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Research Article

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Groundwater Variability Along with The Varying Coastline of Thiruvanathapuram City

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Abstract
Shoreline change is a constantly evolving phenomenon that threatens people and their livelihoods around the globe. India observes this phenomenon strongly at different locations being a tropical peninsular country with 6635kms of coastline. This study tried to analyze the effect of shoreline change on surrounding ground water reserves along Thiruvanathapuram coast in Kerala district of India. Net changes in coastline positions are statistically calculated and observed using Linear Regression Rate (LRR). The shoreline change rate shows most of the region are undergoing erosion, only few accretions or land formation are observed which was mostly artificially formed due to harbor building. The highest erosion rate in terms of LRR was -7m/year and highest accretion was 28m/year. We compared the shoreline change with groundwater variability along the coast and also groundwater salinity using electrical conductivity as the factor. The study observed decreasing trend of groundwater along the eroding coastline. The study also predicted decadal shoreline change along the Thiruvanathapuram coast was predicted using Kalman filter model.

Keywords: Shoreline Change Rate, LRR, Kalman Filter Model, Ground water.

1. Introduction

India has a coastline of about 6635 kilometers long with the Arabian Sea to the west Bay of Bengal to the east and the Indian Ocean to the south which is dotted with several major ports on both its west and east coastlines. According to a report published by National Centre for Coastal Research (NCCR) as much as 32 percent of the coastline has undergone erosion majority of which occurred between 1990 and 2018.

One of the major hazards which accompanies any coastline is its erosion. In order to study the effect of shoreline change on an urban settlement and its subsequent effect on the ground water in the region we chose Thiruvananthapuram coast in Kerala State which is on the western coast of India as studies on the western coast especially towards the southern part of the country was limited. The study focuses on the shoreline change and its implication on ground water (GW) along the Thiruvananthapuram coast for a period from 2002 to 2022 at 4 years interval using Landsat 7/8 (2002-2014) and Sentinel-2 (2018 and 2022). Digital Shoreline Analysis System tool (DSAS) of ArcGIS Desktop was used to understand shoreline change rates using statistical measure like the Linear Regression Rates (LRR). To classify the shoreline, coastal vulnerability index (CVI) is calculated using the LRR, geomorphology data, mean sea-level, tidal range, mean wave height and slope. The result shows major erosion in two locations and a landmass formation owing to the creation of artificial coast for harbor construction.

The change in shoreline for the year 2032 was forecasted using the Kalman filter model and finally, the effect of shoreline changes on groundwater trend and salinity near to coast was observed using data obtained from India Water Resources Information System (India WRIS).

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2. Study Area

The 78 kilometers long study area stretching along the shore of Arabian Sea includes three taluks (Chirayankizhu, Neyyatinkara and Thiruvananthapuram) of Thiruvananthapuram district of Kerala which is situated between 8.17°– 8.54° latitude and 76.41°– 77.17° longitude. The district is mainly divided into three main geographical regions namely highlands, midlands and low lands, the Chirayankizhu and Thiruvananthapuram taluks fall under the mid to low land category whereas Neyyatinkara stretches among all the three.

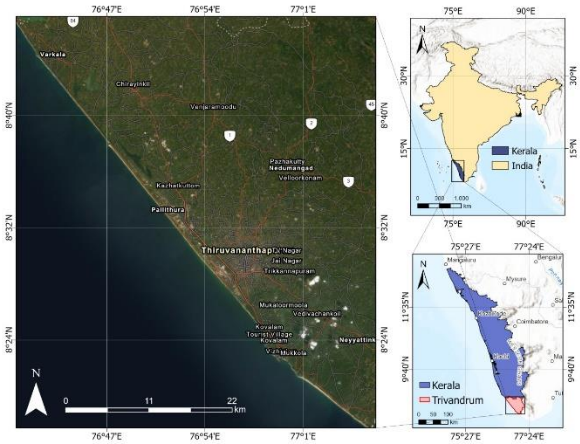

Figure 1: Map showing the study area: Thiruvananthapuram coastline along the Thiruvanathapuram district of Kerala state in India

3. Data and Methodology

3.1. Shoreline Extraction

The Satellite images for the region was obtained from Landsat 7 (2002, 2006 and 2010), Landsat 8 (2014) and Sentinel 2 (2018 and 2022), which were collected from USGS Earth Explorer, these where preprocessed as Landsat 7 images had scan line error which was rectified using 'Landsat gap fill' tool of ENVI and sentinel data needed to be mosaiced using 'mosaic to new raster' tool in ArcGIS Pro. The shorelines were then extracted using various geoprocessing tools in ArcGIS Pro as shown in the figure 2.

