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Mapping Salt-affected Soils Using Remote Sensing Indicators
- A Simple Approach With the Use of GIS IDRISI -

Nasir M. Khan*, Victor V. Rastoskuev**, Elena V.Shalina*** and Yohei Sato*
*Graduate School of Agricultural and Life Sciences, The University of Tokyo
1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan.
E-mail: aa97093@mail.ecc.u-tokyo.ac.jpt
**Research Center for Ecological Safety, Korpusnaya str. 18,
197110 St.Petersburg, Russia.
***CESBIO Bpi 2801, 18 avenue Edouard Belin,
31401 Toulouse, Cedex 4, France.

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ABSTRACT

This research deals with the problem of monitoring saline soils of Faisalabad, Pakistan. The analysis is based on remote sensing data of LISS-II sensor of IRS-1B satellite using GIS-IDRISI functions. We have examined how different remote sensing indicators work for salt-affected soil classification in the study area. The study has suggested some new but simple and practicle approaches for the problem.

We have analyzed the effectiveness of several indicators for the presence of salts in the area: salinity indices, normalized differential salinity index, and ratio of the signals received by the sensor in the 3rd spectral band to others. As salt-affected soils are characterized also by stressed vegetation, we therefore have analyzed vegetation indices concurrently. The probability of correct classification of the satellite image was observed strongly dependent on the season for all indicators analyzed. The best results can be achieved for the dry season (March-April) but not in humid or high temperate periods which may create confusion some times with other classes, specially settlements areas. The most difficult part in the classification processes was to distinguish between soil-affected areas and populated areas, which has muddy roofs similar to dry barren soils along with patchy saline areas within the village. We have come-up with two original schemes of classification through the analysis of the available data for this specific area. The first one uses COMPOSITE and STRETCH modules to produce two new images and then analyze their ratio. The COMPOSITE module takes data received in 1st, 2nd and 4th channels and STRETCH function produces histogram equalization contrast stretch of the 4th channel data. The second scheme uses ISOCLUST function of GIS IDRISI that performs classification based on specifically created images (through salinity indices and PCA analysis) instead of common practice of using just satellite measurements. Both schemes are shown to be able to perform good classification of the study area.

INTRODUCTION

Soil salinization is becoming an increasing problem, espacially in arid and semi arid regions and wherever irrigation is practiced. In some parts of the world, like Pakistan, the population is growing very fast and therefore attempts are made to increase the agricultural production, in many cases by land reclamation, against the limited water resources. It is reported recently that about 10% of presently arable lands are affected by salinity (Tabet et al., 1997). Thus, monitoring saline degraded lands has always been a primary issue for efficient irrigation systems management and rehabilitation policies. This is the case in Pakistan, where the seepage through the large irrigation system gave rise to watertable gradually and substantially contributed to the outburst of twin menace i.e. waterlogging & salinization. Salt-affected lands in the Indus basin covers an area of 4.22 Mha (WAPDA, 1994).

The problem of detection, monitoring and mapping salt-affected soils is known to be a difficult matter being a dynamic process. Recent advances in the application of remote sensing technology in mapping and monitoring degraded lands, espacially in salt-affected soils, have shown great promise of enhanced speed, accuracy and cost effectiveness. The approach to the problem of delinieting saline soils using remote sensing data and GIS techniques has been proved in many recent studies to be most efficient (Sharma and Bhargava, 1988, Rao et al., 1991, Srivastava et al., 1997, Dwividi et al., 1998). This study is devoted to mapping salt-affected soils in Pakistan. The approach of remote sensing indicators (Different Salinity Indices, Rationing, Vegetation Index, PCA-analysis) that is based on different spectral characteristics of different kind of surfaces has been applied here. The work has been accomplished with the use of the capacity of Geographical Information System as a tool for remote sensing data processing and analysis.

AREA DESCRIPTION AND DATA USED

The area under study is located in the centre of Punjab province of Pakistan between latitude 31° 02′ to 31° 45′ N and longitude 72° 50′ to 73° 22′ E. It is a part of subtropical continental low-land region and is designated as semi-arid central Punjab. The climate conditions have marked variations in temperature (mean monthly max. temperature is 19.4°C - 41.2°C) and rainfall over the year (< 350 mm on average) occurs mostly (75 %) during monsoon season (July-Sept.). The mean annual evaporation is as high as 2,100 mm (WAPDA/SMO, 1993). Geologically, the soils are alluvial deposits classified as silt loam, loam, and silt clay loam and loamy sands. The cropping calendar has two seasons, called as Rabi (winter) & Kharif (summer).

