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Determination for automated land-use / land cover change detection of Keti Bunder, Indus Delta, Pakistan, by using satellite remote sensing techniques

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Abstract

The Land use/Land cover (LULC) has a substantial role in planning and monitoring natural resource utilization, in the framework of the ongoing surge in human demands in the current ecosystem. Satellite remote sensing provides modern methods for locating and mapping Land use/Land cover patterns and their spatial changes. This paper discusses the evaluation of the LULC classes characteristic of Keti Bunder during the years 2015 and 2020, by using satellite remote sensing; the paper also uses Geo-informatics to study and investigate the temporal LULC variations that occurred over time. According to the empirical findings, there have been significant spatial changes, with less dry mudflats and unoccupied land overall. In comparison, the findings of the research point to inter-conversion of the area between LULC classes, i.e. mangrove areas, turbid water, wet mudflat, dry mudflat and barren land/vacant land. Overall, these geographical alterations show that the environment has been significantly impacted due to recent extreme weather events in the region.
Keywords: *GIS, satellite remote sensing, environment, mangrove, ecology*

Introduction

Studies on the patterns of land use and land cover have made extensive use of Satellite Remote Sensing technology. It is essential for locating and measuring various physical characteristics on the planet's surface. Digital mapping with Geomatics enables the collection of recurring data over a predetermined period, has a digital format that can be processed by computers, and has locational precision (Jensen, 1996; Rehman et al., 2016). Satellite Remote Sensing (SRS) offers several spectral and synoptic evaluations. It is also useful for observing coastal changes and land degradation, as well as sea tides, wave currents, shallow water, suspended materials, mudflats, wetlands, mangroves, vegetation, and land degradation (SCCDP, 2013; Rehman & Kazmi, 2018).

To observe environmental changes, Satellite Remote Sensing (SRS) and Geographic Information System (GIS) technology offer a set of potent tools that allow us to perform spatial analysis using both spatial and non-spatial information (Osei et al., 2006; Ibrahim, 2008; Tariq et al., 2020). These tools are used in environmental monitoring studies, notably for mapping the spatial distribution of biophysical restrictions on the surfaces that significantly affect climate (Henderson, 1999). SRS and GIS technologies are now widely used. Comprehensive monitoring of LULC changes is provided by SRS in conjunction with GIS and GPS. In Satellite Remote Sensing, comparing two or more satellite pictures is a typical practice to find LULC changes.

Change detection commonly uses pixel-to-pixel comparison and post-classification comparison (Nelson et al., 1983; Martin, 1989; Green et al., 1994; Raza et al., 2020). The first method (pixel-by-pixel) combines satellite images taken at various times and dates. Image classification is not involved. In these studies, the pixel-to-pixel comparison is typically used. In the post-classification detection technique, two or more classed satellite images from various times and dates are examined (Pylon, 1988; Fung & Zhang, 1989; Johnson & Howarth, 1989; Frihy et al., 1998).

This approach is the most widely used and it is regarded as one of the most effective approaches to identify LULC alterations (Jensen et al., 1993; Dewidar K. M., 2004). Human activities that have an impact on a specific area of land can be linked to changes in land cover, whereas changes in land usage are directly impacted by changes in land cover (Jensen, 2007; Abbas, 2012; Jackson & Attia, 2013). The changes in LULC are related to various environmental and landscape characteristics of the land surface, such as the land, water quality, and air resources, as well as the living conditions, method, practices, and functions (Jackson & Attia, 2013).

Keti Bunder is situated in the deltaic zone of the Indus River, at about 200 km southeast of the port city of Karachi, Sindh. Administratively, Keti Bunder is a taluka (tehsil) of the Thatta district, it is spread over 60,969 hectares and consists of 42 *dehs* (clusters of villages). Historically, Keti Bunder was the main port city of this part of the world, connecting the Indus Valley with international sea trade routes before the dams and barrages were constructed over the Indus River, which caused the insufficient discharge of the Indus waters into the sea (delta zone).

This area has four major creeks, i.e. the Chann, the Hajamro, the Khobar, and the Kangri, as well as numerous small creeks. This area has been exposed to sea intrusion, which has caused severe environmental degradation and loss of livelihood opportunities for the locals. WWF mentioned that the sea has engulfed around 46,137 hectares in 28 *dehs* of Keti Bunder (WWF Pakistan, 2004). The progressive seawater intrusion and freshwater scarcity in the rivers of these lands have caused resettlements and migration flows in the study area, where the smaller villages had to shift their location more than once in the last 70 years because of the increased salinity in their agricultural land. The study region for this research is Keti Bunder, Sindh (Figure 1).

For many decades, in the Indus Delta region, the mangrove ecosystem has been adversely affected by the acute freshwater scarcity downstream of the last barrage on the Indus River and by water diversion for inland agriculture in upstream areas, as well as by coastal urbanization, population increase and industrialization and pollution. Overall, out of eight mangrove species previously found in the Indus Delta, four have been completely depleted; currently, three of the remaining four are on the verge of extinction (*Rhizophora mucronata* 8%, *Aegiceras corniculatum* 1.5% and *Ceriops tagal* 0.5%), whereas *Avicennia* covers 90% of mangroves in this region (Figure 1).

