SPATIO-TEMPORAL TRENDS AND PATTERNS OF THE COASTAL BELT ALONG SINDH PROVINCE-PAKISTAN

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Abstract

Coastal habitats, existing on 7% area of earth, are integral in the sustenance of valuable biodiversity and human livelihoods. Prominently, their mangrove forests serve as the most productive ecosystems spread across 147,000 km^2 of the planet. However, escalation in anthropogenic activities and variation in environmental conditions are constantly threating the existence of healthy coastal ecosystems. Realizing the urgency, the performed study evaluates the relationship between environmental changes and fisheries resources through observing the spatiotemporal changes in mangrove forests along the coastal belt of Sindh, Pakistan. The research examines variation in mangrove cover and marine fisheries production, hotspots for coastal pollution, and the combined effects of environmental and anthropogenic factors on marine and coastal ecosystems using Geographic Information Systems (GIS) and remote sensing technologies. The results show a notable increase in mangrove coverage, which acts as a natural defense against cyclones and coastal erosion, in contrast to earlier predictions. Rising sea levels and extreme plastic pollution, however, continue to be risks. Numerous plastic dumping sites along the coast of Karachi were observed to be the main reason for decline in fish biodiversity within close vicinity of the coastline. This decline in fishing resources emphasizes the significance of sustainable coastal management. Whereas restriction in dumping of untreated wastewater is necessarily required to replenish health of the coast and the existing biodiversity. To safeguard the region's ecological and economic health, the study also highlights the significance of mangrove conservation and has focused on pollution reduction measures for long-term sustainability of coastal ecosystem.

Keywords: *Geo-Spatial, GIS, Mangroves, Sindh coast, Environmental pollution, Pakistan.*

1. Introduction:

Coastal ecosystems, covering 7% of the earth's surface, are among the most biologically productive and economically viable environments on the planet (Santos *et al.,* 2024). Within this vibrant ecosystem, mangrove forests cover an estimated 147,000 km^2 area, representing one of the largest and most critical component of the tropical and subtropical regions (Bhagarati & DaSilva, 2024). Mangroves play a very vital role in shoreline stabilization, fisheries productivity and carbon sequestration. Their dense root system trap sediments, reduce coastal flooding and provide resilience against cyclones and storm surges. From climate perspective, mangroves are highly effective blue carbon ecosystem, storing significant amount of carbon in biomass and soils. In addition to ecosystem services, mangroves support the local coastal communities by supporting fisheries, providing timber, fodder and fuel-wood for subsistence needs which make them socio-economically indispensable in the deltaic regions (Zhao *et al*., 2023; Saoum & Sarkar, 2024).

Nevertheless this important ecosystem has been seriously depleted by different anthropogenic stresses. Almost 38% of the global mangrove loss is contributed to land conversion to agriculture, aquaculture and urban infrastructures. Contrarily, the oil spills and discharged nutrient pollution add up about 14% (Islam *et al.,* 2024). In addition, 16% of the overall mangrove degradation has been due to coastal erosion and intrusion of salinity, which has been caused by the rising sea levels and changed hydrological flows (Aeman *et al.*, 2023). Another 10-12% of this decrease in quality and quantity is contributed by oil spills and plastic debris (Mehmood *et al.,* 2025; Saoum & Sarkar, 2024). The compounding impact of these threats not only reduces the biodiversity, but also severely compromises the ecological strength, socio-economic well-being of the coastal communities who rely on these ecosystem to protect their livelihoods, food and lives.

It is estimated that Pakistan possesses 1001 km long coastline which is shared by the Province of Balochistan and Sindh respectively (Pakistan Hydrography Department; UNEP, 2023; World Bank, 2023). The Sindh Coast, which is located along the Arabian Sea around the Southern part of Pakistan, is a vibrant and ecologically rich area which is both economically and environmentally important. Coastal areas are highly exposed to climate change and human activities worldwide as they form a very important interface between the land and sea. Table 1 indicates that Sindh Coast is a region with expansive mangrove systems, which occupy 1.88 million hectare (2.2%) in Pakistan (Akram et al., 2023). Among them, the number of hectares is 0.132 million ha (less than 3%) of estuarine habitats, coastal mangroves, and colorful coastal communities, which is a fascinating case study to untangle dynamic trends of time and space that explain its ecological and socio-economic context (Khwaja & Qureshi, 2020).

Table 1: Mangrove Forest Cover in Pakistan *(Source: IPCC Report by Yamanoshita, 2022).*

Region	Area(ha)	% of mangrove In Pakistan
Karachi Harbor	985.0	1.14
Indus Delta	81,684.0	94.18
Miani Hor	8,479	3.96
Kalamat Hor	479.0	0.22
Jiwani	433.0	0.55

The economic activities connected with fishing and aquaculture, and the livelihood of the people living on the coastline are largely dependent on marine resources. Moreover, the economic growth of the region is highly supported by the impressive and huge infrastructure located in the shoreline, including seaports and industrial districts. However, the region is characterized by numerous threats that are caused by anthropogenic as well as natural causes (Adhikari et al., 2010). Climate change, which involves alteration in the patterns of precipitation and the increased sea levels, presents direct threats to the delicate balance of the Sindh Coast. These shifts, along with the population boom and rapid modernization, are the most important aspects of the coastal regions that should be understood thoroughly (Khan et al., 2020; Leary, 2020; Siddiqui & Shaikh, 2018).