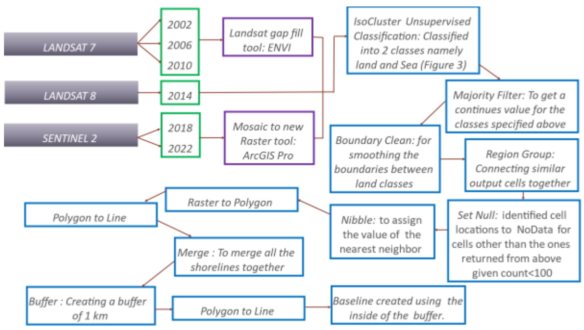

Figure 2: Shoreline extraction process, step by step guide.

All the individual shorelines extracted are merged together using merge tool in ArcGIS Pro and the Baseline created by providing a buffer on the merged shoreline for 1 km distance and taking the inside of the buffer as the baseline.

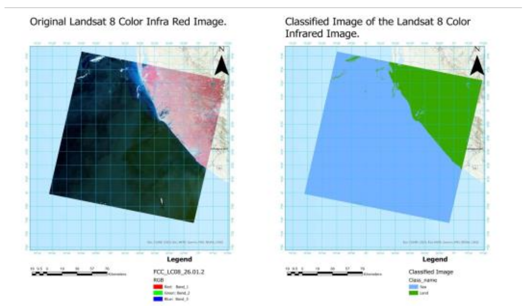

Figure 3: IsoCluster Unsupervised Classification from where Shoreline is extracted in between the two polygons of land and sea. The remining geo processing tools shown in figure2 is used for further cleaning these two classes and to finally extract the shoreline.

4. Coastal Vulnerability Index (CVI)

The CVI index is calculated using DSAS tool in ArcGIS desktop, for the purpose of creating the index, transacts were formed from the baseline obtained. In the attribute table for shoreline and baseline more fields (such as ID, DATE, GROUP, SEARCH DISTANCE, UNCERTAINTY, etc.) were added as documented in the DSAS user manual. Following which the LRR, EPR (End point rate), WLR (Weighted Linear Regression), SCE (Shoreline Change Envelope) and NSM (Net Shoreline Movement) were calculated. Among these only LRR was considered for shoreline change rate calculation for our study.

The equation used for CVI index is:

$$\mathrm{CVI} = \frac{\sqrt{a*b*c*d*e*f}}{6} \qquad \text{.........(eq1)}$$

Where a is geomorphology (data obtained from Bhukosh), b is slope (from SRTM DEM 30m), c is mean sea level rise (from Intergovernmental Panel on Climate Change (IPCC) report), d is mean wave height (1.1m), e is tidal range (from WXTide: 0.45-0.65 meters, these values were taken by averaging the tide height between 10-12 AM for each date corresponding to the Landsat/Sentinel image) and f is LRR or shoreline change. All these parameters where individually classified into three classes (high, medium and low risks) and finally CVI found using the equation (eq1)

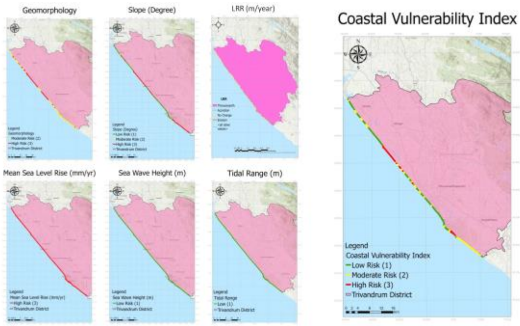

Figure 4: Clock wise from left to right: The geomorphology, slope, LRR, CVI Index, Mean Sea level rise, Sea Wave height and tidal range classified under the three main classes (High, medium and Low Risks).