The main objectives of the paper are the following:

1. to extract the Keti Bunder land use/land cover classification for the years 2015 and 2020, by using Satellite Remote Sensing;
2. to explore temporal land-use / land cover (LULC) changes of Keti Bunder between 2015 and 2020, by using Geo-informatics;
3. to investigate the LULC classes in relation to ground realities.

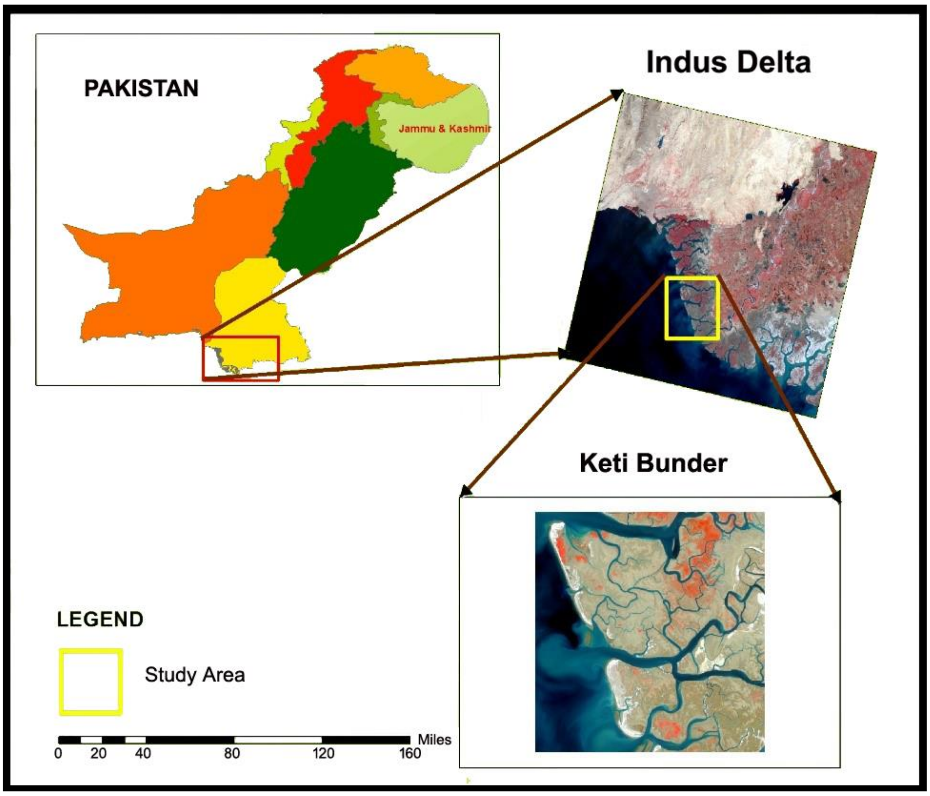

Figure 1: Location of the study area

Data and methods

Data

This study particularly attempts to identify and interpret the land use/land cover changes over five years (2015 - 2020 period) through satellite remote sensing and ground-truthing. The methodological framework is shown in Figure 2. For this, Landsat-8 OLI/TIRS datasets of 21-11-2015 and 18-11-2020 were extracted from the online archives of USGS Earth Explorer, which covers the study area (path 152 and row 043). There are nine (1-9) spectral bands with 30 m spatial resolution in the Landsat-8 OLI dataset, while Landsat-8 TIRS dataset has two spectral bands (10 and 11), with 100 m spatial resolution.

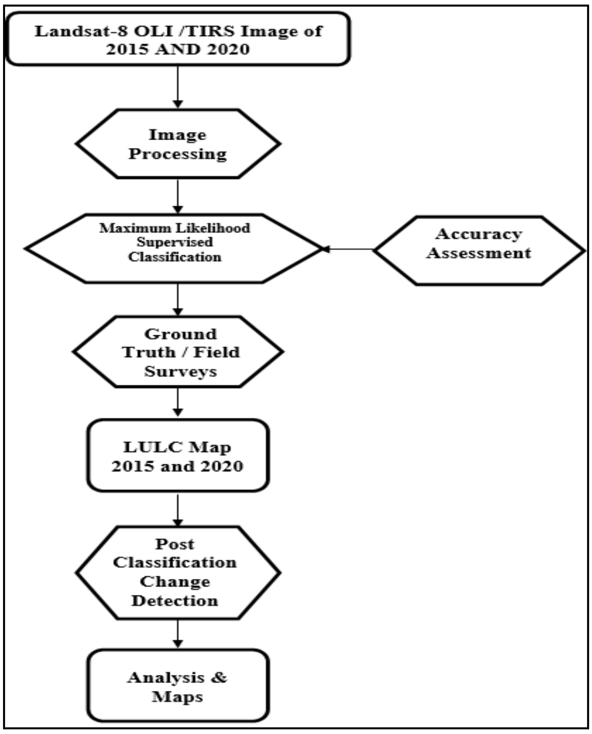

Figure 2: Methodological framework

Techniques and analysis

Maximum likelihood classification

In satellite image classification, there are three main classification techniques: supervised classification, unsupervised classification, and object-based image classification. The supervised classification was chosen for this study, where particularly the Maximum Likelihood Classifier (MLC) algorithm was used. This approach has been widely applied by many scholars for the classification of medium-resolution satellite datasets (Ratnaparkhi et al., 2016; Zaidi et al., 2017; Zubair & Javed, 2018).

