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Research Article

GIS-based Classification of Habitat, Land Use, and Land Cover in Several Creeks within Sindh Province's Indus Delta

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Abstract

Geographic Information Systems (GIS) are used to forecast fish habitats globally, providing extensive data on fish species distribution. Satellite imagery captured by satellites helps identify important stream habitats. In Pakistan's Sindh Coast, over fifty creeks, seventeen of which are large, out of that thirteen were examined. Satellite photography was used to evaluate stream characteristics, and thirteen land use categories were observed. From 1992 to 2014, land cover and land use in creeks fell by 33.68%, with shallow and deep waters making up 29.7% of the land. Sea intrusion led to mud soil erosion in several creeks, with Issaro Creek experiencing the greatest loss of both dry and wet mud lands. Wet Mud Land shrank by 25.8% during the same period. Coverage of bare sand, dry mud land, and turbid water increased. Area covered by mangroves increased by around 4.36%. Agriculture land was found only at the Jhang River, while built-up regions were limited to Chani Creek, with a small jetty area at Keti Bunder.

Keywords: Indus delta, creeks, habitat, land usage, land cover, GIS techniques.

1. Introduction

The Indus delta is recognized as home to a large mangrove belt, which contributes to a thriving ecosystem. There are four species of mangroves; *Avicennia marina* covers 90% of the area, while *Rhizophora mucronata, Ceriops tagal*, and *Aegiceras corniculata* cover 10% [1]. The Sindh Forest Department has planted these mangroves, with support from environmental organizations such as the UNDP, IUCN, and WWF-Pakistan [2]. The mangrove belt is essential for marine species to mate and spawn,. The River Indus' freshwater supplies are essential to the seventh-largest mangrove habitat on Earth and household and industrial effluents in Karachi [1]. The river is now a salty water supply as a result of factors issues such as damming, sea level rise, diverted Indus Rivers, and a shortage of freshwater imports due to the shrinking of the delta [3].

The Indus Delta, the world's fifth-largest delta, is a naturally occurring wetland in the Arabian coastal biogeographic area [4, 5]. It is the 6th largest delta globally, with over 600,000 hectares of mangrove forests, shaped by the Indus River [6]. The biggest mangroves in the world are found in the delta, and they depend on the River Indus for fresh water as well as Karachi City's industrial and residential trash [1]. Creeks in Sindh are essential marine resource ecosystems, both live and inanimate [7]. Agriculture, Water, biodiversity, forests, socioeconomic and health sectors are all impacted worldwide by climate change [8]. The natural environment can be changed by natural catastrophes such as earthquakes, tsunamis, floods, cyclones, and seawater intrusion. The health of millions of people in the region is being impacted by the Arabian Sea's rising temperatures [9].

Global fish habitat forecasting is done using GIS systems using sophisticated statistical methodologies, providing an economical and efficient method for obtaining extensive data [10]. They can visualize fish species distribution and combining it with oceanic and environmental data from satellite imagery to pinpoint significant stream habitats [11-13]. Out of the more over fifty creeks on the Sindh Coast, seventeen were judged appropriate for a detailed analysis.

This study aimed to evaluate fisheries resources over a 12-month period in order to determine habitats, identify species that are present or absent, and determine the recruitment trends of economically viable species. There are thirteen possible study areas in the Indus Delta that have been chosen for investigation based on prior experience, availability, and available resources. The extent and accessibility of a number of streams have been assessed using satellite imagery. The study area in different creeks is shown in Figure-1 [14, 15].

2. Material and methods

The study examines environmental changes in habitat over 22 years from 1992 to 2014 using image classification to study each creek separately. High tide levels are mapped using Google Earth's digitized high water lines, and sample stations are marked with GPS waypoints to identify main channel areas. Creeks are vectorized using Google Earth's polygon feature, with values in feet, miles, and decimal degrees. Bands for Landsat 1992 and 2014 were chosen to enhance satellite dataset visualization. A simple raster-based bright and contrast operation was employed to improve images. The land-cover and land-use of certain streams determine the number of classes. Buffers are made along each mile of river/water body, with slopes set using ArcMap 10.1 for r = 0.7 km from the creek boundary. The bands for Landsat 1992 and 2014 were set to improve visualization in the satellite datasets. Images are divided into 100 classes by an unsupervised classifier, converted into eight classes based on land-cover and land-use of specific streams. IMG Format Donut charts depicting the calculated land-cover and land-use classes are constructed [14, 15].

