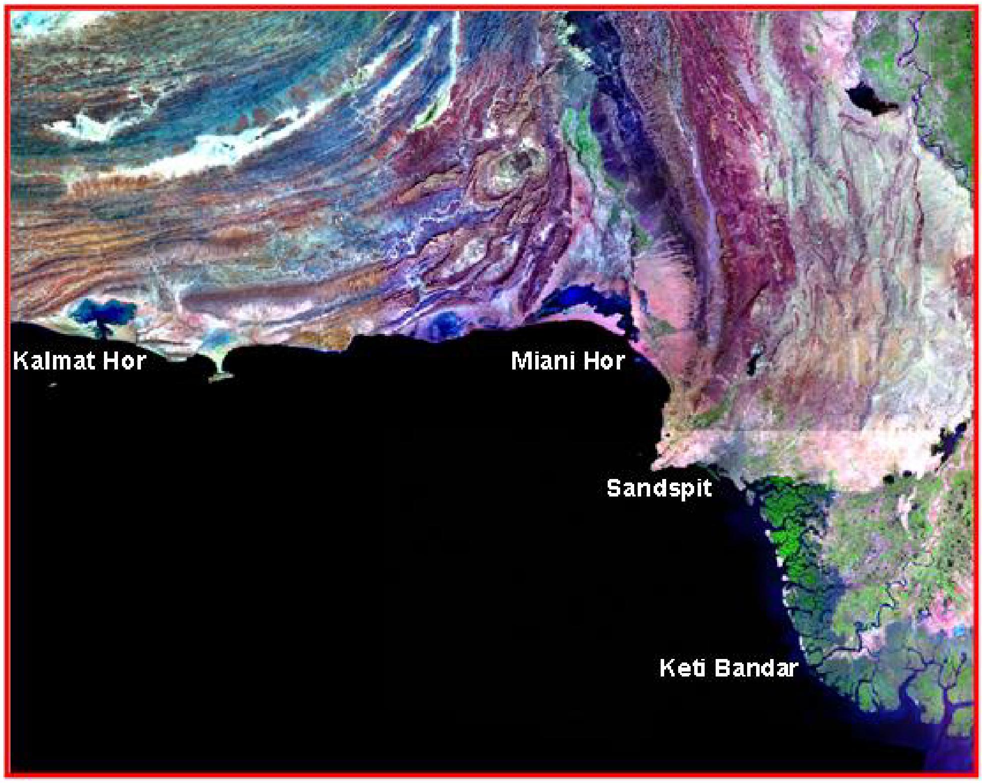
GIS/Remote Sensing based Assessment of Mangroves Resources of selected project sites of Indus Delta and Makran Coast



A technical report submitted to 'Tackling Poverty through Sustainable Livelihood Resources Project'

GIS LAB

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List of Abbreviations

ASTER	Advance Space-borne Thermal Emission Reflection Radiometer
DN	Digital Number
EC	European Commission
ETM+	Enhanced Thematic Mapper
FCC	False Colour Composites
FSMP	Forest Sector Master Plan
GIS	Geographical Information System
GPS	Global Positioning System
IUCN	International Union for Conservation for Nature
MSS	Multi-spectral Scanner
NAVSTAR	Navigation Signal Timing and Ranging
SPOT	System Probatoire d' Observation
SUPARCO	Pakistan Space and Upper Atmospheric Research Commission
TM	Thematic Mapper
US	United States
UTM	Universal Transverse Mercator
WGS	World Geographic Survey
XS	Multi-spectral
WWF	World Wide Fund for Nature

1 INTRODUCTION

Mangrove forest is an integral part of inter-tidal zone of the coastal environment extending throughout the tropics and subtropics of the world (Giri and Delsol, 1993). In Pakistan 8 species of mangroves, belonging to 6 genera and 5 families, have been reported so far (Saifullah, 1983 and Qureshi, 1985). Only four species i.e. *Avicennia marina, Ceriops tagal*, *Aegiceras corniculata and Rhizophora mucronata* are now present along the coastal belt of Pakistan (Qureshi, 1996).

There is a wide spectrum of economic and ecological utility of mangrove forests. These are used in the form of basic forest products such as firewood, charcoal, and as fodder for grazing and browsing of livestock. These forests also serve as breeding and spawning grounds for important fish and shellfish, wildlife habitat, shoreline stabilization and protection against erosion (Keerio, 2004 and Shahid, 2000).

Because of various natural and anthropogenic threats, the extent of mangrove forests has significantly been reduced over the last two decades in Indus Delta and along the Makran coast. These effects are mainly due to the overuse of mangroves for fuel wood, fodder, and grazing particularly camels. Other considerable threats to the Indus Delta are pollution and increasing salinities from industrial effluent discharge from Karachi and the interruption of the flow of the Indus due to the construction of barrages and diversion of water for irrigation. This indirectly reducing input of silt into the system and may have further long term affects (Qureshi, 1985 and Spalding et al, 1997).

To overcome these threats, two large areas within the Indus Delta were declared protected forest in 1958 and are managed by the Sindh Forest Department. In 1977 these areas were further declared as wildlife sanctuaries. There are increasing efforts to establish mangrove plantations and some 50 square kilometres have been planted so far. The remote sensing based analyses conducted by WWF-Pakistan reveal that these efforts remained focused on some easy accessible sites and areas of over exploitation or regions where communities are largely dependent on these natural resources for their survival remained unattended. Moreover, administrative control over protection of creeks and mangroves is more visible near the Karachi and Port Qasim due to the direct economic benefits thus increased mangrove forest cover close to Karachi while there has been an overall trend of decline in the mangroves extent has been observed using remotely sensed data over the period of 8 year i.e. 1992-2000 (Spalding et al, 1997 and Ashraf et al 2004).

Along the Makran Coast, there are three other sites where mangroves do occur out of which Minai Hor holds the largest area covered by this ecosystem. In this region, WWF-Pakistan took initiative of planting mangrove through community participation in their active use zone. Such activity proved effective and sustained as community itself looking after this resource and expanding this plantation through their resources.

1.1 Study Area

Under the current project of "Tackling Poverty of Fishermen Communities through Livelihood Resource" funded by European Commission (EC), four selected areas (two each from Sindh and Balochistan) were chosen for the preservation and restoration of mangrove forest of s. These sites are; Miani Hor and Kalmat Khor along the Makran coast; while Keti Bandar and Sandspit areas lying along the Indus delta.

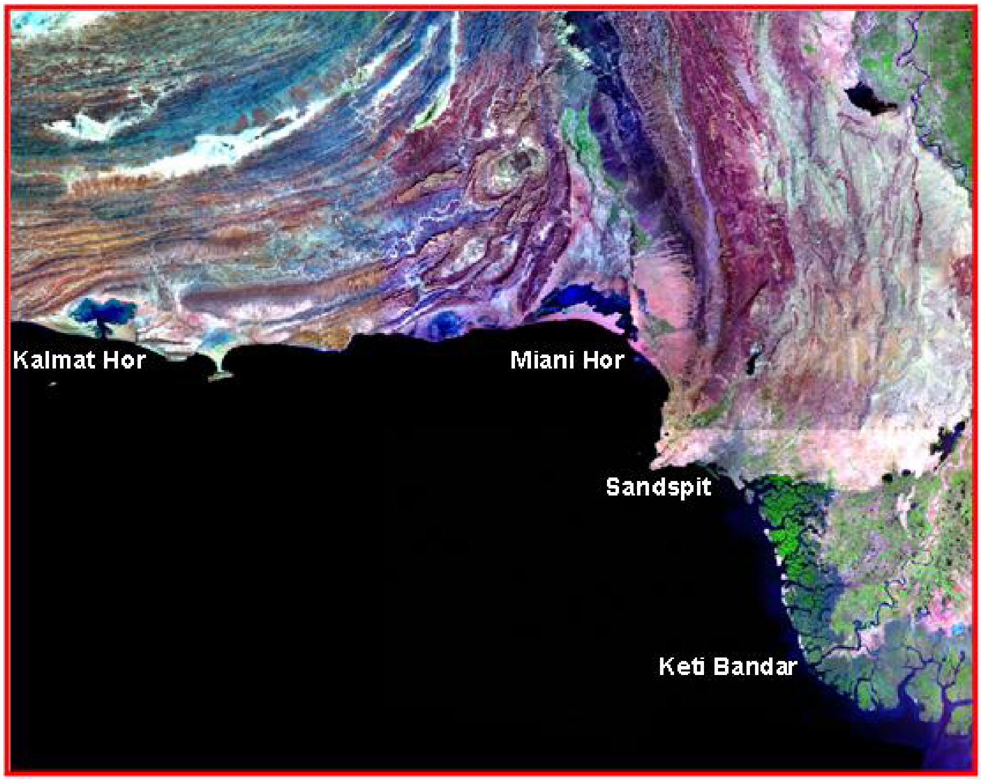

Figure 1: Landsat Satellite Image showing project sites for the mangrove forest estimation

This study covers major mangrove pockets of Pakistan. The coastal climate of Pakistan is typical arid subtropical with a mean annual rainfall of 100 to 200mm. Main vegetation types existing in the project areas are different species of mangroves, *Tamarix sp.*, different species of saltbushes, mixed terrestrial vegetation mainly *Prosopis sp.* and marine algae (Champion et al., 1965 and Qureshi, 1996).

The creeks and mudflats are important areas for wintering, passage 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 Osprey, Shikra, Buzzard, Eagles, Brahminy Kite (*Haliaster indus*), besides passerines, are observed in the areas (WWF, 2002).

1.2 Purpose of Study

In Pakistan, satellite data has been significantly used for the quantification and management of mangroves forest for the last thirty years. But the actual mangrove extent has remained debatable due to the use of different satellite imageries, image processing techniques and the inadequacy in compiling ground truth data about the local species of different vegetation types.

The focus of the current study is two fold, i.e.

1. to map the current extent of mangrove forest, and
2. to identify the changes in the extent using historic remotely sensed datasets.

2 METHODOLOGY

2.1 Satellite Data

Images of varied spatial and temporal resolutions were used to map the forest cover as well as to identify the changes in the forest extent over a certain period of time due to the non-availability of one standard satellite data of one type for all four sites. Moreover, the different sizes of these sites also influenced on the decision of data purchase particularly in terms of its spatial resolution. Preference has been given to acquire data from Terra and Landsat satellites with the emphasis on at least decadal difference of time were used for qualitative and quantitative analysis of the changes in the extent of mangrove forest. High resolution Quickbird satellite imagery for one of the selected sites, i.e. Sandspit was used to develop a representative land cover/forest cover control.

Satellite image processing of tidal biomass is subjective to tide height, as it is affected by the time of the day, season and geographical locations. High tide values may hamper visual interpretation of various features in satellite imagery. Quantification of creek areas, mud flats, algal mats, small mangroves or regeneration areas, saltbush and sandy areas could vary its extent due to the variations in the tidal status. Seasonal variation is another entity that may results in certain discrepancies, as the reflectance of algae in tidal flats is a function of its bloom/phonology and is directly related to the water temperature. So imagery acquired during winter time will certainly reflect more regions of algal existence as compared to images captured during summer time.

For the accurate demarcation and delineation of forest cover changes, identification of best available satellite data was itself lengthy and painstaking job. It is simply not a matter of finding an image and orders it because it costs a lot for some commercially available satellite sensors. The data acquired and ordered compensated both, seasonal/phonological and tidal variations in the project areas. Characteristic details of satellite imagery acquired are shown in Table 1.

Table 1: Tide height data characteristics for the project sites

Project Areas	Satellite Sensor	Acquisition Date	Tide Height (m)
Keti Bandar	Landsat – 5 (TM)	27-04-1992	Not Available
	Terra (ASTER)	24-12-2001	1.3
Miani Hor	Landsat – 5 (TM)	19-10-1989	Not Available
	Terra (ASTER)	12/10/2001	1.8
	Terra (ASTER)	21-05-2001	2.9

Project Areas	Satellite Sensor	Acquisition Date	Tide Height (m)
Kalmat Khor	Landsat – 5 (TM)	29-10-1990	Not Available
	Terra (ASTER)	23-07-2004	1.4
Sandspit	Landsat – 7 (ETM+)	6/10/2001	2
	Quickbird	27-04-2003	2

2.2 Software Used

ERDAS Imagine 8.7 was used for satellite image processing, classification and data transformation, whereas ARC View 3.1 was used for the onscreen digitization of different forest cover features and for the map formation. For word processing, graphs and databases MS WORD and MS EXCEL were used.

2.3 Data Preparation

Initial satellite image processing was applied on all the datasets from Quickbird, Landsat and Terra before conducting assessment of forest cover and change detection in mangrove forest areas. Rectified Terra satellite data were acquired in geographic coordinate system. For accurate area estimation, quantification and to develop a synergy of the delineated polygons from satellite imageries, all satellite data were re-projected into metric coordinate system (i.e. Universal Transverse Mercator - UTM) and WGS 84 datum, according to their relevant zones (See Appendix 1 for more details).

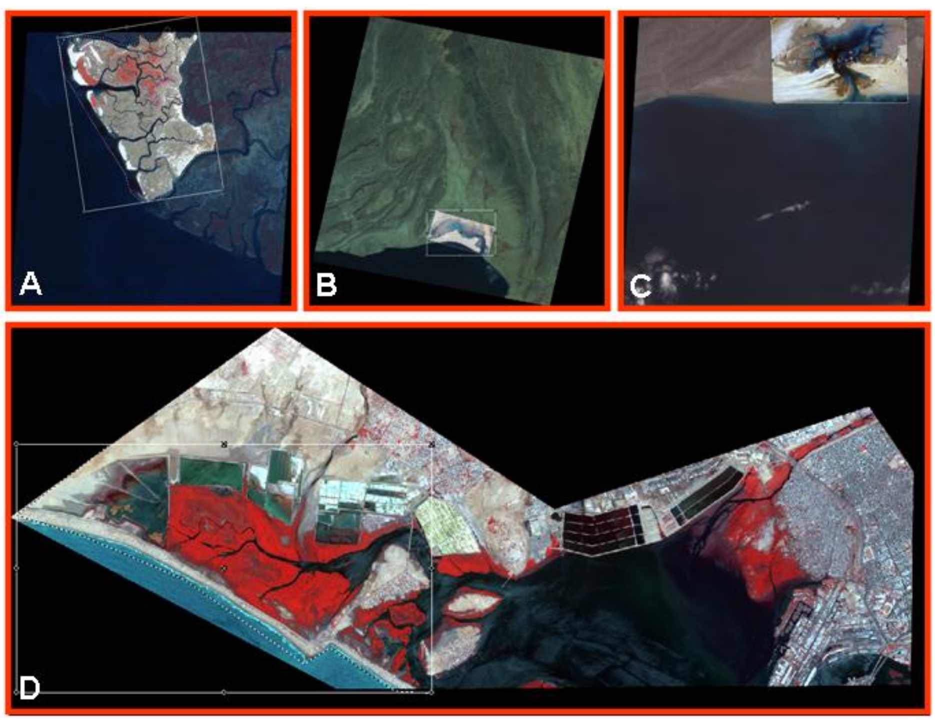

Figure 2: Satellite images highlighting study areas (a) Keti Bandar, (b) Miani Hor, (c) Kalmat Khor and (d) Sandspit

As these images were covering larger regions than the study areas, these satellite images were truncated on required extents for the project sites as shown in (Figure 2) for Keti Bandar, Sandspit, Miani Hor and Kalmat Khor.

