GIS-BASED CHANGE DETECTION OF COASTAL FEATURES ALONG KARACHI COAST PAKISTAN

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ABSTRACT: The fontal Karachi Coast is widely exposed to human activities which impose ecological and environmental degradation of coastal environment and wetland biodiversity. This study aimed to analyze the changes in coastal belt features including built up land cover, mangroves & vegetation cover, and interrelationship of coastline morphology at frontal Karachi coast. We have utilized the satellite images of Landsat-5 TM and Landsat-8 OLI/TIRS to detect the changes and map coastal features using likelihood supervised classification and unsupervised algorithms (NDBI, NDVI). The spectral data analysis of principal components helped us to discriminate various coastal features by analytical interpretation of images whereas, supervised classification and change detection matrices provided quantitative estimates of variability among the thematic features. We have addressed the spatial changes with explicit references of Karachi Shipyard, Karachi Port, PNS Himalaya, Sandspit, Bundal/Bhundar Island and Far Island Mangrove Forest for the year 2010-2018. It was reckoned that major reduction in "dense mangroves" at Karachi Shipyard from 119.7 to 96.3 hectares and about 100 hectares at Bundal Island (over 2010-18), probably under the influence of the well built-up areas and futile coastal management in current scenario of regional climate changes.

Keywords: Landsat, Mangroves, Land use changes, Karachi, GIS.

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INTRODUCTION

The coastline of Pakistan extends more than 1,050 kms along the Arabian Sea in southern regions of Sindh and Balochistan. The Pakistan coastal belt is diversified with large variability in coastal features, climatic & hydrological resources and physical limitations. Sindh coast is endowed in freshwater resources conjunction with Indus river fall into the Arabian sea and contributes in development of large Indus delta with micro-climate of deltaic region and variability of estuaries and consequential biodiversity of coastal wetland (Rehman and Kazmi, 2018).

The 'Karachi Harbor' is a sheltered bay to the southwest of Karachi city, where the Sandspit Beach, Manora Island and the Oyster rocks are prominent sea cliffs and sandstone headlands which protect it from coastal erosion & degradation against high wave actions during storms. The coastline of Karachi is enriched with significant biodiversity and ecosystem. The creeks and estuaries of Indus delta system are found towards southeast of Karachi city, wherein costal morphology is covered with dense mangroves, The rocky mountains of Cape Monze preclude the extension of mangroves to the west and southwest of Karachi city. An area comprising of. FKC is widely exposed to the human activities which impose ecological and environmental degradation.

In the transition between the rocky / sedimentary coastline and the Indus deltaic creeks, the FKC is situated which is an elongated beach comprises of the fine sand and silt; however, the high-water region has some coarse sand combined along with the fine sand (Durrane *et al*., 2008).The fine sand and beach sediments have extensive amounts of mica which are dark in surface shading (Khan *et al*., 2018) Various marine and terrestrial procedures are in charge for changes occurring along the coastal belt. In view of physiographic highlights, Karachi waterfront (coastal) territory can be isolated into three unique areas (West coast, South coast and southeast coast) (Rehman *et al*., 2016). Recent studies (Sheeba *et al*. 2013; Rehman *et al*., 2015) highlighted significant shortening of mangroves, fading of vegetation cover, cossetting of biodiversity and coastal erosion occurred along frontal Karachi coast (FKC) in recent years. The geo-environmental factors coupled with anthropogenic activities i.e. fast growing housing settlements, falling of untreated waste from industrial and domestic use through multiple channels, fusion of industrial waste into the sea water in near-shore and coastal belt, dumping of solid waste increased the degree of coastal feature changes (Rehman *et al*., 2016).

The geographical information system (GIS) and satellite imageries augment in learning data insight, new pattern's identification, inter-relationships in dynamic coastal environment (Lu *et al*., 2004; Ahmed *et al*., 2017). The capabilities of GIS facilitate in smart decisions in assessment of coastal vulnerability, land use & coastal cover, town management, urban planning,

conservation of endangering coastal environment, and shifting of dynamic shoreline (Qureshi *et al.*, 2012; Ogashawara and Bastos, 2012; Ovejero-Campos *et al.*, 2019; Bama *et al.*, 2020.