Social and environmental impact of the dangers and environmental changes in the Sindh coastal areas have been explained by many study articles. A 33-year study conducted by Ahmed *et al*, 2025 through application of Landsat-based machine-learning techniques on the Indus Delta mangroves, have reported a large net increase in mangrove canopy from ≈50,973 ha in 1990 to ≈101,447 ha in 2023. This increase has been linked to natural drivers (sediment accretion) and human interventions such as restoration/afforestation and implementation of conservation programs. Storm wave modelling was used by Ali et al. (2019) to forecast possible dangers in Sindh's coastal regions as it possesses unique bathymetric, topography and climatic patterns. Efficient structures of early detection and catastrophe response plans are dependable in preserving the coastal areas, which the study highlighted. As climate change hazards continue to intensify, early warning dissemination systems and establishment of community-based disaster preparedness programs could facilitate resilience. The susceptibility and climatic resilience of mangrove forests, on the contrary hand, were brought to light by Qureshi & Naeem's (2014) investigation of cyclone effects on these forests. Due to low elevation, high exposure to climate induced disasters and anthropogenic pressures, Indus Delta, supporting 90% of mangroves, is highly vulnerable. Therefore, expansion of protected areas and community-led reforestation may act pivotal in coastal zone management along Sindh coasts. The study by Baloch et al. (2013) on monitoring and managing coastal erosion also found the extent, drivers, and mitigation strategies of erosion in Sindh's coastal regions. It reported that areas along Sindh coast such as, Keti Bandar, Shah Bandar and Indus Delta have seen drastic reduction in natural sediment supply due to water diversion projects and upstream damming. The study's geo-spatial assessment showed some segments of the coastline erosion exceeding 6 meters per year. Moreover, the paper has pointed out the challenges in sustainable management of the shoreline. In addition, Haq and Khan (2017) explored the socioeconomic impact of storms on the communities along the coastal areas and discovered that the areas apply the use of temporary migration, alternative employment, and local support networks to cope with the climatic issues. These strategies have, nonetheless, had quite a few weaknesses that require better legislative measures.

Salim et al. (2019) then used GIS to mark out the Sindh areas that are expected to be especially hit by the disasters along the coasts. The findings gave important information on the risk reduction strategies by highlighting the relationship between land use trends, infrastructural presence, and environmental protection development in prone locations. The subjects of interest to the study such as the population density growth along the coastal regions and land-use changes predisposed not only local ecosystem to risks in case of sea disasters but also uncontrolled and illegal human settlements. Ali et al. (2015) investigate how the altered climates affect the water quality of the coastline of Sindh. The study brings out the fact that increase in sea-surface temperature and sudden precipitation have significantly changed the physico-chemical properties of the coastal waters. With the consideration of growing frequencies of extreme weather conditions attributable to unprecedented climate change, there is a need to keep a watch and preserve the water resources.

The study by Siddiqui et. al. (2018) is an eye-opener, and it provides approaches to sustainable farming, which are flexible. It is notably quoted in this research that storm surge height along Sindh coast can exceed 2 to 3 meters for which coastal defense system remains inadequate. Therefore, it is suggested that cyclone shelters and climate-adaptive infrastructure would prove to be significant in reducing vulnerability of small-scale farmers and fishing communities. Coastal development and risk management benefit greatly from the work by Khan & Memon (2018), which uses GIS and satellite imagery approaches to identify sensitive locations. The study emphasizes Community-Based Adaptation (CBA) measures such as mangrove restoration programs, livelihood diversification, raised housing, and community disaster preparedness plans. The impact of climate variability on the estuarine environment and the reduction in availability of river water in the Indus Delta has led to salinity intrusion, wetland shrinkage and loss of estuarine biodiversity. Industrial pollution coupled with hydrological alterations and coastal urbanization amplifies the risk of storm surges, cyclones and flooding. Integrated water resource management and climate policies adaptive to the estuarine environment of Sindh is the dire need of time (Mustafa & Shahid, 2016; Khan et al., 2017; Kamal, 2023).

On the other hand, the study by Hussain et al (2014) explores the risk perception and adaptation strategies of coastal communities in Sindh. Through surveys and interviews, the report deduces the solution of incorporation of community perceptions into national adaptation as top-down interventions alone would considerably drop the effectiveness of adaptation measures. Sea-level rise contributed by glacial melt of Himalayas and thermal expansion of seawater not only jeopardize the fish population but also is constantly diminishes coastal agriculture through production of barren zones, critical infrastructure, freshwater resources and mangrove forests. Given that agriculture remains the primary livelihood option for the majority of the population of Sindh, the increasing frequency and intensity of cyclonic events, exacerbated by climate change and warming sea surface temperatures, poses a serious challenge to regional food security and economic stability. Previous cyclonic events such as Cyclone 2A (1999) and Cyclone Phet (2010), provided a detailed image of damage to crops, irrigations systems, livestock and agricultural soils, making land unfit for cultivation for years. These events are an example of severe impacts on rural population, inducing poverty, forced migration and reduced agricultural productivity. The increasing vulnerability of the Sindh coastline to erosion particularly Keti Bandar, Shah Bandar, highlights the need for proactive measures (Khan & Jamali, 2015; Memon, 2016; Khatri & Khan, 2012).

