Article

Predicting the shoreline changes in Vishakhapatnam coastal zone using Multi-output Adaptive Neuro Fuzzy Inference System

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Abstract
Coastal erosion is a persistent problem occurring along the Shoreline of India. Several factors that influence the severity of erosion are community infrastructures along the coast, natural disasters, and several man-made activities. There is an increased demand for computing precise information regarding past and present trends and rates of changes in the shoreline. This research investigates the shoreline changes of the Vishakhapatnam district in Andhra Pradesh Coast, as well as finds the quantity of the erosion and accretion rate. Vishakhapatnam having a coastal length of 135 km used for the study, length of study area categorized by fours zones based on the district boundary Zone 1 - Bheemunipatnam, Zone 2 - Vishakhapatnam, Zone 3 - Anakapalli, and Zone 4 - Yellamanchili. The changes in Shoreline were computed with the help of multi-temporal satellite images (Landsat 7 and Landsat 4 & 5) for the past 45 years' period, i.e., from 1974 to 2020 using Digital Shoreline Analysis System (DSAS). The rate of shoreline change was accessed using Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR), and Linear Regression Rate (LRR). Based on the findings the coastal maps are prepared to estimate the geological changes and shifting of shoreline position. This detailed study is found useful for exploring erosion and accretion processes in the region. About 135 km of coastline was found to be accreting in nature with an average rate of +1.13 m/yr followed by erosion of the shoreline - 0.15 m/yr. The highest and lowest SCE of about 63.4 m/yr and 75.25 m/yr were recorded in Vishakhapatnam Coast. In addition, the Multi-output Adaptive Neuro Fuzzy Inference System (MANFIS) technique is used to predict EPR, NSM, SCE, and LRR for monitoring the shoreline changes, and it could be used for further planning and development and also for disaster management authority in the decision-making process in the study area.

Keywords erosion and accretion; End Point Rate; Linear Regression Rate; Net Shoreline Movement, Shoreline Change Envelope; MANFIS.

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1 Introduction

Worldwide, Coastal zone are mostly exposed to natural hazards due to human activities that arise near the shore areas which undergoes rapid degradation of urbanization and industrialization. The coastal areas are considered to be a disaster-prone zone which is vulnerable to regular and irregular hazards they include flooding, cyclones, earthquakes, tsunamis, sea level rise and coastal erosion. All these activities have high impact on static of the coast. One of the major threats to the coast is erosion, which occurs throughout the coastal zone of all parts of the world. Sand deposited on the beach is not static, as the waves constantly erodes and deposits the sand towards the landward side of the shoreline. This process is usually caused by the forces of waves and currents. While constructing an artificial structure near coastal area like jetties, breakwater, building of dams, dredged channels, ports and harbors are the major influences for the causes of Coastal erosion.

India has a coastline of 7516 km and southern coastal state of Andhra Pradesh has a coastline of around 972 km length. Immense value for commercial, recreational, and aesthetic purposes resources are found naturally in long coastline of Visakhapatnam. Following are the 9 districts which falls under coastal region of Andhra Pradesh: Srikakulam, Vizianagaram, Vishakhapatnam, East Godavari, West Godavari, Machilipatnam (Masula Beach), Guntur, Prakasam and Nellore. Totally there are 22 beaches located in Andhra Pradesh in which 7 beaches are located in Visakhapatnam, namely: Rushikonda Beach, Yarada Beach, Ram Krishna Beach, Bheemili Beach, Gangavaram Beach, Lawson's Bay Beach and Sagar Nagar Beach. The shoreline of Andhra Pradesh has been subjected to severe coastal erosion in recent times. During Monsoons, the heights of the tidal waves are about 4m that the shoreline is vulnerable to dynamic changes.

Shoreline changes of Nellore region in Andhra Pradesh coast, just as discover the amount of the disintegration and gradual addition rate of erosion and accretion utilizing multi- temporal satellite information (TM and LISS III, IV) and Geographic information system (GIS) for recent years 25 years, i.e., from 1989 to 2015.The examination tracked down that 87.6 km of coastline was discovered to accumulate nature with normal of +1.40 m/yr followed by 38.4 km of beach front line dissolving with normal of - 1.36 m/yr and stable coastline of 41.4 km. The shoreline changes along Andhra Pradesh coast for last 22 years (1990- 2012) with the aid of Multi-resolution satellite data, in stretch of 974 km long Andhra coast was divided into 89 segments identical to Survey of India. The analysis revealed that 275 km long shoreline was under erosion, 417 km has shown accretion and 153 km coastline is under stable condition (Kannan et al., 2016). The shorelines changes along the south-west coast of Kanyakumari with multi-temporal Landsat TM, ETM Images from 1999 to 2011 using GIS-based Digital Shoreline Analysis System (Kankaraa et al., 2015).

Severe erosion measured to be along Kanyakumari, Kovalam, Manavalakurichi and Thengapattinam coasts are 300.63, 69.92, 54.12 and 66.11 m. Few Coastal zones like Rajakkamangalam, Ganapathipuram, Muttam and Colachel have experienced sediment deposits due to current movement during the north-east monsoon and shoreline change analysis was assessed using Linear Regression (LRR) and End Point Rate (EPR) from 1989-2015 with different sources of remote sensing data (Kaliraj et al., 2014). 74.6 km of coastline was found to be accreting nature with average of +1.08 m/yr followed by 38.4 km of coastal line eroding with average of -1.40 m/yr and stable coastline of 41.4 km. The long-term transformation as well as the patterns of soil loss/sedimentation from 1973 to 2015 were analyzed (Kannan et al., 2016) by Net Shoreline Movement (NSM) and End Point Rate (EPR) statistics. The highest and lowest EPR of about 67.63 m/yr and -43.14 m/yr were recorded in the Andhra coast. The high rate of deposition was recorded in the Godavari delta, whereas Krishna delta experienced low erosion (Sindhu Tyagi and Rai, 2020). The study revealed that high rate of erosion was observed all along the river mouth of northern side of Karnataka River while at the southern side of Kalinadi river faced high accretion during the period of 1989-2006. About 168 km of coastline was found accreting with average rate of 1.5 m/yr followed by 71 km and erosion of about 1.0 m/yr (Chenthamilselvan et al., 2014). The rate of shoreline shift along the 330 km long Krishna-Godavari (K-G) delta coast was estimated using satellite images between 1977 and 2008. It was found that the 42.1 km^2 area was net loss during this 31-year period. It was predicted a net erosion of about 57.6 km^2 along the K-G delta coast by 2050 using digital shoreline analysis system for Kabir-Al Shamali river estuary during the period of 1958-2010 (Akhil Kallepallia et al., 2013). The value of EPR - 2.8 shows the highest eroding on the estuary region and the value of EPR (+1.81) shows the advanced shoreline and the transects are shown in gradients close to the red to indicate sedimentation. The coast of Vishakhapatnam district, Andhra Pradesh was studied with the help of multi-temporal satellite images of 1991, 2001, 2011 and 2018 (Mirna Sebat et al., 2018). Linear Regression Rate (LRR), End Point Rate (EPR) and Weighted Linear Regression (WLR) are used for calculating shoreline change rate. Out of 135 km, high erosion occupied 5.8 km of coast followed by moderate or low erosion 46.2 km. Almost 34.7 km coastal length showed little or no change. Moderate accretion is found along 30.5 km whereas high accretion trend found around 17.8 km (Mirza Razi et al., 2020). The study area of the project is Urmia Lake, the 20th largest, and the second hyper saline lake in the world and it is about area of 5,100 km^2. Based on this investigation, the area of the lake has been decreased approximately 1040 km^2 from August 1998 to August 2001 due to natural and anthropogenic activities. The shoreline evolution occurred along the Elmina, Cape Coast and Moree coast of Ghana, the shoreline data from 1974, 2005 and 2012 (Alesheikh et al., 2006). The analysis of the shoreline changes between 1974 and 2012 found to be eroding at a rate of 1.22 m/yr±0.22 m with an average of 49.13 m of land. It indicated that sandy shoreline sections had significantly higher rates in contrast to rocky and cliff sections where erosion was minimal (Jonah et al., 2016). The study area has been categorized into four groups viz., 1) Beach accretion south of Ennore Port, 2) Beach fill erosion breakwater of Ennore Port, 3) Almost stable coastline at the central part of the study region, and 4) Shifting Pulicat Lake. Evaluated reduction in sediment was from -0.66 x 10^6 m^3/year on the southern side of Ennore port to -0.57 x 10^6 m^3/year on the northern Port. The accreting southern stretch must be controlled with some introduced groynes, since the accreted sediments will close the approach channel of the port and it requires continuous dredging operations (Kasinatha Pandian et al., 2004).