Data recorded by sensor LISS-II (Linear Image Self-scanning Spectrometer) of IRS-1B satellite in four wavebands (B1: 0.042-0.52 μm, B2: 0.52-0.59 μm, B3: 0.62-0.68 μm, and B4: 0.77-0.86 μm), with 74km x 2 swath-width and spatial resolution of 36 x 36m has been used in the study. Different time periods (pre-monsoon and post-monsoon) has been chosen for DIP analysis because of considerable variation in soil surface salinity as well as in vegetation cover (Table. 1). Topographic sheets of survey of Pakistan at 1:50,000 scale, were used as a main supporting data to register all images.

Table 1. Dates of the images used in the study

Image No.	Date
1	31.03.1993
2	22.04.1993
3	05.06.1993
4	15.10.1993
5	06.11.1993
6	20.12.1993

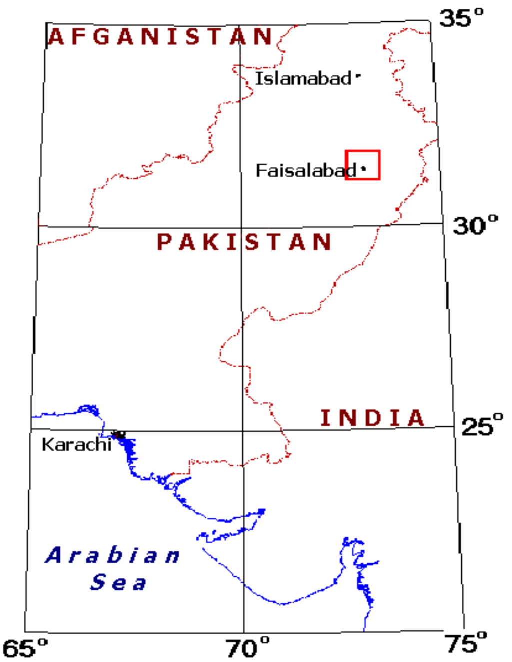


Figure1. A small rectangle on the right topside of the map shows the position of the study area.

REMOTE SENSING INDICATORS APPLICATION

The IRS LISS-II digital data were registered to the topo-sheets for the area using about 15 control points that were easily recognizable on the satellite images. It was presumed that the topographic maps are the most reliable source of information. After registering procedure, satellite data were ready to be used in GIS. The Mercator projection was chosen for data presentation. GIS IDRISI for Windows was used for interpretation and classification of the data results.

For different types of surfaces the amount of reflected solar radiation varies with the wavelength, which makes it possible to identify various kind of surfaces or classes in a satellite image and distinguish them from each other by the differences in reflectance. In our study, five classes were separated: vegetation (crops), populated areas (town & settlements), salt-affected areas (saline soils), water surface of lakes/ponds and of irrigation or drainage channels (canal/drain). The ground truth data were used to help in picking out training sites for the crop, town, lakes, and canal classes. The training sites for salt-affected areas, which have relatively high reflectance coefficient in the first three spectral bands of satellite data, were picked out from satellite images taking into account all surface collected information. For all chosen classes, the spectral signatures were derived from satellite images and through different commonly used indices from satellite data, for retrieval of salt-affected areas, were calculated with the aim to compare their effectiveness. The mentioned indices were as:

Salinity index (SI):

$$SI = \sqrt{B1 * B3} \qquad (1)$$

Normalized Differential Salinity Index (NDSI) for LISS instrument:

$$NDSI = (B3 - B4)/(B3 + B4) \qquad (2)$$

Brightness index (BI):

$$BI = \sqrt{B3^2 + B4^2} \qquad (3)$$

The data recorded in the 3rd spectral band were also used in the analysis to check an idea to use just spectral satellite data in this band for salt-affected area delineation. To play a role of an index this data should be normalized, for example, they can be normalized to the average value of an image.

