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Numerical Analysis of Shoreline Changes along the Coast Batu Hiu-Bojong Salawe, Pangandaran Regency, West Java Province, Indonesia

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ABSTRACT

Shoreline change poses a significant challenge in coastal regions, leading to issues such as abrasion, soil erosion, and the loss of valuable land. This problem is prevalent in various areas of Pangandaran, particularly in the Batu Hiu-Bojong Salawe coastal region of Pangandaran Regency, West Java, Indonesia. The objective of this study is to analyse and quantify the distance and rate of shoreline changes occurring over a decade (2010-2019) in the Batu Hiu-Bojong Salawe coastal area. Utilizing ArcMap software and the Digital Shoreline Analysis System (DSAS), this research aims to provide insights into the coastal dynamics, drawing analytical points from comparable studies for a comprehensive understanding. Batu Hiu's western coast faces substantial erosion (29.70m, LLR 3.10 m/year, EPR 3.22 m/year), while the east experiences accretion (52.76m, LLR/EPR 5.49 m/year, 5.72 m/year). Coastal dynamics, influenced by rocky structures, lead to sedimentation and erosion. Bojong Salawe Beach sees noteworthy accretion (83.01m, LRR/EPR 8.88 m/year, 9.00 m/year), with a maximum at transect 85 (134.5m, LRR 14.27 m/year, EPR 14.58 m/year). Erosion at transects 104 and 107 averages 30.47m, with LLR/EPR rates of 3.41 m/year and 3.3 m/year. The Cijulang River estuary contributes to coastal stability, resulting in significant accretion. This information is vital for coastal management, offering insights to address erosion and accretion impacts in Batu Hiu and Bojong Salawe coastal areas.

1. Introduction

Coastal regions represent some of the most dynamic and rapidly changing environments on Earth [1]. The coastal regions of Indonesia, characterized by their ecological richness and cultural significance, are experiencing dynamic transformations in their shoreline configurations [2]. These

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changes are often attributed to a complex interplay of natural processes and anthropogenic activities [3]. The dynamics of coastlines, encompassing changes in erosion, equilibrium, and accretion, constitute a fascinating and complex natural phenomenon [4]. Erosion occurs when the coastline retreats inland, resulting in the thinning of coastal areas as illustrated in Figure 1. Erosion due to sediment transport and coastal structures can lead to the gradual reshaping of shorelines and impact nearby infrastructure [5,6]. On the other hand, equilibrium indicates stability, where the coastline remains relatively constant without significant changes. Meanwhile, accretion describes the expansion of coastal areas seaward, creating additional space for coastal ecosystems [7].

Fig. 1. Impact of Coastal Erosion in Batu Hiu-Bojong Salawe

A profound understanding of these dynamics is key to sustainable coastal management because changes in the coastline can have significant impacts on the environment, economy, and communities dependent on coastal regions [8]. Therefore, continuous research and monitoring of coastline dynamics are crucial to inform effective coastal policies and environmental conservation efforts. The following are some researchers conducting studies related to coastline changes in Java [9-12]. Study [9] examines the influence of groin application on erosion along the northern shoreline of Balongan, West Java. The modelling of shoreline changes in this research utilizes software called GENESIS. The results of this study indicate that the T-groin effectively mitigated erosion and accretion the coastline by 10,786.62 m^2, or an average of 6.3 meters. Study [10] analyses the shoreline changes in Pamurbaya and Sidoarjo, East Java. This research employs the Digital Shoreline Analysis System (DSAS) technique to identify and measure erosion (retreat of the shoreline) and accretion (shoreline advancement). The research findings reveal the highest accretion distance of 991.57 meters in the Mulyorejo area and the highest erosion distance of 928.75 meters in the Sidoarjo region. Paper [11] examines shoreline change along the northern segment of the Gresik coastal region in East Java, Indonesia. The presence of erosion and accretion was identified and analysed using multi-temporal satellite imagery spanning from 1972 to 2016. The most significant erosion was noted in Ngemboh village, leading to a retreat of the coastline by 242.56 meters inland, with a yearly movement rate of -5.54 meters during the period from 1972 to 2016. Conversely, the Campurejo area demonstrated relative stability, attributed to the implementation of artificial structures like a jetty and groin. Paper [12] investigates shoreline changes along the Kendal Coastal Area in Central Java. The data utilized in this study were obtained from TM data in 1990 to OLI data in 2017. The most extensive accretion process measured 1763.29 meters, while the abrasion processes covered a distance of 792.14 meters.

Current research in coastal management is undergoing a transformation phase with the development and utilization of the Digital Shoreline Analysis System (DSAS) [13-19]. This advanced system integrates advanced technologies such as remote sensing, Geographic Information Systems (GIS), and numerical modelling to provide comprehensive insight into coastal dynamics and shoreline change. The Digital Shoreline Analysis System (DSAS) represents a sophisticated tool in the realm of coastal management, offering valuable insights into shoreline dynamics and changes. DSAS integrates cutting-edge technologies, including remote sensing, Geographic Information Systems (GIS), and numerical modelling, to provide a comprehensive understanding of coastal environments. Its capacity lies in its ability to analyse and monitor shoreline changes with a high degree of accuracy, aiding researchers and decision-makers in making informed choices for sustainable coastal development. However, like any tool, DSAS has its limits. Its effectiveness is contingent on data quality and availability, and it may face challenges in accurately capturing complex coastal processes. Recognizing both its capabilities and limitations is essential for maximizing the utility of DSAS in advancing coastal research and management.

