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An assessment of status and distribution of mangrove forest cover in Pakistan

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Abstract

Since 1980, a 25% global reduction in mangrove area has been observed, categorizing mangrove as one of the most threatened and vulnerable ecosystems of the world. Pakistan is home to five of the world's largest mangroves and receives special attention for their ecological importance and coastal stabilization potential. Anthropogenic and climatic influences, along with slack institutional management, have raised questions about qualitative and quantitative deformation of the country's forest resources. To our knowledge, a comprehensive assessment of the current mangrove cover of Pakistan has not been made. In 1999, in the Forestry Sector Master Plan (FSMP), the mangrove forest extent was visually determined from Landsat images of 1988 - 1991, and was estimated to be 155,369 ha; whereas, in the National Forest and Range Resources Assessment Study (NFRRAS), Landsat images of 1997-2001 were automatically processed and the mangrove areas was estimated to be 158,000 ha. Since then, there have been hardly any studies describing the extent of mangrove cover at the end of first decade of 21st century. To address this gap, this study is particularly carried out to estimate the current mangroves cover of Pakistan based on multi-scale Object Based Image Analysis of ALOS-AVNIR-2 images for the year 2009. Results of current image analysis deciphered that the overall mangroves cover of Pakistan is approximately 98,128 ha, and is distribute distinct five geographic pockets. This national assessment disintegrated at sub-district administrative division is anticipated to support informed decision making and sustainable development of coastal regions of Pakistan.

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Introduction

Pakistan has 3.3 million ha of land covered by forests and planted trees, which is equivalent to 4.1% of the total land area (NFRRAS, 2004). Forest resources in Pakistan are deteriorating both qualitatively and quantitatively due to anthropogenic activities and climatic conditions as well as loose institutional arrangements. According to the estimates of the World Conservation and Monitoring Centre (WCMC) the total forest cover of Pakistan is only 3.7%, and this valuable natural resource is under threat from severe deforestation. A mangrove (Littoral and Swamp) forest is one of the nine forest types found in Pakistan (Champion et al., 1965). The mangrove forest in Pakistan provide important ecosystem services including; habitat and breeding ground for economically important marine life and migratory birds; protect coastline and sea ports from erosion and Siltation; meet fuel wood and fodder requirements of local communities, act as natural physical barrier to cyclones and typhoons and provide livelihood to a coastal population of more than 100,000 people. The Indus delta mangrove forest is the second largest mangrove ecosystem in the subtropics. The Indus Delta is considered as one of the world's most threatened large delta due to upstream freshwater extraction which irrigated 180,000 square kilometer of agriculture area (Spalding 2010).

Intensive mangrove ecosystem conservation efforts are being made since early 1990's in the form of mangrove plantation and awareness raising in the local communities. The most recent initiative in this regards is Mangroves for the Future (MFF) which seeks to support economic development by bringing practical conservation actions more effectively into the development planning process, ensuring that coastal ecosystem goods and services are fully valued and protected as an integral part of the coastal development infrastructure. Current study is a contributing step in providing an up to date and comprehensive assessment of mangrove forest of Pakistan which can serve as a baseline for MMF initiatives in Pakistan, and will also comply with GEAS (Global Environmental Alert Service) objective in devising sustainable management, fulfil the knowledge gap to address new and emerging challenges of coastal communities' development (Schwarzer, 2012).

Geographical Information System (GIS) and Remote Sensing tools and technologies have been in use to assess landcover/landuse (Diaz-Chavez, 2012), particularly forest cover, in the last two decades both worldwide as well as in Pakistan. Remote sensing is an indispensable tool for assessing and monitoring mangrove forests, primarily because many mangrove swamps are inaccessible or difficult to field survey (Giri *et al.,* 2008; Kamal and Phinn, 2011; Kuenzer *et al.,*2011). The national level forest cover studies based upon satellite images include the Forestry Sector Master Plan, 1992, and National Forest & Range Resources Assessment Study, 2004 (FSMP, 1992, NFRRAS, 2004). These national level studies were conducted at a scale of 1:250,000 using Landsat satellite images of 30 m spatial resolution. The result of such relatively coarse studies provides comprehensive baseline information for policy level awareness and decision making. However, no systematic baseline data disintegrated into local administration boundaries (e.g., District and sub-district) is available to accurately measure either the current extent of forest cover or the deforestation rate of a particular district in Pakistan.

Under the Forest Sector Master Plan (FSMP), the mangrove forest extent was visually determined from Landsat Thematic Mapper (TM) images from 1988 to 1991, and was estimated to be 155,369 ha, with 55,697 ha categorized as dense and 99,672 ha categorized as medium mangrove forest (FSMP, 1992). Visual techniques were applied because of insufficient computing and processing techniques and skills to handle large data sets. In the National Forest and Range Resource Assessment Study (NFRRAS), Landsat images of 1997 to 2001 were used for land cover and forest cover interpretation while the study was conducted in 2003-04. NFRRAS resorted to an assumption that field data collected in 2003-04 represents the situation of 2001. The mangrove cover area in this study was estimated bout 158,000 ha (NFRRAS, 2004).

