RESEARCH PAPER

ASSESSMENT OF SEAWATER QUALITY AND ENVIRONMENTAL SUSTAINABILITY FOR SHIPWRECK DIVING TOURISM: A CASE STUDY OF MV BOELONGAN NEDERLAND IN MANDEH BAY, INDONESIA

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ABSTRACT. The purpose of this research is to model the condition of seawater quality based on Government Regulation No. 22/2021 about «Implementation of Protection and Environmental Management», the results of which can later be used as a basis for reference for the concept of environmental conservation. The research was conducted at the MV Boelongan Nederland shipwreck site, focusing on seawater quality measurements including physical, chemical, and pollutant parameters. Sampling was performed at various locations near the shipwreck and nearby estuaries using purposive sampling. Parameters such as pH, temperature, turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), salinity, and concentrations of pollutants like phenol, polyaromatic hydrocarbons (PAH), and pesticides were measured and analyzed using geographic information system (GIS) tools. Data analysis revealed that despite some variations, seawater quality parameters generally met regulatory standards, supporting marine life and tourism activities. However, localized pollution was observed, particularly near estuary areas, emphasizing the need for targeted conservation efforts. The research results indicate that the estuarine areas experience light pollution due to land-based runoff, which could affect the long-term sustainability of the shipwreck site. However, the overall seawater quality at the shipwreck location remains favorablefor marine tourism and conservation. The findings suggest that a zoning system could be beneficial for managing underwater heritage sites, thereby supporting both environmental preservation and the economic development of the region. Furthermore, the research emphasizesthe potential of shipwrecks as tourism assets, suggesting their role as artificial reefs and underwater museums thatcontributeto visitors' recreational and educational experiences.

KEYWORDS: environmental sustainability, Mandeh bay, MV Boelongan Nederland shipwreck, seawater quality, tourism development

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INTRODUCTION

The sinking ship site is considered to have historical, scientific, and economic value. The sunken ship site can be used as an object of research to explore the knowledge connected to it, which is closely related to the development of regional and national character to strengthen national identity and also to serve as an object of marine tourism in the form of shipwreck diving, the implication of which is to preserve the sunken ships while developing them so that they can provide opportunities for sustainable management (such as environmental conservation, cultural heritage preservation, and sustainable tourism development) and community welfare (such as improving the local economy, improving quality life, and preservation of local culture).

Pesisir Selatan Regency is one of the regencies in West Sumatra Province thatis a leading destination for tourism activities, especially marine tourism (Such as Carocok Painan Beach, Cingkuak Island, Mandeh Bay, Langkisau Beach, and Batu Kalang Beach) and cultural tourism (Such as Rumah Gadang Mandeh Rubiah, Langkisau Festival, and Nagari Seribu Rumah Gadang in Koto Baru) (Stanford et al. 2012; El Silisna and Susanti 2020). This is in line with the establishment of

West Sumatra Province as one of the main tourist destinations in Indonesia along with 9 other provinces, including North Sumatra, Bali, West Nusa Tenggara, and others which were declared in the "Visit Indonesia Year" by the Ministry of Culture and Tourism in January 2011, the "Visit Indonesia" brand was discontinued and was replaced with the campaign "Wonderful Indonesia" which was mentioned by the rebranding to increase tourism appeal, increase competition in the global tourism industry, expand the scope of promotion, modernize and adjust to global trends, and respond to evaluation/feedback (Adams 2018; Lemy et al. 2019; Nabhan et al. 2023).

The region of Mandeh Bay is a leading tourist region in the Pesisir Selatan Regency, which is located in the sub-district of Koto XI Tarusan. The type of tourism offered is marine ecotourism (Alhadi, 2018; Triyatno et al. 2020). This is because theregion has many islands, bays, and capes with beautiful panoramas. In this region of Mandeh Bay, the sinking ship MV Boelongan Nederland is also a shipwreck diving tourist location. The waters of Mandeh Bay contain several large estuaries, contributing to the increased sedimentation in the region.. Therefore, it is necessary to carry out an experimental analysis of the sedimentation rate in the waters of the sinking site of the MV Boelongan Nederland (Ridwan 2015). Hermon et al. (2022) add simulated tidal currents and their effects on sediment distribution in the region of Mandeh Bay waters. Therefore, it is important to research sediment accumulation and seawater quality.