Due to inherent low contrast, satellite data require enhancement using different image enhancement algorithms. Keeping in view the subjective land cover, *Histogram Equalize* and *Standard Deviation Stretch* (see Appendix 1) were applied for the extraction of meaningful information regarding different land cover classes, as shown in Fig 3.

Similar enhancement processes were performed for other data sets to achieve a better contrast for the spectral and visual digital mapping of mangroves and other related land cover classes comprising of mud flats, algae, and saltbush.

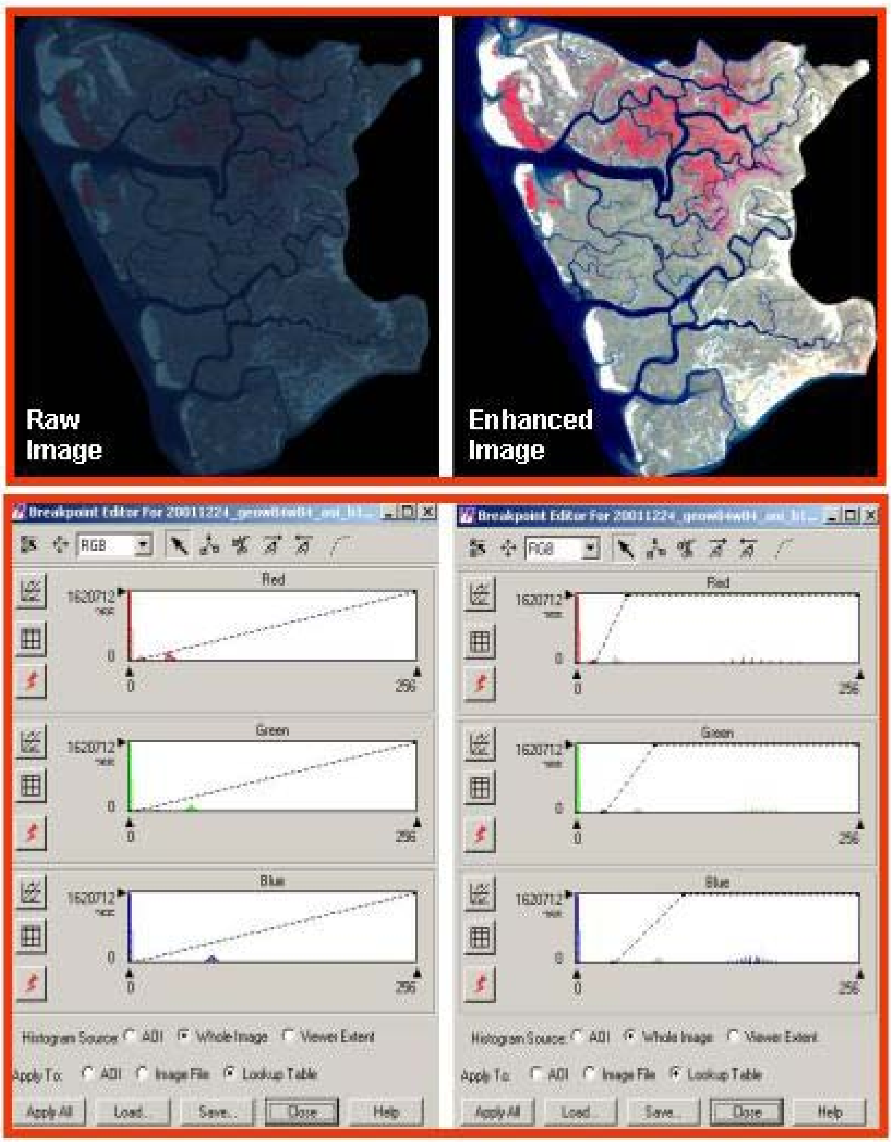

Figure 3: Comparison of raw & enhanced satellite images of Keti Bandar with corresponding histograms

Different band combinations were used, both visually and spectrally to extract the mangrove forest extents. Landsat satellite data provides optimum information about vegetative cover in band combinations 432 and 542 when shown in Red, Green and Blue respectively. Terra satellite data exhibits maximum spectral response to show vegetation details in the band combination of 3N21 when presented in Red, Green and Blue as shown in Fig 4.

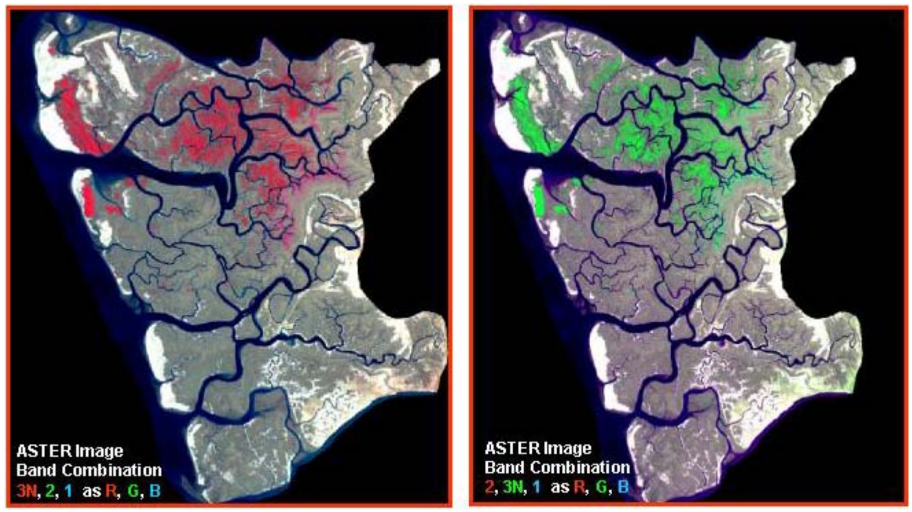

Figure 4: Terra satellite image, showing enhanced imageries with different band combinations

Instead of relying only on the traditional satellite image based maps for the field based verifications of different features, thematic maps were also developed using supervised classification technique (Appendix 1) for all the sites using latest satellite images. To identify the problem areas and unusual spectral tones in the images, this technique was preferred. Other scientific parameters like spectral signatures, scatter-plots, histograms (Appendix 1), visual interpretation tools, and some of the ancillary data like tide-heights at the time of satellite data acquisition from different recording stations also facilitated in developing these thematic maps. On the other hand, Quickbird satellite image for the Sandspit area was used for the ground verification of different spectral tones. Preliminary land cover for the ground truthing was preferred for the areas where medium resolution satellite data i.e. ASTER was available.

2.4 Preliminary Landcover Mapping for Field Surveys

After data preparation, the next important step was to analyse data to find certain areas where before field based investigations are required. To achieve this, un-supervised classification of satellite data was performed and confusion classes were identified.

2.4.1 Keti Bandar

Thematic map of Keti Bandar showed hundreds of hectares as a confusion class where spectral tone in the image was very different form elsewhere and had not been visited or sighted in previous studies.

This land cover class had a smooth texture with reddish pink to light pink tinge different than mangroves reflectance. Spectral signatures of this area showed the presence of some vegetative content, having a high peak, corresponding to a greater reflectance in infrared and green parts of electromagnetic spectrum as shown in Fig 5. Another interesting fact about this confusion class was that it did not exist in satellite data of 1992. This led to visit this site to explore more about the vegetative cover of this region.

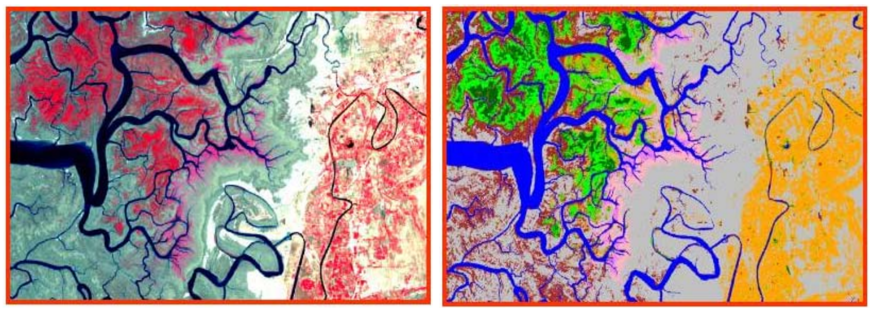

Figure 5: Satellite data and landcover, showing problematic spectral tones in Keti Bandar

2.4.2 Miani Hor

Thematic map of Miani Hor was generated using Terra satellite data, which covered the whole of the project area in two side-by-side scenes. Therefore both scenes were processed separately for the development of landcover thematic layers and exhibited almost similar spectral behaviour for the identification of problem class as shown in Fig 6.

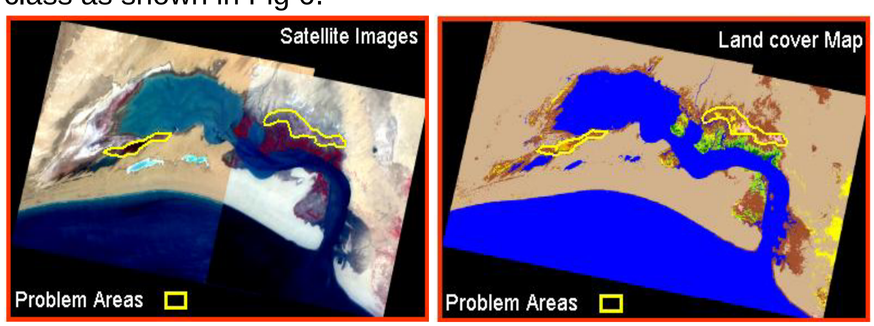

Figure 6: Satellite data and land cover map showing problem areas of Miani Hor

In these images and derived thematic maps, a band of unusual spectral tones was identified which mostly existed in the northern extents of the images, while another un-usual tone was identified in the south-western part of the imagery. These two areas were selected for the ground verification for the development of land cover classes. Some of the prior observations about the problem areas based on the spectral tones and the texture in the image showed the absence of mangroves in the area.

2.4.3 Kalmat Khor

Kalmat Khor lies in the east of Pasni along Makran coast. Mangrove forests in this area are not much different in terms of spectral character, but there exists some unusual spectral tones as shown in Fig 7 in the imagery that were required to be verified for development of land cover maps.

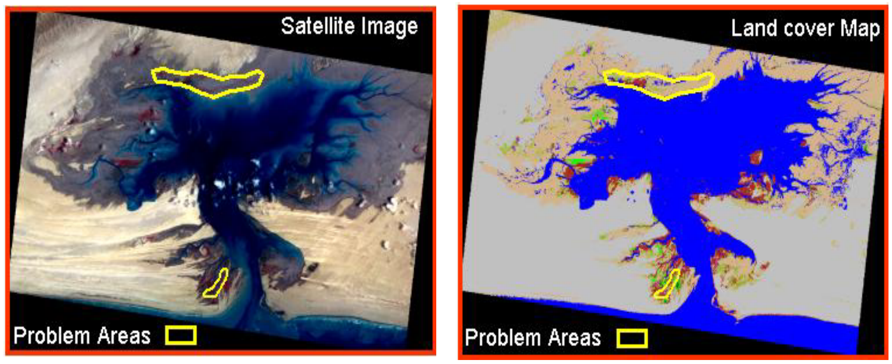

Figure 7: Satellite data and landcover map showing problem areas of Kalmat Khor

In this image, some areas with high spatial frequency were identified appearing in the shade of maroon. On the basis of already conducted studies and ground surveys, these areas appeared quite similar to the landcover class of algae but certainly needed confirmation through ground visit.

2.4.4 Sandspit

The data used for Sandspit region was taken from hi-resolution Quickbird satellite which was providing enough visual comprehension. Its preliminary landcover mapping for ground truthing was not significantly required to identify any confusion class as compared to medium to low resolution satellite data due to its high resolution characteristics. So ground truth survey was directly conducted for this area.

2.5 Ground Truth Surveys

Main objective of the ground truthing[1] was to correlate the reflectance abnormalities as identified from satellite data and from the preliminary land cover maps with the ground reality. Ancillary

[1] Ground truthing refers to the acquisition of knowledge about the study area from fieldwork, analysis of aerial photography, personal experience etc (Schradar and Pouncy, 1997).

data i.e. ground truth geo-coded data using Global Positioning System[2] (GPS) receiver and digital/analogue photographs of landscape was incorporated for the project sites.

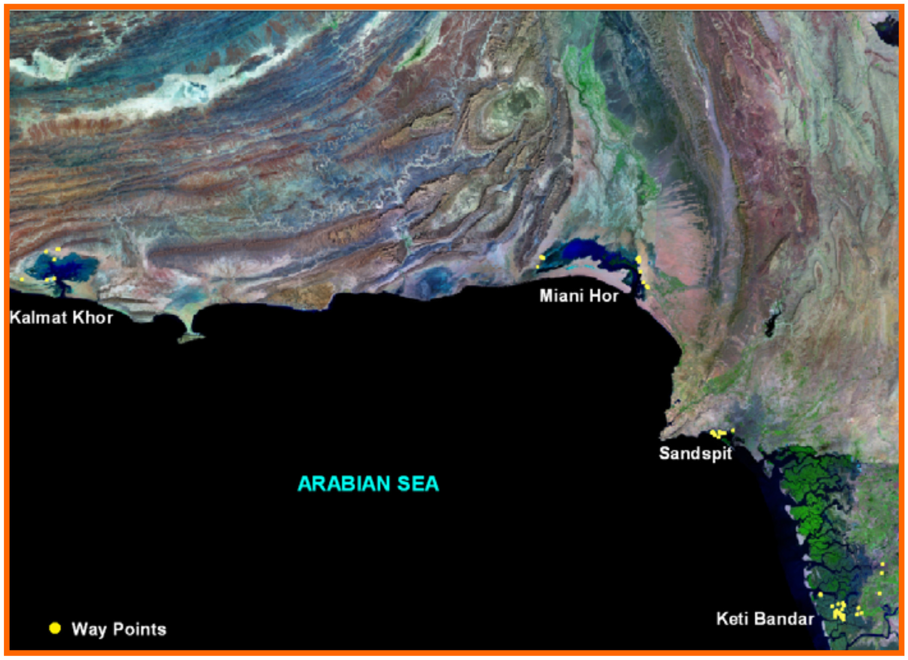

Figure 8: Satellite image showing waypoints collected during ground truth data

A-3 sized field maps of Terra satellite data with False Colour Composites (FCC of band 3N, 2, 1)[3], and thematic Maps, were developed for Keti Bandar, Miani Hor and Kalmat Khor, while for Sandspit area due to availability of Quickbird high resolution satellite data, A-2 sized field maps (FCC of band 432) at 1:5000 and 1:2500 scales, were used for ground truthing. These maps were printed at two different extents, one, showing whole of the project site and others with zoomed in parts of problematic tonal variations.

Ground surveys for all the sites were arranged and conducted by the GIS team and field staff of WWF-Pakistan in three different stages. During these visits a total of 72 ground truth locations were visited and verified by taking waypoints, using Garmin III plus GPS receiver, with all the necessary contextual details (Appendix 2).

Natural Resource Use maps of all the project sites were also developed by incorporating data provided by the local people and

[2] The Global Positioning System, usually called GPS (the US military refers to it as NAVSTAR GPS - Navigation Signal Timing and Ranging Global Positioning System), is a satellite navigation system used for determining one's precise location and providing a highly accurate time reference almost anywhere on Earth.

[3] False-colour Composites (FCC) images are used to increase the interpretability of the data. False colour composite of ASTER data in which band 3N, 2, 1 are represented in red, green and blue spectral ranges respectively enhancing the interpretation of vegetative biomass by presenting it in varying tones of red.