The Batu Hiu-Bojong Salawe coastal stretch is not only environmentally significant but also economically vital for the local communities. The intricate balance between coastal landforms, sediment dynamics, and human activities in this region necessitates a thorough investigation into the spatiotemporal evolution of its shoreline. Recognizing the importance of quantitative analysis, this research endeavours to provide a comprehensive understanding of the factors influencing shoreline changes and their implications for coastal management. The Batu Hiu-Bojong Salawe coastal area, situated within the Pangandaran Regency of West Java Province, presents a compelling case study for understanding and quantifying these shoreline dynamics. The examination and analysis of coastal zones are crucial for monitoring the vulnerability of coastlines to factors such as bio-resource degradation, sea-level rise, coastal erosion, seawater intrusion, and coral bleaching. This process allows us to predict the dynamic state of shoreline trends, providing valuable insights for understanding and addressing the various challenges faced by coastal environments. In response to the pressing need for accurate assessments of coastal changes, this study employs the Digital Shoreline Analysis System (DSAS) to conduct a numerical analysis of shoreline changes along the Batu Hiu-Bojong Salawe coast.

2. Methodology

2.1 Study Area

The research area covers the coastal stretch from Batu Hiu to Bojong Salawe, located in Pangandaran Regency, West Java Province, Indonesia, as indicated in Figure 2. This coastal area serves as the focus of the study for shoreline mapping to quantify erosion and accretion over a span of 9 years (2010-2019). The study is situated at 7.41 to 7.50^0 North latitude, 108.41 to 109^0 East longitude. The coastal regions of Batu Hiu and Bojong Salawe are well-known tourist attractions in Pangandaran Regency and are part of a special economic zone in the region. Notably, a national harbour area has been established in Pangandaran Regency to support economic sectors. However, over the past 10 years, the coastal areas of Batu Hiu and Bojong Salawe have consistently faced pressures from both physical and non-physical processes. These threats, induced by hydrodynamic factors of the Indian Ocean (such as wind, waves, and currents), can easily mobilize sediment materials in this area due to the loose composition of these materials, making them susceptible to erosion and redeposition in response to disturbances.

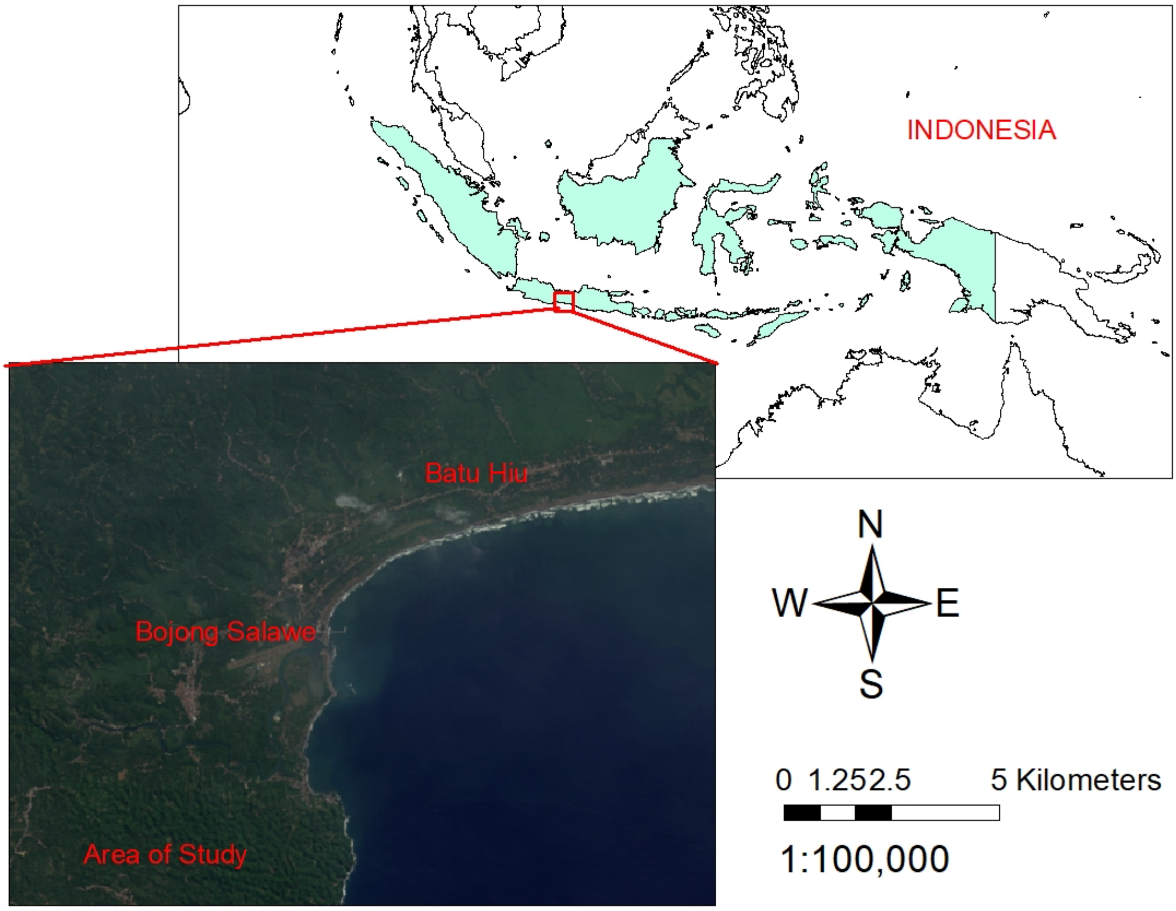

Fig. 2. Area of Study

2.2 Shoreline Data

Dataset used in this research consists of Landsat 7 images from the year 2010, and Landsat 8 images from the years 2014 and 2019. The Landsat images used for this study were downloaded from the USGS Earth Explorer web tool (https://earthexplorer.usgs.gov/). The Landsat system has been widely employed in remote sensing applications for monitoring coastal environmental changes and other related studies [20-22]. The acquired Landsat images had low cloud cover values (<15%). Image rectification was conducted in UTM projection using the UTC-WGS-1984 datum and zone 51S. Shoreline changes were identified through an interdisciplinary approach, integrating remote sensing technology and GIS. Satellite images were downloaded considering the file recovery date. The images were retrieved on days of the same season to anticipate the run-up process caused by rain. In this research, image retrieval dates were chosen from the dry season in Indonesia, which typically occurs from April to October [14]. Detailed information for each image and band used in this study is provided in Table 1.