In the policy framework for managing underwater heritage, the Regulation of the Minister of Maritime Affairs and Fisheries No. 28/2021 about "Organization of Marine Spatial Planning" mentions the existence of a vision for the management of underwater heritage in the future as stated in Law No. 17/2007 concerning "the Development Plan". Regional Long-Term Development Plan (RLTDP), especially related to the 7th mission, namely "Making Indonesia Become an Archipelagic State that is Independent, Advanced, Strong, and Based on National Interest" by generating maritime insight and culture (Ali and Sulistiyono, 2020; Safitri 2020).

The purpose of this research is to model the condition of seawater quality based on Government Regulation No. 22/2021 about "Implementation of Protection and Environmental Management", the results of which can later be used as a basis for reference for the concept of environmental conservation in region of Mandeh Bay, Pesisir Selatan Regency - West Sumatra, Indonesia. Meanwhile, the urgency of the research is as a basis for determining the sustainability of the maritime conservation area by Regulation of the Minister of Maritime Affairs and Fisheries No. 17/2008 about "Conservation Areas of Coastal and Small Islands" to support regional development in an integrated and sustainable manner.

METHODS

The research location is at the MV Boelongan Nederland shipwreck, the estuary of the Mandeh River, and the Nyalo River in

Table 1. Forms of analysis for measuring physical, chemical, and pollutant seawater parameters and the tools used

Parameter types	Parameters	Units	Data results obtained		Tools
			Field results	Labor results	
Physical parameters of seawater	Degree of Acidity (pH)		✓		Litmus Paper/Universal pH Paper
	Temperature	°C	✓		Water Quality Meter AZ Instrument 86031: Digital Sampling System
	Turbidity	ntu	✓		YSI ProDSS: Digital Sampling System
	Brightness	m	✓		Secchi Disk: Standard for measuring water transparency
Chemical parameters of seawater	Dissolved Oxygen (DO)	mg/L	✓		Water Quality Meter AZ Instrument 86031: Multiparameter Meter with Optical DO Probe
	Biological Oxygen Demand (BOD)	mg/L		✓	Hach HQ440D: Dual Input Multi-Parameter Meter
	Salinity	‰	✓		Water Quality Meter AZ Instrument 86031: Digital Sampling System
	Nitrate (NO3-N)	mg/L	✓		YSI ProDSS: Digital Sampling System
	Ammonia (NH3-N)	mg/L	✓		YSI ProDSS: Digital Sampling System
	Phosphate (PO4-P)	mg/L		✓	Hach DR3900: Spectrophotometer
	Sulfide Compounds (H_2S)	mg/L		✓	Hach DR3900: Spectrophotometer
Pollutant parameters of seawater	Phenol Compounds	mg/L		✓	Agilent 7890B GC System: Gas Chromatography
	Polyaromatic Hydrocarbons (PAH)	mg/L		✓	Agilent 7890B GC System with 5977B MSD: GC-MS System
	Polychlor Biphenyl (PCB)	mg/L		✓	Agilent 7890B GC System with 5977B MSD: GC-MS System
	Surfactants (detergents)/ MBAs	mg/L		✓	Agilent 1260 Infinity II LC: Liquid Chromatography
	Oils and Fats	mg/L		✓	Agilent 7890B GC System: Gas Chromatography
	Pesticides	mg/L		✓	Agilent 7890B GC System with 5977B MSD: GC-MS System

the region of Mandeh Bay waters. The research was conducted in the waters of the MV Boelongan Nederland shipwreck as a diving tourism area. Purposive sampling, which considers various water conditions and conditions thought to affect seawater quality, determines the seawater quality measurement stations (Septiariva and Suryawan, 2021; Brown et al. 2020; Isdianto and Luthfi, 2020). Measurement/observation and laboratory testing for seawater quality are shown in the following Table 1 below.

The results of this test of the seawater quality can have an effect on the MV Boelongan Nederland sinking site, either directly or indirectly. This is because of the conditions of the seawater quality, especially the temperature, pH, and salinity. This can be known sooner or later, as the metal hull of the ship could be damaged by corrosion (Ridwan 2019).

The results can later be used as a basis for taking action to reduce the corrosion rate of the sunken shipwreck as partof the preservation efforts. The geographic information system (GIS) software used in this study is ArcGIS Desktop 10.8 and GAT software. The operating system used is Windows 10 on a computer based on Intel® Core™ i5 Processor. One of the advantages of ArcGIS software is that it provides a means for customizing applications with the Avenue language (Kennedy 2013; Dewata and Putra, 2021; Putra et al. 2023). The avenue script runs interpolation, changing the values for each created interpolation model. For the Inverse Distance Weighted (IDW) method, 8 simulations were carried out with the number of samples. Meanwhile, for the IDW method, 13 simulations were performed by changing the interval parameters, type, and several samples. The resulting grid data has a resolution of 100 m, and the interpolated file size is about 277 kilobytes. Fig. 1 below provides more details.