WWF field staff. These maps show habitat of dolphins, cranes, flamingos, fishery ground inhibiting major fish species, camel grazing sites and mangrove foliage cutting areas (Appendix 3).

2.5.1 Ground Truth Survey Findings for Keti Bandar

During this field visit two of the major creeks of Keti Bandar, (Hajamro creek and Chann creek) were visited for the identification of some of the variant spectral tones for the representative forest / Landcover classes, as identified through pre-visit Landcover maps. Using local area knowledge from local fishermen and incorporating ASTER satellite imagery acquired on 24th December, 2001, 32 GPS waypoints were collected and following observations were made:

a. One of the confusion class, that was thought to be some species of mangroves 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 (Fig 11). *Enteromorpha spp.* was spread over hundreds of hectare on the mudflats and the recent growth of this huge landcover class could possibly be due to high inflow of nutrients into the creek areas.

b. Another interesting observation in this area was the presence of *Porteresia coarctata* (soan grass*)*, over the mudflats. Soan grass wasn't identified effectively from the satellite imagery due to its low vigour in chlorophyll and a relatively coarser spatial resolution of satellite data as compare to its subtle spectral response (Fig 12).

c. One of the major threats observed during ground visit 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 visit (Fig 9,10)

d. Extensive cutting of mangroves forest and camel grazing were observed to be the main causes of mudflat erosion (Fig 9, 10, 13).

Figure 9: Camel browsing line through mangrove patches, as observed in Keti Bandar area

Figure 10: Camel, one of the major threats to mangroves as well as mudflat stability, resulting in erosion

Figure 11: Algal mat, spread over hundreds of hectares, observed in the Keti Bandar area

Figure 12: Soan grass spread over mudflats, interspersed with patches of saltbush

Figure 13: Forest cutting, resulting in open mudflats, stunted growth of the trees are visible in the photograph

2.5.2 Ground Truth Survey Findings for *Sandspit*

During this field visit the main purpose was to correlate reflectance abnormalities in satellite imagery with existing land-cover classes. Due to availability of high-resolution satellite data, an attempt for identifying pure patches of tall, medium and small mangroves along with the regeneration was made. Using local area knowledge from local fishermen and by incorporating high-resolution satellite imagery, 15 GPS waypoints were collected and following observations were made.

a. Tallest mangroves were present along the banks of tidal creeks. With increase in distance away from the creek, reduction in the height of mangrove stands was observed. Mangroves were dense along the channels due to proper flushing of the salts and become sparser as distance from the bank of the creek increases due to less availability/poor drainage of water/stagnant water over the mudflats. It might also be due to lopping pressure on mangroves, which are closer to the habitations.

b. The observed height of the mangroves ranges from 4 to 6 metres along the creeks and at the outer peripheries of the mudflats and 1.5 to 2 metres from the outer periphery to inner of the mudflats. Young mangrove stands were 60 to 90 cm in height.

c. Regeneration was observed in swampy/poorly-drained areas and at some places density of regeneration was quite high.

d. Floating Algae were observed at the fishponds and around the abandoned saltpans. While some of the Algae were also observed along the outer slopes of the mudflats.

e. Patches of dead algae were observed mainly on the mud and rarely on water that give greenish black tinge in the image.

f. Patches of saltbush found on ground during field surveys and over satellite data were observed to be at higher parts of mudflats generally lying away from the creeks in water deficient areas.

g. *Avicennia marina* was observed as a dominating species of mangroves in the Sandspit area.

2.5.3 Ground Truth Survey Findings for Miani Hor

Ground truth survey at Miani Hor was accomplished in two stages. During these visits 14 waypoints in first survey and 03 points in the second, were collected for the identification of variant spectral responses. Terra satellite based ASTER data which was acquired on 21st May, 2001, used to developed preliminary landcover map to collect ground truth data.

a. In the north-eastern parts of the outer periphery of Miani Hor two bands of different spectral tones were recorded as saltbush and dead algae in inner and outer bands respectively.

b. Western part of the Miani Hor was visited for identifying one of the variant spectral tones in the imagery. Surprisingly, pattern of these spectral tones were quite similar to the one observed in north-eastern part of the Hor for the algae and very sparse saltbush.

2.5.4 Ground Truth Survey Findings for Kalmat Khor

Field survey of Kalmat Khor was conducted both, by land and by sea. Some of the variant tonal abnormalities in northern peripheries of Kalmat Khor were visited and identified as an algal mat, spread over large area in patches. Presence of the algal mat in this form, using remote sensing techniques had not been previously reported in the coastal belt of Pakistan. During this field survey 8 waypoints were collected with the corresponding registration of ASTER data for the problematic spectral tones.

a In the northern parts of Kalmat Khor some of the patches of algal mat were observed under a very thin layer of clear water. This could be a very temporary water flow over the mudflats due to the high tide.

b Areas with the water evaporation were also observed in this outer periphery of Kalmat Khor. This part of the mudflats were not hosting for any kind of vegetative cover and has salt over the surface and was having a high reflectance in the images.

c Some of the sparse mangrove patches with algae in the base were observed and verified as area, causing a bit dark reddish tinge in satellite imagery.

2.6 Development of Forest Cover Maps

Information collected during ground surveys greatly helped in developing accurate forest cover thematic maps. Two different methodologies were employed to develop forest cover thematic maps. These techniques were:

- Onscreen Digitization
- Spectral Classification (performed only for Sandspit region due to the availability of hi-resolution satellite data).

2.6.1 Onscreen Digitising of Different Vegetation Classes

For three of the project sites namely Keti Bandar, Miani Hor, and Kalmat Khor, polygons were delineated from the enhanced images. Different mangrove density classes were developed on the basis of sparseness and closeness of the canopies. Field observations and the pre-visit classified thematic maps were also used to account for the subtle variations in the land cover.

For uniformity in visual interpretation, satellite images were interpreted and analyzed at a scale of 1:10,000 for Terra satellite data, while for the Landsat data to accommodate the lower spatial resolution this delineation was made at a scale of 1: 20,000 as shown in Fig 14.

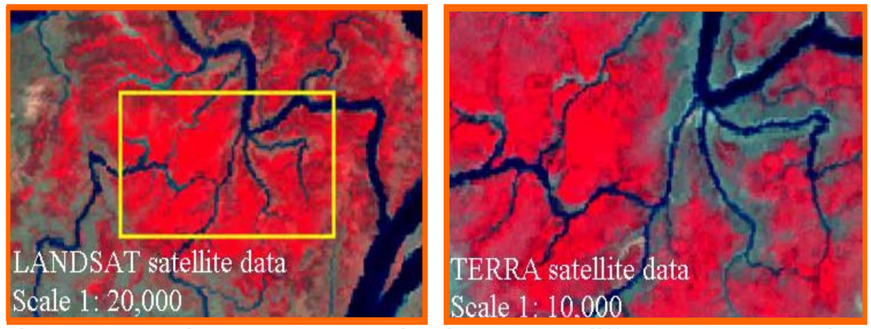

Figure 14: Landsat & Terra satellite data at two different scales used to make different land cover polygons

Number of thematic layers available for delineation in a particular satellite image was dependant on the time of the year as well as the spatial constraints of the satellite data. Terra satellite data provides a better opportunity to identify the land cover classes of algae and saltbush effectively, when compared with Landsat Data.

2.6.2 Coding of Forest Cover Polygons

To populate these digitised polygons, a specific ID based coding mechanism was adopted according to which each of the polygons was assigned with the appropriate ID of the representative class or species. IDs used for the representative land cover classes are shown in the Table 2.

Table 2: Coding used to populate grid-based polygons

ID	Representative Land cover Class
1	Dense Mangroves
2	Medium Mangroves
3	Sparse Mangroves
4	Very Sparse Mangroves
5	Mangroves with algae
6	Mangroves with saltbush
7	Algae

3 RESULTS

Forest cover maps of two different years were prepared for the three sites viz. Keti Bandar, Miani Hor and Kalmat Khor. Due to the non-availability of high resolution satellite data for Sandspit area, only detailed landcover map was prepared.

3.1 Change Analysis of Mangrove Resource in Pakistan

Monitoring forest resources using satellite remote sensing technology is not new in Pakistan. In the past, there has been many attempts to monitor the extent of forest particularly mangrove forest by different institutions mainly by Pakistan Space & Upper Atmospheric Research Commission (SUPARCO) as the custodian of space science and research in this country. These studies did not reach to any certain conclusion about the extent of mangrove resource in the country as different techniques and tools (satellite datasets) were used with every new study which resulted in contradictory figures, some of them were declined by the concerned government departments.

The first indigenous study on the mangrove forest extent was conducted in 1983 by SUPARCO using the visual interpretation technique to Landsat Multi Spectral Scanner (MSS) data of December 4, 1978. This was verified by data collected during field surveys, and a mangrove vegetation map was prepared at the scale of 1:250,000. According to this study, mangrove vegetation covers approximately 260,000 ha, which is about 44 percent of the total Indus deltaic region. Of this total area, only 50,000 ha of existing mangroves were categorized as dense, the remaining 210,000 ha mangroves were in the medium category. Of the remaining total deltaic region, 140,000 ha consist of very sparse to no vegetation (mainly mud flats formed due to silt deposition). In order to assess the temporal variation in the extent of mangrove vegetation, satellite imagery of three different dates specifically December 21, 1973; December 14, 1976 and December 4, 1978 have been used. It is worthy to note that visual interpretation is a problematic technique as it is prone to error especially in plotting the exact boundaries of mangrove patches at such a scale. However, no large scale variation was identified in the study area over the five year period (Mirza et al., 1983).

Another notable exercise to map forest cover was a national scale effort in 1992, under the Forest Sector Master Plan (FSMP). For FSMP, the mangrove forest extent was again *visually* determined from Landsat Thematic Mapper (TM) images of 1988; and was estimated to be 155,369 ha with 55,697 ha categorized as dense and 99,672 ha categorized as medium mangrove forest. Visual techniques were employed because of insufficient computer technology to handle national scale large datasets (FSMP, 1992).

In 2003, WWF-Pakistan used its in-house facility to digitally analyse the Landsat images of April 1992 and November 2000. Using un-supervised classification technique, two densities of vegetation (without segregating mangroves, salt bush and algae) were determined in the selected deltaic part which was not covering the vegetation extent close to the Indian border. The overall extent of deltaic vegetation remained almost static to 73,890 ha and 73,001 ha respectively for 1992 and 2000 while its change analysis revealed an overall shift of the vegetation pattern from the southern part to the northern side of the delta. It is observed that more degradation has happened in the remote parts of the delta while substantial increase is witnessed in the mangroves near Karachi city. There are many justifications of vegetation shift from south to north which instigate propositions like good management, less dependence on this resource due to availability of alternate energy resources resulting less dependence on fuel wood as well as focused plantations activities/projects close to easy accessible areas etc (Ashraf et al., 2004).

In contrast to previous studies, the aerial extent of the mangrove was reported very low which triggered another study by SUPARCO on the request of IUCN to assess and map the Coastal Resources of Pakistan through Satellite Remote Sensing. The assessment included monitoring and mapping the current status of mangrove forests along the coast of Sindh and Balochistan including the Indus Delta, the coast at Miani Hor, Kalmat Khor and Jiwani Lagoon (Gwatar Bay) respectively. For this purpose, high resolution SPOT XS (20m) data of January 2003 were used and mangroves forest maps at 1:100,000 scales were prepared. From the analysis of SPOT XS data, it was estimated that the total mangrove forests along the coast of Pakistan covered 86,728 hectares (214,303 acres), out of which the mangrove forests along the coast of Sindh are spread over an area of 82,669 hectares (about 204,276 acres) and along the Makran coast on an area of 4,058 hectares (10,028 acres). This showed that about 95.1% of mangrove forests were found along the coast of Sindh and 4.7% along the Makran coast, Balochistan. In this study, marine algae was also identified on 20m SPOT XS data in the back waters of Manora Channel and in the Korangi-Phitti Creek area, showing high marine pollution along the coast of Karachi (SUPARCO, IUCN 2003).

In another study by SUPARCO and Sindh Forest Department Indus Delta (from Dabbo Creek to Sir Creek) using SPOT XS (20m) data of Feb/Mar 2005. Landuse thematic maps showing different densities of mangrove forests and other coastal features particularly creeks, mudflats, saline areas, etc, were prepared at 1:250,000 scale. Detailed mangrove forest cover maps of selected sites i.e. Keti Bandar, Shah Bandar and Sir Creek areas were also prepared at 1:50,000 scales. From the Landuse thematic map, the total mangrove forests area has been estimated to be 55,760 ha in the study area (SUPARCO Annual Report, 2006).

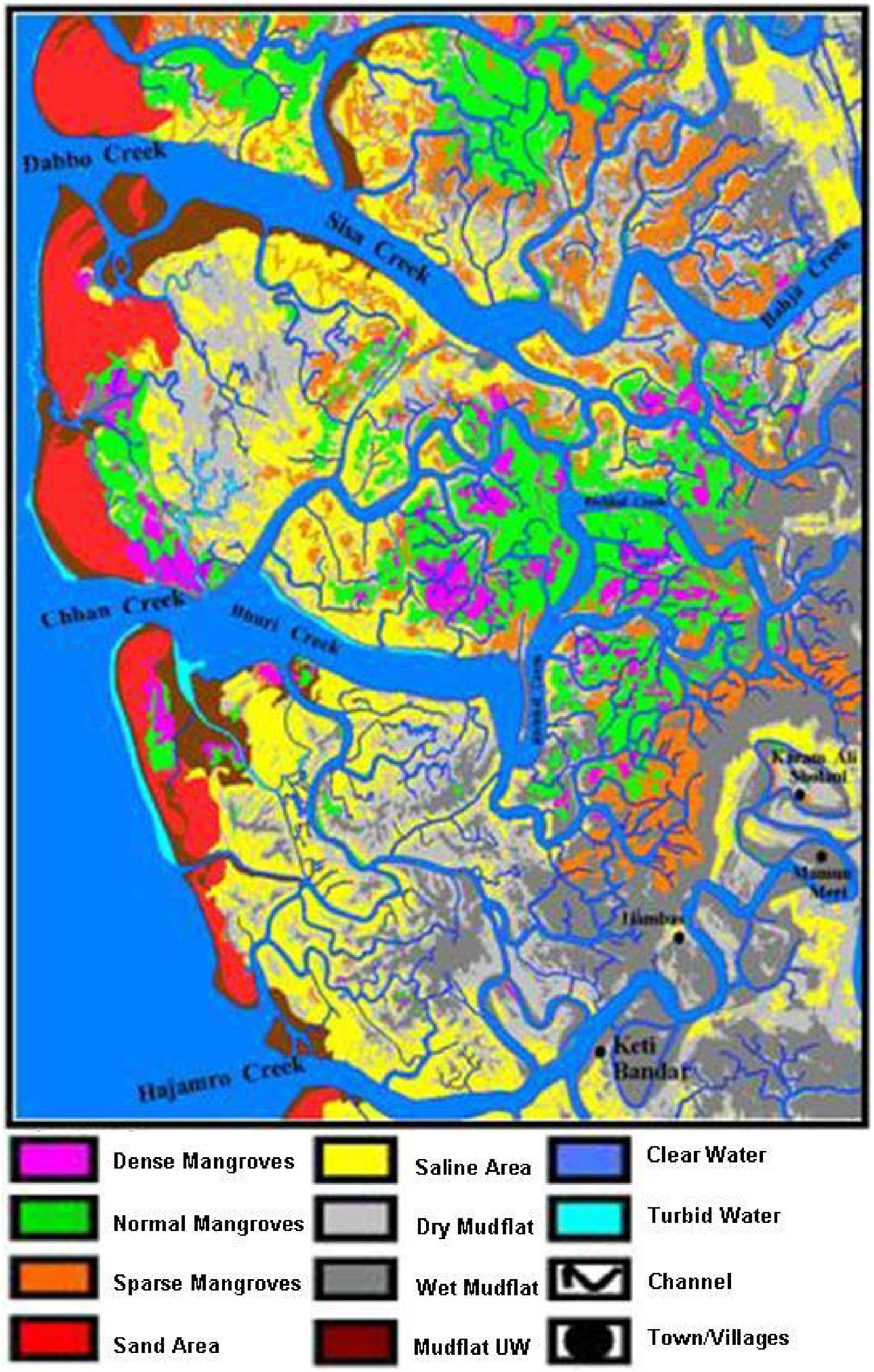

Figure 15: Landuse map of Keti Bandar area based on 2005 SPOT XS data. (SUPARCO 2006).