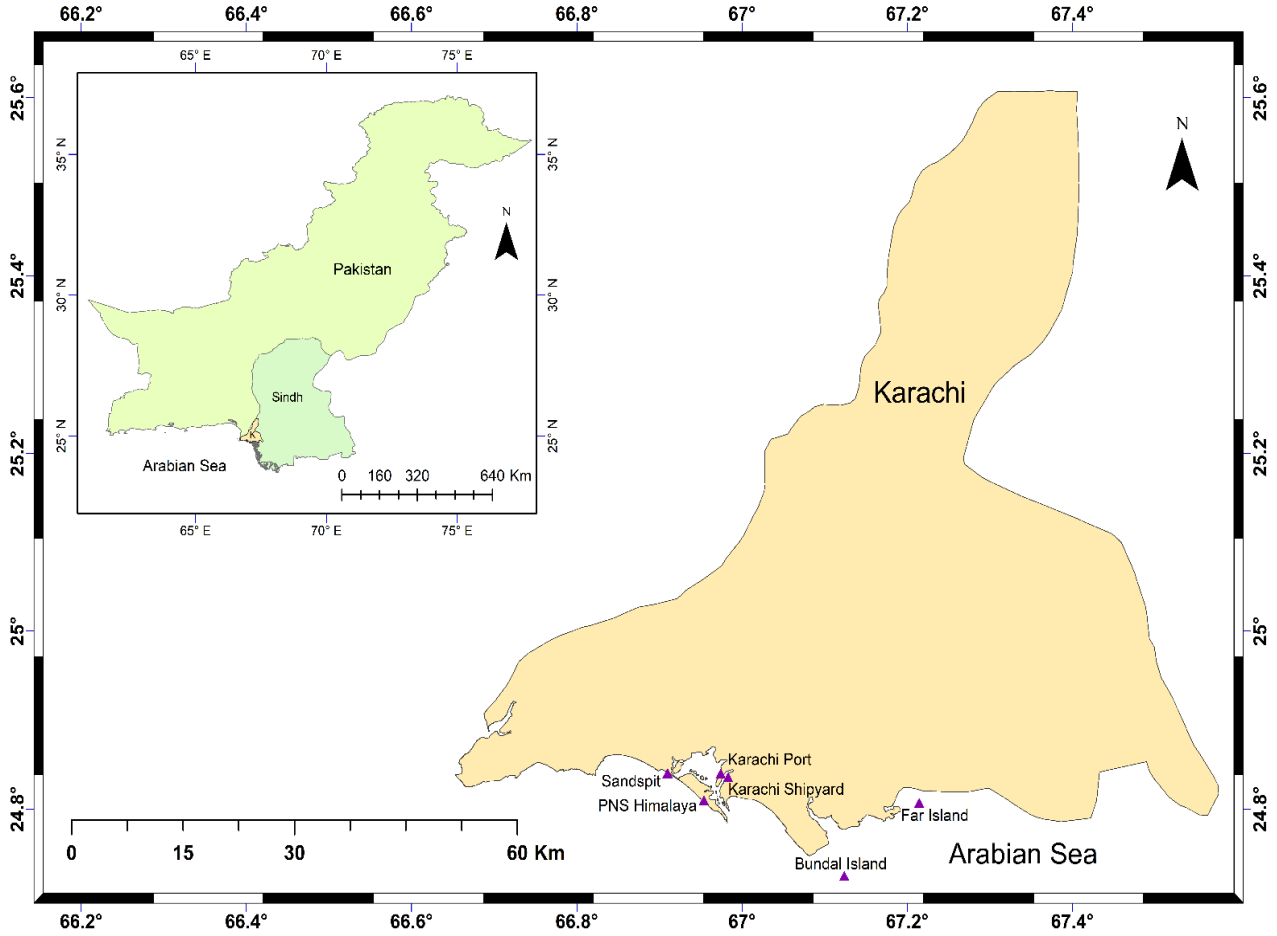


Figure-1: Base map of study area, the areas of interest are shown at frontal Karachi Coast, Sindh, Pakistan

The physiography of coastal belts and wetland areas can be easily mapped using careful interpretation of multi-spectral thematic images (Ferreira *et al.*, 2009). This study was focused to model the coastal features and to quantify respective variations in coastal environment at FKC for the years 2010-2018. The specific objectives of this exhaustive study were: 1) to observe and understand to the land cover changes, *i.e.* Vegetation changes along with Mangroves, Built-up Area changes, and Water changes along the Karachi coast, especially, along Karachi Shipyard, Karachi Port, PNS Himalaya & Sandspit, Bundal/Bhundar Island and Far Island Mangrove Forest region for the year 2010-2018 using multispectral satellite images and GIS; 2) to perform change detection and analysis with a purpose of indicating zones of high risk of degradation in terms of (Water, Mangroves and other Vegetation), which will ultimately be effective for bringing focus of concerned authorities to take actions and preventive measures on those areas primarily.

MATERIALS AND METHODS

Landsat 5 TM (January 07, 2010; 30 m resolution) and Landsat 8 OLI (January 13, 2018; 30 m resolution) data have been utilized for the change detection along FKC for the years 2010 and 2018. The OLI sensor measures the invisible, near infrared and short wave infrared spectrum which was built by Ball Aerospace under the contract to NASA. OLI images consist nine spectral bands. Two new spectral bands i.e. a deep blue coastal/ aerosol band, which is specially designed for coastal zone and water resources investigation and short wave infrared cirrus band, for the detection of high, thin clouds. Landsat images of TM and OLI/TIRS sensors along path/row 152/43 and 153/43 were requested from USGS in Geo Tiff format.

The raster images were processed by Erdas Imagine tools. The systematic workflow consists, stacking of multispectral thematic layers, clipping of area of interest, application of geometric and atmospheric

corrections, principal component analysis (PCA), supervised and unsupervised feature classification on the raster images. A single output multi-band image file is produced from the stacking of multiple (usually single band) images as bands or layers. The output (stacked layers) was saved to an .img file. The bands that were stacked for Landsat 5 TM were 1,2,3,4,5,6 and 7, each having resolution 30m, respectively except band 6 having 120m resolution. Whereas, the bands that were stacked for Landsat 8 OLI were 2,3,4,5,6,7 each having 30m resolution respectively.

Usually, the stacked image files consist areas much larger than required study area. In these circumstances, image clipping help to reduce the image extent focused to area of interest (AOI) *i.e.* outline of FKC. Multispectral satellite imageries have limited dynamic range, appearing as haziness or having a reduced contrast are caused due to Atmospheric effects (Hussain *et al*., 2019). The image quality was enhanced using the Haze Correction (Atmospheric Correction) by adopting Point Spread Convolution method. Principal Components Analysis (PCA) often utilized as a procedure of data compression which helped in change detection over period of years (Udin *et al*., 2017). PCA allows redundant data to compressed into minimum bands, i.e. the dimensionality of the data is minimized. The bands of PCA data are independent and non-correlated and are usually more interpretable as compared to source data. In this study, PCA was performed by setting number of classes to three.

Supervised classification categorized the features using interactive approach of maximum likelihood characteristics of pixels Supervised classification (maximum likelihood) was performed for change detection on regional basis, as well as on local sites (Karachi Shipyard, Karachi Port, PNS Himalaya & Sandspit, Bundal/Bhundar Island and Far Island Mangrove Forest). The unsupervised classification utilized the ISODATA algorithm, to perform Iterative self-organizing data analysis technique which repeatedly recalculates statistics for specific thematic features (Udin *et al*., 2017). The NDVI (Normalized Difference Vegetation Index) and NDBI (Normalized Difference Built-up Index) quantifies built-up and vegetation features, respectively. NDVI always ranges from -1 to +1 such as values near +1 indicates more healthy vegetation whereas values near -1 indicates poor vegetation, or other land features (Badamfirooz and Mousazadeh, 2019). NDVI was calculated by the following formula

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

NDBI was calculated by following formula which helped to extract built-up features (High values of NDBI i.e. +1 usually depict built up)

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

The SAVI (Soil Adjusted Vegetation Index) divided the study area into detailed four classes namely, No Soil Adjusted Vegetation, Slight Soil Adjusted Vegetation, Moderate Soil Adjusted Vegetation and High Soil Adjusted Vegetation, respectively. The NDVI thematic maps helped us to delineate vegetation changes, however better results were achieved with SAVI algorithm as it considers soil emissivity as well (Ahmad *et al*., 2014; Baray *et al*., 2019). With the addition of a "soil brightness correction factor", SAVI is structured like the NDVI. It was calculated using the following formula:

$$SAVI = \frac{NIR - Red}{NIR + Red + L} * (1 + L)$$

Where, NIR is the reflectance value of the NIR band, Red is reflectance of the Red band, SWIR is the reflectance of shortwave infrared band and L is the soil brightness correction factor.