Several factors are involved in the cause of coastal erosion due to natural and anthropogenic activities along the coast. During monsoon season, the sea level rise is higher when compared to winter season. It reveals lowest sea level rise recorded in March and highest in October in an annual cycle. There is about 40 cm difference in sea level between March and October at Vishakhapatnam. The increased volume of seawater during this period is accommodated by eroding the beaches. The main objective of this present study is to carry out a more in-depth assessment of the vulnerability of Visakhapatnam coastal zones to the different impacts of climate change in a more integrated approach. The shoreline changes in spatial and temporal aspect were analyzed within the study area using Multi-output Adaptive Neuro Fuzzy Inference System (MANFIS). Furthermore, the impact of erosion and accretion rate was also evaluated for better understanding of the coastal processes on the coast of Vishakhapatnam. This analysis helps us to develop adaptation strategies as part of national sustainable development plans.

2 Materials and Methods

2.1 Study area

Visakhapatnam is a coastal city with a population of 2.3 million it is a highly populated one in state of Andhra Pradesh. The Coastline extends over a length of 68 km intercepted with several rivers joining the Bay of Bengal as given in Fig. 1. The city is in the middle of the east coast of India and is between Kolkata and Chennai. The Eastern Naval Command has its headquarters at Visakhapatnam. The city has a natural harbor and presently one that handles millions of tons of cargo. In addition, there is also a ship building unit. It starts with Fishing Harbour North, Hotel Novotel, Kaali Temple, YMCA, and Light House. The increase of air pollutants over Vizag city due to the industrial activities, further enhanced due to the development of industrial and urbanization activities, port development and expansion and release of sewage effluents and dredging activities leads to higher residence time of the pollutants. This increased concentration of air pollutants causes acidification of coastal waters of Visakhapatnam, thus impacting biodiversity of these coastal waters. The problem of beach erosion is found to be severe along the coast both at the north of Kakinada Bay and Visakhapatnam. During the period of 1990-2012, erosion was found to be 36.39%. But it has been increased by 10% to a rate of 44.76% in 2006-2012. Based on the computation of shoreline analysis severe erosion was found in Nellore as 108.56 km, East Godavari as 77.58 km and Visakhapatnam 64.1 km.

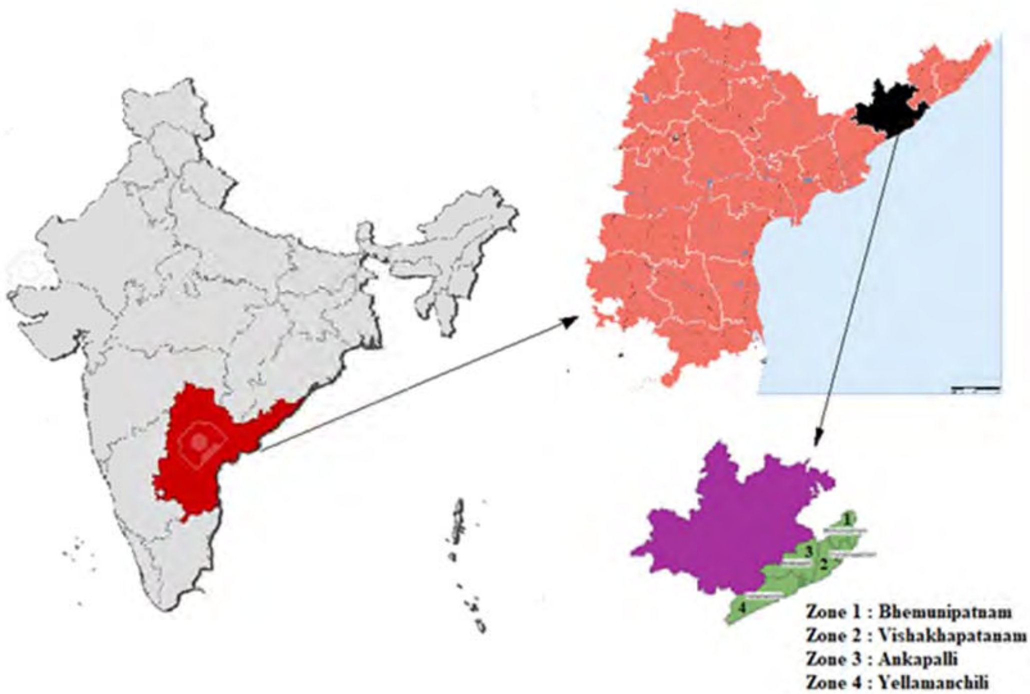

Fig. 1 Study area.

2.2 Data sources

Multi-Spectral (1974-2020) images of Landsat satellite data viz. Landsat MSS (1974, 1992, 2000, 2010 and 2020), has been used to detect shoreline changes. The satellite images are downloaded in UTM Projection with zone 44 and WGS 84 datum, due the selected study area falls under UTM 44 Zone. To study the analysis of changes in shoreline along the coast of Vishakhapatnam, methodology used has been explained in Fig. 2. The shorelines from 1974-2020 extracted through digitization process using satellite images of different time period. The digitized shoreline data is in the form of shape file and given as input to developed MANFIS model to evaluate the shoreline change rate, the process carried out to evaluate the rate of change in shoreline in Fig. 2. The shoreline monitoring has been calculated using DSAS statistics in the form of End Point Rate (EPR), Linear Regression Rate (LRR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE).

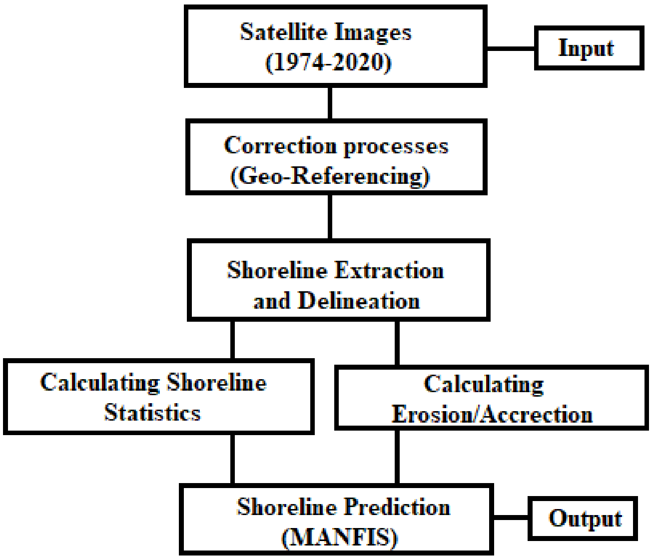

Fig. 2 Methodology for shoreline prediction.

The monitoring of shoreline change of coast of Vishakhapatnam region is studied for the period of 45 years from 1974-2020. The shorelines changes are evaluated based on the extracted shorelines between selected period satellite images. All the Landsat satellite data were downloaded from the USGS website for 1974, 1992, 2000, 2010, and 2020 with the cloud free of 0% to exempt the atmospheric errors. The detailed specifications of multi temporal data are given in Table 1. The various zone and its details used for prediction are listed in Table 2.

Table 1 Multi dataset used in this study.

Sensor	Spatial Resolution (m)	Year	Month	Source
Landsat 1 MSS	60	1974	February	USGS
Landsat 5	30	1992	March	
Landsat 7	30	2000	December	
Landsat 7	30	2010	December	
Landsat 7	30	2020	December	

A brief description of the change statistics used in the study is given below.

2.2.1 Shoreline Change Envelope (SCE)

A measure of the overall change in shoreline (km) at each transect considering the farthest and nearest position of the shoreline for the baseline location irrespective of the dates.

2.2.2 Net Shoreline Movement (NSM)

It is the distance (km) between the oldest and the youngest shorelines.

