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Impact of Port Structures on the Shoreline of Karnataka, West Coast, India

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Abstract The changes in shoreline positions and geomorphic features along the Karnataka, West coast of India, were studied for the period from 1973 to 2014, using multi-dated satellite images and topographic maps. The ten hotspots which are mainly areas nearer to the port region were specially studied for the quantification of erosion and accretion. Dredging for port development normally lead to noteworthy changes in the configuration of the seabed. These changes can meaning fully modify the currents, waves and water quality. The statistical method incorporated with GIS has been used to estimate the rate of change and net shore movement of the coast. The study indicates that gradual recession and accretion at Tadri, Bhatkal, Honnavar, etc. Shorelines extracted for the years 1973, 1998, 2000, 2003 and 2014 indicate that the coastline adjacent to port area experienced both the erosion and accretion. Shoreline change rate of Karnataka coastline is estimated as -1.2354 m/year. Erosion and accretion of shoreline are major impacts of port/harbor. However, minor impacts are like an increase in pollution due to waste dumping and port-related industries, increase in coastal population and related activities and degradation of surrounding environment due to dredging and dumping material. Most of the shoreline sites, though largely get affected due to port structures, during monsoon season, achieve natural partial equilibrium during the non-monsoon season due to reversing currents and wind pattern. And hence, it may be concluded that port/harbors have limited impact on the coastal shoreline.
Keywords *Port Impact; Reversing Wind; Shoreline Change; Geospatial Studies; Karnataka Coast*

1. Introduction

Shoreline changes induced by erosion and accretion are natural processes that take place over a range of timescales. Coastal erosion causes extensive damage to public and private property and to natural resources and jeopardizes human lives. This has resulted in significant economic losses to individuals, private businesses, and the state's economy. Coastal erosion damage has necessitated large public expenditures to remove debris and crumbling structures, and to replace crucial public facilities and services. The management of coastal erosion hazard areas supports to protect coastal habitat areas, inland natural resources, homes, businesses, and communities from wind, water erosion and storm-induced high water.

Construction and development of ports and accompanied civil structures, at different locations in the world, brings about shoreline, environmental, and socio-economic changes. Like Newport harbor which is situated 16 km south of downtown Santa Anaonce supported maritime industries such as boatbuilding, shipbuilding, and commercial fishing, but today it is used mostly for recreation. The shoreline movement has been studied for the period of 1874 to 2002. The accretion has been observed almost 200m from 1901-1983 because of disposal and dredge material and subsequent reclamation of land. During the 1980s and 1990s the accretion pattern continued. During 1983-2002 the shoreline retreated about -10m as in the winter season, the large volume of sand accreting in the offshore, and not coming ashore during summer. Developments at Rous Head prevent any residual dredge material from moving onto Port Beach from the south (Department of Planning and Infrastructure 2004).

Similarly, Port Ijmuiden is located at the mouth of the North Sea Canal to Amsterdam, and situated about 17 km north of Haarlem is a deep water port suited to fully laden Panamax ships, and is fourth port of the Netherlands. The Port of Ijmuiden has been constructed around 1870 and initially had a length of about 1.5 km. After the construction two breakwaters accretion occurred against both breakwaters and erosion at some more distance on either side of the port. During the study, it is observed that in the period 1840 – 1950, the accretion just north of the port was significantly larger than just south, given the fact that the net longshore transport along the Dutch coast is northward directed. After the extension of the harbor moles in 1965 the accretion has been started with a high rate at the coast south while further accretion at the north of the port remained limited. At present, the seaward movement of the shoreline against the southern breakwater since port construction is about 800 m and close to the northern breakwater about 700 m. The inclusion of sediment bypass improves the coastline response north of the port significantly, and the south the transition point between accretion and erosion of the coastline is reproduced well (Luijendijk et al., 2011).

Damietta Port is located at the Damietta branch, a distributary of the Nile, 15 km from the Mediterranean Sea, approximately 200 km north of Cairo has three distinct zones: (1) the western zone is noticeable by shoreline accretion; (2) the central zone which has mixed erosion and accretion; and (3) the eastern zone which is categorized by minor erosion with minor and localized accretion areas. Frihy (1988) stated that much of the eroded material from the tip of Rosetta and Damietta promontory is transported eastward by littoral drift and accreted on the eastern parts of the promontories. Moreover, there has been the formation of a spit on the same (eastern) side of Damietta promontory. Frihy et al. (1991) concluded that the maximum erosion occurred at the tip of the promontory, with accretion taking place to the east along it's bank. The accretion has taken the form of a sand spit growing in the eastern direction. The eastern zone which extends from 22 km east of the mouth of the Damietta to Port Said, and is characterized by slight erosion with minor and localized accretion areas (EL-Raey et al., 1999).

Developments of major/minor ports and fishery harbors consist of the construction of coastal structures like break waters, jetties, groins and reclamation bunds. Improvements of the ports also involve the dredging and disposal activities to maintain these essential depths for navigation. These coastal structures and the dredging activities interfere in the coastal processes of the region. Alterations in the coastal processes have a large impact on the coast line (Kudale, 2010).

Natural forces such as wind, waves and currents are constantly influencing the coastal regions. The combined energy of these forces transports land materials. And the effects of waves, currents, tides and wind are primary natural factors that influence the coastline. The other features eroding the coastline include the sand sources and sinks, changes in relative sea level, slope, geomorphological characteristics of the shore and sand, etc. Anthropological activities that trigger beach erosion are theconstruction of artificial structures, mining of beach sand, offshore dredging or building of dams or rivers. The major coastal process like littoral drift plays an important role in deciding the areas of coastal erosion and deposit, in shaping and orienting coastal landforms and finally in the evolution of the coast (Kunte and Wagle, 2000).

The shoreline changes between Ohtsu Fishery Harbor and Hitachi Port along the Joban Coast are studied during the period 1947-1966, 1966-1975, 1975-1984, and 1947-1984. Cyclic beach changes of accretion or erosion were observed on both sides of the headlands located between Ohtsu Fishery Harbor and Unomisaki Cape. This is because of the predominant wave direction changes seasonally from northeast to the southeast on the coast. Severe beach erosion and accretion were observed because of the elongation of the offshore breakwater at Ohtsu Fishery Harbor and Oharai Port. Along the Kashimanada Coast beach erosion is severe at the south site of Oharai Port, the north of Kashima Port and Hazaki Fishery Harbor. The slope of the beach face becomes steep and the armoring of the bed materials on the shore is under way on the eroded beach on the down drift side of the structure. It is observed that a large amount of sand accumulated inside Hazaki Fishery Harbor with the elongation of the breakwater. Especially the shoreline advanced very much after the completion of the construction work of the parallel offshore breakwater with respect to the shoreline. Regarding the cause of the beach changes inside the harbor, the deposition of a part of the sediment outflow from the Tone River is considered to be important because of the formation of the calm water inside the harbor (Sumiya et al., 2007).

During the last two decades, remote sensing and geographical information system (GIS) techniques have been widely employed in various coastal morphodynamic studies as they are less costlier, reduce manual error, and are useful in the absence of field investigations. The applications of remote sensing and GIS have proved particularly effective in delineation of coastal configuration and coastal landforms, finding of shoreline positions, assessment of shoreline and land form changes, extraction of shallow water bathymetry (White and El Asmar, 1999; Ryu et al., 2002; Siddiqui and Maajid, 2004; Maiti and Bhattacharya, 2009; Chaudhari et al., 2013; Salvan et al., 2014). The Digital Shoreline Analysis System (DSAS) is a freely available software application that works with the Environmental Systems Research Institute (ESRI) Geographic Information System (ArcGIS) software, has been used. DSAS computes rate-of-change statistics for a time series of shoreline vector data (Himmelstoss, E.A. 2009). Digital Shoreline Analysis System (DSAS) version 4.0 — An ArcGIS extension for calculating shoreline changes (U.S. Geological Survey Open-File Report 2008-1278).