Table 1
Details of Landsat Images for Shoreline extraction

Acquisition date	Satellites	Sensor	Band	Resolution (meter)
12/04/2010	Landsat 7	ETM+	2 (Green), 4 (NIR)	30
02/07/2014	Landsat 8	OLI	3 (Green), 5 (NIR)	30
02/07/2019	Landsat 8	OLI	3 (Green), 5 (NIR)	30

2.3 Shoreline Analysis in DSAS

In this study, the digital shoreline analysis system (DSAS) version 5.1 (an extension of ArcGIS) was used to calculate shoreline changes. The process involved four steps: shoreline preparation, baseline creation, transect generation, and shoreline change rate calculation, as illustrated more clearly in Figure 3.

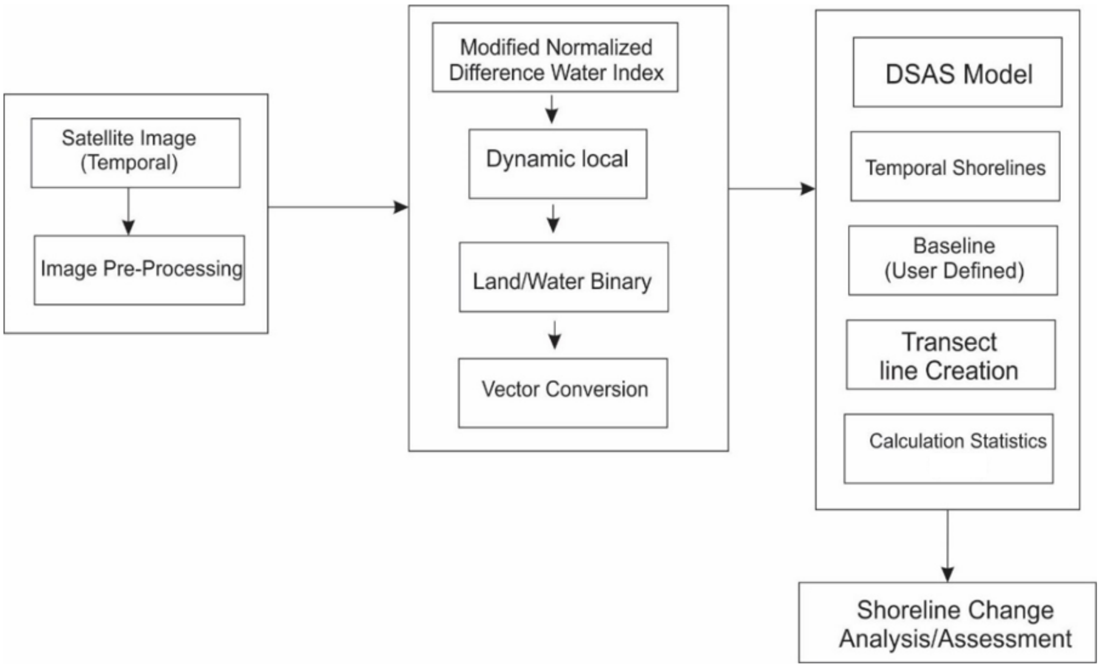

Fig. 3. Methodology for Shoreline Change

The shorelines from different years (2010, 2014, 2019) were digitized and added to a single shapefile in a personal geodatabase, as shown in Figure 4. In the context of shoreline mapping, it is crucial to record and track the acquisition date of shoreline imagery or data. Therefore, the date information was added as an attribute in MM/DD/YYYY format, facilitating users to track and understand changes over time. Additionally, the baseline used in this mapping was represented in a projected meter coordinate system. With this coordinate system, we could measure and map shoreline changes with high accuracy, enabling better monitoring of coastal dynamics. Transects, each spanning 2000 meters perpendicular to the coastline with a 100-meter interval along the shoreline from the baseline, were placed. Measurements were conducted using transect tools within DSAS at a buffer distance of 1500 meters. In total, 160 transects were created for monitoring. Data from transect feature classes were utilized to calculate changes in the coastal area effectively.

