Applications of RS & GIS for Tsunami and Sea Surges Risk Assessment Along the Coast of Karachi

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Coastal areas are vulnerable to various hazards, such as storm surges, inundation from sea-level rise or coastal flooding, tsunamis, and more. The situation becomes particularly disastrous if the coast is densely populated and highly developed. Pakistan has a coastline stretching 1,046 km, with Karachi being the most developed part. The Karachi coast faces frequent storms during the monsoon season and is also threatened by rising sea levels in the coming years. Additionally, Pakistan's coastline is near the boundaries of two major tectonic plates—the Indo-Australian and Eurasian plates—as well as two minor plates, the Arabian and Iranian plates. In the event of a major earthquake in the Arabian Sea, a tsunami could pose a significant threat, potentially engulfing important and densely built-up commercial, residential, industrial, and sensitive military areas. This study aims to analyze potential losses due to inundation of the Karachi coast using Remote Sensing and GIS techniques.

Keywords: GIS, RS, Coastal Inundation, Tsunami, Sea Surges, Karachi.

Introduction:

Globally, coastal areas have suffered significant damage and losses due to tsunamis and tidal surges. Natural disasters such as landslides, volcanic eruptions, earthquakes, and other disturbances of the water contribute to these catastrophic events. To mitigate their impact, it is crucial to understand the underlying mechanisms and anticipate their occurrence. The application of Geographic Information Sciences (GIS) and Remote Sensing (RS) has enabled the analysis and forecasting of the effects of sea surges and tsunamis.

The Karachi coast is considered moderately to highly sensitive to natural hazards such as cyclones, storm surges, and tsunamis, according to a study conducted by the National Institute of Oceanography in Pakistan [1]. The study highlights those coastal areas with dense populations, inadequate warning systems, and poor infrastructure are particularly vulnerable. Additionally, human-induced hazards like coastal erosion and pollution are further impacting the Karachi coast. The decline of mangroves and the deterioration of coastal ecosystems have increased the likelihood of natural hazards [2].

Overall, the Karachi coast is recognized as a hazard-prone region, necessitating significant risk assessment and management strategies to mitigate the potential consequences of natural disasters. Areas with inadequate infrastructure and dense populations are especially at risk, underscoring the need for improved coastal protection measures and enhanced early warning systems [1][3][4][5].

Applications of GIS in Tsunami and Sea Surges:

GIS technology is extensively utilized to analyze and model the impact of tsunamis and tidal surges on coastal regions. Using GIS, Digital Elevation Models (DEMs) of coastal areas can be generated, which are instrumental in estimating tsunami inundation scenarios. Maps of tsunami and sea surge inundation created with GIS are valuable tools for emergency responders, aiding in the planning of evacuation routes and the identification of high-risk areas. Additionally, these maps can pinpoint locations where enhanced infrastructure is needed to withstand the effects of sea surges and tsunamis [6]. GIS also plays a critical role in examining the effects of sea level rise on coastal regions. By forecasting rising sea levels, GIS technology can assist authorities and policymakers in developing strategies for future resilience.

Applications of RS in Tsunami and Sea Surges:

Remote sensing technology has been instrumental in analyzing and predicting the consequences of tsunamis and sea surges. RS can detect shoreline erosion and sea level variations that impact coastal areas. Researchers have used satellite imagery to monitor changes in coastal vegetation, thereby assessing the effects of sea surges and tsunamis. Additionally, oceanic disturbances that trigger tsunamis and sea surges can be tracked using remotely sensed data. Satellite imagery has been utilized to monitor ocean temperature and currents, aiding in the prediction of tsunamis and sea surges [7].

Study Area:

Karachi, a tropical city with a semi-arid climate, receives rainfall primarily during the summer monsoon season, from July to September. The Karachi coast stretches over 70 km, from Cape Monze in the west to Port bin Qasim in the east (Figure 1). Much of this coastline is densely populated and includes major industrial, commercial, and residential areas, making it particularly vulnerable to natural hazards.

Some of the most vulnerable areas along the Karachi coast include:

- **Keamari Town**: Located in the west of the city, Keamari Town is highly susceptible to natural disasters due to its dense population. It also houses Karachi Port, a critical infrastructure component.
- **Lyari Town:** This area, despite being densely populated, has poor living conditions, making it a highly vulnerable region.

