Prediction of Coastal Erosion Rates Using AI Technology

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Abstract - Coastal Erosion is a major concern in countries having coastal zone, and India has very longest coastal zone. In coastal erosion the slope stability is affected rather than the soil particles. About 370 km of Kerala coast is subjected to coastal erosion of various magnitudes, which can be due to several factors like early onslaught of monsoon and subsequent high and steep waves. 23% of Trivandrum's coastal line was affected in the year 2021. Considering some recent researches, it was seen that the coastal areas of Thiruvananthapuram district such as Menamkulam, Puthenthope, Veli, Adimalathura, Valiathura etc. are prone to coastal erosion. The aim of this study is to analyse these identified vulnerable coastal regions and the impacts of coastal erosion caused due to the varying wave action and the beach slopes in these sites on the basis of INCOIS data. Based on these ideas and use of emerging AI Technology, a code is developed which can be used to predict the total erosion or accretion that can occur on these sites.

Key Words: Soil erosion, Wave action, beach slopes, AI codes

1. INTRODUCTION

In order to address the growing threat to life and property in the coastal zone, precise information on coastal erosion based on historical and recent shoreline changes is crucial. These changes could be long term, short term, seasonal or episodic and result in coastal erosion or accretion. Waves, currents, tides and winds, as well as anthropogenic activities cause coastal erosion. One of the most reliable signs of coastal erosion is coastline retreat. A variety of techniques have been put forth to quantify coastal retreat. The baseline approach, area-based approach, dynamic segmentation approach, buffering, and nonlinear least squares estimation approach are these. Numerous scholars have examined the characteristics of coastal erosion in the area surrounding Thiruvananthapuram, which lies on India's southwest coast. Prior research has established a baseline understanding of shoreline change and related erosion and accretion along this coast through the use of Survey of India toposheets, satellite imagery, and aerial images. Thiruvananthapuram is the zone where erosion occurs most frequently along the Keralan coast, according to a recent research by the National Centre for Sustainable Coastal Management. The unique morphologies along this high energy coast were taken into consideration when analysing shoreline change, aside from the typical seasonal dynamics of shoreline.

2. LITERATURE REVIEW

J. Shaji (2020) studied the Thiruvananthapuram district of Kerala, along the southwest coast of India, which is a densely populated coastline and is sensitive to sea surge and severe coastal erosion. This coastal zone is sensitive, as evidenced by the fact that it was flooded in multiple places by the Indian Ocean Tsunami of December 2004. Sensitivity of the coast if considered in conjunction with other social factors may be an input into broader assessments of the overall vulnerability of coasts and their communities [1].

Sheela Nair et al.(2018) made a recent study that uses data from satellite pictures and the 1968 SOI topographic chart to investigate long-term coastline changes along the southwest coast of India from 1968 to 2014. The USGS DSAS programme was utilised to calculate the rate of changes. The study discovered that man-made activities including building dams, hard structure development, and mining sand from beaches and rivers had drastically altered the whole width of the Kerala coast. The paper makes the argument that since shoreline features are constantly changing as a result of both natural and human activity, forecasting future trends may not be feasible. [2]

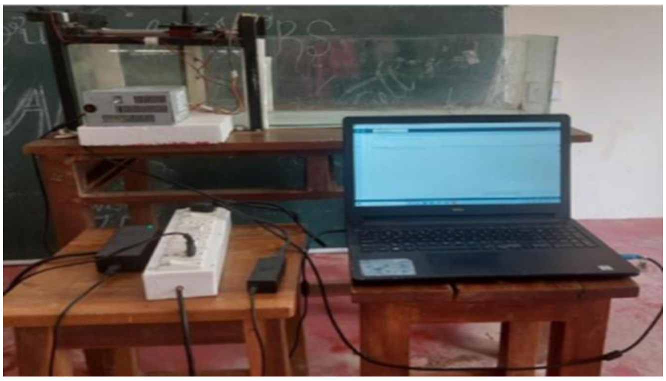
Kim and Lee (2022) in their studies highlight the advantages of machine learning (ML) over traditional regression techniques in coastal and ocean engineering. Many research on forecasting coastal engineering characteristics like waves, wave breaking, hydraulic properties, and beach profile changes have been made. The study focuses on regression analysis using continuous variables in supervised machine learning models, excluding categorical variable classification. It provides a comprehensive review of technological advancements and application examples of ML models in coastal engineering [3].