2.2.3 End Point Rate (EPR)

It is derived by dividing the distance of shoreline change between two time periods by the time interval and expressed as m yr^{-1}. This method provides the net rate of change over the long term. It has both advantages and disadvantages; the advantage is that only two shorelines are required for computation of change rate but unable to use more than two date shoreline data.

2.2.4 Linear Regression Rate (LRR)

It determines a rate-of-change statistic by fitting a least square regression line using all the intersection points all shorelines and individual transect. The slope of the line is the rate of shoreline change. The advantage of linear regression includes:

All the time-series data are used.

Can reduce the impact of spurious values on the overall accuracy of change rate.

To ensure meaningful results from the regression model the temporal intervals of shorelines were kept well distributed over the analysis period.

Table 2 Zone name and its details.

Zone No.	Zone Name	DSAS Transect Numbers	Coastal Length (in km)
1	Bhemunipatnam Taluk	2327-2684	17.45
2	Vishakhapatanam Taluk	1427-2326	45.75
3	Ankapalli Taluk	1284-1426	07.70
4	Yellamanchili Taluk	1-1283	64.10

2.3 MANFIS model development

Among all the Artificial Intelligence (AI) techniques, Adaptive Neuro-Fuzzy Inference System (ANFIS) has been widely used prediction models for various engineering fields. The hybrid ANFIS model is a combination of two soft computing techniques such as Fuzzy Inference System (FIS) and Artificial Neural Network (ANN) into single framework and interpreted with the help of if-then rules. Due to the adaptability, quick convergence, best reliability, and high accuracy, ANFIS model was found to be high caliber in predicting Road Embankment stability (Mamat et al., 2019), evaluation of building design (Elżbieta Szafranko et al., 2022), dissolved metal levels in acid rock drainage (Fattahi et.al., 2018), telecommunication network traffic (Oduro-Gyimah et al., 2018), heat and mass transport in manufacturing industries (Elayarani et al., 2021), etc. This ANFIS model consists of five layers namely the normalized, product, fuzzy, de-fuzzy, and total output layers, respectively (Jang, 1993). The MANFIS model is used to predict the shoreline changes in Vishakhapatnam coastal zone that acquire a similar architecture to a classic ANFIS system, except the fourth layer (Gopi Krishna et al., 2022). The design of the developed MANFIS model for four outputs and one input is shown in Fig. 3, and the MANFIS system logic is stated below:

Layer 1: To generate the Membership Function (MF).

$\mathbb{O}_k^1 = \mathfrak{g}(x)\backslash\mathfrak{g}$:MF of the MANFIS system.

Layer 2: To calculates the "firing strength" of each rule via multiplication.

$$\mathbb{O}_k^2 = \mathbb{w}_k = \prod_{k=1}^{\mathbb{N}} \mathfrak{g}(\mathfrak{s})$$

Layer 3: To normalize the firing strengths of each rule.

$$\mathbb{O}_k^3 = \overline{\mathbb{w}}_k = \frac{\mathbb{w}_k}{\mathbb{w}_1 + \mathbb{w}_2 + \mathbb{w}_3 + \mathbb{w}_4}$$

Layer 4: To calculates rule outputs based on the consequent parameters.

$$\mathbb{O}_k^4 = \mathfrak{t}_k = \overline{\mathbb{w}}_k . \mathfrak{h}_k = \overline{\mathbb{w}}_k . (\mathfrak{p}_k \mathfrak{s} + \mathfrak{q}_k \mathfrak{s} + \mathfrak{r}_k)$$
$$\mathbb{O}_k^{4'} = \mathfrak{t}_k^{'} = \overline{\mathbb{w}}_k . \mathfrak{h}_k^{'} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{'} \mathfrak{s} + \mathfrak{q}_k^{'} \mathfrak{s} + \mathfrak{r}_k^{'})$$
$$\mathbb{O}_k^{4''} = \mathfrak{t}_k^{''} = \overline{\mathbb{w}}_k . \mathfrak{h}_k^{''} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{''} \mathfrak{s} + \mathfrak{q}_k^{''} \mathfrak{s} + \mathfrak{r}_k^{''})$$
$$\mathbb{O}_k^{4'''} = \mathfrak{t}_k^{'''} = \overline{\mathbb{w}}_k . \mathfrak{h}_k^{'''} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{'''} \mathfrak{s} + \mathfrak{q}_k^{'''} \mathfrak{s} + \mathfrak{r}_k^{'''})$$

Layer 5: To sum all the inputs from layer 4.

$$\mathbb{O}_k^5 = \mathfrak{t}_{\mathfrak{a}} = \sum_{k=1}^{\mathfrak{n}} \mathfrak{t}_k = \sum_{k=1}^{\mathfrak{n}} \overline{\mathbb{w}}_k . \mathfrak{h}_k = \overline{\mathbb{w}}_k . (\mathfrak{p}_k \mathfrak{s} + \mathfrak{q}_k \mathfrak{s} + \mathfrak{r}_k)$$
$$\mathbb{O}_k^{5'} = \mathfrak{t}_{\mathfrak{b}} = \sum_{k=1}^{\mathfrak{n}} \mathfrak{t}_k^{'} = \sum_{k=1}^{\mathfrak{n}} \overline{\mathbb{w}}_k . \mathfrak{h}_k^{'} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{'} \mathfrak{s} + \mathfrak{q}_k^{'} \mathfrak{s} + \mathfrak{r}_k^{'})$$
$$\mathbb{O}_k^{5''} = \mathfrak{t}_c = \sum_{k=1}^{\mathfrak{n}} \mathfrak{t}_k^{''} = \sum_{k=1}^{\mathfrak{n}} \overline{\mathbb{w}}_k . \mathfrak{h}_k^{''} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{''} \mathfrak{s} + \mathfrak{q}_k^{''} \mathfrak{s} + \mathfrak{r}_k^{''})$$
$$\mathbb{O}_k^{5'''} = \mathfrak{t}_d = \sum_{k=1}^{\mathfrak{n}} \mathfrak{t}_j^{'''} = \sum_{k=1}^{\mathfrak{n}} \overline{\mathbb{w}}_k . \mathfrak{h}_k^{'''} = \overline{\mathbb{w}}_k . (\mathfrak{p}_k^{'''} \mathfrak{s} + \mathfrak{q}_k^{'''} \mathfrak{s} + \mathfrak{r}_k^{'''})$$

For a given dataset, MANFIS models can be created using Grid partitioning to find the antecedent membership functions. To enhance the developed MANFIS model, nearly 50% (180) of Landsat satellite data set were utilized for training and the remaining 50% (180) data were used for testing the MANFIS behavior. The MANFIS architecture of six input parameters such as Shoreline Date (SD), Transect ID (TID), Shape Length (SL), Transect Length (TL), Transect Spacing (TS), and Distance from Baseline (DB) and the four output parameters are Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR).

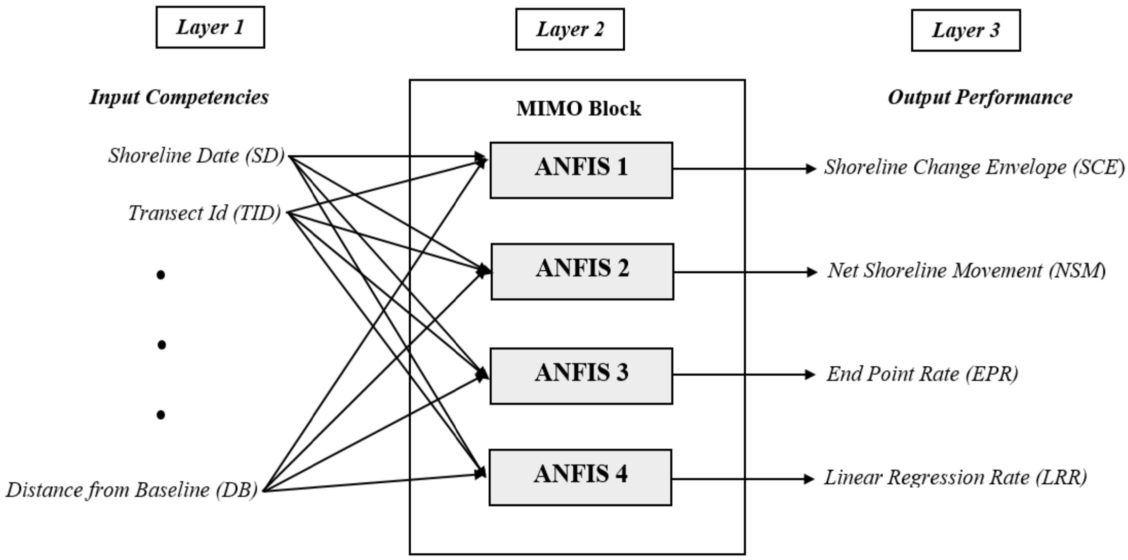

Fig. 3 Developed four output MANFIS architecture.