Since salt-affected soils are usually characterized by poorly vegetated developed areas and such state of stressed vegetation could be an indirect sign of the presence of salts in the soils. Two vegetation indices were, therefore, included in the analysis as:

Normalized differential vegetation index:

$$NDVI = (B4 - B3)/(B3 + B4) \qquad (4)$$

and the ratio of two spectral band data as:

$$Ratio = B3/B4 \tag{5}$$

Where, in all above expressions (1–5) B1, B2, B3, and B4 are 1st, 2nd, 3rd, and 4th spectral bands respectively. In the process of choosing the index that gave the best results in determining salt-affected areas, it was supposed that the values of that index in two other adjacent points belonged to two different classes (salt – any non-salt class) should be far enough one from another in the scale of values of that index. To simplify the comparison of different indices we operated with the ratio of the indices for two adjacent classes, one of them being any non-salt class. It should be pointed out that such ratio differs from one satellite scene to another, which is caused by non-concurrent changes in spectral characteristics of different surfaces. We mentioned here two most suitable solutions that gave the best results for our data analysis approach. The choice of data for the 3rd channel of the instrument, as an index for the presence of salts, in the area could be a good solution.

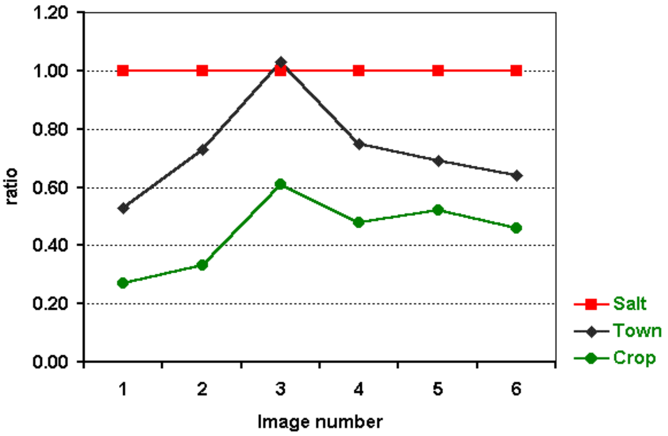


Figure 2. Variation of the ratio of signatures in the 3rd spectral band for different classes to the B3 signature of ‘Salt’ class.

As Fig. 2 shows the ratio of the signals measured in the 3rd channel for different classes, i.e., Salt, Town and Crop to the 3rd channel signal of the ‘Salt’ class for the every processed image.

It can be concluded that in most cases the signal in the 3rd channel of the instrument received from salt-affected areas is substantially higher than the signal received from the other surfaces (the water-classes are not shown in the picture because they have very low signal in this spectral band and can not stand in the way of delineating salt surfaces). The only one class that could mimic the ‘Salt’ class was the ‘Town’ class observed in this case study. Some training sites belonged to the class ‘Town’ had the same spectral signature as the class ‘Salt’ in June, as shown in figure 2, incase of image no. 3 results. This problem is might be because the village infrastructure has muddy roofs similar to dry barren soils along with patchy saline areas within the village, showing almost similar signatures to saline soils.

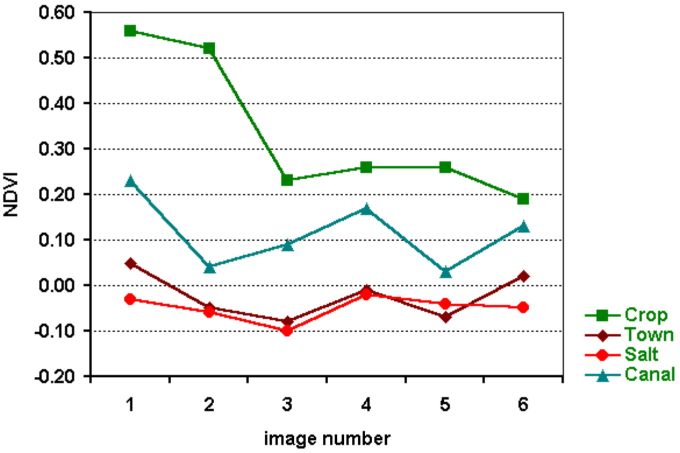


Figure 3. Variation of NDVI (4) for Different Classes of the Surface.