Regardless of the outcome of these studies in terms of aerial extent of the mangrove forest, one point is evident that there is significant decline in the mangrove cover due to several factors including severe geomorphologic changes in the Indus river delta. This change is further exaggerated by the in-situ and ex-situ anthropogenic effects or processes like diversion of water for irrigation, over harvesting of mangrove for fuel wood and timber and un-controlled grazing of cattle including camels.

Current study instigates a mechanism to monitor these changes in a cost effective way using mix blend of research based satellite datasets along with commercially available images. Keeping in mind the scope of current study, i.e. to map the current extent of mangrove forest, and to identify the change in the extent using historic remotely sensed datasets, change analyses were performed on the processed images.

Change analysis help in indicating an overall trend of forest cover increase or decrease for each site and identify certain regions where such changes occur for further investigation. There has been an overall decrease in mangrove forest cover for the sites along Indus Delta, while increase in mangroves forest cover has been detected along the Makran coast.

For the change analysis of digitized vector layers of the time series satellite data, all the polygons were attributed on the basis of specific IDs. To calculate the area, corresponding to a particular forest cover, all the corresponding polygons were merged to form another thematic layer with area attribute attached. Individual layers of polygons digitised from Landsat and Terra satellite data were scrutinised on the basis of coexistence of two land covers, available in the respective thematic layers.

The statistic shown under the forest cover of any site for any particular year is kept limited to vegetation only which is not equivalent to land cover. In land cover statistics, details are mentioned for all the land cover types while a forest cover only describes the vegetation component of the specific site. Keeping in mind this, the summation of forest cover of temporal datasets may not be equivalent.

3.2 Change Analysis for *Keti Bandar*

To analyse forest cover change for Keti Bandar region, Landsat image of 1992 and Aster image of 2001 were processed. Results related to forest cover mapping are described below.

3.2.1 Forest Cover from 1992 Satellite Data

From the analysis of Landsat image of 1992, it was noted that the total mangrove cover around Keti Bandar area in the creeks of Hajamaro and Chann creeks is 9,498 ha, out of which dense mangrove cover is about 1,966 ha (20%), medium mangrove cover is about 1,431 ha (16%), sparse mangrove cover is about 3,494 ha (36%) and very sparse mangrove cover is about 2,607 ha (28%). In addition thin algal mats have also been noted in Landsat image of 1992, covering an area of about 198 ha.

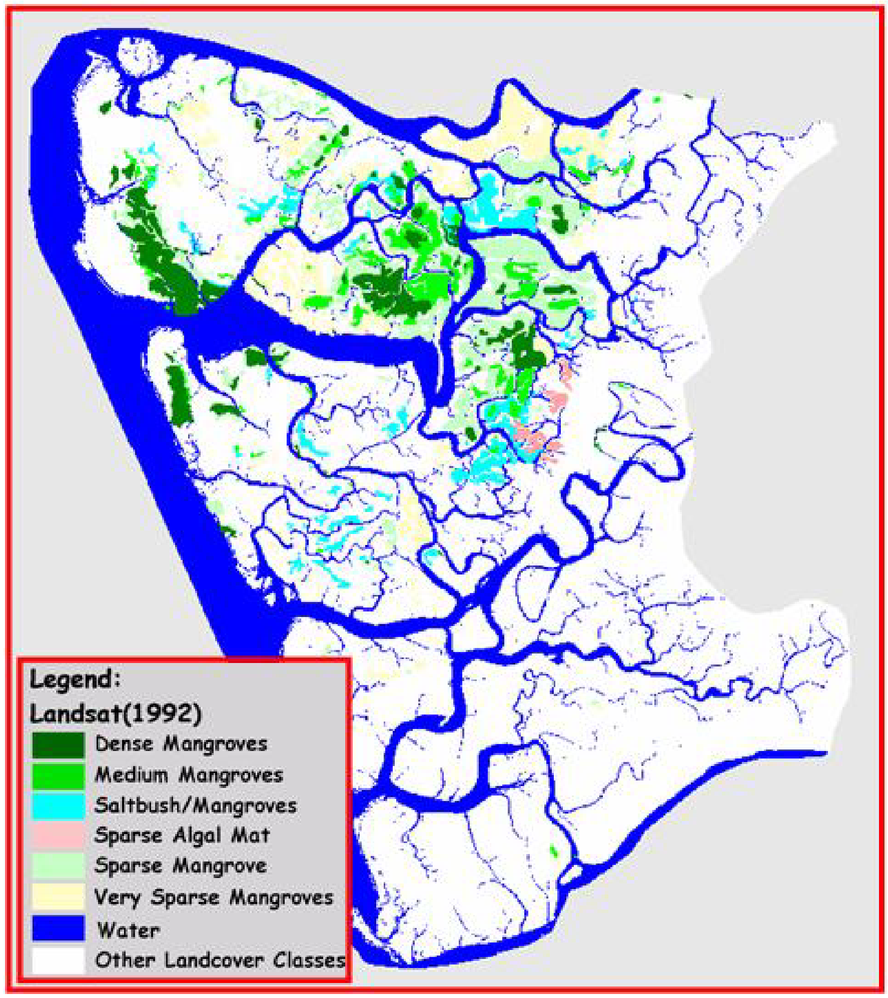

Figure 16: Forest cover of Keti Bandar derived from Landsat TM data acquired on 27th April 1992

3.2.2 Forest Cover from 2001 Satellite Data

Based on Aster data of 2001, the mangrove canopy cover analysis shows that the total mangrove cover in the area is about 7,559 ha. Dense mangrove cover is about 1,532 ha (20%), medium mangrove cover is about 1,265 ha (17%), sparse mangrove cover is about 2,880 ha (38%) and very sparse mangrove cover is about 1,882 ha (25%). Mix response of other vegetation type with mangroves, as found in 1992 satellite data, like saltbush could not be found in this image.

In addition, some of the pure patches of algae were delineated along the inland side. This is encompassing an area about 836 ha that could not be found that clearly in 1992 imagery.

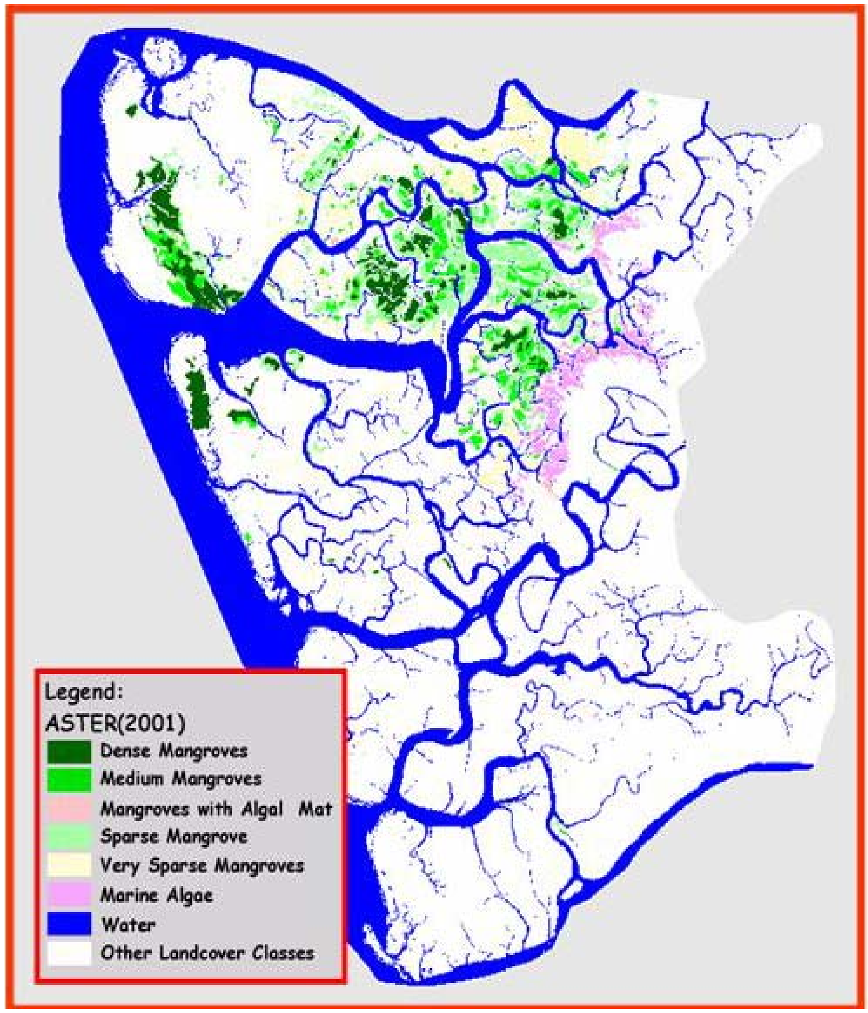

Figure 17: Forest cover of Keti Bandar derived from Terra ASTER data acquired on 24th December 2001

3.2.3 Temporal Change Analysis from 1992 to 2001

This mangrove forest change analysis was carried out using different vegetation cover classes developed from temporal satellite images. Four different levels of densities were identified over satellite imagery, both in; Landsat (TM) and Terra (ASTER) satellite data. These four levels of densities were merged into two broader categories of closed canopy forest (comprising of dense and medium mangroves) and open canopy forest (comprising of sparse and very sparse mangroves) respectively.

Different possible levels of change in mangrove forest were mapped and magnitude of change is shown in terms of intensity of the colours as shown in Table 3.

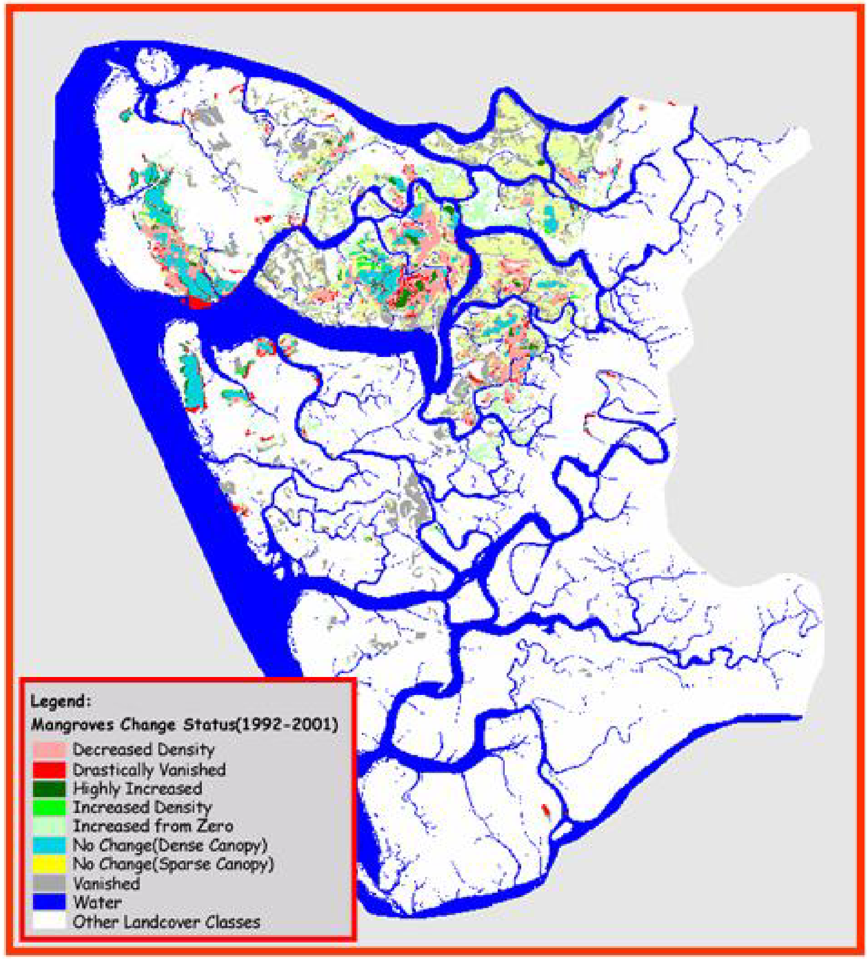

Figure 18: Change detection map of Keti Bandar

Table 3: Tabular representation of change analysis

1992 LANDSAT DATA	2001 TERRA DATA	Mangrove Change Status	Colour Legend
Dense Canopy	No Mangroves	Drastically Vanished*	
Sparse Canopy	No Mangroves	Vanished*	
Dense Canopy	Sparse Canopy	Decreased Density*	
Sparse Canopy	Dense Canopy	Increased Density**	
Very sparse Mangroves	Dense Canopy	Highly Increase density**	
Very sparse Mangroves	Sparse Canopy	Increased From Zero**	
Dense Canopy	Dense Canopy	No Change***	
Sparse Canopy	Sparse Canopy	No Change***	

* Decreased density levels of mangroves forest cover
** Increased density levels of mangroves forest cover
*** No change in mangroves status

3.2.4 Discussion

Although, total vegetation area is not equal in both the datasets, as described earlier, it is due to the fact that this segment of statistics is only covering vegetation while there are other land cover features also exist in this image like water, mud flats and soil. By including their area of extent, the total land cover area of each dataset will be equal in total.

Table 4 shows that the aerial extent of mangroves in this region is in decline while increase in the extent of algae could be due to seasonal difference of both the datasets.

Although, algae remains present in this ecosystem but during low temperatures it proliferates and this could be one of the reason of its increase in the area in December 2001 image as compared to April 1992 image.

Table 4: Statistical analysis of forest cover change from 1992 to 2001 for Keti Bandar

Vegetation Cover	1992 LANDSAT DATA (ha)	2001 TERRA DATA (ha)	Change (ha)
Dense Mangroves	1,966	1,532	-434
Medium Mangroves	1,431	1,265	-166
Sparse Mangroves	3,494	2,880	-614
Very Sparse Mangroves	2,607	1,882	-725
Total Mangroves	**9,498**	**7,559**	**-1,939**
Algae	198	836	638*
Total Vegetation	**9,696**	**8,359**	**-1,337**

Comparing the classification results of 2001 Terra Satellite data (shown in figure 17) with the 2005 SPOT satellite data based classification done by SUPARCO (shown in figure 15), it is quite evident that the dense canopy is identified almost evenly in both the datasets however, there is strong difference in sparse mangrove class. WWF identified stunted and very sparse mangroves mixed with algae in the inland side of the delta while it is totally shown as sparse mangrove by SUPARCO in their latest study which surely is a cause of over stating the extent of rapidly depleting mangroves in this region.