There have been different studies in developing countries related to the assessment of mangrove forests conducted from varying perspectives. For instance, Datta et al., 2012, discussed community-based mangrove management, issues, challenges, and opportunities in India and South Asia. Similarly, Kritensen *et al.* (2008) studied carbon dynamics in mangrove ecosystems in Europe and described the relationship of Mangrove litter and benthic microalgae as they are considered as wicked autochthonous sources of carbon. Matang mangroves of Malaysia have been studied by Alongi *et al.* (1998), and Amir, 2012, from different aspects. The former discussed chemical properties of the sediment organic matter of the Matang mangrove forest reserves of Peninsular Malaysia. The latter study discussed canopy gaps and area covered by the mangrove forests in Matang mangroves of Malaysia, mainly studying the mangroves through estimation and explaining the areas covered and gaps in specific periods of time. A latest study on mangroves was conducted in Bangladesh by Roy *et al.* (2012), and discussed the forest property rights and policy management of one of the largest mangrove ranges of the World (Sundarbans). Another study in Sundarbans, documented an increased in mangroves forest by 1.4% from the 1970s to 1990 and decreased by 2.5% from 1990 to 2000 (Giri *et al.,* 2007). Similarly, such a study is also missing in case of Pakistan to estimate current mangroves resource and distribution in Pakistan. This study is aimed at filling this research gap. In general, a decline in net forest cover loss is observed in South and South East Asia. Rate of net forest loss is reduced from 24,000 sq. km per year in 1990s to 7000 sq. km per year in 2010. Illegal logging, industrialization, unsustainable agricultural practices, pest menaces, poor forest management and weak legal framework are the driving forces causing forest ecosystem degradation in the region (Avishek *et al.,* 2012).

Differences in methods of interpretation, classification techniques, mapping scales, resolution of the satellite images, etc, may have led to discrepancies in estimations. The present study applied an object-based method to recent, finer resolution satellite images to map the mangrove cover in the mangrove ecosystems of Pakistan. The multi-scale object-based method for mangrove cover assessment applied a multi-resolution segmentation and nearest neighbour classifier along with class-specific rules that incorporate spectral properties and relationships between image objects at different hierarchical levels.

The paper has been divided into the following sections: Section 1 consists of Introduction; Section 2 explains the methodology of the research; while Section 3 elaborates the results and discussion part. Lastly, the conclusion is contained by Section 4.

Materials and methods

There are different methods and materials used in order to conduct the assessment of mangrove forest cover. All these processes are described step by step for better understanding.

Study area

Coastal areas are among the most populated in most countries with an estimated 23% of the world's population living within 100 km distance of the coast, and 0100m above sea level (Munji *et al.,* 2013). The coastline of Pakistan is 1,050 km long, shared by the provinces of Sindh (350 km) and Balochistan (700 km). Mangroves mainly exist in five distinct sites including the *Indus Delta, Sandspit, Sonmiani, Kalmat Khor,* and *Jiwani* (Fig. 1).

Fig. 1. Mangroves cover sites in Pakistan.

In the Sindh province, mangroves are found in the Indus Delta and Sandspit. The Indus Delta extends from Korangi Creek in the west to Sir Creek in the east, whereas Sandspit is a small locality in the west of Karachi city. Indus originated from northern part of the country, and the glaciers/ snow cover at these high elevation are under significant impacts of climate change (Yao *et al.,* 2012) that may also effect supply of fresh water in the deltaic region. Ecosystem services from the Himalayan river basins also form the basis for a substantial portion of the region's total Gross Domestic Product (GDP) (Pathak, 2012). In the Balochistan province, mangroves are located at three sites: Miani Hor (Sonmiani bay), Kalmat Khor and Jiwani (Gwadar bay).

Fig. 2. Typifying land cover features of Indus Delta.

The coastal climate of Pakistan is a typical arid subtropical climate with a mean annual rainfall of 100 to 200mm. The main vegetation types existing in the study areas are different species of mangroves, *Tamarix* spp., different species of saltbushes, mixed terrestrial vegetation (mainly *Prosopis* spp.*),* and marine algae (Champion *et al.,*1965).

The creeks and mudflats are important areas for wintering, passing, and summering shorebirds in Pakistan. More than 50,000 water birds, such as waders, pelicans, flamingos, egrets, herons, gulls and terns, are observed in mid winters. Raptors like ospreys, shikras, buzzards, eagles, and brahminy kites are observed in the areas.

Data acquisition

Satellite image processing of coastal areas is subjective to tide height as it is a function of the time of the day, season, and geographical locations. High tide values may impede visual interpretation and spectral analysis of mangroves covered in satellite imagery. Quantification of creek areas, mud flats, algal mats, mangrove cover, and saltbushes could vary its extent due to the variations in tide status. Seasonal variation of vegetation phonology is another factor that varies the extent and health of algae as the reflectance of algae in tidal flats is subject to its phonology, which is directly related to water temperature or moisture content and therefore may also obscure the quantification process of mangrove cover. Considering seasonal and tidal aspects, as well as image availability, multi-spectral satellite images of ALOS - AVNIR-2 were acquired (Table 1).

In addition to satellite images, GIS layers containing topographic information, such as administrative boundaries, populated places, creeks, roads, etc., were digitized from Survey of Pakistan (SoP) topographic sheets of 1:50,000 scale.

