UDC 332; 639

ANALYSIS OF COASTLINE CHANGES ON GILI TRAWANGAN OVER THE LAST TEN YEARS, 2013 TO 2023

Virgota Arben*
Postgraduate School, University of Brawijaya, Malang & Faculty of Mathematics and Natural Sciences, University of Mataram, West Nusa Tenggara, Indonesia

Ciptadi G., **Yanuwiyadi B.**, **Efani A.**
Postgraduate School, University of Brawijaya, Malang, Indonesia

*E-mail: whindy.ppsub@gmail.com

ABSTRACT
Gili Trawangan's development negatively impacts the small island's shoreline, causing erosion and accretion. This development, influenced by human activities, can negatively affect the local community, health infrastructure, and ecological balance. Research on changes in the shoreline is crucial for early warning in managing marine tourism on small islands. The study utilized satellite images, Landsat 8 OLI images, and Landsat 9 images for remote sensing. The Digital Shoreline Analysis System (DSAS) was used to monitor coastline changes, using Net Shoreline Movement (NSM) to calculate changes. Based on the length of the coastline, the Northwest and Northeast zones experienced widespread erosion and accretion, while the Southeast and Southwest zones experienced less. The Northeast and southwest zone experiences the most significant erosion, resulting in substantial land loss every year. At the same time, the northeast and northwest zones experienced significant accretion than others. Overall, Gili Trawangan experienced erosion of 6.77 hectares and accretion of 0.4 hectares, which means a reduction in area of 6.34 hectares over 10 years or 0.634 hectares per year. Rapid development and tourism promotion policies contribute to environmental changes that exacerbate erosion. A comprehensive and sustainable approach is needed to protect the coastline and support sustainable tourism investment.

KEY WORDS
Coastline, erosion, Trawangan, small island.

Gili Trawangan is one of Lombok, Indonesia's most popular tourist destinations. It is known for its unique biodiversity, including coral reefs, flora, and fauna (Yulianto et al., 2007). It is the largest of the three Gili Islands off Lombok and provides substantial economic development opportunities beyond fishing and agriculture for the local economy (Partelow, 2021). Tourism development in Gili Trawangan, Indonesia, has both positive and negative effects on the area. On the positive side, increasing tourist numbers have led to economic growth and development. Tourism income has benefited the local community and government (Halim, 2017). The destination has also evolved from being a backpacker's 'party island' to increasingly hosting dive tourism and more upmarket tourists (Hampton & Jeyacheya, 2013). This shift has led to the growth of tourism infrastructure, such as increased dive operators, accommodation options, restaurants, and other facilities (Hampton & Jeyacheya, 2013).

Infrastructure development can significantly impact coastline change by influencing erosion and accretion processes. The construction of tourism facilities can lead to changes in land use and increased pressure on coastal areas. These changes and pressures can alter natural coastal processes, leading to erosion or accretion of the coastline (R. A. Pratama & Rosyidie, 2017; Prukpitikul et al., 2016).

Erosion occurs when natural processes, such as waves and currents, remove sediment from the coastline, causing the shoreline to retreat. Accretion, on the other hand, occurs when sediment is deposited along the coastline, causing the shoreline to advance seaward. Human activities, including tourism development, can influence erosion and accretion (Daswin Ebenezer & Kumar, 2023).

For example, constructing tourism infrastructure can remove vegetation, destabilize the coastline, and increase erosion risk (Hoang et al., 2020). Additionally, coastal infrastructure development, such as seawalls and breakwaters, can disrupt natural sediment transport processes, leading to erosion in some areas and accretion in others (Phillipsa & Jonesb, 2006).

In some cases, the impacts of tourism development on coastline change can negatively affect the tourism industry, such as beach erosion and the loss of beachfront property. For instance, beach erosion can result in the loss of valuable beachfront property and negatively affect the attractiveness of a destination for tourists (Prukpitikul et al., 2016; Stancheva et al., 2021). This condition can lead to economic losses for the tourism industry and the local community.

Generally, coastline changes on small islands can have several disadvantages, impacting the natural environment and human communities. One of the significant impacts of coastline changes is on health infrastructure. A study on Pacific island countries (PICs) found that 62% of all assessed medical facilities in these countries are within 500 m of the coast. With sea-level rise due to climate change, these facilities are at risk, which could severely affect the health and well-being of the island populations. The low-lying coral atoll countries of Kiribati, Marshall Islands, Nauru, Palau, Tokelau, and Tuvalu are particularly vulnerable, as all their medical facilities fall within this range (Taylor, 2021).

Coastlines are vulnerable to natural erosion and human activities such as urban growth and pollution. In Indonesia, for example, the natural coastline decreased by 5995.52 km over 28 years due to these factors. Losing natural coastlines can lead to ecological degradation and biodiversity loss (Sui et al., 2020).

In conclusion, the increase in population, number of tourists, and changes in land use on Gili Trawangan will likely contribute to changes in the coastline, which will cause more significant losses for tourism businesses and local communities. Based on the description, research regarding changes in the shoreline on Gili Trawangan needs to be carried out so that it can be used as material for consideration and early warning in managing marine tourism on small islands.

MATERIALS AND METHODS OF RESEARCH

Gili Trawangan is a small island off the coast of Lombok, Indonesia, known for its stunning beaches, coral reefs, and vibrant marine life. The island is a popular tourist destination, attracting visitors worldwide for its clear blue waters and laid-back atmosphere. The island is also known for its vibrant nightlife, with various bars, restaurants, and clubs lining the main strip. Many tourists also come to enjoy the local music scene and dance the night away.

Due to its popularity and significant human activity, Gili Trawangan is an excellent location to study coastal changes. The island's small size and relative isolation make it a manageable case study for analyzing environmental impacts in a controlled setting. This condition enables researchers to collect precise data and draw informed conclusions about how human activities affect coastal environments. These findings can be extrapolated to more extensive, less regulated regions to guide policies and conservation initiatives.

Overall, studying coastline changes on Gili Trawangan allows researchers to understand the immediate impacts of human activity on coastal environments and provides valuable insights that can be extrapolated to other, larger areas. Using data from this controlled environment, experts can give well-informed suggestions for sustainable development and conservation to safeguard fragile coastal ecosystems globally. The harmonious coexistence of tourism and environmental conservation in Gili Trawangan was a valuable example for other coastal destinations aiming to reduce their environmental impact.