Goldstein et al. (2019) made studies that explores the use of machine learning (ML) in coastal morphodynamics and sediment transport research, highlighting the shift from traditional empirical methods to data-driven strategies. It emphasizes the importance of computational methodology, data amount, nonlinearity, and high dimensionality. The study identifies various ML applications in sediment transport, morphologic, and hybrid coastal prediction problems, discusses common concepts, future goals, comparisons with standard approaches, and the selection of relevant ML methods [4].

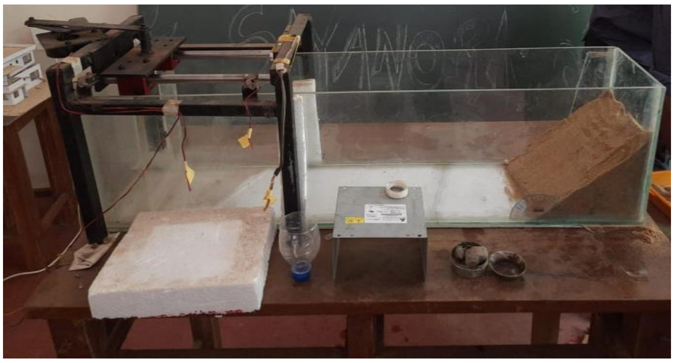
3. METHODOLOGY

3.1 EXPERIMENTAL PROCEDURE

An experimental setup was prepared to analyse wave action's impact on soils. The setup included a wave tank made of glass walls; a wave generator programmed using Arduino UNO, a laptop and a power supply. Experimental setup is shown in Fig. 1



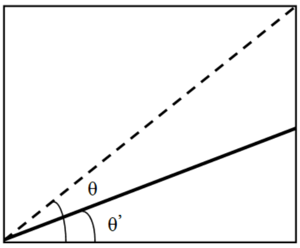
(a) Experimental setup



(b) Experimental modelling

Fig - 3.1: Erosion degree– 30 degrees experimental analysis

The soil slopes of 30 degrees were modelled in the glass tank. The glass walls were chosen to resist the wave impact as well as to offer easy visual analysis of the experiment. The soil samples were mixed in their initial moisture content, compacted and filled in 5 layers and the slopes were made accordingly. The water level was maintained constant at a height of 10cm throughout the experiment. The wave generator operated in three different velocities i.e., 0.06 m/s, 0.07 m/s, 0.08m/s and 0.09m/s respectively. The experiment was conducted for one hour on the slope and soil sample with varying velocities. The wave height and amplitude were also noted during the experiment. The initial height of the slope was noted and the difference in heights was noted down at 0,5,10,15,30,45 and 60mins respectively. The difference in height of the soil slope was used to find out the change in the slope angle of the soil slope. The initial mass of the soil sample was noted and the eroded mass was also found by calculating the difference between the soil mass retained and the mass initially taken. Erosion degree, De is analysed and found out using the formula, De = θ/θ'. Erosion degree is unity when the slope is stable. The reduction in De indicates the soil mass being eroded away.



Where,
Original Slope=θ
Modified Slope =θ'

3.2 INTRODUCTION OF AI IN EROSION ASSESSMENT

Artificial intelligence has been used as a tool to solve numerically complex problems where a number of variables are involved in the field of wave energy and ocean engineering. In recent years, wave height forecasting has been improved by means of diverse artificial intelligence techniques, such as Genetic programming, Neuro wavelet technique, Sequential learning neural networks, Extreme Learning Machine, Bayesian methods, Artificial neural networks. Artifical neural networks(ANNs) arise as a useful tool as they can deal with non-linear function regression. ANNs can be applied to optimize the coastal protection performance of a wave farm, reducing the computational cost of physically-based numerical models.