The next index that gave satisfactory results in retrieving ‘Salt’ class areas was NDSI (expression 2). One could may also use NDVI (expression 4), since two indices are equal in absolute values. Figure 3 demonstrates NDVI values for four classes: ‘Crop’, ‘Town’, 'Salt', and ‘Canal’ for 6 different images. It may be easier to decide what classes are closer to ‘Salt’ in terms of NDVI-index if one looks at the next Fig. 4 that shows the ratio of NDVI indices for different classes to NDVI index of ‘Salt’ class. It can be concluded that again, as in the previous case of using measurements of the 3rd channel, the main difficulty in retrieval of salt-affected areas from satellite data is to distinguish between ‘Salt’ and ‘Town’ classes. To overcome this difficulty one can use up-to-date topographic maps to get information about the settlement/urban area boundaries. Such areas can be vectorized and excluded from the calculation process while monitoring salt-affected soils. The other possibility is to avoid using satellite data when the mentioned difficulty occurs, incase if updated topo-sheets are not available. According to this study experience, the optimal time period for taking

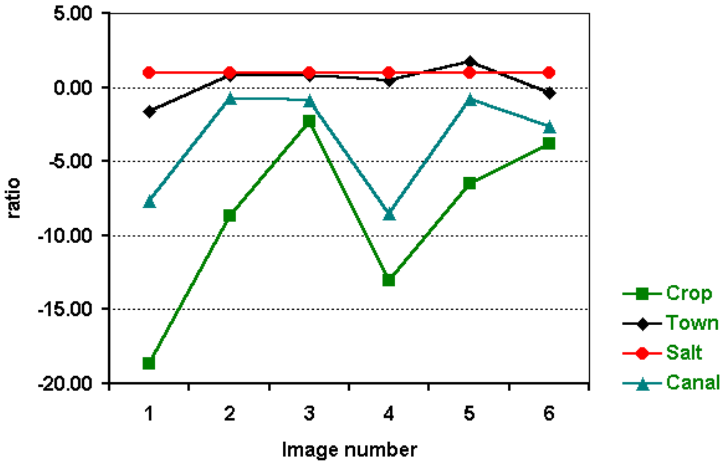


Figure 4. Ratio of NDVI Calculated for Different Classes to NDVI Calculated for the ‘Salt’ Class.

satellite data in order to delineate salt-affected soils under study area with the use of NVDI (NDSI) index is March, to avoid any mix-pixels confusion with urban areas during peek summers time.

CLASSIFICATION APPROACH

In the last part of the paper the new possibilities of classification on the base of using indices are discussed. This part of the work has been accomplished with the use of special functions of geographical information systems that are called image enhancement procedures. In IDRISI for Windows (Eastman, 1995), they are FILTER (different kinds of filtering), STRETCH (rescaling image values to fall within a given range) and COMPOSIT (producing new images with new characteristics on the base of received satellite data). These GIS functions increase the ratio of signal to noise in satellite data and suggest the most efficient use of important information contained in different spectral channels.

The problem of delineation of salt-affected areas is often accompanied by the problem of determination of regions under risk of waterlogging (Dwivedi and Sreenivas, 1998, and Sujatha et al., 2000). The latter task is usually solved on the base of the 4th band (B4) data processing. The main obstacle for good classification in that case is the low contrast between areas that should be delineated and other surface classes. To overcome that difficulty the following index was suggested for the study area:

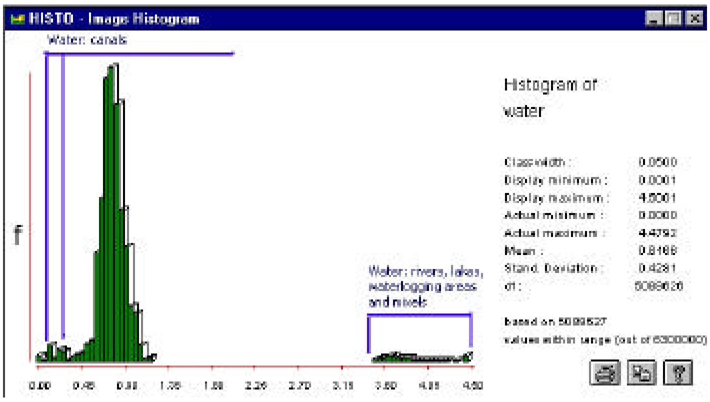
$$WATER = COMP124 / B4\_STR \qquad (6)$$

where, COMP124 is a composite image produced on the basis of B1, B2 and B4 spectral data according to this expression as:

$$COMP124 = +6 * B2 + 36 * B4 \qquad (7)$$

It is obtained by the use of COMPOSIT module of IDRISI for Windows with the type of contrast stretch specified to be linear with saturation level of 2.5%. The parameter B4_STR is a satellite data received in the 4th spectral band and stretched with the use of STRETCH module in the regime of histogram equalization.