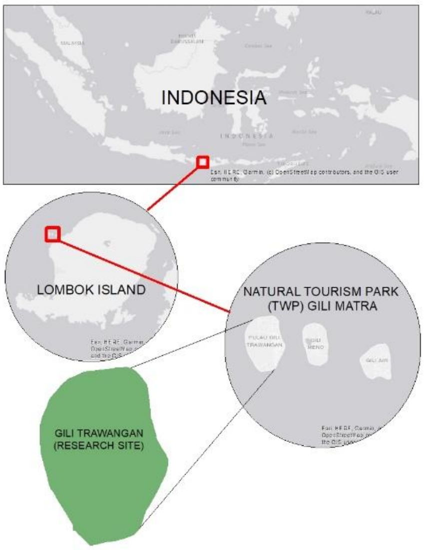

Figure 1 – Map of Research Location

The materials used in this research were satellite images, Landsat 8 OLI images acquired in 2013, and Landsat 9 images acquired in 2023. The image data is obtained free of charge from the USGS EarthExplore website.The image data IDs used in this analysis were:

- LC08_L1TP_116066_20130815_20200912_02_T1;
- LC09_L1TP_116066_20230123_20230123_02_T1.

The method used in this study was remote sensing, using satellite images to monitor changes in the coastline using the software ArcGIS 10.0.8. According to Sugiyono et al (2015), the Digital Shoreline Analysis System (DSAS) is a remote sensing technology that can detect and calculate changes in the coastline of an area automatically. The method used to calculate shoreline changes in DSAS is Net Shoreline Movement (NSM). The NSM method calculates the distance between the oldest and newest shoreline positions at each transect cast perpendicular to the shoreline. The distances are measured from a baseline, typically the oldest shoreline position. Positive NSM values indicate accretion (seaward movement), while negative values indicate erosion (landward movement).

The formula for NSM is:

$$NSM = \text{Newest Shoreline Position} - \text{Oldest Shoreline Position}$$

Before calculating coastline changes using the NSM method, it is first necessary to separate land and water using the Modified Normalized Difference Water Index (MNDWI). MNDWI is an algorithm that can differentiate between water bodies and land with 99.85% accuracy in extracting water information (Xu, 2006).

MNDWI was calculated using the following formula:

$$MNDWI = \frac{(Green + SWIR)}{(Green - SWIR)}$$

Where: $Green$ = Green is the reflectance on the green band; $SWIR$ = SWIR is the reflectance in the short infrared band (Short-Wave Infrared).

After the image data was prepared, geometric and radiometric corrections and cropping were carried out. The satellite image processing phase was carried out first to determine the coastline of each image. In this phase, the satellite image was first corrected by changing the digital value number to the pixel value in the reflective value. The method used to obtain the coastline or separate water bodies from the land is the MNDWI. The analysis results will match the water body part with the non-water body, thus producing the coastline as vector data.

Then, it was analyzed using the Digital Shoreline Analysis System (DSAS) tool in ArcGIS. Before conducting DSAS analysis, the process must be carried out to prepare baseline and coastline data. Baselines are created using initial or previous data. As part of the process, a buffer was made 100 meters from the 2013 coastline and the coastline was created by combining all of the beach data that needed to be analyzed—the current and previous data series.

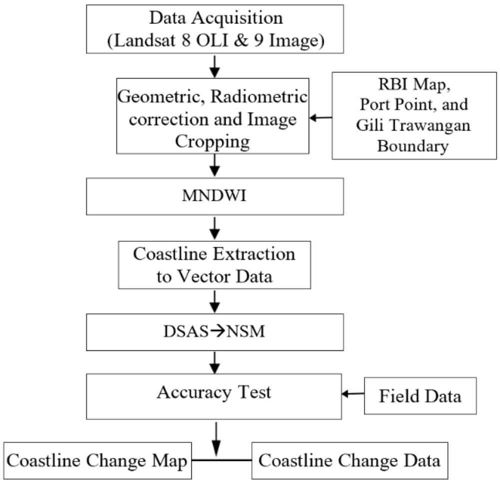

Figure 2 – Schematic diagram analysis of the coastline change in Gili Trawangan

Data validation was carried out through field surveys regarding predetermined reference points. This validation consists of several activities, including direct inspections in the field, documentation, and interviews with residents who have lived around the location for a long time, prioritizing those who have lived there since 2013. The data and information obtained are used to describe the actual situation. Figure 2 shows the stages of the image processing process to produce maps and data on changes in coastlines on Gili Trawangan from 2013 to 2023. Here is a diagram of the process of analyzing changes in the coastline in Gili Trawangan.

After calculating coastline changes, the resulting data is presented in maps and tables. Then, further analysis was carried out to determine the rate of change, as well as both the erosion and accretion rates. This rate of change helps predict changes that will occur in the future. Comparing one side of an area to another helps describe the data as a whole. These comparisons allow researchers to determine trends and patterns of shoreline change over time, which can help inform coastal management and planning decisions.

RESULTS AND DISCUSSION

The results of the Digital Shoreline Analysis System (DSAS) analysis using the Net Shoreline Movement (NSM) method have been obtained in terms of the value of the coastline change in 2013-2023 in Gili Trawangan. The coastline changes in Gili Trawangan are divided into four zones in this study: northwest, northeast, southeast, and southwest. The total length of coastline changes for each zone, both due to erosion and excretion, can be seen in Table 1.

Table 1 – Length of coastline erosion and accretion by zone in Gili Trawangan from 2013-2023

No	Zone	Length of Coastline (meter)		
		Erosion	Accretion	Total
1	Northwest	1363	386	1749
2	Northeast	1402	367	1769
3	Southeast	1619	96	1715
4	Southwest	1646	64	1710

The northeast zone was recorded as having the longest coastline change (1769 meters), followed by the northwest zone (1749 meters), southeast (1715 meters) and southwest (1710 meters). This condition shows that coastline changes, both erosion and accretion rates, are not evenly distributed throughout the Gili Trawangan area. However, changes in coastline in the northeast zone are the longest and the southeast zone are the shortest

Natural and anthropogenic factors influence the stability of a coastline. Natural factors influencing coastline changes include currents, waves, precipitation, sea level rise, coastal geomorphological and bathymetry characteristics, and coastal vegetation.