RESULTS

Seawater Quality parameter values

Seawater quality parameters that can support research in diving tourism areas are related to physical, chemical, and pollution factors. The water area of the research site is often used as a diving tourist destination, a stop for fishers, and is famous for fishing. Since this water area has quite important biological and non-biological resources, it is necessary to carry out a series of sampling activities and measure seawater quality conditions so that they can be implemented in case of significant and negative changes in the environment and seawater quality can be recognized and anticipated in time. Seawater quality measurements are divided into physical, chemical, and seawater pollution measurements. These measurements are crucial to ensuring the sustainability of marine life and the continued attractiveness of the area for tourism and fishing activities. By monitoring the physical properties, chemical composition, and potential pollutants in the seawater, researchers can identify any shifts that might affect the health of the marine ecosystem. The results of the laboratory tests are presented in Table 2 below.

Results of IDW Interpolation for the Physical Parameters of Seawater Quality

Physics of Seawater Quality for pH

From Table 2, it can be seen that the pH range at the observation locations ranges from 7.12-7.61 using the Litmus Paper/Universal pH Paper. The lower values tend to be closer to the estuary (locations 2-3 and 4-5), while the pH values increase towards the sea. This phenomenon aligns with the findings of Hall et al. (2021), which observed a similar trend of decreasing pH near freshwater inputs and estuarine regions. This isbecause the estuary areas (the Mandeh River and the Nyalo River) receive a higher supply of fresh water, thus lowering the pH. The mixing of fresh and saltwater creates a gradient, affecting the buffering capacity of seawater and its ability to maintain pH stability (Christensen 2023). The research by Hammer et al. (2014) showed that the closer to the sea, the pH value usually has a pH of more than 8. The condition of the pH value is caused by the influence of freshwater from the river that reaches the location due to high precipitation in June-July 2023, thereby increasing the volume of river water. Additionally, the impact of rainfall and river water on pH variation has been widely observed in tropical regions, where high precipitation often leads to significant pH fluctuations in coastal waters (Rahman et al. 2023). The pH range above the observation locations in the research areais still the natural pH of marine waters. It is known that the pH of the waters in