1.1. Study Site

Karnataka State is located between 11°30' and 18°30' N latitudes and 74° and 78°30' E longitude. The State is bounded by Maharashtra and Goa States in the north. Karnataka's coastline extends over a length of 320 km. It is one of the most indented shorelines with numerous river mouths, lagoons, bays, creeks, promontories, cliffs, spits, sand dunes and long beaches (Figure 1). The coastal stretch of Karnataka has no major delta formations. The shelf off Karnataka has an average width of 80 km and the depth of shelf break is between 90 and 120 m. There are a few islands off the coast, the major group being St. Mary's Island. Fourteen rivers drain their waters into the shore waters of Karnataka. The important estuaries include the Netravati-Gurpur, Gangolli, Hangarkatta, Sharavthi, Aganashini, Gangavali, and Kalinadi. Sand bars have developed in most of the estuaries. There are a number of barrier spits at Tannirbavi, Sasithitlu, Udyavara, Hoode, Hangarkatta and Kirimanjeswara formed due to migration of coastal rivers. There are 90 beaches out-of-which 22 beaches are classified as unfit for use due to erosion, human settlements and activities linked to ports/harbors, industries, and fisheries. Coastal zone comprises of districts of Uttara Kannada, Udupi and Dakshina Kannada. The coastal plain experiences a tropical humid climate with very hot summer and high monsoon rainfall. The average annual maximum temperature is 30.9° C and a minimum of 23.7° C. On an average, annual rainfall is ~3,900 mm (Kumar et al., 2010).

During June–September, a period referred to as the summer monsoon, the general direction of winds, to the north of the equator, is southwesterly and its strength is considerably larger than that during the rest of the year. During November–March, referred to as the winter monsoon, winds over the same region have overall northeasterly direction. October and April–May are times of transition between the two monsoons (Shetye et al., 1985). The coastal segment along the study region is bounded by the Western Ghats in the east and the Arabian Sea in the west. The coastline at Karwar is inclined to the west by 24° from the true north. The bathymetry contours aligned approximately parallel to the coastline. The coastline at Honnavar and Malpe are inclined to the west by 17° from the true north. There are a few islands off the coast, the major one being St. Mary's Island, 4 km off the coast near Malpe. The coast is exposed to the seasonally reversing monsoon winds and the annual rainfall is 3 m. The tides in this region are mixed semi-diurnal dominant, the range of which increases towards the north (Kumar et al*.,* 2011a). The monthly mean sea level at Karwar varies from 1.06 m in September to 1.3 m in January. The average tidal range at Karwar is 1.58 m during springs and 0.72 m during neaps. During the summer monsoon along the west, coast of India, significant wave height (*Hm*0) up to 6 m has been reported (Kumar et al*.,* 2006), *Hm*0 is normally <1.5 m during rest of the period (Kumar et al., 2003)

The main aim of this investigation is to provide systematic and accurate historical measurements on shoreline change along the Karnataka coast using multi-resolution, multi-date satellite data and Geographic Information System (GIS) as the location of the shoreline and its historical rate of change can provide important information for the design of coastal protection, plans for coastal development, coastal and social vulnerability study, and the calibration and verification of numerical models, etc. A further attempt is also made to study the impact of port-related structures on shoreline changes of Karnataka coast, India.

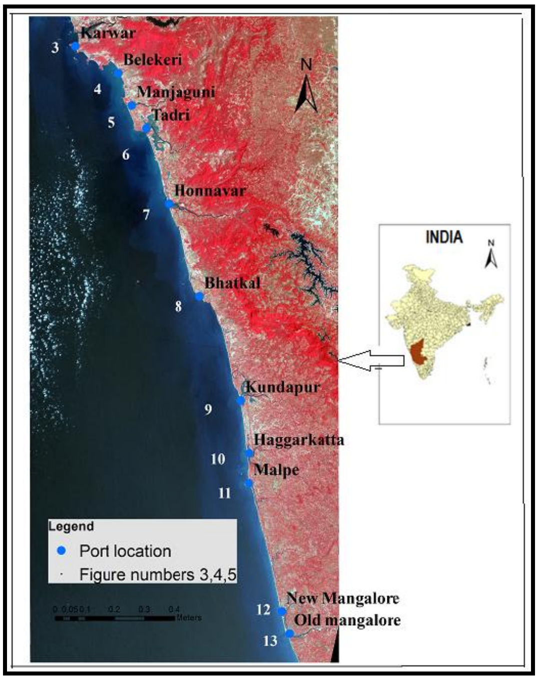

Figure 1: *Karnataka, West Coast of India*

2. Materials and Methods

For the present study, Geospatial techniques have been used to analyze the shoreline changes. As remote sensing data provide synoptic coverage and GIS helps in the analysis of more temporal data sets, so that dynamic areas, which are changing due to the erosion-accretion processes can be identified easily. The details of the data products used in this study are listed in Table 1.

Table 1: *List of the Data Product Used for the Study*

Data	Date and Year	Sensor	Source
Satellite images	2 March 1973	Landsat-MSS	www.usgs.gov.in
	17 March 1998	Landsat-TM	
	14 March 2000	Landsat-TM	
	23 March 2003	Landsat-TM	
	8 January 2014	Landsat-OLI	
Topo graphic maps (1:50,000)	1975	Grids:48J/1,6,7,12 48K/9,10,11,15,16, 48L/13	Survey of India
Nearshore Bathymetry	-----------------------	---------------------	National Institute of oceanography
Geomorphology map	8 January 2014	Landsat-OLI	Self-prepared

2.1. Methods

The shoreline changes for 5 different years (1973, 1998, 2000, 2003 and 2014) have been studied using statistical method incorporated with GIS. Normalized difference water index has been calculated using ERDAS imagine software which enhances the water body so as to differentiate from land masses. The shorelines for 5 different years have been digitized using ArcGIS10. Survey of India topographic maps (1975) was geo-referenced in ERDAS Imagine 9.2 and reprojected to UTM, WGS 84, 43 north zones and used as a source of reference. Erosion-accretion maps were produced using these digitized shorelines. Geomorphology map has been created in ERDAS imagine using Landsat OLI 2014 Image. Contour map has been prepared to study the coastal region slope, as geomorphology and slope play an important role in understanding erosion and accretion processes. The rate of shoreline change and net shoreline movement has been estimated using digital shoreline analysis system (DSAS) tool which is a freely available software application (USGS 2005) that works within the Environmental Systems Research Institute (ESRI) Geographic Information System (ArcGIS) software.

DSAS requires more than two shorelines and those must reside in a single feature class. DSAS also requires that the feature class be in meter units in a projected coordinate system. The baseline i.e. simple vector line has been drawn, onshore, and parallel to the shorelines (Himmelstoss, 2009). The techniques involve the computation of the change in the position of the shoreline through time by drawing perpendicular transects to the baseline. Accordingly, 300 m long transects at a spacing of 500 m were casted along the 320 km long shoreline of Karnataka with the help of the DSAS TOOLBAR in ArcGIS 9.3 (Figure 2). The different methods used to calculate the rate of shoreline change include the End Point Rate (EPR), Net Shoreline Movement (NSM), Average of Rates (AOR), Linear Regression (LR), and Jackknife (JK). The advantage of the EPR method is its ease of computation, as it considers only two shoreline positions to calculate the rate of shoreline change (Dolan et al., 1991). At each transect along the shoreline, the NSM and EPR were estimated and the rate of shoreline change and associated risk ratings were calculated.

Shorelines extracted for the years 1973, 1998, 2000, 2003 and 2014 from Indian Remote Sensing satellite (IRS) data and using DSAS tool, were examined for possible shoreline change. The study estimates the area which experienced both the erosion and accretion, adjacent to ports. Net erosion and accretion rate for the period 1973 to 2014 is shown in Figures 3-12, with red and green color respectively. The eroded and accreted areas for periods 1973-1998, 1973-2000, 1973-2003, and 1973-2014 are shown in red and green color, in fours maps of each figure. The cumulative Shoreline change rate for the period 1973-2014 for every port is estimated and mentioned in Table 2.