ArcMap tools facilitated in presenting the interpretation and thematic maps. The quantitative analysis for different feature classes was performed by change detection matrix tools which produce a cross-tabulation statistics by comparing two thematic files. The selected Zone File and the Class File were used as the two input files. The class value areas including number of points in common, number of hectares/acres/square/miles in common, and percentages as well. The output was a report in a text file, not an image.

RESULTS

The GIS modeling of Land-use/Land Cover patterns helped us to understand the diversified land cover features of FKC using PCA and feature class indexes (NDBI, NDWI, NDVI, SAVI) to generalize the division of features. However, supervised classification was performed with ample test samples from various coastal features to facilitate pixel based likelihood mapping for change detection. The results of changes in coastal land cover features at reference sites (Karachi Shipyard, Karachi Port, PNS Himalaya & Sandspit, Bundal/Bhundar Island and Far Island Mangrove Forest) were animated by themes such as 1) Well Built-up is indicated by Red, 2) Moderate Built-up by Magenta, 3) Slight Built-up by Pink color, 4) Other Vegetation or Moderate Mangroves by Light green, 5) Dense Mangroves and Vegetation by Dark Green and 6) Water by Blue.

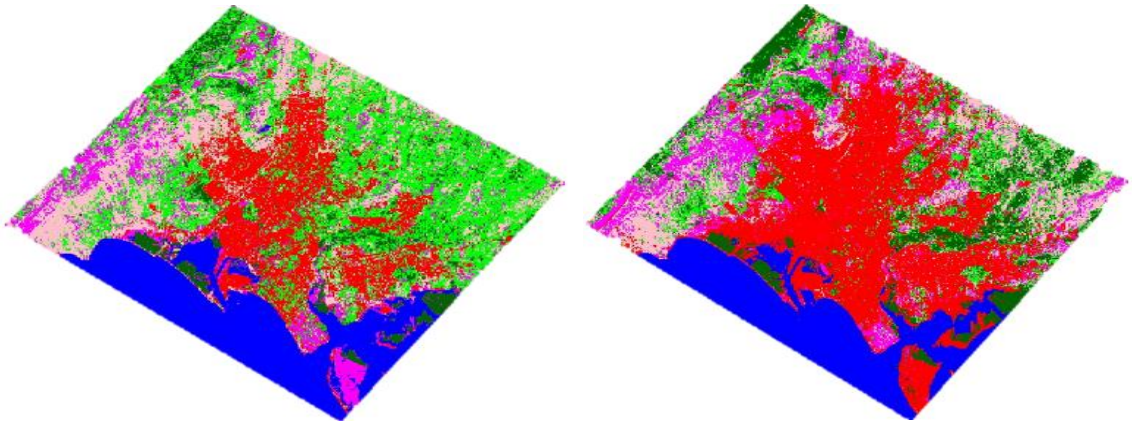


Figure 2: The thematic map of land use for 2010 and 2018.

Figure-2: (a) Land Use Map of KCA 2010 (Well Built-up Area is indicated by Red, Moderate Built-up by Magenta, Slight Built-up by Pink color, Other Vegetation or Moderate Mangroves by Light green, Dense Mangroves and Vegetation by Dark Green and Water by Blue) (2b) Land Use Map of KCA 2018 (Well Built-up Area is indicated by Red, Moderate Built-up by Magenta, Slight Built-up by Pink color, Other Vegetation or Moderate Mangroves by Light green, Dense Mangroves and Vegetation by Dark Green and Water by Blue).

The time series analysis was conducted for detection of spatial variation in Mangroves, Vegetation, Water-land and Built-up. The supervised classification of targeted sample features of the FKC was classified into few classes of built up (Well Built-up, Moderate Built-up, Slight Built-up) Vegetation (Moderate Mangroves, Dense Mangroves) and Water-land (Figure-3, 4, 5, 6 and 7)

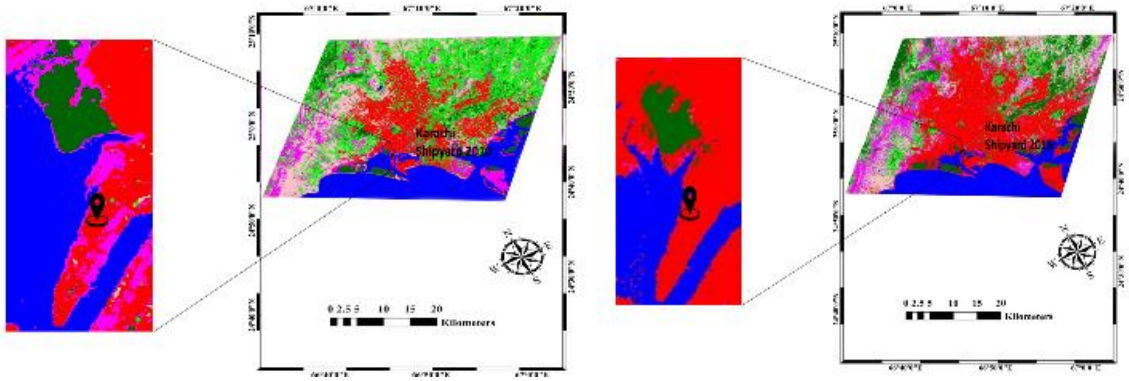


Figure-3: Land Use Map of Karachi Shipyard for 2010 and 2018.