Pre-processing

The satellite images provided by the data distributors required further processing procedures in order to use them effectively (Ali *et al.,* 2012). The electromagnetic radiation signals collected by satellites in the solar spectrum are modified by scattering and by absorption of gases and aerosols while travelling through the atmosphere from the Earth's surface to the sensor. The data processing sequence for classification of remotely sensed data is required to go through a number of pre-processing steps in which correction for atmospheric effects is often considered a primary task before classification. However, Song *et al.* (2001) described that it is unnecessary to correct atmospheric affects prior to image classification if the spectral signature characterizing the desired land cover / land use classes is derived from the image to be classified.

Accurate per-pixel registration of multi-temporal satellite images is mandatory for precise mapping since registration alignment errors could lead to a wrong estimation of actual change (Stow, 1999). To overcome this problem, adjacent satellite images were tied together using ERDAS IMAGINE's AutoSync tool that uses an automatic edge to edge point matching algorithm.

The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features. The process of visually interpreting digitally enhanced imagery attempts to optimize the complementary abilities of the human mind and the computer. The mind is excellent at interpreting spatial attributes on an image and is capable of identifying obscure or subtle features (Lillesand *et al.,*2004). Due to inherent low contrast, the satellite data required enhancement for which different image enhancement algorithms were used. Keeping in view the subjective land cover, Gamma Correction was applied to increase inter-class and intra-class separability of land cover features for visual interpretation and extraction of particular information regarding different land cover classes.

Preliminary land cover mapping

Before going into the field, preliminary land cover maps of Indus Delta were prepared by performing supervised object based image analysis of the satellite data. For this, visual and spectral interpretation keys of remote sensing data (e.g., tone, texture, context, and association etc.) were carefully analysed to identify and mark out expected land cover classes and confusion classes as well.

To conduct supervised object-based image analysis, sample plots were selected by generating random points. 500 random points were generated and, after careful examination of these points, well distributed and representative of almost all types of land cover features of the study area, 171 sample points were selected and analysed. As a first step high resolution Google image based survey of these samples point was conducted. Against these random points high resolution Google images were interpreted to fill an attribute table regarding land cover type corresponding to each sample point (Conchedda *et al.,*2008). At the end, images were classified with these selected training areas.

Ground reference information

For land cover mapping, it is very essential to verify satellite image interpretation with ground reference data. The main objective of field survey is to correlate the spectral patterns identified from the satellite images with ground reference data. In the present study, A3 and A2 sized field maps of satellite images in False Colour Composites (FCC) of NIR and green and red spectral bands were developed for field data collection activities at scales of 1:25,000; 1:75,000 and 1:50,000, with different geographic grid intervals ranging from 20 sec to 1 minute intervals. Garmin Map 76 GPS Receiver, digital camera, and binoculars were used to record a different number of ground control points and respective field observations. During the survey, spectral abnormalities identified from the satellite images were the prime focus to be visited. Accessible localities were surveyed while the inaccessible areas were verified through the information from government officials and local communities. Ground reference data used in previous studies carried out by WWF – Pakistan (Ashraf *et al.,* 2004; Saeed *et al.,* 2008) were also incorporated. In addition, the classification processes of the images were further validated by visual inspection of high resolution images available on the World Wide Web (2010 Google™ Earth). Google™ Earth combines different resolution images and updates them on a rolling basis (Conchedda *et al.,* 2008).

Some of the field survey findings are as follows

a) *Avicennia marina* (Timer) was the dominant mangrove species of Indus Delta; however, in Port Qasim mangroves, *Rhizophora mucronata* mixed with *Avicennia marina* was sited to have been planted by Sindh Forest Department.

b) Another species of mangrove, *Agiceras corniculatum* , has also been planted by Sindh Forest Department in Shah Bandar.

c) In Bandal island, two salt bush species, *Arthocnemum indicum* and *Allurops lagopoides*, the former with dominance, along with *Prosopis juliflora* (Shrub) and Ipomeal bilobe (creeper) were found.

d) One of the confusion class that was thought to be some species of mangrove other than *Avicennia marina* or saltbush was surprisingly found to be an algae, *Enteromorpha spp*. Enteromorpha appears bright green due to the presence and vigour of chlorophyll and has thin ribbon-like strands, spread over a large area. *Enteromorpha spp*. was spread over hundreds of hectares on the mudflats and the recent growth of this huge land cover class could possibly be due to high inflow of nutrients into the creek areas.

e) Another interesting observation in this area was the presence of *Porteresia coarctata* (soan grass) over the mudflats. Soan grass was not identified effectively from the satellite imagery due to its low vigour in chlorophyll and a relatively coarser spatial resolution of satellite data as compared to its subtle spectral response.

f) One of the major threats observed during ground visits was the indiscriminate camel grazing taking place all over the area. This could be one of the reasons for sparseness in the canopies as seen through satellite imagery. Browsing line indicated the same during ground visits.

g) Extensive cutting of mangrove forests and camel grazing were observed to be the main causes of mudflat erosion or presence of sand.

h) Industrial and domestic waste (from Layari River) in the surroundings of Karachi may threaten mangrove extinction.

i) Terrestrial vegetation, *Prosopis juliflora* (mesquite), was also observed during the field survey that may be due to the debris carried with black water from Layari River.

j) One of the key observations was that the outer peripheries of the mangrove islands were often covered with dense and tall mangrove trees that reduce in size and density moving inland and ultimately become mudflats (sand/Mud) in the centre of the islands.