Table 2: *Net Shoreline Movement During 1973 to 2014 adjacent to Ports/harbors of Karnataka State*

Net Shoreline Movement during 1973_2014			
Ports/harbours		Net Recession	Net Progradation
1	Karwar	-1.6497m	3.3082m
2	Belekeri	-51.7700m	162.4500m
3	Manjaguni	-42.9891m	51.2880
4	Tadri	-80.1070m	50.6750m
5	Honnavar	-52.5720m	32.5733m
6	Bhatkal	-182.5083m	22.2600m
7	Kundapur	-58.0925m	62.4367m
8	Hangarkatta	-50.3829m	62.5900m
9	Malpe	-95.4862m	43.9900m
10	New Mangalore	-4.8400m	2.1500m

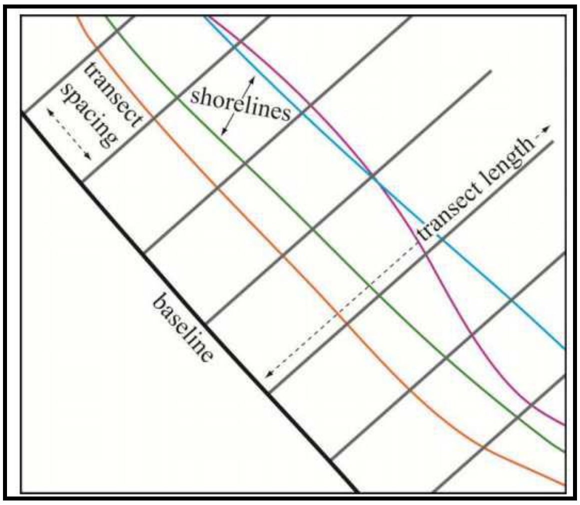

Figure 2: *DSAS Input Data Structure*

3. Results

The coastal zone of Karnataka is one of the better-developed geographical areas of the state with a high degree of economic development and density of population. The coastline is dotted with one major port at Mangalore, nine minor ports at Karwar, Belekeri, Tadri, Honavar, Bhatkal, Kundapur, Hangarkatta, Malpe and New & old Mangalore Port. Besides, there are 110 fish landing centers and 150 fishing villages. A single major intervention in the coastal zone is the project Sea Bird, where an area of around 32 sq. km. is being converted into an area with several structures. The port-wise study is presented as below.

3.1. Karwar Port

Karwar port is located at Baithkol, Karwar Bay. Karwar is one of the major fishing zones in Karnataka. The Kali River flows through Karwar which is also a prominent tourist destination. The entire city of Karwar is situated on beach ridges formed due to the influence of Kali River and the Arabian Sea confluence during the past. The area covered geomorphology classes such as tidal flat, spit, Marine

Island, sandy beach, creek, coastal plain, Channel Island and alluvial plain. Spit shows a gradual decrease in the area. Sediment discharge takes place near the river mouth, it is very dynamic and changes seasonally; long-term observation shows a shift of Kali River mouth towards the north. The area surrounding Karwar port (Figure 3) has the rate of erosion -1.6497m/yr and rate of accretion +3.3082m/yr. during the period of 1973 to 2014. Net shoreline recession during this period is -71.2837m and net pro gradation is +114.7100m.

Hills and coastal islands make the port a natural harbor, sheltered from the Arabian Sea. The length of the port is 355 m. The quay has two berths, with a draft capacity of 9.25 m. Karwar port also berths coastal vessels and there is a jetty for fishing vessels. The Government of Karnataka has planned to develop Karwar port on a Public Private Partnership (PPP) basis to provide six additional berths, a container terminal, and a rail link to Shirwad railway station. The port is able to handle all types of commodities, including "B" and "C" class petroleum products. The port has liquid storage tanks for bitumen, furnace oil, molasses, and HSD. A ban on iron ore mining and export in Karnataka state reduced congestion at the port. The port has arrangements for berthing coastal vessels, and a jetty for fishing boats (http://en.wikipedia.org/wiki/Karwar).

In 2012, the Government of Karnataka carried out maintenance dredging in the port, the approach channel, and the nearby anchorage. INS-Kadamba is an Indian Navybase located near Karwar in Karnataka. INS Kadamba is currently the third largest Indian naval base and is expected to become the largest naval base in the eastern hemisphere after completion of expansion Phase IIB. Erosion accretion areas surrounding Karwar port is shown in Figure 3.

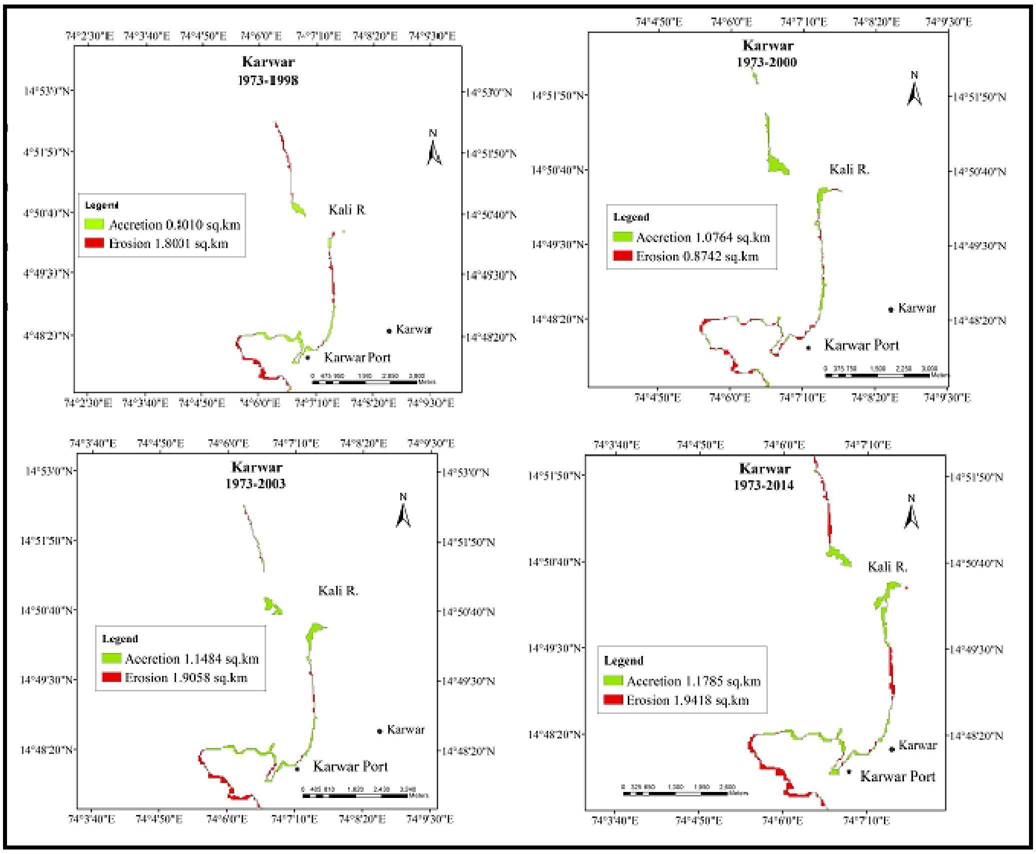

Figure 3: *Erosion and Accretion Adjacent to Karwar Port*

3.2. Belekeri Port

Belekeri Port is located 8 km north of Ankola and 15 km South of Karwar, in Uttara Kannada District of Karnataka. The Port is built on a rocky head land and is well protected from the southern side. It is built on the bank of Kalinadi River and has spits on north and south side of the river. It is second biggest port after Mangalore Port in Karnataka. This port is mainly used for exporting of Iron Ore. The area surrounding port shows (Figure 4) rate of erosion as 1.267m/y and the rate of accretion +3.977 m/y for the period 1973-2014. The shoreline retreats by -51.77m and is prograded by +162.45m.

The tidal inlets and the river mouths are located on littoral transport shore lines; they are often in a natural equilibrium with respect to bypassing of the littoral drift, which normally occurs on a shallow bar across the inlet. The area is characterized by sandy beaches and coastal plain. Erosion is noticed on one side of the port and accretion is observed on another side. This port is mainly used for exporting iron ore. Ore is transported to ships in the sea by barges. For now, three jetties are available for barge loading. Recent filings and reclamation works by the iron ore exporting companies have aggravated the intensity of erosion. Survey showed that the coastal dunes, which play a key role in preventing erosion, have been dug up for creating fields by the local farmers, thereby making the sea coast more prone to sea erosion (EMPRI 2007).

