Delineation of Water Logging and Salinity for Salvaging Built Environment

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Abstract: Millions of acres of splendidly productive land and valuable infrastructure are deteriorated continuously. The reason for such deterioration in majority of areas is mainly due to water logging and salinity. Rise of water table level and the dearth of drainage and lack of continuous monitoring and timely remedial measures, extended the circle of devastation to historical heritage and precious archeological sites as well.

Mohenjo-Daro has been selected for this study, it has global significance but due to water logging and salinity, it is in danger of total destruction. The archeological buildings and other infrastructure and land in its environs are being gradually eroded by the capillary rise of saline ground the intensity of which constitutes a serious threat.

For delineating and periodic monitoring of the salinity and waterlogging and to effectively implement the appropriate remedies, use of the latest technologies is essential. In this study the remote sensing technologies are used to address this issue with the help of Soil investigation parameters mainly EC and pH.

The aftermaths of this study would provide a methodological framework along with practical application in delineation saline areas using satellite technology. The final value-added products of this research would be useful for all interested stakeholders including conservationists, environmentalists, archeologists, planners and decision-makers at various levels. The international community at large would be the beneficiary of this study since Mohenjo-Daro is the heritage of entire mankind.

Keywords: Mohenjo Daro, water logging and salinity, Remote Sensing, EC, pH.

INTRODUCTION

Resolution of different conventional issues using Science and technology is what making this world develop faster than anyone could have imagined. Most of the important problems of our region we live in can be addressed through the effective means of the latest technology at very large scale.

Pakistan is an agricultural country and the majority of the land consisting of rural area.Water logging and salinity are the issues which are being faced to the habitat in rural areas (GOP, 1999) [1].

The cultivable areas are heavily affected not only by the ill irrigation practice but also by the excessive infiltration from the unlined canal systemstem; this infiltration increases the water level of the area. The continuous cultivation of high water requirement crops (high delta crops) in such areas where the soils are permeable also increases the water table of that area in absence of proper drainage. The construction of drainage with an alignment not suited for the area and construction of other infrastructure like building roads etc. disturbing the natural drainage and catchment areas can also add up to the salinity and water logging problem. According to the survey there is about 11 million hectares of area in Pakistan which has water table depth of 5-10 feet [1].

Sodicity or secondary salinity is also found in irrigated areas. According to an estimation more than 2.8 million hectares of Pakistan are affected by either salinity or sodicity. Due to the salinity/sodicity and Water logging, the drainage properties of the soils is reduced, causing infertility of the land or low yields from affected areas [2].

Lack of proper and drainages with proper slopes and catchment areas is also the reason of the prolonged sustainability of such conditions which are disastrous for both agriculture and adjacent existing and future built infrastructure.

Due to the ever changing nature of water logging and salinity patterns the conventional methods are found costly and time consuming. This problem can be overcome by adopting latest techniques offered by the geographical information systems (GIS) and Remote Sensing (RS).

Combining them with traditional as well as frontier techniques to achieve sustainable development [3].

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Space technologies will no doubt provide advance information on land use patterns, environmental degradation, water stress, and other issues take appropriate and timely remedial measures [4].

RESEARCH OBJECTIVES

To model the spatial as well as an empirical method for delineation of waterlogged and saline areas in the rural areas of Pakistan using the sampling methods and satellite technologies.

- The point of focus of research is an appraisal of waterlogged and saline areas and discrimination of slightly, moderately and highly saline soils with the help of satellite images.
- To provide timely information which can help Increase agricultural production and can be used to prevent the infrastructure present in the salt affected lands
- Prevention of deterioration of productive land through finding options for adoption of appropriate soil and water management practices

This research also highlights the role, future directions, and impacts of space technologies in Infrastructure development and other matters related to the utilization of land and sustainability of the built structures and to check the feasibility of the future developments to reduce costs and for the betterment of peoples living on the satellite effected areas. All of this is possible if appropriate tools and techniques are adapted by scientists, policy makers and by governments especially in developing countries.

Study Area

Mohenjo-daro and its surroundings has been selected as Study Area. The ruins were discovered in 1922 and they are located in district Larkana, Province of Sind in Pakistan. It is approximately 400 Km in the north of Karachi (Figure **1**). The coordinates of the locations are 27°19′45″Northing and 68°08′20″Easting or 27.32917°N and 68.13889°E. The maximum temperature of the study area recorded is 53.5 °C (128.3 °F) which was recorded on 26 May 2010 and it was the highest reliably measured temperature ever observed Pakistan as well as in Asia and also the fourth highest temperature of the world. The weather is dry most of the time of the year rainfall of moderate range occur in the season of monsoon and sometimes other than that [5].

Historical Significance

Mohenjo-daro (lit. Mound of the Dead), was one of the earliest urban settlements and in the Indus (3300–1700 BCE, flowered 2600–1900 BCE). The

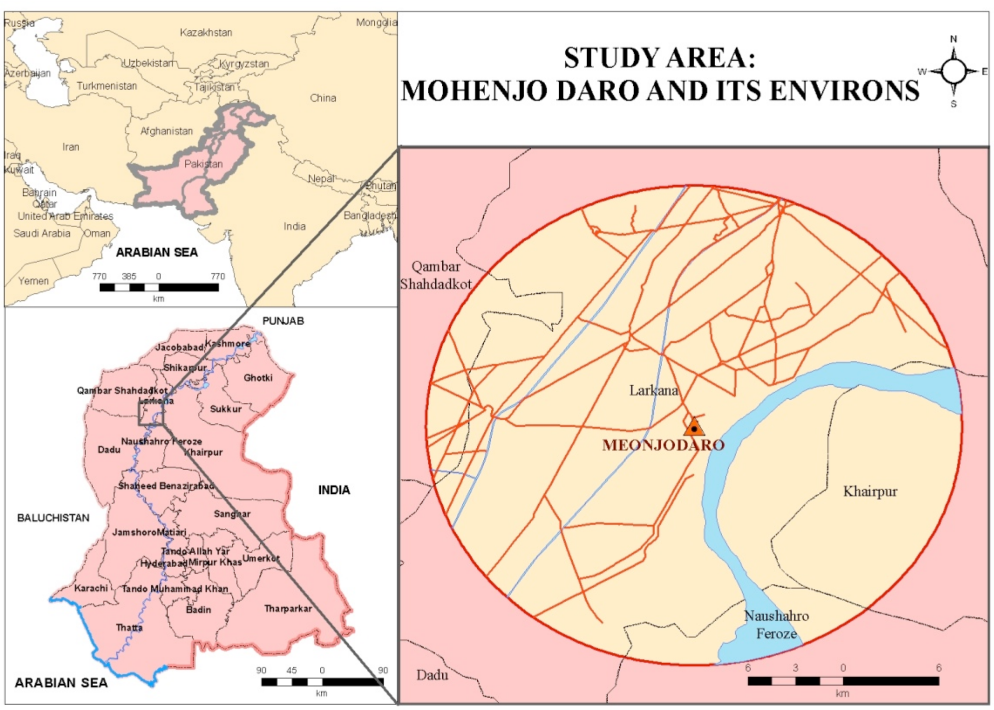

Figure 1: Study Area.

significance of the archeological remains can be estimated by that fact that Mohenjo-daro is designated as "UNESCO World Heritage Site" [6].