- **Hawksbay:** A popular tourist destination in Karachi, Hawksbay is known for its scenic coastal features. However, its low elevation and proximity to the sea make it particularly vulnerable.
- **Ibrahim Hyderi**: A fishing village on the southeastern coast, Ibrahim Hyderi's low elevation increases its vulnerability to natural hazards.
- **Port Qasim:** Situated in the eastern part of the city's coast, Port Qasim is the busiest port in Pakistan. Its low elevation makes it susceptible to natural disasters.
- **Clifton and DHA:** Clifton and Defense Housing Authority (DHA) are upscale areas characterized by low-lying, reclaimed land. These regions, covering significant commercial and business sectors, are vulnerable due to their elevation and proximity to the sea. Clifton Beach and Sea View Beach, popular tourist sites, are also located here.

These are some of the most vulnerable areas along the Karachi coast, though other regions may also be at risk due to their specific locations and characteristics [1][3][4][5].

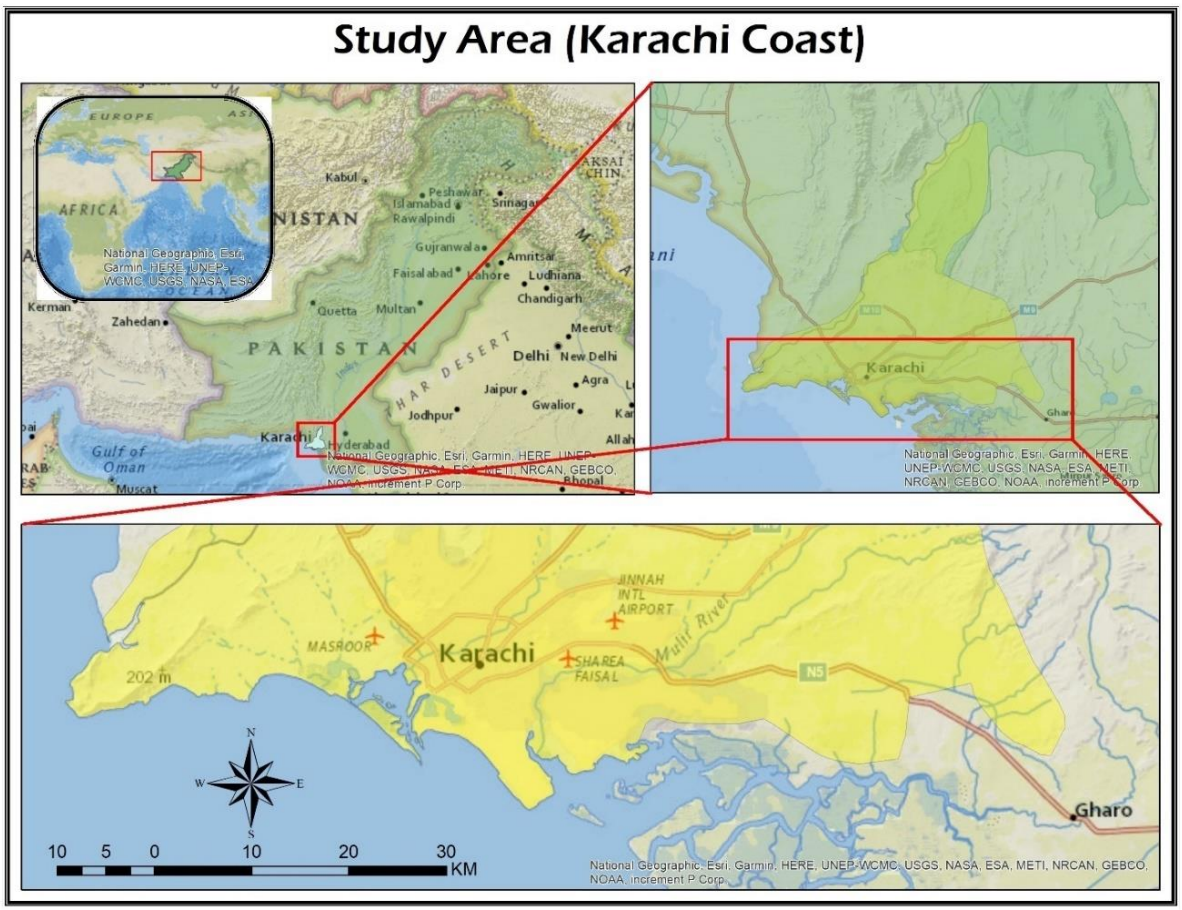

Figure1: Study Area

Materials and Methods:

