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Satellite Sensing for Evaluation of an Irrigation System in Cotton - Wheat Zone

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***Abstract*—**Efficient utilization of existing water is a pressing need for Pakistan. Due to rising population, reduction in present storage capacity and poor delivery efficiency of 30 to 40% from canal. A study to evaluate an irrigation system in the cotton-wheat zone of Pakistan, after the watercourse lining was conducted. The study is made on the basis of cropping pattern and salinity to evaluate the system. This study employed an index-based approach of using Geographic information system with field data. The satellite images of different years were use to examine the effective area. Several combinations of the ratio of signals received in different spectral bands were used for development of this index. Near Infrared and Thermal IR spectral bands proved to be most effective as this combination helped easy detection of salt affected area and cropping pattern of the study area. Result showed that 9.97% area under salinity in 1992, 9.17% in 2000 and it left 2.29% in year 2005. Similarly in 1992, 45% area is under vegetation it improves to 56% and 65% in 2000 and 2005 respectively. On the basis of these results evaluation is done 30% performance is increase after the watercourse improvement.

***Keywords*—**Salinity, remote sensing index, salinity index, cropping pattern.

I. INTRODUCTION

PROJECT on Rehabilitation of Lower Chenab Canal (LCCS) sponsored by JBIC (Japan Bank for International Cooperation) is being executed by the irrigation Department Punjab since 1995. However, a new component named as Research and Development Component was initiated in 2006 with objective for introducing modern farm technologies to the farmers in selected distributaries of LCC area in order to augment the canal improvement and their impacts on crop productivities. For this purpose, three distributaries namely; Mungi, Killianwala, and Khurriawala were selected for introduction of modern farm technologies / farm practices in addition to provision of several crop inputs that are to be subsidized.

According to Burhan *et al.*, 2005[2] In 1950, Pakistan had about 5,132 m^3 of water per capita, which has reduced to about 1,200 m^3 per capita in 2005. It will reduce to 600 m^3 per capita in 2025. Therefore, with the passage of time it will require demand management of water. Moreover, it is imperative for food security to increase water productivity, which in Pakistan is among the lowest in the world. In case of wheat for example it is 0.5 kg/ m^3as compared to 1.0 kg/m^3 in India and 1.5 kg/m^3 in California. For maize it is even worse, i.e. 0.3 kg/m^3 as compared to Argentina’s 2.7 kg/m^3, This shows how much opportunity is to increase water productivity. Irrigation management deals with efficient use of water resources, canal system, command areas, plants, soils and knowledge of technical disciplines to bring water to the root zone at proper rate, time and place to produce food and soil salinity. Some of the key elements of irrigation management are performance monitoring, diagnostic appraisal, action research and people's participation.

II. DATA AND METHODS

A. Study Area

The study was conducted at Mungi bangle tehsil of Gojra District of Toba Takh Singh.It is located between 30°33' to 31°2' Degree north latitudes and 72°08' to 72°48' Degree longitudes., as shown in Figure 1.The climate of Mungi Bangla touches two extremes. The maximum temperature in summer reaches up to 50°C. In winter, it may, at times fall below the freezing point at night time. The soils of the study area are predominantly medium to moderately coarse with favorable permeability characteristics and show a similarity throughout the area. The soils are generally low in organic matter, with a pH in the range of 7 to 7.9. The soils are adoptable to wide variety of crops. To quantitatively measure land surface salinity in the study area, Landsat Imagies of years (1992, 2000& 2005) was selected. The images have been rectified to the Universal Transverse Mercator (UTM) coordinate system, and a digital topographic map with a scale of 1:125000 for the Mungi site.

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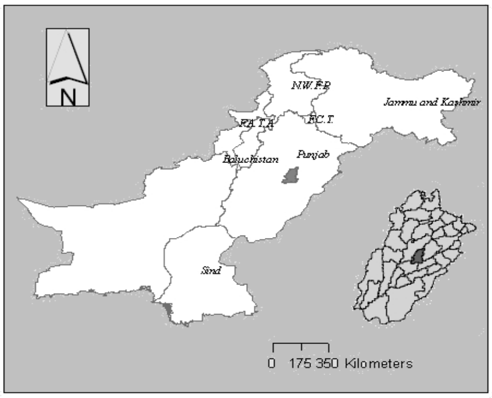


Fig.1 Geographic location of Study area

B.Deleneation of Cropped Area

Using knowledge of the temporal growth pattern of the various crop types in the command area. A hierarchical classification approach was followed to classify the scene into various land cover classes. Soil Adjacent Vegetation Index (SAVI), as define by Huete (1988)[4], was calculated for each crop pixel.