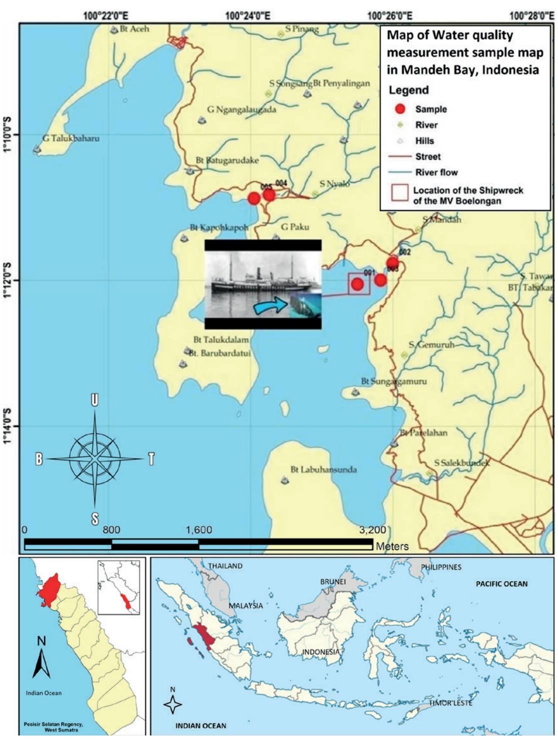

Fig. 1. Map of seawater sampling locations

Table 2. Values of seawater quality parameters from laboratory analysis

No	Parameter	Quality standards the Government Regulation No. 22/2021		Unit	Locations		
		Biota	Tourism		1	2-3	4-5
Physics							
1	pH	7-8,5(d)<0,2 unit of change pH	7-8,5(d)		7,61	7,21	7,12
2	Temperature	natural 3(c)	natural3(c)	°C	30,3	29,1	29,1
3	Turbidity	<5	5	ntu	4,2	6,2	6,5
4	Brightness	coral: >5 <10% changes in the euphotic depth of mangroves: -seagrass: >3	<6	m	8	3	3
Chemistry							
1	DO	>5>6 (>80-90% saturation)	>5	mg/L	4,8	5,6	5,2
2	BOD	20	10	mg/L	3,67	2,72	2,42
3	Salinity	natural3(e)	natural3(e)	‰	33,3	32,2	32,9
4	NO_3-N	0,008-0,002	0,008	mg/L	1,15	1,3	1,3
5	NH_3-N	0,3	nothingl	mg/L	0,05	0,1	0,11
6	PO_4-P	0,015	0,015	mg/L	0,13	0,21	0,33
7	H_2S	0,01 Pesticide (acrolein) = 0,0002	nothingl	mg/L	0,005	0,05	0,09
Pollutants							
1	Phenol Compound	0,002	nothingl	mg/L	0,0035	0,0151	0,0239
2	PAH	0,003	0,003	mg/L	ttd*)	0,0007	0,00111
3	PCB	0,01	nothingl	mg/L	ttd*)	ttd*)	ttd*)
4	Surfactant (detergent)/MBAS	1	0,001	mg/L	0,2	7	7
5	Oil and fat	1	1	mg/L	0,305	0,823	0,959
6	Pesticide	0,01	nothingl(f)	mg/L	ttd*)	0,025	0,03

*) ttd = not detected

Indonesia ranges from 6.0 to 8.5. Government Regulation No. 22/2021 stipulates that the pH value for marine tourism is in the range of 7-8.5 (Putra et al. 2023). The rise and fall of pH are mainly influenced by freshwater input. Seawater can buffer very large changes in pH to prevent changes in pH.

Physics of Seawater Quality for Temperature

The seawater temperature at the observation locations, which ranged from 29.1-30.3°C using the Water Quality Meter AZ Instrument 86031. This temperature value includes the natural value in the seawater quality standard for marine biota and marine tourism according to Government Regulation No. 22/2021, where the water temperature in Indonesia generally ranges from 27-32°C (Junaidi et al. 2019). According to Tortell (2005),temperature is one of the limiting factors for marine ecosystems and biota, where temperature changes can affect physical, chemical, and biological processes in water bodies. Hemraj et al. (2023) found in similar research that small temperature fluctuations can influence nutrient cycling and the metabolic rates of marine organisms. An increase in water temperature from the natural temperature range can cause a decrease in the solubility of gases in water such as O_2, CO_2, N_2, and CH_4. Judging from the measurement results obtained, the water temperature is natural so that it does not interfere with the ecosystem, the biota that lives in it, and the preservation of the remains of the sinking ship. According to Candra et al. (2024), stable sea temperatures within the natural range help maintain biodiversity and the health of coral reefs, which are crucial for supporting marine life in tropical regions. Prarikeslan et al. (2020) added that high temperatures can cause the death of marine biota, so an increase in temperature from the threshold can disrupt the physiology of marine biota. The vulnerability of marine species to temperature changes is heightened in tropical ecosystems where many species are already near their thermal tolerance limits (Beaty et al. 2019). Temperatures in the ocean vary depending on depth, water masscirculation, turbulence, geographical conditions, and distance from heat sources such as underwater volcanoes. The sea surface temperature is highly dependent on the amount of heat it receives from the sun.

Physics of Seawater Quality for Turbidity

The measurement results had a turbidity range of 4.2 to 6.5 ntu at the observation locations. Turbidity ranges between 0 and 4.2 mg/L using the YSI ProDSS. The further into the river from the estuary, the higher the turbidity value, namely 6.2 mg/L. The turbidity value specified according to Government Regulation No. 22/2021 for marine tourism is 5 ntu and for marine biota is <5. The turbidity value is still below the quality standard value threshold in Government Regulation No. 22/2021, so it is still suitable for marine tourism purposes. However, according to the research by Yi et al. (2024), prolonged exposure to elevated turbidity levels, even if they are within the regulatory limits, can still have detrimental effects on marine organisms by reducing the light penetration necessary for photosynthesis. In the research of Butler and Ford (2018), turbidity and total dissolved solids (TDS) are interrelated:if the TDS is high, the turbidity will be high and the brightness low. This will affect the penetration of sunlight into the waters, which then continues in the process of photosynthesis. The research by Mills et al. (2023) also confirmed that high turbidity can significantly reduce the photosynthetic efficiency of coral reefs, impacting their resilience against environmental stressors. The existing river flow, which empties into the observation locations, produces the mixed sandy silt substrate that causes the turbidity. . This causes high turbidity and sedimentation, which can block the growth of marine life in the region's waters, as well as the development of access revitalization connecting roads in the observation locations. It has been noted by MacIntosh et al. (2023) that increased sedimentation not only harms marine flora and fauna but also disrupts the ecological balance of coastal areas by altering habitats and nutrient cycles. The mangroves at that location in the Mandeh Bay region have transformed into built-up areas, specifically roads. The turbidity also has a very large impact, especially the silting of the sea surface.