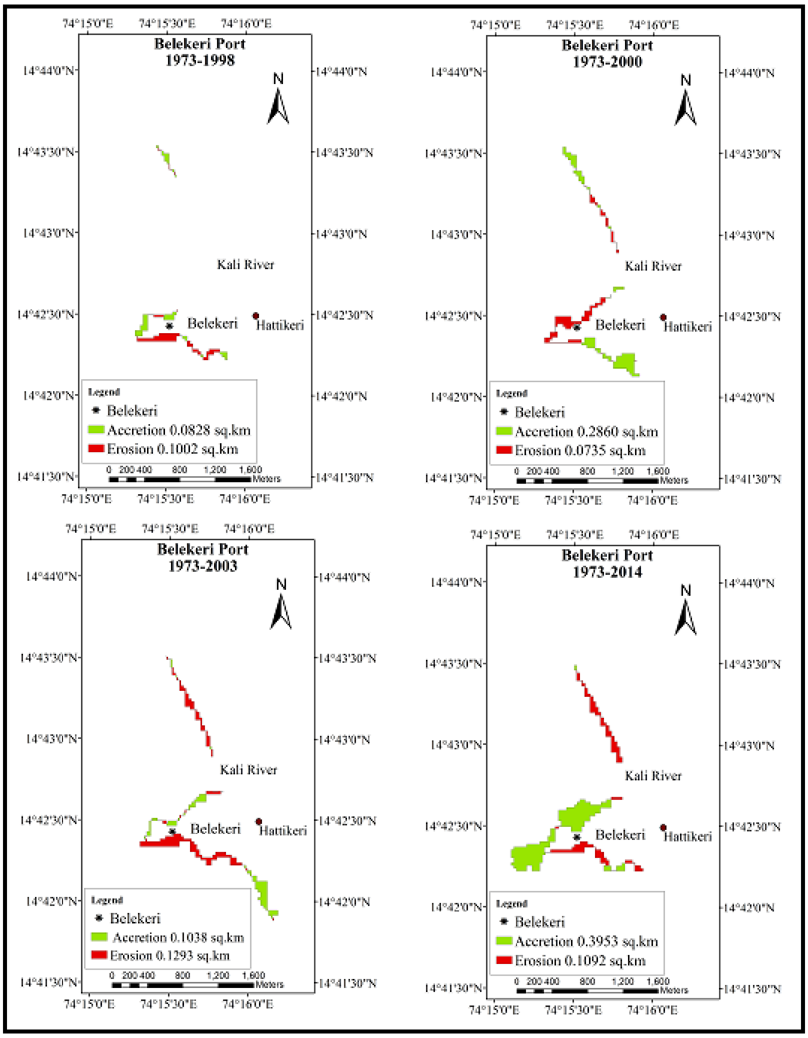

Figure 4: *Erosion and Accretion near Belekeri*

3.3. Manjaguni Port

Manjaguni port is located in the Uttara Kannada districts of Karnataka state. The port is on Gangavali River. The surrounding area shows a (Figure 5) rate of erosion-1.0545m/y and rate of accretion is +1.2560m/y for the period of 1973 to 2014. During this period shoreline is retreated -42.9891m and pro graded +51.2880m.shows erosion and accretion at Manjaguni port area. Due to the northward growth of sand spit across the river Gangavali, the river mouth has shifted northwards.

The Northern most side of the river is characterized by sand and followed by a rocky structure which suggests less erosion and near mouth, spit formation which indicates the source of sediment as a river rather than littoral drift. Sand dunes are dominantly observed in this area. At the Gangavali, the long shore current mostly persisted around 0.2 - 0.25 m/s in October, November and December and about 0.25 - 0.3 m/s in January, February, May, July, August and September (Tirodkar et al., 2014).

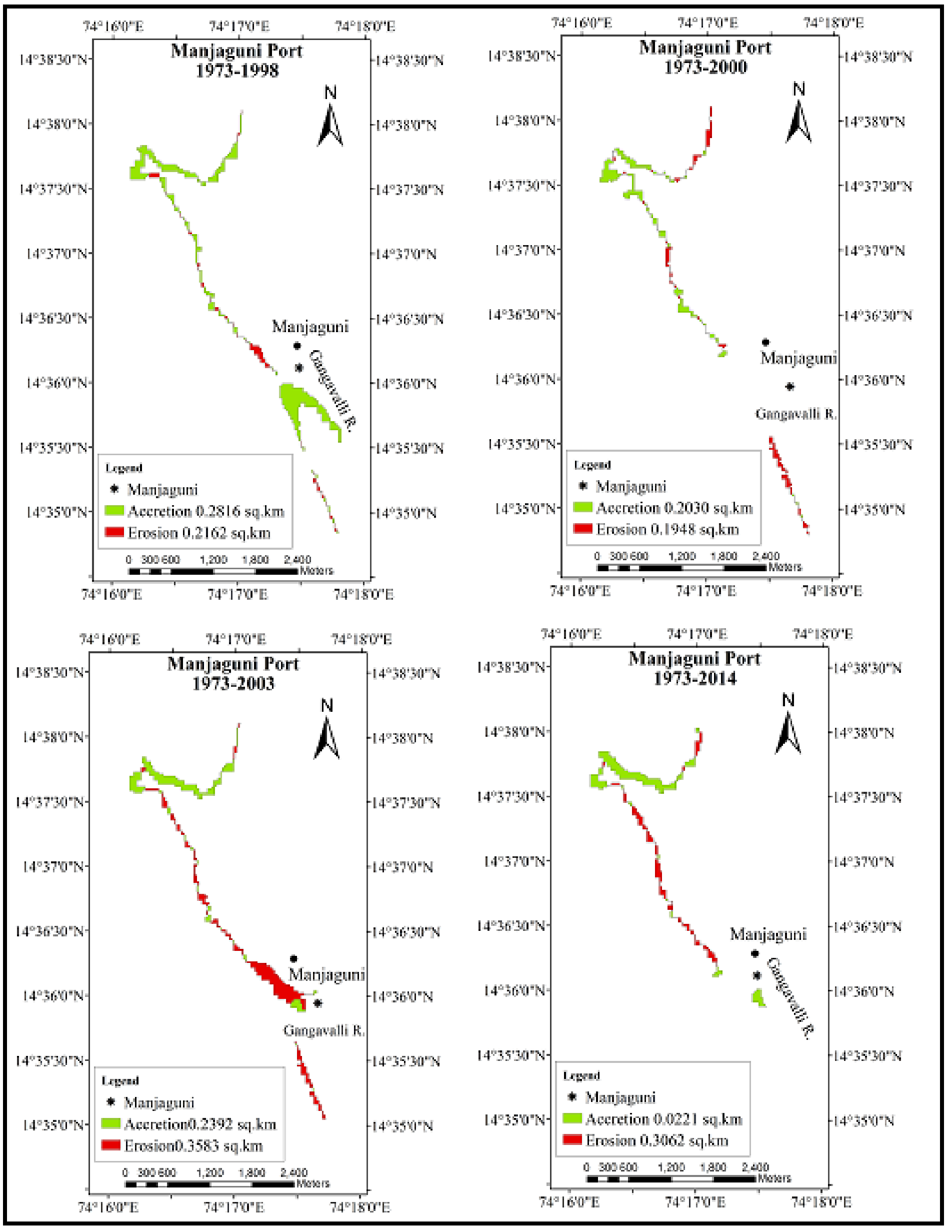

Figure 5: *Erosion and Accretion near Manjaguni*

3.4. Tadri Port

The Tadri port is located on the bank of Tadri/Aghanashini River. The rocky structure with a small fillet of sand has been observed at the northern side of the port. Sandy beach is observed at the southern side of the port. This port is projected for development under the BOOST (Build, Own, Operate, Share, and Transfer) concept through private participation. The coast shows a (Figure 6) rate of erosion -1.9992m/y and rate of accretion is +1.4150m/y for the period of 1973 to 2014. About -80.1070m shoreline recession has been recorded and shoreline progradation is recorded about +50.6750m for the period of 1973-2014.

The coast has a high productive ecosystem and is ecologically sensitive. The area is covered with the sandy beaches and cliffs. Sedimentation at river mouth has led to an arrowing of river mouths. The shoreline erosion on another hand is responsible for shifting of the mouth. From February to August the direction of longshore current was southward, whereas in December it is northward. Long shore currents are erratic in January and September (Tirodkar et al., 2014).