5. Shoreline Change Prediction

The decadal shoreline change was predicted using a forecasting method based on Kalman Filter model in the DSAS tool.

The formula used for predicting the shoreline is:

$s' = s + scr * dt$ ....……………(eq2)

where s' is the predicted shoreline for year 2032, s is the shoreline for year 2022, scr is the shoreline change rate (obtained from LRR along the shoreline) and is time gap between the years (10 in this case).

6. Ground Water Variability Along Shoreline

Ground water level was obtained from India WRIS for 21 well points (Figure 5) along the shoreline for determining its variability with respect to varying coastline. Out of which some points were omitted as we only took those points which had negative LRR values, the physical implication of which is we just studied groundwater variability with only erosion and not accretion. The water level for these well points were observed for a period of 20 years (2002-2022), the missing data were populated with the average of observations. The new average for each well point and corresponding LRR of the shoreline were used to create a linear regression model for determining the effect of shoreline change on ground water near the coast.

6.1. Ground Water Salinity Along Shoreline

Electrical conductivity of 7 well points (the points were chosen based on the availability of data for the time period) were obtained from India WRIS for studying the effect of shoreline on groundwater salinity in the region (Figure 5). Electrical conductivity was chosen as a parameter for determining the salinity as it is a direct factor which shows for the presence of ions in water. A linear regression model was applied with well points and electrical conductivity as parameters for determining the correlation between the two.

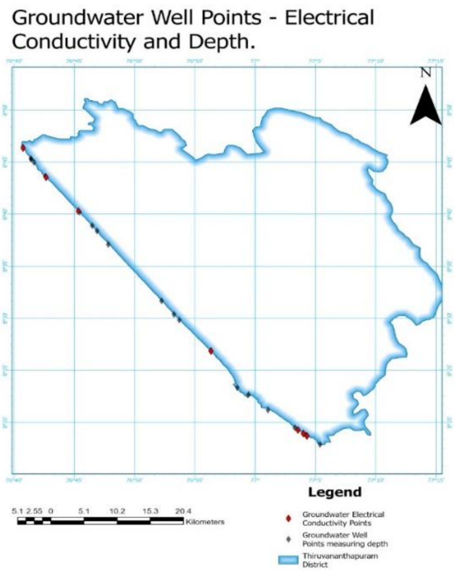

Figure 5: well points along the coastline where the black colored shows the well points considered for ground water level and the red colored ones are considered for electrical conductivity.

7. Results and Discussion

7.1. Shoreline Change

The shoreline change rate shows most of the region are undergoing erosion only few accretions or land formation were observed. The highest erosion rate in terms of LRR was -7m/year and highest accretion was 28m/year. From figure 4 it is observed that high rates of erosion are present in Shangumugham and Pozhikkara beaches and also among Varkala and Anchuthengu coasts. Instances of accretion mainly along the Vizhinjam coast due to artificial land mass formation for the upcoming International Sea port construction.

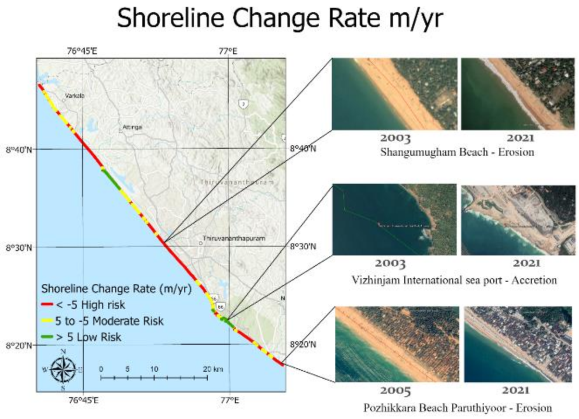

Figure 6: The map shows shoreline change for the past decade and how the shoreline changed in the major regions. Here the red color denotes regions of high risk (erosion), green for low (accretion) and yellow for moderate risk.