The direction of the wind determines the strength and direction of a wave, the wind speed, and the distance the wave travels. Coasts with a long and open coastline toward the sea will receive more extensive and even wave energy along the coastlines (Syahari et al., 2017). This wave energy can lead to more intense erosion and coastal erosion. A study in the Gulf of Awur waters found that maximum erosion occurs in areas with a longer coastline open to the sea (Ibrahim et al., 2023).

The same is true of the length of the wind or the fetch. Fetch has a significant influence on the coastline. The long retrieval allows the wind to transfer more energy to the ocean waves, thus producing larger and stronger waves. These larger waves have the potential to cause more significant coastal erosion. Studies show that in long fetch conditions, the wave energy generated is higher, which can increase erosion and change the coastline (Pettersson et al., 2010; Prahalad et al., 2015; Serizawa et al., 2017).

The openness of the northwest and northeast zones is enormous regarding receiving wave energy. The zone's position on the treaty's northern side will likely have a broad impact (Figure 1 & 2); when the west monsoon winds, the winds will blow from the northwest to the southeast. Western monsoon winds moving from the northwest bring high humidity and cause significant rainfall on Lombok Island. On the contrary, the dry east monsoon winds blow from the southeast and cause the rainy season in the region (Hasanah, 2019; Hidayatun Nufus et al., 2023). In addition, on the northern side of the river, there are no islands or barriers that can shorten the fetch. As a result, the wind range increases, and the wave energy can reach the coast at its maximum.

Meanwhile, land formation or accretion in the zone results from the sedimentation of material carried by waves and ocean currents (Kurniawan et al., 2016). Waves can influence coastal sedimentation patterns through changing angles coming waves that affect coastal parallel currents. This pattern allows the base sediment to move along the coast and settle in areas avoided by longshore currents using a wave breaker. Coastal protection structures, such as breakwaters, can change flow patterns, hydrodynamics, and sediment transport, impacting erosion-deposition patterns in the coastal zone by reducing wave energy and allowing sediment deposition on the shoreward sides of the structure. Dynamic nearshore processes, environmental factors, and coastal structures all have an impact on sediment transport (Fitri et al., 2019; Geyer et al., 2004; Orford & Carter, 1982)

The northwest and northeast zones have coastline profiles facing and parallel to the wave's coming direction, thus causing significant changes in the sedimentation patterns in the region. The accretion occurs at a position somewhat distant from the energy center of the wave and has a weak longshore current. In contrast, the erosion occurs in a position parallel to the direction of wave arrival. Thick longshore currents can carry sediments along the coast, causing erosion in one place and deposits elsewhere. It causes a change in the coastline through erosion and sedimentation processes (D. P. Pratama et al., 2023). In both these zones, the waves generate a longshore current on the fairly dense coast towards the south.

The position of Gili Trawangan, which is in the Lombok Strait, has a non-tidal or steady current from the north and enters the Lombok Strait towards the south. These non-tidal or steady currents play an essential role in current patterns in the Lombok Strait. This steady current has varying speeds depending on depth and seasonal conditions (Utami, 2008). Besides that, the monsoon season significantly influences current patterns in the Lombok Strait. During the western monsoon season, currents are very fast and move southward. In contrast, during the east monsoon season, currents can move northward at higher speeds (Akbar et al., 2024; Akhena, 2013). However, the position of Gili Trawangan, which is north of Lombok Island, was not significantly affected by this current.

The length of the transect in Table 2 illustrates the level of change in the coastline perpendicular to the sea, where the southwest zone experiences the most significant pressure compared to other zones. This zone experiences erosion of -31.76 meters, or -3.18 meters per year, and accretion of 1.35 meters, or 0.14 meters per year. In this zone, there are no breakwaters apart from damaged coral reefs. On the other hand, the southeast zone experiences the slightest pressure, as far as -16.98 meters or -1.70 meters per year, and experiences the most significant accretion, namely as far as 13.75 meters or 1.38 meters per year perpendicularly from the coastline towards the sea.

Table 2 – Longest transects of erosion and accretion by zone in Gili Trawangan from 2013–2023

No	Zone	Long of Transect (meter)	
		Erosion	Accretion
1	Northwest	-27,38	5,58
2	Northeast	-29,64	11,63
3	Southeast	-16,98	13,75
4	Southwest	-31,76	1,35

Figure 4 shows that the most extended transect in the southwest zone faces south of the Lombok Strait. This position allows the coastal area to experience significant wave pressure because it has the furthest fetch during the east season, which is around 40-60 kilometers, and can even come from the direction of the Indian Ocean. The opportunity for accretion is minimal in this zone because it always experiences significant wave pressure in the east season and does not have a profile to trap sediment carried by currents from the north. Meanwhile, Figure 3 shows that the most extended accretion transect in the southeast zone faces the islands of Lombok and Gili Meno, with an estimated fetch of 6.78 kilometers and 1.07 kilometers. Apart from that, the position of the accretion that occurred is slightly to the north above the headland, which can function to hold sediment carried by currents from the north. Islands and headlands can block incoming waves, causing wave diffraction and reflection, which reduces wave energy reaching the shore behind the barrier.

For example, in the waters of Nyamuk Island, Karimunjawa National Park, a group of large and small islands, influences the direction, speed, and pattern of currents and wave characteristics in the surrounding area (Alam et al., 2003). These islands function as natural barriers that dampen wave energy before it reaches the coast.

Thus, coastal areas in the southwest zone experience significantly more erosion than others due to intense pressure from waves and ocean currents, resulting in substantial land loss every year. On the other hand, because ocean currents frequently deposit new sediment, coastal areas in the southeastern zone experience land addition.

Table 3 – The area affected by erosion and accretion by zone in Gili Trawangan from 2013–2023

No	Zone	Changing	
		Erosion (Hectar)	Accretion (Hectar)
1	Northwest	1,50	0,11
2	Northeast	2,08	0,21
3	Southeast	1,27	0,10
4	Southwest	1,92	0,01

Table 3 describes the area affected by erosion and accretion in each zone. The northeast zone is the zone with the largest area in terms of reduction and increase in land area over ten years; namely, there is a land reduction of 2.08 hectares or 0.21 hectares per year and an additional land area of 0.21 hectares or 0.02 hectares per year. Meanwhile, the zone that experienced the most minor land loss was the southeast, namely 1.27 hectares or 0.13 hectares per year, and the zone that experienced the smallest land gain was the southwest, namely 0.01 hectares or 0.001 hectares per year.