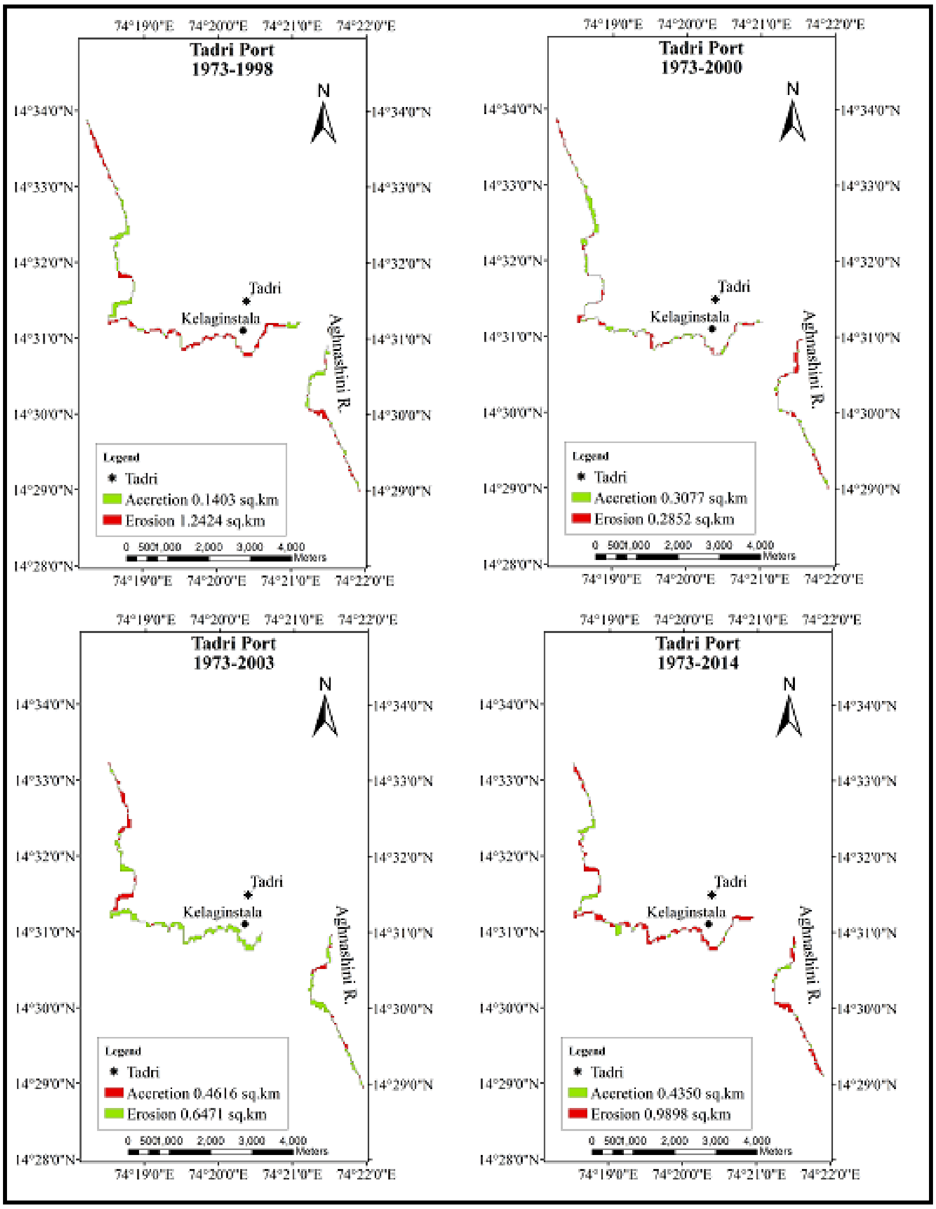

Figure 6: *Erosion and Accretion near Tadri Port*

3.5. Honnavar Port

Honnavar port is located on 10 km long Kasarkode stabilized spit pointing northwards at the mouth of Sharavati River. The port is near to the town of Honnavar in Uttara Kannada district. Honnavar shows (Figure 7) the rate of erosion is -1.2875m/y and rate of accretion is +0.7967m/y during the period 1973 to 2014. It is a major fishing harbor. Pavinakurve spit is to the northern side of the river mouth and is affected by erosion. Kasarkode spit which situated on the southern bank of Sharavati River shows accretion. Northerly drift prevailing during the post-monsoon season favors spit growth across the river mouth from south to north. Detached breakwater is a coast-parallel structure located inside or close to the surf-zone. Groins are normally built perpendicular to the shoreline for protecting a section of the shoreline by blocking (part) littoral transport, whereby sand is accumulated on the upstream side of the groin and the erosion shifts to the downstream area.

A spit on the northern side of the Sharavati River mouth is affected by erosion and the spit on the southern side shows accretion. The shoreline recession is observed about -52.5720m and +32.5733m progradation is recorded for the period of 1973-2014. Northerly drift prevailing during the post-monsoon season favors spit growth across the river mouth from south to north, whereas the southerly drift during December to February is responsible for the erosion of the portion of the beach to the north of the river mouth. The spit growth across river mouths is narrowing river mouth.

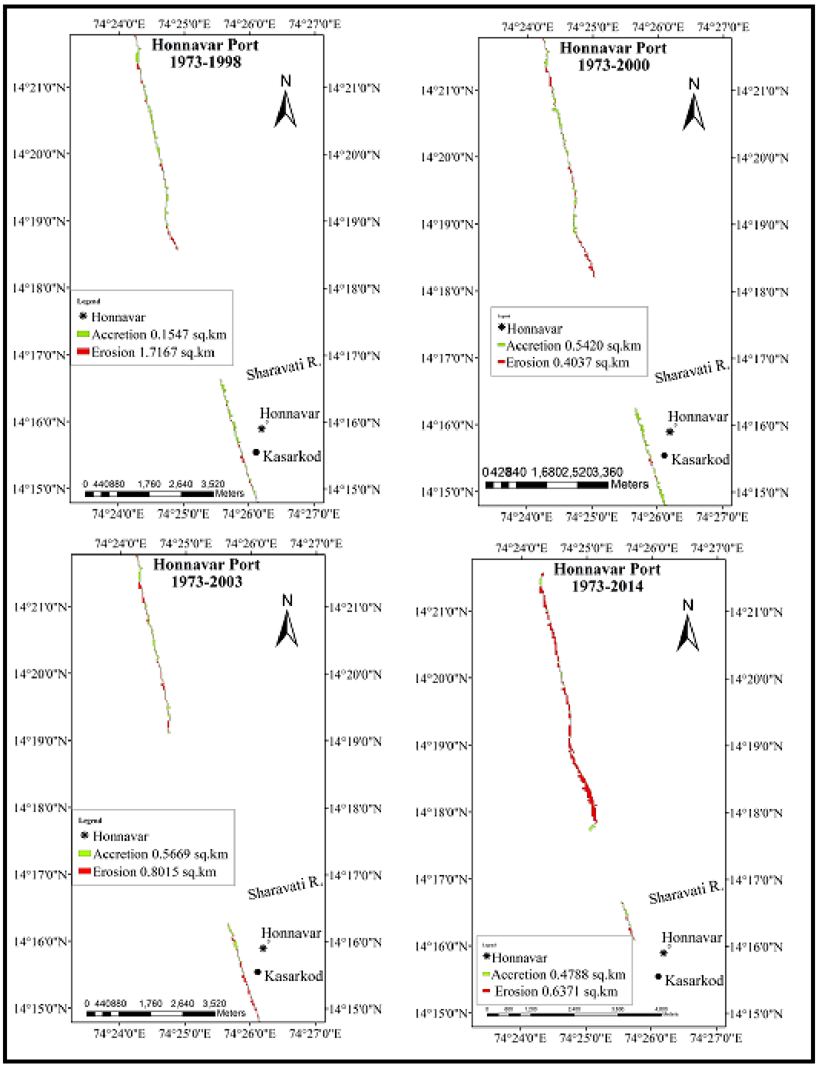

Figure 7: *Erosion and Accretion at Honnavar*

3.6. Bhatkal Port

This port is situated at the mouth of Bhatkal River. The Bhatkal port is protected from northward longshore by constructing a breakwater at the southern side of river mouth which is built perpendicularly to the coast. The rocky headland at northern side stops southward drift from clogging river mouth. Presently fishing vessels are utilizing the facilities of this port. This port could be developed as a modern fishing harbor with full-fledged fish handling facilities. The Port is surrounded by hills and river.

Figure 8 shows the area of erosion and accretion 0.534481 km^2 erosion and 0.005247 km^2 accretion are observed during 1973-1998. The coastline is characterized by the head land, shore line, and river mouth, beaches. The threat to the port is not much due to shore drift but is due to sediment siltation due to River. The shoreline is shifted backward about -182.5083m and forward about +22.2600m. The two breakwaters are observed at river mouth to stabilize the mouth, as the shifting of river mouth is very common along this coast. Erosion is observed at the north side of the port because of the northerly drift is dominant over the southerly drift and during monsoon the north side of the river mouth experiences more severe erosion than the southern side (Nayak et al., 2010).

