Automatic Demarcation of Coastal line using RS and GIS Techniques along the Gulf of Khambhat Region

Pratima Shah [1], Dr. Gargi Rajpara[2]

[1]*Research Scholar, KSV University, India*
[2]*Principal, LDRP Institute of Technology and Research*
* Corresponding author's

Abstract: The study highlights the coastline extraction methodology using remote sensing images for the years 1991, 2001, 2011 and 2021. Extraction has been carried out for the post monsoon season, to understand deeply about the coastline changes due to environmental factors. Optical sensors of Landsat satellite imagery have been utilized to extract coastline using pixel dynamics. OTSU algorithm and NDWI (Normalized difference vegetation index) is used to mark the water boundaries and landforms, which can be further used for coastline extraction.

Keywords: Coastline extraction, LANDSAT, NDWI, OTSU and coastline delineation

1 Introduction

Coastal zone is one of the most complex ecosystems that has a large number of non-living and living resources [1]. Physical processes such as land erosion and delineation, tidal flooding, sea level rise, land subsidence are the natural processes which impacts the nearby environment at the higher impact. According to [2], over 70% of the worlds coastal are experiencing coastal erosion and this presents a serious hazard to many coastal regions. Various development along the coastal line or nearby areas increases its vulnerability to various natural consequences. Hence the study of shoreline changes at regular intervals becomes very important to assess the impact of it on surrounding areas. Presently, the application of Geographic Information System (GIS) and remote sensing is used extensively in every field. GIS integrates storing, manipulating, and displaying of spatial data with reference to the real-world scenarios whereas, remote sensing is the field of studying almost all the elements of world and space too through the use of satellite imagery. Combining the applications of both can be utilized as a powerful tool to study and analyse larger area accurately that too by using less resources. Using updated technology of GIS and remote sensing, several techniques have been introduced to extract shoreline and detect shoreline changes from satellite imagery [3], [4].

This study will carry out the methodology to obtain the shoreline extraction using Landsat 4-5, 7 and 8 images. Shoreline extraction has been carried out for the year 1991, 2001, 2011, and 2021. Extraction for the post monsoon season has been carried out to analyze the seasonal effect on coastal areas during the year.

Gulf of Khambhat is the bay on Arabian sea situated on the western coast of India. Many rivers form estuaries in Gulf of Khambhat out of which the major rivers are Mahi, Tapi, Sabarmati, and Narmada. Over the past years, many drastic changes have been observed in this region.

2 Literature Review

Automatic Coastline Extraction and Changes Analysis Using Remote Sensing and GIS Technology (Muhammad Yasir et al.,2020) [7] This study highlights the coastline position changes of Qingdao coastal area from 2000 to 2019, using GIS and remote sensing technologies through Digital Shoreline Analysis System and LANDSAT images. Understanding the coastline movement by suitable method is an important challenge for this extremely dynamic coast. The shoreline changes were statistically measured using three techniques, namely; Linear Regression Rate, End Point Rate and Net Shoreline Movement. For the automatic coastline extraction, different methods were applied, but among them most suitable techniques are the canny edge algorithm technique, which gives the accurate result. The result show maximum accretion reached was 266.07m/yr, 2391.85m,124.47m/yr for End point rate, net shoreline movement and linear regression rate, respectively. While, the maximum erosion was -142.55m/yr, -1234.59m, -63.22m/yr for End point rate, net shoreline movement and linear regression rate, respectively. This paper hence presents the monitoring processes of coast and analyzing the coastline change by the use of geospatial techniques that would be helpful for the coastal planning and management of the Qingdao coast. The applicability of the proposed model is tested with other generic edge detection algorithms that include; Sobel, Prewitt, and Robert edge detection techniques and it was concluded that our model outperforming in accurately detecting the coastline. [7]