Figure 1 (b, c, d) provide an overview of the position and extent of changes in area due to erosion and accretion in the northeast, southeast, and southwest zones. The northeastern zone experienced dominant erosion along the northeastern and eastern sides. At the same time, accretion occurred on the northern side and at the bottom of the east side, precisely above the headland, which also played a role in accretion in the southeastern zone. Like the southwest zone, the northeast zone is also open to the north and has a fetch of approximately 633.37 kilometers, so this zone always faces strong currents and large waves in the west monsoon season. The formed current moves from north to south parallel to the east coast, so the potential for erosion is very high during that season.

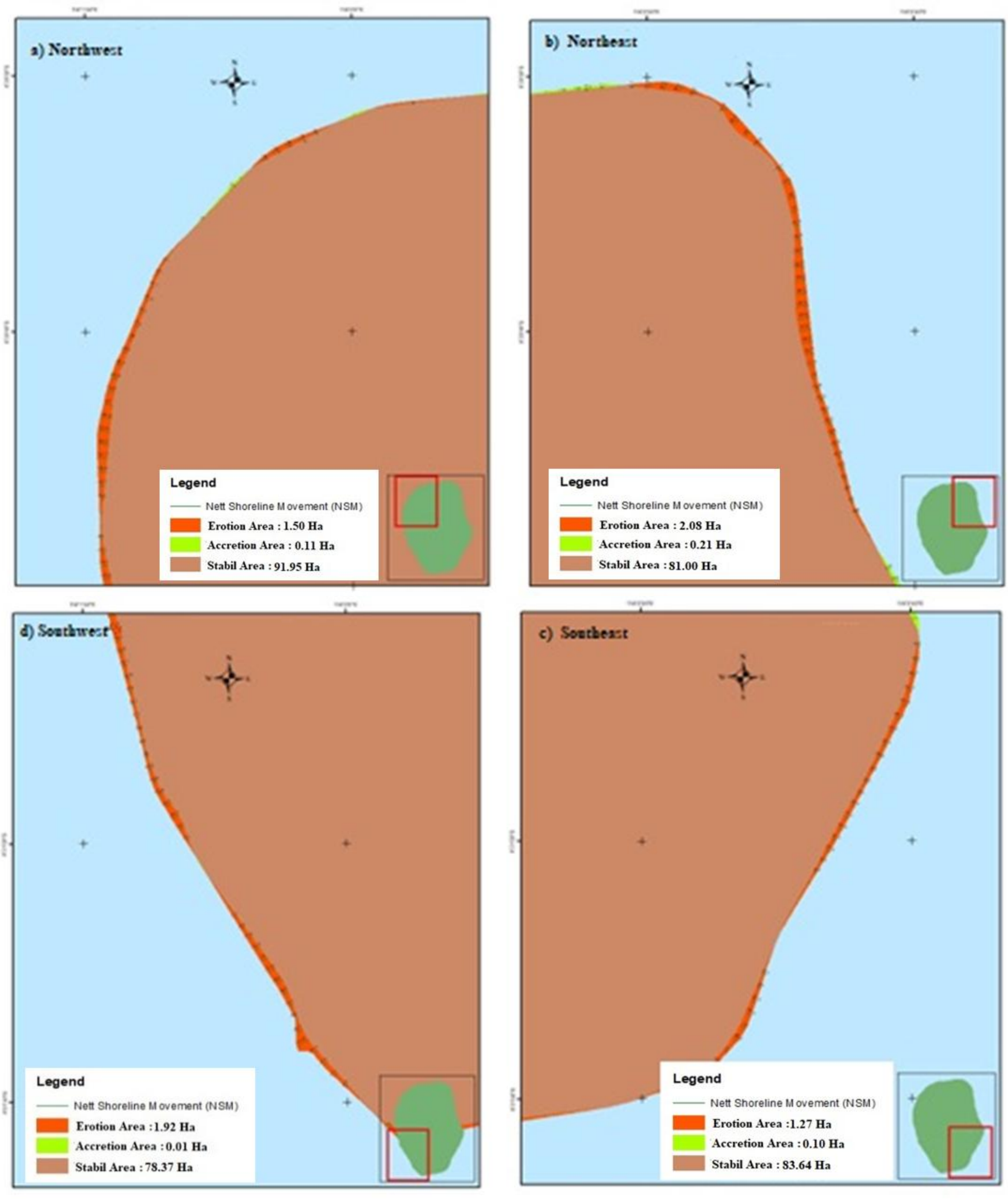

Figure 1 – Map of coastline changes in Gili Trawangan, period 2013–2023. a) Northwest zone, b) Northeast zone, c) Southeast zone, and d) Southwest zone

Even though the eastern side of this zone has a very close fetch, the strength of the current has a more significant influence on the erosion process. The strength of this current is not only caused by tides, waves, and wind but also by the narrow strait between Gili Trawangan and Gili Meno, which plays a role in increasing the pressure and speed of the current. Narrow straits tend to increase current speed because large volumes of water have to pass through a limited space. For example, in the Lepar Strait, Indonesia, tidal currents reach up to 1.5 m/s in the narrow northern part of the strait (Ajiwibowo & Pratama, 2021). This high current speed can affect sedimentation and erosion on the seabed and surrounding beaches.

However, the north and east sides of the northeastern zone can still trap sediment because they are protected from strong currents parallel to the coast, and headlands act as current barriers. In addition, the large amount of suspended material due to wave turbulence during the western season can increase sedimentation.

As previously explained, the southeast zone experienced at least land loss due to erosion. The fetch factor is close, and currents moving from north to south do not significantly influence changes in the coastline.

Likewise, with the influence of waves, because it has a short fetch between Gili Trawangan, Gili Meno, and Lombok Island, this zone has a minimal wave influence compared to other zones. The southeastern zone is also influenced by easterly winds coming from the south. However, this is not very significant because it only reflects waves heading towards Gili Meno.

The southwest zone has experienced the least accretion compared to other zones around Gili Trawangan. In addition to constantly receiving high wave pressure during the east winds, most of this zone's coastline also has longshore currents that come from the north to the south without any adequate constraints, both in the form of barriers and headlands.

Global warming is a natural factor that cannot be avoided and also increases the impact of erosion on Gili Trawangan. Rising temperatures and sea levels and changes in weather patterns can worsen coastal erosion.