Mangrove ecosystems are recognized as highly productive and crucial in supporting coastal biodiversity. In research performed by Shoaib et al., 2017, it was identified that 37 phytoplankton species were present along mangrove forests around Sandspit area of Karachi. These include major groups including diatoms, dinoflagellate and cyanobacteria. Among these, diatoms are the most abundant, reflecting the typical composition of productive coastal waters. These microbial populations have been found in abundance during the monsoon season when ample nutrient influx is provided through riverine and urban runoff. The authors showed concern about the threats to the existing species such as warming of seas, increase in salinity concentration and change in hydrology, which could result in disturbance of healthy co-existence. The present research will try to fill these research gaps to enable better planning and environmental management in the coastal areas of Sindh.

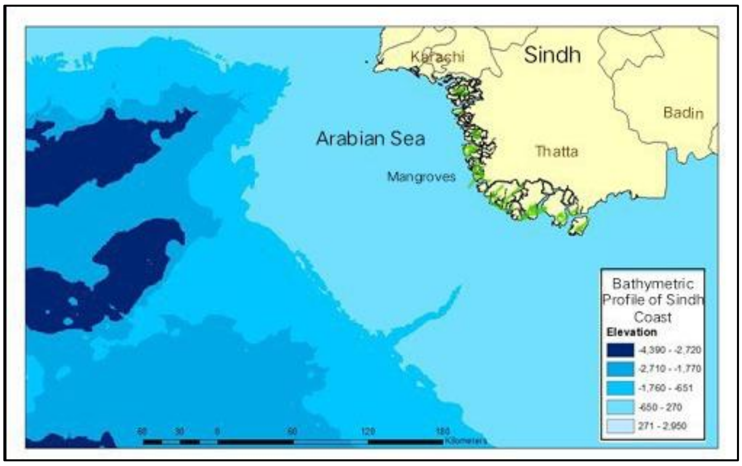

Fig. 1: Variation in Sea Level along Sindh Coast *(Source: GEBCO)*.

The bathymetric profile of the Sindh Coast, which serves as the main focus of this study, is depicted in Figure 1 and clearly illustrates the underlying topography of the coastal waters. A comprehensive map which has been generated due to analysis of depth information at sea depicts a large variety of complex seafloor traits that play a critical role in defining the actions of the coastlines. The bathymetric data presents a comprehensive system of complex interactions between coastland and seafloor and demonstrates that there is an essential relationship between topography of the seabed and the visible changes in the erosion or accretion of the coast. (Li et al., 2023). Also, the map can be a good instrument to assess the impacts of human activities on the underwater setting such as offshore development. The bathymetric profile is a very important aspect of the management of the coastal zone as it provides the necessary information needed to make well informed decisions on conservation of habitats, use of resources and fair development along Sindh Coast.

1.1 Aims and Objectives

- To review and compile the literature on the environmental issues and their impact on the coastal ecosystem, between 2000 and 2025.
- To examine the spatio-temporal dynamics of the mangrove forests in the Sindh Coast in 1995-2025.
- To determine change in production of marine fisheries for 25 years.
- To map and track hotspots of coastal pollution and impact on the marine and coastal environments.

1.2 Study Area

The Coast of Sindh, approximately 350 kilometers long strip along the Arabian Sea, located in the southern part of Pakistan, is very interesting evidence of a natural diversity of the coastline, and a sharp contradiction with human dynamics. The coastal Sindh region is an overlap of different ecological zones, especially vast mangrove forests, tidal mudflats, estuarine and sandy beaches. It is worth mentioning that Sujawal (district of Lower Sindh), with one of the largest deltas in the world, the Indus River delta, has a very complicated influence on the landscape of the Sindh Coast.

Rapid urbanization and economic growth in the coastal area (especially the Karachi region) of Sindh have taken place in the last few decades. Its coastline begins at Cape Monze westwards, and at the east end at the Indian border. The active interface of the research area between marine and coastal environments, which is the Indus River Delta, and the system of mangrove ecosystems in particular is their key characteristic. The Sindh Coast has a singular chance to examine temporal and spatial trends in environmental and socioeconomic variables because of its susceptibility to both natural and man-made effects. Shoreline loss, rising ocean levels, and higher salinity levels have all had a significant impact on local communities, fisheries, and mangrove habitats. The Sindh coast is a constituent element of the Pakistan coastline, and it is affected by several environmental concerns, such as the decline of the habitats, industrial waste, and global warming (Abbasi and Ullah, 2018; Husain et al., 2019).