The temporal change analysis indicates total destruction or reduction of mangroves has happened in the close proximity of human habitation centres. Whereas large mangrove forest clusters towards open sea are relatively intact with no variation in their middle regions. However, their peripheries are subject of negative change due to the dynamic geomorphology of the area. It is evident from the image that some large parts of the outer forest are totally vanished due to it.

In contrast to this, there are some central deltaic areas in the midst of no-change and high-decrease forest where there is significant increase in the mangrove density is observed. Although, this area is not visited during the ground truthing surveys but it requires further investigation to come across the reason of this positive change.

3.3 Forest Cover Analysis of Sandspit

3.3.1 Landcover Map using High Resolution Data

From the analysis of thematic map developed by using Quickbird image of 2003, it was noted that the total mangrove cover in the area is 370 ha, out of which dense mangrove cover is about 57.45 ha (15.5%), medium mangrove cover is about 125.9 ha (34%), sparse mangrove cover is about 180.89 ha (49%) and regeneration is 5.35 (1.5%) ha. Saltbush covered an area about 38.57 ha. Algae were classified in two main classes i.e. floating algae and algae on mud covering a total extent of about 173.85 ha.

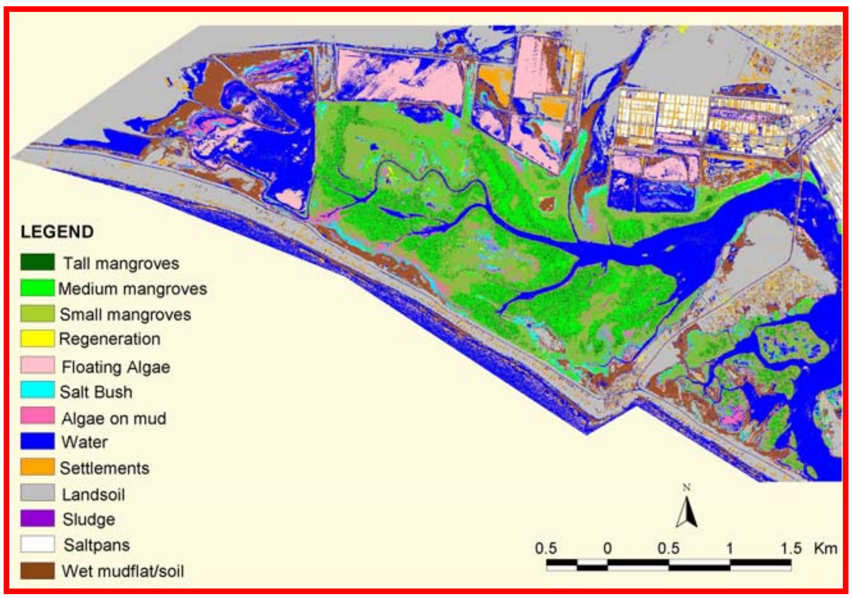

Figure 19: Landcover map of Sandspit, derived from Quickbird satellite

Table 5: Different landcover classes for Sandspit project site

Land cover Classes	Area (Ha)
Dense Mangroves	57.45
Medium Mangroves	125.90
Sparse Mangroves	180.89
Total Mangroves	364.24
Saltbush	38.57

Land cover Classes	Area (Ha)
Algae	173.85
Sludge / wet soil	11.18
Water	364.04
Settlements	45.86
Salt pans	25.61
Mudflats	149.52
Land soil	444.66
Total	**1617.53**

3.3.2 Discussion

High resolution satellite image is very recent development in the field of remote sensing and unfortunately past data at this resolution is not available. Non-availability of historic high-resolution satellite data ceased the possibility of conducting change analysis of the Sandspit region.

3.4 Change Analysis for Miani Hor

3.4.1 Forest Cover from 1989 Satellite Data

From the analysis of Landsat image of 1989 (Fig. 20), it was noted that the total mangrove cover in the area is 2,546 ha, out of which dense mangrove cover is about 551 ha (21.6%), medium mangrove cover is about 749 ha (29.4%), sparse mangrove cover is about 1,246 ha (49%). Algae on mud were observed in the outer peripheries of the Hor, covering an area about 2,293 ha. Saltbush covered an area about 357ha.

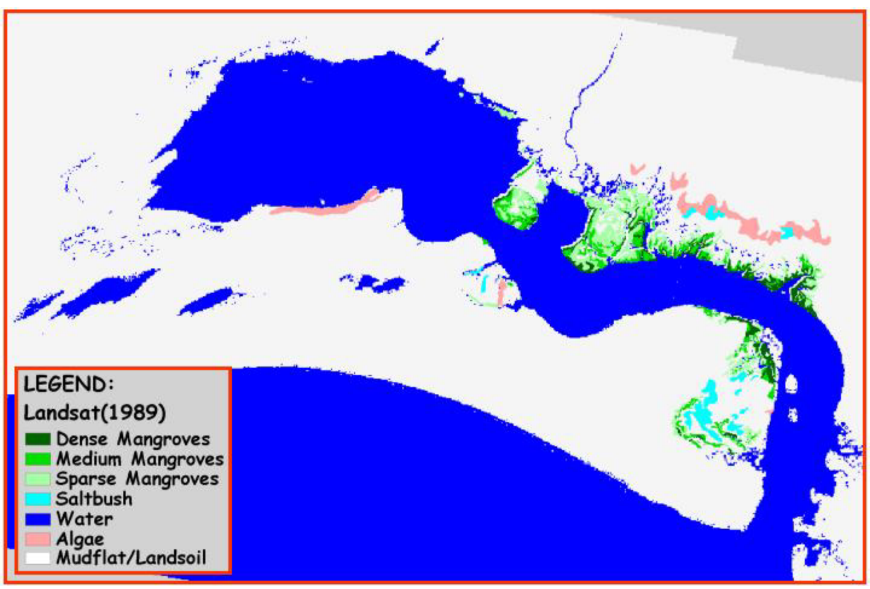

Figure 20: Forest cover of Miani Hor derived from Landsat TM data acquired on 19th October 1989

3.4.2 Forest Cover from 2001 Satellite Data

Based on Aster data of 2001, the mangrove canopy cover analysis (Fig. 21) shows that the total mangrove cover in the area is about 3716 ha. Dense mangrove cover is about 1,281 ha (34.5%), medium mangrove cover is about 1,133 ha (30.5%) and sparse mangrove cover is about 1,302 ha (35%). Algae on mud were observed in the outer peripheries of the Hor, covering an area about 637 ha. Some of the large patches were polygonised as algae on the south western parts of the Hor, comprising of an area about 972 ha.

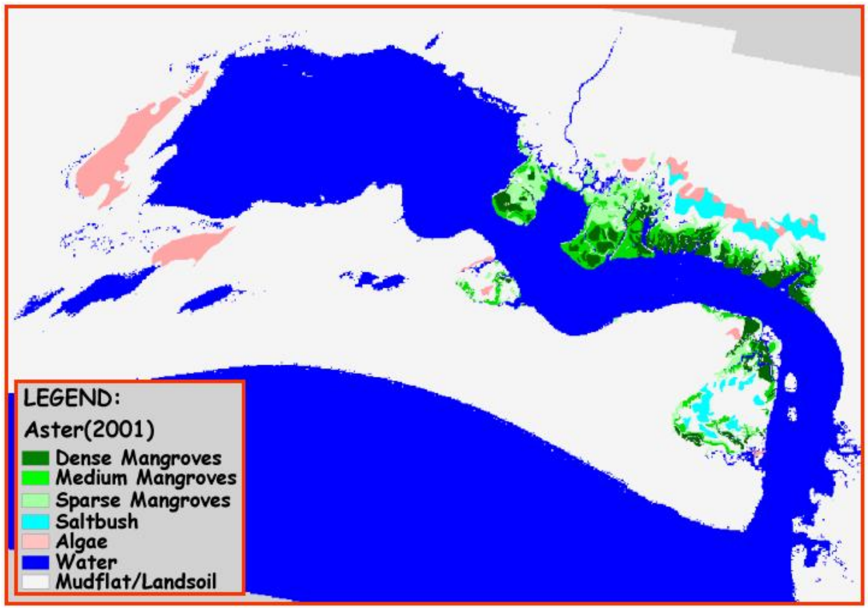

Figure 21: Forest cover of Miani Hor derived from Terra ASTER data acquired on 12th October 2001 and 21st May 2001

3.4.3 Temporal Change Analysis from 1989 to 2001

Three different levels of densities were identified over satellite imagery, in both Landsat (TM) and Terra (ASTER) satellite data. Different possible levels of change in mangrove forest were mapped and magnitude of the change is shown in Table 6, in terms of intensity of the colours.

Table 6: Tabular representation of change analysis

1989 LANDSAT DATA	2001 TERRA DATA	Mangrove Change Status	Colour Legend
Dense Canopy	No Mangroves	Drastically Vanished*	
Sparse Canopy	No Mangroves	Vanished*	
Dense Canopy	Sparse Canopy	Decreased Density*	
Sparse Canopy	Dense Canopy	Increased Density**	
Very sparse Mangroves	Dense Canopy	Highly Increase density**	
Very sparse Mangroves	Sparse Canopy	Increased From Zero**	

Dense Canopy	Dense Canopy	No Change***	
Sparse Canopy	Sparse Canopy	No Change***	

* Decreased density levels of mangroves forest cover
** Increased density levels of mangroves forest cover
*** No change in mangroves status

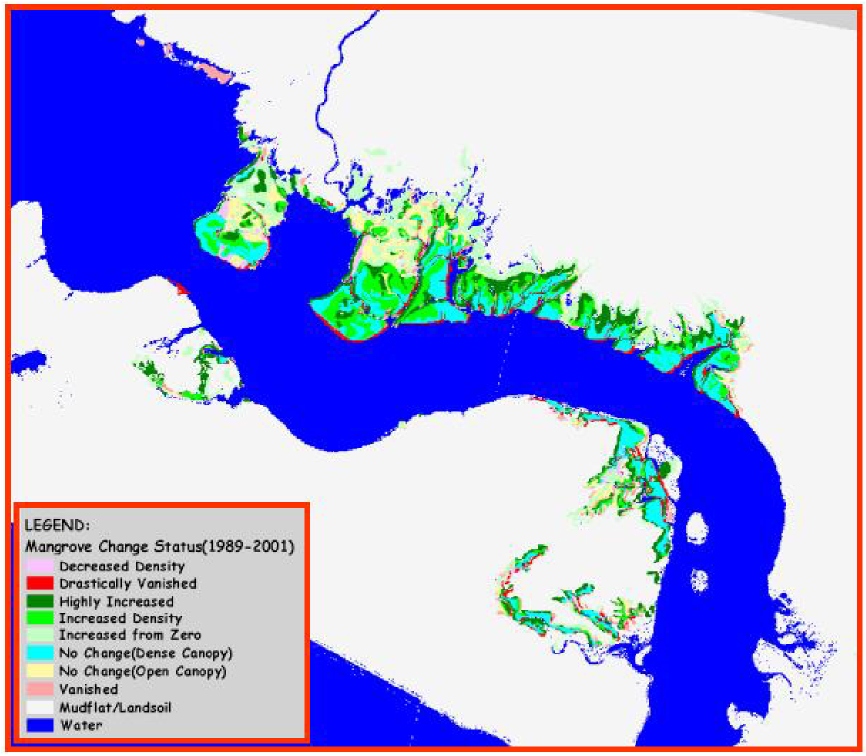

Figure 22: Change detection map of Miani Hor area

3.4.4 Discussion

The largest mangrove patch is occurring in the northern shore of the Hor which is fed by Porali River carrying rain water from the Pub range catchment. This water is diverted in the upstream regions for the agriculture use thus decline of freshwater supply in the Minai Hor has activated geomorphologic changes. If compared with the historic satellite images, substantial increase in the mud flat region is visible in the bay. During the field surveys, it was observed that the soil of the Miani Hor is very swampy and thus provide natural restriction for humans to extract mangroves in some new recruitment areas. This factor has considerably increased the extent of mangrove in this bay; however more studies are needed to monitor the geomorphologic changes by quantifying the shift in the freshwater supply system and its long term impacts on the overall health of the mangroves.

In one of the islands, where WWF-Pakistan has initiated mangrove plantation with the help of local community, increase in the mangrove forest is also visible.

There are certain areas opposite to the *Windor* river delta, where sand dune shift is causing big threat to mangroves. Besides these few patches of mangrove degradation in the entire Hor, there is an overall increasing trend (Table.7) in the mangrove forest cover which is significantly different from the Indus Delta region (Table 9).

Table 7: Statistical analysis of forest cover change from 1989 to 2001 for Miani Hor

Vegetation Cover	1989 LANDSAT DATA (ha)	2001 TERRA DATA (ha)	Change (ha)
Dense Mangroves	551	1,281	+730
Medium Mangroves	749	1,133	+384
Sparse Mangroves	1246	1,302	+56
Total Mangroves	**2,546**	**3,716**	**+1,170**
Algae	2,293	972	-1,321
Saltbush	357	732	+375

3.5 Change Analysis for Kalmat Khor

3.5.1 Forest Cover from 1990 Satellite data

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

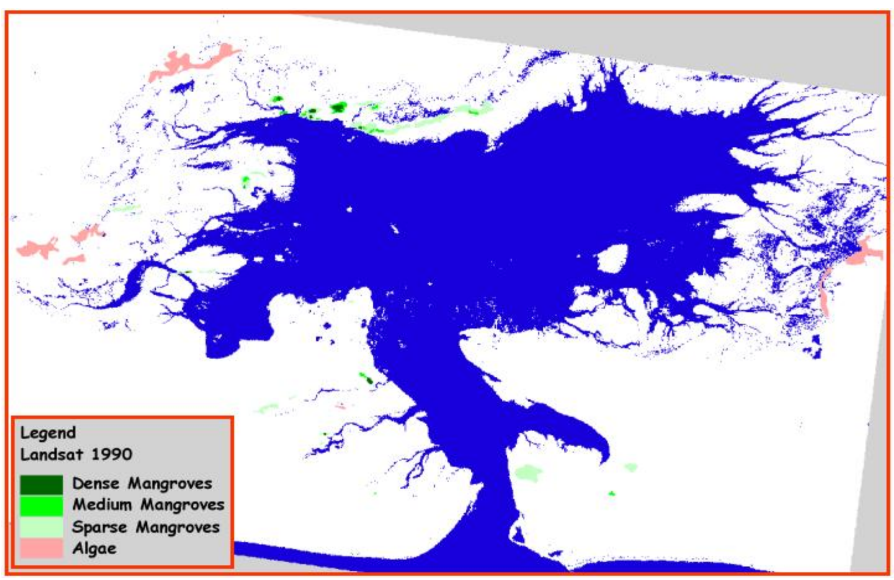

Figure 23: Forest cover of Kalmat Khor, derived from Landsat TM data acquired on 29th October 1990

From the analysis of Landsat image of 1990 (Fig. 23), it was noted that the total mangrove cover in Kalmat Khor area is 255 ha, out of which dense mangrove cover is about 18 ha (7%), medium mangrove cover is about 33 ha (13%), sparse mangrove cover is about 204 ha (80%). However some of the large patches of vegetation were digitised as algae on the north-western and western parts of the Khor comprising of an area about 260 ha.

3.5.2 Forest Cover from 2004 Satellite data

During digitization on satellite Aster image (2004), increase in mangroves area was observed. Mangrove canopy cover analysis shows that the total mangrove cover in the area is about 526 ha. Dense mangrove cover is about 12 ha (2.3%), medium mangrove cover is about 149ha (28.3%), sparse mangrove cover is about 365 ha (69.4%). However some of the large patches were digitised as algae on the north-western and western parts of the Kalmat Khor comprising of an area about 172 ha.