The increase in sea surface temperatures from early to mid-2016 caused coral bleaching in several locations in the Gili Matra TWP, including Gili Trawangan. This coral bleaching results in decreased coral cover and recruitment of new coral, slowing down the recovery of affected coral reef ecosystems (Setiawan et al., 2018). Damaged coral reefs can no longer protect the coast from wave energy, increasing erosion risk. Meanwhile, rising sea levels cause more intensive coastal erosion. Rising sea waters erode coastlines, causing coastline retreat and land loss (Setianingsih et al., 2018; Tamba et al., 2016; Yesiana et al., 2015). On Gili Trawangan, this phenomenon exacerbates erosion that has already occurred due to other factors, such as the loss of mangrove vegetation and coastal forests.

As previously described, the general size of erosion in the Gili Trawangan area is not only caused by natural factors. It is also influenced by human factors, such as cutting down mangrove forests or coastal forests to develop tourist infrastructure and damaging coral reefs as barriers to waves and currents.

The development of infrastructure and tourist activities is focused on Gili Trawangan's east side; the northeast and southeast zones are included. The impact of the loss of mangrove vegetation and coastal forests that has occurred since the past and damage to coral reefs have also contributed to the high level of erosion in this area. Mangroves and coastal forests function as natural protection from coastal erosion. The solid and dense roots of mangroves can bind the soil and dampen wave energy, while coastal forests protect coastlines from winds and storms (Apelabi, 2019; Nugraha et al., 2019). However, land clearing for ponds, settlements, and other activities has caused the loss of this protective vegetation, leaving beaches vulnerable to erosion (Nugraha et al., 2019).

Coral reefs also play an essential role in protecting beaches from erosion by reducing wave energy (Harris et al., 2018; Yates et al., 2017). However, damage to coral reefs due to global warming, pollution, and unsustainable tourism activities has reduced their ability to protect beaches (Storlazzi et al., 2023). Other research also shows that coral reef degradation can increase the risk of flooding and coastal erosion in coastal areas (Storlazzi et al., 2021).

The combination of the loss of mangrove vegetation and coastal forests and damage to coral reefs has increased the vulnerability of beaches on Gili Trawangan to erosion. Waves and sea currents that are not adequately dampened can erode beaches intensively, causing loss of land and infrastructure in this area (Mohanty et al., 2021; Nehemia et al., 2017; Sohel Ahmed, S. M, 2019).

The northeast zone is the most concrete example to illustrate the negative impact of tourism in this region. Meanwhile, the small level of erosion in the southeast zone cannot be separated from the adaptation efforts made by tourism entrepreneurs, where many barriers and sandbags have been installed to curb the erosion rate. Attention or efforts to deal with very intensive erosion on the east side of Gili Trawangan were closely related to safety and continued investment in the tourism sector because coastal erosion can cause damage to tourism infrastructure such as hotels, restaurants, and other facilities near the coastline. Research shows that tourism development in Gili Trawangan has increased the construction of accommodation facilities in coastal areas vulnerable to erosion impacts (Anggreni et al., 2022). Damage to this infrastructure can also reduce tourist attractions and threaten investment in the tourism sector.

Research discussing land cover changes in Gili Trawangan shows that rapid development and tourism promotion policies also contribute to environmental changes that can exacerbate the impact of erosion (Bakti et al., 2023). Suboptimal waste management and violations of spatial planning in the construction of accommodation facilities can also worsen environmental conditions in Gili Trawangan, increasing vulnerability to erosion (Hurum et al., 2023; Saputra, 2020).

Dealing with erosion in Gili Trawangan requires a comprehensive and sustainable approach, considering the area's importance for tourism and the local economy. This approach involves planting coastal vegetation, building protective structures, strict spatial management, effective waste management, and public education and awareness. This comprehensive and sustainable approach can help protect the Gili Trawangan coastline from erosion and support sustainable investment in tourism.

ACKNOWLEDGEMENTS

The first author and the Ikip Mataram Development Foundation funded this research. Thanks are expressed to Prof.Dr.Ir. Gatot Ciptadi, DESS., IPU, DR. Bagio Yanuwiadi, and Dr. Ir. Anthon Efani, MP, as a team of supervisors at the Environmental Science Doctoral Program at Brawijaya University, who provided a lot of guidance and input on this paper.

CONCLUSION

The Digital Shoreline Analysis System (DSAS) analysis in 2013-2023 revealed that coastline changes in Gili Trawangan were divided into four zones: northwest, northeast, southeast, and southwest. Changes in the coastline in the northeast zone were the longest and the southeast zone was the shortest.

The stability of the coastline is influenced by natural and anthropogenic factors such as wind direction, waves, precipitation, sea level rise, coastal geomorphology, and vegetation. The northwest and northeast zones receive significant wave energy, leading to more intense erosion and accretion. Their coastline profiles face and parallel to wave direction, causing significant changes in sedimentation patterns.

Based on the length of the coastline, the Northwest and Northeast zones experienced widespread erosion and accretion, while the Southeast and Southwest zones experienced less. The Northeast and southwest zone experiences the most significant erosion, resulting in substantial land loss every year. At the same time, the northeast and northwest zones experienced significant accretion than others. Overall, Gili Trawangan experienced erosion of 6.77 hectares and accretion of 0.4 hectares, which means a reduction in area of 6.34

hectares over 10 years or 0.634 hectares per year. The northeast zone faces strong currents and large waves in the west monsoon season, with a fetch of approximately 633.37 kilometers. The southeast zone has minimal wave influence due to its short fetch between Gili Trawangan, Gili Meno, and Lombok Island, while the southwest zone has the least accretion compared to other zones around Gili Trawangan.

Erosion in Gili Trawangan is a significant issue due to factors such as global warming, rising sea levels, and human activities. The southeast zone experiences high wave pressure and longshore currents without adequate constraints. Coral bleaching and rising sea levels exacerbate the erosion risk, as coral reefs become less protective against wave energy. The development of infrastructure and tourism activities, particularly in the northeast and southeast zones, has also contributed to the erosion. The southeast zone faces small erosion rates due to adaptation efforts by tourism entrepreneurs. Rapid development and tourism promotion policies contribute to environmental changes that exacerbate erosion. A comprehensive and sustainable approach is needed to protect the coastline and support sustainable tourism investment.