The histogram of the image that contains index WATER calculated for the 1st satellite scene (31.03.1993) is demonstrated in Fig.5. The analysis of the image and its histogram shows that the values of WATER index for irrigation channel pixels are close to zero, being more than 3.0 for other water objects (lakes/ponds and waterlogged areas). The main achievement of the described procedure is the act of getting an image where water-objects (including waterlogged areas) are definitely separated from other surface classes. This has become possible due to stretching the B4 satellite image and using it in the way that is described in expression (6). The classification procedure adopted using this index is described here.



Histogram of water

Class width : 0.0500
Display minimum : 0.0001
Display maximum : 4.5001
Actual minimum : 0.0000
Actual maximum : 4.4792
Mean : 0.8166
Stand. Deviation : 0.4281
df : 5089626

based on 5089627 values within range (out of 6300000)

Figure 5. A Working Window of IDRISI showing histogram of WATER Index

To get classified image of the surface under study one can use classification procedure of GIS. Here we have tried to describe how to get satisfactory results using unsupervised classification criteria. In IDRISI for Windows, unsupervised classification is usually applied to a composite image. The routine procedure to get that composite is with the use of satellite data of different spectral channels, like B1, B2, and B4 data for our task. Obviously, a composite can be produced on the other base. In our case, we have calculated a composite image using three indices: NDSI (2), WATER index (6), and NDVI (4). Then we have applied an ISOCLUST module of IDRISI for Windows to

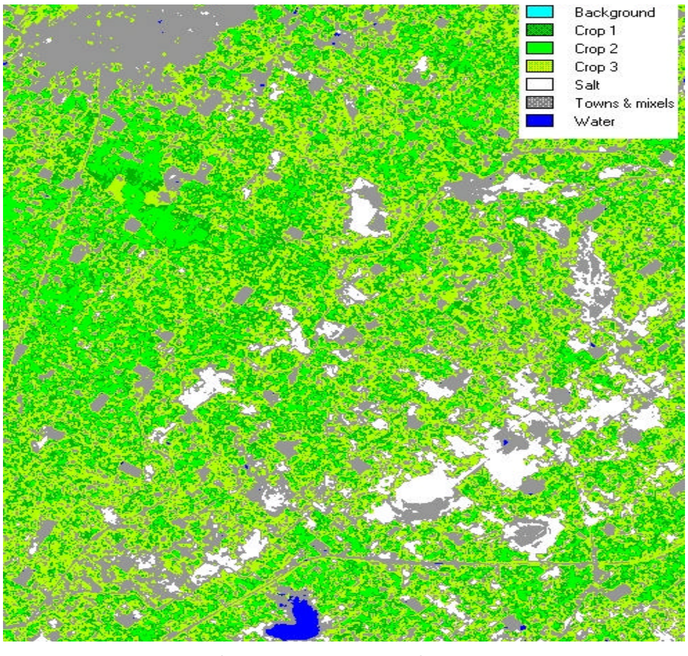


Figure 6. The Result of Usupervised Classification (ISOCLUST Module) Based on Salinity, Vegetation and WATER Indices.

that image. The result is shown in Figure 6. Salt-affected areas are shown in white tone in the image. One of the main advantages of the described procedure is that water objects can be classified correctly in this case with a high probability of success.