7. Decadal Prediction

Kalman filter model predicted the decadal shoreline as following the same trend as observed in the previous decade (2002-2022) with regions of high erosion continuing to erode and vice versa.

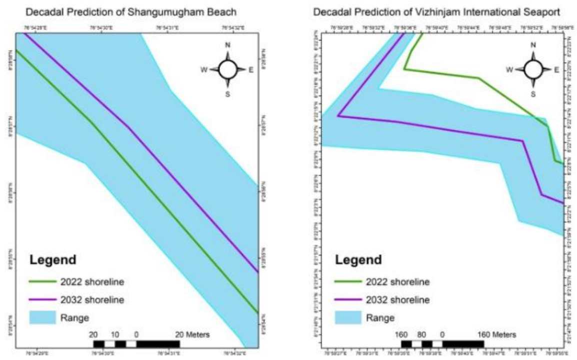

Figure 7: from left to right: Shangumugham beach showing erosion tendencies and next figure shows Vizhinjam coast which shows accretion tendencies. The green color depicts 2022 shoreline and the purple color 2032 shoreline and the cyan color shaded portion shows the range polygon within which the decadal shoreline could lie.

7.1. Groundwater Variability and Salinity

The plot between shoreline change rate and ground water depth (Figure 8) shows a linear relationship which implies that there is an increase in ground water level in areas of erosion and decrease in areas of accretion. This may be due to the sea actually merging with the aquifers deep below the earth. The plot obtained from shoreline change rate and electrical conductivity (Figure 9) of selected well points were observed to be linear which implies that the conductivity (which is a property of salinity) of ground water increase with increase in shoreline change. This could be due to the intrusion of saline sea water into the GW table during erosion which causes the ion concentration in GW to rise.

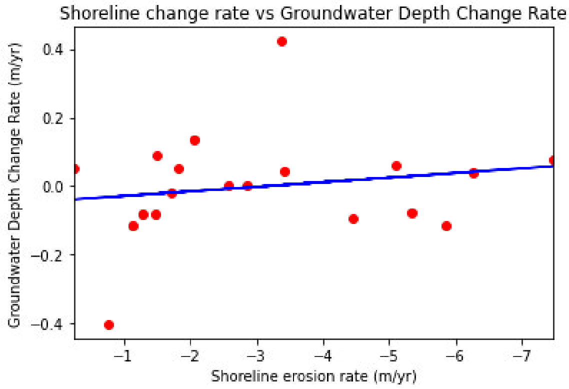

Figure 8: Regression line showing a linear relationship between shoreline change rate and ground water depth.

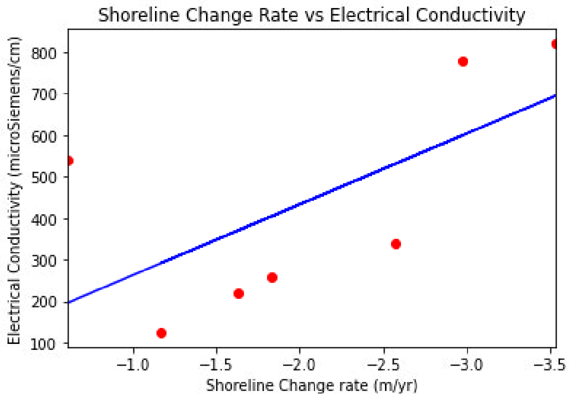

Figure 9: Regression line showing a linear relationship between shoreline change rate and electrical conductivity which is a direct measure of salinity.

8. Conclusions

The current study helps us to conclude that the highest shoreline change rate for erosion and accretion are -7m/year and 28m/year respectively in terms of LRR for the study region. The decadal shoreline prediction showed that the coastline mostly showed erosional tendencies apart from isolated section like Vizhinjam International Sea port region where artificial land mass formation was taking place. The study further showcased linear relationship between ground water depth and shoreline change rate and also between shoreline change and GW electrical conductivity (salinity). This may be dependent on the population allocation along the shorelines or due to the sea actually merging with the aquifers deep below the earth or a combination of both the parameters [1-13].

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