Based on the visual interpretation of land use features on the satellite image and Google Earth, the sample polygons were marked as training areas. Based on their spectral signature, seven major LULC classes were delineated, namely dense mangrove, sparse mangrove, barren/vacant land, wet and dry mudflat, deep water and turbid water. The maximum likelihood of unknown pixels in each class would be computed and assigned to these seven main land use classes.

Accuracy assessment

The satellite image classification process is followed by accuracy assessment, which evaluates to what degree the ground features are truly classified to the corresponding LULC class (Foody, 2002). The ERDAS imagine software and its toolset, i.e. the accuracy assessment tool of the supervised classifier, have been used to perform this procedure. Using stratified random sampling approach, random reference points were generated (i.e. 187 in 2015 and 294 in 2020). The associated class of the point on the classified image was matched with the visually interpreted point on Google Earth. The kappa statistics and error matrix for both 2015 and 2020 classified images were generated from ERDAS Imagine. In the error matrix, the rows denote the points where the pixels are classified to certain LULC classes and the columns show the LULC classes recognized by the user from the referenced data.

The diagonal cells show the correctly recognized pixels for each land use class of classified and reference data. The pixels incorrectly designated to the right LULC class do not occur in diagonal and indicate inaccuracy between reference and classified data.

Ground survey

Field surveys were conducted to assess the socio-economic conditions of the selected area through interviews; this went along with the GPS survey of ground features for image classification.

Change detection

Because of its cost-effectiveness and accessibility of high temporal resolution, RS and GIS-based change detection methods are widely used across the Globe.

Some researchers have used the post-classification comparison technique, employing maximum likelihood supervised classification, with overall greater classification accuracy (Torahi & Rai, 2011; Muttitanon & Tripathi, 2005).

The classification of satellite images and the comparison of the related individual classes allow for the spatial identification of the locations where the change occurred.

Results and discussion

Kappa coefficient and overall accuracy for the 2015 and 2020 images

The accuracy assessment was performed for the LULC classification maps of 2015 and 2020. In the case of the 2015 LULC map, 187 points were randomly selected. The overall kappa statistics value for the 2015 LULC map was found at 0.9280, whereas the overall accuracy was computed at 90.67% (Table 1). The producer's accuracy for each LULC class was found to be equal to or higher than 85.75% and the user's accuracy for each LULC class was observed to be equal to or higher than 76.42%.

In the case of the 2020 LULC classification, there were selected 294 random points. The overall kappa statistics and LULC classification accuracy were found to be 0.9670 and 96.82%, respectively (Table 2). The producer's accuracy of all individual LULC classes was higher than 92%. The user's accuracy of all LULC classes was more than 90%, except for the dense mangrove (87.50%).

Overall, in both LULC classification maps, the accuracy of each LULC class was found to be satisfactory. The general accuracy results and kappa coefficient for the LULC classification maps of 2015 and 2020 are presented in Tables 1 and 2, respectively.

Table 1. The accuracy assessment of classified image 21-11-2015

S. no.	LULC Class Name	Producers Accuracy (%)	Users Accuracy (%)	Kappa Atatistics
1	Dense mangrove	99.20	99.54	0.9017
2	Sparse mangrove	93.71	88.00	0.7378
3	Wet mudflat	87.50	100.00	1
4	Dry mudflat	100.00	82.61	0.8009
5	Barren/Vacant Land	85.75	76.42	0.8504
6	Turbid water	100.00	100.00	1
7	Deepwater	94.00	98.15	0.8352
Overall Classification Accuracy = 90.67%. Overall Kappa Statistics = 0.9280				

Table 2. The accuracy assessment of classified image 18-11-2020

S. no.	LULC Class Name	Producers Accuracy (%)	Users Accuracy (%)	Kappa Statistics
1	Dense mangrove	100.00	87.50	0.8689
2	Sparse mangrove	100.00	100.00	1
3	Wet mudflat	92.31	92.31	0.9069
4	Dry mudflat	96.43	90.00	0.877
5	Barren/Vacant Land	100.00	100.00	1
6	Turbid water	100.00	100.00	1
7	Deepwater	100.00	94.74	0.9402
Overall Classification Accuracy = 96.82%. Overall Kappa Statistics = 0.9670				

Land use/land cover classification

Land use/land cover pattern of Keti Bunder in 2015

The LULC classification map of 2015 generated from the Landsat-8 data set is depicted in Figure 3. The largest category was found to be the turbid water, which covered 14,265.7 ha (as shown in Figure 4) (31.19% of the total area), whereas the deep water accounted for 2,417.31 ha (5.28%), and the wet mudflat for 12,631.2 ha (27.61%). The sparse mangrove accounted for 5,324.76 ha (11.64%) and the area under dense mangroves covered 197.55 ha (0.43%).