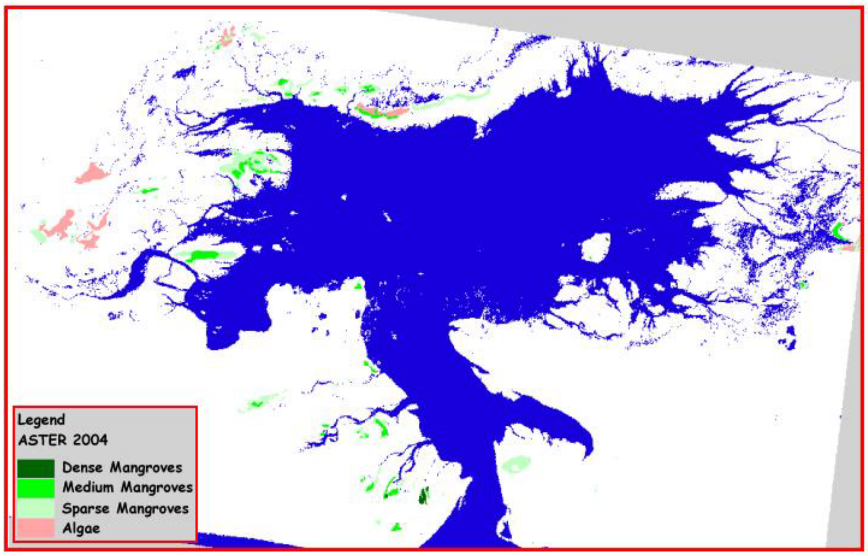

Figure 24: Forest cover of Kalmat Khor, derived from Terra (ASTER) data acquired on 23rd July 2004

3.5.3 Temporal Change Analysis from 1990 to 2004

This mangrove forest change analysis was based on the canopy closure. Three different levels of densities were identified over satellite imagery, in both Landsat (TM) and Terra (ASTER) satellite data. These three levels of densities were defined on the basis of openness and closeness of the canopies and were further merged into two broader categories of dense canopies, and sparse canopies. Different possible levels of change in mangrove forest were mapped and magnitude of the change is shown in terms of intensity of the colours in Table 8.

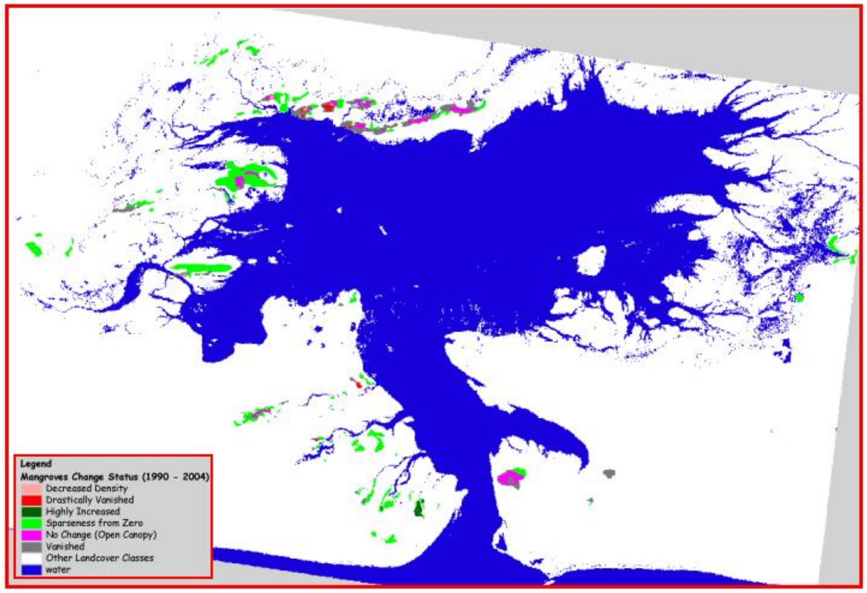

Figure 25: Change detection map of Kalmat Khor area.

Table 8: Tabular representation of change analysis for Kalmat Khor

1990 LANDSAT DATA	2004 TERRA DATA	Mangrove Change Status	Color Legend
Dense Canopy	No Mangroves	Drastically Vanished*	
Sparse Canopy	No Mangroves	Vanished*	
Dense Canopy	Sparse Canopy	Decreased Density*	
Sparse Canopy	Dense Canopy	Increased Density**	
No Mangroves	Dense Canopy	Highly Increased Density**	
Dense Canopy	Dense Canopy	No Change***	
Sparse Canopy	Sparse Canopy	No Change***	

* **Decreased density levels of mangroves forest cover**

** **Increased density levels of mangroves forest cover**

*** **No change in mangroves status**

3.5.4 Discussion

Kalmat Khor is found more dynamic region in terms of vegetation cover change than any other project site. There could be many reasons yet to be found out.

This is the only mangrove site in the country that lacks perennial freshwater supply. The nearest river to the Kalmat Khor is the Basol River, which runs 15 km east of Khor. It is stated that this river was once flowing into the Kalmat Lagoon but due to some plate tectonic movements in the recent past it changed its course and now the freshwater supply is restricted to seasonal run-off of rain water from the surrounding mountains. This factor makes this entire mangrove ecosystem more vulnerable as compared to others mangrove sites.

Table 9: Statistical analysis of forest cover change from 1990 to 2004 for Kalmat Khor

Vegetation Cover	1990 LANDSAT DATA (ha)	2004 TERRA DATA (ha)	Change (ha)
Dense Mangroves	18	12	-6
Medium Mangroves	33	149	+116
Sparse Mangroves	204	365	+161
Total Mangroves	255	526	
Algae	260	172	-88
Saltbush	-	-	-

It was observed in the field survey (which was conducted after heavy flash floods in the Basol and Dasht rivers in early 2005) that a new layer of earth/soil has taken over the algae patches that were visible in the pre-flood images of 2004 in the outer periphery of the lagoon. One of reason of decline in the algae extent is its seasonal variation in both the datasets.

Similarly, most of the mangrove forest (observed during field verification surveys) was found in small stunted clusters. As this area is quite active in geo-morphological changes, such variations in the mangrove growth are justifiable, however, to reach to any certain conclusion it requires close monitoring of this site with improved resolution images.

4 Conclusion and Recommendations

This section of the report is divided into many logical segments which either provided clues about the type of change happened in the mangroves or highlighted limitations to conduct remotely sensed data based investigations to monitor the dynamic scenario of vegetation change.

4.1 Historic Studies on Mangrove Forest Extent

As discussed earlier, there have been numerous studies conducted on this issue but failed to document the extent of mangrove forest in a standardised way. There have been numerous figures available about the extent of mangroves in Pakistan using satellite data. In some initial studies, SUPARCO and consultants to Forest Sector Master Plan (1992) identified large areas under mangrove cover but later studies (conducted in the recent past by WWF-Pakistan) which showed considerable low extent of mangrove forest cover using improved classification techniques for the similar time frame datasets. This was later confirmed by SUPARCO in another study for IUCN-Pakistan. Although in this study, if compared with this current activity, some discrepancies exist. Like, a large area (ground verified by WWF as algae) in the north of Keti Bandar is primarily classified as sparse mangrove by SUPARCO (Fig. 15). This single factor, in it self, is quite enough to justify the fact that mangroves were not mapped accurately in the past and based on these results, any management strategy, if existed may require revision.

4.2 Current Findings on Mangrove Forest Extent

In general, a decreasing trend in the extent of mangroves forest is observed in the Indus Delta while an increasing trend was observed in the project sites of Miani Hor and Kalmat khor along Makran coast.

4.2.1 Site Specific Findings for Indus Delta

In Keti Bandar in the southeast of Karachi city, there is an overall loss of 1939 ha (around 20%) in the mangrove forest extent in a period of ca 10 years (1992 to 2001). In the year 1992, mangroves as identified mainly under sparse category, were under heavy pressure of consumption in the area of Hajamro creek near Keti Bandar village. In 2001, this region has shown drastic reduction in the extent of these mangroves clearly indicating its unsustainable utilization.

Large patches of forest exist in the north of Keti Bandar around Chan and Bhuri creeks where mix response of forest change has been observed. For example, towards the open sea side especially at the mouth of Chan creek, most of the forest is intact while in the inner side of creek, close to the human population, the decrease in the forest cover is evident indicating the anthropogenic effect on the health of forest extent.

Furthermore, this decrease in mangroves forest extent along the Indus Delta might also be due to the reduction in freshwater flow, low silt deposition, loss of soil fertility which is associated with soil erosion and un-sustainable forest management.

4.2.2 Site Specific Findings for Sandspit

It is evident from the previous studies that the area estimation of mangrove forest in the past remained debatable. In this connection, WWF-Pakistan decided to establish detailed inventory of the forest cover by using high resolution satellite data and to test improved techniques to develop land cover maps. For this purpose, Sandspit was chosen as pilot study area due to its small size. Moreover, repetitive visits were possible easily for ground truthing, if needed.

There was another advantage of high-resolution satellite image as it was used as ground verification data to analyse medium resolution satellite images in an experimental study under this project. Advance satellite classification technique like sub-pixel classifier was applied to medium resolution satellite images (from Landsat). The derived results using maximum likelihood and sub-pixel classifier techniques were compared. The results from improved classification technique provided very close match for vegetation area estimation from medium and high resolution satellite images. Even with limited high resolution data, vegetation area estimation using medium resolution images for other sites can be improved using sub-pixel classifier technique.

4.2.3 Site Specific Findings for Makran Coast

Contrary to the Indus Delta, analysis shows an increase in the mangroves forest cover along the Makran coast particularly in Miani Hor (46% increase) and Kalmat Khor (106% increase) areas. A reason for this significant increase can be the result of conservation work done by WWF-P and other organisations including CBOs and Forest Department.

Although, increase in mangroves extent along the Makran coast is encouraging; however, there are numerous factors which require further investigation. For example the increasing mud flats in the Porali River, due to geo-morphological changes in the coastal region of Mianni Hor area, can be a cause to the regeneration of mangroves. On the other hand, such changes indicate an association with freshwater water scarcity in the river delta which in turn may be due to the increased agriculture practices upstream. This decreasing pressure of water flow or discontinuous discharge at the delta may not be able to clear up deposited silt which reaches there during flush flooding times. Therefore, regenerated mangroves on the delta may not survive in the long run due to reduced fresh water content and the subsequent flooding.

4.3 Algae Mapping in the Mangrove Ecosystem

The identification and mapping of algal species namely *Enteromorpha sp., Ulva sp., Cyanophyta sp.* on ASTER of 15 meter resolution as well as on Landsat data of 30 meter resolution images is no doubt encouraging which separated algae from mangroves which has been previously misclassified and considered as mangroves forest.

Further investigation to find out the occurrence and spreading of algae species on vast areas around and in the creeks would further benefit the project in terms of its advantages and disadvantages to the ambient environment. It is, therefore, recommended to study the soil chemistry, pollution sources in the creek systems and seasonal variation in the algal extent in contrast to mangroves forest. Moreover, it is recommended to study the algae mangroves association and the factors that cause algae to grow along the coastal regions of Pakistan.

4.4 Satellite Data Handling Capacity of Concerned Line Departments

Besides this fundamental fact that remotely sensed data is a quick way to establish land cover baseline, but in Pakistan, access to remotely sensed data has experienced not very cost effective for regular monitoring. The other factor restricting its sustained and continual use is lack of data analyses capabilities in the concerned line departments. In the past, most of these studies were conducted by different consultants (either government agency or from the corporate sector) like SUPARCO and Reid & Collins Consultants for Forest Sector Master Plan study in 1992. To ensure regular monitoring of mangrove forest, concerned line departments (particularly Sindh and Balochistan Forest and Wildlife departments) should have favourable environment to conduct such studies by their own.

It is recommended that future monitoring after every five years should be conducted with the concerned forest department and their capacity should be improved to understand this technology independently for the long term monitoring of this resource.

4.5 Availability of Satellite Data/Results in Digital Format

One of the major limitations in monitoring mangrove forest using remotely sensed data is to find such datasets which perfectly match with the objectives of the study. Countries who own earth resource monitoring satellites capture data of their areas of interest very regularly. While in Pakistan, areas are not very regularly captured. While conducting this study, temporal datasets were either not available for the same sensor or not for the same season. This factor, to some extent eroded the quality of investigation.

One other interesting dimension of this aspect is the non-availability of previous satellite data classification results in digital format for others to make further analyses. Like, SUPARCO used quite recent SPOT satellite images which were classified digitally. However, these results were shared only in the paper format which makes it difficult to use by others to make further analyses.

It is recommended to make arrangements to distribute current data or at least classified images and GIS vector layers of current study in digital format using interactive digital mapping utilities.

4.6 Availability of High-resolution Data on Google Earth

In order to get more informed, precise and comprehensive information on the occurrence and extent of mangroves forest, high resolution satellite data such as 1m resolution IKONOS and/or 0.6m resolution Quickbird satellite data can provide best available option to study and classify mangroves. This will facilitate the process of change detection over time as well.

Google Earth is a web based utility which has augmented GIS and remote sensing knowledge. This utility has freely offered updated GIS and RS data to general public which enhanced their aptitude to understand this complex science through very interactive and participatory way like it introduced high-resolution images of major cities which attracted attention of many people. Very recently, they have updated the entire coast of Pakistan with the mosaic of high resolution images. This data is very valuable and can be utilised to correct some problematic regions.

It is recommended to convert forest cover datasets into Google Earth readable format (*KML files*) and show with hi-resolution satellite data. This will enable Google Earth Users Community to access forest cover data as well as help the project to compare results developed from medium resolution satellite data with the Google Earth based high-resolution images to see the correctness of the study.

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APPENDIX 1: Remote Sensing/GIS Terms & Techniques

Classification:
Classification is the process of assigning thematic values to continuous pixels into a finite number of landcover classes / themes. A pixel is assigned a landcover theme if it satisfies a certain set of criterion corresponding to a particular Landcover class.

Ground Truthing:
Ground truthing refers to the acquisition of knowledge about the study area from fieldwork, analysis of aerial photography, personal experience etc (Schradar and Pouncy, 1997).

Histogram:
Histogram is a frequency graph in which Digital Number (DN) values are represented with number of occurrence of pixels with in an image.

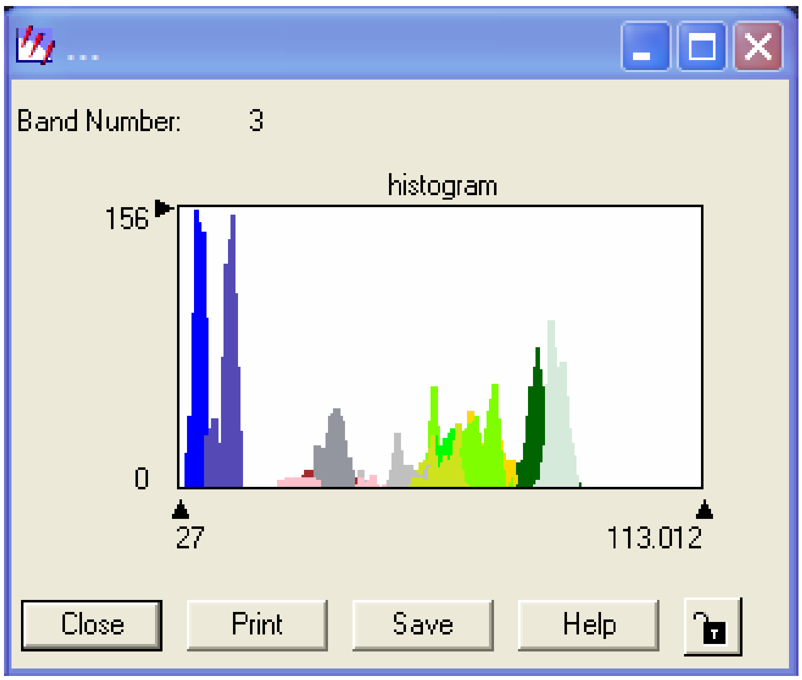

Figure 26: Histogram for data points included in training areas for cover types in ASTER data

Histogram Equalize:
Histogram Equalize is a nonlinear contrast stretch that redistributes pixel values so that there is approximately the same number of pixels with each brightness value within the spectral sensitivity range of the sensor.