Physics of Seawater Quality for Brightness

The brightness level and visibility at the observation locations ranged from 3-8 m using the Secchi Disk. This variation in water brightness and visibility is most likely due to the influence of sedimentation and tide times. The existence of several rivers (Mandeh and Nyalo) that empties into the observation locations will carry mud particles and wastes from land to sea waters. At high tide, which is in the morning until around 10 am, the brightness of the water is high because the sediment from the river has not entered the sea, as it is held back by the rising tide. The brightness level will decrease during the day because, at low tide, there will be sediment input carried by river water that enters the sea. This phenomenon is consistent with the findings of Figueroa and Son (2024), which showed that tidal cycles have a significant impact on water clarity, especially in areas with high sediment influx from river sources. For marine tourism, the quality standard value for brightness is >6 m,according toGovernment Regulation No. 22/2021. When brightness falls below this threshold, it can negatively affect marine tourism activities, particularly those involving snorkeling or diving, where water clarity is crucial for visibility (Baker et al. 2019). Furthermore, sedimentation not only impacts water clarity but also affects the health of benthic ecosystems, as sediments can smother habitats and reduce light availability for photosynthetic organisms like seagrass and corals (Ajwang 2024). The ongoing influx of sediments from rivers and the resuspension caused by tidal movements create a fluctuating environment that challenges both the marine ecosystem and the tourism industry,which relieson clear waters.

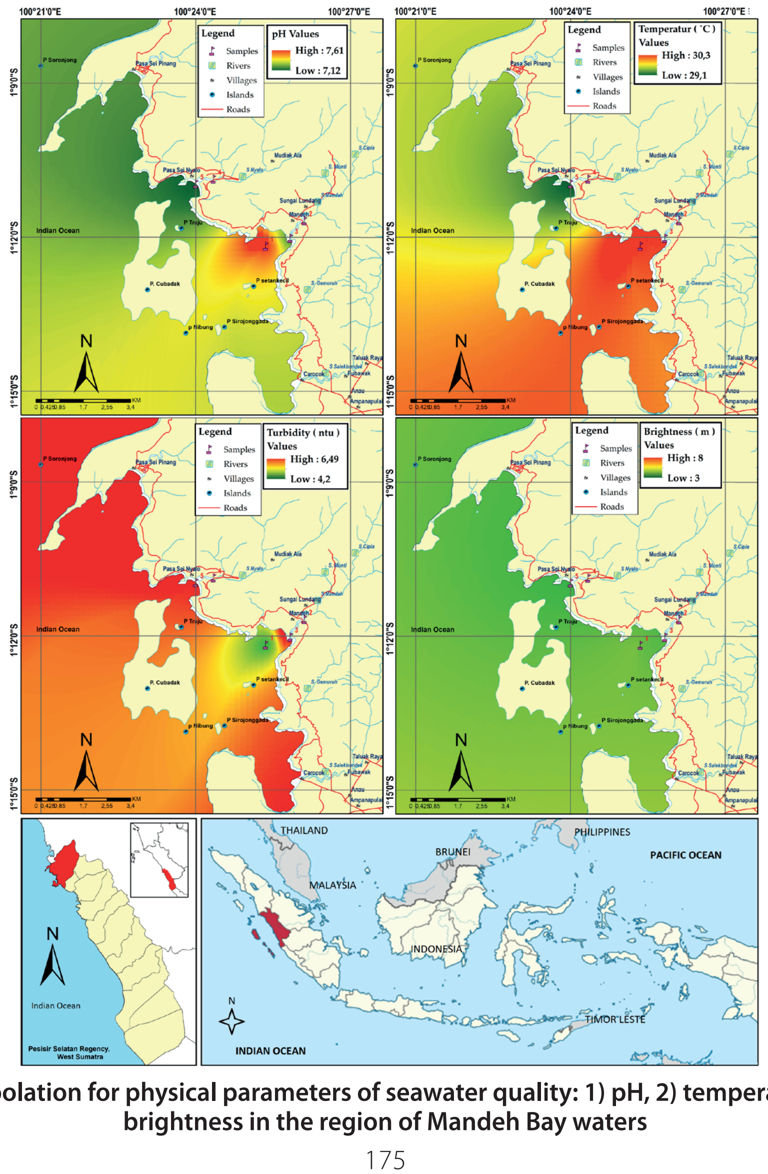

Fig. 2. Map of IDW interpolation for physical parameters of seawater quality: 1) pH, 2) temperature, 3) turbidity, and 4) brightness in the region of Mandeh Bay waters

