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Research Article

# Mapping and Analyzing Coastal Morphological Changes due to Rising Sea Level: A Case Study of Karachi Port, Pakistan

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**Abstract:** Climate is noticeably changing because of several natural and anthropogenic causes i.e. deforestation, the use of fossil fuels, emission of CFCs, etc. consequently, it is disturbing the natural settings of the environment including glacial lake outburst floods, flash floods, cloud bursts, etc. Likewise, the sea level is also rising. The sea level is rising because of thermal expansion when water expands after getting warm in the ocean and the melting of glaciers. These changes in sea levels result in coastal morphological changes over time. In this context, Karachi is selected as a study area for the present research. Karachi Port and Port Muhammad Bin Qasim are the busiest port in Pakistan. For the study purpose, sea level data is obtained from National Oceanic and Atmospheric Administration (NOAA) Tides, Currents, and coastal morphological changes are digitized in Google Earth with the help of a historical timeline. The result shows that the sea level is rising at a rate of about 0.02 mm/year from 1916 to 2016 and 0.0032 mm/year from 1916 to 2016, 2020. Coastal morphological changes are identified in the Southern Karachi coast (accretion) and Eastern Karachi (erosion). NDWI also performed on satellite images for better assumption to detect a difference between 2000 and 2021 and the result shows the difference in the Southern Karachi coast and near Goth Manjar. These slow morphological changes are important to study for sustainable development in coastal areas

**Keywords:** Accretion, Coastal mapping, Erosion, Karachi port, Morphology, Rising Sea Level.

## 1. INTRODUCTION

Climate change is an emerging problem worldwide. Anthropogenic activities increased the concentration of greenhouse gases (GHGs) which caused many extreme weather events e.g., drought, floods, etc. worldwide in 2019 [1]. Due to climate changes (spatially-temporally), trends in sea level are very risky [2]. According to some observations, the rising sea level observed in the 20th century was due to global warming [3]. The global sea level is rising because glaciers are melting, ocean water expands when it warms [4], and on a local level because of tectonic plates, winds, tides, storms, sea surface temperature, currents, barometric pressure, and land subsidence [3]. According to Intergovernmental Panel on Climate Change (IPCC), sea levels will rise to 1 m in 2100 [4]. From 1993 to 2009, tide gauge data shows that the sea level had risen about $2.8 \pm 0.8$ mm year-$^1$, and satellite data shows about $3.2 \pm 0.4$ mm year-$^1$ [5]. For example, Copenhagen capital city of Denmark, Calcutta city of India, Venice city of Italy, and Vancouver city of Canada are cities facing the problem: of rising sea levels [6]. It is estimated that rising sea levels may cause 20 million environmental refugees, 32% loss of rice production, and 8% loss of wheat production [7]. Countries at the edge of the Arabian Sea and the Bay of Bengal are at risk of rising sea levels [8]. Coasts are changing because the processes of oceanographic and geomorphic are taking place at a spatial-temporal (space and time) scale [9].

According to Intergovernmental Panel on Climate Change (IPCC) report in 2013, said that rising sea levels will cause many problems to the shoreline. Coastal morphology is a natural process that structure and restructure the coast by rising sea level, rainfall, and ocean waves in (spatial-temporal) space and time [10]. Coastal zones are

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at risk for coastal erosion as it affects public safety, and coastal infrastructure [11]. For example, in Ghana sea level had risen about 3.3 mm/year and caused coastal erosion at beaches in 2013 [1].