Image analysis

There are various methods that can be used to generate land cover using satellite imagery. However, forest cover maps have been derived from the methods that are more effort-intensive than others (Jensen, 2007; Lillisand *et al.,* 2007). At the outset of this study, it was decided that applying a semi-automated (i.e. computer-assisted) classification technique would be more appropriate to this exercise for a variety of reasons. First of all, applying an automated technique would require less time and also be less interpreter-dependent than attempting a visual interpretation of the imagery, which would require an excessive number of hours for digitizing (i.e. tracing the outlines of) land cover features. The time that would have been required to digitize 6 images, each spanning 22,000 km^2, would have been impractical. Furthermore, performing an automated classification such as supervised classification is considered to be desirable to repeat similar activities after a sufficient time period to monitor the state of the forest in future. The training areas can easily be used, as well as refined (if new information is available), in future exercises of a similar nature (Cherrington *et al.,* 2010)

In the present study multi-scale Object Based Image Analysis (OBIA) was performed to develop the satellite image based land cover maps of the study sites. OBIA has emerged a decade before as a promising methodology to extract objects of interest (or information) from satellite images, particularly high resolution satellite images. Unlike the conventional “pixel-based methods” which only use the layer pixel values, the “object-based techniques” can also incorporate shape, texture and contextual information of the image objects. These extra features associated with image objects have proved to be very useful to recognize surface objects (Abbas *et al.,* 2010). Typically an “Object Based Image Analysis” starts with the crucial step of *Image Segmentation*, in which meaningful image objects are created and then these image objects are classified in the later step of classification (Blaschke, 2010). OBIA combined with nearest neighbour classification algorithm and rule-based methods have proven to be best classification methods to map mangroves cover distribution (Kamal & Phinn, 2011).

In the present analysis the following steps of *Definien Developer 7.0* (commercial software available for object based classification) were carried out throughout the process of land cover classification: a) Multi-resolution Segmentation; b) Hierarchical Classification; c) Classification based Segmentation and; d) Inspection of classification and Manual Editing.

A hierarchical network with three levels of image objects was created to extract the corresponding land cover features. Segmentation of the image data at fine and coarse scales is important in object-based multi-scale analysis in order to extract boundaries of the dominant objects occurring at corresponding scales (Mallinis *et al.,* 2008). Image segmentation with various combinations of parameters (Scale, shape and compactness), was performed and analyzed. After a number of trials, three optimum scales were determined by visual inspection of segmentation results to construct image segmentation hierarchy (Table 3). Once appropriate scale factors were identified, the colour and shape criterion were modified to refine the shape of the image objects. Most published works have found that more meaningful objects are extracted with a higher weight for the colour criterion (Mathieu *et al.,* 2007).

Following the segmentation hierarchy from a plethora of image object attributes, 'Mean Object Value', relation to super object, and hierarchy were considered to be potential sources of information for the classification procedures.

Accuracy assessment

Classification accuracy assessment is another area that is continuing to receive growing attentions among remote sensing specialists (Lillesand *et al.,* 2004). It is a process to determine the agreement between the selected reference material and the classified data. The importance of accuracy assessment is embodied in the expression "A classification is not complete until its accuracy is assessed". The most commonly used method of representing the degree of accuracy is to prepare a classification confusion matrix (often known as error matrix or a contingency table) (Lillesand *et al.,* 2004; Mather, 2004).

To determine the degree of error in the end product (classification results), a '*K* x *K* confusion matrix' was generated using *'Definiens'*. Error matrices that describe the patterns of mapped class relative to reference data were generated. Image objects were considered as basic validation units because, individual pixels cannot be considered as independent objects (because of autocorrelation effects) and could potentially bias the classification assessment (Mathieu et al., 2007). Descriptive statistics (user's accuracy, producer's accuracy, overall accuracy and Kappa Coefficient) were computed and analyzed for each site to assess the accuracies of the classification maps (Lillesand et al., 2004).

Results and discussion

Land cover maps of the five study sites were developed using object based image analysis. Description and statistics of each land cover map is discussed in the following sub-sections, one by one.

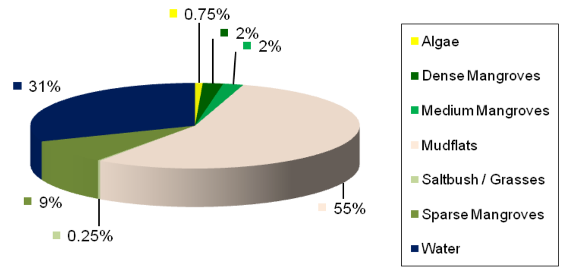

Fig. 3. Land cover distribution of Indus Delta.