Analysis of Coastline Extraction from Landsat-8 OLI Imagery (Yaolin Liu et al ,2017) [8] As coastline extraction is a fundamental work for coastal resource management, coastal environmental protection and coastal sustainable development. Due to the free access and long-term record, Landsat series images have the potential to be used for coastline extraction. However, dynamic features of different types of coastlines (e.g., rocky, sandy, artificial), caused by sea level fluctuation from tidal, storm and reclamation, make it difficult to be accurately extracted with coarse spatial resolution, e.g., 30 m, of Landsat images. To access this problem, in presented paper, they had found out coastline extraction by integrating downscaling, pan sharpening and water index approaches in increasing the accuracy of coastline extraction from the latest Landsat-8 Operational Land Imager (OLI) imagery. In order to prove the availability of the proposed method, three strategies were designed: (1) Strategy 1 uses the traditional water index method to extract coastline directly from original 30 m Landsat-8 OLI multispectral (MS) image; (2) Strategy 2 extracts coastlines from 15 m fused MS images generated by integrating 15 m panchromatic (PAN) band and 30 m MS image with ten pan sharpening algorithms;(3) Strategy 3 first downscales the PAN band to a finer spatial resolution (e.g., 7.5 m) band, and then extracts coastlines from pansharpened MS images generated by integrating downscaled spatial resolution PAN band and 30 m MS image with ten pan sharpening algorithms. Using the coastline extracted from ZiYuan-3 (ZY-3) 5.8 m MS image as reference, accuracies of coastlines extracted from MS images in three strategies were validated visually and quantitatively. The results show that, compared with coastline extracted directly from 30 m Landsat-8 MS image (strategy 1), strategy 3 achieves the best accuracies with optimal mean net shoreline movement (MNSM) of 2.54 m and optimal mean absolute difference (MAD) of 11.26 m, followed by coastlines extracted in strategy 2 with optimal MNSM of 4.23 m and optimal MAD of 13.54 m. Further comparisons with single-band thresholding (Band 6), AWEI, and ISODATA also confirmed the superiority of strategy 3. For the various used pan sharpening algorithms, five multiresolution analysis MRA-based pan sharpening algorithms are more efficient than the component substitution CS-based pan sharpening algorithms for coastline extraction from Landsat-8 OLI imagery. Among the five MRA-based fusion methods, the coastlines extracted from the fused images generated by Infusion, additive à torus wavelet transform (ATWT) and additive wavelet luminance proportional (AWLP) produced the most accurate and visually realistic representation. Therefore, pan sharpening approaches can improve the accuracy of coastline extraction from Landsat-8 OLI imagery, and downscaling the PAN band to finer spatial resolution is able to further improve the coastline extraction accuracy, especially in crenulated coasts.[8]

Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans (Jackson T.J., et al,2004) [9]In the present paper, the potential of using satellite spectral reflectance measurements to map and monitor VWC for corn and soybean canopies was evaluated as a part of the Soil Moisture Experiments 2002 (SMEX02), Landsat Thematic Mapper and Enhanced Thematic Mapper Plus data and ground-based VWC measurements were used to establish relationships based on remotely sensed indices. The two indices studied were the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). The NDVI saturated during the study period while the NDWI continued to reflect changes in VWC. NDWI was found to be superior based upon a quantitative analysis of bias and standard error. The method developed was used to map daily VWC for the watershed over the 1-month experiment period. It was also extended to a larger regional domain.

3 Materials and Methods

Gulf of Khambhat is located between latitude 20° 30' 30" N and longitude 72° 53' 30" E. (Fig. 1). At its northern end between the Sabarmati and Mahi mouths, the Gulf is barely 5 km wide and opens out southwards like a funnel, reaching its maximum width south at Gopnath point. The gulf is intercepted by several inlets of sea and creeks formed by confluence of major rivers such as Narmada, Mahi, Sabarmati, Shetrunji and many major rivers. All the major river form estuaries and their inflow carry heavy load of sediments into the gulf.

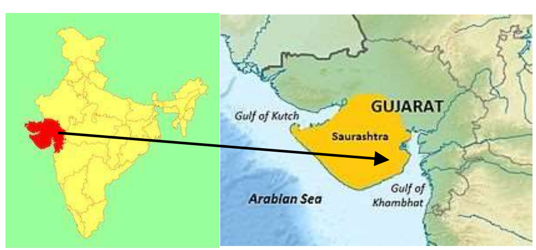

Fig. 1 Map of Saurashtra and Gulf of Khambat

For the purpose of this study, toposheets from Survey of India (SOI) are downloaded from the official website and georeferenced to map the extent of the region of interest. In total, 16 toposheets are digitized to form the base map for the study as shown in Fig. 2. The reference number of toposheets are as per Fig: 3.