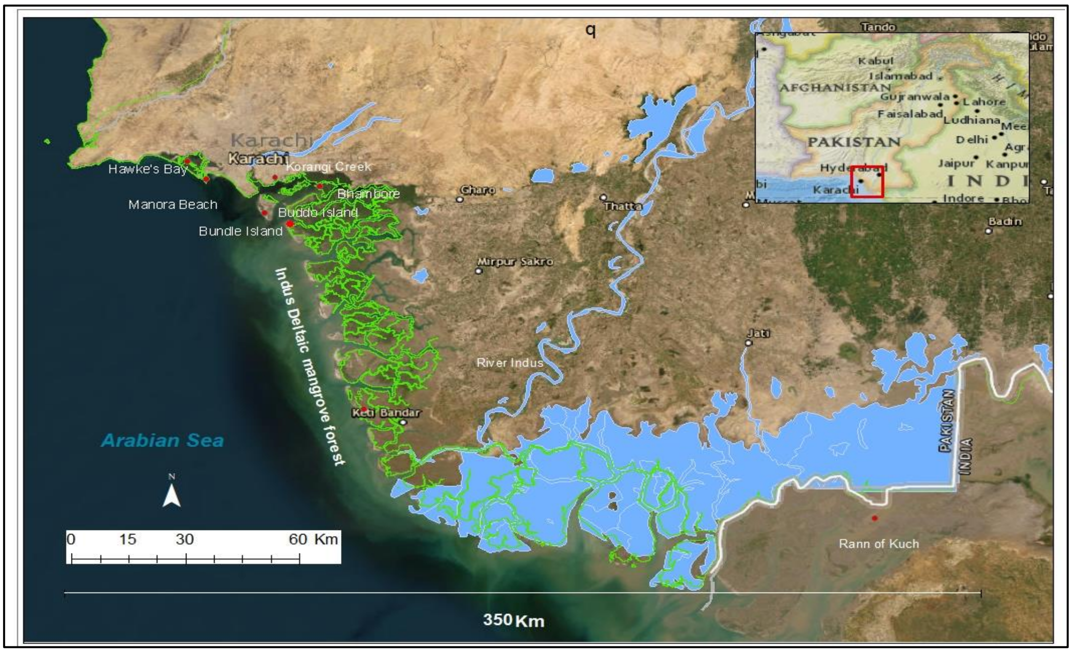

Fig. 2: Study Area (Sindh Coast).

2. Methodology

The current research has assumed a mixed-method research approach, which has combined both quantitative remote sensing and spatial analysis with qualitative field-based observations to evaluate the degree of coastal changes along the Sindh coastline in the last two decades.

Multi-temporal satellite data of Landsat archive (30m spatial resolution) and the MODIS dataset (250m resolution) were obtained to conduct the quantitative aspect of the research for the year 2000 to 2025. These datasets were selected due to their reliability in monitoring coastal processes, vegetation cover, and long-term ecological dynamics. Besides the data of remote sensing, various geo-spatial layers were also compiled such as topography, land use and land cover, identification of coastal erosion areas and delineation distribution of mangrove forest, among others. Global repository of Climatic Research Unit (CRU) was used to integrate climatic variations i.e. precipitation and temperature to give a wider environmental perspective of the observed changes.

The qualitative data collection was done to supplement and validate the remote sensing analysis. Google Earth Pro in this process has made the imagery of the spatial patterns and revealed understandings of fine-scale ecological changes to be simplified. Other wider qualitative approaches like structured interviews by way of questionnaires and a great deal of focus group deliberation were performed at the selected areas like Turtle Beach, Sandspit and Hawk's Bay. Such visits comprised observational evaluations of the coastal and ecological situation, which was backed by informal focus group discussions with the local stakeholders. The qualitative data obtained informed the interpretation of the spatial data and gave meaningful intuitions about the socio-ecological dynamics.

Data analysis and processing were realized on the basis of GIS platform (ArcGIS). Some of the pre-processing procedures are data cleaning, correction, and standardization of projections to provide spatial consistency. Digitization of coastline features, spatial masking to isolate area of interest, raster algebra to obtain indices, projection of raster data, and local spatial functions used in fine scale analysis were all ways of analysis. These processes allowed the measurement of mangrove area, observation of coastal processes and surveying of regions of erosion susceptibility with a higher degree of accuracy. Spatial and temporal analysis in ArcGIS was applied using formulae:

2.1 Spatial Masking (Extraction by Mask):

Spatial masking involves restricting analysis to a defined spatial extent (mask layer) (Burrough & McDonnell 1998; ESRI, 2022a).

$$R'(x,y) = \begin{cases} R\,(x,y) & if\ (x,y) \in M \\ No\ Data & if (x,y) \notin M \end{cases}$$

Where:

- R(x,y) = raster value at location (x,y).
- M = spatial mask polygon/feature.
- R'(x,y) = masked raster output.

2.2 Raster Algebra and Local Function:

Raster algebra performs cell-by-cell mathematical operations (Tomlin, 1990; Jensen, 2015; ESRI, 2022b; ESRI, 2022d)

$$R_{out}(x,y) = f\{R_1(x,y), R_2(x,y), \dots \dots \dots \dots . R_n(x,y)\}$$

Where:

- R_i(x,y) = input raster(s) at (x,y).
- f = algebraic function (e.g., addition, subtraction, ratio, logical test).

2.3 Change Detection:

Change detection compares raster values from two different dates (Singh, 1989; Coppin *et al*., 2004; Lu *et al*., 2004).

$$\Delta R(x,y) = R_{t2}(x,y) - R_{t1}(x,y)$$

Where:

- R_{t1}, R_{t2} = raster values at time 1 and time 2.
- ΔR(x,y) = change magnitude.

2.4 Proximity Analysis (Euclidean Distance):

Proximity analysis computes the shortest distance from each cell to the nearest feature (Burrough & McDonnell 1998; ESRI, 2022c).

$$D(x,y) = \min_{f \in F} \sqrt{(x - x_f)^2 + (y - y_f)^2}$$

Where:

- F = Set of feature coordinates.
- D(x,y) = distance from cell (x,y) to nearest point feature (x_f, y_f)

