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Full Length Research Paper

Detection of salt affected soil in rice-wheat area using satellite image

Faheem Iqbal

Institute of Geographical Information Systems, National University of Sciences and Technology,
H-12 Campus, Islamabad, Pakistan. E-mail: faheem.engr@gmail.com. Tel: 0092-0333-897123, 0092-051-90854477.

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Pakistan's agricultural system is predominately irrigated, which consumes 90% of fresh water resources and contributes 80% to the national production. It is ironic that the irrigated areas are the ones that are afflicted most by the twin menaces of waterlogging and salinity. Climate change is likely to exacerbate this soil degradation process by way of heavy rainfalls and by increased evaporation, respectively. Detection of soil salinity is usually done by laborious soil sampling. A study, to delineate surface soil salinity in the prime rice-wheat cropping area of Pakistan, was conducted. The study employed an index-based approach of using optical remote sensing data in combination with geographic information system. The effectiveness of different satellite imagery indicators was examined. 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 from the non saline area. Results showed that 19% of the rice-wheat cropping area of Gujranwala district in Rachna Doab of central Punjab province of Pakistan is salt affected. These results are in agreement with the published survey data. Seasonal dependency of salinity was also analyzed so as to obtain correct classification.

Key words: Salinity, remote sensing index, salinity index.

INTRODUCTION

Soil salinity and water logging are becoming a drastic problem, especially in arid and semi-arid regions wherever irrigation is practiced. In some parts of the world, like Pakistan, food need is on increase due to growing population pressure as a result soil and water resources are continuously degraded, horizontal expansion of crop production is not an option. The available natural resources must be conserved and used judiciously and therefore, all efforts are made to increase the agricultural production, in many cases by land reclamation, but facing limited water resources. It is reported recently that about 10% of presently arable lands of the world are affected by salinity (Tabet et al., 1997). Salinity and sodicity affect an estimated 952 Mha of land (Szabolcs, 1992). In Pakistan, seepage and percolation from large irrigation network has given rise to high water table, resulting in twin menaces, of water logging and salinization. The magnitude of the salinity/sodicity problem can be gauged from the fact that in the past, the area of productive land was being damaged by salinity at a rate of about 40,000 Ha/year in the country (WAPDA, 1981). Salt-affected lands in the Indus basin of Pakistan cover an area of 4.22 Mha, which is 26% of the total irrigated area of the country (Ghassemi, 1996). Thus, monitoring saline degraded lands has always been a primary issue for efficient irrigation systems management and rehabilitation policies. The problem of detection, monitoring and mapping salt-affected soils is known to be a difficult matter because dynamic processes are involved. Recent advances in the application of remote sensing technology in mapping and monitoring the degraded lands, especially the salt-affected soils, have shown great promise for enhanced speed, accuracy and cost effectiveness. The approach to the problem of delineating saline soils using remote sensing data and geographical information system (GIS) techniques has been proved efficient in many recent studies (Dwivedi, 1992; Dwivedi