Based on the analysis of seawater quality's physical parameters, it is evident that factors such as pH, temperature, turbidity, and brightness play a significant role in influencing the marine environment at the observation sites. These interconnected variables provide insight into the overall health and suitability of the water for marine biota and tourism activities. For more details, see Fig. 2 below for the distribution of the value of physical parameters of seawater quality (pH, temperature, turbidity, and brightness) at the observation locations.

Results of IDW Interpolation for the Chemical Parameters of Seawater Quality

Chemical of Seawater Quality for DO

The next parameter is DO, or dissolved oxygen, which marine biota, including microorganisms, use for their metabolismwhere this oxygen is then utilized by marine biota, including microorganisms, for their metabolism (Davis 1975). Under natural conditions, DO balance will be maintained through a continuous process. However, human activities such as agricultural runoff or wastewater discharge can introduce excess nutrients into the water, leading to eutrophication, which depletes dissolved oxygen levels over time (Dewata et al. 2024). If there is a disturbance, such as the entry of excessive organic matter, it will trigger an increase in microorganisms. This riseis followed by an increase in the need for dissolved oxygen. With a steady supply of oxygen but an increase in demand, the amount of oxygen content will automatically decrease. The ideal DO value for marine biota considered good enough for marine tourism according to Government Regulation No. 22/2021 is above 5 mg/L using the Water Quality Meter AZ Instrument 86031. The DO values measured at the observation sitesranged from 5.6 to 4.6 mg/L. This means that the DO content in the research location is high enough to support marine life and benefit marine tourism. The research results by Yu et al. (2023) have indicated that DO levels above 5 mg/L are typically sufficient to sustain diverse marine ecosystems and prevent hypoxic conditions that can harm marine organisms. The observation locations fall into the lightly polluted category when compared to the pollution criteria issued by Lee et al. (1978); Kenney et al. (2009) based on DO. .This classification suggests that while the water quality is still relatively good, continuous monitoring and management are needed to prevent further degradation that could affect both marine biota and tourism activities. More details can be seen in

Chemical of Seawater Quality for BOD

BOD, or biological oxygen demand, is the amount of dissolved oxygen needed by marine microorganisms to oxidize organic matter in water. This BOD value is usually used to see the level of seawater quality degradation through a decrease in dissolved oxygen levels (Jin et al. 2010). A high BOD indicates that microorganisms use a lot of oxygen to break down organic material. According to Lee et al. (2023), elevated BOD levels can lead to oxygen depletion, which severely impacts aquatic life, especially in areas with limited water circulation. BOD is usedto determine the standard BOD level. According to Dasgupta and Yildiz (2016), this BOD shows the dissolved oxygen level used by microorganisms in breaking down organic material within 5 days in a certain volume of water at a temperature of 20°C. According to Government Regulation No. 22/2021 for marine biota,the highest BOD value specified is 20 mg/L,and for marine tourism, it is10 mg/L. If this maximum limit is compared with the measurement results, then the value in the observation locations is still far below the value suggested by the Decree of the Minister of Environment, which is in the range of 2.42-3.67 mg/L using laboratory analysis with the Hach HQ440D. These values indicate that the water quality is relatively good and suitable for marine tourism and biota, as low BOD levels reflect minimal organic pollution (Weis., 2023). However, the observation locations fall into the lightly polluted category when compared to the classification values of Lee et al. (1978); Kenney et al. (2009), the observation locations are included in the lightly polluted category. This suggests that while pollution levels are low, continuous monitoring is necessary to ensure that BOD levels remain within safe limits, especially as nearby human activities increase. More details can be seen in Table 4 below.