On the other hand, the barren land/vacant land covered 6,508.8 ha (14.23%) and the dry mudflats, including Goths and villages, accounted for 4,398.84 ha (9.62%).

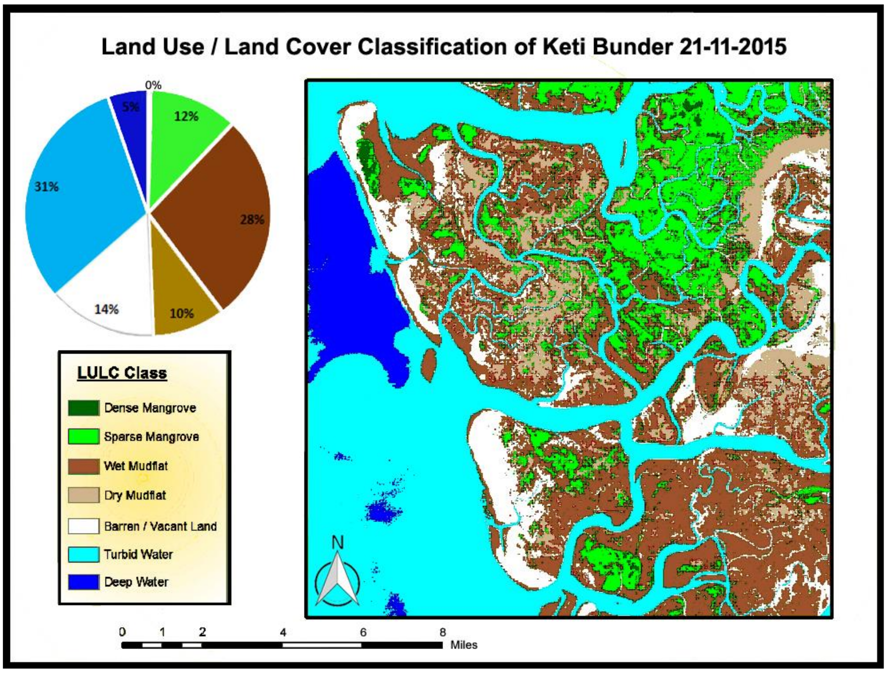

Figure 3: LULC map of the study area in 2015

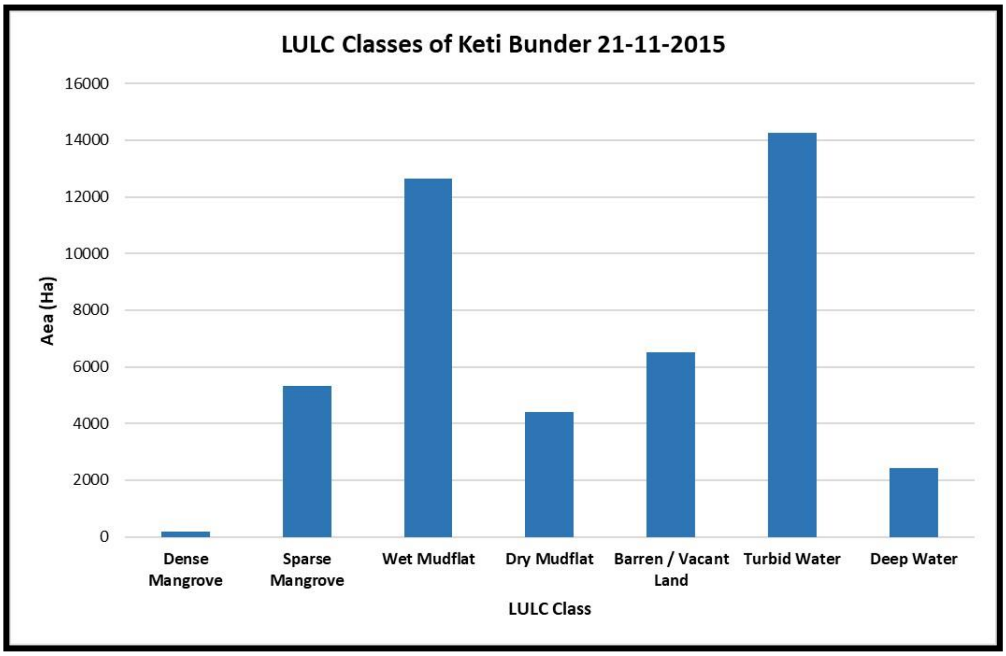

Figure 4: LULC characteristics of Keti Bunder in 2015

Land use/land cover pattern of Keti Bunder in 2020

According to the 2020 LULC classification dataset (Figure 5), the turbid water accounted for 21,044.20 ha (as shown in Figure 6), i.e. 46% of the study area, the deep water covered over 3,860.01 ha (8.44%), while the area under wet mudflat accounted for 487.80 ha (1.07%).