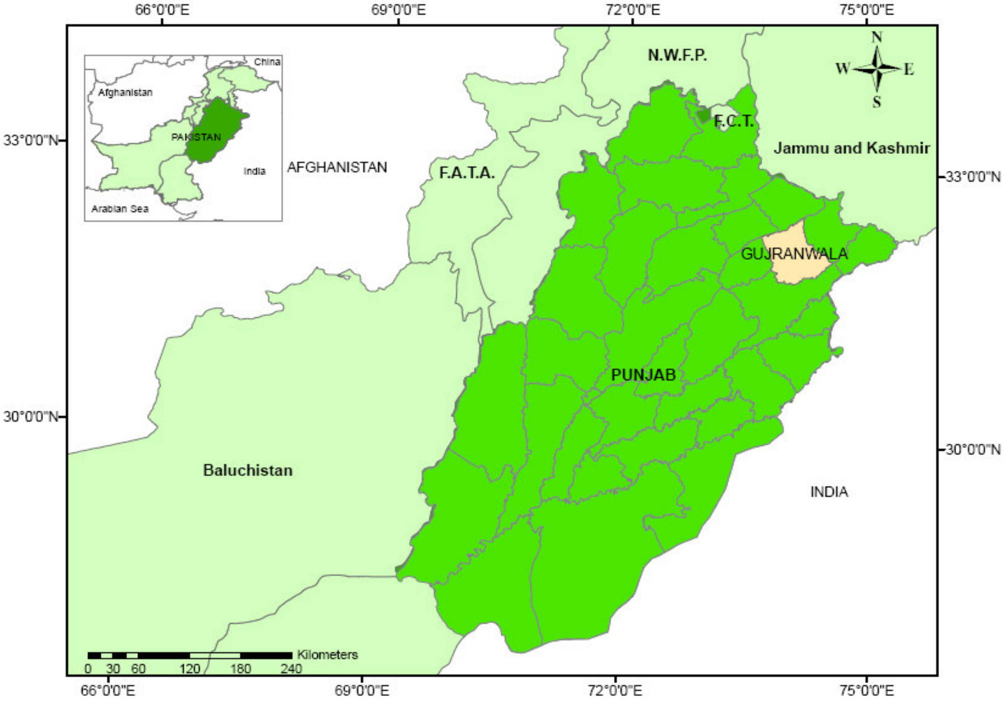

Figure 1. Location of Gujranwala, Punjab Pakistan.

and Sreenivas, 1997; Iqbal and Mehdi, 2008; Khan et al., 2005; Rao et al., 1991; Sharmaet al., 1988). Buces et al. (2005) described the method of soil salinity mapping using a combined spectral response index for bare soil and vegetation The combination of remote sensing with GIS is very promising, especially for the monitoring of soil salinization (Goossens, 1996). This study is planned for mapping salt-affected soils in Pakistan as a secondary objective to spatial modeling of soil suitability for zero-tillage wheat sowing. An approach using remote sensing indicators, different salinity indices (SI), vegetation indices and supervised classification, which are based on spectral characteristics of different kind of surfaces, has been applied for this study as digital image processing (DIP) and GIS techniques (Goossens, 1996; Naseri, 1998; Steven et al., 1992). However, the work has been accomplished with the use of the functionality of Arc GIS and IDRISI for windows (Eastman, 1995; Khan and Sato, 2001; Metternicht and Zinck, 2003 and Khan et al., 2005) through its special modules and mathematical operator functions for remote sensing data processing and analysis.

MATERIALS AND METHODS

Study area

The study area, district Gujranwala in Central Punjab province, is located in Rachna Doab, which lies between longitudes 73°38’52”, 74°34’55” East and latitude 31°47’36”, 34°34’2” North (Figure 1). The soils of the study area include well drained, moderately well drained and imperfectly drained. The soils are formed by mixed calcareous silty alluvium derived from Himalayas and deposited during the late Pleistocene in semiarid subtropical continental climate in recent and Sub-recent sediments along the river Chenab and the Pleistocene lying in old river terrace, the centre portion of the Rechna Doab (Soil Survey of Pakistan, 1985).

The river Chenab and irrigation canal influence the hydrology of the area. Most of the area has good quality groundwater, therefore area under irrigation has increased due to installation of tube wells and about 50304 tube wells are in operation in the area (Government of Punjab, 2003). The climate of the area is subtropical continental semi-arid to sub-humid. Average annual rainfall in the study area is 628.3 mm (Soil Survey of Pakistan, 1985) of which two third is received in the form of high intensity showers during Monsoon from July to September and the remaining as low intensity winter showers. Average annual pan evaporation is 1995.6 mm and the annual excess of evaporation over rainfall is 1367.3 mm in Gujranwala (Soil Survey of Pakistan, 1985).

To quantitatively measure land surface salinity in the study area, Landsat 7 ETM+ image (September 30, 2001) was selected. The images have been rectified to UTM (Universal Transverse Mercator) coordinate system, and a digital topographic map with a scale of 1:125000 for the city of Gujranwala were used to obtain a soil classification.

Salt affected soil delineation

Satellite imagery of Landsat and published map by SSP (Soil Survey of Pakistan) were used for detection of salt affected soils. The methodology shown in Figure 2 was used to extract the salt