So the code is coded for calculating erosion degree as follow:

```
import numpy as np

import math

def calculate_erosion(initial_slope_degrees,
final_slope_degrees, velocity, time_interval):

# Convert slope from degrees to radians

initial_slope = math.radians(initial_slope_degrees)

final_slope = math.radians(final_slope_degrees)

# Calculate erosion degree using the equation: erosion =
final_slope / initial_slope
```

```
erosion = final_slope / initial_slope

# Calculate reduction percentage

reduction_percentage = ((initial_slope - final_slope) / initial_slope) * 100

return erosion, reduction_percentage

# Example parameters

initial_slope_degrees = 30 # Initial beach slope in degrees

final_slopes_by_velocity = {

0.06: [30, 24.62, 23.24, 21.25, 21.21, 20.81, 20.53],

0.07: [30, 22.62, 22.08, 21.80, 21.25, 20.70, 19.86],

0.08: [30, 18.20, 16.11, 10.08, 6.25, 5.36, 3.20],

0.09: [30, 8.53, 5.40, 2.23, 3.18, 3.18, 3.18] }

time_intervals_minutes_list = [0, 5, 10, 15, 30, 45, 60]  # Different time intervals in minutes

velocities = [0.06, 0.07, 0.08, 0.09]  # Different velocities in m/s

# Calculate erosion for different velocities, final slopes, and time intervals

erosion_degrees = []

for velocity in velocities:

erosion_degree_for_velocity = []

print(f"Velocity: {velocity} m/s")

print("{:<25} {:<25} {:<20}".format("Time Interval (minutes)", "Final Slope (degrees)", "Erosion Degree"))

for final_slope_degrees, time_interval in zip(final_slopes_by_velocity[velocity], time_intervals_minutes_list):

erosion, _ = calculate_erosion(initial_slope_degrees, final_slope_degrees, velocity, time_interval)

erosion_degree_for_velocity.append(erosion)

print("{:<25} {:<25} {:<20.3f}".format(time_interval, final_slope_degrees, erosion))

erosion_degrees.append(erosion_degree_for_velocity)

print("\n")

# Calculate reduction percentage based on erosion degrees for the first and last velocities

reduction_percentages = []

for i in range(len(time_intervals_minutes_list)):

reduction_percentage = ((erosion_degrees[0][i] - erosion_degrees[-1][i]) / erosion_degrees[0][i]) * 100

reduction_percentages.append(reduction_percentage)

# Print reduction percentage table

print("Reduction Percentage:")

print("{:<25} {:<20}".format("Time Interval (minutes)", "Reduction Percentage"))

for time_interval, reduction_percentage in zip(time_intervals_minutes_list, reduction_percentages):

print("{:<25} {:<20.2f}".format(time_interval, reduction_percentage))
```

the above code will provide the output in tabulated form with the erosion degrees and reduction percentage.

The following code, when included, will provide the output for reduction percentage corresponding to each velocity in graphical data

```
# Plot reduction percentages against time intervals for each velocity

for velocity, erosion_degree_for_velocity in zip(velocities, erosion_degrees):

    plt.plot(time_intervals_minutes_list, erosion_degree_for_velocity, label=f'Velocity: {velocity} m/s')

plt.xlabel('Time Interval (minutes)')

plt.ylabel('Erosion Degree')

plt.title('Erosion Degree vs Time Interval')

plt.legend()

plt.grid(True)

plt.show()
```

For predicting the total erosion or accretion happening at the site define the following as well;

```
import math

def calculate_erosion_accretion(velocity_data,
time_interval, relative_density,
original_beach_slope_degrees,
erosion_slope_reduction_degrees):

  total_erosion = 0

  total_accretion = 0

  # Calculate sediment density from relative density

  sediment_density = relative_density * 1000  # Density of
water is 1000 kg/m^3

  for i in range(len(velocity_data)):

    velocity = velocity_data[i]

    time = time_interval[i]

    erosion_slope_reduction =
erosion_slope_reduction_degrees[i]

    # Calculate the slope ratio from the original beach
slope in degrees

    original_slope_ratio =
math.tan(original_beach_slope_radians)

    # Assuming erosion and accretion are proportional to
velocity and adjusted beach slope

    sediment_transport_rate = velocity *
reduced_slope_ratio

    # Calculate erosion or accretion for this time interval

    erosion_accretion = sediment_transport_rate * time *
sediment_density

    # Update total erosion or accretion

    if erosion_accretion < 0:

      total_erosion += abs(erosion_accretion)

    else:

      total_accretion += erosion_accretion

  return total_erosion, total_accretion
```

4 .RESULT AND DISCUSSIONS

4.1 FROM EXPERIMENTAL DATA

The result obtained for the experiment is tabulated below

Table 4.1: Erosion degree– 30 degrees

Time (min)	θ (degree)	Wave velocity 0.06m/s		Wave velocity 0.07m/s		Wave velocity 0.08m/s		Wave velocity 0.09m/s		% reduction
		θ' (degree)	Erosion degree, De	θ' (degree)	Erosion degree, De	θ' (degree)	Erosion degree, De	θ' (degree)	Erosion degree, De	
0	30	30.00	1.00	30.00	1.00	30.00	1.00	30.00	1.00	0.00
5	30	24.62	0.82	22.62	0.75	18.20	0.61	8.53	0.28	65.36
10	30	23.24	0.77	22.08	0.74	16.11	0.54	5.40	0.18	76.79
15	30	21.25	0.71	21.80	0.73	10.08	0.34	2.23	0.07	89.52
30	30	21.21	0.71	21.25	0.71	6.25	0.21	3.18	0.11	85.01
45	30	20.81	0.69	20.70	0.69	5.36	0.18	3.18	0.11	84.72
60	30	20.53	0.68	19.86	0.66	3.20	0.11	3.18	0.11	84.51

From Table 4.1, the extreme case is observed in velocity 0.09m/s after 15 minutes of wave action where the slope noted was almost 2 degrees, Erosion degree at that point is noted as 0.07. After 60 minutes of experiment, it is observed that the erosion degree is reduced by almost 85%. The variation in Erosion degree of 30-degree slope with respect to variation in time and velocities are plotted in Fig. 4.1.