According to United Nations Environmental Programme (UNEP) in 1989 said that due to climate change Pakistan is also vulnerable to rising sea levels [12]. In Pakistan, the mean sea level (MSL) is slowly but gradually rising at a rate of about 1.1 mm/year and 10% of the population is living in coastal areas, 20% of the coast is developed and only 40% of industries are located near the coastal areas [13]. From 2007 to 2016, sea levels increased by about 3.6 mm/year and 2.1 mm/year for mean and extreme sea levels respectively at the Karachi coast [8], and coastal morphological processes e.g., erosion was recorded at about 2.43 ± 0.45 m/year at Karachi coast [14]. In the next 25 to 30 years, the sea level will rise to 15.62 centimeters, and the Karachi coastline experience erosion of about 2.43 ± 0.45 m/year [15]. The main purpose of the study is to find out how much the sea level is rising and how it affects the coast because in recent years, there is a few numbers of evidence studies regarding rising sea levels and extreme weather events [8]. For example, a research study found ground displacements, erosion, and sea level rise along the Karachi coast, of Pakistan [18]. One more study was conducted through remote sensing techniques for monitoring land subsidence in the coastal city of Pakistan. In the study sentinel using persistent Scatterers, In-SAR techniques were assessed [19]. This study aimed at finding rising sea levels from National Oceanic and Atmospheric Administration (NOAA) tides and current and morphological changes like temporal coastal erosion on the Karachi coast using Google earth imageries. The main aim of my study is to identify morphological changes in the rising sea level at Karachi Port. The objective of my study includes identifying sea level rise at Karachi port and detecting coastal morphological changes by rising.

## 2. MATHEMATICAL MODEL

### 2.1 Study Area

The study area of the present research is Karachi Port as shown in the Figure 1. Karachi is the capital of Sindh the province of Pakistan. It is one of the largest cities in Pakistan and a highly populated city [16]. It has a coastline of about 990 km [17] The Karachi coast is situated between Cape Monze and the Korangi creek and has many beautiful beaches i.e., Clifton beach, Paradise Point, Sea View beach, French beach, and Devil's point as shown in Figure 2. The purpose of choosing this area is because Pakistan is vulnerable to climate change and Pakistan has a coastline of about 990 km. Karachi is facing problems related to climate change i.e., rising sea levels.

Due to the rising sea level in Karachi, the coastline of Karachi faces some morphological changes. That is why we choose the Karachi coastline to detect morphological changes at Karachi Port to rising sea levels. Karachi coast has two ports, two fish harbours, nuclear power plant, a steel mill, and two industrial estates [14] Karachi port is an industrial and financial center of Pakistan. Pakistan and other countries mostly trade through this port. Now, Gwadar port through China Pakistan Economic Corridor (CPEC) will also play a role in developing better economic conditions for Pakistan.

### 2.2 Data and its Sources

Both types of data sources i.e., Primary and Secondary data sources are used. Coastal morphological changes were collected at the Karachi coast by a primary source. Coastal morphological changes are identified by digitizing the coast of the year December 1985, September 2001, December 2003, November 2010, and February 2021 at Karachi through Google earth (historical image) as shown in the Figure 4. The strategy for the study follows the following steps as shown in Figure. 3 below.

Sea level data is collected by secondary sources from National Oceanic and Atmospheric Administration (NOAA) Tides and Currents. Sea level data is collected from the year 1916 to 2016. Also collected the data for the first five months of 2020 for better assumptions from the Sea Level Station Monitoring Facility. On the other hand, for better assumptions collected the satellite images from a secondary source from the United States Geological Survey (USGS) department to determine coastal morphological changes through