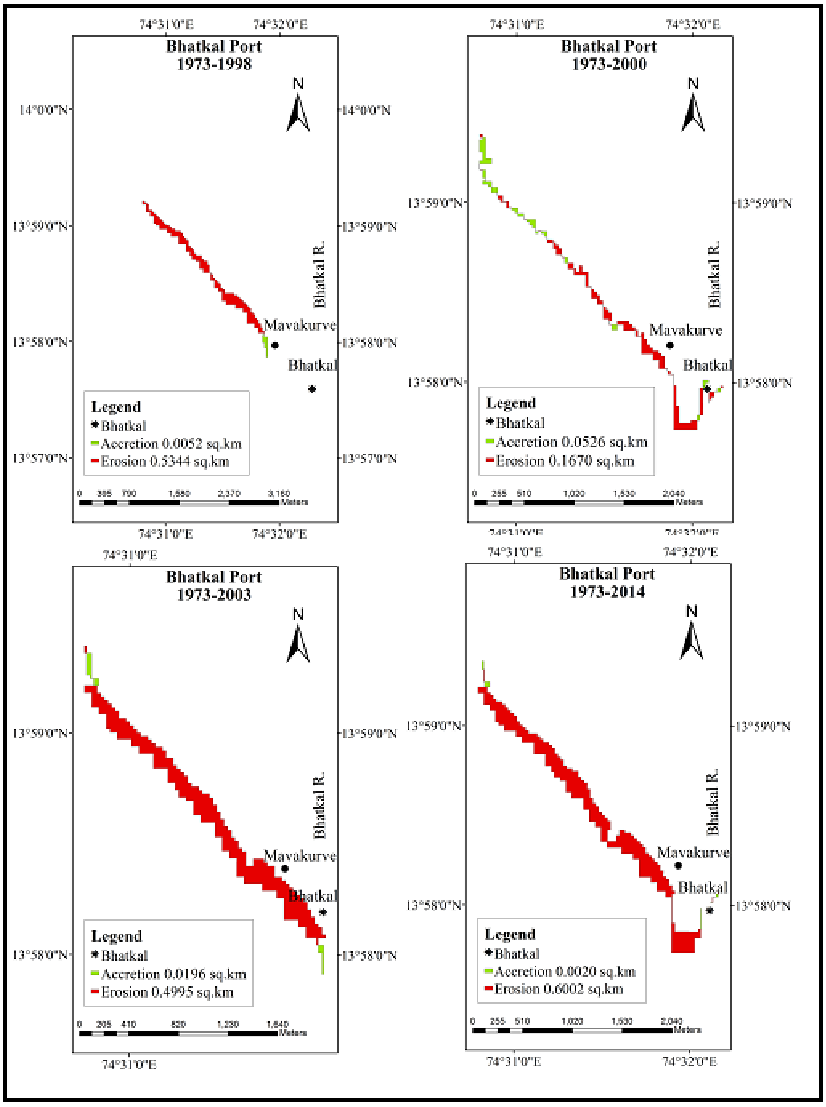

Figure 8: *Erosion and Accretion at Bhatkal*

3.7. Kundapur Port

The port area covers 7.644 Km and is situated on the confluence of Kollur-Chakkara and Haladi rivers and the Arabian Sea. At Kundarpur, spits namely Koravadi and Gangoli are situated on either bank of the river, which play an important role in coastline changes. The port is surrounded by sandy beaches which lead to erosion. The wide estuary which supplies sediment in greater amount is the main reason for accretion and thus both processes balance each other, in this region. Kundapur shows (Figure 9) the rate of erosion is -1.5065m/y and rate of accretion is +1.5300m/y during the period 1973 to 2014. During this period shoreline is retreated -58.0925m and prograded +62.4367m.

Rocky beach, sandbar and alluvial plane are the characteristics of Kundapur morphology. No changes have been detected in rocky beaches, Marine Island, and alluvial plain. It is detected that the coastal plain and channel Island have gradually increased. Coastal plain area increased by 0.159 Km² (Jayappa and Kumar, 2009).

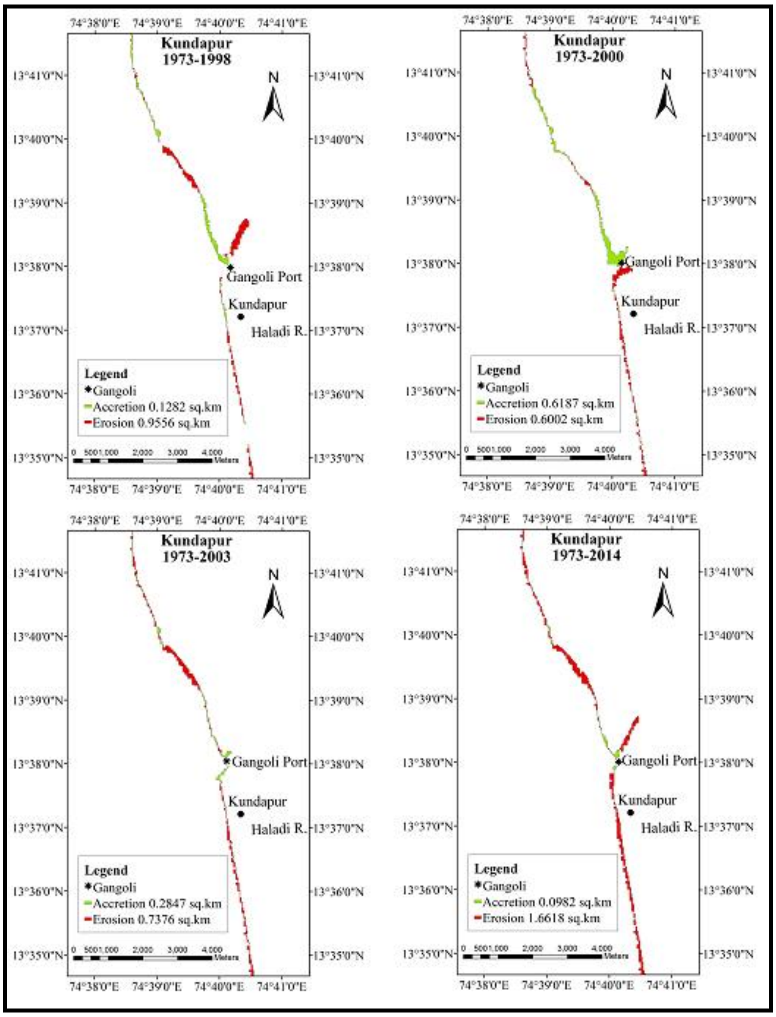

Figure 9: *Erosion and Accretion near Kundapur*

3.8. Hangarkatta Port

This port is located in Udupi district of Karnataka state. Hangarkatta port is mainly used by fishing boats. Hangarkatta Port is located on the bank of Sita and Swarna rivers. Prominent spits namely Kodi Bengre and kodithale are located at the southern side and at the northern side of the river mouth respectively. The growth of these spits is responsible for narrowing the river mouth. Mud flats are observed in the middle region of the estuary. Shallow sand bars are observed at the inlet. Overall accretion is dominant in this region. The sediments removed from the foreshore are caught in the circulation cells and are re-circulated locally, which provide stability to the beaches during the season.

The area shows (Figure 10) the rate of erosion is -1.2343m/y and rate of accretion is +1.5300m/y during the period of 1973 to 2014. During this period, the shore line retreats by -50.3829m and prograded is +62.5900m. The estimate and pattern of erosion and accretion are shown in Figure 10. The area covers geomorphic classes like as andy beach, spit etc. Accretion is observed on the left bank of the river and on the other bank of river, erosion is noticed. Erosion and accretion pattern is unpredictable for this region**.**