REFERENCES

1. Ajiwibowo, H., & Pratama, M. B (2021). Hydrodynamic Model and Tidal Current Energy Potential in Lepar Strait, Indonesia | Semantic Scholar. https://www.semanticscholar.org/paper/Hydrodynamic-Model-and-Tidal-Current-Energy-in-Ajiwibowo-Pratama/7f9564302eac3746b2e2cb213a503bab971f34ed
2. Akbar, H. I., Harsono, G., Sutejo, B., Pianto, T. A., Rudiastuti, A. W., Ambarwulan, W., Sumargana, L., Priyadi, H., Hudayat, N., & Sugama, A. Y (2024). Studi Pendahuluan Pengaruh Arus Laut Musiman terhadap Waktu Tempuh Kapal Melalui Perairan Selat Lombok: Preliminary Study of The Influence of Seasonal Ocean Currents on Vessel Travel Time Through The Waters of The Lombok Strait. Jurnal Hidrografi Indonesia, 5(2), 91–98. https://doi.org/10.62703/jhi.v5i2.25
3. Akhena, N (2013). Pengaruh Monsun Terhadap Pergerakan Arus Lintas Indonesia (Arlindo) Secara Vertikal and Horizontal Di Selat Makassar. https://www.semanticscholar.org/paper/pengaruh-monsun-terhadap-pergerakan-arus-lintas-dan-Akhena/2ec90942af5294b5cc3894b4911e6812f1e98cfd
4. Alam, M. F., Indrayanti, E., & Yusuf, M (2003). Simulasi Pola Arus Permukaan 2 Dimensi di Perairan Pulau Nyamuk Taman Nasional Karimunjawa Pada Musim Peralihan II. Indonesian Journal of Oceanography. https://www.semanticscholar.org/paper/Simulasi-Pola-Arus-Permukaan-2-Dimensi-di-Perairan-Alam-Indrayanti/cbed29d43ae96917e52a6e1c2d2336f65f892198
5. Anggreni, M. A., Suteja, I. W., & Indrapati, I (2022). Dampak Perkembangan Pariwisata Pada Lingkungan Fisik (Sarana Prasarana) and Pengaruhnya Terhadap Sempadan Pantai Di Desa Wisata Gili Gede Indah Kecamatan Sekotong Kabupaten Lombok Barat. Journal Of Responsible Tourism, 1(3), 301–312. https://doi.org/10.47492/jrt.v1i3.1373
6. Apelabi, G. O (2019). Persepsi Masyarakat Terhadap Pelestarian Hutan Mangrove Dengan Pendekatan Nep (New Environmental Paradigm) (Studi Kasus Kelurahan Kota Uneng and Desa Talibura Kabupaten Sikka). Gema Wiralodra. https://www.semanticscholar.org/paper/persepsi-masyarakat-terhadap-pelestarian-hutan-nep-Apelabi/104e360d767737b649a80669b45ee55fd1f21047
7. Bakti, L. A. A., Selvia, S. I., Sukartono, S., Suwardji, S., & Kusumo, B. H (2023). Komparasi Perubahan Tutupan Lahan di Gili Meno, Gili Trawangan and Gili Air (Gili Matra): Comparison Land Cover Change in Gili Meno, Gili Trawangan and Gili Air (Gili Matra). Jurnal Sains Teknologi & Lingkungan, 9(4), 611–620. https://doi.org/10.29303/jstl.v9i4.499
8. Daswin Ebenezer, M., & Kumar, M (2023). Coastline change rate estimation on the southern coastal districts of Tamil Nadu, India using the multi temporal Google Earth images and GIS based statistical approach [Review of Coastline change rate estimation on the southern coastal districts of Tamil Nadu, India using the multi temporal Google

Earth images and GIS based statistical approach, by M. Kumar]. Global NEST Journal, 25(4), 95–103. https://doi.org/10.30955/gnj.004482
9. Fitri, A., Hashim, R., Abolfathi, S., & Maulud, K. N. A (2019). Dynamics of Sediment Transport and Erosion-Deposition Patterns in the Locality of a Detached Low-Crested Breakwater on a Cohesive Coast. Water, 11(8). https://www.mdpi.com/2073-4441/11/8/1721
10. Geyer, W. R., Hill, P. S., & Kineke, G. C (2004). The transport, transformation and dispersal of sediment by buoyant coastal flows. Continental Shelf Research, 24(7), 927–949. https://doi.org/10.1016/j.csr.2004.02.006
11. Halim, H. S (2017). Scrutinizing Coastal Ecotourism in Gili Trawangan, Indonesia. International Journal of Marine Science. https://doi.org/10.5376/ijms.2017.07.0025
12. Hampton, M. P., & Jeyacheya, J (2013). Bio-rock and roll? Dive Tourism and Island Communities: the case of Gili Trawangan, Indonesia. https://www.semanticscholar.org/paper/Bio-rock-and-roll-Dive-Tourism-and-Island-the-case-Hampton-Jeyacheya/f1c31c271a33bddd94b09df4fae818d32d64f631
13. Harris, D. L., Rovere, A., Casella, E., Power, H., Canavesio, R., Collin, A., Pomeroy, A., Webster, J. M., & Parravicini, V (2018). Coral reef structural complexity provides important coastal protection from waves under rising sea levels. Science Advances, 4(2), eaao4350. https://doi.org/10.1126/sciadv.aao4350
14. Hasanah, F (2019). Anomali Arah Vektor Angin Pada Zona Konvergen and Sifat hujan di pulau lombok. https://www.semanticscholar.org/paper/anomali-arah-vektor-angin-pada-zona-konvergen-dan-Hasanah/2163ca93adc4cf3988c284ddf651caaa16bdb5cf
15. Hidayatun Nufus, I Nyoman Soemeinaboedhy, Mahrup, & Baharuddin (2023). Pengaruh Angin Muson Australia Terhadap Sifat Hujan Pada Musim Kemarau di Wilayah Lombok. Jurnal Ilmiah Mahasiswa Agrokomplek, 2(2), 195–203. https://doi.org/10.29303/jima.v2i2.2609
16. Hoang, T. T. H., Van Rompaey, A., Meyfroidt, P., Govers, G., Vu, K. C., Nguyen, A. T., Hens, L., & Vanacker, V (2020). Impact of tourism development on the local livelihoods and land cover change in the Northern Vietnamese highlands. Environment, Development and Sustainability, 22(2), 1371–1395. https://doi.org/10.1007/s10668-018-0253-5
17. Hurum, P. H., Bakti, L. A. A., Sukartono, S., Kusumo, B. H., Suwardji, S., & Raehanayati, R (2023). Pengelolaan Sampah Pariwisata and Rumah Tangga Dengan Sistem Terpadu Di Gili Trawangan. Jurnal Pepadu, 4(1), 59–65. https://doi.org/10.29303/pepadu.v4i1.2238
18. Ibrahim, Muh. L. G., Atmodjo, W., & Widada, S (2023). Perubahan Garis Pantai Perairan Teluk Awur Kabupaten Jepara Menggunakan DSAS (Digital Shoreline Analysis System) Dari Tahun 2012 Sampai 2021. Indonesian Journal of Oceanography, 5(2), 198–206. https://doi.org/10.14710/ijoce.v5i2.16519
19. Kurniawan, F., Adrianto, L., Bengen, D. G., & Prasetyo, L. B (2016). Vulnerability assessment of small islands to tourism: The case of the Marine Tourism Park of the Gili Matra Islands, Indonesia. Global Ecology and Conservation, 6, 308–326. https://doi.org/10.1016/j.gecco.2016.04.001
20. Mohanty, P. C., Shetty, S., Mahendra, R. S., Nayak, R. K., Sharma, L. K., & Rama Rao, E. P (2021). Spatio-temporal changes of mangrove cover and its impact on bio-carbon flux along the West Bengal coast, Northeast coast of India. European Journal of Remote Sensing, 54(1), 525–537. https://doi.org/10.1080/22797254.2021.1977183
21. Nehemia, A., Huyghe, F., & Kochzius, M (2017). Genetic erosion in the snail Littoraria subvittata (Reid, 1986) due to mangrove deforestation. Journal of Molluscan Studies, 83(1), 1–10. https://doi.org/10.1093/mollus/eyw040
22. Nugraha, R. B. A., Syaharani, L., Iska, R., Mulyana, D., Wahyudin, Y., Purbani, D., Jayawiguna, H., Triyono, Setiawan, A., & Fajar, P (2019). The impact of land used changes on mangrove forest and shoreline dynamic in Muara Gembong, Bekasi, West Java. IOP Conference Series: Earth and Environmental Science, 241, 012018. https://doi.org/10.1088/1755-1315/241/1/012018