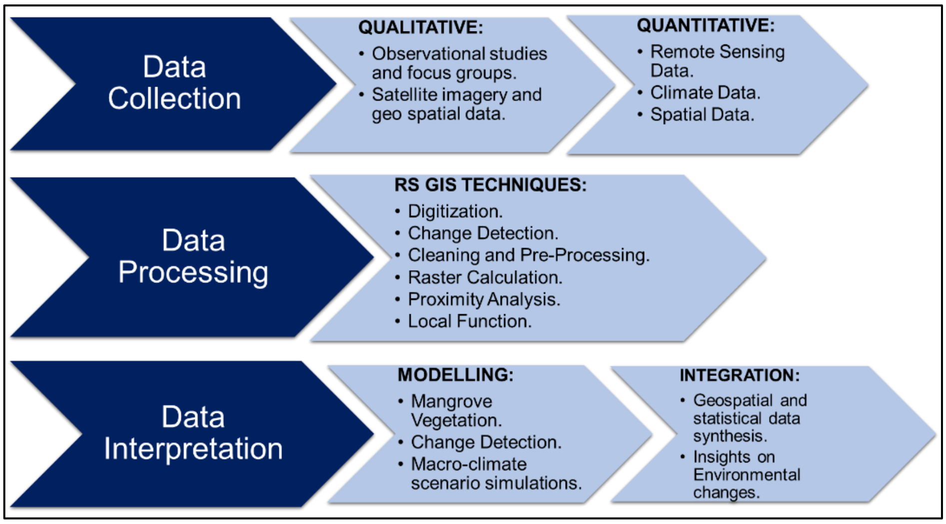

Fig. 3: Methodological Framework

3. Results and Discussion

A comprehensive examination of the temporal and spatial patterns along the Sindh Coast provides significant insights into the dynamic environment in fig. 4 and 5. The Sindh coastal region is distinguished by three dominant mangrove species i.e. *Avicennia marina, Ceriops tagal,* and *Rhizophora mucronate*. These species are vital to the local communities through their major supply of resources like timber, fodder and fuel. A time-lapse satellite imagery of space shows a steady rise in the mangrove canopy cover over the Sindh coast, and more so, in the Indus Deltaic region, during the last twenty-five years. In 1995, the mangrove area was estimated in 0.0540 ha/km^2 and it increased to 0.0703 ha/km^2 and 0.0805 ha/km^2 in 2000 and 2005 respectively. There was also a great increase in the period 2005-2010 wherein the mangrove area increased to 0.1045 ha/km^2, which shows a faster regeneration stage. The mangrove cover had increased to 0.1199 ha/km^2 in 2015 and 0.1396 ha/km^2 in 2020.

The trend line has a more or less straight line of recovery, which indicates that the mangrove habitats have been continuously restored during the period under study. This is a recovery trend that is in line with large-scale afforestation efforts, recuperation programs by provincial forestry agencies and community-based initiatives financed by organizations such as WWF-Pakistan and the International Union to Conserve Nature (IUCN). The observed long-term positive trend is also a reflection of the improved processes of sedimentary deposition in the Indus Delta, which consequently form favorable conditions in the mangrove seedling recruitment.

The taxonomically grouped spatial dataset projected in 2025 shows that the total area covered by mangroves was of about 0.2188 ha/ km^2, that is, a growth of 0.0792 ha/km^2 compared to that determined in 2020. This is a 56.8% increase in five years (2020-2025) and an aggregate increase of 305% when compared to the level of 1995. The estimated corresponding annualized growth rate of the latest period is 9.4%, per year, which reflects the increased restoration efforts and possibly favorable hydrodynamic and sedimentological circumstances to promote natural regeneration.

The figures elaborated in table 2 shows that during this 30-year period of Vegetation cover analysis, the mangroves have shown a Compound Annual Growth Rate (CAGR) of approximately 4.1%. This gradual growth shows that the mangrove cover of the Sindh coast has grown by over three-fold in relational terms. The ascending trend indicates number of massive scale efforts and processes:

- A long-term programme of mangrove restoration, planting or natural regeneration on a decade-by-decade basis.
- Higher landscape connectivity and patch size (when the area values are in agreement with spatial measures) that would suggest healthier mangrove ecosystems and not just small and fragmented patches.
- It is only in the mid-2000s that the acceleration phase may have taken place, as the extent of growth would have been significant to get to the greater density seen in 2025.

This favorable development is the opposite of the loss rates of mangroves around the world, which in most places have been negative or constant, and hence reflects the importance of specific interventions. Ecologically, the greater density of mangroves increases the resilience of the coastlines, with mangroves acting as buffer zones that decrease the wave energy, storm surges and coastal erosion; therefore, the almost four-fold increase in the mangrove density is converted to the more robust natural defense of the Sindh coast. Increased mangrove area has been shown to have greater benefits in terms of fish catch, crustacean, bird and other taxa habitat. It has been shown in literature that the Indus delta is a habitat of a great number of fish species (98 documented) and migratory birds and the increase in mangrove cover is likely to add to the economic benefit of these services. Closer mangroves enhance blue-carbon storage capacity, and therefore, help the Sindh coast contribute more to the actions of climate mitigation as part of the recent agenda of the Delta Blue Carbon project (Sindh Forest Department; Sanaullah et al. 2025)

Spatially, the smallest and most active mangroves are clustered in the region of the Korangi Phitti Creek, Keti Bunder and Kharo Chan, which are characterized by strong tidal flows and high sediment input. The invaded mangroves into immature mudflats of the deltaic areas to the south supports positive geomorphic feedback, in which the accretion of sediment facilitates the further occupation. On the other hand, the districts adjacent to the Karachi metropolitan coastline have continued to experience fragmentation and reduced density of canopies, which is likely to be caused by the release of industrial effluents, encroachment by cities, and reclamation of lands to build a port. These have been observed to be in line with the results of Ahmed et al. (2025) that indicated that significant recovery of mangroves along the Indus Delta coastline had been achieved due to the continuous restoration efforts, improvement of management structures, and involvement of people.