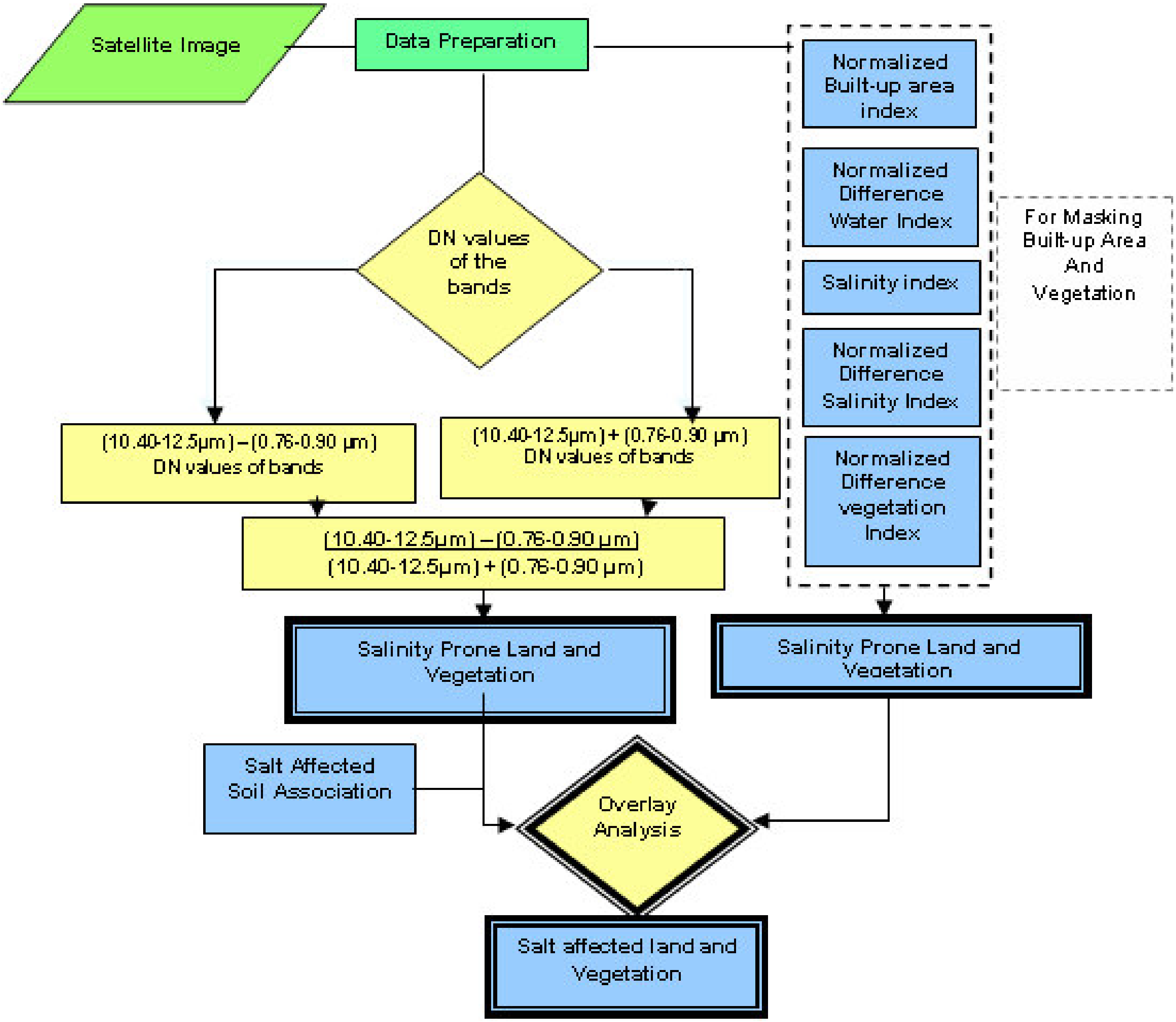

Figure 2. Image processing.

affected soil associations. Geo-referenced satellite imagery was used to extract the vegetation, the built-up and the barren land. Equations available in Table 1 were used for this methodology. Many natural surfaces are almost equally bright in red and near-infrared part of the spectrum with notable exception of green vegetation. Red light is strongly absorbed by photosynthetic pigments (such as chlorophyll) found in green leaves, while near infrared light either passes through or is reflected by live tissues, regardless of their colour. It means that the areas of bare soil having little or no green plant material are similar in both red and near infrared wavelengths, while areas with much green vegetations show more brightness in the near-infrared and are very dark in red part of the spectrum.

The healthy vegetation can absorb the red light and is found to have very dark tone and thus are present as higher digital value pixels. While bright tone represents the barren soil and stressed vegetation with minimum digital pixel values. But in near-infrared band all classes are 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 to 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

Table 1. Salinity distribution in study area as determined by NDSI with Equation 5.

Soil association	Saline area (Ha)
Argan-Pindorian	201
Bhalwal	336
Eminabad	42,246
Gujranwala	1316
Hafizabad	777
Kamoke	3,384
Miranpur	232
Pacca	650
Pindorian	5,465
Pindorain-Sagar	278
Satghara	4,845
Wazirabad	1756
Wazirabad-Rasulpur	570
Total	62,056

bands to extract the salt affected areas. This mathematical characteristic of digital numbers in terms of indices is explained in next section.