Chemical of Seawater Quality for Salinity

The results of the measurement of salinity values tend to show characteristics of seawater salinity that are not affected by freshwater, although lower salinity is measured at the estuary location. Salinity values ranged from 33.3-32.2‰ with successive values of 33.3 at location 1; 32.2 at location 2-3, and 32.9 at location 4-5 including the

Table 3. Seawater quality based on DO content

mg/L	Status
>6,5	Not polluted until very lightly polluted
4,5-6,4	light polluted
2,0-4,4	Medium polluted
<2	heavy polluted

Source: (Lee et al. 1978; Kenney et al. 2009)

Table 4. Seawater quality based on BOD content

mg/L	Status
≥2,9	Not polluted until very lightly polluted
3,00-5,00	light polluted
5,10-14,90	Medium polluted
≤15	heavy polluted

Source: (Lee et al. 1978; Kenney et al. 2009) impact of the revitalization of the connecting road access in the research location using the Water Quality Meter AZ Instrument 86031. Salinity describes the concentration of the total ion contained in water with the main constituent ions, such as sodium, potassium, magnesium, and chloride (Millero 2013). Salinity will vary vertically and horizontally depending on the input of freshwater, rainwater, and evaporation. Research by Duan et al. (2018) highlights that salinity variations are critical in influencing the distribution and health of marine ecosystems, as sudden changes can lead to stress in sensitive species. Salinity playsan important role in marine organisms'livesas well asthe solubility of gases in seawater. When compared with the standard value for seawater quality for biota according to Government Regulation No. 22/2021, the pH range is still within normal limits for marine life such as coral, seagrass, and mangroves. In terms of salinity, some marine biota, such as mangroves, can adapt to very low salinity conditions. Mangroves are known for their unique ability to thrive in brackish water, making them highly adaptable to fluctuating salinity levels (Meera et al. 2023). The salinity of coral reef waters in Indonesia is generally 31‰. Where is the salinity condition at the research location with a value of with a value of 33.3‰ is still natural salinity where salinity in Indonesian marine waters generally ranges from 30-35‰.This meansthat the salinity levels at the observation sitesare well within the range thatlocal marine life can handle.This protects important ecosystems like coral reefs and seagrass beds.

Chemical of Seawater Quality for NO3-N

NO_3-N is a form of nitrogen compound that is important for the metabolism of autotrophic organisms (Kamp et al. 2015). The formation of nitrate occurs through the oxidation of ammonia compounds to nitrite, followed by the conversion of nitrite to nitrate, a process commonly referred to as nitrification (Paśmionka et al. 2021). The measured nitrate value in the observation locations is 1.15-1.3 mg/L using the YSI ProDSS. The highest value was measured at the mouth of the river, while the lowest was at the research location. This demonstratesthe impactof organic matter input from land to water. High NO3-N levels, especially near river mouths, are often caused by agricultural runoff or sewage discharge, which adds to the amount of nutrientsin coastal waters (Jiang et al. 2023). According to Government Regulation No. 22/2021, the NO_3-N value is 0.008 mg/L. This discrepancy suggests that the NO_3-N levels in the observation locations are significantly higher than the threshold, potentially indicating nutrient pollution that could lead to eutrophication if left unmanaged. Elevated NO_3-N levels can lead to excessive growth of algae, which depletes oxygen and disrupts marine ecosystems. Nutrient pollution from sources such as agriculture and urban runoff is a growing concern in many coastal regions, as highlighted by Röthig et al. (2023), where long-term accumulation of nutrients has led to detrimental effects on water quality and biodiversity.

Chemical of Seawater Quality for NH_3-N

In addition to NO_3-N, NH_3-N is also a typeof nitrogen compound found in the sea. NH_3-N is formed from the fixation of nitrogen gas and ammonification of organic nitrogen during the decomposition process of organic matter. In addition, NH_3-N comes from the secretions of organisms as well as the input of organic waste from land (domestic waste, industry, and fertilizers). This form of nitrogen is particularly relevant in coastal ecosystems, where nutrient-rich runoff from agriculture and urban areas contributes to elevated NH3-N levels, leading to potential eutrophication (Sarma and Kumar, 2024). NO_3-N is toxic to marine biota because it interferes with the process of binding oxygen in the blood (Sánchez et al. 2017). The maximum limit value of NH_3-N for marine biota according to Government Regulation No. 22/2021 is 0.3 mg/L. The value of the measurement results in the research location showed that the NH_3-N level was at a low level with a range of 0.05-0.12 mg/L using the YSI ProDSS. These levels are well below the regulatory threshold, indicating that the waters in the research location are still safe for marine organisms and do not pose a significant risk of toxicity (Luo et al. 2023). Thus, the levels of NH_3-N in the research location are not toxic to the existing biota. However, it is essential to continue monitoring NH_3-N levels, as prolonged exposure to even low levels of NH_3-N can lead to chronic stress in sensitive marine species, potentially affecting biodiversity and ecosystem health.