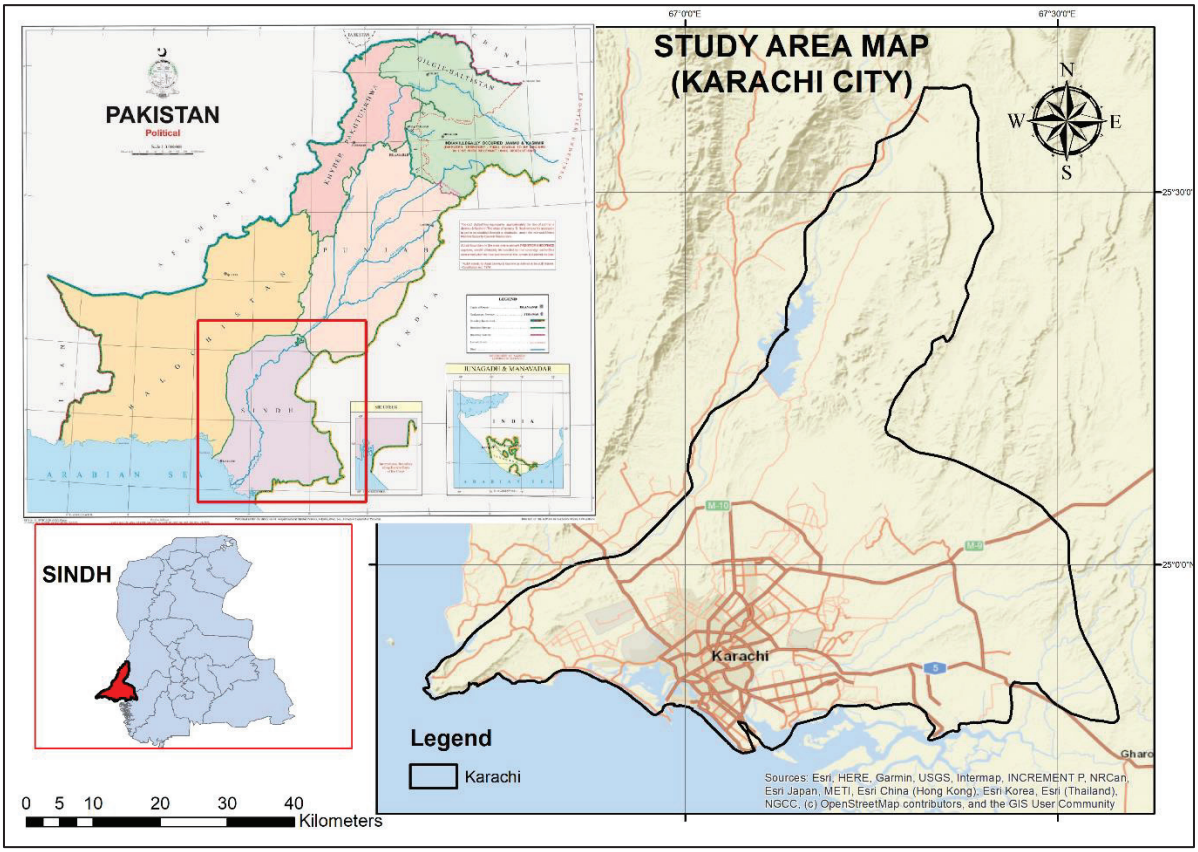


**Fig. 1.** Depicting the study area (Karachi), Pakistan

**Fig. 2.** Shows the coastline of Karachi (February 2021)

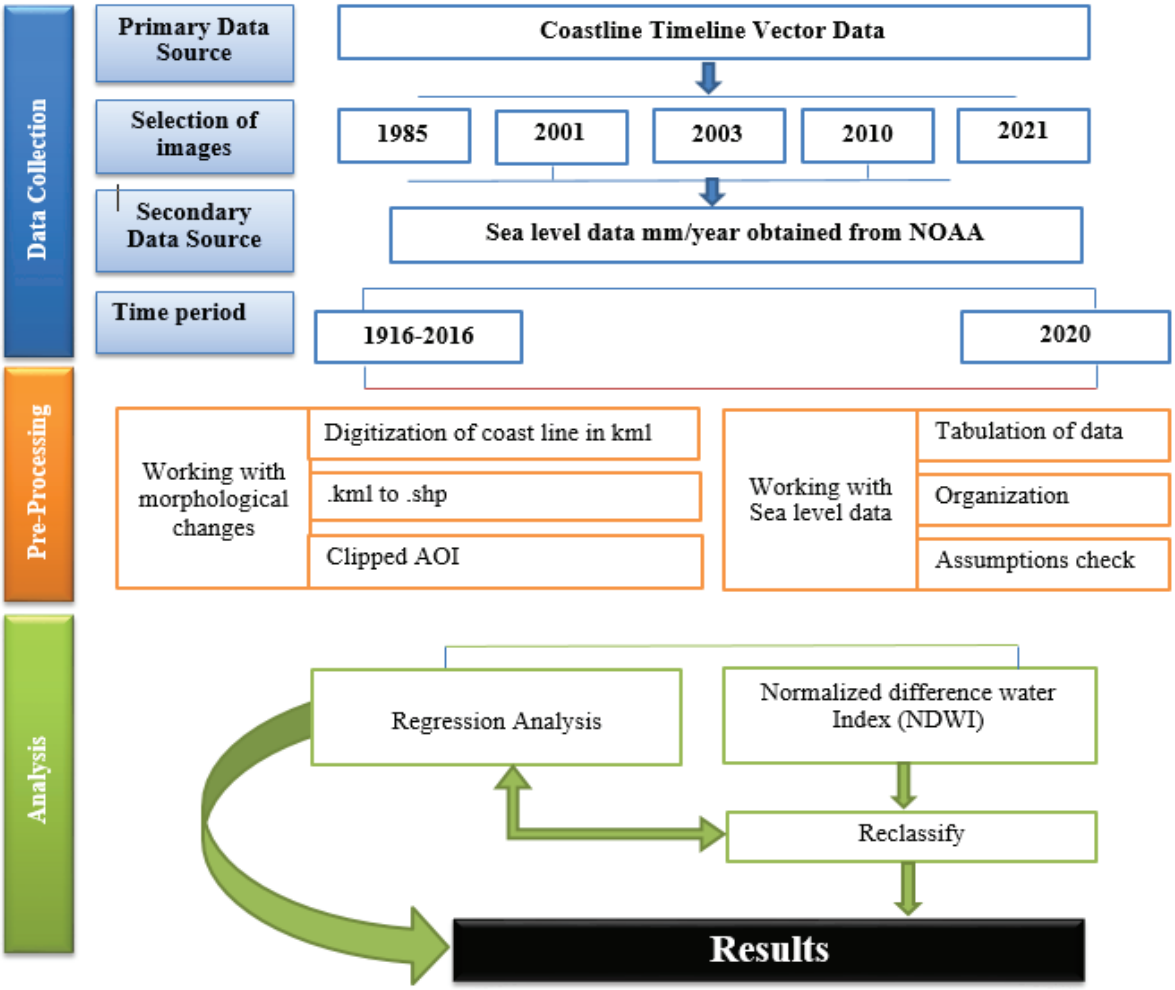


**Fig. 3.** Flowchart of Research Methodology

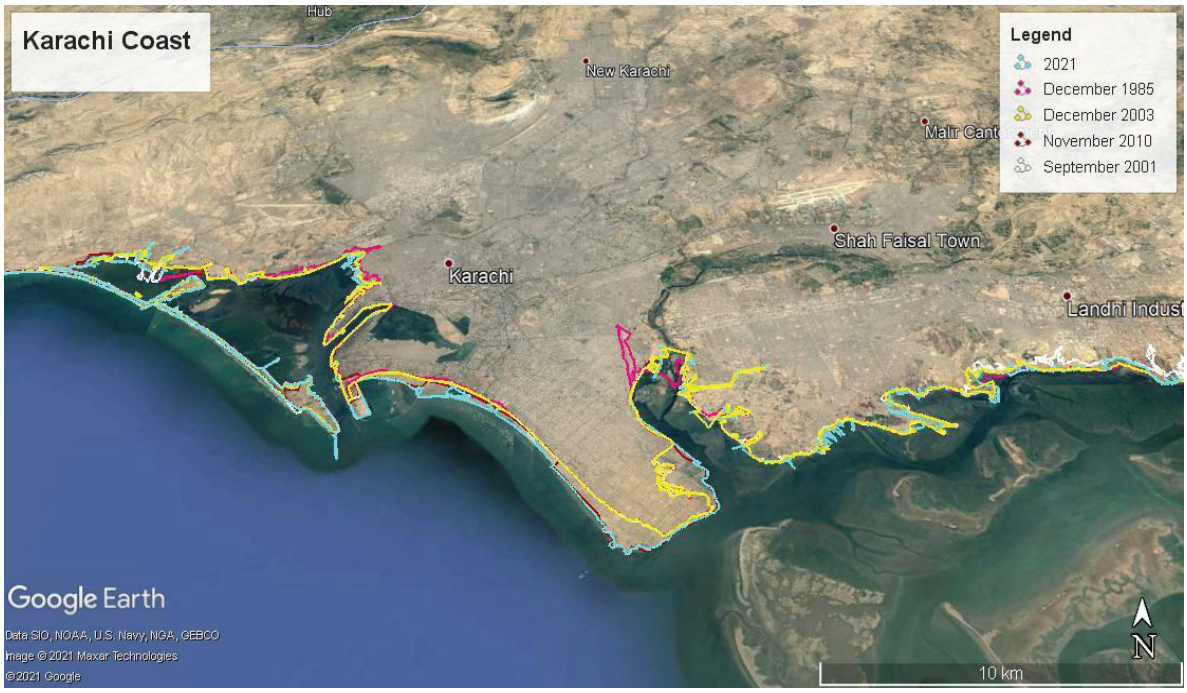


**Fig. 4.** Mapping morphological changes from 1985 to 2021 in Karachi Coast, Pakistan

Normalized Difference Water Index (NDWI). For this purpose, Landsat 8 Operational Land Imager and Thermal Infrared Sensor (0LI/TIRS) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) were used. Sea level data is tabulated and organized in excel. Coastal morphological changes are tabulated and organized in Arc GIS.