However, it is still important that long-term sustainability depends on the reduction of anthropogenic stressors. The Karachi wastewater (characterized by its untreated nature, estimated at approximately 472 MGD) and industrial effluent flow are still posing a threat to near-shore mangrove ecosystems. Moreover, the reduction in freshwater inflow caused by the Indus due to upstream abstraction and climatic rise in sea level can cause a change in the salinity regimes and present long term ecological problems. In general, the decadal scale analysis reveals that mangrove ecosystems in Pakistan are in a positive recovery trend which can be regarded as a regional success story in terms of recovery of the coastal ecosystems. The trend of constant expansion highlights the prospect of integrated coastal zone management and nature-based solutions to supplement the sequestration of carbon, enhance coastal protection, and biodiversity conservation in the Indus Delta.

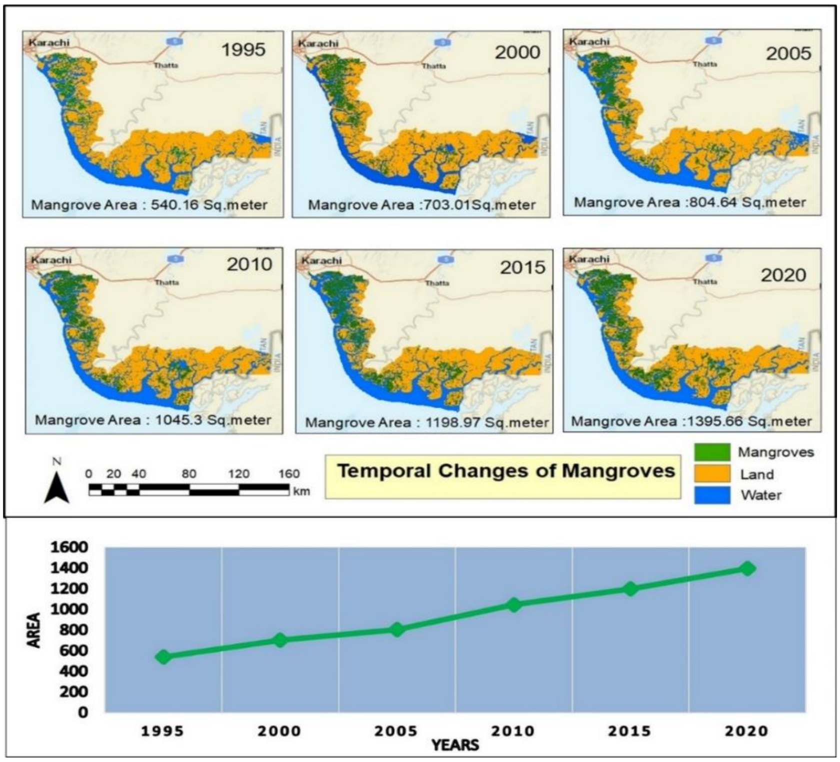

Fig. 4: Spatio-Temporal Changes in LULC of Coastal area during (1995-2020)

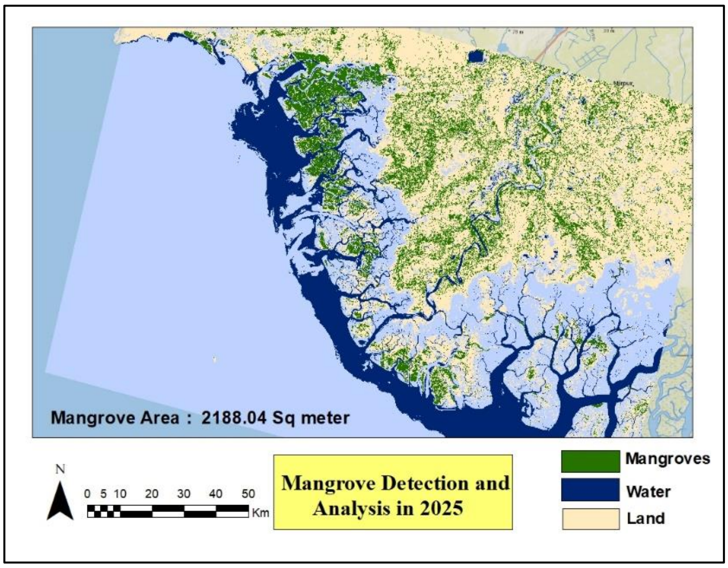

Fig. 5: Spatial Distribution of Mangroves in 2025

Table 2: Mangrove Cover Change in Hectare/ Km^2.

Years of analysis	Mangrove Cover (Ha/Km^2)
1995	0.0540
2000	0.0703
2005	0.0805
2010	0.1045
2015	0.1199