Image pre-processing

Noise reduction is necessary for remotely sensed images, especially for the thermal infrared (TIR) band. The noise may affect the spectral reflectance values. There is periodic noise (for example, stripes in the TM/band 6) and non-periodic noise (for example, speckles). In this study, a self-adaptive filter method was used to remove non-periodic noise and the FFT (Fast Fourier Transform) method was used to automatically remove periodic noise. Both the removal of periodic and non-periodic method was performed by using software ERDAS Image v8.6. the results showed that the increase or decrease in the digital numbers (DNs) was more than 3% caused by periodic noise for the ETM+/TIR band on 30, September 2001. To analyze the pattern of salinity in the study area, the published maps must be co-registered in the same coordinate system (for example, UTM/WGS84). In this study, the raw images were geo-referenced to a common UTM coordinate system based on the published map of 1:10,000 scales by Survey of Pakistan, and re-sampled using the nearest neighbor algorithm with a pixel size of 30 m x 30 m for all bands, including the thermal band. The RMSE of rectification was less than 0.5 in this study.

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 the satellite images. The schematic methodology for detection of salt affected soils is shown in Figure 2. For salt affected soil detection, NDVI, NDSI, SI, MSI and SR indices were applied.

The raw image was stacked and different band combinations were checked for classification and visual interpretation. Finally, supervised classification was performed using Erdas imagine. The signature for supervised classification was developed on the basis of local knowledge and high resolution satellite imagery from Google earth pro. 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 the reflectance of salt affected soil and other land covers. Maximum reflectance of salt affected soils was observed in the range of 10.5 -12.5 µm and minimum reflectance in the range of 0.76 - 0.90 µm. With the help of maximum and minimum reflectance value bands, the relative maximum differences values bands were selected for developing a salinity index.

Built-up area and barren soil were represented by 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 the 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 (Vidal, at al. 1996). 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 was added to mask the built up area and then was converted into vector using ArcGIS (Iqbal, 2008). Extracted polygons were generalized using majority filter; the resulting built up area was corrected using visual interpretation. The salt affected area was extracted by NDSI and Salinity Index developed by (Khan et al., 2005). The new NDSI was developed with selected bands having maximum and minimum reflectance for salinity (Iqbal and Mehdi, 2008 and Iqbal, 2010). The salt affected soil gave maximum reflectance value in Thermal IR band and minimum in 0.76-0.90 µm range (Iqbal, 2008). 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.

GIS analysis

To generalize the extracted salt affected area, majority filter of 8 × 8 was applied. The area under salinity and the built up area were masked by NDBI and MSI. The built up area was subtracted from