The sparse mangroves covered 12,113.10 ha (26.48%), while the dense mangroves covered 335.61 ha (0.73%). In the same year, the dry mudflat covered 7,210.80 ha (15.76%) and the barren/vacant land accounted for 692.73 ha (1.51%).

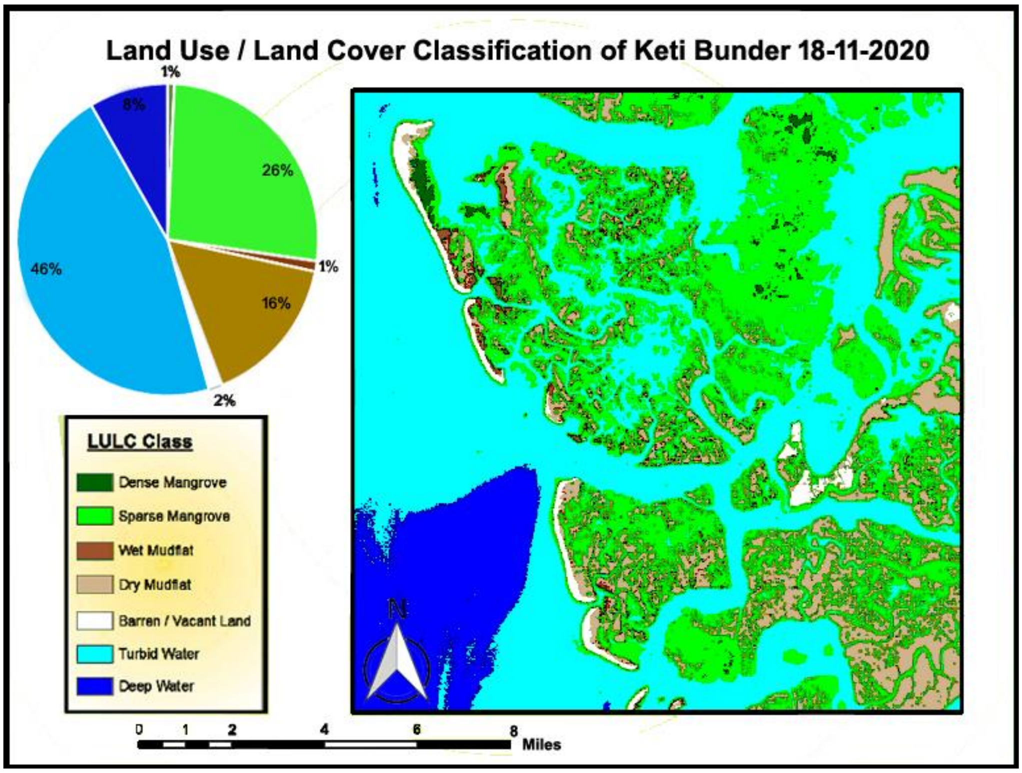

Figure 5: LULC map of the study area in 2020

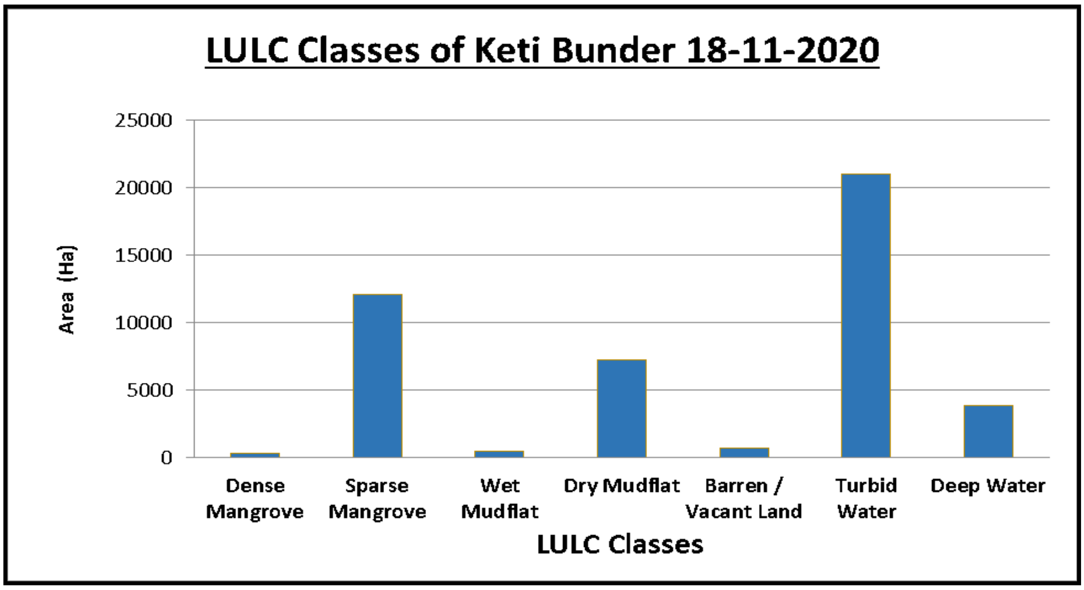

Figure 6: LULC characteristics of Keti Bunder in 2020

LULC classification comparative analysis and change detection between 2015 and 2020