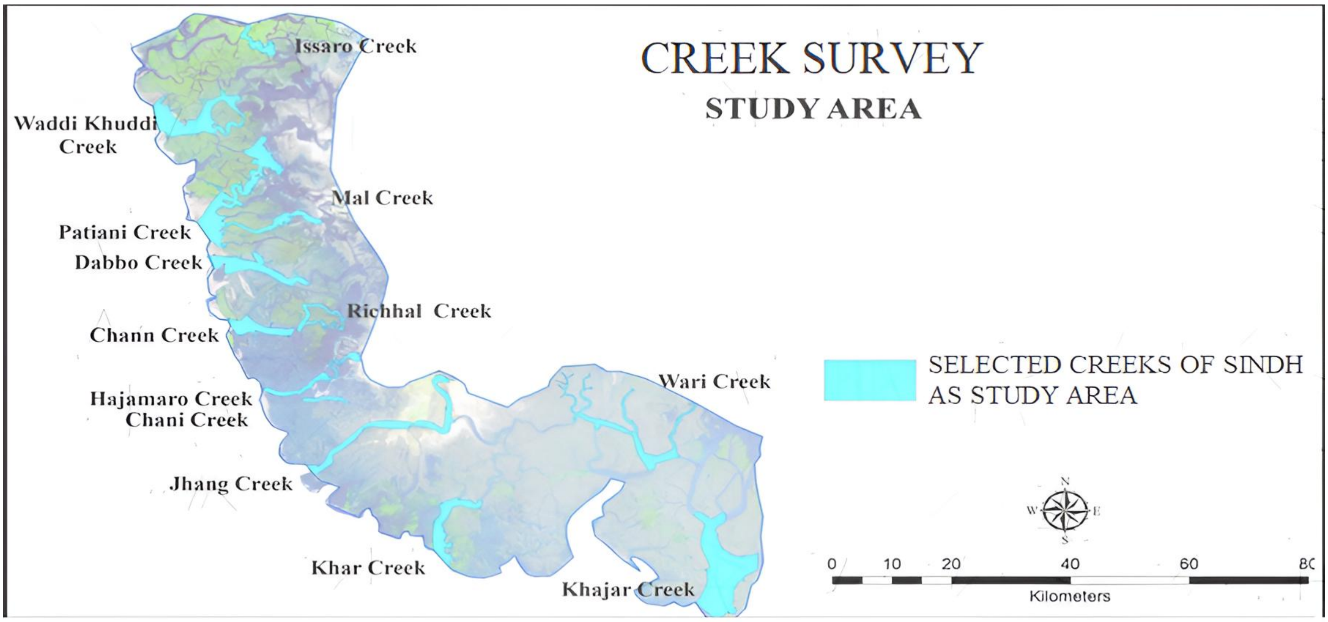

Figure 1. Study area in different creeks along Sindh coast of Pakistan.

3. Results and Discussion

3.1. Habitat classification of Issaro Creek

Figure 2A-2B displays proportion of habitat types found in the Issaro creek during the current study. In 1992, 33% of the area was wet mud land, followed by bare sand (3%), thick mangroves (2%), turbid water (8%), shallow water (4%), deep water (24%), dry mud land (15%), and mangroves (11%). 20%, the bare sand to 14%, and the dense mangrove to 6%.

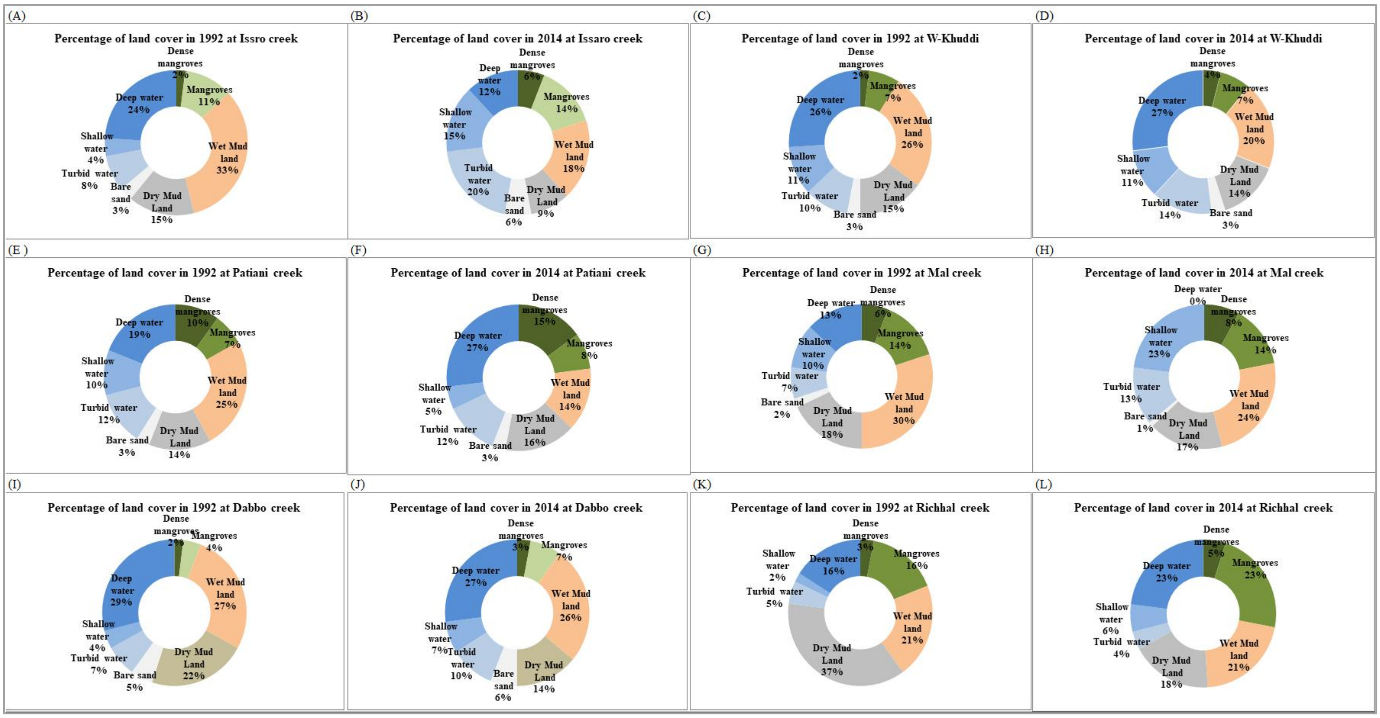

Figure 2. Land-use classification of Habitat during 1992 and 2014: (A and B) Issro Creek; (C and D) Waddi-Khuddi Creek; (E and F) Patiani Creek; (G and H) Mal Creek; (I and J) Dabbo Creek; (K and L) Richhal Creek.