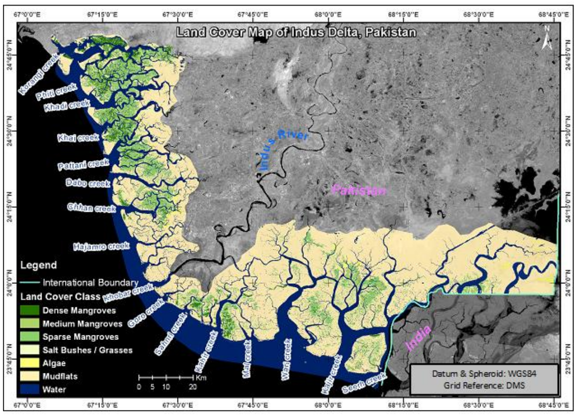

Fig. 4. Land cover map of Indus Delta.

Land cover analysis of Indus delta

Seven major land cover classes were delineated in Indus Delta, viz., Dense Mangroves (canopy cover >70%), Medium Mangroves (canopy cover >40%), Sparse Mangroves (canopy cover < 40), Salt Bushes / Grasses, Algae, Mudflats (all non-vegetated area other than water), and Water. Fig. 4 depicts the thematic output of the land cover analysis of the Indus Delta. The distribution statistics of each land cover class are given in Table 4 and Fig. 3. The entire Indus Delta approximately lies in the Thatta district; therefore, Tehsil-wise distribution of land cover statistics has also been evaluated and is presented in the Table 4 and Fig. 5-6. Land Cover classification, for the year 2008-2009, of 726,625 ha area of Indus Delta shows that the total mangrove cover is 92,411 ha, or about13% of the total area (Table 4).

Table 1. Description of satellite data used.

No.	Satellite/Sensor	Site	Data of Acquisition	Tide Height (m)
1	ALOS/AVNIR-2	Indus Delta	29/02/2008	0.9
2	ALOS/AVNIR-2	Indus Delta	15/04/2008	1.3
3	ALOS/AVNIR-2	Indus Delta	02/02/2009	0.9
4	ALOS/AVNIR-2	Indus Delta	19/02/2009	0.9
5	ALOS/AVNIR-2	Indus Delta	19/02/2009	0.9
6	ALOS/AVNIR-2	Indus Delta & Sandspit	05/03/2008	1.8
7	ALOS/AVNIR-2	Kalmat Khor	31/01/2009	1.8
8	ALOS/AVNIR-2	Miani Hor (Sonmiani bay)	19/09/2008	0.9
9	ALOS/AVNIR-2	Jiwini (Gwatar Bay)	01/02/2008	1.1

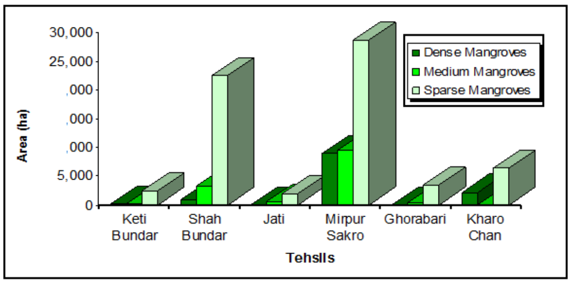

Fig. 5. Tehsil-wise Mangrove Cover distribution.

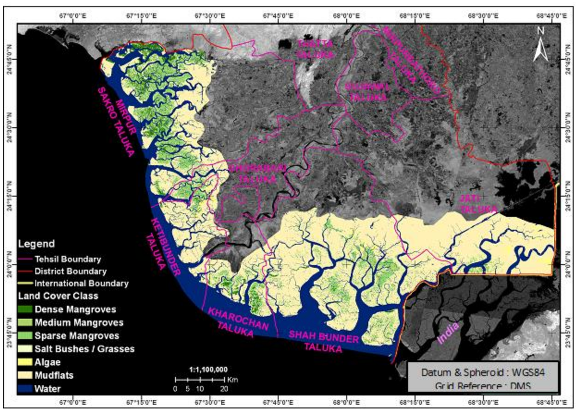

Fig. 6. Mangroves cover map of Thatta District, Indus Delta.

Tehsil-wise distribution of Indus Delta mangrove cover in Thatta district

The total mangrove cover in the Thatta district is 92,124 ha. Within the mangrove cover, 14% is classified Dense Mangroves (12,503 ha), 15% is classified as Medium Mangroves (13'917 ha) and 71% is classified as Sparse Mangroves (65,704 ha). Mirpur Sakro Tehsil has 47,127 ha of mangrove which is the highest mangrove cover amongst all six tehsils (table 5).

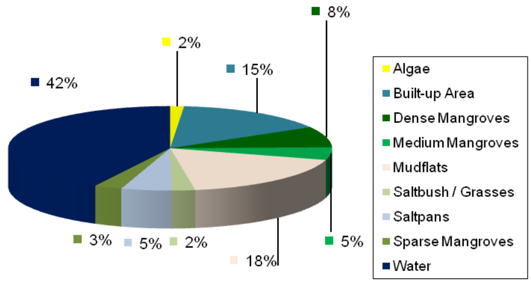

Fig. 7. Land cover distribution of Sandspit.