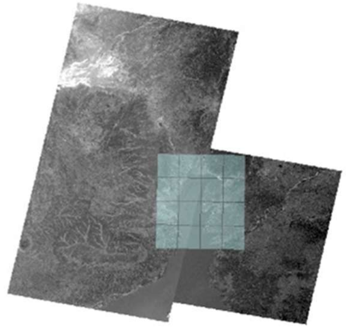

Fig. 2 Georeferenced Toposheets

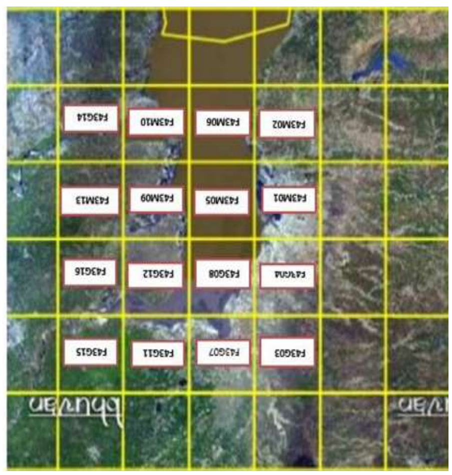

Fig. 3 Georeferenced Toposheets Number (**Source:** www.soinakshe.uk.gov.in)

A. Data Processing

Landsat Images are downloaded from the United States Geological Survey website from the year 1991 to 2021 for every 5 years period for the post monsoon season. Details about the time and sensor are given in the Table 2.

Table 2 Data Acquisition Information

Year	**Satellite Sensor**	**Date of Acquisition**	**Spatial Resolution**
1991 (Post-monsoon)	Landsat 4-5 TM	18^{th} Feb 1992	30 m
2001 (Post-monsoon)	Landsat 7 ETM+	10^{th} November 2001	30 m
2011 (Post-monsoon)	Landsat 7 ETM+	15^{th} November 2011	30 m
2021 (Post=monsoon)	Landsat 8 OLI	25^{th} November 2021	30 m

B. Methodology

In this research work, the pre-processing steps are applied for automatic extraction of coastline by using ERDAS IMAGINE and ArcGIS 10.6 software. The overall methodology to achieve the objectives are shown in Fig: 4

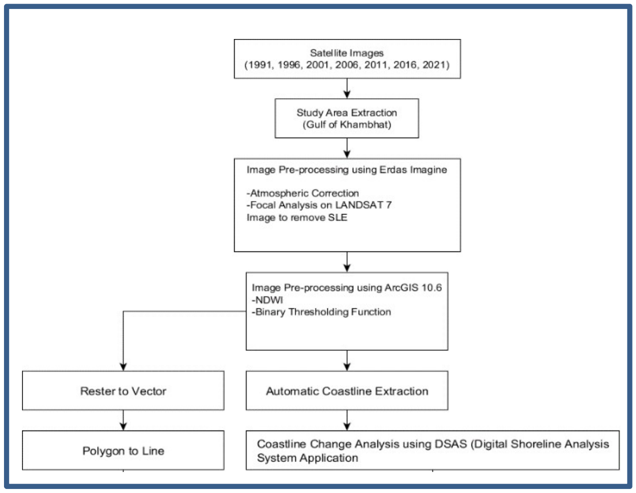

Fig: 4 Work Flow Chart of Overall Methodology Adopted for Coastline Delineation

Most of the pre-processing tasks are carried out in ERDAS IMAGINE which includes atmospheric and geometric corrections. After the preliminary corrections, all the images are clipped to the study extent as shown in Fig. 2. Landsat 7 ETM+ sensor images had different approach as the images contained slack lines which were then removed using Focal Analysis.

Every year image's bands were then stacked together for the false colour composite (FCC) to visualize the landforms and pattern of the study area. Fig. 5 shows the FCC image for the study region.

In order to segregate the water pixels from the imagery, normalised difference water index (NDWI) is calculated for all the imagery. After the NDWI calculation, OTSU algorithm is applied to extract the coastline which is then converted to vector format shapefile.

Fig. 5 FCC Image of Gulf of Khambhat

C. Normalised Difference Vegetation Index (NDWI) Calculation

The normalised difference vegetation index (NDWI) is a satellite derived index calculated based on Near-Infrared (NIR) and Short-Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content [5]. The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content [6]. Its usefulness for drought monitoring and early warning has been demonstrated in different studies. The band numbers for all the three sensors are different. Refer to the fig. 6 for index calculations.

$$NDWI_t = \frac{NIR_t - SWIR_t}{NIR_t + SWIR_t}$$

Fig. 6 NDWI Index Calculation Formulae

NIR band for Landsat 4-5 and 7 is band 4 while for Landsat 8 is band 5. SWIR band for Landsat 4-5 and 7 is band 5 while for Landsat 8 is band 6. Fig. 7 shows the NDWI result for the year 2021 post monsoon season.