### 2.3 Data and Analysis

After tabulation and organization of sea level data. Calculated the averages of sea level data obtained from National Oceanic and Atmospheric Administration (NOAA) Tides and Currents from 1916 to 2016 and 1916 to 2016 and 2020 in excel. After the organization of coastal morphological changes of the year 1985, and 2001. 2003, 2010, and 2021 in Keyhole Markup Language (kml) format and inserted these kml files into Arc GIS and use the tool: detect feature change. On the other hand, satellite images want to identify the Normalized Difference Water Index (NDWI). Higher NDWI refers to sufficient moisture while lower NDWI refers to the stress of water.

$$\text{NDWI} = \frac{\text{Green}-\text{NIR (Near Infrared)}}{\text{Green}+\text{NIR (Near Infrared)}} \ldots\ldots\ldots \text{(E.1)}$$

Landsat 8, 2021 images.

$$\text{Landsat}_8 = \frac{\text{Band 3}-\text{Band 5}}{\text{Band 3}+\text{Band 5}} \ldots\ldots\ldots \text{(E.2)}$$

Landsat 7, 2000 images.

$$\text{Landsat}_7 = \frac{\text{Band 2}-\text{Band 4}}{\text{Band 2}+\text{Band 4}} \ldots\ldots\ldots \text{(E.3)}$$

Then used the tool: Map Algebra from the Arc toolbox. Hence, NDWI is performed. Then classified both NDWI images into threshold values. The threshold value of Landsat 8 (OLI/TIRS) and Landsat 7 (ETM+) is 0.05 and 0.15 respectively. Then Difference is applied to both images. It performs a change detection feature and creates a new layer with change in two categories (highest change and lowest change). Sea level data is presented in the form of scatter charts and also find the regression (trend line) of these charts. Coastal morphological changes are presented in form of maps in Arc GIS. Satellite images for NDWI are also presented in form maps in Arc GIS.