The methodology employed in this research involves the use of GIS and Remote Sensing (RS) techniques. A Digital Elevation Model (DEM) and contour mapping were created using the SRTM-1 Arc-Second Global image, acquired from NASA Earth Data. Data processing and mapping were conducted using ArcScene and ArcGIS Pro (Figure 2). The SRTM data was utilized to extract general elevation information, helping to identify high-risk areas, while Landsat imagery was used to pinpoint major land use and cover near the coast that is exposed to hazards.

Remote Sensing data and GIS technologies provide a robust platform for monitoring, mapping, analyzing, planning, and decision-making. These technologies allow for the accurate

acquisition and analysis of large-scale spatial data, such as geomorphic or man-made features, on a regional scale with minimal time and effort. The scientific community globally recognizes the accuracy and effectiveness of RS and GIS technologies for such purposes [8][9].

SRTM data has proven to be highly valuable in studying Earth's surface, geomorphology, and related processes. Consequently, it plays an integral role in planning, risk assessment, hazard management, and mitigation. Large-scale hazards like storms, tsunamis, coastal flooding, and inundation can be frequently monitored with minimal ground surveys, yielding better outcomes when analyzed in conjunction with other data, such as seismic and meteorological information. [10] adopted a similar approach to emphasize the importance of remote sensing and other observational platforms in earth measurement, decision support systems, and hazard management.

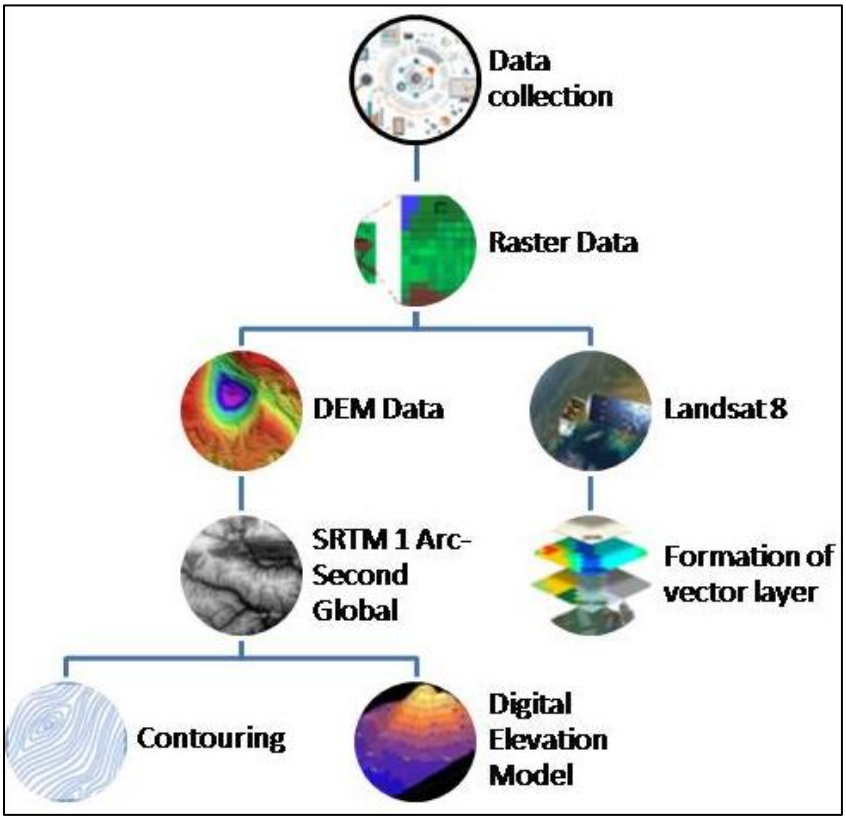

Figure 2: Methodological framework

In a megacity like Karachi, where dense population clusters and extensive commercial and industrial activities prevail, satellite technology and GIS play a crucial role in mapping and planning. Geospatial techniques are essential for regularly monitoring and recording multitemporal variations in land use and land cover (LULC) [11][12][13][14]. Various types of land uses along the coast were identified and mapped using Landsat satellite imagery, with Google Earth Pro also employed to assist in identifying specific locations. Remote sensing data and techniques, particularly Landsat images, are invaluable for studying and classifying large-scale LULC features [15].