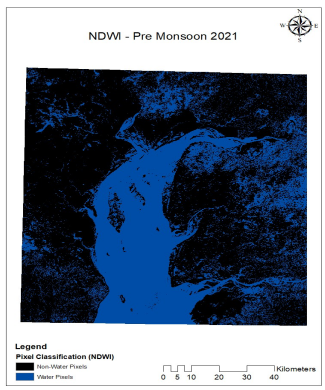

Fig. 7 NDWI - Monsoon 2021

The value of NDWI ranges from -1 to +1. The water pixels range from 0.1 to 1 while other pixels are ranged from -1 to 0. Only water and non-water pixels are required to demarcate the line of separation as a coastline and after that binary image classification algorithm i.e., OTSU algorithm is applied.

D. OTSU Algorithm

OTUS's system is a means of automatically chancing an optimal threshold grounded on the observed distribution of pixel values. The algorithm assumes that the histogram of the image is bimodal (i.e., two classes). In the simplest form, the algorithm returns a single intensity threshold that separates pixels into two classes, focus, and background. This threshold is determined by minimizing intra-class intensity friction, or equally, by maximizing inter-class friction.OTSU algorithm can be applied using ArcMap's binary thresholding function. This tool returns the imagery having two, pixel values which is 0 and 1. In this case, 1 corresponds to the water areas while 0 is the left-out area. The BTF image is then converted into integer form and then it is converted into vector format using raster to polygon tool in ArcMap. The polygon is converted into polyline feature resulting into the shoreline shown in to Figure 8.

Fig. 8 OTSU Applied Imagery - Monsoon 2021

4 Results and Discussion

After the NDWI generation of all the images and applying OTSU algorithm, the obtained water pixels are converted into the polygon and then polyline conversion is applied to extract the coastline. The generated coastlines are assessed manually by overlaying them on the toposheet base map to check its accuracy. Some manual corrections are carried out to by editing the polyline feature.

All the shorelines generated and processed are combined into the single feature class and their lengths in meter are calculated by applying attribute query function of length. Fig.9 indicates the variation of shorelines over the past 30 years.

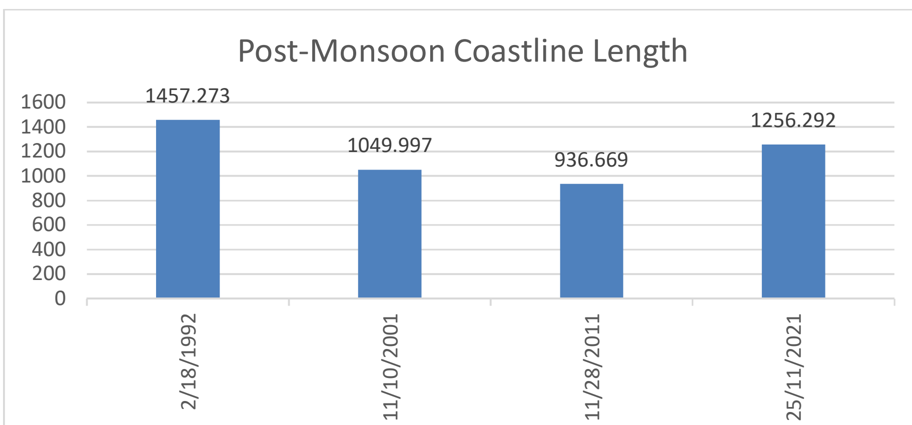

Fig. 9 Coastline length (km) variation

From the Fig. 10, the shorelines extracted for the post-monsoon season for the year between 1996 to 2021. At the two instances, i.e., for the year 1992 and 2021, post-monsoon extracted shoreline has more length. The maximum shoreline length during past 30 years is during the year 1991, post monsoon. Detailed research can be carried out to assess such patterns in coastline lengths. Fig. 10 shows the timeseries maps of coastlines extracted overlayed with the base satellite imagery for post monsoon season. Through the above given timeframe, major coastline variation is observed at the Sabarmati estuary. For the rest of the areas, there has not been any major change on a larger scale.

Year 1991 Year 2001 Year 2011 Year 2021

Fig. 10 Extracted Shoreline for Post-monsoon season

As it can be inferred from Fig.11, there is drastic change in shoreline pattern for the Sabarmati estuary region over the past 30 years. In 1991, the total shoreline for the area of interest considered in this research was 1187.93 kms. In the year 2016 and 2021 it was 866.99 kms and 1150.407 kms respectively during post monsoon season. Highest coastline length i.e., 1457.273 kms is observed during the year 1991 in post monsoon season. While the lowest in the year 2006 in post monsoon season which was 832.606 kms.