## 3. RESULTS AND DISCUSSION

The highest mean sea level was recorded at about 7.27 mm/year in 2015. The lowest mean sea level was recorded at 6.95 mm/year in 1986. The sea level increased at a rate of about 0.002 mm/year from 1916 to 2016 (Figure 5).

In the year 2020, the highest mean sea level was recorded at about 8.52 mm/year in May. The lowest mean sea level was recorded at about 8.05 mm/year in January. The sea level increased at a rate of about 0.0032 mm/year from 1916 to 2016 2020 as shown in the Figure 6.

Coastal morphological changes show both erosions due to rising sea levels and accretion due to the reclamation of land on the entire coastline.

Figure 7 shows that's the changes in 1985, 2001, 2003 and 2010. The result shows that the entire coastline indicates N, which means there are, changes on the entire coastline. D indicates those features that are completely eroded by water and most probably covered with water. It means the entire coastline has shown changes since December 1985. Mostly, coastal accretion changes are identified in South Karachi in DHA Phase 6 and Korangi Creek. Mostly, coastal erosion changes are identified in East Karachi in Muhammad Bin Qasim Port. West Karachi also shows a sign of erosion but not an at-risk level.

The result shows a difference in NDWI between satellite images of 2000 and 2021 (Figure 8). It shows areas with coastal morphological changes. It indicates high and low coastal morphological changes. The difference shows changes near Goth Manjar from 2000 to 2021. Changes also show in South Karachi i.e., Manora Island (expansion of water). It will help to assess the impact of rising sea levels on coastal morphology. This study will help to plan a development project in the future at Karachi's coastline.