In order to determine the statistical performance of the developed MANFIS models the following mathematical indices are used and are defined as:

$$MSE = \frac{1}{N_{\text{satellite data}}} \sum_{k=1}^{N_{\text{satellite data}}} (MT_{actual} - P_{MANFIS})^2$$

$$MAE = \frac{1}{N_{\text{satellite data}}} \sum_{k=1}^{N_{\text{satellite data}}} |MT_{actual} - P_{MANFIS}|$$

$$RMSE = \sqrt{\frac{1}{N_{\text{satellite data}}} \sum_{k=1}^{N_{\text{satellite data}}} (MT_{actual} - P_{MANFIS})^2}$$

$$R^2 = 1 - \frac{\sum_{k=1}^{N_{\text{satellite data}}} (MT_{actual} - P_{MANFIS})^2}{\sum_{k=1}^{N_{\text{satellite data}}} (MT_{actual} - \overline{MT})^2}$$

here, $N_{\text{satellite data}}$ denotes the number of samples, MT_{actual} denotes the target and measure value, P_{MANFIS} denotes the predicted value and $\overline{MT}$ denotes the average of the measure.:

3 MANFIS Model Development

The End point Rate (EPR), Linear Regression Rate (LRR), Net shoreline Movement (NSM) and Shoreline Change Envelope (SCE) approaches were used to evaluate the changes. The estimation of shoreline change was computed along the coast of Vishakhapatnam which covers about 135 km length. In this study, satellite images of 1974, 1992, 2000, 2010 and 2020 were used to digitize and extract the shoreline for each time period. With the help of these shorelines and baseline positions transects were cast perpendicular to shoreline to compute the statistic changes in shoreline. As a result of these preliminary analysis found that the most significant changes all along the coast. The changes in shoreline position were observed and recorded along the zone wise categories, to determine which part of zone is eroding higher or accreting along with the percentage.

3.1 Shoreline change using LRR

A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a transect. Linear regression rates are the typical rate of change that are measured by employing a number of shoreline position over time. Based on the results of DSAS Output, the change in shoreline position is computed and several maps were prepared to categorize the vulnerable and coastal hot spots of the coast with the previous mentioned parameters. The linear regression rate of change for all the categories of zonal division, according to the statistical computation zone 1 as Bheemunipatnam taluk found that the 41.34% of erosion with 53.63% of accretion along the coast of zone 1. For zone 2 of Vishakhapatnam, the coastal erosion was found to be 49.45% and 39.41% of accretion. Similarly, for zone 3 of Anakapalli taluk found 23.08% of erosion and 66.67% of accretion along the coast. Zone 4 of Yellamanchili Taluk has reported with 2.57% of erosion and 94.93% of accretion along the coast of Vishakhapatnam. From this statistical approach Vishakhapatnam taluk was found to be the highest eroding region over the coast of Vishakhapatnam district with 49.45% stable shoreline of about 11.14% with no evident of erosion and accreting nature and 39.41% of accretion as discussed in Fig. 4.

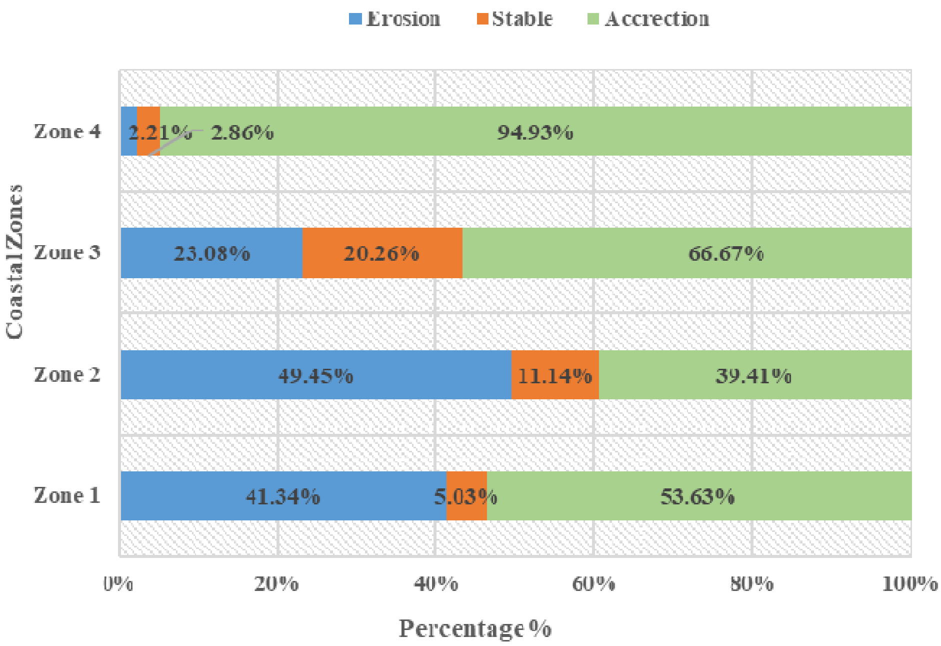

Fig. 4 Rate of change in shoreline (using LRR).

3.2 Rate of change in length of shoreline using LRR

Based on the statistics of Linear Regression Rate from DSAS output, found that the length of shoreline gets changed due to the impact of coastal erosion. The computation helps us to predict the vulnerable spots over the zones of Vishakhapatnam district. The linear regression rate of change for all the categories of zonal division, according to the statistical computation the change in shoreline length found. The change of length along the Vishakhapatnam district categorized into three groups as erosion, stable and accretion as elaborated in Table 3. Zone 1 as Bheemunipatnam taluk with the length of 17.45 km, over which 7.21 km found to be eroding and 9.36 km is accreting. For zone 2 of Vishakhapatnam taluk with the coastal length of 45.75 km, erosion was found along 22.63 km and accretion to be of 18. 03 km. Similarly for Zone 3 Anakapalli taluk of 7.7 km of coastal length, 1.78 km was found to be eroding and 5.13 km is accreting along the coastal length of Vishakhapatnam district. For zone 4 as Yellamanchili Taluk with the coastal length of 64.1 km, erosion was found along 1.65 km and accretion to be of 60.85 km.

Table 2 Change in the length of shoreline in different zones using LRR.

Zonal Division	Zonal Name	Length of Zone (km)	Change of Length (km)		
			Erosion	Stable	Accretion
Zone 1	Bhemunipatnam Taluk	17.45	7.21	0.88	9.36
Zone 2	Vishakhapatanam Taluk	45.75	22.63	5.09	18.03
Zone 3	Ankapalli Taluk	7.70	1.78	0.79	5.13
Zone 4	Yellamanchili Taluk	64.10	1.65	1.6	60.85

3.3 Shoreline changes using EPR

The End Point Rate is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. Using EPR Model, the percentage of shoreline changes has been extrapolated for the long-term period of 45 years. In this analysis, the coastline rate of change has been generated from past shoreline movements using satellite images from 1974 to 2020. The results of this computation provide the maximum erosion/accretion that takes place in the Vishakhapatnam region. Zone 1 as Bheemunipatnam taluk found that the 41.06% of erosion with 52.79% of accretion along the coast of zone 1. For zone 2 of Vishakhapatnam, the coastal erosion was found to be 59.21% and 32.28% of accretion. Similarly, zone 3 of Anakapalli taluk found 36.54% of erosion and 39.74% of accretion along the coast. Zone 4 of Yellamanchili Taluk has reported 3.43% of erosion and 92.36% of accretion along the coast of Vishakhapatnam. From this statistical approach, Vishakhapatnam taluk was found to be the highest eroding region over the coast of Vishakhapatnam district with 59.21%, a stable shoreline of about 8.51% with no evidence of erosion and accreting nature, and 32.28% of accretion as per bar chart shown in Fig. 5.