Results and Discussions:

The convergence of the Arabian, Eurasian, and Indian plates is located approximately 220 km from Karachi (Figure 3), though this distance may vary along the coast from east to west. Despite this separation, tectonic activity among these three plates continues to affect the coast and surrounding areas in multiple ways, including seismic activity, tsunamis, geological hazards, sea level rise, and subsidence. These events can cause significant damage to nearby infrastructure, threaten human life in vulnerable areas, and impact local ecology and climate.

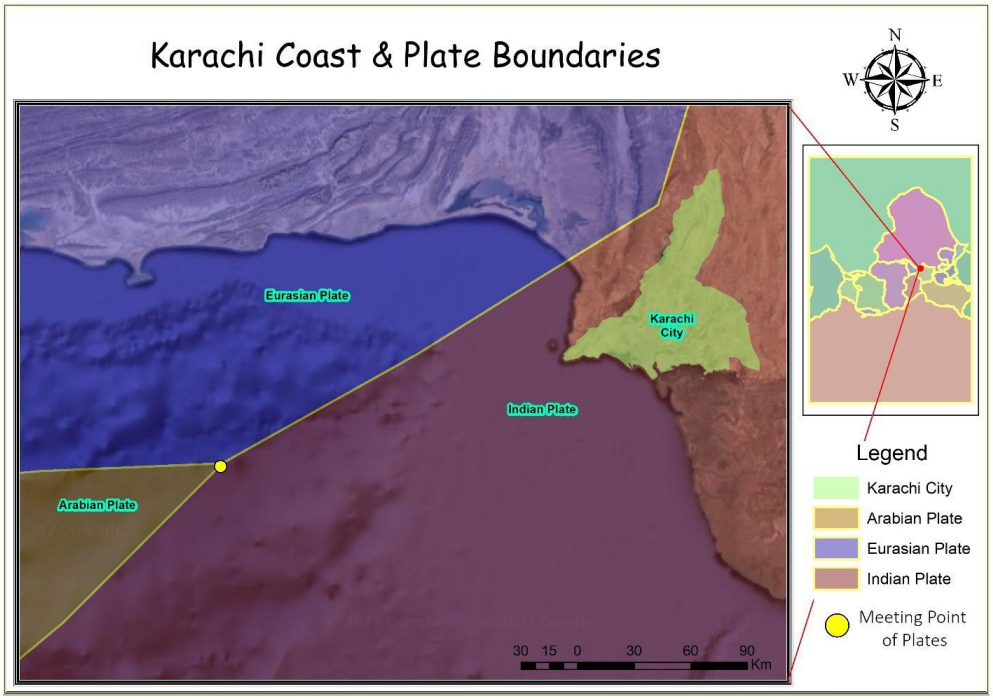

Figure 3: Location of Plate Boundary Near Karachi Coast

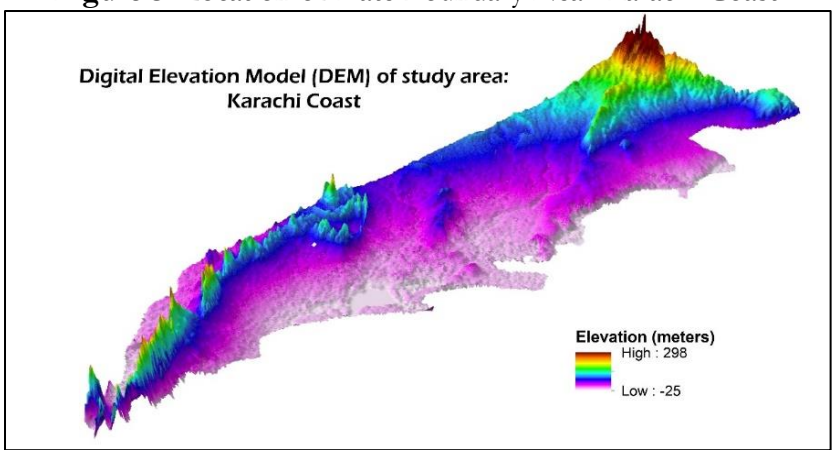

Figure 4: Digital Elevation Model (DEM) of Karachi Coast

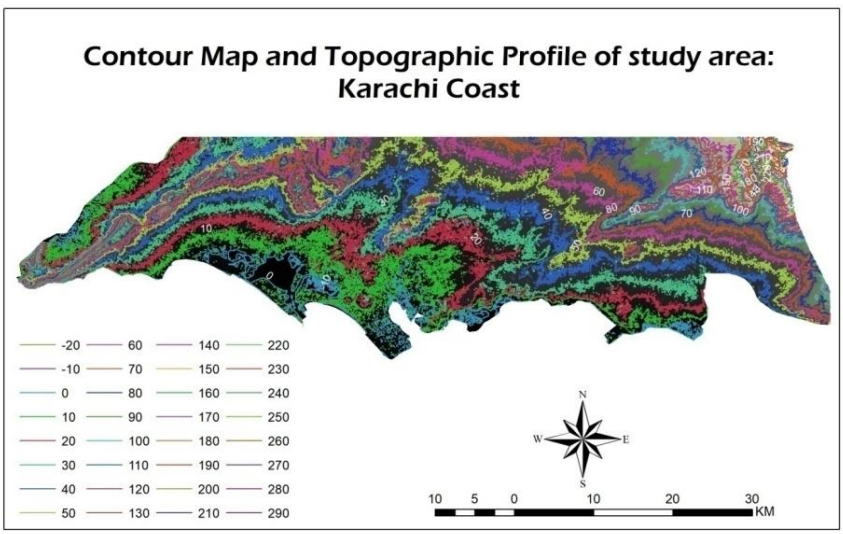

Figure 5: Contour map and topographic profile of Karachi Coast

A Digital Elevation Model (DEM) was generated using SRTM imagery to assess the altitudes of the coastal area of Karachi, which range from -25 to 298 meters. The DEM and topographic profile of the area indicate that elevations up to 20 meters are at high risk, especially without