This stretch favourably expands some parts of the digital number (DN) range at the expense of others by dividing the histogram into classes containing equal numbers of pixels.

Scatter plot:

Scatter plot is a graph, usually in two dimensions, in which data file values of one band are plotted against the data file values of another band. Different colours in scatter plot represent densities of pixels corresponding to a particular brightness value in image. (Schradar and Pouncy, 1997)

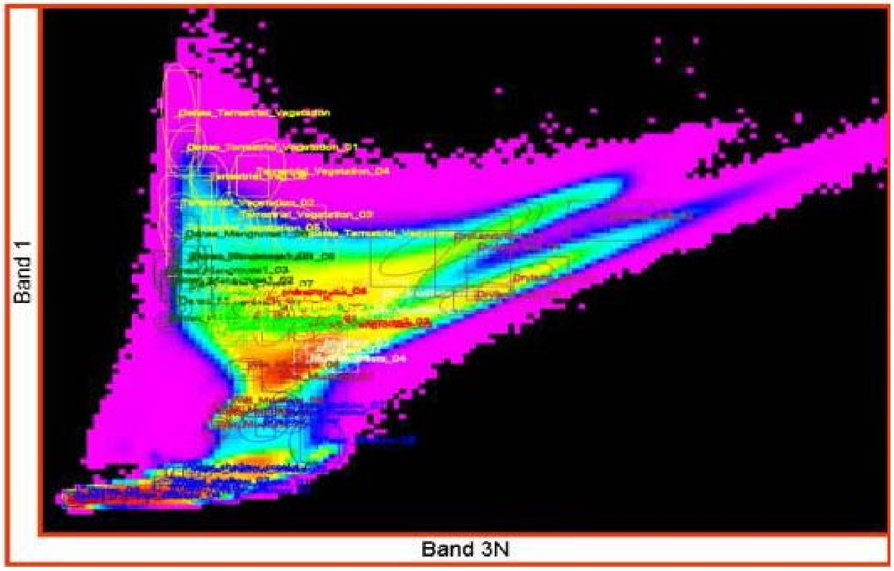

Figure 27: Scatter-plot of band1 and band3N of ASTER data

Spectral Signatures:

Spectral signatures are measurements of the percentage of solar reflectance as a function of wavelength (electromagnetic spectrum) as shown in the following figure.

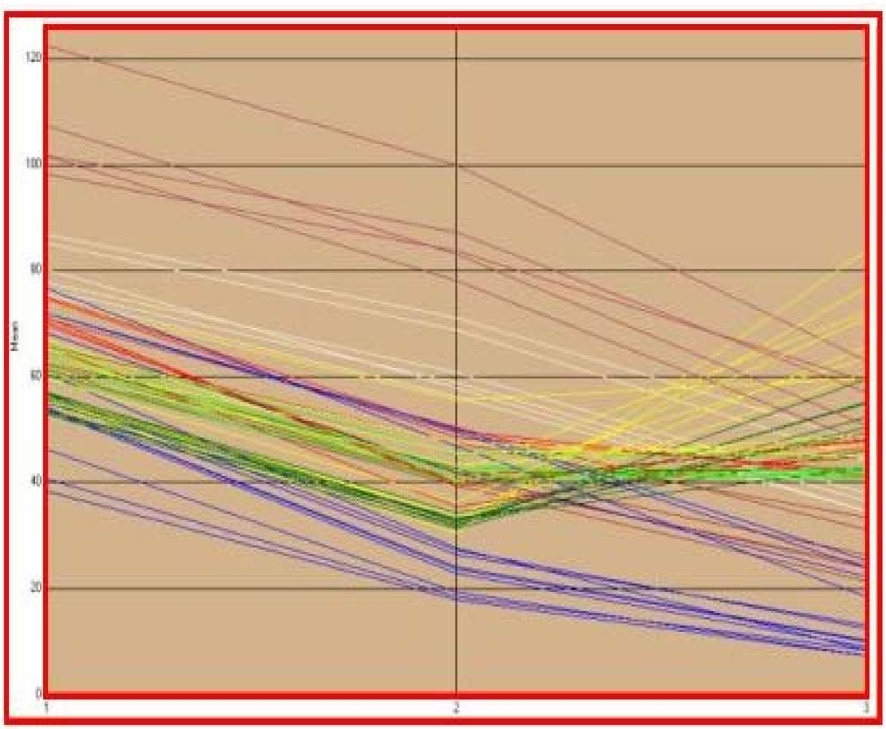

Figure 28: Spectral signatures of different Landcover classes

Supervised Classification:
In supervised classification a small area, called training site, which is representative of each terrain category or class on the image is defined by the analyst. Spectral values for each pixel in a training site are used to define decision space for each class (Floyd, 1996) a high reflectance in the NIR band

WGS-84:
A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth, transformations from major geodetic datums, and the potential of the earth (usually in terms of harmonic coefficients).

Global Positioning System:
The Global Positioning System, usually called GPS (the US military refers to it as NAVSTAR GPS - Navigation Signal Timing and Ranging Global Positioning System), is a satellite navigation system used for determining one's precise location and providing a highly accurate time reference almost anywhere on Earth.

False Colour Composite (FCC)
In satellite image processing, false-color Composites (FCC) images are used as they increase the interpretability of the data. False color composite of ASTER data in which band 3N, 2, 1 are represented in red, green and blue spectral ranges respectively enhancing the interpretation of vegetative biomass by presenting it in varying tones of red.

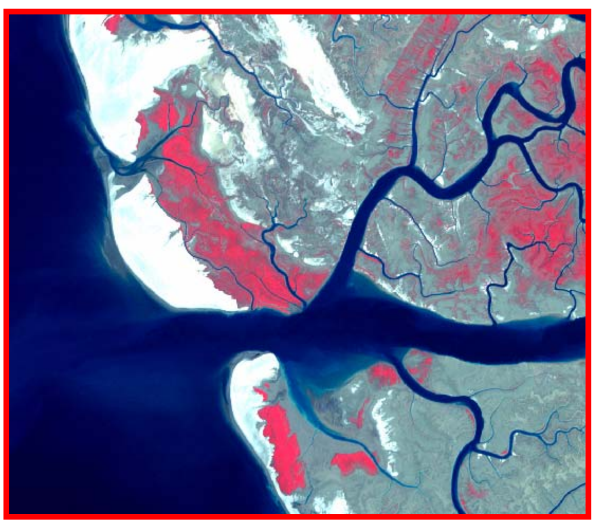

Figure 29: FCC (3N, 2, 1) of ASTER data

APPENDIX 2: Ground Control Points Collected During Field Visit

Table 10: Sandspit area coordinates in UTM zone 42N grid of the filed observation locations

Waypoint ID	Date	Easting	Northing
1	10/03/2004	286719	2750811
2	10/03/2004	286689	2750775
3	10/03/2004	286703	2750703
4	10/03/2004	286240	2751294
5	10/03/2004	286162	2751271
6	10/03/2004	285848	2751242
7	10/03/2004	287175	2750020
8	11/03/2004	288841	2749145
9	11/03/2004	288837	2749194
10	11/03/2004	288849	2749253
11	11/03/2004	289249	2751254
12	11/03/2004	289035	2751340
13	11/03/2004	290011	2750789
14	11/03/2004	291383	2750694
15	11/03/2004	294964	2751996

Table 11: Keti Bandar and Miani Hor area coordinates in decimal degree grid of the filed observation locations

Way Point	Longitude	Latitude	Date
1	67.53320	24.16134	15-FEB-05
2	67.53285	24.16113	15-FEB-05
3	67.45361	24.14736	15-FEB-05
4	67.43981	24.15786	15-FEB-05
5	67.42774	24.16358	15-FEB-05
6	67.42423	24.16744	15-FEB-05
7	67.42196	24.16161	15-FEB-05
8	67.51137	24.15604	15-FEB-05
9	67.61550	24.31730	15-FEB-05
10	67.43667	24.16172	15-FEB-05
11	67.44647	24.14606	15-FEB-05
12	67.41817	24.15751	15-FEB-05
13	67.41932	24.15791	15-FEB-05
14	67.43948	24.15625	15-FEB-05
15	67.45436	24.13293	15-FEB-05
16	67.51784	24.18186	15-FEB-05
17	67.45095	24.14295	15-FEB-05
18	67.45092	24.14292	15-FEB-05

Way Point	Longitude	Latitude	Date
19	67.42056	24.14532	16-FEB-05
20	67.42115	24.16022	16-FEB-05
21	67.42027	24.16608	16-FEB-05
22	67.40567	24.18573	16-FEB-05
23	67.35862	24.22841	16-FEB-05
24	67.35521	24.23399	16-FEB-05
25	67.43201	24.19408	16-FEB-05
26	67.45327	24.19270	16-FEB-05
27	67.45735	24.19051	16-FEB-05
28	67.45781	24.19049	16-FEB-05
29	67.45009	24.19703	16-FEB-05
30	67.44648	24.17415	16-FEB-05
31	67.44918	24.15225	16-FEB-05
32	67.60693	24.23955	16-FEB-05
33	67.59106	24.74073	16-FEB-05
34	67.61871	24.35304	16-FEB-05
35	66.55625	25.52684	17-FEB-05
36	66.55721	25.52855	17-FEB-05
37	66.55405	25.54149	17-FEB-05
38	66.54868	25.53508	17-FEB-05
39	66.54846	25.53553	17-FEB-05
40	66.54704	25.53516	17-FEB-05
41	66.57418	25.44451	17-FEB-05
42	66.56315	25.48435	17-FEB-05
43	66.58805	25.42965	17-FEB-05
44	66.59575	25.42334	17-FEB-05
45	66.11697	25.49874	18-FEB-05
46	66.61046	25.67589	18-FEB-05

Table 12: Kalmat Khor area coordinates in decimal degrees of the filed observation locations

Number	Waypoints	Latitude	Longitude	Date
1	WWF-Kalmat Khor Office	25.5100100	64.0480600	29-Apr-05
2	Mundari Locality	25.5000000	64.0000000	29-Apr-05
3	Bhal Village	25.3873600	63.9017100	29-Apr-05
4	Makola Village	25.5095300	64.0561900	30-Apr-05
5	Phole	25.4674500	64.0380000	30-Apr-05
6	Chundi Locality	25.3960800	64.0406100	30-Apr-05
7	Garoud Locality	25.3893700	64.0075000	30-Apr-05
8	MCSTHW	25.2792200	62.2723900	1-May-05
9	Salt Bush	25.5356400	66.1339300	3-May-05
10	Saltbush Zone Termination	25.5328100	66.1393000	3-May-05
11	Greyish Mud	25.5314700	66.1419300	3-May-05

APPENDIX 3: Resource Use Maps

As part of the ground truthing, preliminary resource use maps were developed with the help of local community participation. These maps show basic resource use areas for different project sites. This information is quite useful to analyse the causes of forest cover change due to the direct anthropogenic impacts for certain types of resource harvesting.

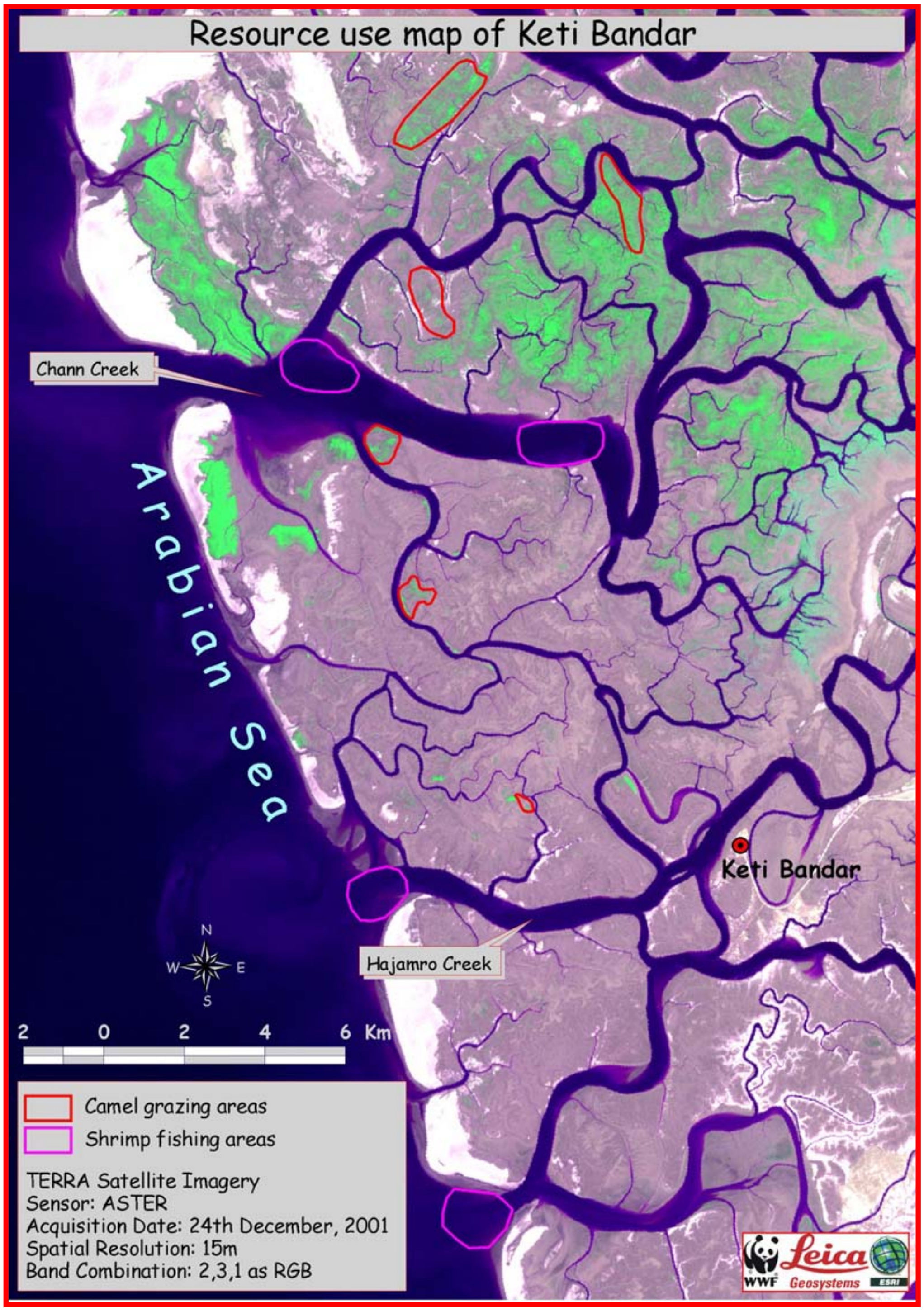

Figure 30: Resource use map of Keti Bandar area showing camel grazing and shrimp fishing areas