Data Sources

The Primary Data used for the research are Satellite images, GPS coordinates and analysis results of the soil samples collected during surveys and other relevant information of the area, whereas the secondary data consists of Topographical sheets/Maps of the study area and its adjacent localities by survey of Pakistan, vector data created using the satellite images and topographical sheets. The Satellite imageries used are MODIS (2013, 2010), Google Earth, Spot (2005) and Land Sat (1992, 2000 and 2013).

Salinity Assessment Survey

The field Survey was conducted in December as it is the best period to survey for salinity from December to mid of February as majority of the harvesting is done in this period. The samples were collected from the points located reasonably apart from each other at a minimum depth of (10-15) cm. The depth was variable according to the land conditions and morphology of soil. Most of the points taken in water logged area were also the points on the saline soils as the most of the water logged area have the surrounding soil as high or at least moderately saline as per visual interpretation (Figure **2**).

Details of each sample were properly noted in a spreadsheet which already had Coordinates, reference information on the point, Physical condition on the ground for that particular point etc. Surveys of Pakistan Topographical Maps were also used to aid the purpose.

Analysis of the Samples

Soil samples were mainly tested for Electrical Conductivity (EC) and pH values. Since pH is the measure of acidity and alkalinity of the solution and Electrical conductivity is provides the procedure through which the salt contents of the soil samples can be estimated.

By using electrical- conductivity measurement on a saturated soil paste or a the application of the conductivity meter in comparatively more dilute solution of soil samples containing suspended soil in it or extract of the soil paste of the concerned soil sample which provides the best estimate of soluble salts. The increase in electrical conductivity reflects that there is an increase in salinity of that area as well.

The laboratory analyses of 188 out of more than 200 samples were conducted for pH, EC, soluble ions and soil texture in order to do salinity assessment.

For the sake of workability within limited resources area of interest was cropped out. An area of 15 Km diameter was taken as the area of interest keeping the

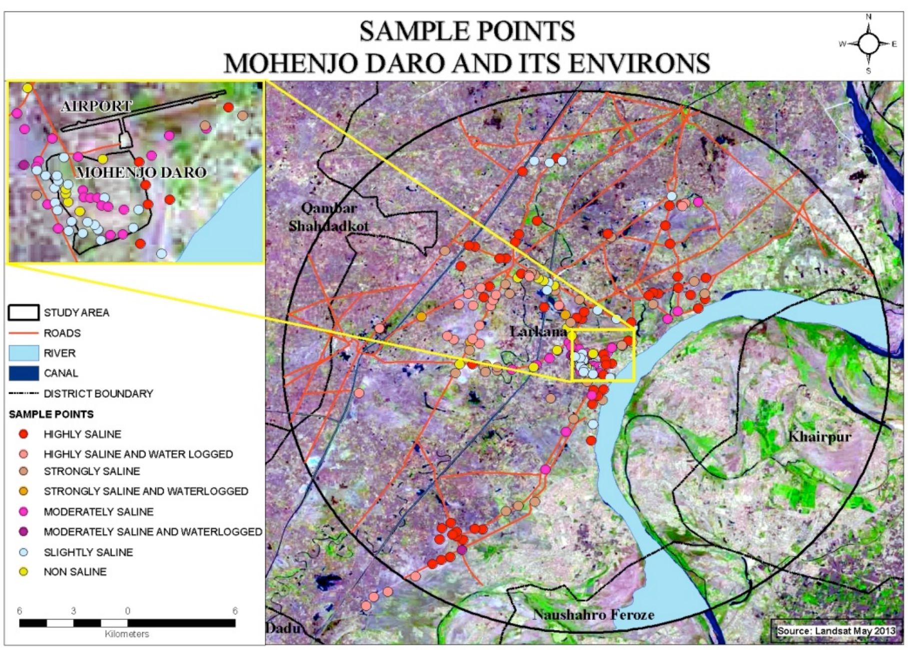

Figure 2: Distribution of GCPs.

Ruins of Moen Jo Daro as the center or the area of interest.

The mosaicking was done of the images in case of the images from quick bird, the other images were ortho-rectified and georeferenced. The subset was taken out from the image which was the area of interest. Some other enhancements were also performed which improved the visibility of the images.

Image Analysis

Land Use land cover classifications were applied using the supervised and unsupervised classification techniques. In supervised classification the classes of water, barren land, saline areas and, waterlogged area.

In order to rectify the problem of wrongly classified pixels the raster image was filtered using the majority of filters, special care was taken to place the similar or homogeneous area in each of the defined class. In this regard the help was taken from the survey statistics. After preparing the sample set, the procedure was applied and output classified map was obtained. The NDVI and SI were also used to have a reflection of the area features. The representation of the saline and water logged areas using such technologies for taking protective measures to control the distress caused by the same.

RESULTS AND DISCUSSIONS

The maps produced using the satellite images and field data, reasonably reflects the saline and non-saline areas which shows the potential of the methods towards the representation of the salinity for any similar area. The results produced by the imageries of different time and time frames are also showing the changes in saline areas over the period of years. The results are presented and discussed in the following part of this section.

As the three images of land sat were used and 15 km of the area was buffered for the ease in the analysis. The data limitations were present in the image resources as all the images were differing in resolution and along with the band data issues.

By the visual comparison of the images it was revealed that the spot, the land sat and the quick bird images seem to provide adequate margin to work with. By doing the analysis on them for delineation of water logging and salinity one can at least get some reasonable results out of them. The image from MODIS Terra can be excluded as odd one out since the spectral features are not even sufficient to identify the prominent area and obtaining the desired level of results by analyzing this image concerning saline areas will be of no good use.

Image Classification

Landuse and Landcover Classes by Vectorization

The quantify the land cover attributes of the area of study the classification was done initially with the help of the digitization of different major land cover features which are given below in the Table **1**.

Table 1: Landuse and Landcover Classes

S. No.	LANDCOVER CLASSES	AREA (Km^2)
1	BARREN LAND	119.0031358
2	SALINE AREA	118.9738154
3	SETTLEMENT	105.7180102
4	CANAL	105.5276187
5	AGRICULTURAL AREA	103.5304701
6	VEGETATION	68.02618984
7	RIVER	39.13186779
8	STREAM	28.71932677
9	SALINE AND WATERLOGGED AREA	27.99314633
10	MOHENJO DARO	1.39346282
11	AIRPORT	0.169050679
12	INLAND WATER BODY	0.376028666
13	WATERLOGGED AREA	0.252646017

The land cover and land use classes provide a general idea of the area. The statistics show that the saline area has covered the area almost equal to the other important classes like Barren land, Settlement, Canal, Agricultural area etc. being an unwanted attribute, these statistics may be considered as an alarming situation for the area. With current domestic practices and lack of awareness and proper drainage, these numbers seem to have a tendency to increase (Figure **3**).