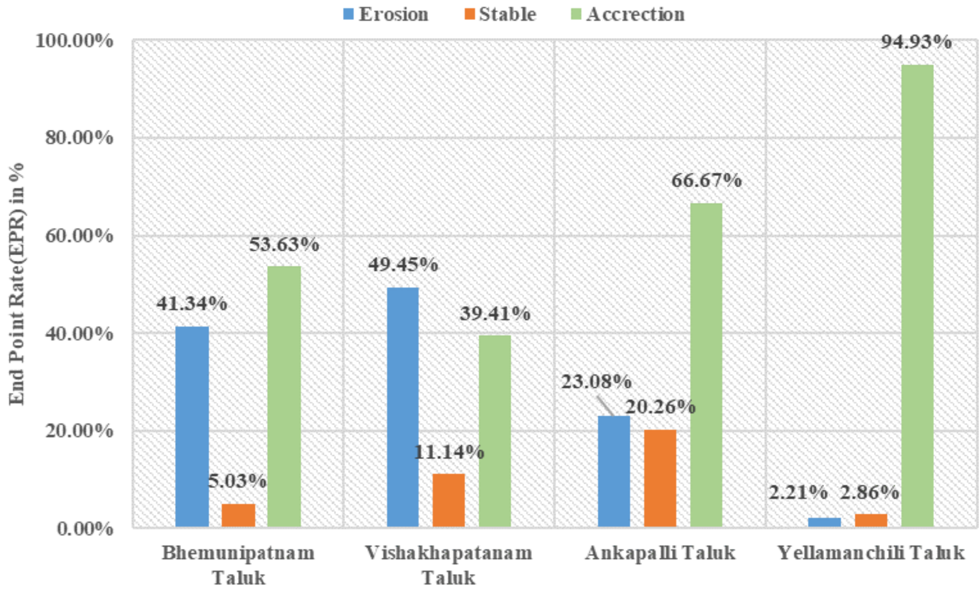

Fig. 5 Change in End Point Rate between the zones.

3.4 Rate of change in length of shoreline using EPR

Based on the computation of End Point Rate from DSAS output, found that the length of the shoreline gets changed due to the impact of man-made activities on the coast and natural disasters. This statistic helps us to predict the vulnerable spots over the zones of the Vishakhapatnam district. The End Point Rate of change for all the categories of zonal division, according to the statistical computation the change in shoreline length found. The change of length along the Vishakhapatnam district categorized into three groups as erosion, stable and accretion and was illustrated in Fig. 6. Zone 1 is Bheemunipatnam taluk with a length of 17.45 km, over which 7.17 km is found to be eroding and 9.21 km is accreting. For zone 2 of Vishakhapatnam taluk with a coastal length of 45.75 km, erosion was found along 27.09 km and accretion to be of 14.77 km. Similarly, for Zone 3 Anakapalli taluk of 7.7 km of coastal length, 2.81 km was found to be eroding and 3.06 km is accreting along the coastal length of Vishakhapatnam district. For zone 4 as Yellamanchili Taluk with the coastal length of 64.1km, erosion was found along 2.20 km and accretion to be 59.20 km.

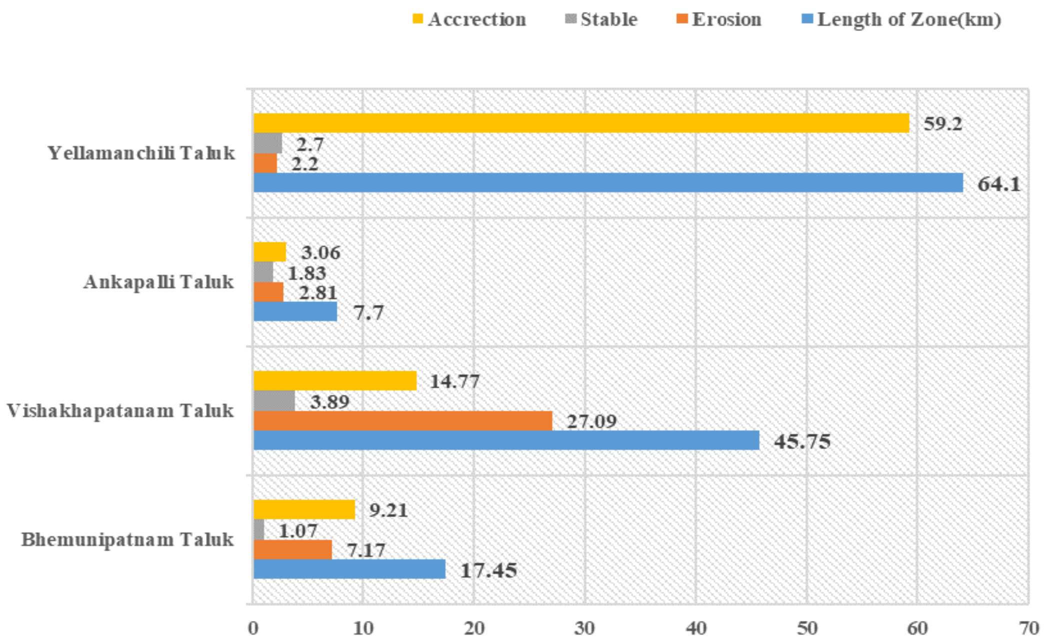

Fig. 6 Graphical Representation of change in length along Vishakhapatnam coast.

3.5 MANFIS model verification and validation

The six digitized shoreline data and four shoreline monitoring statistics were the MANFIS model input and output parameters, respectively. In this study, the number of membership functions (MFs) set as two and the different types of MF were used to predict the shoreline change rate. Table 4 shows thetraining data performance measure of MANFIS-GPM model RMSE and R values of SCE, NSM, EPR, and LRR of various MF types. It is observed that, in NSM and EPR the trimf provides the maximum and minimum values of R and RMSE, and remaining SCE and LRR the psigmf and trapmf type estimates the highest values and lowest values of R and RMSE. Table 5 illustrates the statistical measures of the developed four output MANFIS model. The minimum error levels and the maximum R points of training and checking sets plays to conduct of the MANFIS systems.

Table 4 Training data performance measures of MANFIS-GPM model.

MF Type	SCE		NSM		EPR		LRR	
	RMSE	*R*	*RMSE*	*R*	*RMSE*	*R*	*RMSE*	*R*
trimf	0.00218	0.999999998	**24.38561**	**0.927140017**	**0.525946**	**0.927577168**	1.049537	0.707043507
gbellmf	2.12E-03	0.999999998	2.53E+01	0.924509996	5.42E-01	0.924684975	5.44E-01	0.930365053
gaussmf	0.002118	0.999999998	2.55E+01	0.922689476	5.49E-01	0.922659983	5.56E-01	0.927166033
gauss2mf	2.13E-03	0.999999998	2.50E+01	0.926269084	5.37E-01	0.926263163	5.49E-01	0.929112968
trapmf	2.13E-03	0.999999998	2.61E+01	0.919275584	5.61E-01	0.91925465	**5.41E-01**	**0.935817786**
psigmf	**2.12E-03**	**0.999999998**	2.62E+01	0.918347438	5.63E-01	0.918377282	5.90E-01	0.917588025
dsigmf	2.12E-03	0.999999998	2.55E+01	0.922848838	5.49E-01	0.922804232	5.60E-01	0.926061901

Table 5 Efficiency indicators of the developed MANFIS model.

DSAS statistics	Phases of data	Statistical measures				
		MAE	MSE	RMSE	SSE	R
Shoreline Change Envelope (SCE)	Training	9.17E-04	4.46E-06	1.12E-03	6.70E-07	0.999999
	Checking	0.001319	7.73E-06	0.002781	0.00116	0.999999
Net Shoreline Movement (NSM)	Training	17.12625	614.429	24.38561	92664.36	0.927140
	Checking	20.78181	798.9395	28.26552	119840.9	0.904467
End Point Rate (EPR)	Training	0.371088	0.278056	0.525946	42.70847	0.927577
	Checking	0.442667	0.367074	0.605866	55.06106	0.904961
Linear Regression Rate (LRR)	Training	3.84E-01	2.05E-01	5.41E-01	4.42+01	0.935817
	Checking	0.462614	0.402308	0.634278	60.34625	0.904076

Fig. 7 represents the RMSE values in the checking and training stages of Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR) against epoch. It is observed from these figures that the checking and training errors converge and attain minimum value within 400 epochs.The MANFIS output of the SCE, NSM, EPR, and LRR were calculated using FIS1 for checking data and FIS2 for training data. Figs. 8-11 exhibit the analogy between experimental and predicted values of SCE, NSM, EPR, and LRR for training, checking, and over all data stages. From these figures, the diagonal line connects the training data points and predict hiatus. The predicted and the experimental values of the training data sets are in better agreement. The predicted values are in good concord with the experimental values of the checking data set with errors of less than 5%. As a result, the developed MANFIS model can accurately predict the vulnerability of Visakhapatnam coastal zones due to climate change.