any natural or man-made obstructions (Figure 5). When comparing the topographic profile with the land use map of the Karachi coast, it becomes evident that many of the city's highly built-up areas are concentrated within the 20 to 30-meter elevation range. These areas include residential, commercial, and industrial zones, as well as several sensitive and strategic locations (Figure 6).

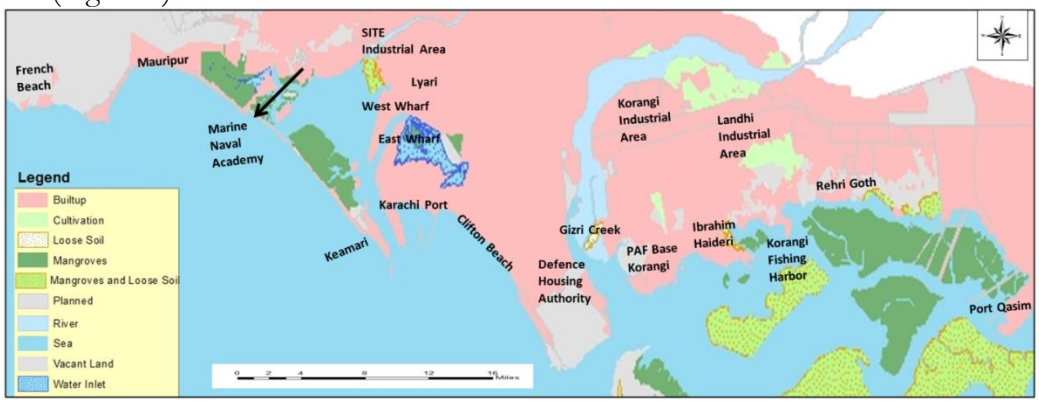

Figure 6: Lanusse and Land Cover along Karachi Coast

Conclusion:

In conclusion, GIS and Remote Sensing (RS) are effective methods for assessing and predicting the impacts of sea surges and tsunamis on coastal regions. Geospatial technology enables the study and monitoring of sea-level rise forecasts, inundation maps, and oceanic disturbances that could lead to tsunamis and sea surges. This study offers valuable insights into potential losses from storm surges, tsunamis, and similar events. By applying remote sensing and GIS for disaster management, emergency responders can reduce property damage, minimize fatalities, and enhance preparedness for natural disasters.

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