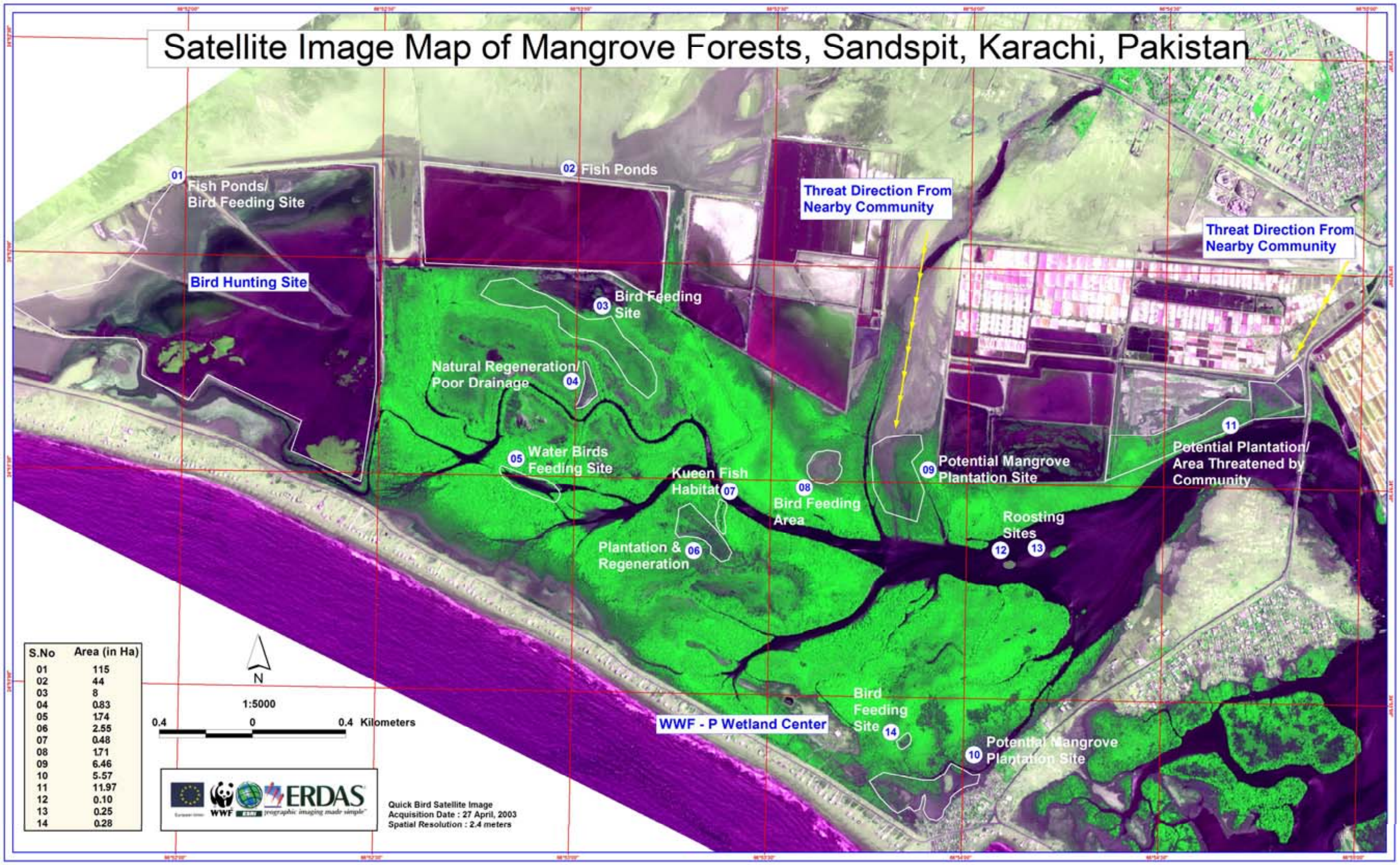

Figure 31: Map of Sandspit showing resource use areas and potential plantation sites

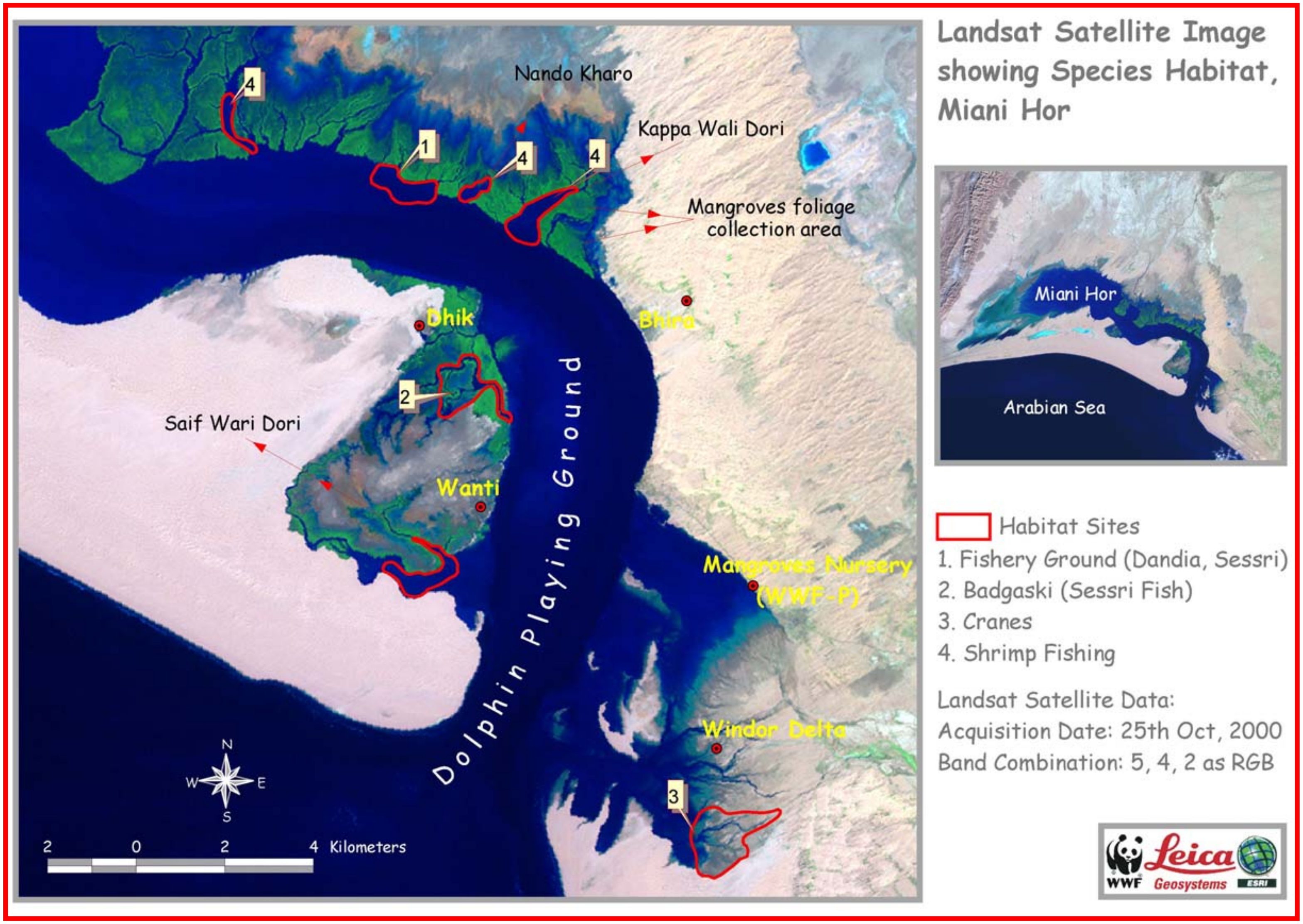

Figure 32: Habitat map of dolphins, fish and crane of eastern Miani Hor

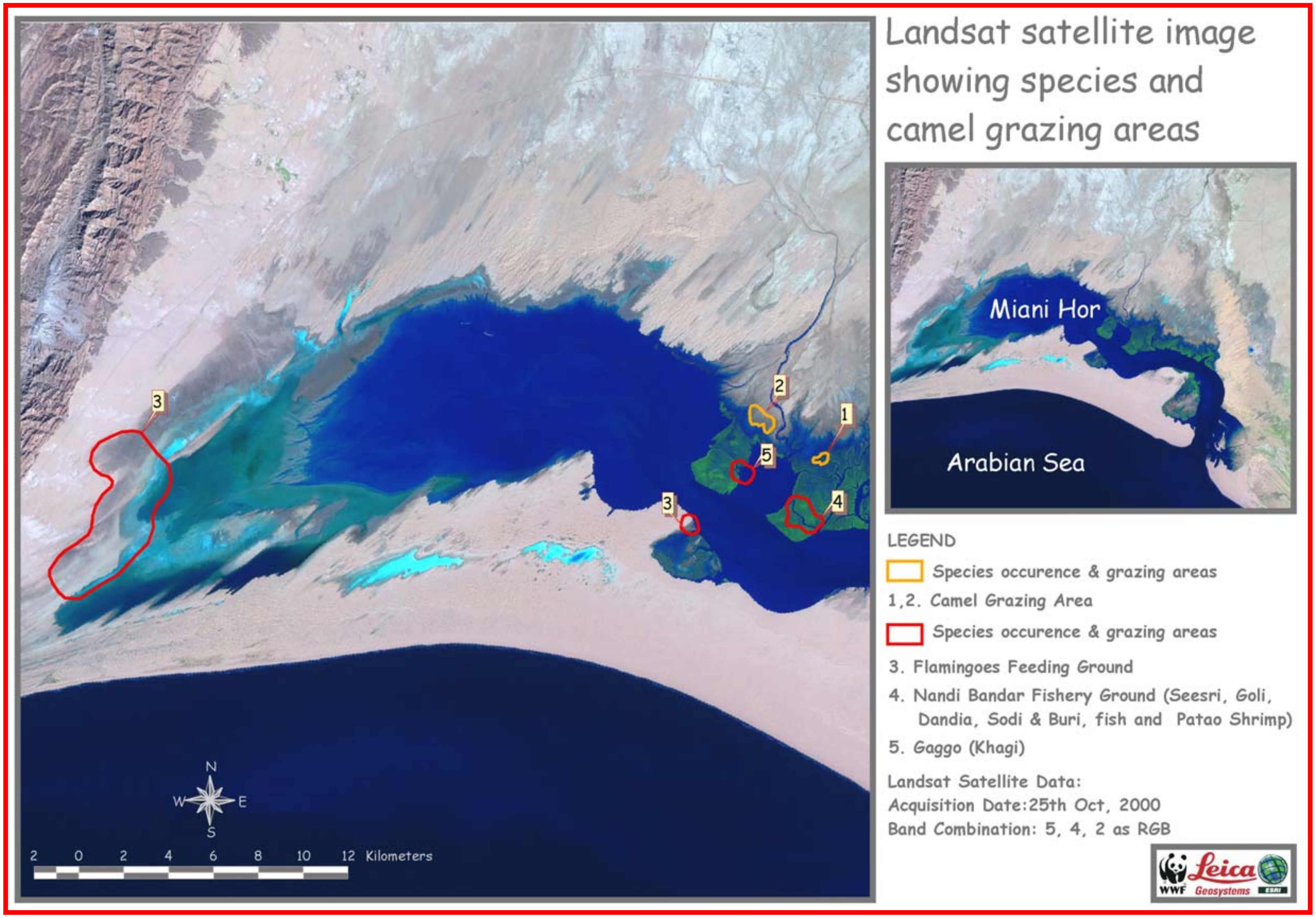

Figure 33: Fish and Flamingos habitat and camel grazing area in the eastern side of Miani Hor

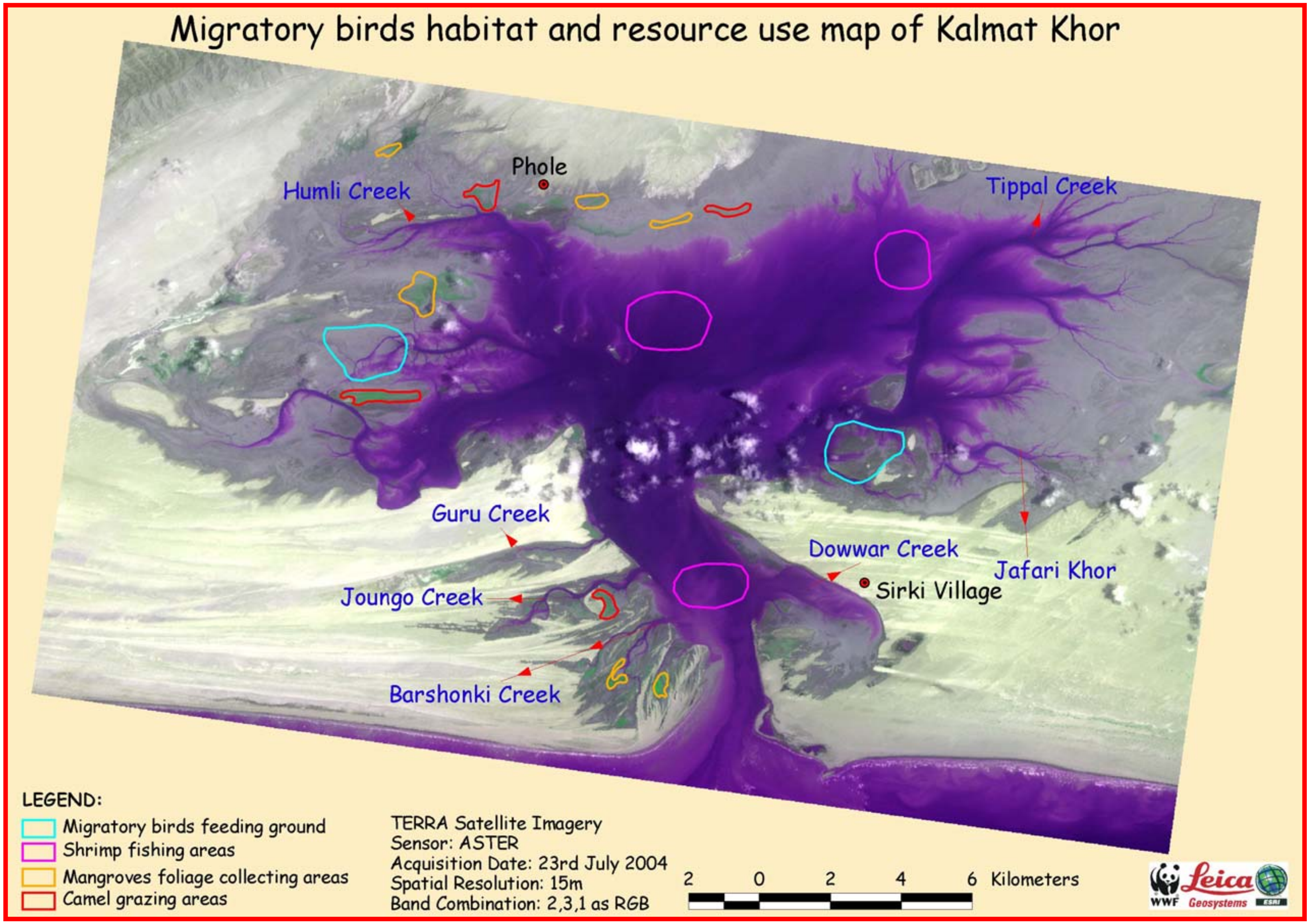

Figure 34: Migratory birds habitat and resource use map of Kalmat Khor