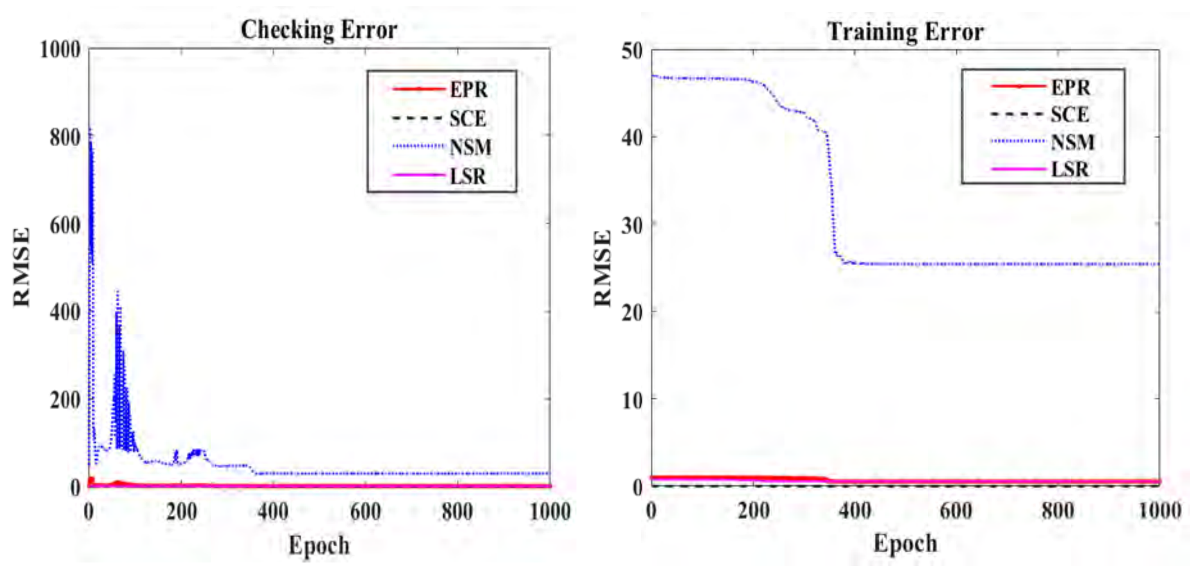

Fig. 7 MANFIS model checking and training error curve.

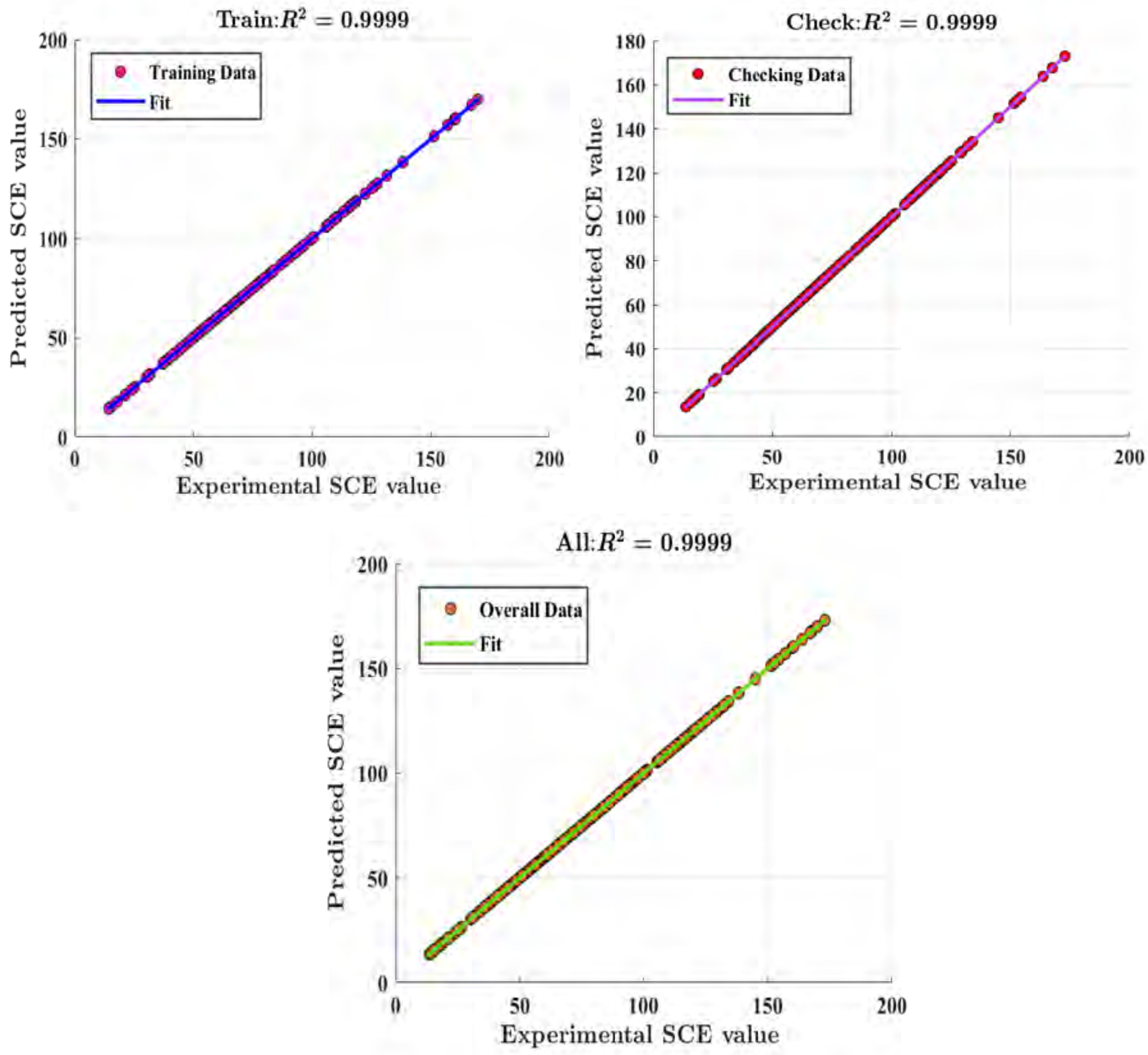

Fig. 8 Experimental *vs* predicted SCE.

