AI-Driven Assessment Of Coastal Soil Erosion: A Predictive Framework For Veli, Trivandrum

Abstract -Soil erosion in coastal areas is a critical environmental issue that affects land stability, agriculture, and infrastructure. This study explores the use of Artificial Intelligence (AI) techniques to assess soil erosion rates in the coastal regions of Veli. Machine learning models, remote sensing data, and Geographic Information System (GIS) technologies are integrated to develop a predictive framework for soil erosion assessment. The study aims to provide an accurate and automated method for monitoring and mitigating erosion risks.

Keywords_ Soil erosion, coastal erosion, Trivandrum, Artificial Intelligence (AI)

1. INTRODUCTION

Coastal erosion is a critical environmental issue that threatens land stability, infrastructure, and ecosystems. It is caused by natural forces such as waves, tides, and storms, as well as human activities like deforestation and urbanization. Approximately 33.6% of India's coastline is vulnerable to erosion, with 46.4% of Kerala's coastline classified as highly vulnerable. Rising sea levels, global warming, and climate change further accelerate coastal erosion, leading to shoreline retreat and saltwater intrusion into freshwater reserves.

Understanding soil erosion patterns is essential for mitigating its adverse effects. Traditional erosion assessment methods involve field studies and empirical models, which are often labour-intensive and time-consuming.
However, AI-driven approaches offer a more efficient alternative by processing large volumes of satellite imagery, climate data, and topographic information to identify high-risk areas. By integrating machine learning models with Geographic Information System (GIS) technologies, this study aims to develop a predictive framework for assessing and managing soil erosion in the coastal areas of Veli.

2. SOIL EROSION

Soil erosion is a natural process that involves the detachment and transportation of soil particles by various erosive forces such as water, wind, and human activities. In coastal areas, erosion is predominantly driven by wave action, tidal currents, and extreme weather events, leading to the gradual loss of landmass. Human interventions, including deforestation, construction activities, and unsustainable land use practices, further exacerbate soil erosion, disrupting coastal ecosystems and threatening biodiversity.

Coastal erosion is a pressing concern in many regions, particularly in Trivandrum, where a significant portion of the shoreline is classified as highly vulnerable. The primary consequences of soil erosion include loss of fertile topsoil, degradation of agricultural land, increased sedimentation in water bodies, and damage to infrastructure. Additionally, erosion can lead to the displacement of coastal communities and economic losses due to declining land resources.

Climate change intensifies erosion rates by altering precipitation patterns, increasing the frequency of storms, and contributing to rising sea levels. These factors accelerate the breakdown of soil structure, making coastal zones more susceptible to erosion. Mitigation strategies such as afforestation, beach nourishment, and the implementation of protective structures like seawalls and breakwaters are essential in controlling erosion. However, conventional approaches require continuous monitoring and adaptation to changing environmental conditions.

The integration of AI technologies in soil erosion assessment offers a promising solution for real-time monitoring and predictive analysis. Machine learning models can process vast datasets, identify high-risk areas, and forecast erosion trends, enabling proactive measures for coastal management. By leveraging AI-driven insights, policymakers and environmental agencies can develop sustainable strategies to mitigate soil erosion and protect vulnerable coastal regions.

3. LITERATURE REVIEW

Research highlights the vulnerability of coastal regions to erosion due to wave action, tides, and human activities. Remote sensing and GIS technologies have been effectively utilized to monitor shoreline changes and identify high-risk erosion zones. These tools provide crucial insights into historical erosion trends and future projections, aiding in mitigation strategies.

Experimental studies have assessed various erosion control methods, with coir geotextiles proving effective in reducing soil loss and controlling surface runoff. These materials enhance soil stability, decrease erosion rates, and improve water infiltration. Additionally, research on extreme weather events, such as the 2018 Kerala floods, underscores the significant increase in soil erosion following heavy rainfall, emphasizing the need for proactive soil management strategies.

AI-driven research has leveraged machine learning models and artificial neural networks to predict erosion patterns. By incorporating environmental parameters like slope gradient, soil texture, rainfall intensity, and vegetation cover, these models achieve high accuracy in forecasting erosion rates. Advanced deep learning techniques, including Convolutional Neural Networks, have been employed to analyze satellite imagery, facilitating precise detection of erosion-prone areas over time.

Machine learning models like Support Vector Machines and Random Forest have significantly improved erosion zone classification. Hybrid AI frameworks integrating multiple algorithms further enhance predictive accuracy. The combination of AI, remote sensing, and GIS has emerged as a powerful approach for large-scale erosion assessment and monitoring.

Coastal erosion risk assessments emphasize systematic evaluation of hazard and vulnerability indexes. High-resolution remote sensing imagery and GIS methodologies have been used to analyze beach profile changes, erosion rates, and coastal slope variations, playing a key role in developing management strategies.