As we can see in the image the ruins are surrounded by the saline areas and this salinity causing the deterioration in the different parts of the Mohenjo-Daro ruins and the infrastructure including public park and the Museum and administrative buildings. As we can see that salinity is also present in areas where many roads are situated causing deterioration to the roads and reducing their life span (Figure **4**).

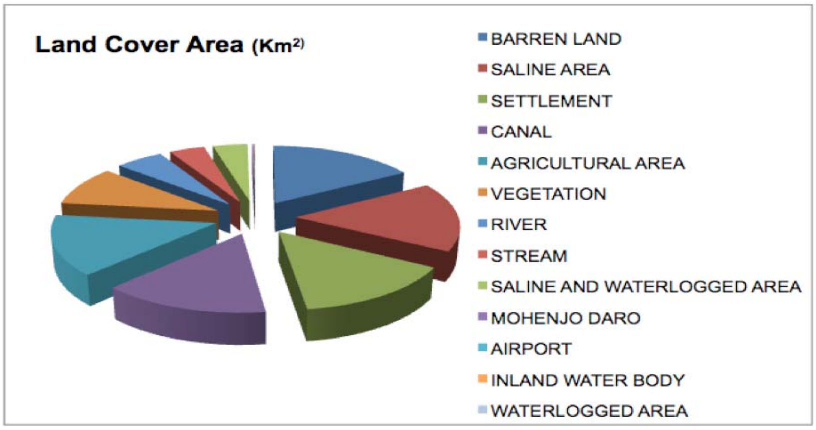

Figure 3:

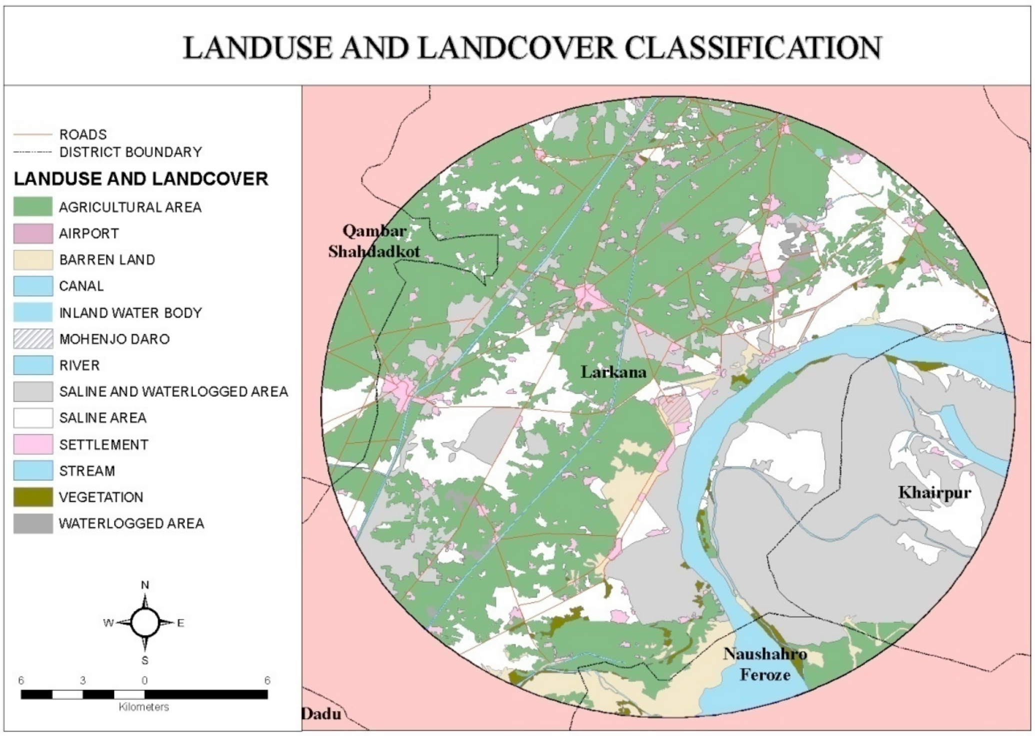

Figure 4: Landuse and Landcover Classes.

Unsupervised Landuse and Landcover Classes using Raster Images

Classification of saline areas performed on the land sat images of 1992, 2000 and 2013 were compared to match the results. Results showed the increase in salinity area in 2013 as compared to the results of 1992 image. The introduction of the new water channels in the area has increased the cultivable area decreasing the barren or empty land percentage but due the lack of drainage facilities which should be made available simultaneously, the increase in salinity took place significantly (Table **2**).

It can be observed easily the variations of different attributes from the graphical representation shown above in which the we can see that agricultural areas has decreased in 2013 image as compared to the image of 2000. We can see the increase in water logging as compared to the statistics from the 1992. The improved supply of irrigation water and other factors may have increased the productivity but on the other hand because of the ill practices of irrigation and the inadequate drainage caused the increase in water logging and salinity. The barren land was also decreased as the irrigation increased in 2003 but an overall statistic of the combination of barren land,

Table 2: Land Use Land Cover Classes

S. No.	LANDUSE and LANDCOVER CLASSES	AREA (Km^2)		
		1992	2000	2013
1	SALINE AND WATERLOGGED	540.3255852	-	1096.528858
2	AGRICULTURAL AREAS	1021.996785	1682.294223	1472.306805
3	WATER	152.4184239	206.0670451	80.22633359
4	BARREN LAND	1699.930498	1427.77692	399.5917788
5	SALINE AREA	419.388039	517.9211434	435.3494264
6	WATERLOGGED AREA	-	-	350.0561285

saline land, and the waterlogged and saline land is exceeding the agricultural areas pointing towards inefficiency of the irrigation system. As far as the freshwater is concerned, it flows into the channels so we are having the area of the freshwater lesser than the area of the saline water which is usually spread out over large areas.

As we can see in the above images that the extent of saline areas is shown according the values given in the statistical charts and as we can see through the image that the area near the river is highly saline but salinity can be seen quite away from the river as well and we can also find the water logged patches there which shows that some catchment areas are present on the basis of gradient of the earth causing water logging due to high water table level and ultimately leading towards different levels of salinity based on surrounded soil and environmental condition (Figures **5**, **6** and **7**).