The Normalized difference vegetation index (NDVI) is use to find out the crop area from the satellite imagery. This is most commonly used index for satellite imagery. The difference in reflectance is divided by the sum of two reflectance. This compensates for difference amounts of incoming light and produces a number between 0 and 1. The typical range actual values are about 0.1 for Bara soils to 0.9 for dense vegetation. NDVI is thought to be more sensitive to low level of vegetation cover, while the RVI is more sensitive vegetation in dense canopies.

Digital data was use for crop acreage estimation of selected distributions. Crop acreage was estimated using a supervised classification approach with the ground truth data collected during field trips. Crop condition assessment was done by computing the normalized difference vegetation index (NDVI) values of crop pixel.

So, if we subtract the red light image from the near-infrared image, everything that has about the same brightness level in the two wavelengths becomes dark, and everything that is brighter in the near-infrared become light. The image above is the result of subtracting the red image from the near-infrared image plus a bit from mathematical trickery discussed later. Notice that even this ribs of the green leaves disappear since there is no chlorophyll in that part of the leaf. The little patch of green on the mostly yellow leaf is about the only part of that leaf still visible. The soil and stone have completely disappeared.

C.Deleneation of Salt Affected Area

Imagery of Landsat and published map by SSP was used for detection of salt affected soil. The methodology of section 2.2 was used to extract the salt affected soil area and cropping pattern. Georeferenced satellite imagery was used to extract the vegetation, built-up and barren land.

The health vegetation can absorb the red light and are found to have very dark tone and thus were present as higher digital value pixels. While bright tone represented the barren soil and stressed vegetation with minimum digital pixel values. But in near-infrared band all classes were found to have very bright tones. Salinity creates water stress in plant tissues, which, as a result creates change in the amount of chlorophyll. The signature of salt affected soil differs from the healthy vegetated soil.

In 8-bit satellite imagery data, every pixel corresponds to a number from 0-255. Zero represents black and 255 represents white tone and all the numbers between 0 and 255 represent varying shades of gray. Pixels contain numeric values, on which mathematical operations were performed on different spectral bands to extract the salt affected areas. This mathematical characteristic of digital numbers in terms of indices is explained in next section.

D.Satellite Image Processing

The Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR), Normalized Difference Salinity Index (NDSI), Moisture Stress Index (MSI) and Normalized Difference Built-up Area Index (NDBI) were computed using satellite images.

TABLE I IMAGE PROCESSING

Indices		Equation	References
1	Normalized Difference Salinity Index	$\text{NDSI} = \frac{(0.63\text{-}0.69\ \mu m)\text{-}(0.9\text{-}0.76\text{-}\mu m)}{(0.63\text{-}0.69\ \mu m)+(0.76\text{-}0.9\ \mu m)}$	Khan *et al.*, 2005[6]
2	Normalized Difference Vegetation Index	$\text{NDVI} = \frac{(0.76\text{-}0.9\mu m)–(0.63\text{-}0.69\ \mu m)}{(0.76\text{-}0.9\ \mu m)+(0.63\text{-}0.69\ \mu m)}$	Deering *et al.*, 1975[3]

3	Simple Ratio	SR $= \frac{0.75\text{-}0.90\ \mu m}{0.63\text{-}0.69\ \mu m}$	Birth and Mcvey, 1968[1]
4	Moisture Stress index	MSI $= \frac{1.55\text{-}1075 \mu m}{0.75\text{-}0.90\ \mu m}$	Rock *et al.*, 1986[7]
5	Normalized Difference Salinity Index (1)	NDSI $= \frac{(10.40\text{-}12.5 \mu m) - (0.75\text{-}0.90 \mu m)}{(10.40\text{-}12.5 \mu m) + (0.750.90 \mu m)}$	Iqbal and Mehdi, 2008[5]
6	Salinity Index	SI $= \{(0.43\text{-}0.515 \mu m) x (0.63\text{-}0.690\ \mu m)\}1/2$	Khan *et al.*, 2005[6]
7	Soil Adjacent Vegetation Index	SAVI $= \{\frac{((0.630.69 \mu m)(0.90.76 m)}{(0.63\text{-}0.69 \mu m)+(0.76\text{-}0.9 \mu m)+(0.5)\}} X(1+0.5)$	Huete, 1988[4]

The schematic methodology for work is given in the fig.2.