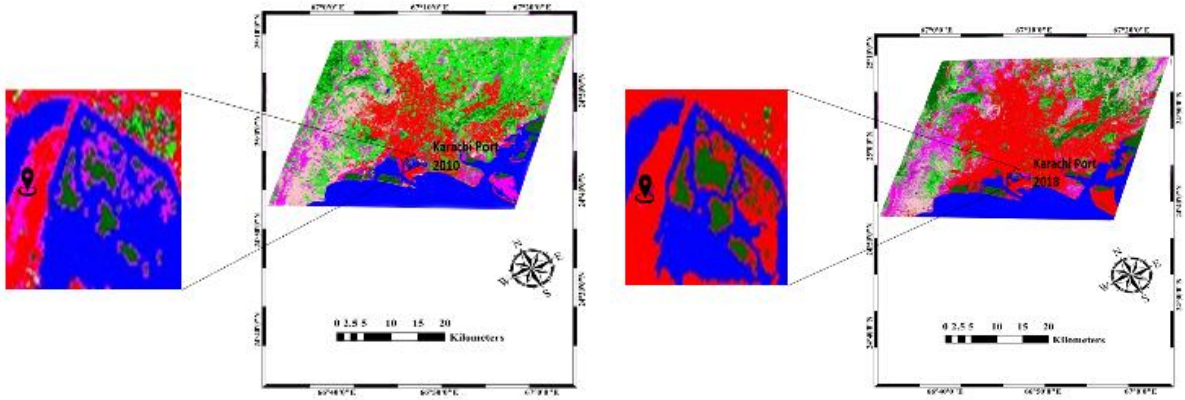


Figure-4: Land Use Map of Karachi Port for 2010 and 2018.

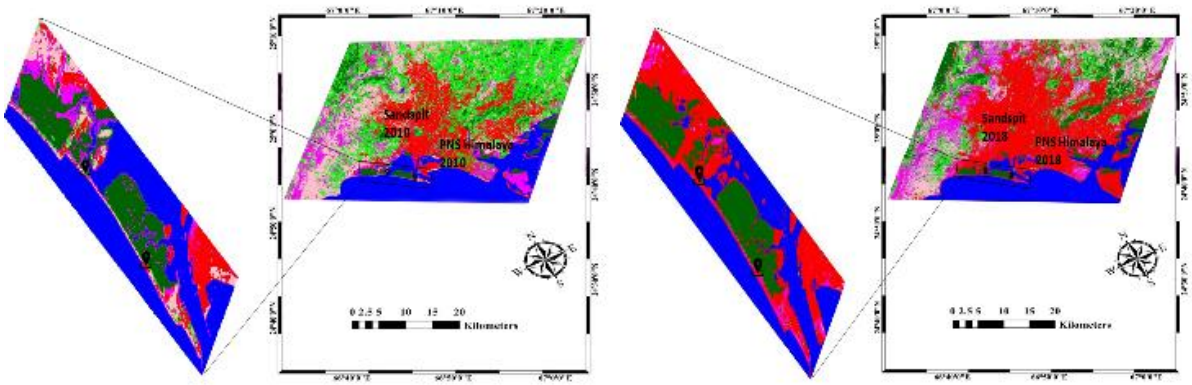


Figure-5: Land Use Map of PNS Himalaya & Sandspit for 2010 and 2018.

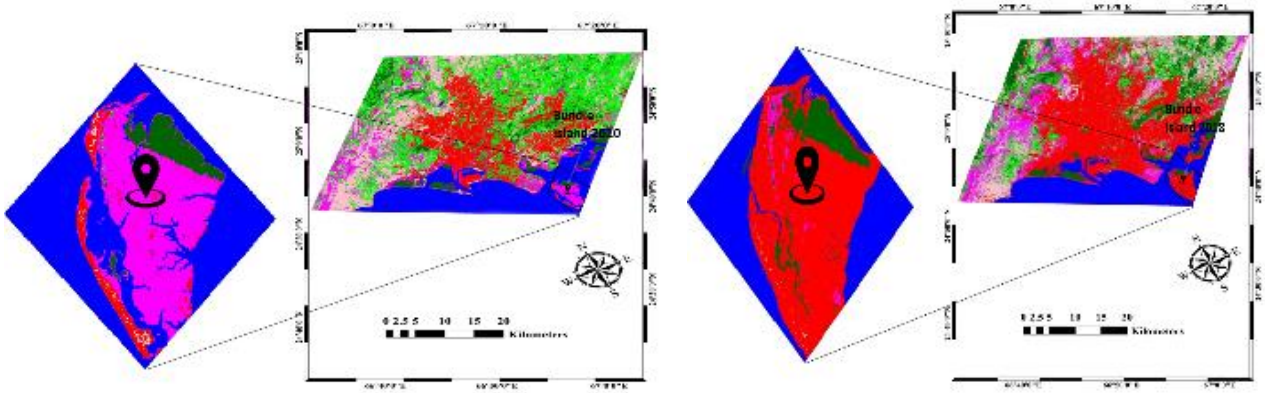


Figure-6:. Land Use Map of Bundle/Bhundar Island for 2010 and 2018

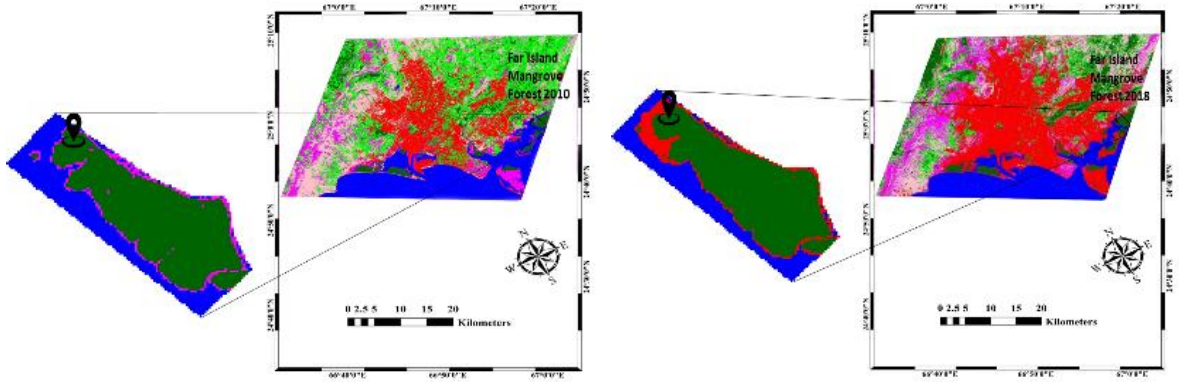


Figure-7: Land Use Map of Far Island Mangrove Forest for 2010 and 2018.