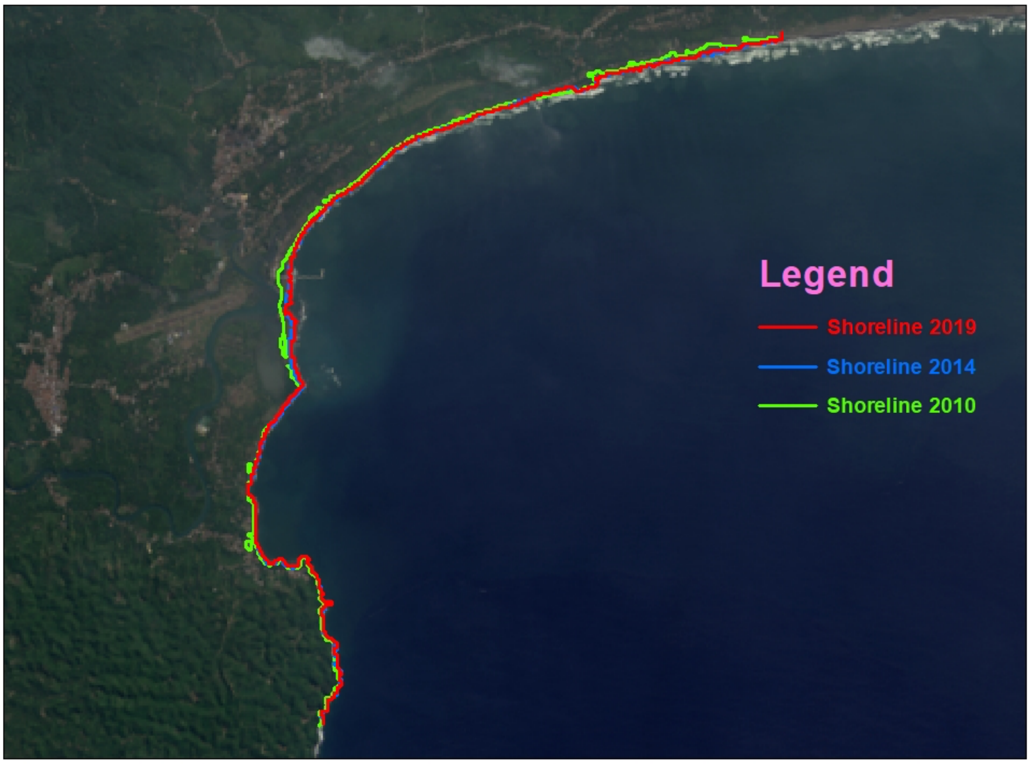

Fig. 4. Shoreline Data

3. Results and Discussion

In this study, statistical methods such as net shoreline movement (NSM), linear regression rate (LRR), and end point rate (EPR) were employed. Net Shoreline Movement (NSM) is a statistical parameter crucial in coastal studies. It quantifies the real distance between the oldest and most recent shorelines for each transect positioned perpendicular to the coastline [23]. The graph illustrating the changes in Net Shoreline Movement (NSM) from this study can be found in Figure 5 and Figure 6, providing a clear visualization of the coastline evolution during the research period. NSM provides valuable insights into the dynamic changes occurring along the coastal areas, aiding researchers in understanding the patterns and trends of shoreline evolution over time. This parameter serves as a fundamental tool for assessing erosion, accretion, and overall coastal stability, contributing significantly to the broader field of coastal management and environmental monitoring. Positive values of shoreline change rate indicate accretion, while negative values indicate erosion [18]. The outputs were formatted as tables in the same personal geodatabase after completing the statistical analysis.