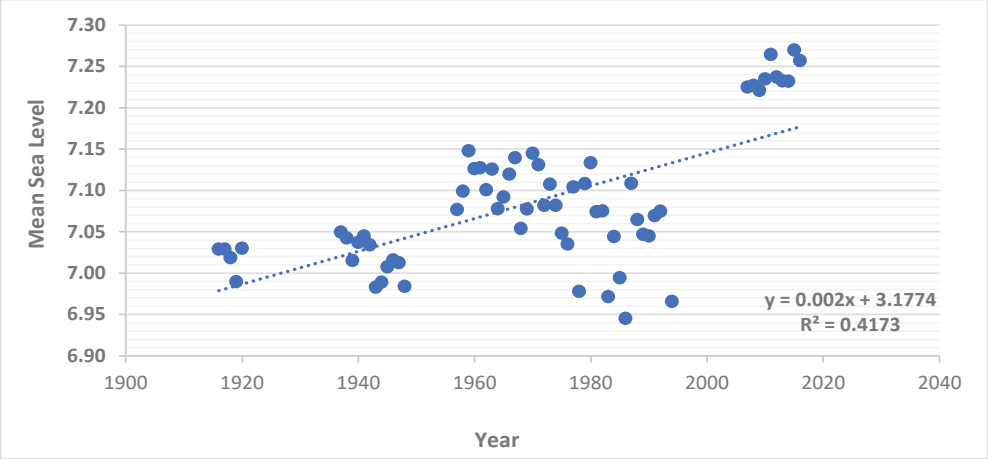


**Fig. 5.** Scatter chart with regression from 1916 to 2020.

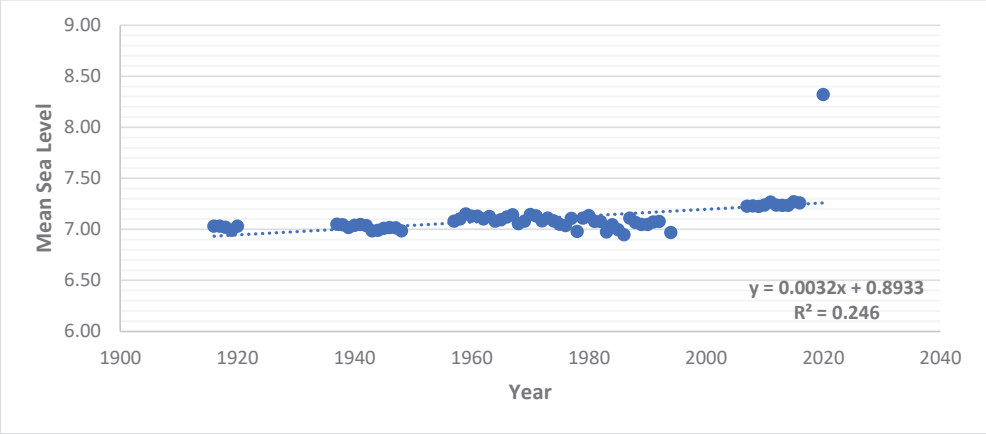


**Fig. 6.** Scatter chart with regression from 1916 to 2016 and 2020

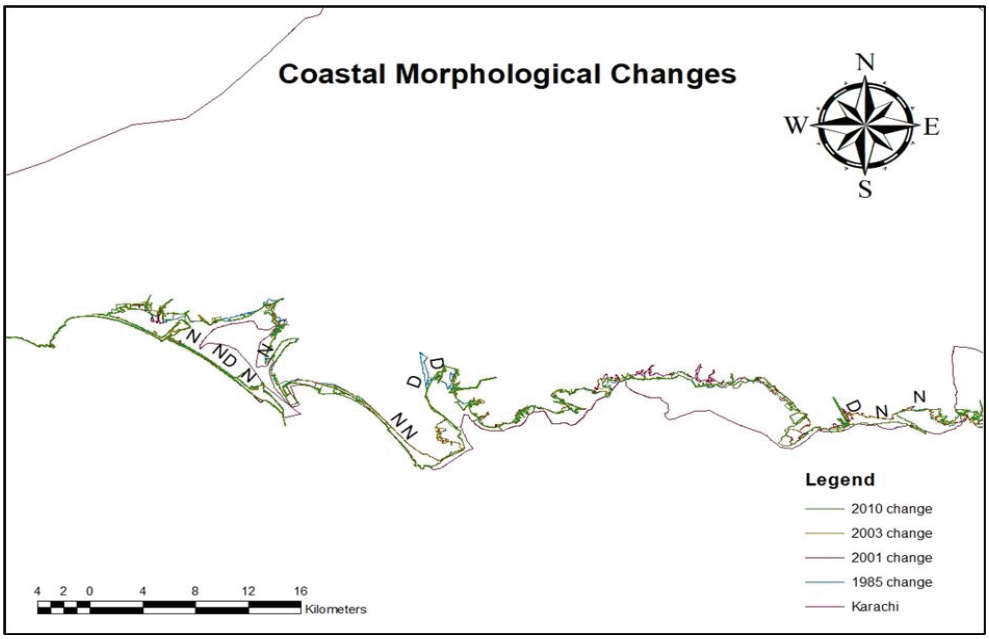


**Fig. 7.** Coastal morphological changes from 1985 to 2021

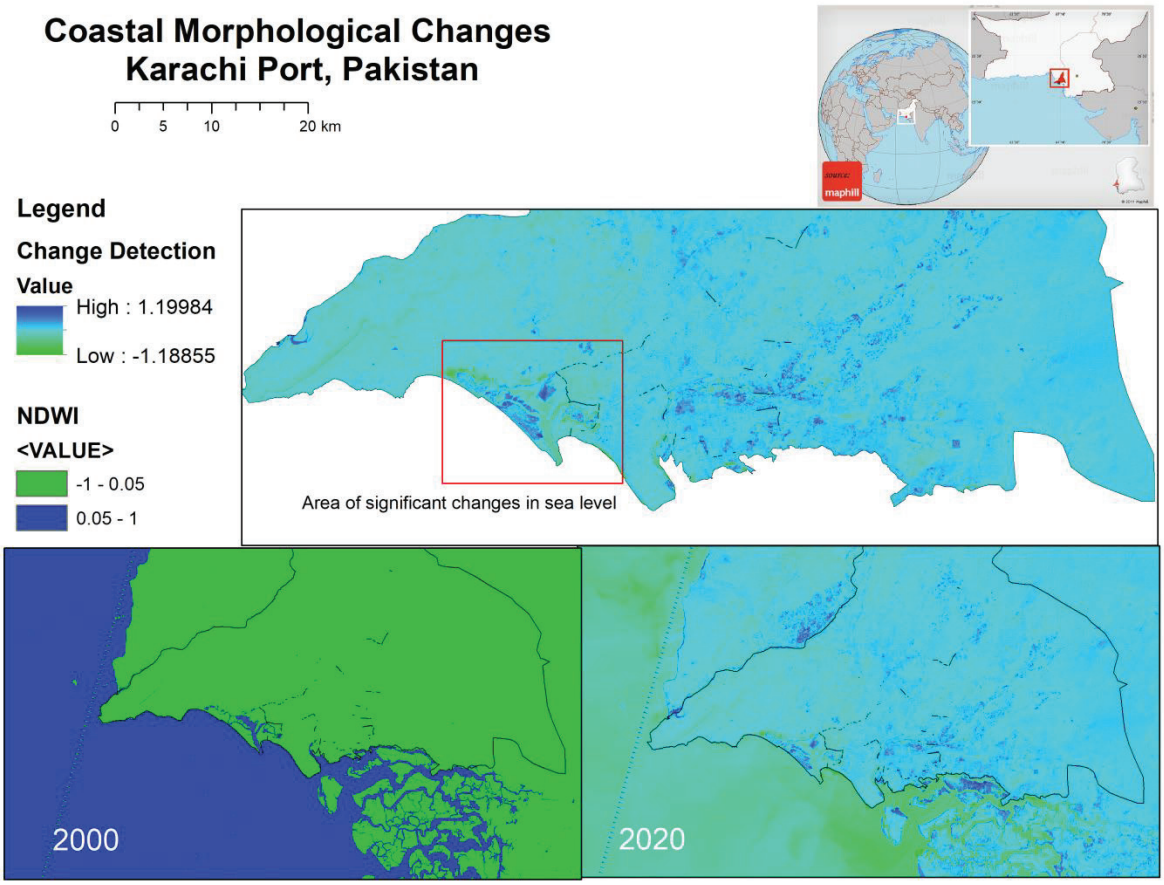


**Fig. 8.** Results of NDWI difference between 2000 and 2021

## 4. CONCLUSION

Climate is changing. It changes the trends of natural phenomena e.g., drought, floods, etc. Climate change also creates a problem for coastal communities by altering the patterns of rising sea levels. Copenhagen, Calcutta, Venice, and Vancouver are cities facing the rising sea level problem. Rim countries in the Arabian Sea are also at risk. Rising sea levels cause coastal morphological changes on the coast. It creates problems for those people who are residing in coastal areas or near coastal areas. Sandy beaches are also at risk due to rising sea levels and coastal erosion. Pakistan is also one of the rim countries of the Arabian Sea and the sea level is gradually increasing by about 1.1 mm/year. Karachi is also facing a rising sea level problem and it creates coastal morphological changes there like coastal erosion. I identified rising sea levels at the Karachi coast as about 0.002 mm/year from 1916 to 2016 and 0.0032 mm/year from 1916 to 2016 and 2020. Coastal erosion is mostly identified in East Karachi and West Karachi but not at-risk levels. Coastal accretion is identified in South Karachi (DHA Phase 6 and Korangi Creek). Some coastal morphological changes are also identified in South Karachi (Manora Island) and near Goth Manjar. To reduce the effect of rising sea levels, jetties, sea walls, and dolos should be planned. It is also necessary to promote ideas about coastal protection and provide awareness of climate change. So, that we protect our country from any disaster. Improve conditions for communities that are residing in coastal areas.

## 5. CONFLICT OF INTEREST

There is no conflict of interest among the authors.

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