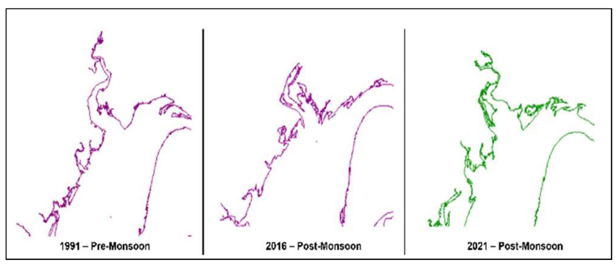

Fig.11 Shoreline Pattern change over the past 30 years – Sabarmati Estuary

5 Conclusion

With the application of GIS and Remote sensing, coastline monitoring and assessment can be achieved on a larger scale with using minimal resources. The model derived in this study shows the ability to extract shoreline using open-source imagery with average results. Long term analysis is carried out from the year 1991 to 2021 to investigate the changes for post monsoon season. Such analysis becomes very handful while planning any development or expansion nearby the coastal areas. Along with it, it becomes very important factor while planning for disaster management strategies and carrying out rescue operations in case of floods.

6 Future scope

The study can be expanded further to look for more detailed hydrological factors affecting the coastal processes. For more scaled in analysis, high resolution satellite images can be used to detect the changes in meters. After extracting coastline for such timeframes in series, it can be modelled to predict the future coastline structures in upcoming years. Land cover classification can be carried out to know in depth about the environmental changes affecting shoreline. Calculation of Sediment concentration at the river mouth can be studied to know more about the accretion and erosion processes along the shoreline.

Acknowledgements

The authors are grateful to Dr. M. B. Dholakia, Former Principal, Govt. Engg. College, Gujarat; Dr. M B Joshi, Former General Manager, SSNNL, Gadhinagar; Dr. R. Ratheesh, SAC ISRO, Ahmedabad for their valuable advice and support during the research work. We are also very thankful to B B Talavia,,CE, GMB and Dr. Manan Shukla, Manager, Env. Cell, GMB, Gandhinagar for their great guidance and support to acquire data.

Conflicts of Interest

"The authors declare no conflict of interest."

Author Contributions

This study was designed, directed and coordinated by the both authors. Dr. Gargi Rajpara provided technical guidance for all aspects of the project. Pratima Shah planned for collect data and performed the analysis for whole project. The manuscript was written by Pratima Shah and Dr. Gargi Rajpara.

References

[1]	R. Costanza, R. Arge, R. D. Groot, S. Farber, M. Grasso, B. Hannon and P. Sutton, "The value of the world's ecosystem services and natural capital," *Nature,* p. 253, 1997.
[2]	K. Addo and K. and Kufogbe, "Quantitative analysis of shoreline change using medium resolution satellite imagery in Keta," *Ghana Marine Scioence,* p. 1, 2011.
[3]	L. Chen and J. and Rau, "Detection of shoreline changes for tideland areas using multitemporal satellite images," *Inter. J. Remote Sensing,* p. 19, 1998.
[4]	M. Lipakis and N. and Chrysoulakis, " Shoreline extraction using satellite imagery," *BEACHMEDe/OpTIMAL,* p. 81, 2005.
[5]	P. Ceccato, S. Flasse and J. and Gregoire, "Designing a spectral index to estimate vegetation water content from remote sensing data," *Remote Sensing of Environment,* pp. 198-207, 2002.
[6]	C. Tucker, "Remote sensing of leaf water content in the near infrared," *Remote Sensing of Environment,* vol. 10, pp. 23-32, 1980.
[7}	Abdoul Niong, Muhammad Yasir, Hong Fan, Sulaiman Khan. Automatic Coastline Extraction and Change Analysis using Remote Sensing and GIS Technology
[8]	Yaolin Liu, Xia Wang -Analysis of Coastline Extraction from Landsat-8 OLI Imagery.
[9]	Jackson, T.J., Chen, D., Cosh, M., Li, F., Anderson, M., Walthall, C., Doriaswamy, P., and Hunt, E.R. 2004. Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans. Remote Sensing of Environment 92: 475−482.

Web Links:

- http://www.hydrobharat.nic.in
- http://kalpasar.gujarat.gov.in
- http://cwc.gov.in
- http://www.nio.org
- www.eathexplorer.gov.us
- https://bhuvan.nrsc.gov.in/
- www.soinakshe.uk.gov.in