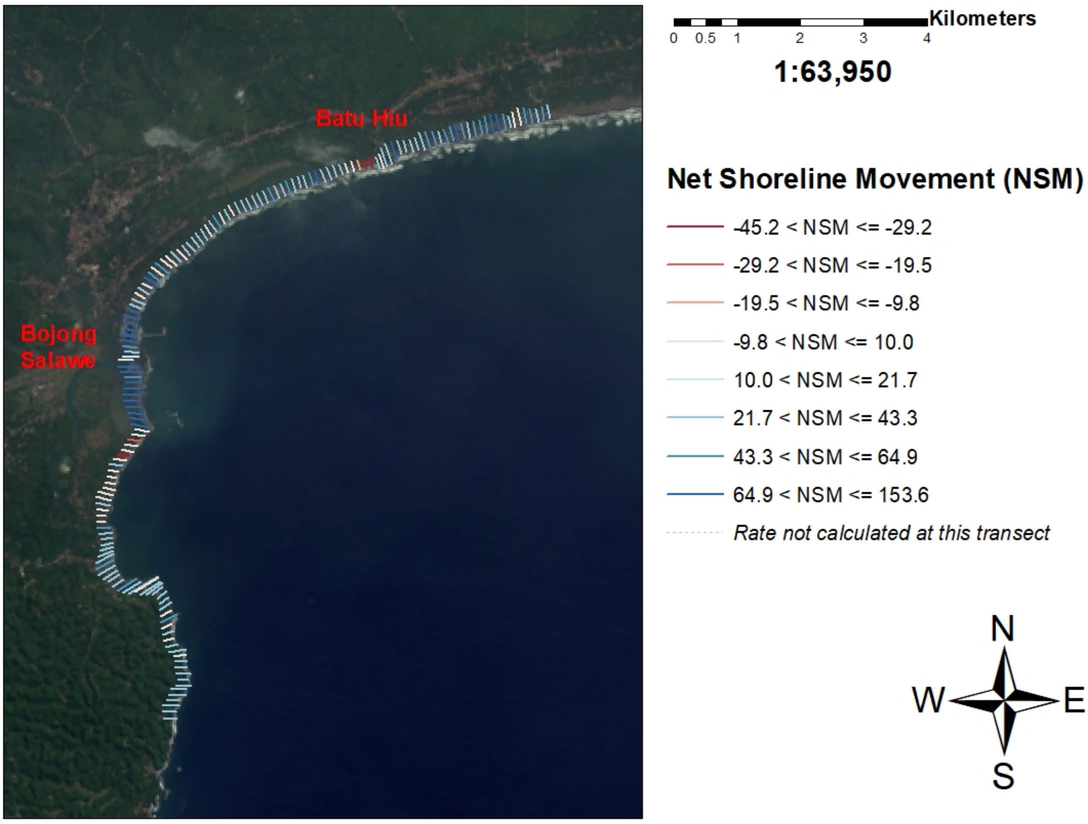

Fig. 5. Superimpose the Net Shoreline Movement (NSM) onto the map

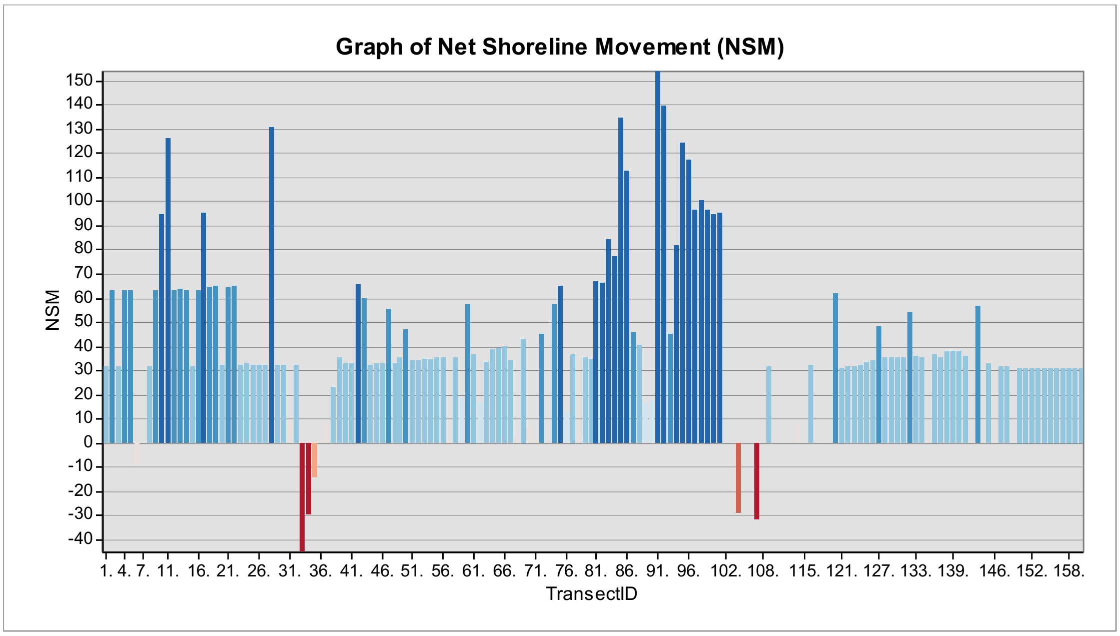

Fig. 6. Graph of Net Shoreline Movement (NSM)

The Linear Regression Rate (LRR) is a crucial method in coastal research. This method utilizes the least squares quadratic regression approach to estimate the rate of variation by considering all shoreline points of a transect. The primary advantage of LRR lies in its inclusivity of all data without regard to modifications in trends or accuracy, making it a reliable method for analysing shoreline changes. The results of the LRR calculations from this study are presented in Figure 7, while Figure 8 visualizes these results in a more detailed graph format. The computational calculation process is based on widely accepted statistical concepts presented by Zoysa *et al.,* [18], Baig *et al.,* [16] and Natesan *et al.,* [23]. LRR is also recognized as the most suitable method for predicting future shoreline positions and their associated confidence intervals [24]. Its reliability makes it a highly valuable tool in understanding shoreline evolution and coastal management.