These habitats showed significant change in the percentage makeup in 2014. Deep water declined to 12%, wet mud land dropped to 18%, and dry mud land to 9%. The shallow water has increased to 15%, the turbid water to

3.2. Habitat classification of Waddi Khuddi Creek

Habitat classification of Waddi Khuddi Creek as a percentage is shown in Figure 2C-2D. In 1992, 15% of the ground was dried mud, 10% turbid water, 11% shallow water, mangroves 7%, bare sand 3%, and dense mangroves 2% of the total, while deep water and wet mud land comprised 26%. These habitats have significantly changed in 2014: with 14% dry mud land, 20% wet mud land. However, deep water rose to 27%, thick mangrove to 4%, and murky water to 14%. However, shallow water (11%) and bare beach (3%), as well as mangroves (7%), remained unchanged.

3.3. Habitat classification of Patiani Creek

Figure 2E-2F demonstrates the habitat composition of Patiani Creek as a percentage. In 1992, 25% of the area was made up of wet mud land, 14% was dry mud land, 19% was deep water infiltration, and 10% was each of dense and shallow mangrove, turbid water at 12%, mangrove (7%), and bare sand (3%). The overall composition of these habitats changed substantially in 2014, with deep water making up 27%, dry mud land 16%, thick mangroves 15%, and mangroves 8%. However, wet land dropped significantly to 14% and shallow water dropped to 5%, but turbid water (12%) and bare sand (3%), however, remained same.

3.4. Habitat classification of Mal Creek

The habitat's percentage composition in Mal Creek is shown Figure 2G-2H. In 1992, 30% of the total made up of wet mud land, mangroves at 14%, dry mud land 18%, shallow water (10%), deep water at 13%, turbid water (7%), thick mangrove (6%), and bare sand (2%). In 2014, these ecosystems' percentage composition saw a substantial shift: Wet mud land rose to 24 percent, land covered by dry mud dropped to 17%, bare sand decreased to 1%, deep water decreased to 0% and mangrove stayed at 14%. However, shallow water rose to 23%, dense mangrove to 8%, and murky water to 13%.

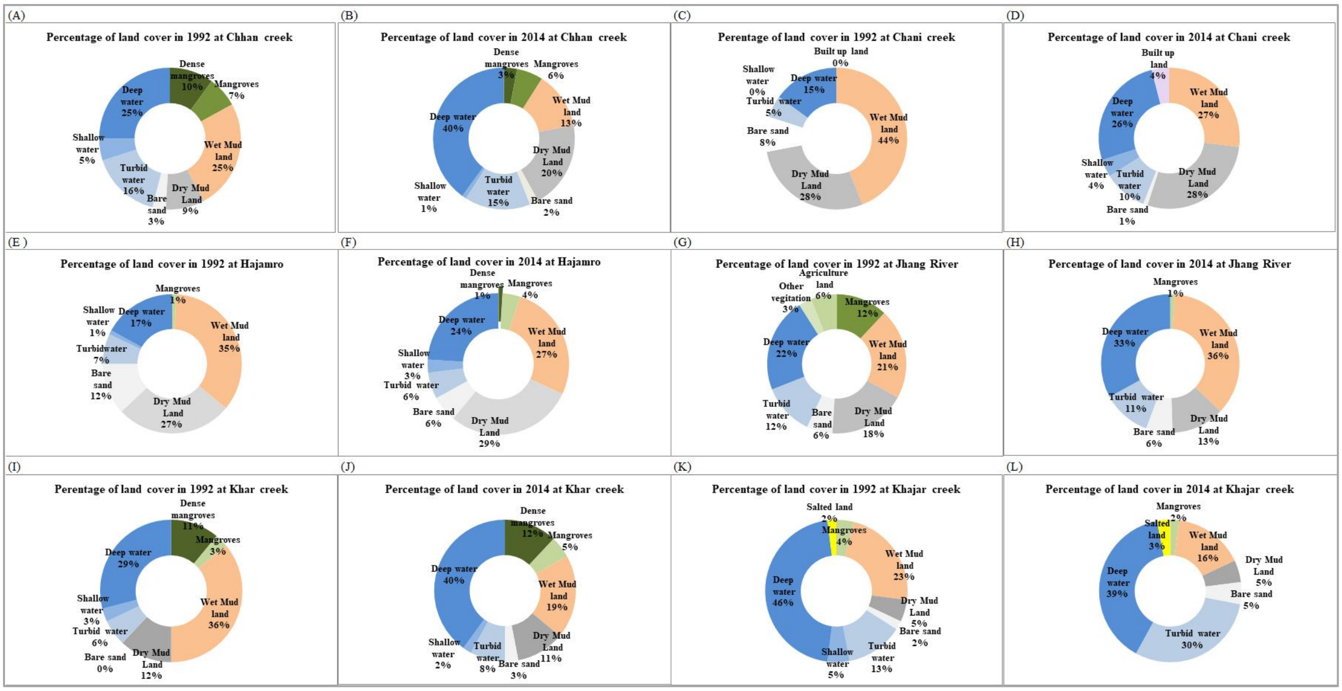

Figure 3. Land-use classification of Habitat during 1992 and 2014: (A and B) Chhan Creek; (C and D) Chani Creek; (E and F) Hajamro Creek; (G and H) Jhang River; (I and J) Khar Creek; (K and L) Khajar Creek.