23. Orford, J. D., & Carter, R. W. G (1982). Crestal overtop and washover sedimentation on a fringing sandy gravel barrier coast, Carnsore Point, Southeast Ireland. Journal of Sedimentary Research, 52(1), 265–278. https://doi.org/10.1306/212F7F2C-2B24-11D7-8648000102C1865D
24. Partelow, S (2021). Social capital and community disaster resilience: Post-earthquake tourism recovery on Gili Trawangan, Indonesia. Sustainability Science, 16(1), 203–220. https://doi.org/10.1007/s11625-020-00854-2
25. Pettersson, H., Kahma, K. K., & Tuomi, L (2010). Wave Directions in a Narrow Bay. Journal of Physical Oceanography, 40(1), 155–169. https://doi.org/10.1175/2009JPO4220.1
26. Phillipsa, M., & Jonesb, A. L (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. https://www.semanticscholar.org/paper/Erosion-and-tourism-infrastructure-in-the-coastal-%3A-Phillipsa-Jonesb/a94a4e6f053d2a1e8f78d72a16d0eac2a1cbb828
27. Prahalad, V., Sharples, C., Kirkpatrick, J., & Mount, R (2015). Is wind-wave fetch exposure related to soft shoreline change in swell-sheltered situations with low terrestrial sediment input? Journal of Coastal Conservation, 19(1), 23–33. https://doi.org/10.1007/s11852-014-0352-x
28. Pratama, D. P., Atmodjo, W., & Wirasatriya, A (2023). Pengaruh Arus Sejajar Pantai (Longshore Current) Terhadap Proses Perubahan Garis Pantai di Pantai Marunda, Jakarta Utara. Indonesian Journal of Oceanography, 5(2), 108–117. https://doi.org/10.14710/ijoce.v5i2.16198
29. Pratama, R. A., & Rosyidie, A (2017). Social Impacts Of Tourism Industry Caused By Agricultural Land Use Change In Tourism Infrastructure Development In Ubud Region, Gianyar Regency, Province Of Bali, Indonesia. ASEAN Journal on Hospitality and Tourism, 15(1), 12. https://doi.org/10.5614/ajht.2017.15.1.3
30. Prukpitikul, S., Narangjavana, P., & Tokrisna, R (2016). Assessment of the Effects of Community Expansion and Land Use Transformation on a Coastal Area in Thailand. International Journal of Environmental Science and Development, 7(7), 537–541. https://doi.org/10.18178/ijesd.2016.7.7.835
31. Saputra, L. A. D. N (2020). Pelanggaran Pemanfaatan Tata Ruang Dalam Pembanguana Sarana Akomodasi Pariwisata Di Gili Trawangan. https://www.semanticscholar.org/paper/pelanggaran-pemanfaatan-tata-ruang-dalam-sarana-di-Saputra/5c759898ca5db60426ba4362f5967445c988720c
32. Serizawa, M., Uda, T., & Miyahara, S (2017). Segmentation Of Water Body Given Probability Of Occurrence Of Wind Direction By Circular Or Elliptic Distribution. Coastal Engineering Proceedings, 35, 6. https://doi.org/10.9753/icce.v35.sediment.6
33. Setianingsih, W., Sasmito, B., & Bashit, N (2018, May 2). Analisis Sea Level Rise Di Laut Utara Jawa Terhadap Perubahan Garis Pantai Wilayah Demak Pada Tahun 2006-2016. https://www.semanticscholar.org/paper/analisis-sea-level-rise-di-laut-utara-jawa-terhadap-setianingsih-Sasmito/beb0c91246e72dab45b37bf0124deb79ed876efc
34. Setiawan, F., Muttaqin, A., Tarigan, S. A., Muhidin, M., Hotmariyah, H., Sabil, A., & Pinkan, J (2018). Dampak Pemutihan Karang Tahun 2016 Terhadap Ekosistem Terumbu Karang: Studi Kasus Di TWP Gili Matra (Gili Air, Gili Meno and Gili Trawangan) Provinsi NTB Coral Bleaching Impact in 2016 Towards Coral Reef Ecosystem: Case Studies TWP Gili Matra (Gili Air,. Jurnal Kelautan: Indonesian Journal of Marine Science and Technology, 10(2), 147. https://doi.org/10.21107/jk.v10i2.2878
35. Sohel Ahmed, S. M (2019). Risks of Climate Change at Coastal Tourism in Bangladesh: A Study on Cox's Bazar. Information Management and Business Review, 11(3(I)), 1–12. https://doi.org/10.22610/imbr.v11i3(I).2942
36. Stancheva, M., Stanchev, H., Young, R., & Parlichev, G (2021). Coastal erosion driven Land-Sea Interactions in Maritime Spatial Planning—A case of Bulgaria. Journal of Coastal Conservation, 25(6), 54. https://doi.org/10.1007/s11852-021-00841-4
37. Storlazzi, C., G. Reguero, B., K. Yates, K., A. Cumming, K., D. Cole, A., B. Shope, J., Gaido L., C., G. Zawada, D., R. Arsenault, S., W. Fehr, Z., A. Nickel, B., & W. Beck, M