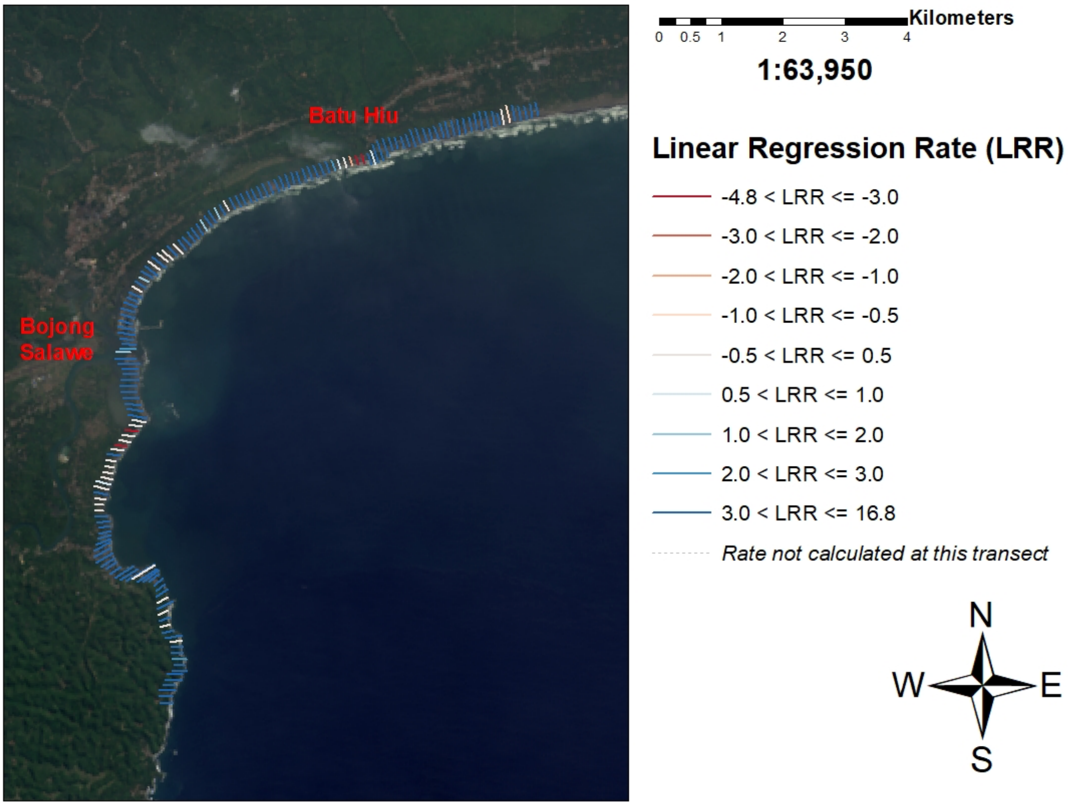

Fig. 7. Superimpose the Linear Regression Rate (LRR) onto the map

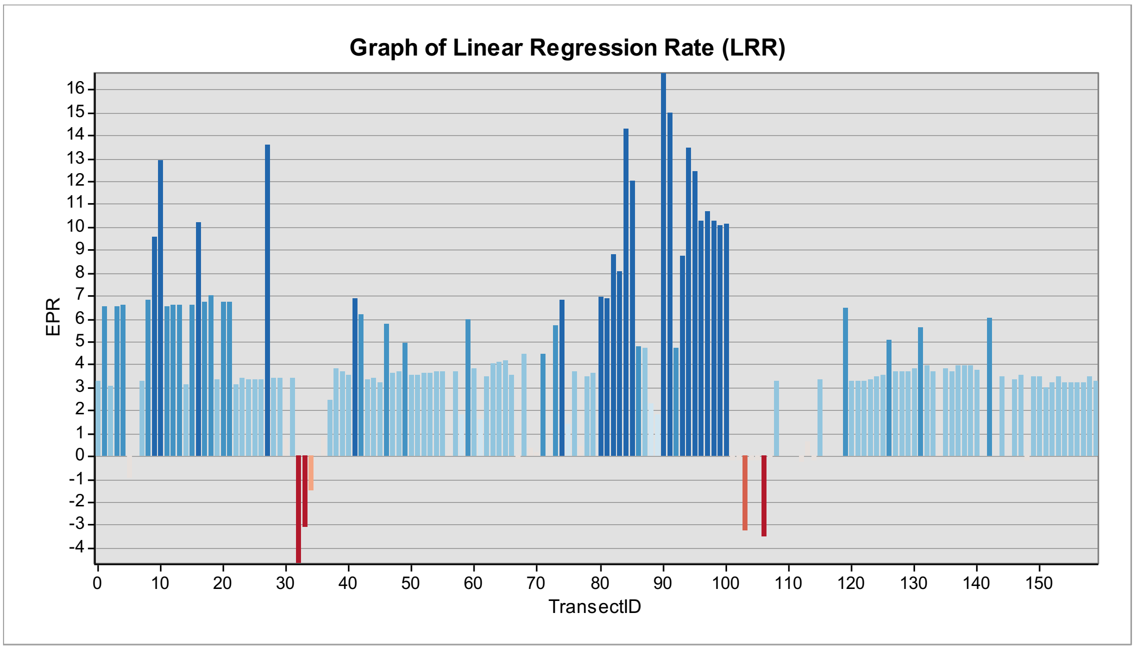

Fig. 8. Graph of Linear Regression Rate (LRR)

The End Point Rate (EPR) is a calculation that yields a value by dividing the Net Shoreline Movement (NSM) by the time elapsed between the oldest and the most recent shoreline [23]. To perform this calculation, at least two shoreline dates are required, along with additional information such as erosion and accretion rates, magnitude, or cyclical trends, if such data is available. This process provides an overview of shoreline changes over time and offers further insights into the potential dynamics of the coastal area. The approximate results of the EPR calculation are presented in Figure 9.

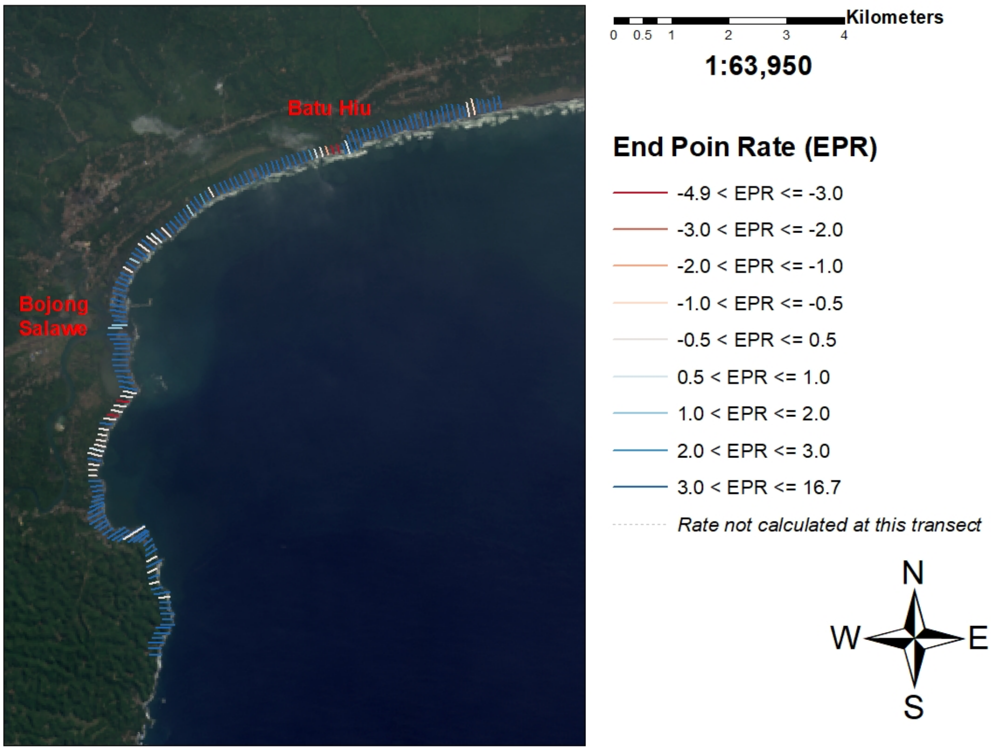

Fig. 9. Superimpose the End Point Rate (EPR) onto the map

Meanwhile, Figure 10 illustrates a clearer presentation of the EPR calculation results in the form of a bar graph.