Quantitative analysis of change detection along FKC using the change matrix function suggests relative changes of features classes (Table-1). The well Built-up area of the year 2010 was 28166.22 hectares, which was increased by 54372.15 hectares for the year of 2018 in FKC. On the other side, the Moderate Built-up area was 167121.99 hectares for the year 2010, which decreased after 8-year period and became 20352.6 hectares in 2018 due conversion of Moderate Built-up into Well Built-up areas in the FKC. The slight Built-up increased from 31000.23 hectares in 2010 to 174688.92 hectares in the year 2018 which indicates the rapid increase in urbanization. On the other hand, a drastic amount of Mangroves and other vegetation were diminished from the year 2010 to 2018 in the overall FKC. The other vegetation or moderate Mangroves were disseminated from 43967.43 hectares in 2010 to 17866.62 hectares in 2018 in the FKC as well. Likewise, the dense Mangroves were also depleted and decreased from 16451.46 hectares in 2010 to 10689.12 hectares in 2018, respectively. Similarly, the decrease of rainfall in the city, the availability of sweet water from landward channels to the FKC and other synthetic factors/activities along coastal areas and nearby places, also accounted for decrease in Water-land from 28086.48 hectares in 2010 to 25299.72 hectares in 2018.

Table 1. Estimated changes in different land use/cover features during the years 2010 and 2018.

Class ID	Feature Class	2010 (Hectares)	2018 (Hectares)	Relative Change (Hectares)
1	Well Built-up Area	28166.22	54372.15	26,205.93
2	Moderate Built-up Area	167121.99	20352.6	-146,769.3
3	Slight Built-up Area	31000.23	174688.92	143688.7
4	Moderate Mangroves	43967.43	17866.62	-26100.81
5	Dense Mangroves	16451.46	10689.12	-5762.34
6	Water	28086.48	25299.72	-2786.76

This study was significant to highlight the major changes in dense Mangroves at Karachi Shipyard (reduced from 119.7 to 96.3 hectares over 2010-18), Bundal Island (reduced from 336.78 to 238.32 hectares over 2010-18). The PNS Himalaya and Sandspit areas were characterized with major change in other vegetation or moderate Mangrove class from 84.69 to 17.19 hectares over 2010-18.