The area under the LULC classes and its changes between 2015 and 2020 are presented in Table 3, Figure 7, and Figure 8. During these five years, significant changes were observed among the LULC classes within the area under study. The wet mudflat and the barren/vacant land use categories revealed a considerable decrease in their covered area, while the mangroves (dense and sparse) and the water bodies, particularly the turbid water category, exhibited an increase.

Dense mangrove

The area under dense mangroves increased from 197.55 ha in 2015 to 335.61 ha in 2020, representing a net increase of 138.06 ha (shown in Table 3, Figure 7, and Figure 8). Figure 8 shows that the dense mangrove converted to sparse mangrove represents about 61 ha (0.13%). At the same time, the dense mangrove area that shifted to barren/vacant land represented about one ha (0.01%). Some dense mangrove was converted to dry mudflat.

Sparse mangrove

The area under sparse mangroves increased from 5,324.76 ha in 2015 to 12,113.1 ha in 2020, which represents a net increase of 6,788.34 ha (shown in Table 3, Figure 6, and Figure 7). Figure 8 and Figure 9 show the sparse mangrove area conversion to other LULC classes. About 72 ha (0.16%) were converted to dense mangroves, 23 ha (0.05%) to wet mudflat, 778 ha (1.70%) to turbid water, 107 ha (0.23%) to dry mudflat, while about 5 ha (0.01%) shifted to barren/vacant land.

Wet mudflat

The area under the wet mudflat decreased significantly about 12,143.40 ha, from 12,631.20 ha (in 2015) to 487.8 ha (in 2020) (Table 3, Figure 8, and Figure 9). It is important to mention the conversion of wet mudflats to certain other LULC categories, i.e. about 7,392 ha (16.16%) to turbid water, 4,408 ha (9.64%) to sparse mangroves, 599 ha (1.31%) to dry mudflat, while some 5 ha (0.01%) of wet mudflats shifted to barren/vacant land.

Dry mudflat

The area under dry mudflat increased significantly, namely with circa 2,811.96 ha, from 4,398.84 ha (in 2015) to 7,210.80 ha (in 2020). Figure 9 shows the conversion of dry mudflat into other LULC classes. About 2,686 ha (5.87%) of dry mudflat were converted to wet mudflat, 1411 ha (3.08%) to sparse mangroves, and 58 ha (0.13%) to wet mudflat.

Barren/Vacant land

The area under barren/vacant land decreased from 6,508.80 ha in 2015 to 692.73 ha in 2020, which represents a net decrease of 5,816.07 ha. This decrease is due to the rise in the plantation of mangroves.

Figure 9 shows the area under barren/vacant land that was converted to other LULC classes. About 2,257 ha (4.93%) were converted to dry mudflat, 1,671 ha (3.65%) to sparse mangrove cover, 1,591 ha (3.48%) to turbid water, 212 ha (0.46%) to wet mudflat, and 128 ha (0.28%) to dense mangrove.

Turbid water

The area under turbid water increased around 6,778.50 ha, from 14,265.70 ha (in 2015) to 21,044.20 ha (in 2020). Figure 9 shows the area under turbid water that was converted to other LULC classes. About 3,738 ha (8.17%) were converted to deep water, while 223 ha (0.49%) shifted to sparse mangrove cover.

Table 3: The area under each LULC class in the 2015 and 2020 data sets, along with changes in the area of each LULC class over the five years

S. no.	LULC classes	2015 Area (hectares)	2020 Area (hectares)	Change (2015-2020) Area (hectares)
1	Dense mangrove	197.55	335.52	138.15
2	Sparse mangrove	5324.76	12113.1	6788.34
3	Wet mudflat	12631.2	487.8	-12143.4
4	Dry mudflat	4398.84	7210.8	2811.96
5	Barren/vacant Land	6508.8	692.73	-5816.07
6	Turbid water	14265.7	21044.2	6778.5
7	Deep water	2417.31	3860.01	1442.7
TOTAL		45744.16	45744.16	