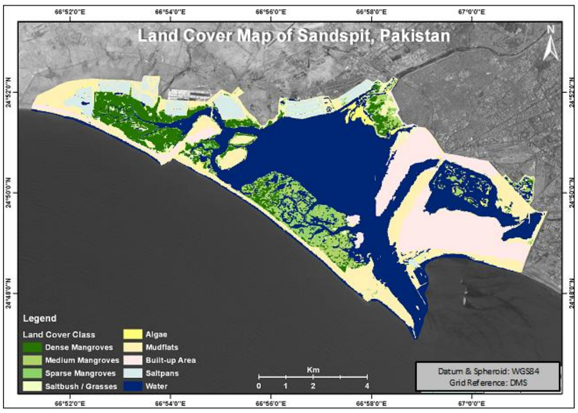

Fig. 8. Land Cover Map of Sandspit.

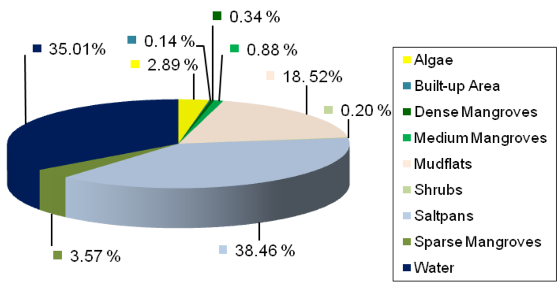

Fig. 9. Land cover distribution of Sonmiani.

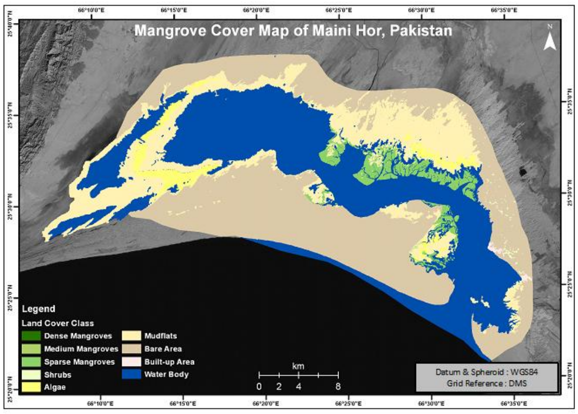

Fig. 10. Land cover map of Sonmiani (Miani Hor)

Table 2. Results of geometric correction.

Image Date	No of control points	RMSE (m)
29/02/2008	29	0.9
15/04/2008	31	0.69
02/02/2009	36	0.71
19/02/2009	41	0.76
19/02/2009	35	0.81
05/03/2008	42	0.89

Table 3. Parameters used for segmentation hierarchy.

No.	Level	Scale Parameter	Shape	Compactness
01	L1	40	0.15	0.9
02	L2	25	0.05	0.5
03	L3	10	0.05	0.5

Land cover analysis of Sandspit

In the thematic map of Sandspit (Fig. 8), nine land cover/land use classes identified from the analysis of satellite images are; Dense Mangroves (canopy cover >70%), Medium Mangroves (canopy cover >40%), Sparse Mangroves (canopy cover <= 40), Salt Bushes / Grasses, Algae, Mudflats (all non-vegetated area other than water, Saltpans and Built-up Area), Saltpans, Built-up Area and Water. From the analysis of the land cover map it was observed that the total mangrove cover in the area is 1056 ha, out of which dense mangrove cover is about 540 ha (51%), medium mangrove cover is about 328 ha (31%), while sparse mangrove cover is about 188 ha (18%) (Fig. 7 and Table 6).

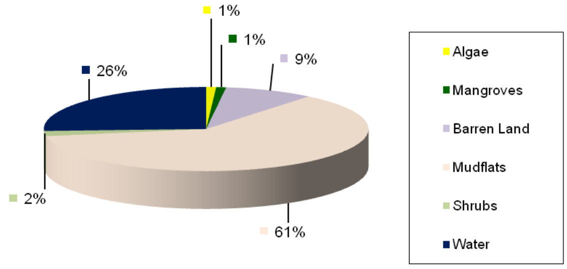

Fig. 11. Land cover distribution of Kalmat Khor.

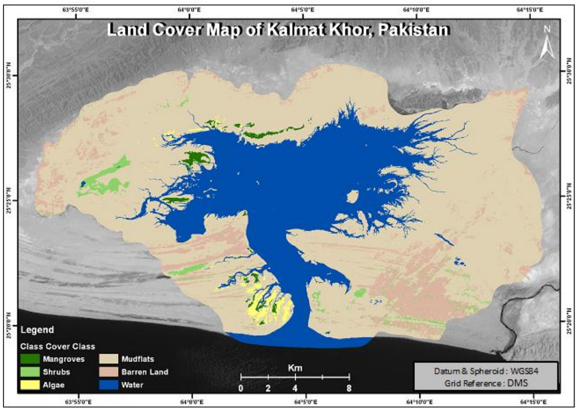

Fig. 12. Land cover map of Kalmat Khor.

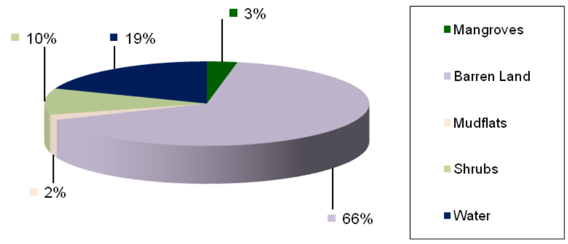

Fig. 13. Land cover distribution of Jiwini.