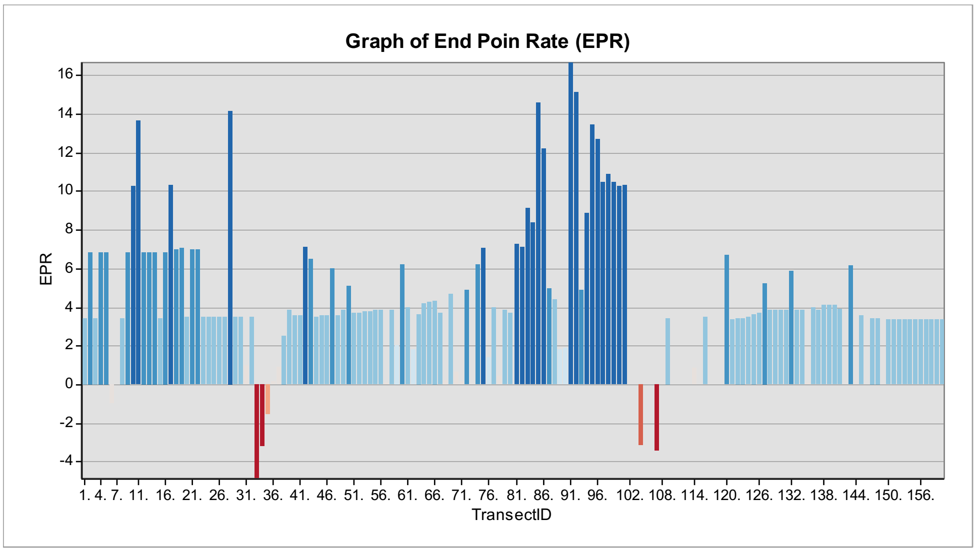

Fig. 10. Graph of End Point Rate (EPR)

Based on the research findings depicted in Figure 5 to Figure 10, it can be concluded that the western coast of Batu Hiu, particularly at transect positions 31, 32, and 33 (Figure 6), experiences significant erosion with lengths of 45.12 m, 29.75 m, and 14.24 m, respectively. Meanwhile, for the detailed numerical values of this analysis, you can refer to Table 2 in the appendix. The erosion rates (LLR) for these transects are 4.71 m/year, 3.11 m/year, and 1.49 m/year, while the end point rates (EPR) are 4.89 m/year, 3.23 m/year, and 1.54 m/year. Conversely, the eastern coast of Batu Hiu, especially from transects 1 to 30, undergoes accretion overall, except for transect 6, which experiences erosion over a length of 8.79 m with LLR and EPR rates of 0.98 m/year and 0.95 m/year, respectively. Overall, the average accretion on this coastal part reaches 52.76 m, with average LLR and EPR rates of 5.49 m/year and 5.72 m/year, respectively. The most significant accretion is recorded at transect 28 with a value of 130.35 m and LLR and EPR rates of 13.62 m/year and 14.13 m/year, respectively.

Table 2
DSAS Output

Transect No	NSM (m)	LRR (m/year)	EPR (m/year)	Transect No	NSM (m)	LRR (m/year)	EPR (m/year)
1	31.43	3.28	3.41	81	66.57	6.95	7.22
2	62.72	6.55	6.8	82	65.84	6.87	7.14
3	31.42	3.05	3.41	83	84.09	8.78	9.12
4	62.69	6.54	6.8	84	77.09	8.05	8.36
5	62.82	6.56	6.81	85	134.5	14.27	14.58
6	-8.79	-0.98	-0.95	86	112.42	11.97	12.19
7	0	0	0	87	45.77	4.79	4.96
8	31.53	3.29	3.42	88	40.6	4.74	4.4
9	62.95	6.8	6.83	89	16.74	2.29	1.81
10	94.28	9.61	10.22	90	17.23	1.84	1.87
11	125.97	12.92	13.66	91	153.6	16.72	16.66
12	63.24	6.52	6.86	92	139.3	15	15.11
13	63.3	6.61	6.86	93	45.14	4.71	4.89
14	63.18	6.59	6.85	94	81.67	8.75	8.86
15	31.54	3.16	3.42	95	124.24	13.43	13.47
16	63.13	6.59	6.85	96	116.91	12.43	12.68
17	95.23	10.17	10.33	97	96.44	10.3	10.46
18	64.15	6.7	6.96	98	100.33	10.7	10.88
19	64.85	7.01	7.03	99	96.1	10.26	10.42
20	32.08	3.35	3.48	100	94.27	10.07	10.22
21	64.31	6.71	6.97	101	95.03	10.15	10.31
22	64.57	6.74	7	102	0	-0.23	0
23	32.35	3.14	3.51	103	0	-0.23	0
24	32.4	3.38	3.51	104	-29.18	-3.26	-3.16
25	32.22	3.36	3.49	105	0	-0.23	0
26	32.14	3.35	3.48	106	0	-0.23	0
27	32.2	3.36	3.49	107	-31.75	-3.55	-3.44
28	130.35	13.62	14.13	108	0	-0.01	0
29	32.34	3.38	3.51	109	31.49	3.29	3.41
30	32.29	3.37	3.5	110	0	0	0
31	8.77	0.74	0.95	111	0	0	0
32	32.32	3.37	3.5	112	0	0	0
33	-45.12	-4.71	-4.89	113	0	-0.24	0
34	-29.75	-3.11	-3.23	114	7.51	0.6	0.81
35	-14.24	-1.49	-1.54	115	0	-0.2	0
36	1	0.1	0.11	116	31.84	3.32	3.45
37	8.06	0.84	0.87	117	0	0	0
38	23.37	2.44	2.53	118	0	0	0