2020	0.1396
2025	0.2188

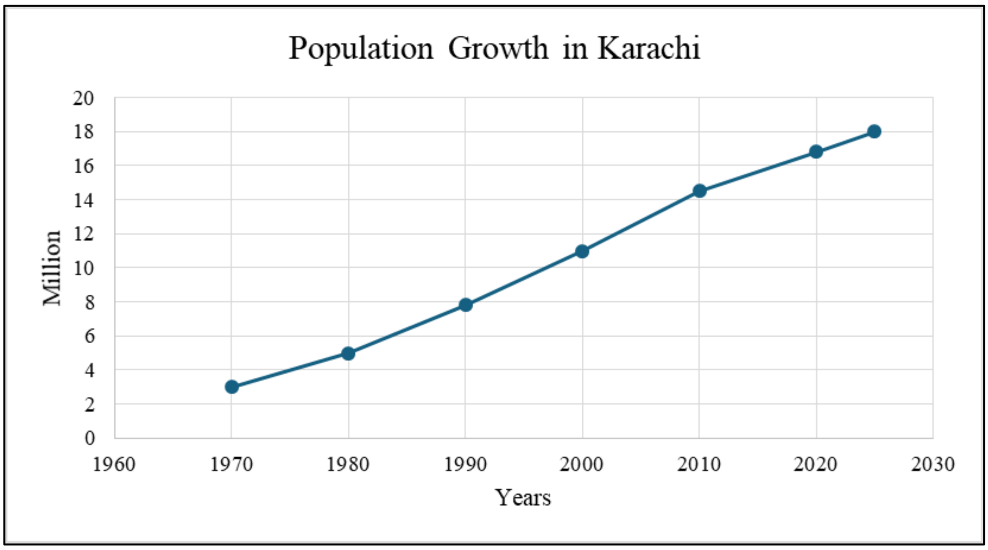

Fig. 6: Population Growth Trends in Karachi.

Over the past fifty years, the population of Karachi has grown rapidly. The city's population is expected to increase from 1.05 million in 1950 to 18 million by 2025. Unplanned settlements, industrialization, and increased waste production are all consequences of this urban growth, major contributors to marine pollution. The statistics mentioned in fig 6, showing the exponential increase in population of the coastal city, can hypothetically result in intensification of dumping of toxic sewage concentration. Presently, the city is already discharging more than 500 million gallons of untreated waste (Sheikh, Hamna & Hameed, Gul. 2024). Population growth in the upcoming years can be the potent cause of threat to the mangrove forests along the Sindh coast.

A fascinating insight into the variety of attractions that line the shore is illustrated by map (Fig 7). Every carefully selected location is not only visually stunning but also comprehensively documented, offering prospective tourists an in-depth guide to the hidden coastal gems. But during the field visit to Karachi's coastline region, especially Turtle Beach, some disturbing scenes marked by many dead marine creatures and a widespread problem with plastic waste were captured, both of which illustrated unsustainable coastal tourism (Siddiqui & Khan, 2019). Sustainable tourism practices and conservation of sensitive coastal ecosystems can prevent and mitigate forthcoming anthropogenic impacts.

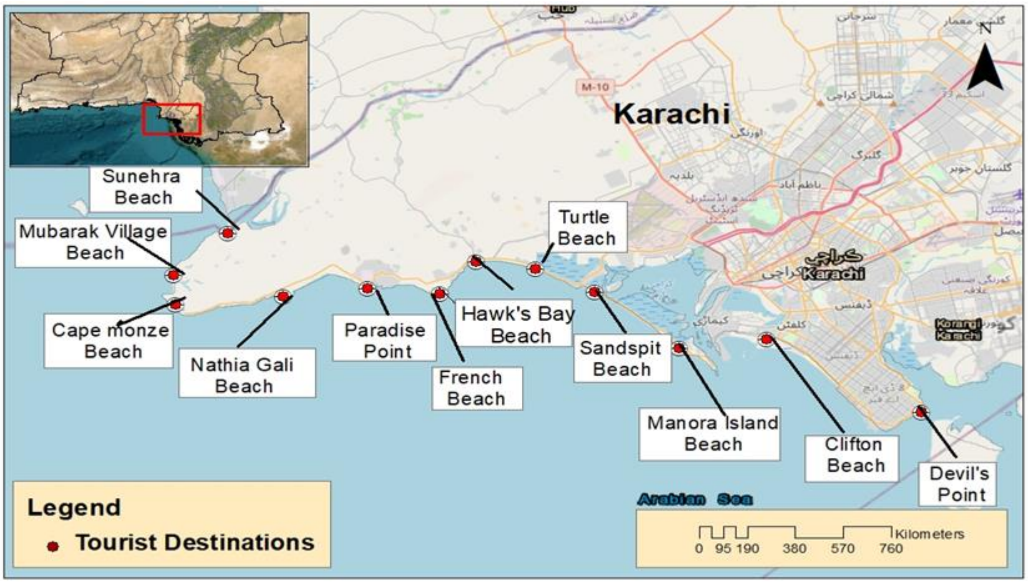

Fig. 7: Major Tourist Spots along Karachi Coast.