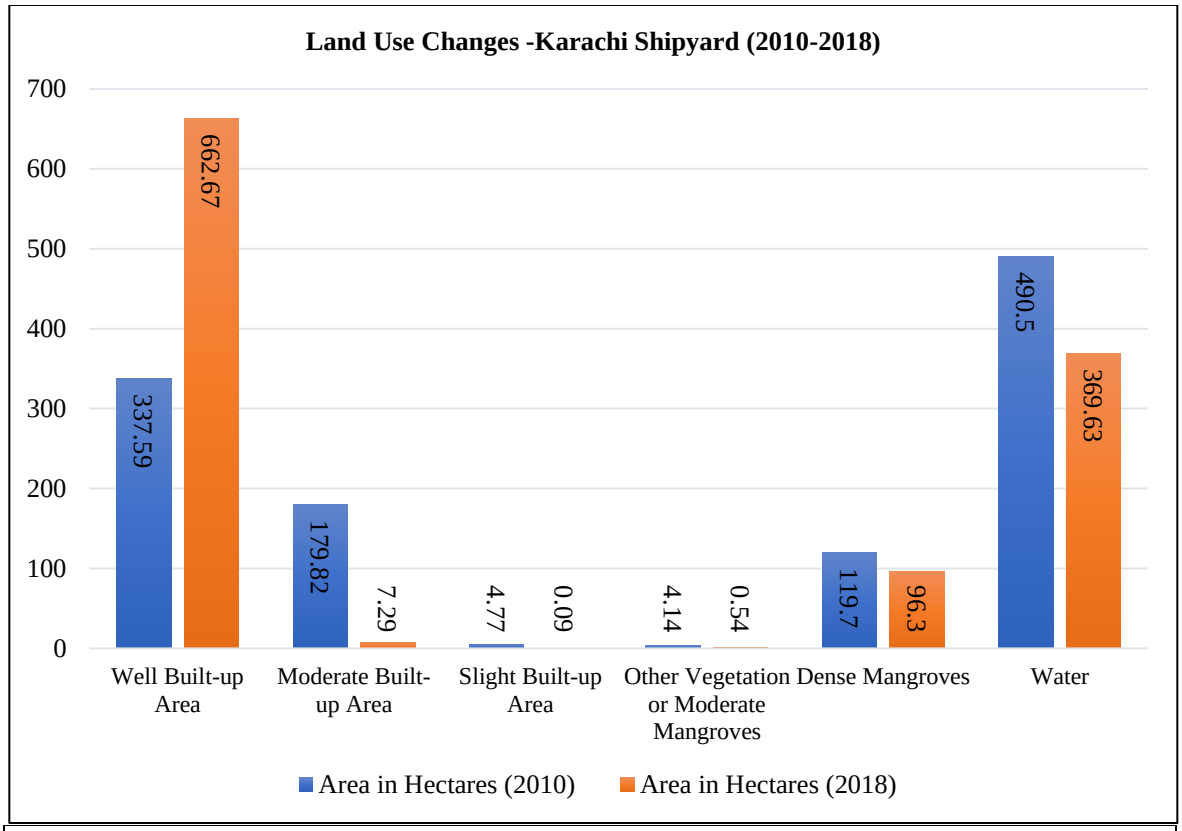
DISCUSSION

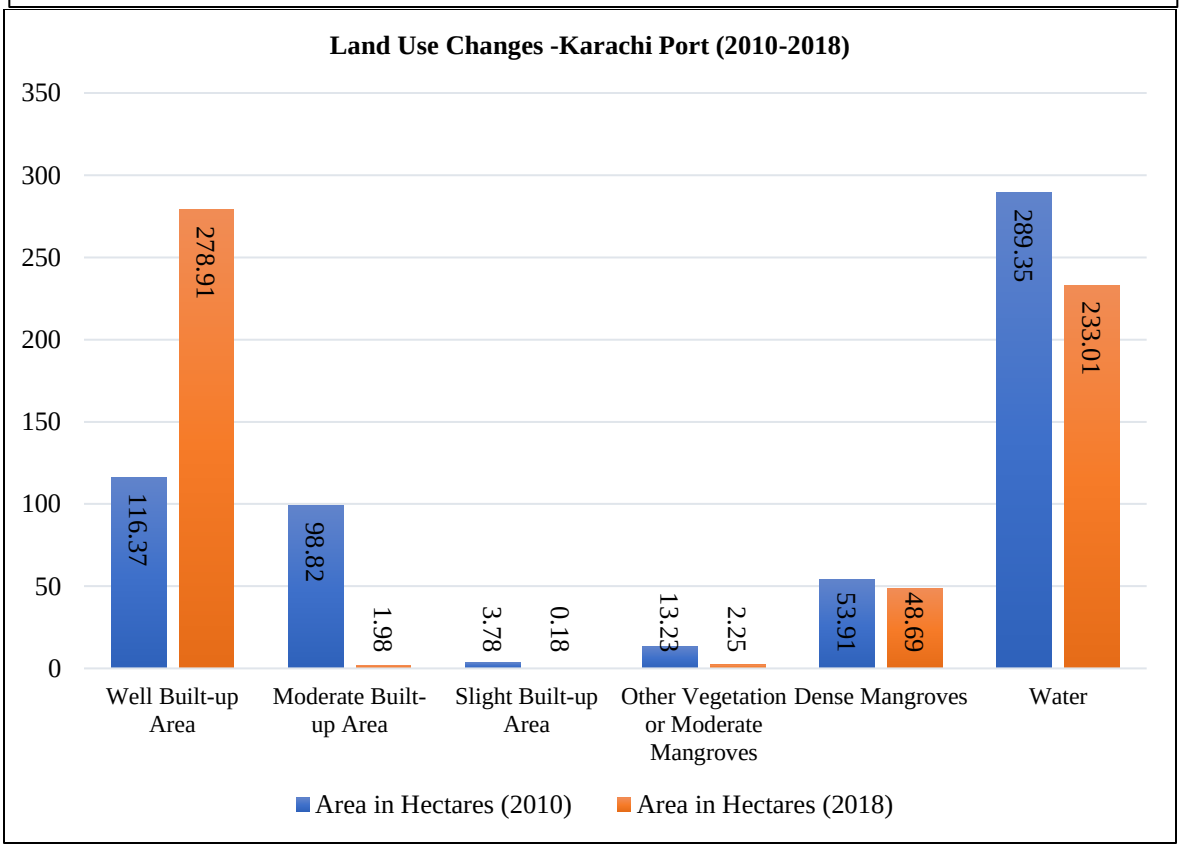
The Landsat images helped us to quantify the coastal environment variations over 2010 to 2018. The GIS data analysis of satellite images helped us to model the coastal belt features such as built up-land cover change, mangroves & vegetation cover changesand interrelationship of coastline environment of frontal Karachi coast. The comparative results of the selected features are shown in Fig-8. The well Built-up area of the year 2010 was increased for the year of 2018 in FKC due to conversion of Moderate Built-up patches into Well Built-up areas at various sites of the FKC.

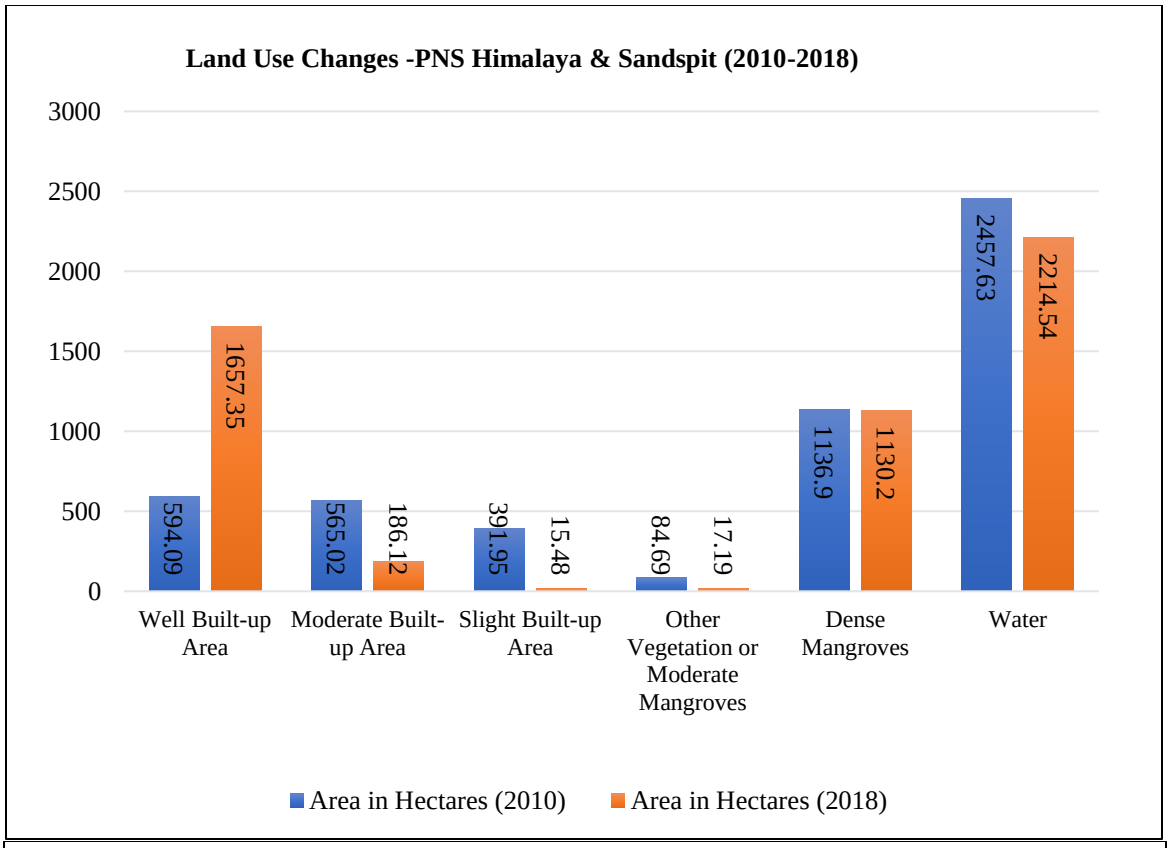
The interpretation of NDVI thematic maps helped us to delineate further vegetation changes, however better results were achieved with SAVI based thematic maps, since SAVI function considered soil emissivity in addition to the precise spectrums (Rehman *et al.,* 2016). We found that the landcover of Mangroves in the south, east and central parts of Karachi Shipyard were dense and healthy and remain similar till 2018, whereas significant in Mangroves were found to the northwestern portion. Those mangroves patches located to the northwest of Karachi Shipyard were not dense during 2010 (Khan *et al.,* 2018). The feature class of moderate Mangroves missing from the northwestern side, probably, these Mangroves may be converted from moderate into slight Mangroves. In the Karachi Port area, dense Mangroves were interpreted at south, southeastern, northeastern and central part, while south-western part consists of moderate Mangroves and the northern part bears slight healthy Mangroves as well in the year 2010. It has been identified that the Mangroves in the central and southern regions of Karachi Port were dense in 2018, however, the dense Mangroves of 2010 were completely vanished in the year 2018 on eastern and northeastern side of Karachi port. On the southwestern side, some dense Mangroves converted into moderate and on the north side, the slight healthy Mangroves were reduced, probably under the influence of urban units and commercial settlements in this part of FKC (Noor *et al.,* 2016).