AI applications extend to geotechnical property assessments, predicting soil characteristics such as liquid limit, plasticity index, and moisture content based on variables like sand and clay composition. Studies confirm that AI models provide reliable estimates of soil properties and their impact on erosion.

Overall, literature underscores AI's role in enhancing soil erosion assessment. The integration of data-driven techniques with remote sensing and field studies offers a comprehensive approach to mitigating coastal erosion. Future research can focus on real-time monitoring, early warning systems, and sustainable erosion control strategies to protect vulnerable coastal regions like Trivandrum.

4. METHODOLOGY

The

experimental setup designed to simulate rainfall and study its impact on soil erosion incorporates several key components to replicate natural conditions and allow precise measurement of erosion rates. The core element of the system is the Rainfall Generator, which is controlled by a programmable Arduino Uno. This generator is capable of adjusting water pressure to produce raindrop sizes ranging from 0.5 mm to 3.0 mm, simulating various rainfall intensities. The Soil Tank used in the setup consists of three tiled walls and a glass front, providing clear visibility for observing soil erosion. The tank is filled with soil samples that are compacted into five distinct layers, replicating the natural stratification of soil, which ensures accurate representation of real-world conditions.

To facilitate the consistent application of water, the Water Supply System includes a pipe grid that ensures uniform distribution over the soil surface, mimicking the natural flow of rainwater. The Runoff Collection system is designed to capture any soil particles that are displaced during the rainfall simulation. A metal tray underneath the soil tank collects the surface runoff, and fine fabric is used to trap the eroded soil while allowing the water to drain freely. This system enables precise measurement of the volume of soil lost during the experiment.

The experimental procedure includes taking Measurements at specific intervals, such as 0, 5, 10, 15, 30, 45, and 60 minutes, to determine erosion rates. The weight of the soil collected in the runoff tray is recorded and analyzed to quantify erosion. Additionally, changes in the soil slope angle are monitored before and after the rainfall to assess the impact of erosion on terrain stability. Control experiments are conducted with and without the addition of Coir Geotextiles, an erosion control material, to evaluate its effectiveness in mitigating soil erosion under different rainfall intensities. This comprehensive experimental setup allows for a detailed analysis of the factors influencing soil erosion in coastal regions, particularly under the influence of rainfall.

(a) Experimental setup

(b) Experimental modelling

5. INTRODUCTION OF AI IN EROSION ASSESSMENT

The integration of Artificial Intelligence (AI) in rainfall action experiments enhances the understanding and prediction of soil erosion under simulated rainfall conditions. AI algorithms, particularly machine learning, analyze complex data from experiments, such as erosion rates, runoff patterns, and soil properties. These models can identify trends and predict erosion rates under various rainfall intensities, improving the accuracy of experimental results. Additionally, AI aids in real-time monitoring of soil changes and evaluates the effectiveness of erosion control measures like coir geotextiles. This approach provides more precise and adaptive solutions, making AI a valuable tool in studying and mitigating rainfall-induced soil erosion in coastal environments.

The code for calculating rainfall erosion degree as follows:

```
byte pulses;

unsigned long t, totalML;

void setup ()

{
 Serial.begin(9600);


Attach interrupt (0, [] {pulses ++;},
RISING);

}

void loop () {

 if (Serial.available()) {

    static bool run = false;

    run = Serial.read() == 's' ? 1 :

Serial.read() == 'e' ? 0 : run;

  if (run && millis () - t > 1000) {

      float flow = pulses * 1000.0 / (millis ()
- t) / 4.5;

    totalML += (flow / 60) * 1000;

    pulses = 0;

     t = millis ();

  Serial.print("Flow: ");
 Serial.print(int(flow)); Serial.print("
```

```
L/min\tOut: ");

    Serial.print(totalML); Serial.print(" ML\t"); Serial.println(totalML / 1000);

    if (!run) Serial.println("s: Start, e: Stop");
```

6. RESULT AND DISCUSSION

FROM EXPERIMENTAL DATA

The result obtained for the experiment is tabulated below

SAMPLE	INITIAL MASS OF SOIL (kg)	TIME INTERVAL (mins)	SURFACE FLOW VOLUME (L)		
			FLOW RATE 3.5L/min	FLOW RATE 6.5L/min	FLOW RATE 19L/min
TVS1	30kg	0	0	0	0
		5	9.1	16.2	19.4
		10	10.64	15.42	20.86
		30	12.72	18.62	22.48
		45	18.34	21.22	25.32
		60	22.12	25.62	29.14
	FINAL MASS OF SOIL (kg)	1.02	1.93	2.36	
	VOLUME OF SOIL EROSION (L)	22.12	25.62	29.14	
	MASS OF SOIL EROSION (kg)	1.02	1.93	2.36	
	EROSION RATE (kg/min)	0.017	0.032	0.039	

Table 1: Erosion rate at 19L/min (treated)

