Spectral behaviour of salt affected soils. *International Journal of Remote Sensing* **16** : 2125-2136.

Saha, S.K., Kudrat, M. and Bhan, S.K. (1990). Digital processing of Landsat TM data for wasteland mapping in parts of Aligarh district (Uttar Pradesh), India. *International Journal of Remote Sensing* **11** : 485-492.

Sharma, R.C. and Bhargava, G.P. (1988). Landsat imagery for mapping saline soils and wet la nds in north-west India. *International Journal of Remote Sensing* **9** : 39-44.

Sharma,R.C., Saxena, R.K. and Verma, K.S. (2000). Reconnaissance mapping and management of salt affected soils using satellite images. *International Journal of Remote Sensing* **21** : 3209-3218.

Singh, A.N. and Dwivedi, R.S. (1989). Delineation of salt affected soils through digital analysis of Landsat MSS data. *Proceedings of Seventeenth International symposium on Remote Sensing* **10** : 83-92.

Townshend, J.R.G. (1984). Agricultural land covers discrimination using thematic mapper spectral bands. *International Journal of Remote sensing* **5** : 681-698.

Vidal, A., Maurel, P., Durand, H. and Strosser, P. (1996). Remote sensing applied to irrigation system management. Example of Pakistan. *EURISY Colloquium on Satellite Observation for Sustainable Development of the Mediterranean Area ESA/ESRIN*, Frascati, Italy, 2-3 October 1996, 1-10.

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