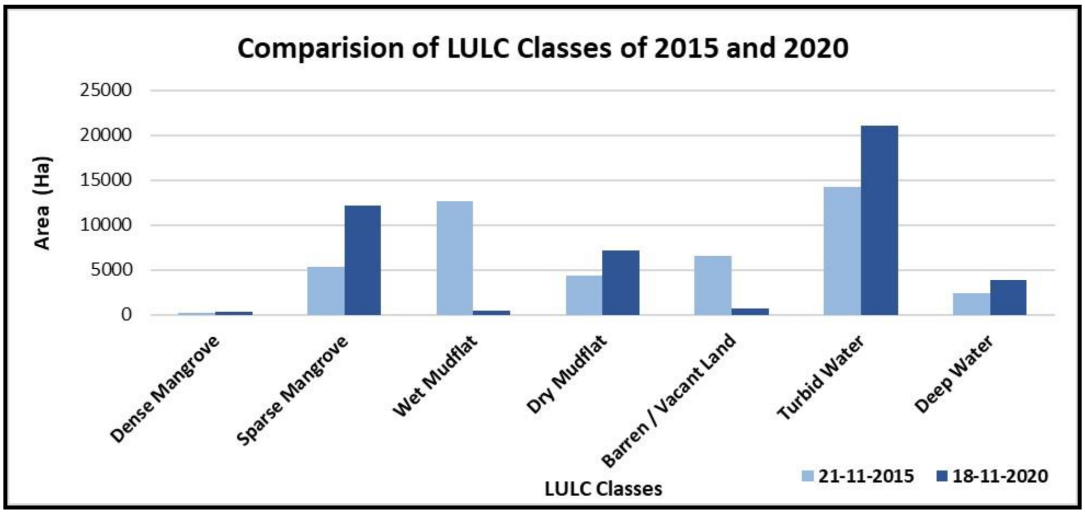

Figure 7: Comparison of LULC classes specific to different years

Deepwater

As shown in Figure 8, the area under deep water increased 1,442.70 ha (from 2,417.31 ha in 2015 to 3,860.01 ha in 2020). Around 2,298 ha (5.02%) of the area underwater shifted to the turbid water class.

The field surveys revealed that certain drastic changes in the socio-economic conditions have been triggered by climate change impacts associated with the LULC transformations in the Indus Delta regions. The agricultural land, mangroves and biodiversity of this region face severe conditions. During the survey, the responses regarding the last few decades revealed that red rice used to be grown in the area, but it has almost become non-existent at present. Apart from rice, this area was also suitable for producing different types of fruits, i.e. bananas, coconuts, and melons. Over the years, because of a number of factors, among which the reduced water flows of rivers and the sea intrusion, which caused water logging and salinity, it was estimated that more than 117,823 acres of agricultural land have been affected.

Because of climate changes, the Indus Delta region is more prone to floods, droughts, and cyclones. Keti Bunder is also vulnerable to cyclones and tsunamis. In the last 30 years, because of global warming, the intensity and frequency of cyclones have particularly increased. The migration within local communities is obvious over time, this also being an effect of extreme weather incidents, which may increase in the coming few years because of the impacts of storms, rising sea levels, and other expected effects of climate change (Gowdy & Salman, 2010). The climate projection indicates that at least a 5°C rise will occur in the Indus Delta by the end of the 21^{st} century (Rehman et al., 2015).

In the year 2020, the rainfall was 38% above the average precipitation specific to Pakistan (the 4^{th} wettest year since 1961), while Sindh received 105.5% additional annual rain as compared to its average rainfall.

Particularly in August, the monsoon rains were the highest ever recorded, as 363% of the average rain fell during this month. The seasonal rain from July to September accounted for 332 mm, which was 148% more than the seasonal average of 133 mm. This led to floods along the Indus River in August and September. The same has been reflected in the inter-conversion of land cover classes, where a significant area under wet mudflats was converted into turbid water, while a substantial proportion of barren/vacant land has been transformed into sparse mangroves, turbid water, and dry mudflats. In the case of mangroves, a significant proportion of dry and wet mudflats contributed 3% and 9.6% of their respective area in 2015 to the sparse mangroves.

For the last decade, on administrative grounds, the Provincial Forest Department and nongovernmental organizations have been aggressively working for the plantation and conservation of mangroves in the Indus Delta region (IUCN, 2018; WWF Pakistan, 2021).

Generally, these geographical alterations in the Indus Delta area show that the environment has been significantly impacted because of recent extreme weather events in the region.