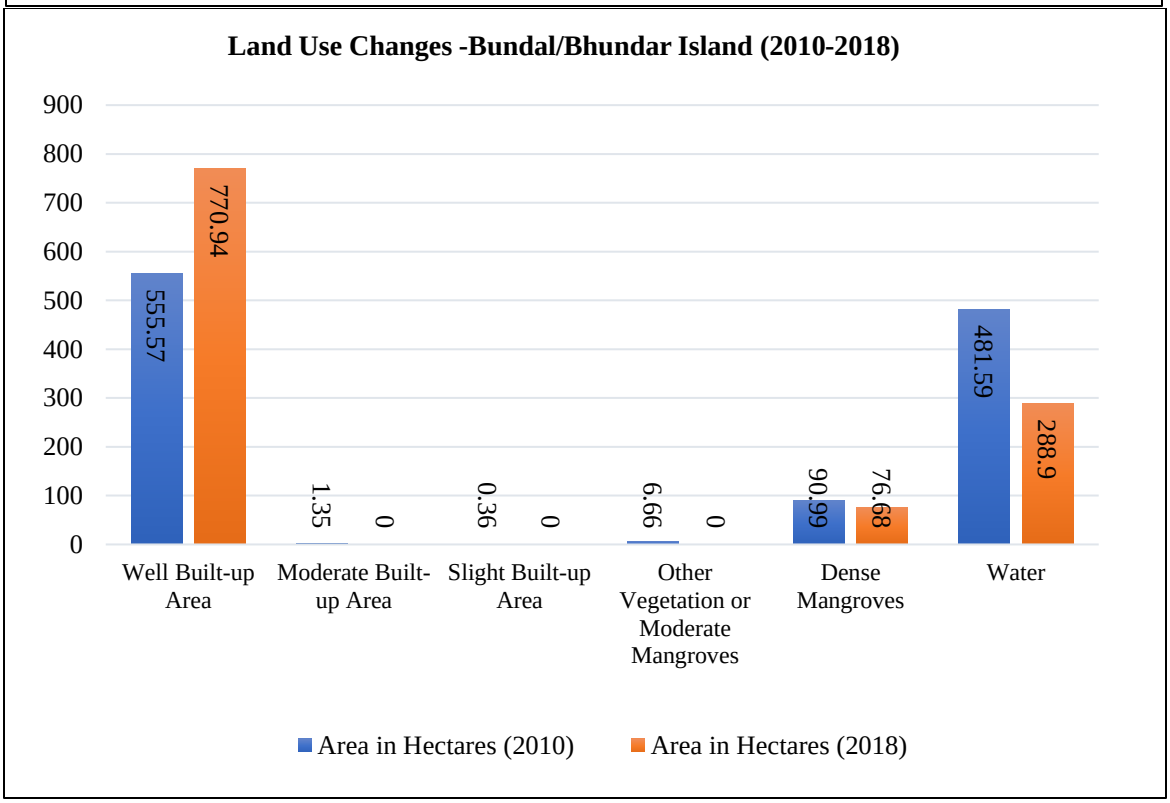
We have observed that the dense Mangroves on the east, west and southern side of the PNS Himalaya unit. There were moderate Mangroves on the central and northern side however, the southeastern side of PNS Himalaya bears slight vegetation cover. The Mangroves on the Sandspit area were classified as dense mangroves during the study period. The western side also bears slight to moderate Mangroves for the year 2010. Whereas, it was observed (in 2018) that the Mangroves on the eastern side were vanished as compare to 2010. The Mangroves on the northern and eastern and western side of Sandspit area were converted from dense to moderate and slight healthy Mangroves on the northwestern side were solely vanished. The vegetation cover in the Sandspit area were severely affected by the open sea and poor management of near shoreline environment (Sheeba *et al.,* 2013).

We have interpreted dense/healthy Mangroves on the north central and northeastern side of the Bundal/Bhundar Island, there were slight to moderate Mangroves at western side, The central part and southern part consist of slight to moderate Vegetation, in which, western part consists of more vegetation for the year 2010. On the other side in 2018, the north-central and northeastern side consists of dense/healthy Mangroves, but Mangroves on the western side damaged and vanished at an alarming rate. Other vegetation cover was vanished over 8 years, on the central and western part of Bundal/Bhundar Island. Far Island Mangrove forest area was consisted of dense/healthy Mangroves in the year 2010. However, the Mangroves were dense in all the area except on the southern and southwestern side, which was converted from dense to moderate Mangroves in the year 2018.