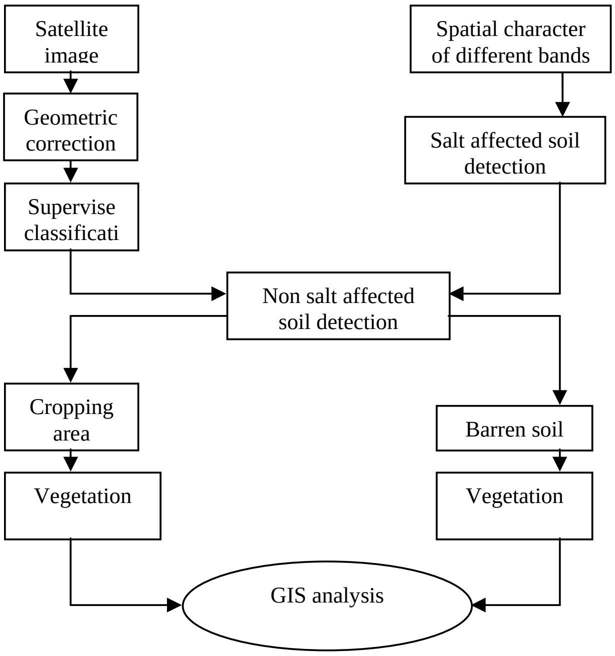


Fig. 2 Analysis Frame work

Then the resulting built up area and salt affected soil pixel reflectance values in all bands were examined using spectral profile tool shown in Figure 3, which depicts that reflectance of salt affected soil and other land covers. Maximum reflectance of salt affected soils was observed in 10.5 -12.5 µm range and minimum reflectance in the 0.76 - 0.90 µm range. With the help of maximum and minimum reflectance value bands, the relative maximum differences values bands were selected for developing a salinity index.

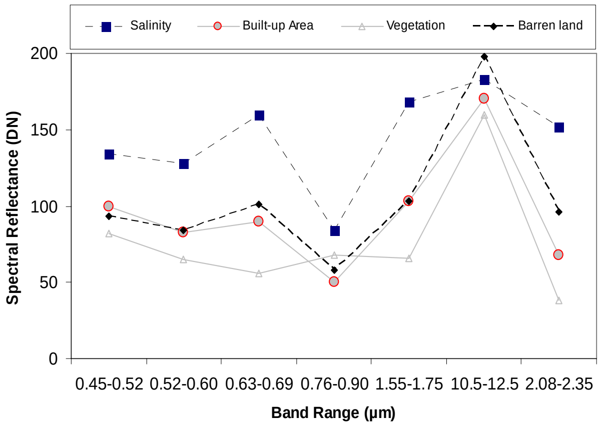


Fig. 3 Spectral reflectance of various land covers

Built-up area and barren soil were found same reflectance in all bands other than 10.5 -12.5 µm and 2.08 – 2.35 µm ranges. The selected bands were added and minimum reflectance value band was subtracted from maximum reflectance band. Finally, subtraction of bands was divided by addition of bands to extract the salt affected area. The extracted salt affected area and cropped areas were compared with NDVI, simple ratio of 4th and 5th spectral bands and MSI. The result of MSI and NDVI was used to mask the vegetation area. Built up area was also detected by the simple ratio of 0.75-0.90 µm and 0.63-0.69 µm spectral bands (Rock *et al.*, 1986) and by the subtraction of 0.76-0.9 µm – 1.55-1.75 µm. The extracted data in raster format were added to mask the built up area and then was converted into vector using *AcrGIS*. Extracted polygons were generalized using majority filter, resulting built up area which was corrected using visual interpretation. The salt affected area was extracted by NDSI and Salinity Index developed by Khan *et al*. (2005). The results of both salinity indices were compared. Then the salt affected areas of both equations were reclassified into 1 and 0 and both the NDSI results in raster format were overlaid to delineate the common salt affected areas.

E. Performance Evaluation

Differences in cropped area between head and tail zones the water course studied. The command areas were divided into two zones from head to tail. The area of zones I is under healthy vegetation and the area of Zone II under normal vegetation. For all the study year performance can be calculated. The value above than 0.2 show the vegetation and below value show the saline or barren land, while the value above than 0.4 show the healthy vegetation.

It was studied for the year 1992, 2000 and 2005. The NDVI value from head to tail was calculated at three different points on the basis of this value the results find out about the performance.