Wet mud land made up 44%, dry mud land made up 28%, deep water made up 15%, bare sand made up 8%, turbid water made up 5%, and shallow water made up 0% in 1992.

3.5. Habitat classification of dabbo Creek

Figure 2I-2J displays the habitat composition of Dabbo Creek as a percentage. In 1992, 29% of the area was deep water, wet mud land (27%), dry mud lands (22%), followed by 7% turbid water, 5% bare sand, 4% each of mangroves and shallow water, and thick mangrove at 2%. The percentage of these habitats changed notably in 2014, deep water to decline to 27%, wet mud land to 26%, and dry mud land dropped to 14%. However, turbid water (10%), bare beach (6%), dense mangrove (3%), shallow water (7%), and mangrove (7%) all perceived a significant increase.

3.6. Habitat classification of Richhal Creek

The habitat composition in percentage of Richhal Creek is shown in Figure 2K-2L. In 1992, 37% of the land was dry mud land, 21% was wet mud land, 16% was deep water with mangroves, 5% was turbid water, 3% was thick mangrove, and 2% was shallow water. In 2014, the proportional makeup of these ecosystems underwent a substantial change: dense mangrove increased to 5%, shallow water to 6%, mangrove and deep water increased to 23% each. Turbid water dropped to 4% and dry mud land dropped to 18%, whereas, wet mud land stayed at 21%, respectively.

3.7. Habitat classification of Chhan Creek

The habitats composition in percentage of Chhan Creek is displayed in Figure 3A-3B. About 25% of land cover was makeup by deep sea water and wet mud land in 1992, while turbid water accounted for 16%, dense mangroves for 10%, dry mud land for 9%, mangroves for 7%, shallow water for 5%, and bare sand for 3%. 2014 witnessed a substantial change in these ecosystems' proportional makeup, deep water increased to 40%, dry mud land rising to 20% and 6% in mangrove. Turbid water declined to 15%, wet mud land reduced to 13%, dense mangrove to 3%, bare sand to 2%, and shallow water to 1%.

3.8 Habitat classification of Chani Creek

The habitat composition as a percentage for Chani Creek is given in Figure 3C-3D.

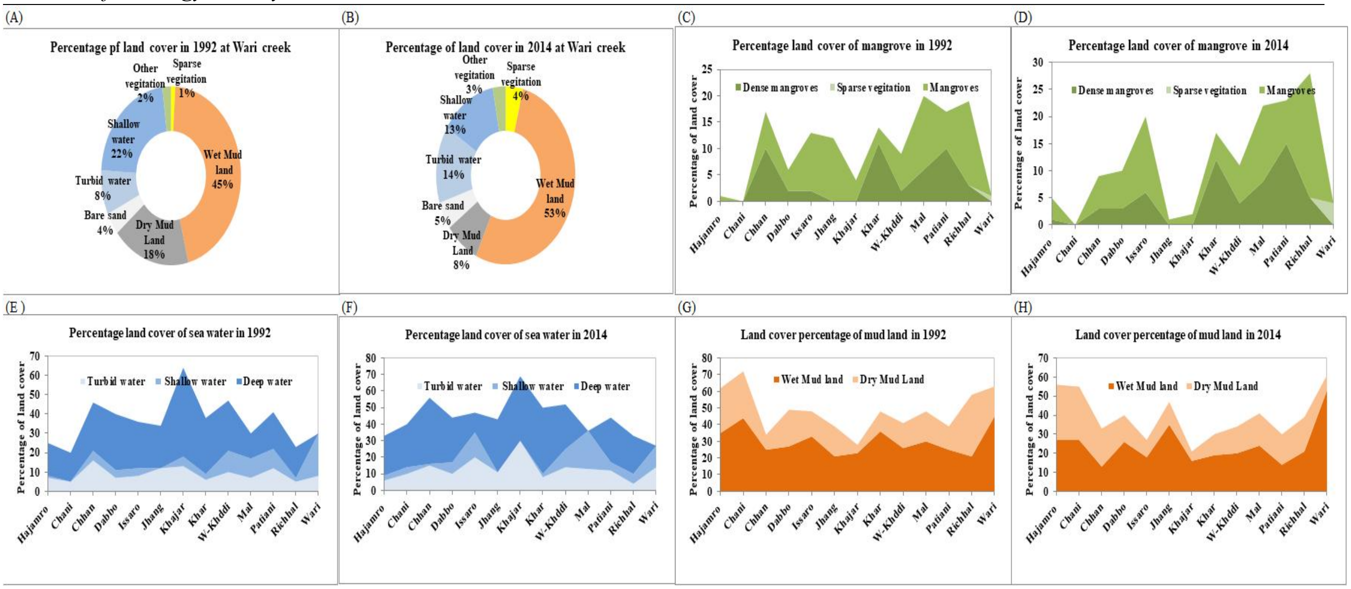

Figure 4. (A,B) Land use classification of Habitat during 1992 and 2014 at Wari Creek; (C and D) Land-use cover during 1992 and 2014-Mangroves; (E and F) Land-use cover of Sea Water; (G and H) Land-cover of Mud-land.