Land cover analysis of Miani Hor (Sonmiani)

From the analysis of the land cover (Fig. 10), it is noted that the total mangrove cover in the area is about 4020 ha out of which dense mangrove cover is about 283 ha (7 %), medium mangrove cover is about 738 ha (18.35 %), and sparse mangrove cover is about 2997 ha (74.5 %) (Fig. 9 and Table 7). The largest mangrove patch occurs in the northern shore of the Miani Hor, which is fed by the Porali River that carries rain water from the Pub range catchment.

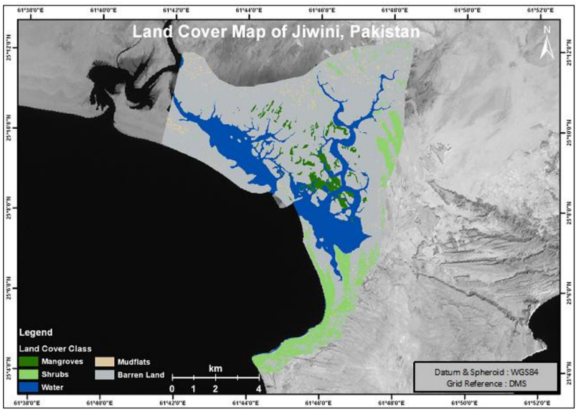

Fig. 14. Land cover map of Jiwani (Gwadar Bay).

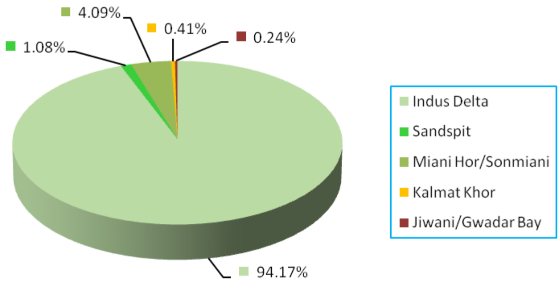

Fig. 15. Mangroves cover distribution among the study sites.

Table 4. Distribution statistics of land cover classes of Indus Delta.

Land Cover Class	Area (ha)	Percentage Area
Dense Mangroves	12,679	2
Medium Mangroves	13,944	2
Sparse Mangroves	65,789	9
Saltbushes / Grasses	2,356	0.25
Algae	5,449	0.75
Mudflats	398,288	55
Water	228,120	31
Total	**726,625**	**100**
Total Mangroves Cover	**92,411**	**13**

Land Cover Analysis of Kalmat Khor

Mangroves in Kalmat Khor are not widely distributed over a large area. Instead they are distributes in small and fragmented patches, mainly on the northern end of the bay and in the lateral creeks at the mouth of the bay.

Table 5. Tehsil –wise Land cover distribution in Thatta District (areas in ha).

Land Cover Class	Keti Bundar	Shah Bundar	Jati	Mirpur Sakro	Ghorabari	Kharo Chan	Total
Dense Mangroves	299	864	44	8,967	102	2,226	12,503
Medium Mangroves	175	3,328	580	9,450	382	1	13,917
Sparse Mangroves	2,490	22,560	1,997	28,709	3,519	6,428	65,704
Mudflats	33,973	168,033	97,748	61,345	10,369	0	371,468
Salt Bushes / Grasses	13	57	6	2,193	8	4	2,281
Algae	1,373	1,003	2,077	695	312	0	5,459
Water	33,465	82,617	13,584	57,866	4,527	34,668	226,727
Total	71,789	278,462	116,036	169,227	19,218	43,327	698,059
Total Mangrove Cover	**2,965**	**26,752**	**2,621**	**47,127**	**4,003**	**8,655**	**92,124**

Table 6. Statistical distribution of land cover classes of Sandspit

Land Cover Class	Area (ha)	Percentage Area
Dense Mangroves	540	8
Medium Mangroves	328	5
Sparse Mangroves	188	3
Saltbush / Grasses	157	2
Algae	94	1
Mudflats	1224	18
Built-up Area	1037	15
Saltpans	341	5
Water	2874	42
Total	**6783**	**100**
Mangroves Cover (total)	**1056**	**16**

Table 7. Statistical distribution of land cover classes of Miani Hor (Sonmiani)

Land Cover Class	Area (ha)	Percentage Area
Dense Mangroves	283	0.34
Medium Mangroves	738	0.88
Sparse Mangroves	2997	3.57
Shrubs	164	0.20
Algae	2419	2.89
Mudflats	15525	18.52
Bare Area	32245	38.46
Built-up Area	117	0.14
Water Body	29354	35.01
Total Mangroves Cover	**4020**	**4.79**
Total	**83846**	**100.00**

Table 8. Statistical distribution of land cover classes of Kalmat Khor

Land Cover Class	Area (ha)	Percentage Area
Algae	491	1
Barren Land	4951	9
Mudflats	34414	61
Shrubs	963	2
Water	14712	26
Mangroves	**407**	**1**
Total	**55938**	**100**

Table 9. Statistical distribution of land cover classes of Jiwani (Gwadar Bay)

Land Cover Class	Area (ha)	Percentage Area
Barren Land	5238	66
Shrubs	830	10
Water	1515	19
Mudflats	183	2
Mangroves	**235**	**3**
Total	**8001**	**100**