39	35.04	3.81	3.8	119	0	0	0
40	32.77	3.66	3.55	120	61.89	6.46	6.71
41	32.77	3.54	3.55	121	31.05	3.24	3.37
42	65.62	6.85	7.12	122	31.31	3.27	3.4
43	59.44	6.2	6.45	123	31.64	3.3	3.43
44	32.22	3.36	3.49	124	32.22	3.36	3.49
45	32.42	3.38	3.52	125	33.1	3.45	3.59
46	32.58	3.2	3.53	126	34.23	3.57	3.71
47	55.23	5.76	5.99	127	48.38	5.05	5.25
48	32.93	3.6	3.57	128	35.38	3.69	3.84
49	35.22	3.68	3.82	129	35.38	3.69	3.84
50	46.92	4.9	5.09	130	35.38	3.69	3.84
51	33.95	3.54	3.68	131	35.41	3.83	3.84
52	34.2	3.57	3.71	132	53.97	5.63	5.85
53	34.51	3.6	3.74	133	35.62	3.98	3.86
54	34.86	3.64	3.78	134	35.35	3.69	3.83
55	35.08	3.66	3.8	135	0.81	0.09	0.09
56	35.18	3.67	3.82	136	36.29	3.79	3.94
57	0.53	0.06	0.06	137	35.58	3.71	3.86
58	35.46	3.7	3.85	138	37.89	3.96	4.11
59	18.72	1.83	2.03	139	37.98	3.96	4.12
60	56.9	5.94	6.17	140	38.11	3.98	4.13
61	36.39	3.8	3.95	141	36.12	3.76	3.92
62	16.85	1.61	1.83	142	0	0	0
63	33.56	3.47	3.64	143	56.57	6.07	6.13
64	38.37	4	4.16	144	0	0	0
65	39.18	4.09	4.25	145	32.97	3.44	3.57
66	39.97	4.17	4.33	146	0	0	0
67	33.77	3.53	3.66	147	31.73	3.31	3.44
68	1.61	-0.14	0.17	148	31.42	3.51	3.41
69	42.77	4.46	4.64	149	0	-0.23	0
70	6.04	0.35	0.65	150	31.04	3.47	3.37
71	1.38	0.14	0.15	151	30.96	3.46	3.36
72	44.99	4.43	4.88	152	30.95	3	3.36
73	0	0	0	153	30.94	3.23	3.36
74	57.17	5.68	6.2	154	30.94	3.46	3.36
75	64.99	6.78	7.05	155	30.94	3.23	3.36
76	13.08	1.37	1.42	156	30.94	3.23	3.36
77	36.59	3.68	3.97	157	30.95	3.23	3.36
78	3.93	0.41	0.43	158	30.95	3.23	3.36
79	35.48	3.44	3.85	159	30.98	3.46	3.36
80	34.31	3.58	3.72	160	31.06	3.24	3.37

Erosion along the western coast and accretion on the eastern coast of Batu Hiu are attributed to the rocky structure protruding towards the sea. This structure forms a rock formation that extends into the sea. Based on the research conducted by Subiyanto *et al.,* [25], sedimentation flow rates along the Pangandaran coast tend to move westward, following the global sedimentation flow on the south coast of Java. Consequently, the sediment flow towards the west cause's sediment accumulation on the eastern part of Batu Hiu's coast, while the western part experiences sediment reduction, eventually leading to erosion over time. This information provides crucial insights into shoreline changes that can aid in coastal management and mitigate the impact of erosion in the Batu Hiu region.

Based on the results of this study, the coastline changes of Bojong Salawe Beach from 2010 to 2019 are illustrated in Figure 6. Significant accretion occurred on this part of Bojong Salawe Beach, particularly in transects 80 to 100, with an average accretion of 83.01 meters, an average LRR of 8.88 meters per year, and an average EPR of 9.00 meters per year. The maximum accretion was observed at transect number 85 with an NSM value of 134.5 meters, an LRR of 14.27 meters per year, and an EPR of 14.58 meters per year. On the other hand, erosion occurred at only a few points on the Bojong Salawe Beach, specifically at transects 104 and 107, with an average erosion of 30.47 meters, an average LRR of 3.41 meters per year, and an average EPR of 3.3 meters per year. This is attributed to the relatively simple processes on this part of Bojong Salawe Beach, where coastal structures in the form of groins and the Cijulang River estuary are present. The presence of groins can contribute to the stability of the coastline [5]. According to research conducted by Hidayat *et al.,* [5] on the impact of coastal development on coastline changes, sediment flow towards the west (right) can cause accretion on the left side of coastal structures, while erosion may occur on the right side. In the case of Bojong Salawe Beach, accretion is indeed observed on the east side of the groin, aligning with the findings of Hidayat *et al.,* [5]. However, on the west side of the groin, there is no erosion; instead, significant accretion is noted. This is due to the presence of the Cijulang River. The Cijulang River introduces sediment from its upstream to the estuary of Bojong Salawe Beach.

4. Conclusions

Significant erosion affects Batu Hiu's western coast, with an average length of 29.70 m, LLR rates of 3.10 m/year, and EPR rates of 3.22 m/year. The eastern coast experiences overall accretion, averaging 52.76 m, with LLR/EPR rates of 5.49 m/year and 5.72 m/year. The coastal dynamics are linked to the protruding rocky structure towards the sea. Sedimentation flow along Pangandaran's coast moving westward causes sediment accumulation on the east, leading to erosion on the west. Bojong Salawe Beach displays significant accretion from 2010 to 2019. Notable accretion at transects 80 to 100 averages 83.01 meters, with LRR/EPR rates of 8.88 m/year and 9.00 m/year. Maximum accretion at transects 85 is 134.5 meters, with LRR of 14.27 m/year and EPR of 14.58 m/year. Erosion at transects 104 and 107 averages 30.47 meters, with LRR/EPR rates of 3.41 m/year and 3.3 m/year. The Cijulang River estuary contributes to coastline stability, causing significant accretion on the Bojong Salawe Beach. This information provides crucial insights into shoreline changes, aiding in coastal management to mitigate the impacts of erosion and accretion in the coastal areas of Batu Hiu and Bojong Salawe.

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