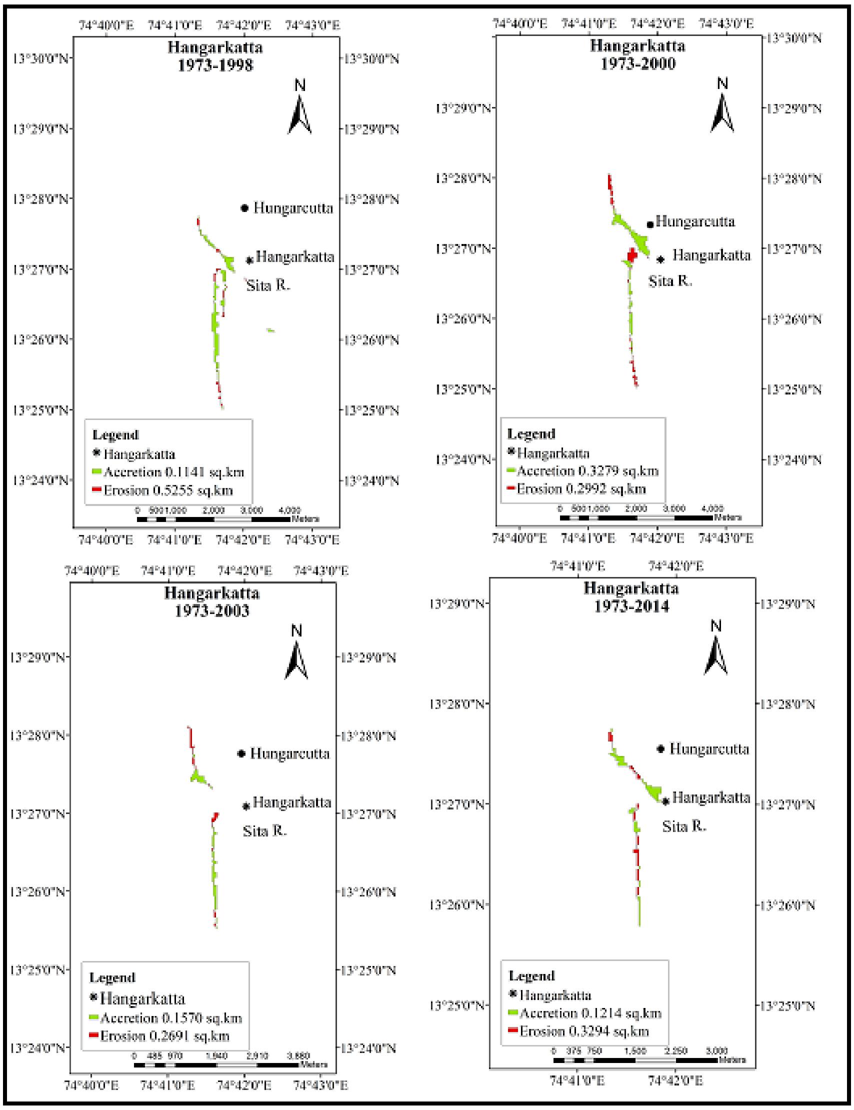

Figure 10: *Erosion and Accretion near Hangarkatta*

3.9. Malpe Port

Malpe fishing harbor is situated near the town of Udupi. Shoreline covers 14.383 Km and it lies at the confluence of Udyavara river and the Arabian Sea. The port mostly handles fishing activities and sometimes cargo also. Malpe is the largest fishing harbor in Karnataka. The shoreline retreats -95.4862m and forwarded +43.9900m during the period 1973-2014.

The estimate and pattern of erosion and accretion are shown in Figure 11. The port is protected from southerly drift by constructing breakwater on the northern bank of River Udyayara. Whereas, long narrow stabilized Udapi beach protects the harbour from northerly shore drift. The northerly drift prevailing during the post-monsoon season favors Udapispit growth across the river mouth from south to north.

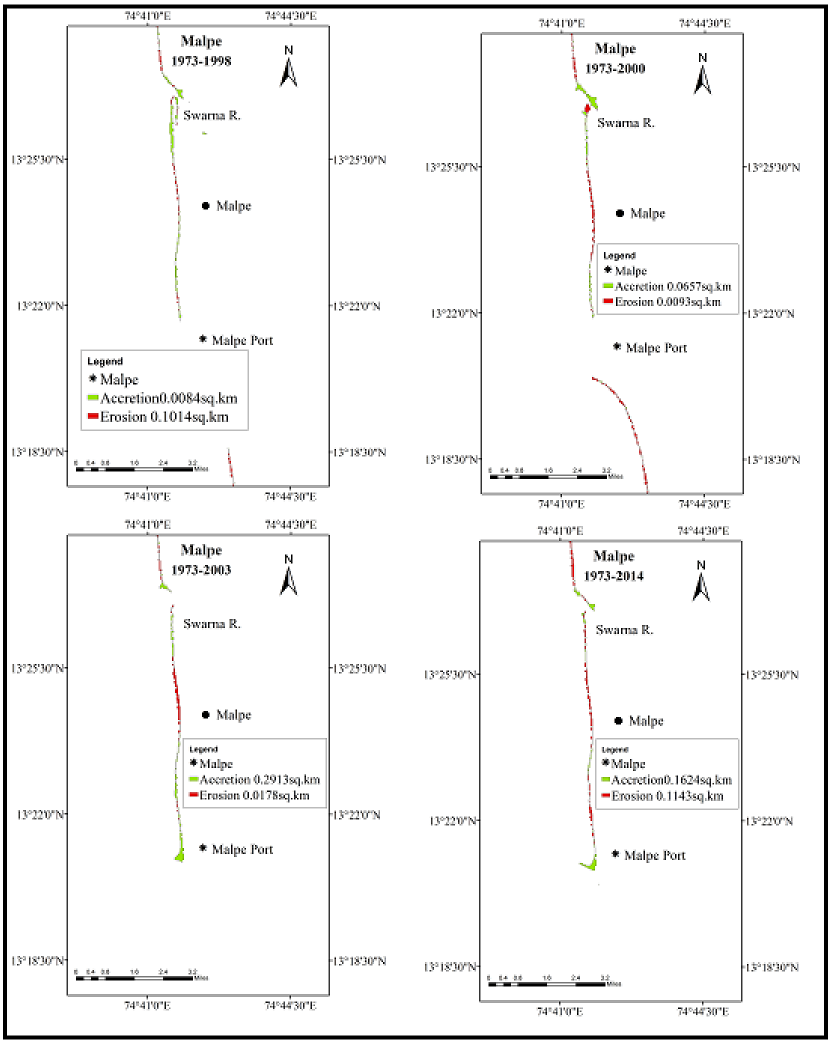

Figure 11: *Erosion and Accretion near Malpe*

3.10. New Mangalore Port

Mangalore is located at 12.87°N - 74.88°E in the Dakshina Kannada district of Karnataka. Panambur is the site of seaport called New Mangalore Port. It is located to the north of the Gurupura river confluence with the Arabian Sea. There is a beautiful beach on the shore of the Arabian Sea at Tanniru Bhavi to the south of sea port at Panambur (Figure 12). Gurpur River is to the south of Panambur. Panambur has an average elevation of 22 meters (72 feet) above mean sea level. It is the administrative headquarters of the Dakshina Kannada district, the largest urban coastal center of Karnataka. The government operates the deep-water, all-weather port at Panambur, Mangalore in Karnataka state. It is the only major port of Karnataka and is currently the ninth largest port in India.

The major commodities exported through the Port are Iron Ore Concentrates & Pellets, Iron Ore Fines, POL Products, granite stones, containerized cargo, etc. The major imports of the Port are Crude and POL products, LPG, wood pulp, timber logs, finished fertilizers, liquid ammonia, phosphoric acid, other liquid chemicals, containerized cargo, etc. Geomorphologically, the area covers classes such as rocky cliffs, alluvial plain, sand beaches, lagoon and sand spits.

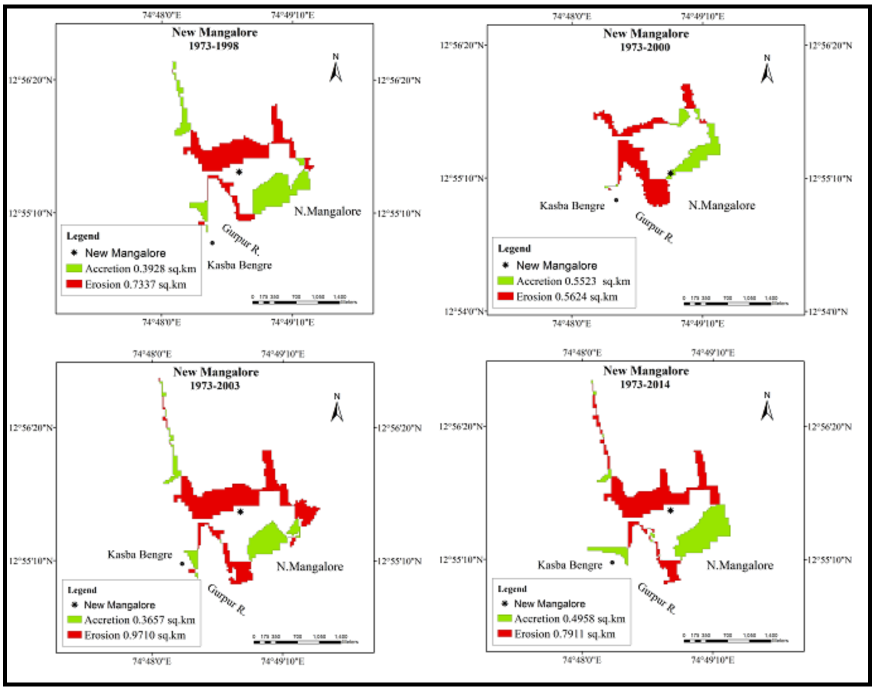

Figure 12: *Erosion and Accretion Adjacent to New Mangalore Port*

3.11. Old Mangalore Port

The Old Mangalore Port is located to the south of New Mangalore Port. It is popularly known by the name of Bunder. The port was used to ferry goods and passengers to Lakshadweep Island and Middle East countries. Now fishing has become main activity of this harbor. Old Mangalore port has the rate of accretion is +1.2900m/yr and rate of erosion is not recordable during the period of 1973 to 2014. Net accretion during this period is +52.6550m. The study area covers geomorphological classes such as rocky cliffs, alluvial plain, sand beaches, sand spits and manmade feat. In Netravati estuary contributed a major amount of sediments for the growth of spits.