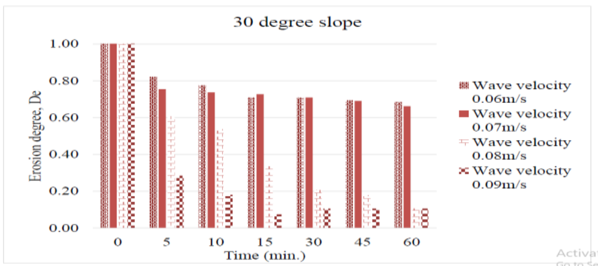


Fig - 4.1: Erosion degree– 30 degrees

From the graph, it was observed that with the increase in velocity, the erosion degree decreases which represents that the amount of soil being eroded away increases. This increase is due to the increased impact caused by the waves. Also, the variation in erosion degree is found to be more in the initial stages of the experiment. The erosion degree appears to be more stable in the final stages which might be an indication of the soil particles trying to achieve a state of stability. Also, at a higher velocity of 0.09m/s, after 15 minutes some of the particles already eroded away are found to be deposited in the initial slope position. This might be due to the swash and backwash effect of the waves.

4.2 FROM AI CODE

From the AI Code the output generated is as given below,

Velocity: 0.06 m/s

Time Interval (minutes)	Final Slope (degrees)	Erosion Degree
0	30	1.000
5	24.62	0.821
10	23.24	0.775
15	21.25	0.708
30	21.21	0.707
45	20.81	0.694
60	20.53	0.684

(a)

Velocity: 0.07 m/s

Time Interval (minutes)	Final Slope (degrees)	Erosion Degree
0	30	1.000
5	22.62	0.754
10	22.08	0.736
15	21.8	0.727
30	21.25	0.708
45	20.7	0.690
60	19.86	0.662

(b)

Velocity: 0.08 m/s

Time Interval (minutes)	Final Slope (degrees)	Erosion Degree
0	30	1.000
5	18.2	0.607
10	16.11	0.537
15	10.08	0.336
30	6.25	0.208
45	5.36	0.179
60	3.2	0.107

Velocity: 0.09 m/s

Time Interval (minutes)	Final Slope (degrees)	Erosion Degree
0	30	1.000
5	8.53	0.284
10	5.4	0.180
15	2.23	0.074
30	3.18	0.106
45	3.18	0.106
60	3.18	0.106

(c)

Reduction Percentage:

Time Interval (minutes)	Reduction Percentage
0	0.00
5	65.35
10	76.76
15	89.51
30	85.01
45	84.72
60	84.51

(d)

Fig 4.2: Erosion degree– 30 degrees code output for different velocities and the reduction percentage

5. CONCLUSIONS

- The erosion degree of soil slopes made in the apparatus was calculated from the experiment.
- It is found that increase in velocity decreases erosion degree which indicates more amount of soil mass eroded.
- Numerical study was conducted using AI codes and the erosion rates are calculated.
- The values of erosion degree obtained from the experiment is comparable to that of the output obtained from the AI code, hence the code is validated.
- Similarly the code can be used to validate the data for different sites

REFERENCES

[1] J. Shaji. Coastal sensitivity assessment for Thiruvananthapuram, west coast of India. *Natural Hazards* **2014**, 73 (3), 1369–1392.

[2] L. Sheela Nair, R. Prasad, M.K. Rafeeque, T.N. Prakash. "Coastal Morphology and Long-term Shoreline Changes along the Southwest Coast of India". *Journal of the Geological Society of India* **2018**, 92 (5), 588–595.

[3] T. Kim, W.-D. Lee. Review on Applications of Machine Learning in Coastal and Ocean Engineering. *Journal of Ocean Engineering and Technology* **2022**, 36 (3), 194–210.

[4] E.B. Goldstein, G. Coco, N.G. Plant. A review of machine learning applications to coastal sediment transport and morphodynamics. *Earth-Science Reviews* **2019**, 194, 97–108.