(2021). Rigorously Valuing the Impact of Projected Coral Reef Degradation on Coastal Hazard Risk in Florida (Open-File Report 2021–1055).

38. Storlazzi, C., Norris, B., Pomeroy, A., Roelvink, F., Dongeren, A. V., Reguero, B., & Beck, M (2023). Modeling Coral Reef Restoration To Reduce Coastal Hazards From Scales Of Centimeters To Kilometers. Coastal Engineering Proceedings, 37, 3. https://doi.org/10.9753/icce.v37.management.3
39. Sui, L., Wang, J., Yang, X., & Wang, Z (2020). Spatial-Temporal Characteristics of Coastline Changes in Indonesia from 1990 to 2018. Sustainability, 12(8), 3242. https://doi.org/10.3390/su12083242
40. Syahari, E., Lizadiliawati, L., & Sudarsono, S (2017, December 1). Studi Pengaruh Energi Gelombang Laut Terhadap Perubahan Garis Pantai Padang Bakung Kecamatan Alas Maras Kabupaten Seluma Provinsi Bengkulu. https://www.semanticscholar.org/paper/studi-pengaruh-energi-gelombang-laut-terhadap-garis-syahari-Lizadiliawati/6fe37e90e47b92dee4d6c09b4bcc6aaddab10233
41. Tamba, A. Y. P., Sasmito, B., & Hani'ah, H (2016, May 2). Analisis Sea Level Rise and Penentuan Komponen Pasut Dengan Menggunakan Data Satelit Altimetri Jason-2 Tahun 2011-2014 (Studi Kasus: Perairan Sumatera Bagian Timur). https://www.semanticscholar.org/paper/analisis-sea-level-rise-dan-penentuan-komponen-data-tamba-Sasmito/16998842150c6072f9d22119e2f094ea96c0ae50
42. Taylor, S (2021). The Vulnerability of Health Infrastructure to the Impacts of Climate Change and Sea Level Rise in Small Island Countries in the South Pacific. Health Services Insights, 14, 11786329211020857. https://doi.org/10.1177/11786329211020857
43. Utami, D. A (2008). Studi Arus Pasang Surut and Arus Tetap Di Selat Lombok. https://www.semanticscholar.org/paper/studi-arus-pasang-surut-dan-arus-tetap-di-selat-utami/5d1afda86840683d6012f9a23d92893f0c5661d6
44. Wildlife Conservation Society – Jl. Tampomas no. 35, Bogor, Jawa Barat, Indonesia, Setiawan, F., Muttaqin, A., Wildlife Conservation Society – Jl. Tampomas no. 35, Bogor, Jawa Barat, Indonesia, Tarigan, S. A., Wildlife Conservation Society – Jl. Tampomas no. 35, Bogor, Jawa Barat, Indonesia, Muhidin, Mr., Program Pascasarjana, Institut Pertanian Bogor - Jl. Raya Darmaga Kampus IPB, Dramaga, Bogor, Jawa Barat, Indonesia, Hotmariyah, Mr., Balai Kawasan Konservasi Perairan Nasional (BKKPN) Kupang Wilker TWP Gili Matra – Jl. Raya Pemenang-Bangsal, Kec. Pemenang, Kab. Lombok Utara, NTB, Indonesia, Sabil, A., Balai Kawasan Konservasi Perairan Nasional (BKKPN) Kupang Wilker TWP Gili Matra – Jl. Raya Pemenang-Bangsal, Kec. Pemenang, Kab. Lombok Utara, NTB, Indonesia, Pinkan, J., & Wildlife Conservation Society – Jl. Tampomas no. 35, Bogor, Jawa Barat, Indonesia (2017).
45. Pemutihan Karang Akibat Pemanasan Global Tahun 2016 Terhadap Ekosistem Terumbu Karang: Studi Kasus Di TWP Gili Matra (Gili Air, Gili Meno and Gili Trawangan) Provinsi NTB. JFMR-Journal of Fisheries and Marine Research, 1(2), 39–54. https://doi.org/10.21776/ub.jfmr.2017.001.02.1
46. Yates, K. K., Zawada, D. G., Smiley, N. A., & Tiling-Range, G (2017). Divergence of seafloor elevation and sea level rise in coral reef ecosystems. Biogeosciences, 14(6), 1739–1772. https://doi.org/10.5194/bg-14-1739-2017
47. Yesiana, R., Yuniartanti, R. K., & Wulansari, A (2015, September 8). Pengelolaan Kawasan Pesisir Kota Semarang: Sebuah Potret Berkelanjutan. https://www.semanticscholar.org/paper/Pengelolaan-Kawasan-Pesisir-Kota-Semarang%3A-Sebuah-Yesiana-Yuniartanti/42dea792275eca9809cf18c65fe8d1848ebd89e6
48. Yulianto, G., Fahrudin, A., & Kusumaningsih, N (2007). Analisis Permintaan Rekreasi and Strategi Pengembangan Wisata Bahari di Gili Trawangan Kabupaten Lombok Barat Provinsi Nusa Tenggara Barat. https://www.semanticscholar.org/paper/analisis-permintaan-rekreasi-dan-strategi-wisata-di-yulianto-fahrudin/b176a0054ebad21374e297c787653d178d3b3861