The net shoreline movement during 1973 to 2014 adjacent to Ports/harbors of Karnataka state is mentioned in Table 2. Ports like Karwar, Belekeri, Manjaguni, Kundapur and Hangarkatta show prograding shoreline movement whereas, Tadri, Honnavar, Bhatkal, Malpe and New Mangalore show receding shoreline movement.

4. Discussion

During the study, it was observed that the Karnataka coast is subjected to three types of erosion; erosion along open beaches, along river/estuaries mouth, and the tidal reaches of rivers, causing loss of land, vegetation and revenue. Around 60 Km of the beach is confronted with appreciable or severe erosion. Erosion is more severe in Dakshina Kannada and Udapi coasts, where about 28 % of the total stretch is critical. In Uttar Kannada region, just 8% of this is subjected to severe erosion. The erosion becomes severe due to synchronization of high flood in the rivers and strong wave activity during the southwest monsoon. Erosion/bank collapse in the tidal reaches of the river is also severe and extends at least to about 12 Km. The maritime port requires transportation corridors for conveyors and road and rail access, a container terminal, staging yards, dry bulk stockpiles, a bulk liquid tank farm, and port administration buildings to manage which causes lot of landform changes at the particular site.

Subsequently, anthropogenic pressure increases which triggers the coastal erosion. Major development has been observed along the harbor/port region of the coast line channel and the port basin which is also a cause of erosion.

Above cumulative erosion makes huge sediments available for alongshore sediment transport process to distribute sediments along the shore line. Along Karnataka coast, it was observed that all ports are located at or near the river mouth. Now the ports are invariably made up of structures like breakwater wall, groins etc. These port structures act as a barrier against along shore transport (Kunte, 1994). These man-made structures accumulate sediments on the updrift side and the down drift side experiences sediment starvation and subsequent erosion (Taggart & Schwartz, 1988). The entire Karnataka coast is exposed to an onslaught of the southwest monsoon and so the coast has to face high wave conditions during the period which develops strong southwards littoral currents. These littoral currents, with the easy availability of sediments, distribute sediments along the shoreline. The ports obstruct sediment flow and get sediment enriched on updrift side whereas down drift side gets eroded during the monsoon period. The seasonally reversing wind pattern influences northward drift during northeastern monsoon which gradually redistributes the sediments and regain sediments at eroded sites.

Karnataka ports like Belekeri, Manjaguni, Tadri, Honnawar, Kundapur, Hangarkatta, Malpe and old Mangalore ports are all situated in the estuary, well inside the coastline. These ports are well protected due headlands or large spits exits at the mouth of the estuary. Alongshore currents have little or no impact on these ports, however, for coastal erosion, accretion and estuary mouth closer, alongshore currents are accountable. Siltation of river-transported sand is a major worry for port maintenance. Karwar port is within headland and safe and protected. New Mangalore port is facing Open Ocean but for protecting port two large breakers are constructed. These breakers are responsible for shoreline change.

Unplanned development surrounding port areas and industrial locations leads to objectionable and use practices. Expanding infrastructure facilities, surrounding the port area, lead to the transformation of a large tract of agricultural land to built-up areas. These are more pronounced in areas adjacent to industrial centers, fish landing centers and big projects like Seabird at Karwar. Conversion and reclamation of wetlands have caused coastal biodiversity loss.

The increased use of trawl nets accentuates deprivation of non-target groups along with juveniles and sub-adults of needed fishes and another benthic organism. Most of the bycatches are of low economic value but are vital for the food web. The discarded by-catches are thrown overboard which adds to pollution. The haphazard dumping of fish wastes near fish landing centers, processing of fish catch and a large number of ice factories cause water pollution. Improper solid waste disposal and inadequate treatment of sewage contribute to the water pollution. The marine pollution, though low at present, may lead to bioaccumulation of toxic chemicals in the long run. Selective scooping by trawl nets has exerted tremendous pressure on benthic organisms and their survival, as these are thrown overboard and are discarded dead which adds to pollution. Increased pumping of water required by port and other affiliated industries, in the coastal sandy areas, lead to landward movement of saline water-freshwater interface and upcoming of saline water in dug wells.

Eighty-eightpercent of rainfall received during four months of the rainy season leads to dis-appropriate run off. Reduced flow in rivers during non-rainy periods hinders proper flushing. Excessive siltation consequently raises the riverbed. Tidal inlets and river mouths are often, by nature, becomes shallow and are sometimes blocked due to excessive sediments, which make them unsuitable for navigation. In order to improve navigational conditions and, flushing sediments, many tidal inlets, and river inlets have regulated mouths. The regulation may consist of maintenance dredging programs. In this region, near Belekeri, Tadri, Majaguni and Honnavar ports, this is common practices. The siltation is also high at New Mangalore Port, where the annual maintenance dredging varied from 1.67 million cubic meters to 4.28 million cubic meters during the last ten years.

The dredging leads to habitat disruption due to the removal of bottom sediments and/or accumulation of sediments. The water quality change subsequently leads to habitat inhibitions. As a result of dredging, re-suspension of bottom sediments, accumulation of/dispersion of toxic substances, oxygen depletion, reduced primary production, temperature alteration, increased nutrient level and bed load movement take place. This will alter the benthic community system.

Though sediment transport activity along Karnataka coast is very high, the presence of bi-direction littoral drift maintains natural equilibrium to the utmost extent. The results of the Coastal Vulnerability index study of Karnataka shoreline indicate this equilibrium. The CVI results reveal that, except a spot in Uttara Kannada, Karnataka coast has no Very High Vulnerability shore; the large extent of the coastline, 57% is classified as Low Vulnerability; medium and high vulnerable classes recorded 31.76% and 9.54% respectively (INCOIS 2007). CVI study carried out at Mangalore coast from Talapay to Surathkal indicate that Ullal coast is highly vulnerable, followed by Tannirbavi and most other segments are less vulnerable (Hegde and Reju, 2007). Udupi coast CVI study, also show that out of 95 km stretch of coastline, 59% Very high vulnerable, 7% high, 4% moderate, and 30% low vulnerable (Dwarakish et al., 2009).

5. Conclusions

Shorelines extracted for the years 1973, 1998, 2000, 2003 and 2014 and processed using DSAS software indicates that the coastline near port area experienced both the erosion and accretion. Shoreline change rate of Karnataka coastline is estimated as -1.2354m/year even though sediment transport along the Karnataka is dynamic. Dynamic equilibrium of erosion and accretion are observed along the coast during the study. Erosion is observed during monsoon season and accretion is observed during the non-monsoon season. Long shore currents and river sediment transport are mainly responsible for shoreline changes. Karwar, Belekeri, and new Mangalore ports are Open Ocean facing, the ports are well protected either by headlands or breakwaters and hence are safe. Other all ports/harbors are located well within estuary mouth are protected from alongshore transport by headlands or largely stabilized spits. Riverine erosion and sediment transport is a major threat for sediment siltation surrounding ports/harbors. Erosion and accretion of shoreline are major impact of port/harbor. However, minor impacts are like an increase in pollution due to waste dumping and port-related industries, increase in coastal population and related activities and degradation of surrounding environment due to dredging and dumping material. Most of the shoreline sites, though largely get affected due to port structures, during monsoon season, achieve natural partial equilibrium during the non-monsoon season due to reversing currents and wind pattern. And hence, it may be concluded that port/harbor has some impact on the coastal shoreline.

Port structures play an important role in erosion and accretion. This study estimates the amount of erosion and accretion in the neighborhood of Karnataka ports and also provides spatial visualization at one glance; this study will be useful for future development and management of these ports and similar ports elsewhere in the world.

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