Supervised Landuse and Landcover Classes

As far as the supervised classification is concerned in order to point out the salinity, three main classes were made to identify the extent of the relevant type. The figure shows the slightly and moderately saline areas have covered the buffer area in majority where as large patches of strongly saline areas can also be seen near river as well as also in the catchment areas away from the river. This image shows some green areas which are heavily surrounded by the saline soils

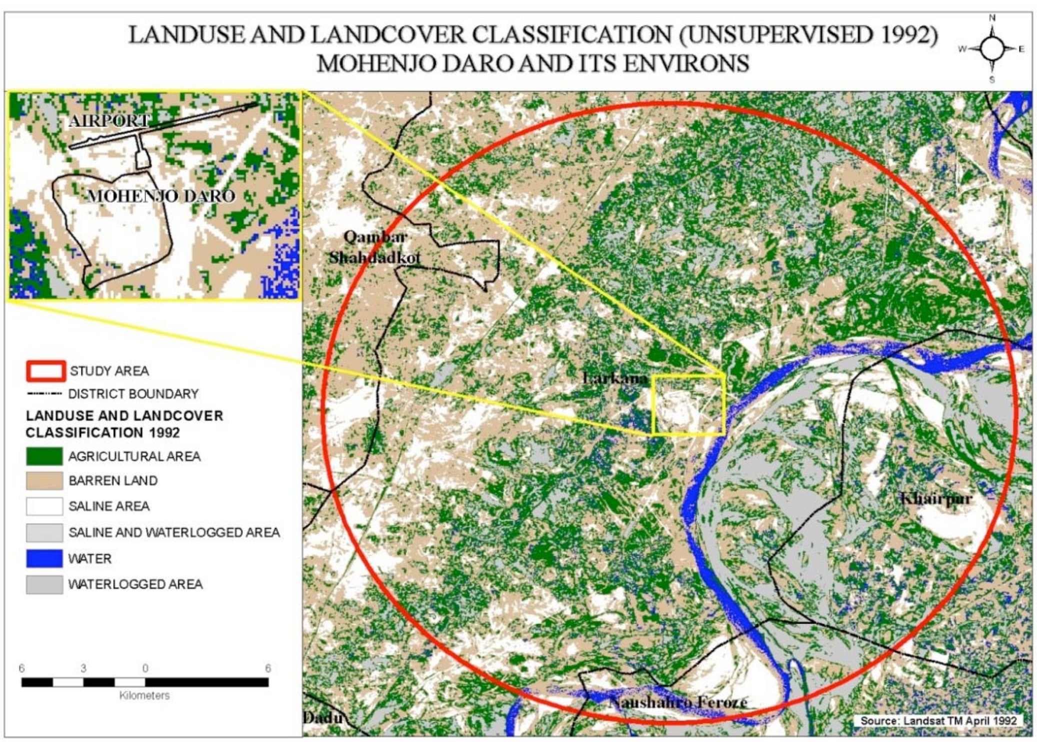

Figure 5: Mohenjo-Daro and its Environs Landuse and Landcover Classes 1992.

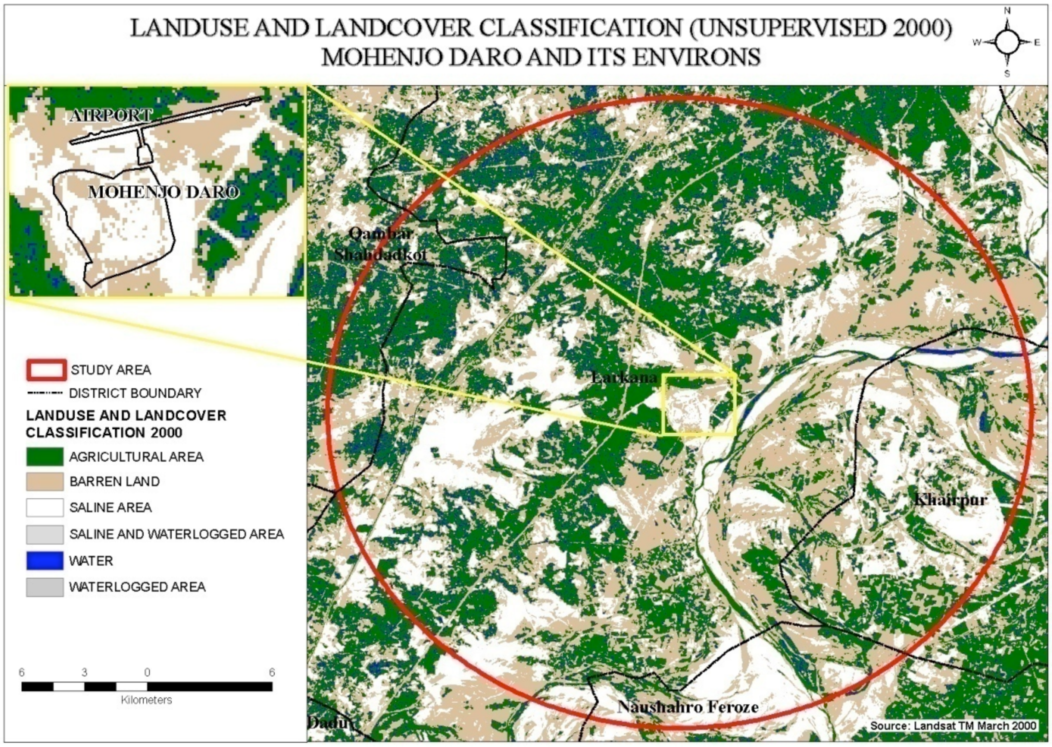

Figure 6: Mohenjo -Daro and its Environs Landuse and Landcover Classes 2000.