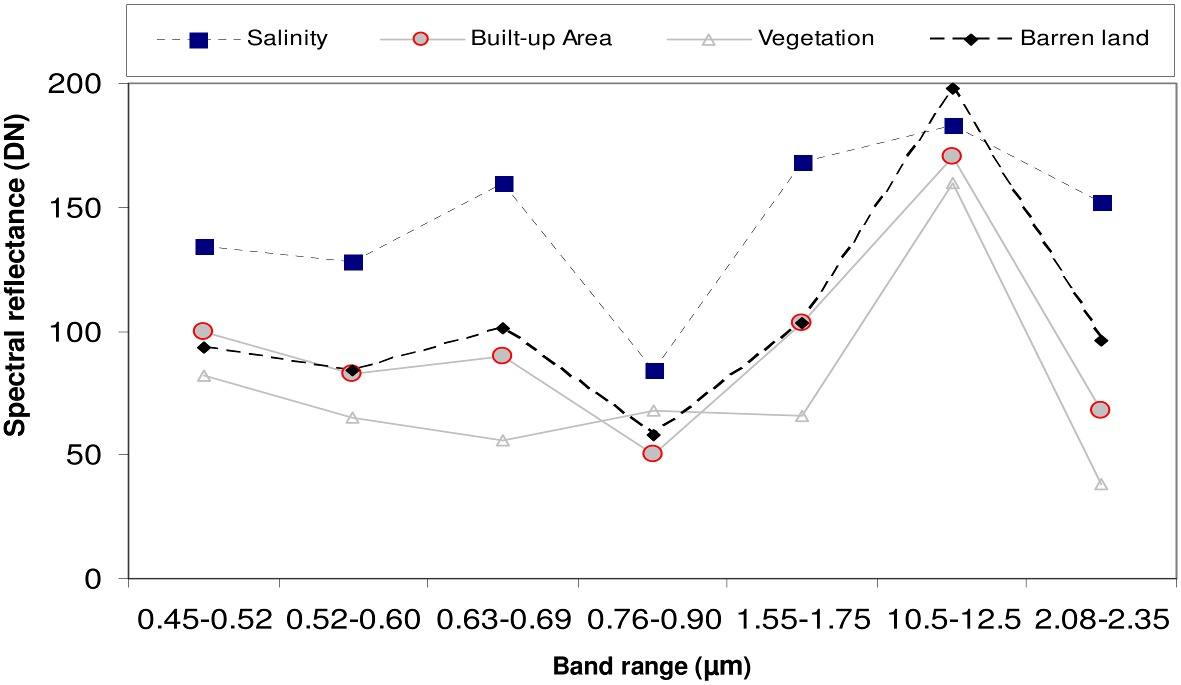

Figure 3. Spectral reflectance of various land covers.

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 extracted through soil association map which consisted of Eminabad and Satghara association, same result was reported by (Iqbal, 2008). Finally the overlay of both NDSI was performed to extract the common saline areas. The vegetation area was masked by NDVI and MSI and overlapped with built-up area to prepare the final map of land cover.

RESULTS AND DISCUSSION

The results of salt prone soil show significant reflection in thermal IR band (Khan et al., 2005; Iqbal, 2008; Iqbal, 2010), minimum in near infrared band (Figure 1). Accurate salt affected soil detection is possible through the integration of satellite imagery and field surveyed maps. NDSI results by Equation 4 results the built-up area, salt prone land and river sandy area in above one range and below 0 provides the cultured area, classification of vegetation health is difficult (Figure 4). NDSI by Equation 5 provides the salt affected soil cropped area in the saline class; normal soil vegetation area was easily separated these results also confirm the (Iqbal, 2008; Iqbal, 2010) (Figure 5). For more accurate delineation of salt affected soil, SI by Equation 6 was used (Figure 7). Then by using local knowledge built-up area was delineated. NDBI provides built-up area (Figure 6).

Extracted built-up land and saline lands were interpreted visually. Results of salt affected areas were also checked with NDVI and MSI for validation. The end combination map of soil classification and built up area provided precise result (Figure. 8). Results conformed to those of SSP. who also reported 80% of the same study area under salt. An area of 612 sq km was found salt affected which corresponds to 19% of the study area.

A larger patch of salt affected area is within a triangle of Chenab River, Qadrabad-Baluki link canal and lower Chenab canal. About 75% of this area is within a distance of 20 km from Lower Chenab canal. About 70 % of salt affected area computed through satellite imagery presented in the SSP map, which shows Eminabad and Satghara association under salinity. The NDVI of area provide the state of plant health on the basis of their response towards ET. MSI also provides the clear look of stressed vegetation. 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 provide the look of salinity status 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 Figure 8 were checked with the salt affected association map prepared by SSP and were also validated with many indices and found satisfactory. The NDSI of NIR and TIR provides precise results. Table 2 shows the distribution of salinity within

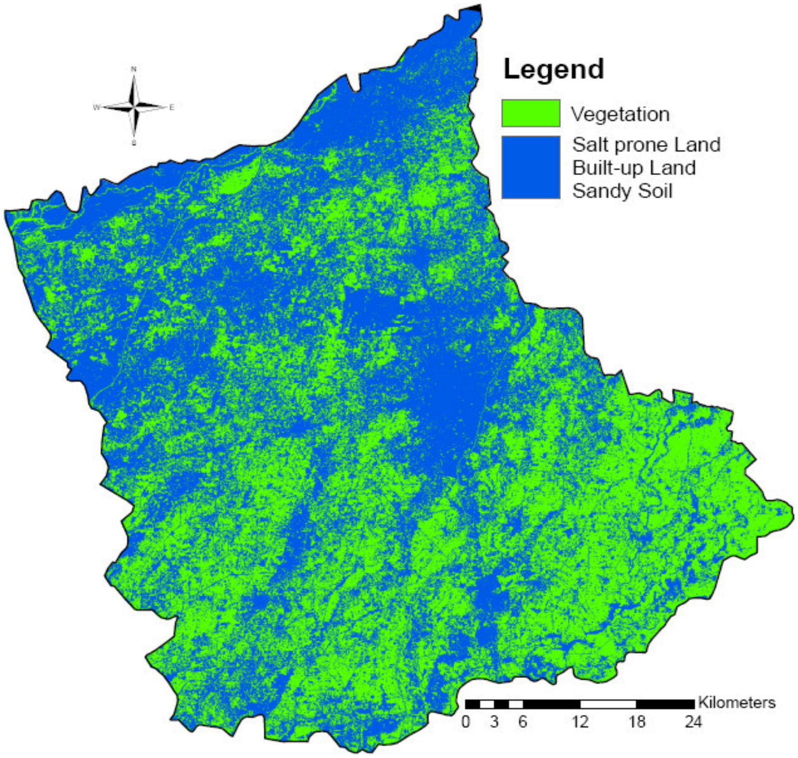

Figure 4. NDSI with Equation 1.