Table 1. Summarized mangrove cover statistics

Mangroves Status in Pakistan					
Site Name	**Mangrove Cover** (ha)				
	Dense	**Medium**	**Sparse**	**Sub-Total**	**Cover (%)**
Indus Delta	12,679	13,944	65,789	9,2412	94.17
Sandspit	540	328	188	1,056	1.08
Miani Hor/ Sonmiani	283	738	2,997	4,018	4.09
Kalmat Khor		407		407	0.41
Jiwani/ Gwadar Bay		235		235	0.24
Total Mangroves		98,128			100.00

Table 11. Summary of accuracy assessment

Site	No. of Samples	Overall Accuracy	Kappa Coefficient
Indus Delta	184	80.2	0.71
Sandspit	58	84.6	0.74
Kalmat Khor	76	80.5	0.76
Miani Hor	48	78.9	0.69
Jiwini	39	83.8	0.73

Analysis of the land cover map of Kalmat Khor depicts that the total mangrove cover in the area is about 407 ha (Fig. 12). Some of the large patches of vegetation are classified as algae on the northwestern and western sides of the study and comprise an area about 491 ha; whereas, the remaining land cover classes are, Bare Soil, Bare Soil/Rocks, Mudflats, Shrubs/Mesquite, and Water. Statistical distribution of each land cover class is given in Table 8 and Fig. 12.

Land cover analysis of Jiwani (Gwadar Bay)

From the analysis of the land cover map (Fig. 14) it can be observed that the total mangrove cover in the area is about 235 ha, while the remaining classes are Barren Land (bare rocks in the north of the lagoon and bare soil around the lagoon), Shrubs (mesquite, saltbush, grasses and shrubs), Water, and Mudflats (Fig. 13 and Table 9).

Mangroves cover statistics of Pakistan

The study covered the assessment and monitoring of mangrove forests along the Makran coast of the Balochistan Province, including Sonmiani Bay, Kalmat Khor and Jiwani as well as the entire Indus Delta within the Sindh Province from Sandspit to Sir Creek.

It is estimated that total mangrove forest cover is around 98,128 ha, out of which 93,468 ha (or 95. 25%) of the forest exists along the Indus Delta (92,412 ha) and Sandspit (1056 ha) in the Sindh province, whilst the remaining 4.75% (4,660 ha.) occurs along the Makran coast in 3 isolated pockets at Sonmiani Bay (4,018 ha), Kalmat Khor (407 ha) and Jiwani (235 ha) (Table 10; Fig. 15).

The results of classification assessments derived from confusion matrices are listed in (Table 11). The overall accuracies of the five sites, Indus Delta, Sandspit, Kalmat Khor, Miani Hor, and Jiwini are indicated as 80.20 %, 84.6 %. 80.50 %, 78.90 % and 83.8 % respectively. The results also indicated that 'sparse mangroves' are confused mainly with 'Mudflats'. "Grasses" are also confused with 'Sparse Mangroves'. Most of the vegetation communities had higher user's and producer's accuracy.

Conclusions

The mangrove forests of the Indus Delta region are under great stress due to human interventions and environmental degradation. This article is intended to fulfil the need to map this ecosystem on a continuing basis. Remote Sensing & GIS based techniques have been employed and land cover thematic maps showing different densities of mangrove forest (dense, medium and sparse) and other coastal features, particularly algal mats, mudflats, etc., have been prepared at 1:25,000 scale and mangrove forest cover was estimated accordingly. This study is based on the best available medium resolution data of ALOS-AVNIR-2 (10 m resolution), so far the largest scale and up-to-date estimation of the mangrove cover of Pakistan. Mostly, publically available studies are based on Landsat MSS and TM and / or ETM + data set. Object based analysis of mangrove cover is more realistic than pixel-based estimation, particularly in defining the density classes of mangroves. These density classes are self-explanatory in terms of mangrove cover area and will be very useful to compare with other pixel-based methods as well. For example, medium density mangrove objects are defined as areas with mangrove trees cover from 40 % to 70 % of the object size. This literal definition is more helpful in clearing the confusion of horizontal distribution of mangrove cover. However, due to mixed plantations, it had been difficult to distinguish between different mangrove species grown in the same parts of Indus Deltaic region. It is to be noted that the satellite sensors can discriminate mangrove zonation on the basis of canopy cover but discrimination between different species under prevailing environmental conditions cannot be made. The detailed maps at 1:25,000 scale, with Minimum Mapping Unit of 0.5 hectare for the mangrove cover in corresponding sub-district administrative regions, have also been prepared as significantly important and useful sources of information regarding rehabilitation and/or conservation of mangrove forests. These maps could help the Coastal Forest

Division in identifying appropriate sites for plantation of mangroves in barren areas of the delta because a large portion of the mud flats near the mouth of Indus River and in the upper eastern part of delta are barren. This study will significantly contribute in providing an up to date and comprehensive assessment of mangrove forest of Pakistan which can serve as a baseline for MMF initiatives in Pakistan, and will also comply with GEAS (Global Environmental Alert Service) objective in devising sustainable management while fulfilling the knowledge gap to address new and emerging challenges of coastal communities' development.

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