Significant changes occurred in the relative makeup of these ecosystems in 2014: reduction in wet mud land to 27%, bare sand decreased to 1%, and 28% of the ground was still dried mud. However, deep water increased to 26%, turbid water rose to 10%, shallow water fell to 4%. Compared to 1992, there is now a new habitat with 4% build-up land.

3.9 Habitat classification of Hajamro Creek

The habitat component % for Hajamro Creek is displayed in Figure 3E-3F. In 1992, dry mud accounted for 27% of the total area, while wet mud accounted for 35%, deep water at 17%, bare sand at 12%, shallow water at 1%, mangroves at 1%, and turbid water at 7%. In 2014, these ecosystems' relative makeup changed significantly: deep water made about 24%, shallow water for 3%, dry mud land for 29%, and mangroves for 4%. The percentages of bare sand and turbid water dropped to 6% apiece, but the amount of wet mud land dropped dramatically to 27%. The dense mangrove habitat that was not there in 1992 was recorded to include 1% in 2014.

3.10 Habitat classification of Jhang River

Figure 3G-3H displays the proportion of the Jhang River's habitat. In 1992, deep water accounted for (22%), wet mud land 21%, dry mud land (18%), mangroves and turbid water (12%) each, agricultural land and bare sand (6%) each, and other vegetation (3%). These ecosystems' relative composition changed significantly in 2014: with deep water and wet mud land seeing the largest increases, these increase to 33% and 36%, respectively. While mangroves decreased to 1%, turbid water to 11%, and dry mud land to 13%, bare sand stayed at 6%. The amount of land utilised for vegetation and agriculture was not documented in 2014.

3.11 Habitat classification of Khar Creek

The habitat's % composition for Khar Creek is shown in Figure 3I-3J. In 1992, 36% of the land was wet mud land, followed by deep water (29%), thick mangroves (11%), dry mud land (12%), turbid water (6%), mangroves and shallow water (3% apiece), and 0% bare sand. 2014 saw a significant change in these ecosystems' relative makeup. The percentage of deep water rose to 40%, followed by dense mangroves (12%), mangroves 5%, murky water 8%, and bare sand 3%. Conversely, shallow water decreased to 2% and dry mud land to 11%.