SAMPLE	INITIAL MASS OF SOIL (kg)	TIME INTERVAL (mins)	SURFACE FLOW VOLUME (L)		
			FLOW RATE 3.5L/min	FLOW RATE 6.5L/min	FLOW RATE 19L/min
TVS1	30kg	0	0	0	0
		5	12.1	19.9	22.6
		10	13.3	21.1	24.8
		30	20.7	23.4	27.5
		45	24.3	28.7	31.9
		60	28.6	31.6	35.3
	FINAL MASS OF SOIL (kg)	2.3	2.9	3.2	
	VOLUME OF SOIL EROSION (L)	28.6	31.6	35.3	
	MASS OF SOIL EROSION (kg)	2.3	2.9	3.2	
	EROSION RATE (kg/min)	0.03	0.04	0.05	

Table 2: Erosion rate at 19 L/min (untreated)

FROM LAB TEST

Sample →	TVS1		
Properties↓	December	January	February
Specific Gravity	2.43	2.47	2.46
Moisture Content	6.8%	3.87%	4.2%
Direct Shear	C=0.11 Ø=41^0	C=0.15 Ø=31^0	C=0.16 Ø=29^0
Permeability (cm/sec)	$14*10^{-3}$	$21*10^{-3}$	$18*10^{-3}$
Sieve Analysis (D50)	1.27	1.23	1.25

FROM AI CODE

```
Output

Beach Slope: 18.33° (Initial Weight: 30 kg, Time Interval: 60 min)
Flow Rate: 3.5 L/min,
Final Weight after erosion: 1.02 kg, Erosion Degree (calculated): 0.03,
Total Erosion: 0.12 kg/hr

Flow Rate: 6.5 L/min,
Final Weight after erosion: 1.93 kg, Erosion Degree (calculated): 0.06,
Total Erosion: 0.81 kg/hr

Flow Rate: 19 L/min,
Final Weight after erosion: 2.36 kg, Erosion Degree (calculated): 0.08,
Total Erosion: 3.53 kg/hr
```

Fig c. Erosion degree –output for different flow rate

7. CONCLUSIONS

•Higher velocity increases soil erosion due to stronger surface flow.

•Greater wave velocity leads to more soil displacement.

•More rainfall increases surface runoff and erosion, especially on loose soils.

•Finer soils erode more, while compact/clay-rich soils resist erosion.

• Treated soil shows less runoff and erosion than untreated soil.

8. REFERENCES

1. Al Balasmeh, O., Karmaker, T., & Babbar, R. (2023). Experimental investigation and modelling of rainfall-induced erosion of semi-arid region soil under various vegetative land covers. Journal of Hydroinformatics, 25(3), 1029–1053.

2. Apollonio, C., Petroselli, A., Tauro, F., Cecconi, M., Biscarini, C., Zarotti, C., & Grimaldi, S. (2021). Hillslope Erosion Mitigation: An Experimental Proof of a Nature-Based Solution. Sustainability, 13(11), 6058.

3. Baig, M. R. I., Ahmad, I. A., Shahfahad, Tayyab, M., & Rahman, A. (2020, October 1). Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: an application of digital shoreline analysis system (DSAS). Annals of GIS, 26(4), 361–376.

4. Chinnasamy, P., Honap, V. U., & Maske, A. B. (2020, September 10). Impact of 2018 Kerala Floods on Soil Erosion: Need for Post-Disaster Soil Management. Journal of the Indian Society of Remote Sensing, 48(10), 1373–1388

5. Galiforni Silva, F., Wijnberg, K. M., de Groot, A. V., & Hulscher, S. J. (2019). The effects of beach width variability on coastal dune development at decadal scales. Geomorphology, 329, 58–69. 26

6. Gangapriya P, Indulekha K P (2013), "Development of GIS based disaster risk information system for decision making ", Proceedings Of International Conference On Energy And Environment-2013 (ICEE 2013)

7. Gaviola, J. C. L., Borong, B. L. G., Cutanda, S. M. R., & Loreto, E. G. (2020, May 31). Effectiveness of coconut fiber geotextile and vetiver grass as bio-engineering technique in mitigating soil erosion along bato bontoc road. International Journal of Engineering Applied Sciences and Technology, 5(1), 13–19.

8. Gholami, V., Sahour, H., & HadianAmri, M. A. (2021). Soil erosion modeling using erosion pins and artificial neural networks. CATENA, 196, 104902. https://doi.org/10.1016/j.catena.2020.104902

9. Goldstein, E. B., Coco, G., & Plant, N. G. (2019, July). A review of machine learning applications to coastal sediment transport and morphodynamics. Earth-Science Reviews, 194, 97–108.

10. Guo, Z., Ma, M., Cai, C., & Wu, Y. (2017). Combined effects of simulated rainfall and overland flow on sediment and solute transport in hillslope erosion. Journal of Soils and Sediments, 18(3), 1120–1132.