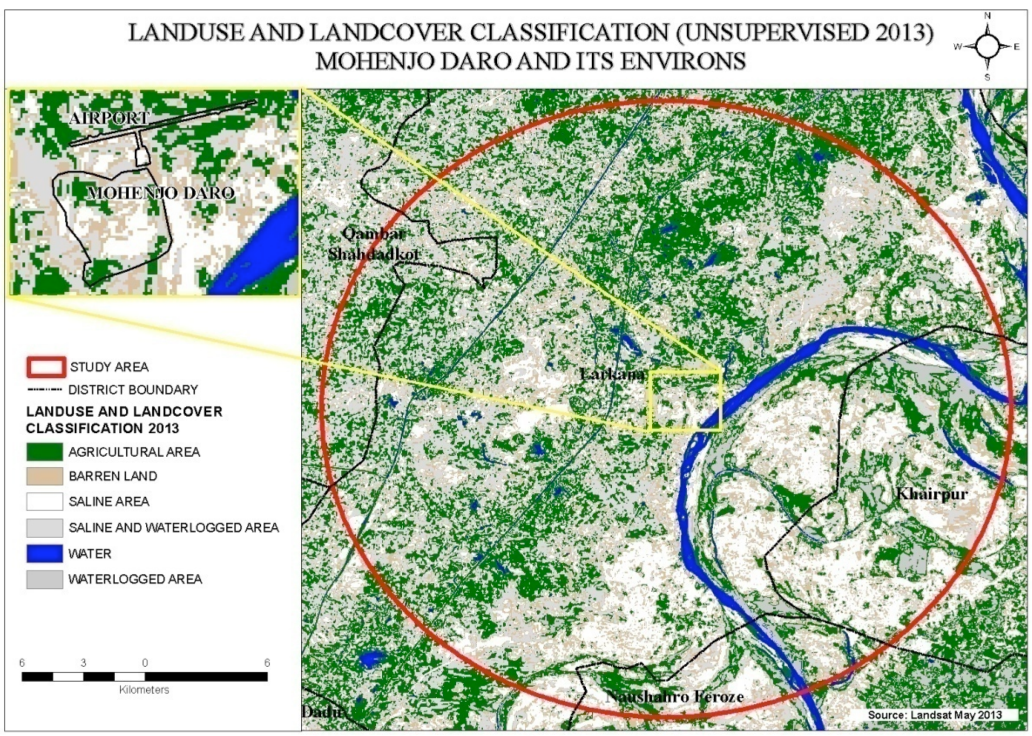

Figure 7: Mohenjo -Daro and its Environs Landuse and Landcover Classes.

and waterlogged areas. The ambiguity might be seen in slightly saline, non-saline and vegetation or agricultural areas. The results show that targeting slightly saline areas may be difficult even using the supervised classification. It is to be noted that for planning and estimation purposes, info of highly and moderately saline areas usually considered as quite sufficient (Figure **8**).

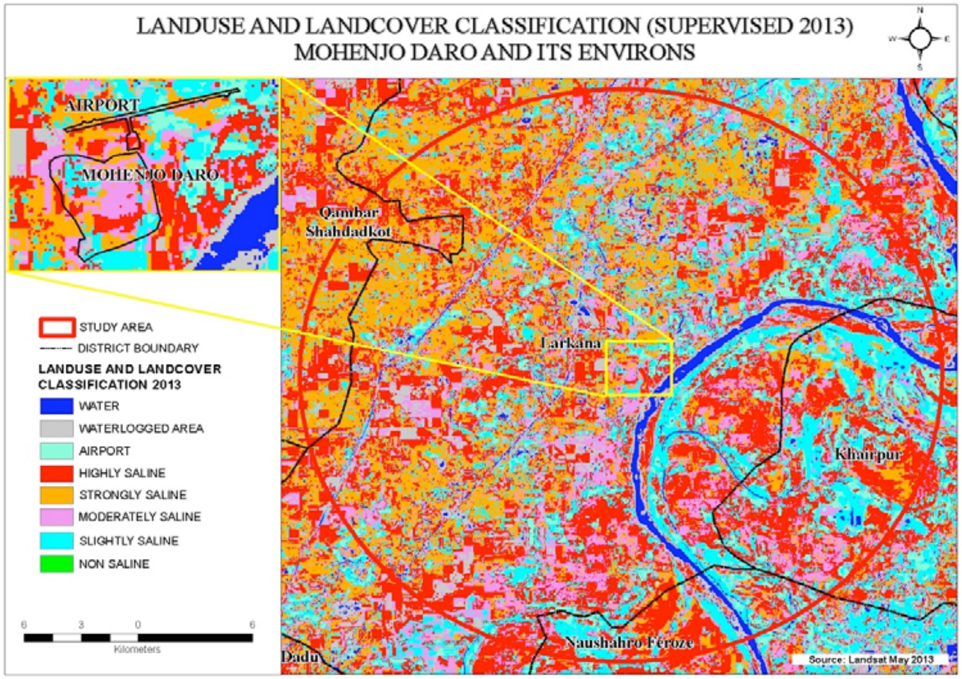

Figure 8: Supervised Landuse and Landcover Classes.

Normalize Difference Vegitation Index (NDVI)

Since the Normalized Difference Vegetation Index (NDVI) is one of the most extensively and widely used indexes for the purpose of analyzing the vegetation area and it also helps detecting changes in vegetation by using satellite images (Figures **9**, **10** and **11**) and (Table **3**).

NDVI can be defined as

NDVI = (Near InfraRed – Red) / (Near InfraRed + Red)

The working logic of the index is, vegetation absorbs red light in quite well manner, in fact red light is the main element which is responsible for driving photosynthesis phenomenon. In presence of infrared

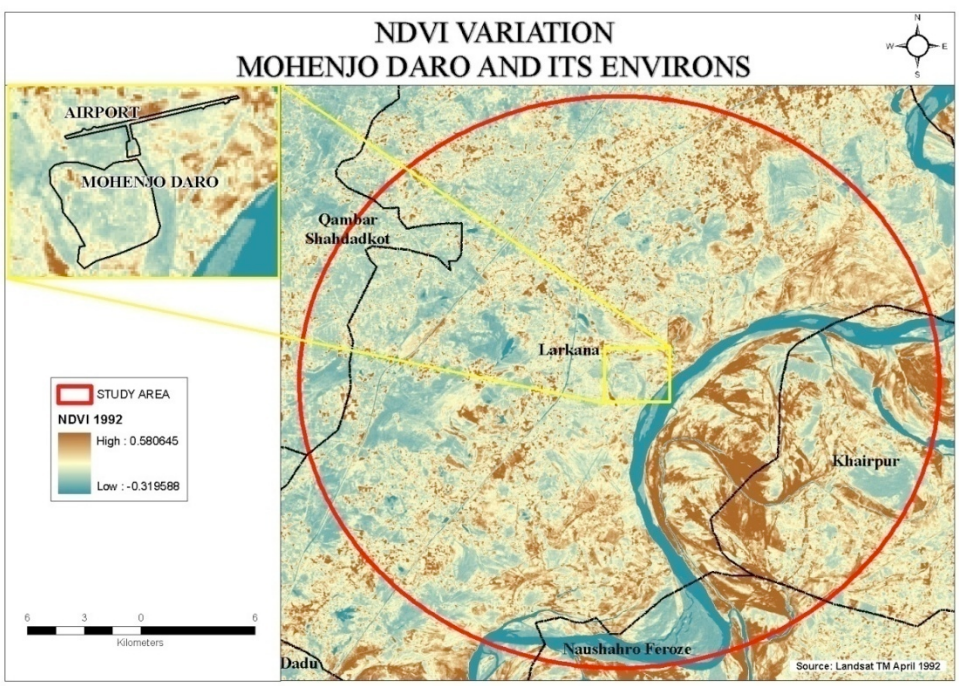

Figure 9: NDVI 1992.