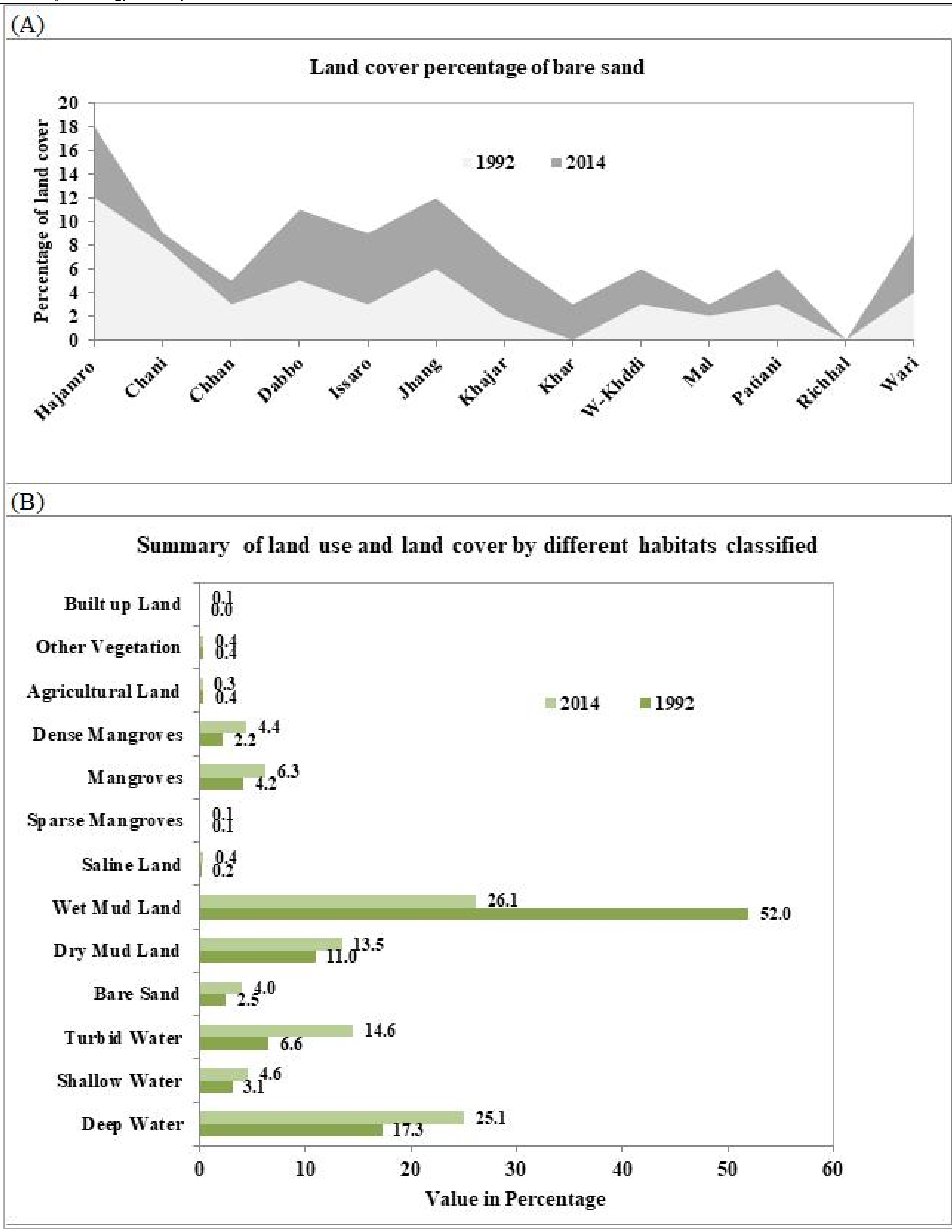

Figure 5. (A) Percentage of Land Covers by Bare Sand during study period; (B) Summary of Land-use and Land-cover by different Habitats Classified.

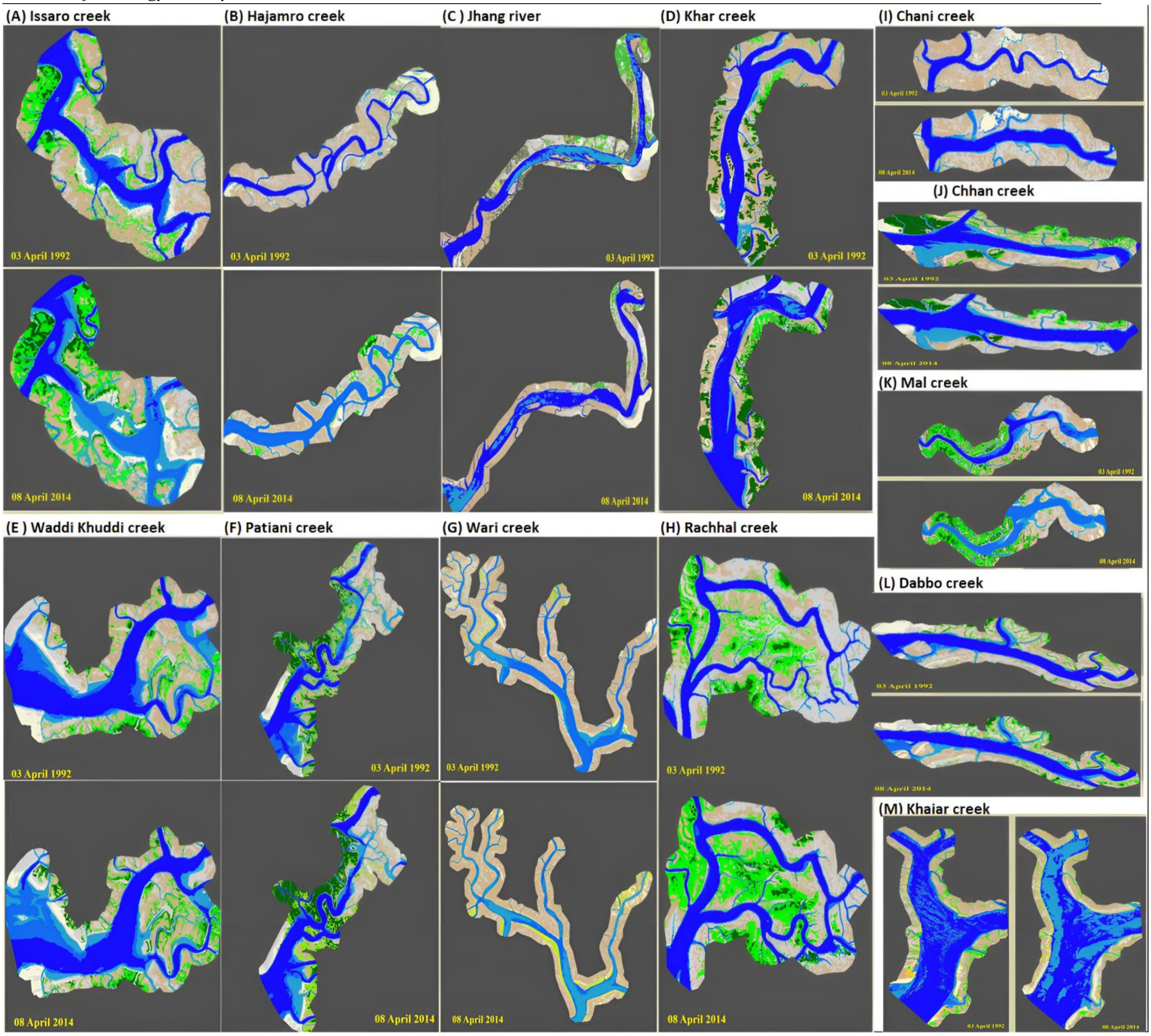

Figure 6. Satellite images of Land-cover in different creeks during 1992 and 2014. (Source: WWF, 2015).