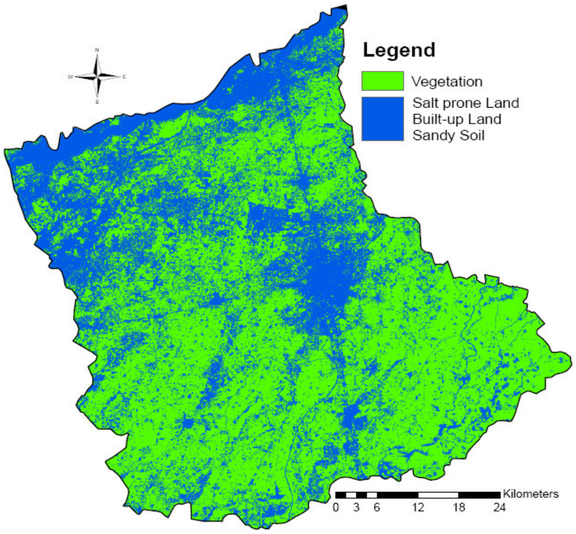

Figure 5. NDSI with Equation 5.

each soil association in the study area.

Conclusions

The Landsat sensor has a variety of bands, and the surface reflectance of the bands relates to the soil properties:

0.63 to 0.69 µm) – (0.76 to 0.9 µm) (Khan et al., 2005)

(0.63 to 0.69 µm)+ (0.76 to 0.9 µm)

A combination of bands in Equation (1) is useful for the detection of salt affected soil.

The salinity index, which is produced by LANDSAT bands equation (2) accurately, detects overall salinity in the bare agricultural soil:

(10.40 to 12.5 µm) – (0.76 to 0.90 µm) (Iqbal, 2008, 2010)

(10.40 to 12.5 µm) + (0.76 to 0.90 µm)

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

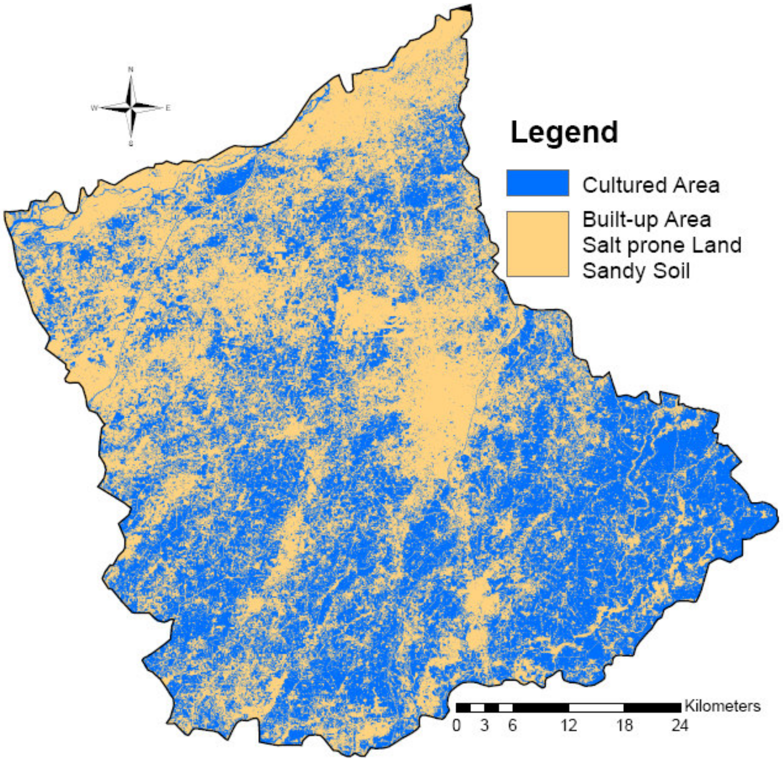

Figure 6. NDBI with Equation 4.