Land Use Changes -Karachi Shipyard (2010-2018)
700
600
500
400
300
200
100
0
337.59
662.67
179.82
7.29
4.77
0.09
4.14
0.54
119.7
96.3
490.5
369.63
Well Built-up Area
Moderate Built-up Area
Slight Built-up Area
Other Vegetation or Moderate Mangroves
Dense Mangroves
Water
Area in Hectares (2010)
Area in Hectares (2018)


Land Use Changes -Karachi Port (2010-2018)
350
300
250
200
150
100
50
0
116.37
278.91
98.82
1.98
3.78
0.18
13.23
2.25
53.91
48.69
289.35
233.01
Well Built-up Area
Moderate Built-up Area
Slight Built-up Area
Other Vegetation or Moderate Mangroves
Dense Mangroves
Water
Area in Hectares (2010)
Area in Hectares (2018)


Land Use Changes -PNS Himalaya & Sandspit (2010-2018)
3000
2500
2000
1500
1000
500
0
594.09
1657.35
565.02
186.12
391.95
15.48
84.69
17.19
1136.9
1130.2
2457.63
2214.54
Well Built-up Area
Moderate Built-up Area
Slight Built-up Area
Other Vegetation or Moderate Mangroves
Dense Mangroves
Water
Area in Hectares (2010)
Area in Hectares (2018)


Land Use Changes -Bundal/Bhundar Island (2010-2018)
900
800
700
600
500
400
300
200
100
0
555.57
770.94
1.35
0
0.36
0
6.66
0
90.99
76.68
481.59
288.9
Well Built-up Area
Moderate Built-up Area
Slight Built-up Area
Other Vegetation or Moderate Mangroves
Dense Mangroves
Water
Area in Hectares (2010)
Area in Hectares (2018)

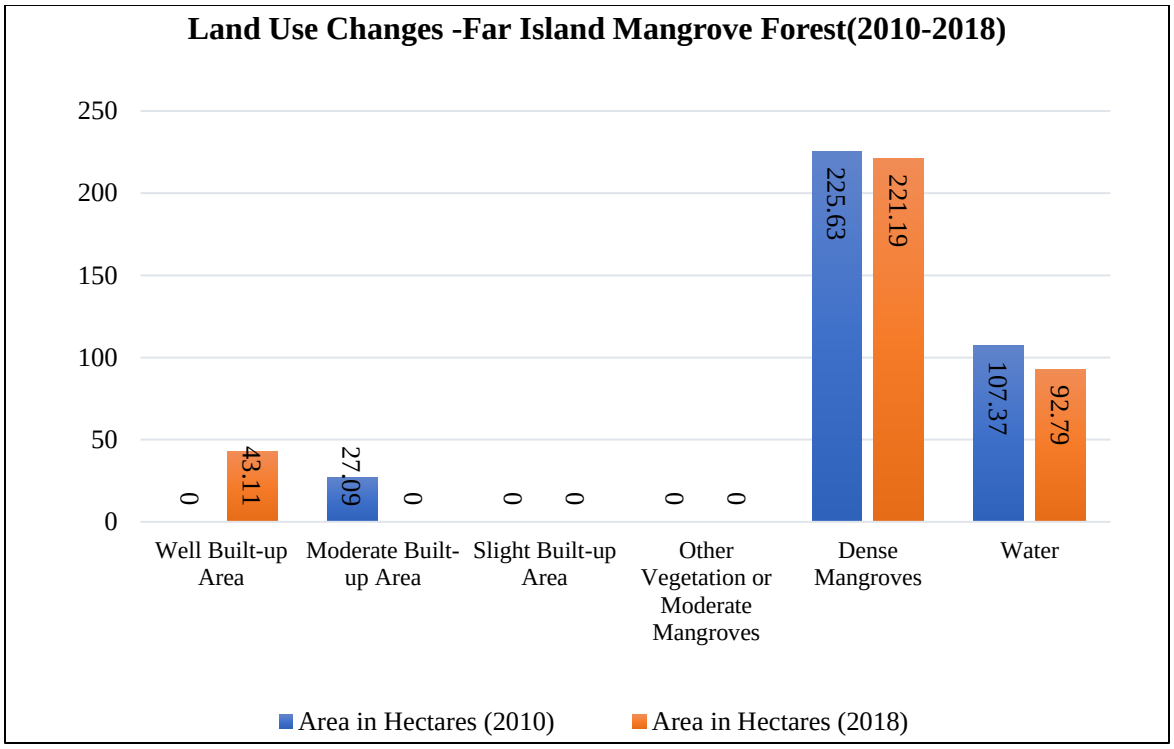


Fig. 8. Histogram of estimated changes in coastal features at explicit references of FKC during 2010-2018.

A drastic number of Mangroves and other vegetation cover changes were highlighted from the year 2010 to 2018 in various zones of the FKC. The studies of Durranee *et al.*, (2008), Sheeba *et al.*, (2013), Noor *et al.*, (2016) also reported the depletion or decrease in vegetation cover of mangroves in various parts of the FKC, however, the reduction can be overcome with the help of proper monitoring and mitigation plan for plantation of mangroves at degraded land parcels identified in this study. The coastal environment and biodiversity of FKC are threatened by geo-environmental hazards and ill-protected coastal processes (advancing salt-water intrusion, tides, wave action, coastal erosion) and human interventions (construction of ports and coastal structures, land reclamation, and land use practices). It was highlighted that the coastal environment of frontal Karachi coast is under serious threats mainly engendered by anthropogenic activities (growing urbanization along the coast, draining untreated industrial-domestic waste into the sea, cutting of mangrove forests, poor maintenance of coastal features, etc). Hence, the applied sciences and modern imaging technologies led us to assess the environmental changes and may contribute in mitigation plans.

Conclusion: This study was significant to highlight the major changes in dense Mangroves at Karachi Shipyard (reduced from 119.7 to 96.3 hectares over 2010-18), Bundal Island (reduced from 336.78 to 238.32 hectares over 2010-18). The PNS Himalaya and Sandspit areas were characterized with major change in other vegetation or moderate Mangrove class from 84.69 to 17.19 hectares over 2010-18. The land parcels identified with reduction in vegetation cover of mangroves at FKC were occupied by the built up at respective sites of FKC. A recent study is recommended to map the high risk zones all along the Sindh coast which may be helpful in effective coastal planning on regional scale.

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