3.12 Habitat classification of Khajar Creek

Figure 3K-3L shows the percentage makeup of Khajar Creek's habitat. 46% of the area was deep water in 1992, followed by wet mud land (23%), turbid water (13%), shallow water and dry mud land (5% each), mangroves (4%), salty land and bare sand (2% each). In 2014, there was a noticeable change in the percentage composition of these ecosystems: turbid water rose to 30%, bare sand to 5%, and salty land to 3%. On the other hand, deep water dropped to 39%, mangroves to 2% and wet mud land to 16%. Dry mud land remained steady at 5%.

3.13 Habitat classification of Wari Creek

The habitat's percentage composition for Wari Creek is shown in Figure 4A-4B. Bare sand made up 4%, dry mud land had 18%, turbid water had 8%, wet mud land had 45%, other vegetation had 2%, and sparse vegetation had 1% in 1992. The proportions of these habitats changed significantly in 2014: 53% of the total were wet mud land, 14% were turbid water, 5% were bare sand, 4% were sparse vegetation, and 3% were other vegetation. Shallow water dropped to 13% and dry mud land to 8%.

3.14 Mangrove cover

There are three types of mangroves: dense, dispersed, and scattered. Thick mangroves have significantly increased in Patiani and Issaro Creeks, with Patiani Creek seeing a growth of 10% to 15% and Issaro Creek seeing an increase of 2% to 6% (Fig. 4C-4D). In spite of these modifications, the total number of mangroves increased by 3%. Because of mangrove planting and increased freshwater availability, the creeks on the west bank of the Jhang River, include Patiani, Mal, Dabbo, Issaro, Waddi Khuddi, Chann, Hajamro, Chani, and Richhal, have stayed steady. The efforts of the Sindh Forest Department, volunteers, and the coastal people have resulted in the growth of mangroves in these waterways. In 2014, the percentage of thick mangroves in Hajamro Creek increased to 1%.

3.15 Impact of sea level rise

There are three different kinds of water habitats in the survey area: turbid, shallow, and deep water. Over a 22-year period, all of the creeks' water levels increase, with the exception of Wari Creek, which has decreased by 3%. Water levels in the smallest brook, Chani brook, have significantly increased from 20% to 40% (Fig. 4E-4F). A similar trend can be seen in Hajamro Creek, where deep water levels increase from 17% to 24%. The water channel of Chani Creek extended and became a straight route by 2014, whereas the water channel of Hajamro stream became a single channel with a bigger creek in 2014 as a result of the rise in water levels (Figure 6).

3.16 Mud lands

According to the study, mud soil erosion has occurred in numerous streams as a result of climate change, with Issaro Creek seeing the largest loss in both dry and wet mud lands. Khajar, Hajamro, Wari, Chann Creeks, Dabbo, Patiani, Richhal, Khar, Chani, and Mal and Waddi Khuddi are further locations where mud lands have decreased (Figure 4G-4H). However, in the Jhang River, where the river narrows and bends, resulting in water deposits of silt and sediments, the mud land area has grown by 8%.

3.17 Bare sand

Each of the streams in the study area has a little strip of exposed sand, which is a crucial component of their ecosystem. During cyclones, the exposed sands surrounding stream mouths, known as sand bars, are essential for breaking waves in the water. At the mouths of the Patiani, Khajar, Chann, Dabbo, Chani, Waddi Khuddi and Hajamro Creeks, there is bare or barbed sand. The streams of Richhal, Issaro, Chani, Wari, and Mal also include bare sand (Figure 5A).

3.18 Land-cover and usage summary for several streams

The study found that land utilisation and land cover in several streams decreased by 33.68%, from 139,854 hectares in 1992 to 92,752 ha (Figure 5B). Thirteen different land use classes that were found in the study area include dense mangroves, mangroves, sparse mangroves, wet mud land, dry mud land, turbid water, deep water, shallow water, bare sand, agricultural land, saline land, other vegetation. The percentage of land covered by deep and shallow waterways rose from 20.35% to 29.7%. While bare sand, dry mud land, and turbid water all sharply rose, wet mud land fell by 25.5%. Mangrove cover increased by 4.44%, 6.29%, and 0.11% for typical, thick, and sparse mangroves, respectively. Buildings, other plants, and agricultural land types were somewhat altered, nevertheless. Figure 6 shows a GIS picture of each creek.

4. Discussion

Mangrove trees, which are vital to the Indus Delta, help adapt to climate change and shield the local inhabitants from cyclones and sea storms. They also serve as very efficient locations for storing carbon [16]. The Indus River is home to 97% of Sindh's mangroves, compared to just 3% in Baluchistan [17]. The mangrove cover in Chann Creeks has dropped by 7%, from 10% to 3%, over the course of the study period. This resulted from the ongoing intrusion of seawater, which also caused mud land erosion and the loss of mangrove cover. During the research period, Chani Creek's mangrove and vegetative cover totally disappeared due to the continuous inflow of seawater into the stream's broader mouth (Figure 6).

The study demonstrates a consistent rise in mangrove cover, with 7% of normal mangroves found in Waddi Khuddi and Mal Creeks. In 1992, in streams west of the Jhang River, the average mangrove cover was 16% in Richhal, 4% in Dabbo and 1% in Hajamro. By 2014, it increased to 23%, 7%, and 4%, and respectively. However, from 1992 to 2014, mangrove cover decreased from 7% to 6% in Chann Creek.