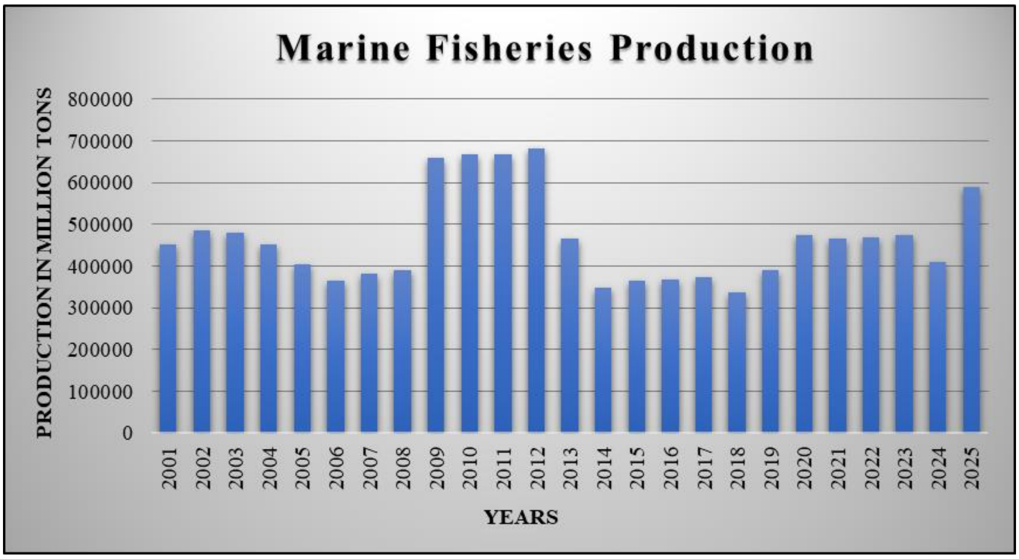

Fig. 8: Production of Marine Fisheries *(Source: Economic Survey of Pakistan)*

Fig. 9: Coastal pollution and its impacts observed along the Karachi Coast. (*Source: Authors)*

The image of dead fish lying on the beachline was a vivid demonstration of environmental distress, which was directed at the problems with the marine ecosystem (Marine Fish

Production) as represented in figure 10. There is also the issue of plastic pollution which is largely the result of tourist visits, stating the necessity of sustainable and responsible behaviors while visiting the beaches. The production of marine fisheries in the Sindh coast varied significantly during 2001 and 2025 as the systems of the Pakistan coast were ecologically and economically variable. The statistics indicate that production will increase by 30.6%, taking an average of 452,000 tons in 2001 to 590,480 tons in 2025:

- **2001-2008**: This was a moderate production period of between 366,000 and 485,000 tons. A slight decrease in the period since 2005 could be explained by over-utilization, lack of control over regulations, and the deterioration of coastal habitats.
- **2009-2012:** A strong peak was found between 2009 and 2012 (high of 68170000 tons), which could have been caused by good oceanography and more fishing activity.
- **2013-2018:** Between 2013 and 2018 there was a significant decline in the fish output by about 50000 tons in 2018 to 338,000 tons. This decrease is a sign of excessive exploration and a subsequent decrease in the productivity of the ecosystem.
- **2019-2025:** There was a slow recovery followed by a sharp increase in 2025 to 590,480 tons, perhaps owing to improved coastal management, mangrove restoration, and an improved monitoring system.

Although there is pressure on the mangroves, the recovery will require long-term mangrove preservation, pollution reduction, and controlled fishing activities to sustain the recovery, although it is projected to be positive. The existence of a correlation between an expanding mangrove cover and an increment in fish production demonstrates that there is a necessity to combine the management of coastal ecosystems.

4. Conclusion

The research highlights the environmental issues of the Sindh coast which are of significant concern due to climate change, pollution, and unrestricted industrial and port development. Although the growing area of mangroves is a promising sign of improved coastal resilience, the competing challenges such as rise in sea surface temperature, sea-level rise, plastic pollution, and habitat degradation are a major threat to marine biodiversity and livelihood of local communities. These findings demonstrate the crucial need to practice sustainable management of our resources, strict measures against pollution and ensure sustainable coastal management policies in order to reduce these environmental pressures. It is important to remember that intervention is necessary to avoid any further ecological degradation that can not only put the environmental integrity of the Sindh coast at risk but the economic stability of the dependent communities as well. This delicate coastal ecosystem must be preserved to ensure that future generations have the opportunity to enjoy a sustainable environment due to proper policy implementation, community involvement and global collaboration. Hence, it is suggested to combat the increasing challenge of the marine pollution in Sindh coastal regions.

In order to protect the environment, oil and chemical containers at Karachi and Bin Qasim port need to be handled securely. The adoption of the International Convention for the Prevention of Pollution of Ships (MARPOL) by the International Maritime Organization (IMO) are some of the frameworks that are significant in this regard. As Pakistan is complying with MARPOL, it has to comply with its provisions, in particular Annex I and II, which are geared towards averting oil and toxic liquid pollutions. Local enforcement procedures should be strengthened, modern spill detection devices such as real-time sensors should be acquired, port authorities and reaction teams should be trained on the emergency response procedures regularly to improve further in protecting the environment. Prioritizing readiness, heavy control over observance of the established regulations, and swift response in the first place could significantly help to stop the growth of marine pollution and create a safer and more robust future of our docks and communities.

The development of innovative spill detection systems will be able to identify and control the leaks swiftly reducing the chances of extreme environmental degradation. On the same note, sustainable industrial practices need to be encouraged. This involves the requirement of all industries located close to the coast to install oil-water separator and wastewater treatment systems, circular economy principles applied in waste management and the application of stiffer penalties to those businesses that violate environmental laws. All these actions may help to minimize environmental pollution in its origin and to preserve the coastal and marine biodiversity.

It is also necessary to add that the development of the community and the collaboration on the international level is also of great importance. Introducing and growing educational opportunities in the local communities, businesses and fishermen will ensure that the local communities grow to be more aware about the atrocities of marine pollution besides enabling them to take part in the conservation work. Healthy community development can also be enhanced by providing incentives to report cases of pollution. At a larger level, partnership with other international organizations like IMO, WWF (World Wide Fund) and ITOPF (International Tanker Owners Pollution Federation Limited) will assist Pakistan improve its marine environmental governance through incorporating global practices in waste management and hazardous substances spill control. The objectives of these efforts, using local action and international expertise, include resilience, protection of marine ecosystems and sustainable coastal development.

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