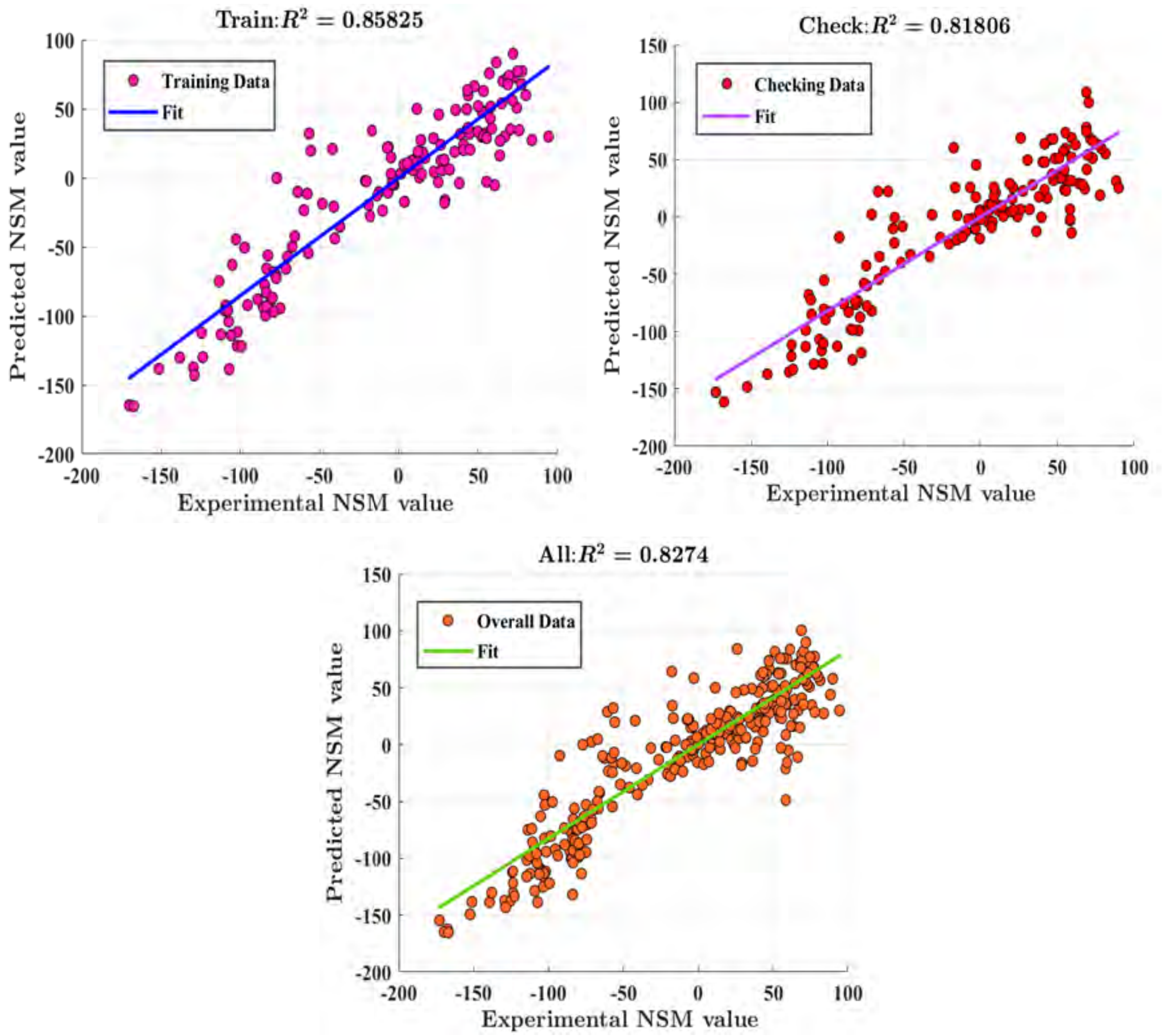

Fig. 9 Experimental *vs* predicted NSM.

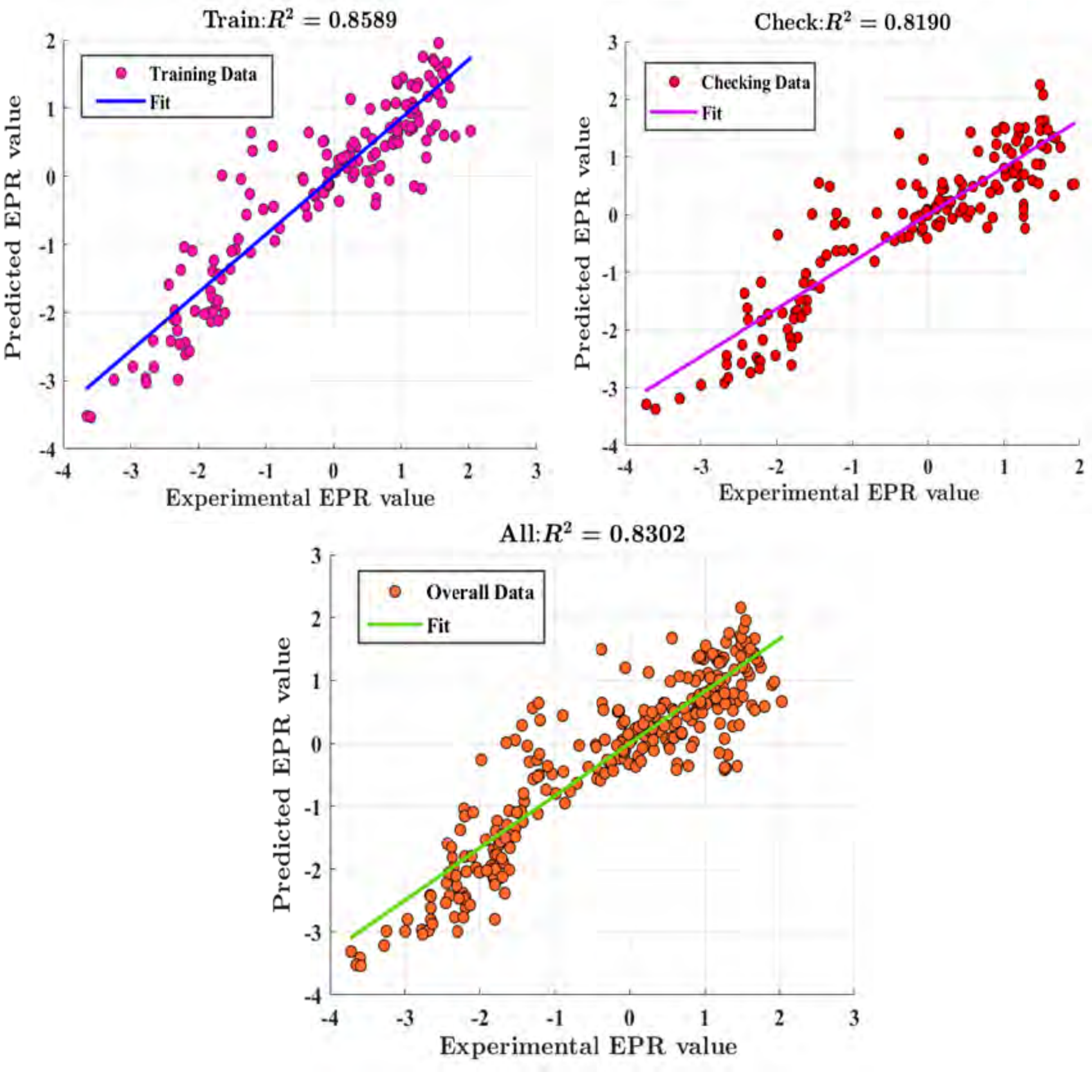

Fig. 10 Experimental *vs* predicted EPR.