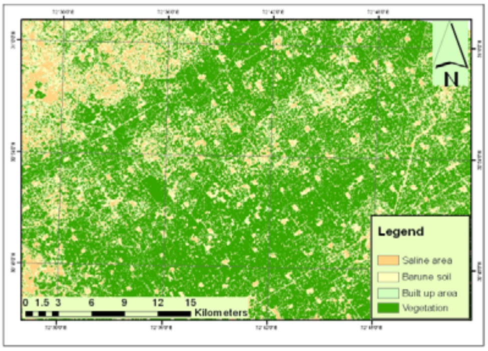
F.GIS Analysis

To generalize the extracted salt affected area and cropped area majority filter of 8X8 was applied. The area under salinity and built up area was masked by NDBI and MSI. The built up area was subtracted from salt affected area which was delineated by supervised classification, NDBI and visual interpretation in initial session. The extracted soil through satellite imagery was superimposed with the salinity maps. Finally the overlay of both NDSI was performed to extract the common areas. Vegetation area masked by NDVI and MSI results and overlapped with built-up area to prepare the final map of land cover for further analysis. Then with the consideration of this salt affected area and vegetated area the head to tail ratio was calculated on the basis of this ration the performance of the canal find out.

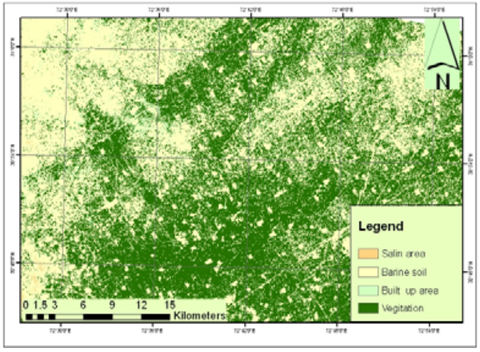
III. RESULTS AND DISCUSSION

A. Cropping Pattern

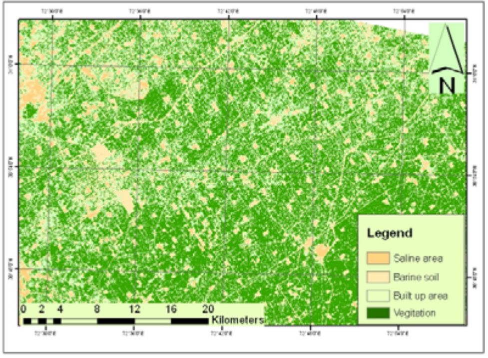
The NDVI of area provides the health of plant on the basis of their response towards ET. It can be concluded that how much area is under healthy vegetation and same is the case with MSI which provides the clear look of stressed vegetation. The results of cropping pattern significant reflection in thermal IR band, minimum in Near Infrared band for all three year those are under find out according to the NDVI value the maps are given in fig. 4.



a. Cropping pattern map of year 1992



b. Cropping pattern map of year 2000



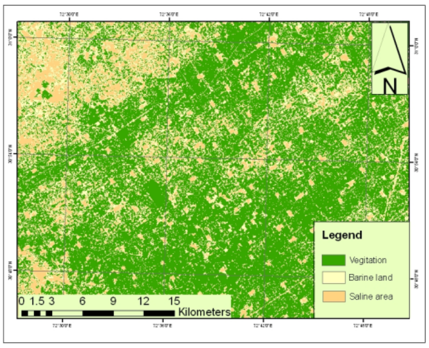
c. Cropping pattern map of year 2005

Fig. 4 Cropping pattern Maps

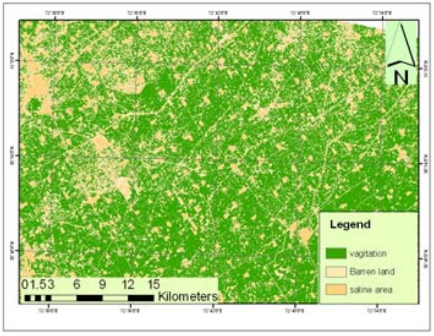
From the analysis it is shows that the cropping pattern is increase 20%. In 1992 the 543.54154km^2 area was covered by vegetation in 2000 it was 676.5399km^2 while in 2005 in increase 20% and area cover is 781.8354km^2. The total area study was 1191.4641km^2.