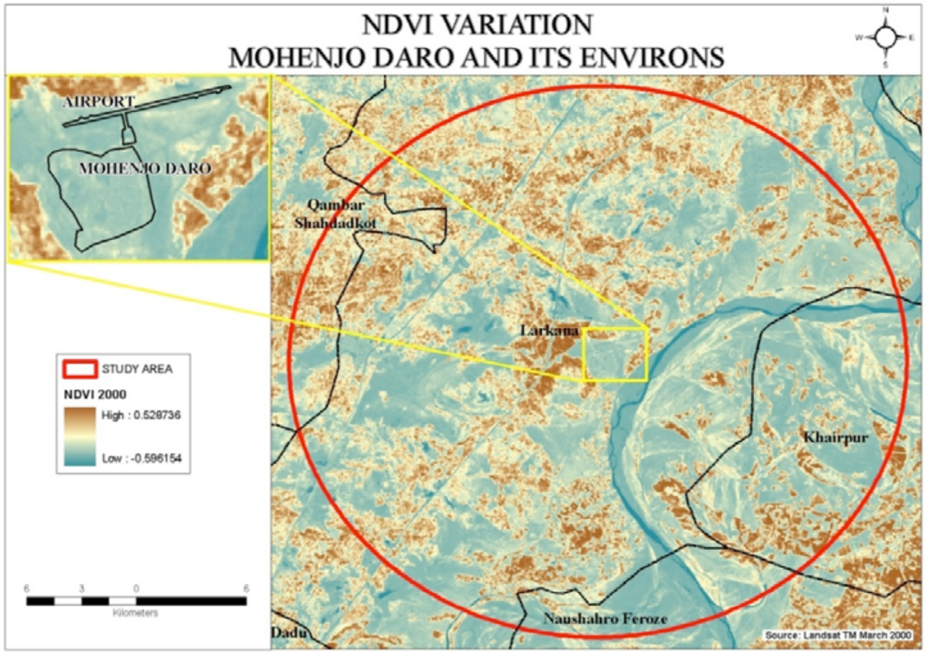

Figure 10: NDVI 2000.

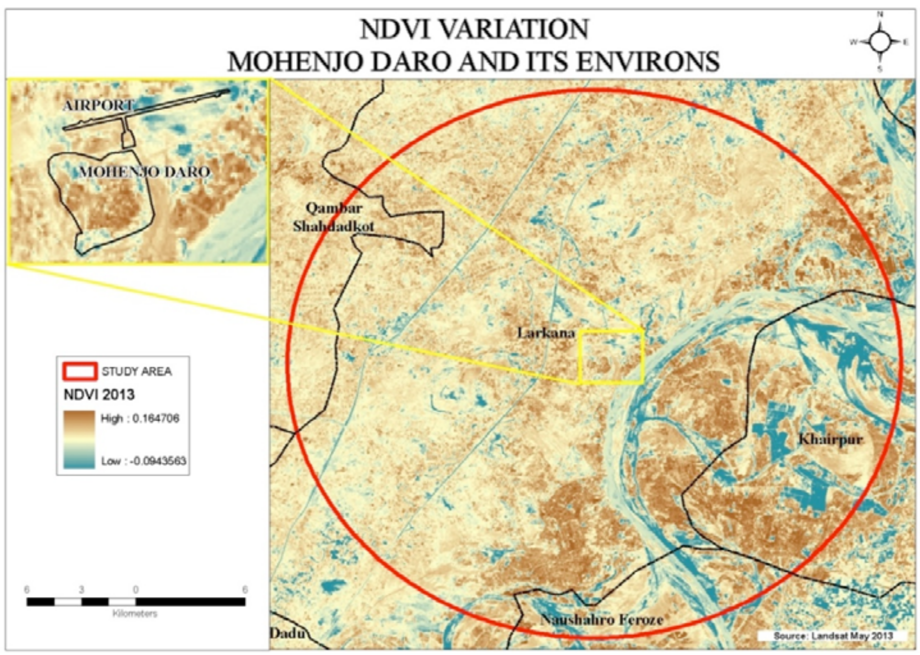

Figure 11: NDVI 2013.

Table 3: NDVI Aiport

	1992	2000	2013
Count:	8140	8140	8140
Min	: -0.19008264	-0.393442631	-0.034990486
Max:	0.329032272	0.3928571341	Max: 0.078853771
Sum:	-336.0030954	-1178.874859	
Mean:	0.041278022	-0.144824921	0.036362101
Standard Deviatian:	0.07020037	0.182821041	0.15193068

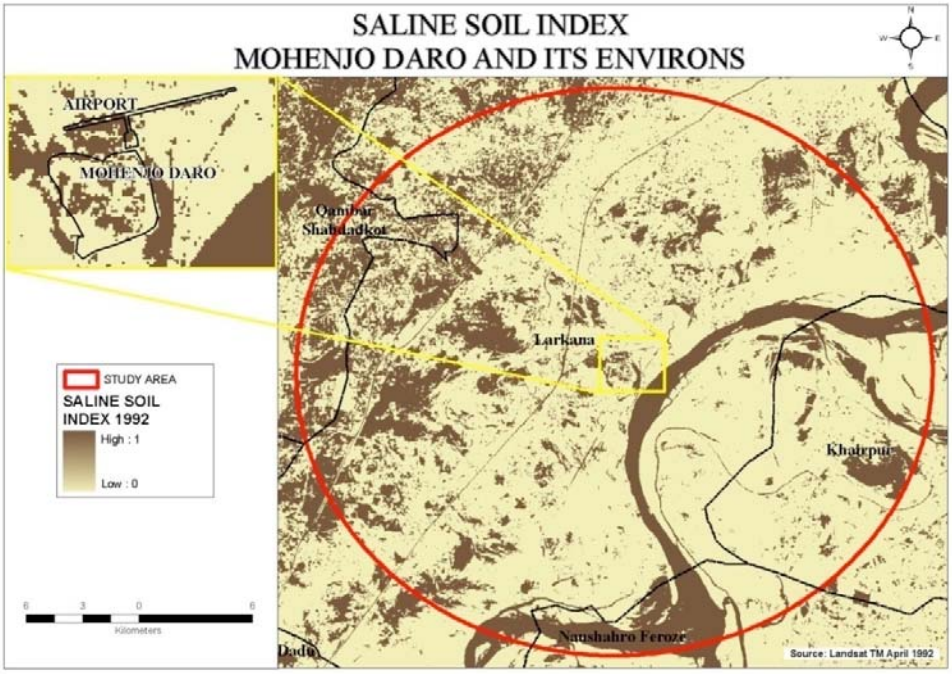

Figure 12: Saline Soil Index (SI) 1992.

light the energy is lower and cannot be harnessed by plants for undergoing the photosynthesis phenomenon, this it is reflecte. The difference of ratio between absorption and reflection of red and infrared light works for mapping vegetation [7].

The results of NDVI and the ones we got from image classification were quite similar to each other the vegetation can be seen increased in 2013 after falling according to the results of the image by 2000. This could be observed in the window of airport area in the layouts of indices.