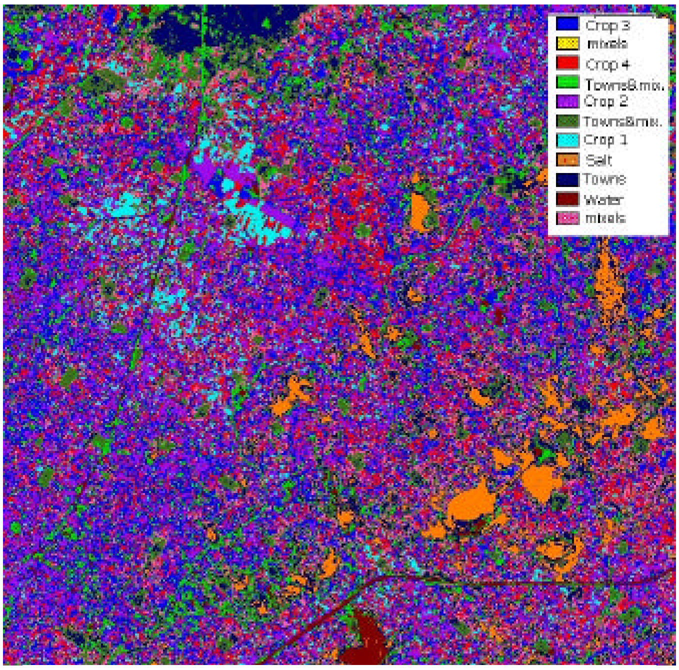


Figure 7. Classification Results After PCA Analysis

The next example of classification of satellite data described below uses different approach based on the principal component analysis (PCA). This sort of analysis of a set of images produces a new set of images, i.e., components that are uncorrelated with each other and explain progressively less of the variance found in the original set of spectral bands. In our case, we have built principal components with the use of all satellite measurements: B1, B2, B3, and B4 spectral bands. We have got that the first component explains 92.52% of the variance in the original sat of band and the second one explains 6.81% of variance, giving together more than 99%. The percentage of the first component (PCACMP1) was not enough to use it alone for classification. We have taken two first components and produces a composite image using an expression as:

PCACMP2 + 6*PCACMP2 + 36*PCACMP1

where, PCACMP*i* is the *i*-th component of the principal component analysis (PCA). The described composite image has been used as a base for unsupervised classification (ISOCLUST module). The analysis of the result (Fig.7) proves a good quality of classification. The classes ‘Salt’, ‘Crop’, 'Canal', and ‘Lake’ are delineated correctly for the displayed part of the satellite image, being mostly difficult area for the classification. We have applied this procedure to different scenes taken in different time of the year and it constantly gave good results of classification.

It is concluded that this simple approach based on remote sensing indicators and specialized classification procedures has shown promising potential in delineating the salt-affected soils for this specific area and IRS-1B satellite data.

REFERENCES:

Dwivedi, R.S. and Sreenivas, K., 1998. Delineation of salt-affected and waterlogged areas in the Indo-Gangetic plains using IRS-1C LISS-III data. *Int. J.Remote Sensing,* 19 (14), pp. 2739-2751.

Dwivedi, R. S., 1992. Monitoring and the study of effects of image scale on delineation of salt-affected soils inthe Indo-Gangetic plains. *Int. J. Remote Sensing,* **13,** pp. 1527-1536.

Dwivedi, R.S., and Sreenivas, K., 1998, Delineation of salt-affected soils and waterlogged areas in the Indo-Genetic plains using IRS-1C LISS-III data. *Int. J. Remote Sensing*, **19**, 2739-2751.

Eastman, R. J., 1995. IDRISI for Windows, User's Guide. Clark University, Worcester, Massachusetts, USA.

Sharma, R.C.,and Bhargawa, G.P., 1988. Landsat imagery for mapping saline soils and wetlands in north-west India. *Int. J. Remote Sensing,* ***9****, pp. 69-84.*

Srivastava, A., Tripathi, N.K., and Gokhale, K.V.G.K., 1997. Mapping groundwater salinity using IRS-1B LISS II data and GIS techniques. *Int. J. Remote Sensing*, **18**, pp. 2853-2862.

Srivastava, A.,Tripathi,N.K.,and Gokhale, K.V.G.K.,1997. Mapping groundwater salinity using IRS-1B LISS II data and GIS techniques. Int. J. Remote Sensing, 18 (13), pp. 2853-2862.

Sujatha G., Dwivedi R.S., Sreenivas K., Venkataratnam, L., 2000. Mapping and monitoring of degraded lands in part of Jaunpur district of Uttar Pradesh using temporal spaceborne multispectral data. *Int. J.Remote Sensing*, 21 (3), pp. 519-531

Tabet, D., Vidal, A., Zimmer, D., Asif, S., Aslam, M., Kuper, M., and Strosser, P., 1997. Soil salinity characterization in SOPT images, A case study in one irrigation system of the Punjab, Pakistan. *Physical Measurements and Signatures in Remote Sensing,* Guyot & Phulpin Eds-Balkema, pp. 795-800.

WAPDA (SMO)., 1994, Monitoring and Evaluation Fourth Drainage Project, Annual Report, Vol. 1 and 2. *SM publications, M&E Directorate (WAPDA)*, Lahore, Pakistan.