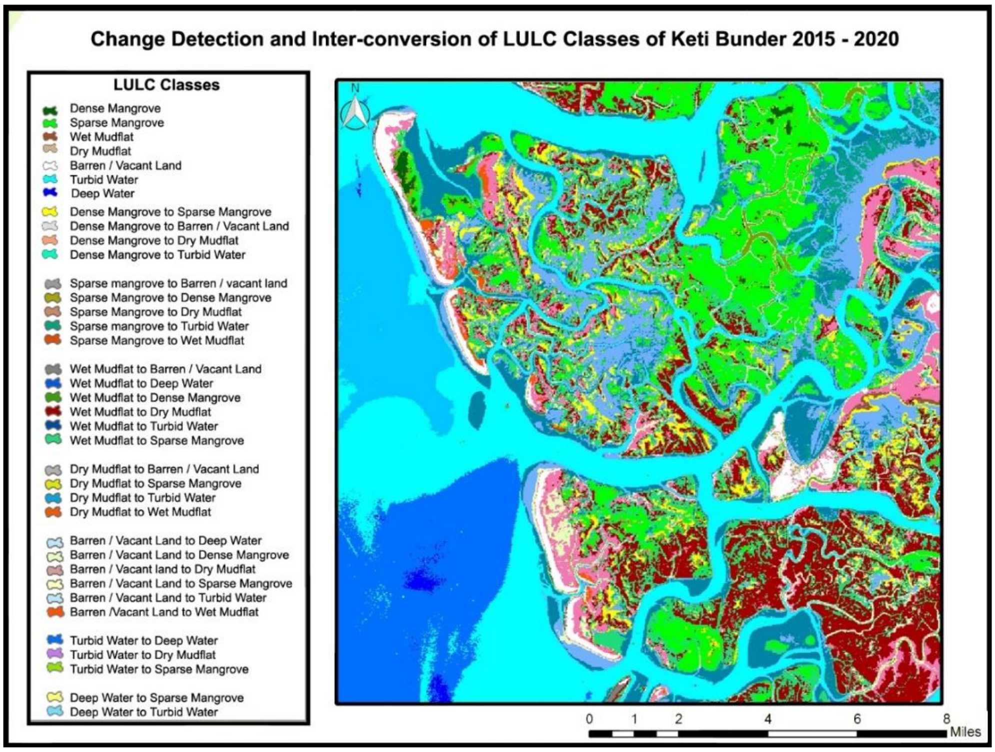

Figure 8: Change detection and Inter-conversion of LULC Classes in Keti Bunder between 2015 and 2020

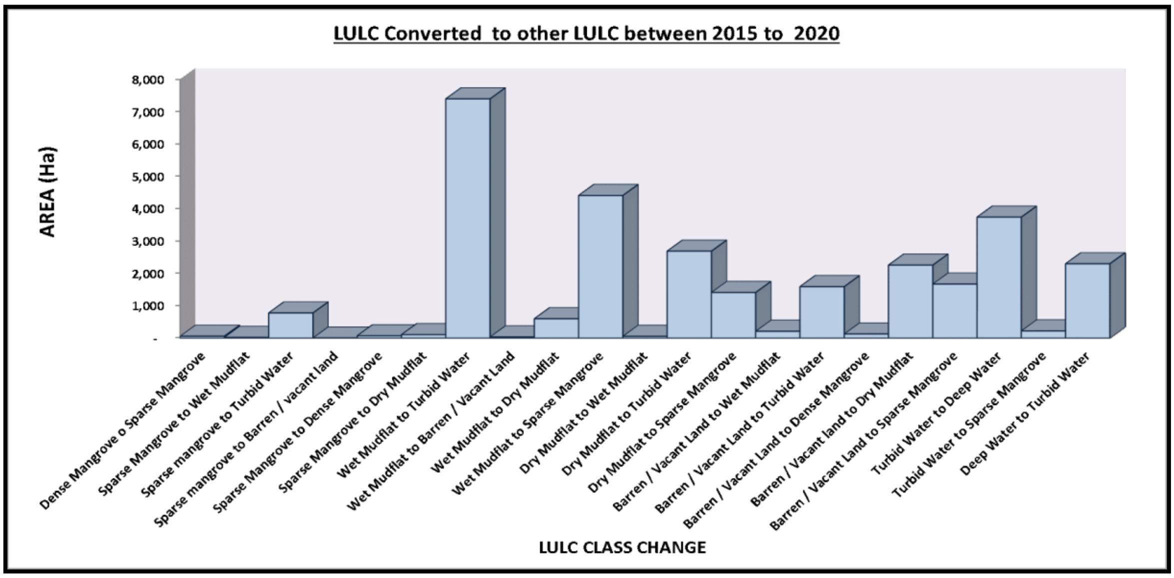

Figure 9: Post-classification changes of LULC classes between 2015 and 2020

Conclusions

This work has quantified the spatial variations in LULC between 2015 and 2020, based on GIS and remote sensing methods. The methods used in this investigation are reasonably straightforward and inexpensive.

The multi-temporal satellite imagery has been used in order to determine the extent of land use changes in Keti Bunder. The overall classification accuracy for the present analysis was determined to be within acceptable limits. In the post-classification comparison, significant changes were seen in the LULC of the region under study, during the research period.

Over the course of these five years, an increase in the area under thick mangroves, sparse mangroves, murky water, and deep water was observed, while the effects of extreme weather events in recent months have also been noticed. Mangrove species were abundant, but now only four species survived because of the lack of fresh water, along with the sea water intrusion. The findings could be used in the ecological management and planning.

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Authors contributions

Dr. Zia ur Rehman conceived the original idea. While Dr. Zia ur Rehman, Dr. Asif Gul and Prof. Dr. Jamil Hasan Kazmi contributed to the design and implementation of the research, to the analysis of the results and the writing of the manuscript. Prof. Dr. Jamil Hasan Kazmi supervised the project.

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Declaration of interests

We declare that this submission has not been published elsewhere, nor is under consideration for publication and there is no conflict of interest among the authors before submitting it in this reputed journal.

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