Saline Index or Saline Soil Index (SI)

As we know from NDVI that band 3 (red band) provides the best separation for vegetation, while band

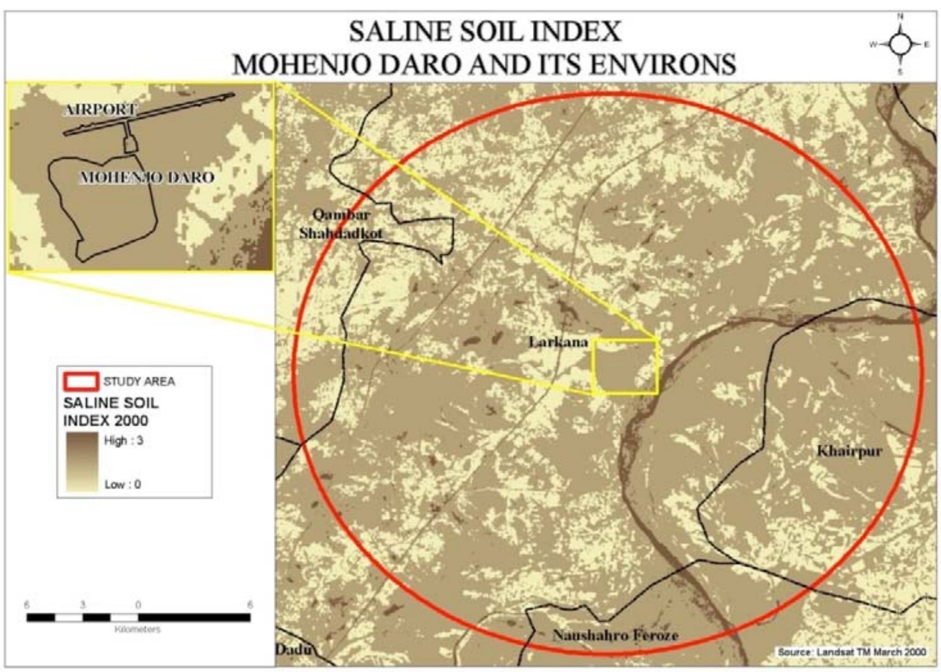

Figure 13: Saline Soil Index (SI) 2000.

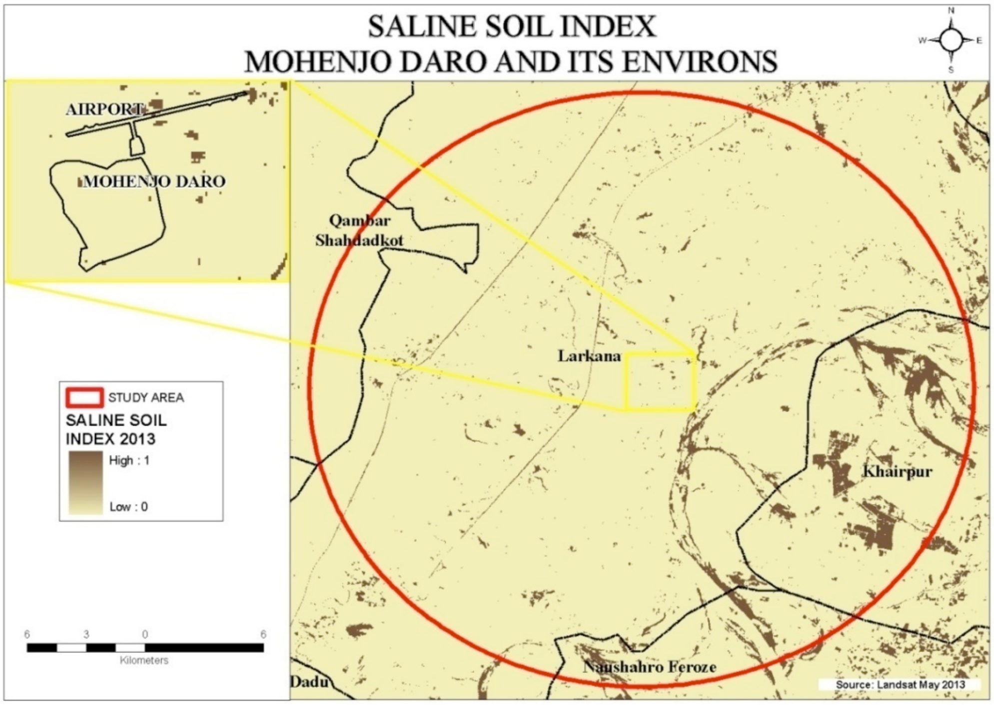

Figure 14: Saline Soil Index (SI) 2013.

Table 4: SI Airport Clip

	2013	2000	1992
Count:	38713106	38854121	38721740
Minimum:	0	0	0
Maximum	1	228	12
Sum:	3,082,579	31,851,606	18,803,168
Mean:	0.079626238	0.819774201	0.485597187
Standard Deviation:	0.270713691	0.524936421	0.499813087

4 (near infrared band) provides the besant separation for the area with salt, while water is distinct in all the bands (Figures **12-14**, Table, **4**).

$$SI = \frac{(Band3)}{(Band4)}$$

The results can be compared under the buffer area of 15 Km.

Interpolation

The results of EC and pH were transformed over maps using the Inverse Distance Weights (IDW) technique and spline technique. Range of EC and pH were applied to see the quality of the soil and the salinity degrees i.e. non-saline, slightly, moderately or highly saline areas. These maps are shown for EC in pH in which we can see that the area near the river and near the Ruins of Mohenjo Daro are mostly moderately to highly saline and we can see some large patches of slightly saline as well it was so difficult in classification to exactly pick the slightly saline signatures since behaviour gets changes with the soil type and soil colour but with the help of interpolation techniques using the field samples results an estimation of the behaviour of the areas can be obtained which gives an idea of overall distribution of EC and pH of the area. This distribution excludes every other attribute and gives an estimate about the salinity behaviour present in the area (Figures **15**, **16**).

The statues of the ground and satellite imageries results were analyzed to verify the results of the interpolation from IDW and Spline. The results were similar for most of the prominent salinity areas in all the sources and an approximately more than 50 percent of