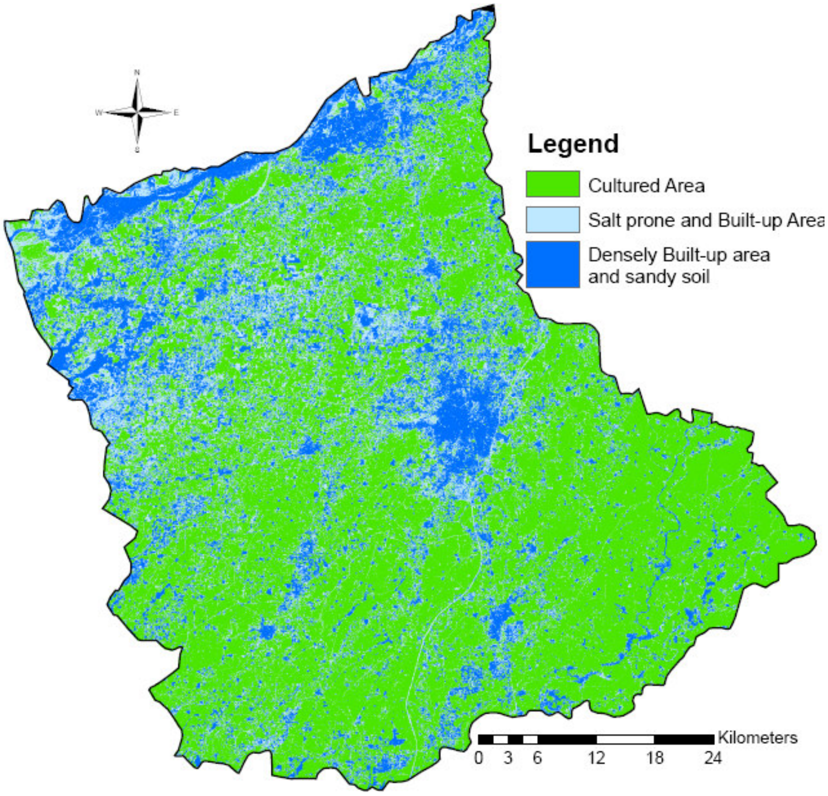

Figure 7. SI with Equation 3.