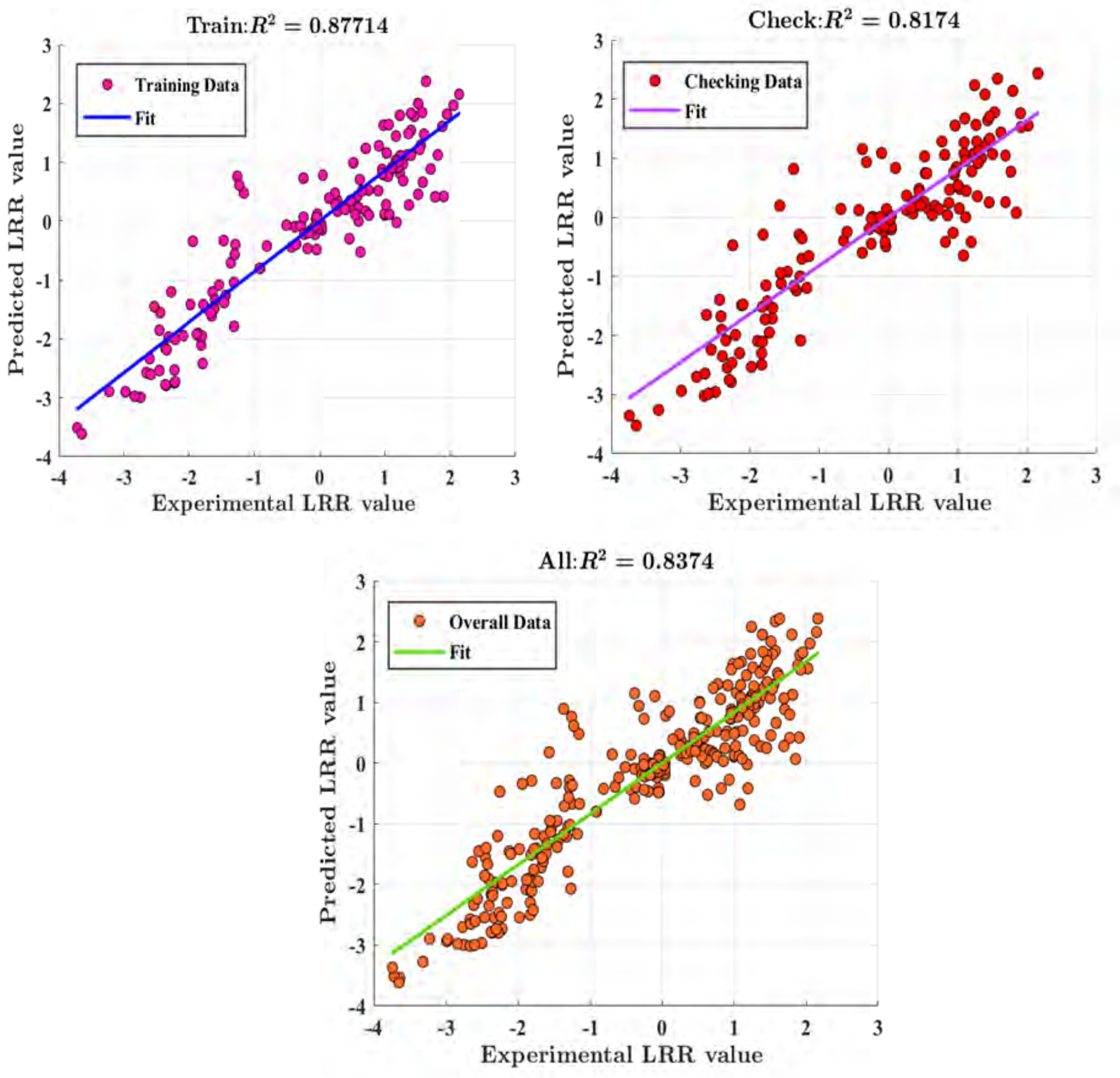

Fig. 11 Experimental *vs* predicted LRR.

4 Conclusions

This study demonstrates that the integration of remote sensing and GIS technology is very useful for long-term shoreline change studies with reasonable accuracy. The result of the shoreline change map will be more useful for coastal engineers and coastal zone management authorities to facilitate suitable management plans and regulations of coastal zones. The shoreline change estimation was carried out for the entire Vishakhapatnam coast which is about 135 km of coastal length. In this study, shorelines are extracted from satellite images for 1974, 1992, 2000, 2010, and 2020 using Remote sensing and GIS. Using DSAS (Digital Shoreline Analysis System) the rate of change in the coastline is evaluated under two statistical outputs like End Point Rate (EPR) and Linear Regression Rate (LRR). For computing accurate change in the coastline, the length of Vishakhapatnam is divided into four coastal districts relative to the district's boundary from zone 1 to zone 4. The rate of shoreline change was calculated at each transect using statistical output. As a result of the study, the most significant changes were observed at Vishakhapatnam coast (Zone 2) facing severe erosion about 22.63 km and high accretion was noticed in Yellamanchili Taluk about 60.85 km. The rate of accretion and erosion is derived as + 2.03 m/yr and -3.72 m/yr. Overall, during the study periods, erosion activities are moderately high compared to accretion in the study area. The results of this study will be useful for policymakers and coastal communities' livelihoods. It is suggested that the regular monitoring of the coastline is vital for proper planning and management of the coast to prevent the shoreline from erosion using appropriate remedial measures.

References

Akhil Kallepallia, Kakani NR, James DB, Richardson MA. 2017. DSAS-based change detection along the highly eroding Krishna-Godavari delta front, Environmental Science, 2017: 1-22

Alesheikh, A. Ghorbanali, N. Nouri. 2006. Coastline change detection using remote sensing. International Journal Environment Science and Technology, 4: 61-66

Chenthamilselvan S, Kankara RS, Rajan B. 2014.Assessment of shoreline changes along Karnataka Coast, India using GIS & Remote sensing techniques. Indian Journal of GeoMarine Sciences, 43: 1286-1291

Elayarani M, Shanmugapriya M, Senthil Kumar P. 2021. Intensification of heat and mass transfer process in MHD carreau nanofluid flow containing gyrotactic microorganisms. Chemical Engineering and Processing-Process Intensification, 160: 108299

Elżbieta Szafranko, Srokosz PE, Jurczak M, Śmieja M. 2022. Application of ANFIS in the preparation of expert opinions and evaluation of building design variants in the context of processing large amounts of data. Automation in Construction, 133: 104045

Fattahi H, Agah A, Soleimanpourmoghadam N. 2018. Multi-Output Adaptive Neuro-Fuzzy Inference System for Prediction of Dissolved Metal Levels in Acid Rock Drainage: a Case Study. Journal of AI and Data Mining, 6: 121-132

Gopi Krishna S, Shanmugapriya M, Senthil Kumar P. 2022. Prediction of bio-heat and mass transportation in radiative MHD Walter-B nanofluid using MANFIS model, Mathematics and Computers in Simulation, 201: 49-67

Gopi Krishna S, Shanmugapriya M, Sundareswaran R Senthil, Kumar P. 2022. MANFIS approach for predicting heat and mass transport of bio-magnetic ternary hybrid nanofluid using Cu/Al2O3/MWCNT nano additives. Biomass Conversion and Biorefinery, https://doi.org/10.1007/s13399-022-02989-x

Jang JSR. 1993. ANFIS: adaptive-network-based fuzzy inference system, IEEE Transactions on Systems, Man, and Cybernetics, 23: 665-685

Jonah FE, Boateng Osman A. 2016. Shoreline change analysis using End Point Rate and Net Shoreline Movement Statistics: an application to Elmina, Cape Coast and Moree Section of Ghana's Coast. Regional Studies in Marine Science, 7: 1-25

Kaliraj S, Chandrasekar N, Magesh NS. 2014. Impacts of wave energy and littoral currents on shoreline erosion/accretion along the south-west coast of Kanyakumari, Tamil Nadu using DSAS and geospatial technology. Environmental Earth Sciences, 71: 4523-4542

Kankaraa RS, Chenthamil Selvana S, Vipin J. Markosea, Rajana B, Arockiaraj S. 2015. Estimation of long- and short-term shoreline changes along Andhra Pradesh coast using Remote Sensing and GIS techniques. 8th International Conference on Asian and Pacific Coasts, Procedia Engineering, 116: 855-862

Kannan R, Ramanamurthy MV, Kanungo A. 2016. Shoreline Change Monitoring in Nellore Coast at East Coast Andhra Pradesh District Using Remote Sensing and GIS. Journal of Fisheries and Livestock

Production, 2016: 1-6

Kannan R, Kanungo A, Murthy MVR. 2016. Detection of Shoreline Changes Visakhapatnam Coast, Andhra Pradesh from Multi-Temporal Satellite Images. Journal of Remote Sensing and GIS, 5:1-7

Kasinatha Pandian P, Ramesh S, Ramana Murthy MV, Ramachandran S, Thayumanavan S. 2004. Shoreline changes and near shore processes along Ennore Coast, East Coast of South India. Journal of Coastal Research, 20: 828-845

Mamat, R.C, Kasa, A, Razali, SF. 2019. The applications and future perspectives of Adaptive Neuro-Fuzzy Inference System in road embankment stability. Journal of Engineering Science and Technology Review, 12: 75-90

Mirna Sebat, Juliet Salloum. 2018. Estimate the rate of shoreline change using the statistical analysis technique (EPR), Journal Business & IT, 8:59-65

Mirza Razi Imam Baig, Ishita Afreen Ahmad. 2020. Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: an application of digital shoreline analysis system (DSAS), Annals of GIS 26: 361-376

Oduro-Gyimah FK, Boateng KO. 2018. Application of canfis model in the prediction of multiple-input telecommunication network traffic. ITU Journal: ICT Discoveries, 2: 16

Sindhu Tyagi, Rai SC. 2020. Monitoring shoreline changes along Andhra coast of India using remote sensing and geographic information system. Indian Journal of Geo Marine Sciences, 49: 218-224