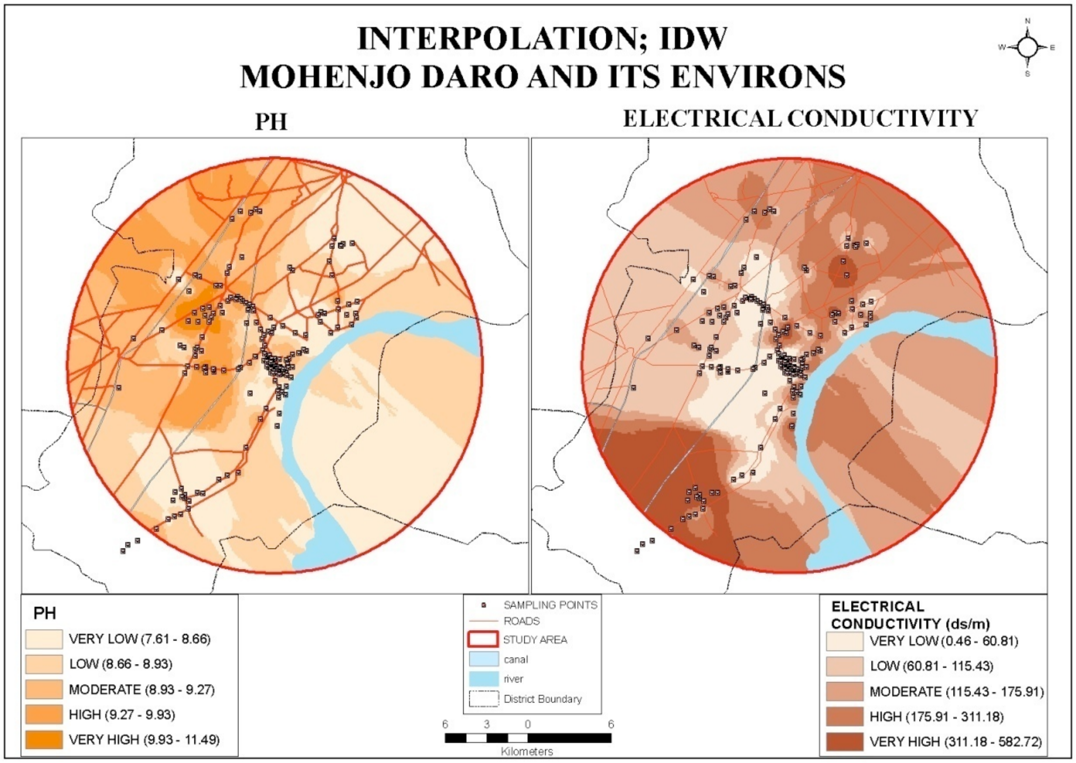

Figure 15: Interpolation using IDW.

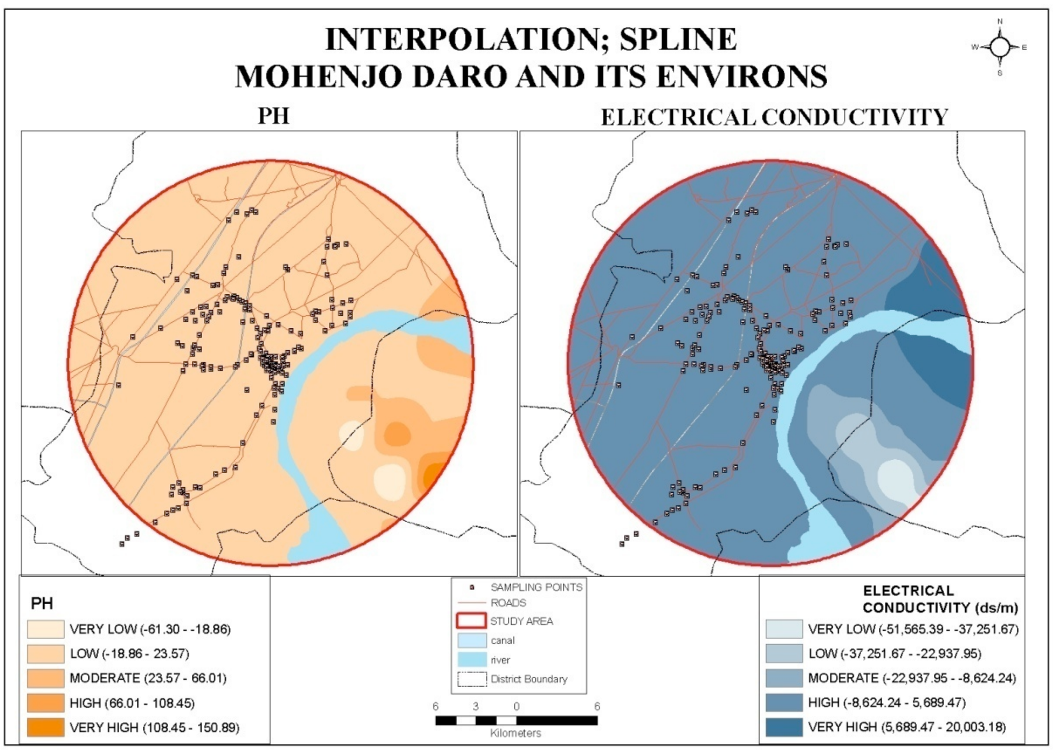

Figure 16: Interpolation using SPLINE.

the area was showing the similarities of saline areas. If the results were not adequately similar with the results of the satellite image analysis then different interpolation techniques could have been applied to have the best method according to the results and field conditions (Figure **17**).

Figure 17: Field photograph.

CONCLUSION AND RECOMMENDATIONS

All the descriptions discussions and investigations using different types of data have led us to the conclusion that salt is undeniably a natural substance present in our landscape. And this problem is not only harmful for the agricultural activities but also throws the challenges for engineers, infrastructure planners and designers, different government agencies and the communities living in the salt affected areas. Collective community efforts are required to adopt such habits which can abate salinity impacts.

A good framework for addressing and managing salinity can only be achieved by having the knowledge of how salinity occurs, how it looks like in different conditions, and what are the empirical ways to handle it. While planning for the new developments, planners and managers will be better prepared for handling the land and infrastructure currently affected by salinity and also will be able to control the increasing cost which will come over maintenance of the proposed structures by incorporating appropriate measures during developments in the salinity control areas.

The results produced from the executed methodology related to the salinity issues shows that the satellite technology has the capability of estimating and identifying the salinity over large areas and use of such information can be used to recover the losses occurred to agricultural land as well as it can help salvaging the existing infrastructure and provide reliable platform for taking appropriate decisions for needed for future developments.

The output of the applied methods over different satellite images shows that using the greater resolution images can provide a better depiction of the salinity as there were problems being faced to select the signature classes of the slightly saline areas and also there were problems with the classes of water which were being merged with the land and the water logged areas because of the reflection of the water and land in sunlight or due to other soil water factors.

The comparison of the results with the SI and NDVI indices can provide a good validation of the statistics of the area.

It doesn’t matter that an approach is simple, as far as it is quite practical. An approach having RS data as its base along with the use of the salient GIS techniques can be a promising procedure with reasonably good output even with low resources have a potential in delineating the waterlogging and salinity and other land degradation problems. The frequency of the salinity exercise using this particular technology should be managed according to the results obtained. The periodic monitoring in combination with random monitoring may help reveal the hidden pattern and occurrence of this issue which may help save the cost for maintenance to plan for the development of the proposed infrastructure within the affected areas.

The waterlogging and salinity will continue to be a problem if the irrigation practices are not coped up with the drainage facilities. Improvements in irrigation practice and drainage facilities are essential for the sustainability of the agriculture based activities.

Since Salinity occurs in patches and there is no single way which exactly defines salinity different procedures can be adopted according to the time and resource limitations.

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