B.Salt Affected Area

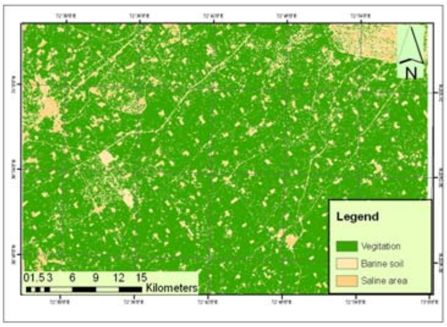
The NDSI of 3rd and 4th band of Landsat satellite provides the area under saline condition and other land types. The NDSI using Near IR and Thermal IR bands provides the look of saline and some heath variation of vegetation. The term “physiological drought” points to the apparent shortage of water when a plant is growing in a moist saline soil or solution. The results shown in Fig.5 are checked with the salt affected association map prepared by SSP and also validated with many indices and found satisfactory. The NDSI of NIR and TIR provides precise results but required more research for their validation.



a. Salinity map of year 1992



b. Salinity map of year 2000



c. Salinity map of year 2005

Fig. 5 Salinity Maps

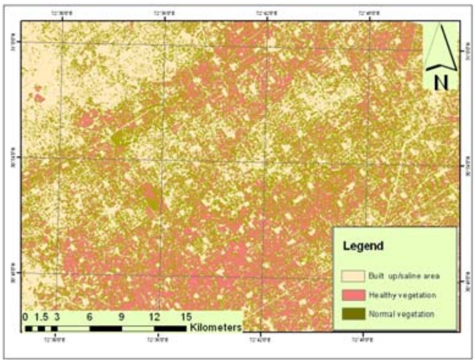
In 1992 the saline area was 119.006 km^2, in 2000 it was 109.2771km^2. The saline area is almost four time decreases as shown by the map, it left 27.39km^2 in 2005. Barren land also can be develop it left t an area of 164.322km^2. After the discussion of the all year salinity maps it is analysis that the salinity and barren land decrease with the improvement of the canal lining up to 80% and 40% respectively.

C. Performance Evaluation

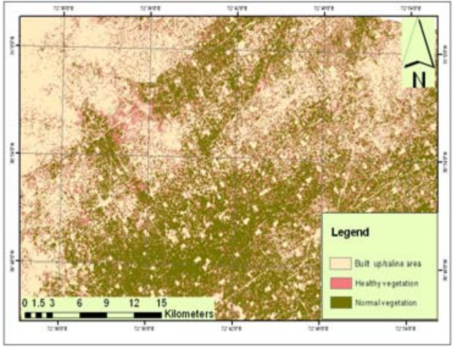
For performance evaluation the cropping pattern, salinity and head to tail difference are use. The same maps use for this as use for performance evaluation are in figure 6.Only change in color to see he clear view. The crop area is divided into two zone according to the head to tail ratio of the crop. In zone I the normal vegetation and in Zone II healthy vegetation. The performance of all year is given in table 1 where cropped area is given in percentage.

TABLE II HEAD TO TAIL DIFFERENCE IN CROPPED AREA

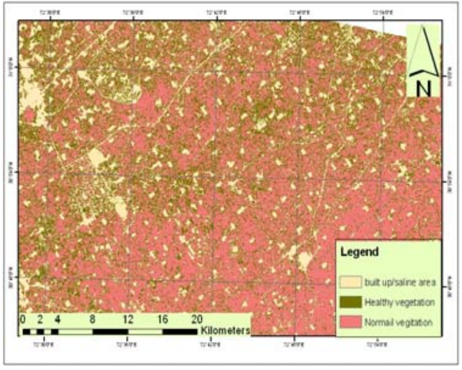
YEARS	ZONE I	ZONE II
1992	***13.79%***	***2.29%***
2000	***29.24%***	***19.96%***
2005	***45.61%***	***36.37%***



a. Performance map of year 1992



b. Performance map of year 2000



c. Performance map of year 2005

Fig. 6 Performance Maps

IV. CONCLUSION

The overall impact of the irrigation system has been two to three-fold increases in the gross cropped area and average crop yield and the generation of a high net additional income for the region. With the improvement of the canal the performance of the system increases 32%. However, in the last 40 years, there has been an increase in the problems of salinity.

This study showed the possibilities of accurate salinity detection using Landsat imagery. This study concluded that the Thermal infrared band (10.40-12.5µm) provide more reflectance at salt affected areas than other bands. The Near infrared band (0.76-0.90 µm) has a minimum reflectance. The ratio of TIR and NIR is useful for salt prone land detection.

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