East of the Jhang River, the Wari, Khajar, and Khar Creeks are seeing a rise in sea level as a result of a freshwater deficit, leading to a decrease in mangrove coverage and salty land. Despite these challenges, the Sindh Forest Department has made significant contributions to improving mangrove cover in the deltaic region, with the help of WWF-Pakistan, IUCN Pakistan, and local people [16]. In a single day, the Sindh Forest Department planted seven hundred fifty thousand mangrove plants near Kharo Chan, Thatta, breaking a previous global record [18]. Wari Creek and Khajar Creek's mangrove areas have decreased, while the Jhang River's mangroves have seen a 11% decrease due to agricultural operations. However, from 2005 to 2021, the Indus Delta's mangrove forest cover has grown significantly, thanks to local communities, non-profits, and government agencies. Rehabilitation of mangroves is improving residents' quality of life and regenerating fish populations, as they are crucial for the Indus Delta's survival and carbon storage [16].

Pakistan is experiencing similar patterns to global sea level rise, partly due to glacier and ice melt loss. The country faces risks of flooding and saltwater intrusion due to its heavily populated coastal regions, particularly Karachi. The average temperature rose by 0.60°C between 1901 and 2000, and sea levels are predicted to rise by 1.1 mm annually [19]. Changes in creeks like Chann Creek, Patiani Creek, Dabbo Creek, Waddi Khuddi Creek, and Jhang River have occurred due to rising water levels. Some creeks, like Mal, Richhal, and Issaro, have decreased mud and sand, making them more susceptible to sea level rise and erosion. Higher streams like Mal, Richhal, and Issaro also experienced similar decreases in mud lands and rising water levels.

The study area east of the Jhang River is threatened by seawater intrusion, endangering its freshwater supply. Water level increases significantly in Khajar Creek and Khar Creek (Figure 4E and 4F), with salinised land altering along Khajar Creek increased from 0% in 1992 to 3% in 2014, complicating fishing surveys due to strong sea waves. Of all areas studied, only Khajar Creek has saline terrain. Intense rainfall and floods (2010–2012) elevated water levels in Chani and Hajamro Creeks, especially near the Jhang River. Flood patterns are seasonal, and the delta does not consistently benefit from irregular floodwaters [20]. Seawater corrosion affects the mouths of multiple creeks: Dabbo, Waddi Khuddi, Hajamro, Patiani, Chann, Khajar, and Khar [15].

Climate change has caused mud soil erosion in several streams, with Issaro Creek experiencing the most significant loss. Other streams, including Dabbo, Patiani, Mal, Waddi Khuddi, Khajar, Hajamro, Wari, Chann Creeks, Richhal, Khar, and Chani, have also experienced reductions in mud land. However, the Jhang River has seen an 8% increase due to silt and sediment deposits. Flash floods in the Indus Delta promote the restoration of mangroves, aquifers, and aquatic life [21]. Each stream in the study area has exposed sand or bare sand, which is crucial for breaking ocean waves during storms. The 2014 built-up area near Chani Creek; particularly, jetty at Keti Bunder may have been contributed to this erosion [15].

The Jhang River's freshwater flow limits agricultural land use due to its dilute nature. Over the past 22 years, agricultural land has decreased by 3%, with major losses from floods in 2010 and 2011. The ocean incursion has also significantly impacted Sindh's cropland [22]. Industrial waste, sewage pollution, and land reclamation have affected spawning grounds in the Indus Creek region [23]. Mangrove swamp degradation has led to fish loss, erosion, and coastline alterations [24]. Human activities disrupt the food chain and nutritional levels [25]. More freshwater reaches the Jhang Rivers, Chani, and Hajamaro streams, where hundreds of fish are caught [26]. The seasonal and regional variations in prawn species collected from the Indus delta have also been studied [27].

The Indus river has been severely damaged by mangrove destruction, erosion, and the use of prohibited fishing gear [23, 28, 3]. The Khar, Khajar, and Wari creeks, which are relatively fruitful due to strong currents and little human activity, have a high number of fish species [3]. However, flash floods can restore mangroves, aquifers, and aquatic life in the delta [21]. Unpredictable flood patterns vary from year to year, and increasing salinizing land and declining fish yields are causing calamities, making cultivation difficult for 1.2 million people [29]. Cyclone Phet in 2010 and the 2004 Indian Ocean tsunami also affected Pakistan's coastline. An unusual water surge in 2022 raised concerns, particularly in Karachi, highlighting the need for urgent action [15, 30].

5. Conclusion

The Indus River is home to 97% of Sindh's mangroves, and a study shows that between 1992 and 2014, land cover and stream usage decreased by 33.68%. Thirteen land use classes were identified, including dense mangrove, normal mangrove, sparse mangroves, dry mud land, wet mud land, salty land, bare sand, agricultural land, built-up land, vegetation, turbid water, shallow water, deep water, and shallow water. The percentage of land covered by deep and shallow waterways increased from 20.35% to 29.7%. Three categories of mangroves were identified in the study that has been increases of 0.11%, 6.29%, and 4.44%, respectively. Sea intrusion has led to mud soil erosion in a number of creeks; Issaro Creek has had the greatest loss of both dry and wet mud lands.

Data Availability statement

The data will be available upon justifiable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Author Contributions

Muhammad Wasim Khan contributed to the investigation, methodology, and writing of the original draft. Ghulam Abbas was responsible for conceptualization, supervision, and review and editing. Shahnaz Rashid and Abdul Rauf conducted the review editing, while Hameeda Kalhoro carried out the formal analysis and editing.

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