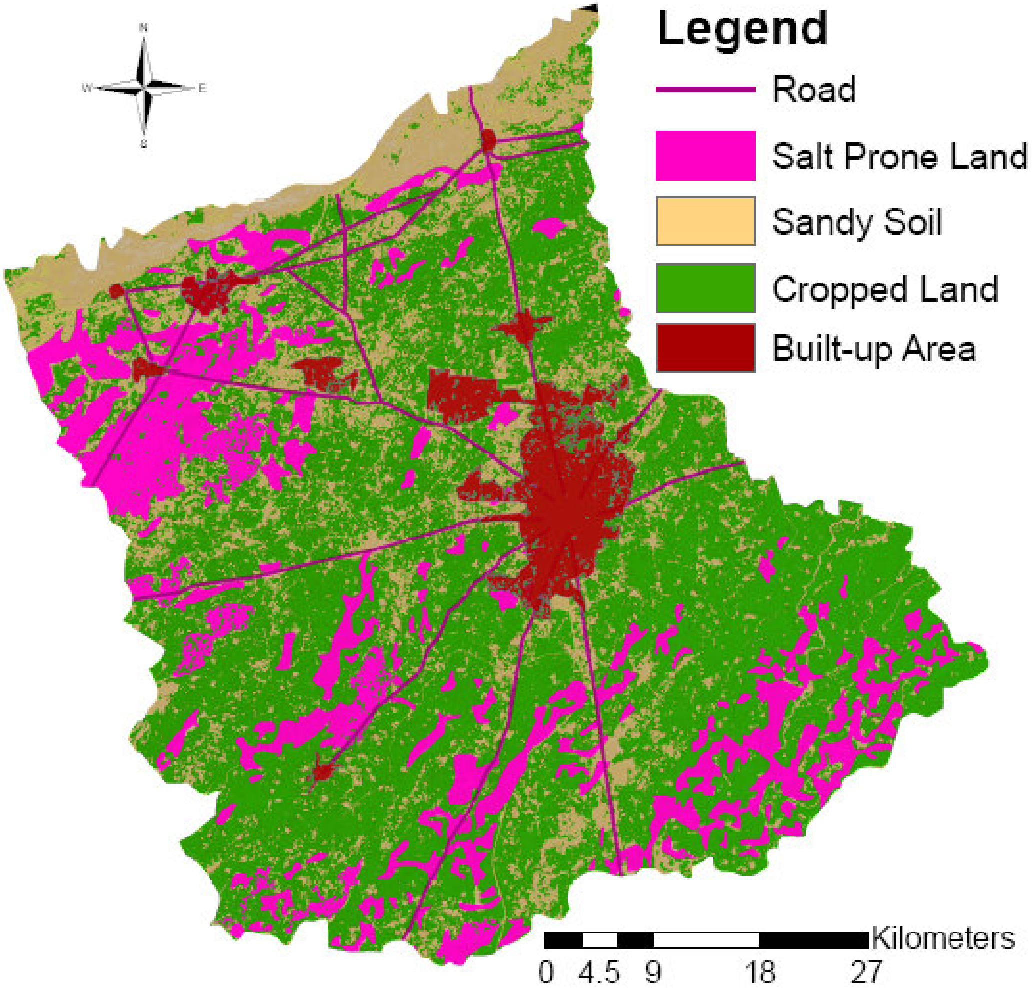

Figure 8. Salt affected soils in study area as determined by NDSI with Equation 5.

Table 2. Remote sensing Indices and equations.

Indices		Equation	References
1	Normalized Difference Salinity Index	$\text{NDSI} = \frac{(0.63\text{ to }0.69\ \mu\text{m}) - (0.9\text{ to }0.76\text{-}\mu\text{m})}{(0.63\text{ to }0.69\ \mu\text{m}) + (0.76\text{ to }0.9\ \mu\text{m})}$	Khan et al. (2005)
2	Normalized Difference Vegetation Index	$\text{NDVI} = \frac{(0.76\text{ to }0.9\ \mu\text{m}) - (0.63\text{ to }0.69\ \mu\text{m})}{(0.76\text{ to }0.9\ \mu\text{m}) + (0.63\text{ to }0.69\ \mu\text{m})}$	Deering et al. (1975)
3	Simple Ratio (SR)	SR = 0.75-0.90 µm/0.63-0.69 µm	Birth and Mcvey (1968)
4	Moisture Stress index	MSI = 1.55-1075 µm / 0.75-0.90 µm	Rock et al. (1986)
5	Normalized Difference Salinity Index (1)	$\text{NDSI} = \frac{(10.40\text{-}12.5\mu\text{m}) - (0.75\ .90\mu\text{m})}{(10.40\text{-}12.5\mu\text{m}) + (0.750.90\mu\text{m})}$	(Iqbal, 2008; Iqbal 2010)
6	Salinity Index	SI = {(0.43-0.515µm) × (0.63-0.690 µm)}1/2	Khan et al., 2005

The main difficulty in previous researches is the retrieval of salt-affected areas from satellite data is to distinguish between 'Salt' and 'Town' classes, because in previously developed index it was not possible to differentiate salinity from town dares. But by using the derived index (based on TIR and NIR) salt affected soil can easily be detected and result are verified by using up-to-date topographic maps to get information about the settlement/urban area boundaries and excluding it after vectorizing from the calculation process while monitoring salt-affected soils. The other possibility when that information is not available is to avoid using satellite scenes where such distinction cannot be made but other images taken at different times. The optimal time period for taking satellite data in order to assess salt-affected soils in the test area with the NDVI (NDSI) index is March to avoid spectral confusion of mixing with urban areas that is occurring in peek summers times. The proposed index detects only the salt on the surface of the soil. For detailed study as salinity classification, field measurements below the surface are preliminary. The proposed Salinity Index does not require sophisticated calculations and weather data for salt detection. Remote sensing can be used to map soil salinity directly from bare soil and indirectly from vegetation with some accuracy. Other tools and available technology may be useful to improve the accuracy of salinity mapping using remote sensing. Additional research is needed to refine the methodology and determine what tools and technology are best suited to improve the accuracy of remote sensing to map soil salinity. For example, multiple images from the same year or different years, topographic data or digital elevation models, more data on soils and geology, and ground truthing could help improve the accuracy of salinity mapping using remote sensing. Remote sensing technology will play an even greater role in crop and soil monitoring in future when new remote sensing systems with higher spatial and spectral resolution become readily available. This approach is the first study adopted for the selected area of Indus basin and can be utilized for any satellite. The approach stated above has also been carried out in further studies to monitor and assess the status and cause-effect relationships of water logging, groundwater quality indicators and salinization through an integrated methodology of remotely sensed and field data as input for GIS analysis.

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