Chemical of Seawater Quality for PO_4-P

One form of PO_4-P compound that exists in water is orthophosphate. Phosphate playsan important role in the metabolic process of biota through the process of protein formation and energy transfer (Hamal et al. 2024). Orthophosphate is a vital nutrient for marine organisms, as it plays a key role in cell growth, reproduction, and overall ecosystem productivity. But when present in excess, it can lead to serious ecological imbalances, particularly in coastal areas (Devlin and Brodie, 2023).According to the Ministry of Environment, 0.015 mg/L is a good PO_4-P content for marine biota. This highconcentration suggests not only the influence of external pollutants, but also a potential risk of long-term ecological degradation if these inputs continue unchecked. The measured PO_4-P value in the research location is above the value set according to Government Regulation No. 22/2021 in the range of 0.13-0.35 mg/L using laboratory analysis with the Hach DR3900: Spectrophotometer. This indicates the useof industrial waste or agricultural runoff as fertilizer. Such inputs are often associated with nutrient pollution, where excess phosphorus, along with nitrogen compounds, can significantly alter water quality (Devlin and Brodie, 2023). High levels of PO_4-P in the waters can trigger eutrophication. This process leads to overgrowth of algae, which blocks sunlight and diminishes oxygen levels, creating dead zones that are inhospitable to most marine life. If left unmanaged, this condition could result in hypoxic zones, severely impacting marine biodiversity and threatening local fisheries.In the long term, such nutrient pollution can also lead to changes in species composition, favoring those that can tolerate lower oxygen levels and reducing the overall resilience of marine ecosystems.

Chemical of Seawater Quality for H_2S

H_2S in water are usually the result of anaerobic bacterial respiration in addition to methane (CH_4). Anaerobic bacteria increase when there is a decrease in DO in the water, which causes a decrease in aerobic bacteria. Like aerobic bacteria, anaerobic bacteria also break down organic components in the absence of oxygen (Dhanaraj 2024). This process typically occurs in nutrient-rich environments where organic matter accumulates and depletes oxygen, creating favorable conditions for anaerobic activity. The presence of H_2S is a key indicator of hypoxic or anoxic conditions in aquatic environments, often signaling significant organic pollution and low oxygen levels (Hao et al. 2023). The H2S is not only toxic to marine organisms but also contributes to the characteristic foul odor in stagnant or polluted water bodies, further emphasizing its role as a sign of water quality deterioration. According to Government Regulation No. 22/2021, the recommended H_2S value is 0.01 mg/L. The H_2S content in the region of Mandeh Bay waters ranges from 0.005-0.09 mg/L using laboratory analysis with the Hach DR3900: Spectrophotometer. High H_2S levels were measured at two locations in the estuary with values of 0.05 mg/L and 0.09 mg/L, respectively, indicating localized areas of potential concern, particularly near sources of nutrient runoff or organic matter deposits. Two other locations, some distance from the estuary, have low levels of H_2S. Elevated levels of H_2S can be harmful to marine life, particularly in estuarine areas where nutrient loading and organic matter accumulation are more common (Bastami et al. 2023). This condition, if left unaddressed, could lead to severe ecological disturbances, including fish kills and the degradation of benthic habitats. Long-term monitoring and management efforts are essential to mitigate the effects of H_2S and improve water quality in such vulnerable areas.

After analyzing several chemical parameters affecting seawater quality at the observation locations, including DO,BOD, salinity, NO3-N, NH_3-N, PO_4-P, and H_2S, we can conclude that the water quality in the area is still relatively good to support marine life and tourism activities. However, the elevated levels of certain parameters, such as NO_3-N and PO_4-P, indicate the influence of agricultural and industrial runoff, which could potentially trigger eutrophication if not properly managed. Similarly, the higher H_2S values at the estuary locations suggest anaerobic processes driven by elevated organic matter content. Continuous monitoring is essential to maintain the ecological balance and prevent further environmental degradation due to changes in these chemical parameters. Fig. 3 below provides a detaileddistribution of the value of chemical parameters of seawater quality (DO,BOD, salinity, NO_3-N, NH_3-N, PO_4-P, andH_2S) at the observation sites.

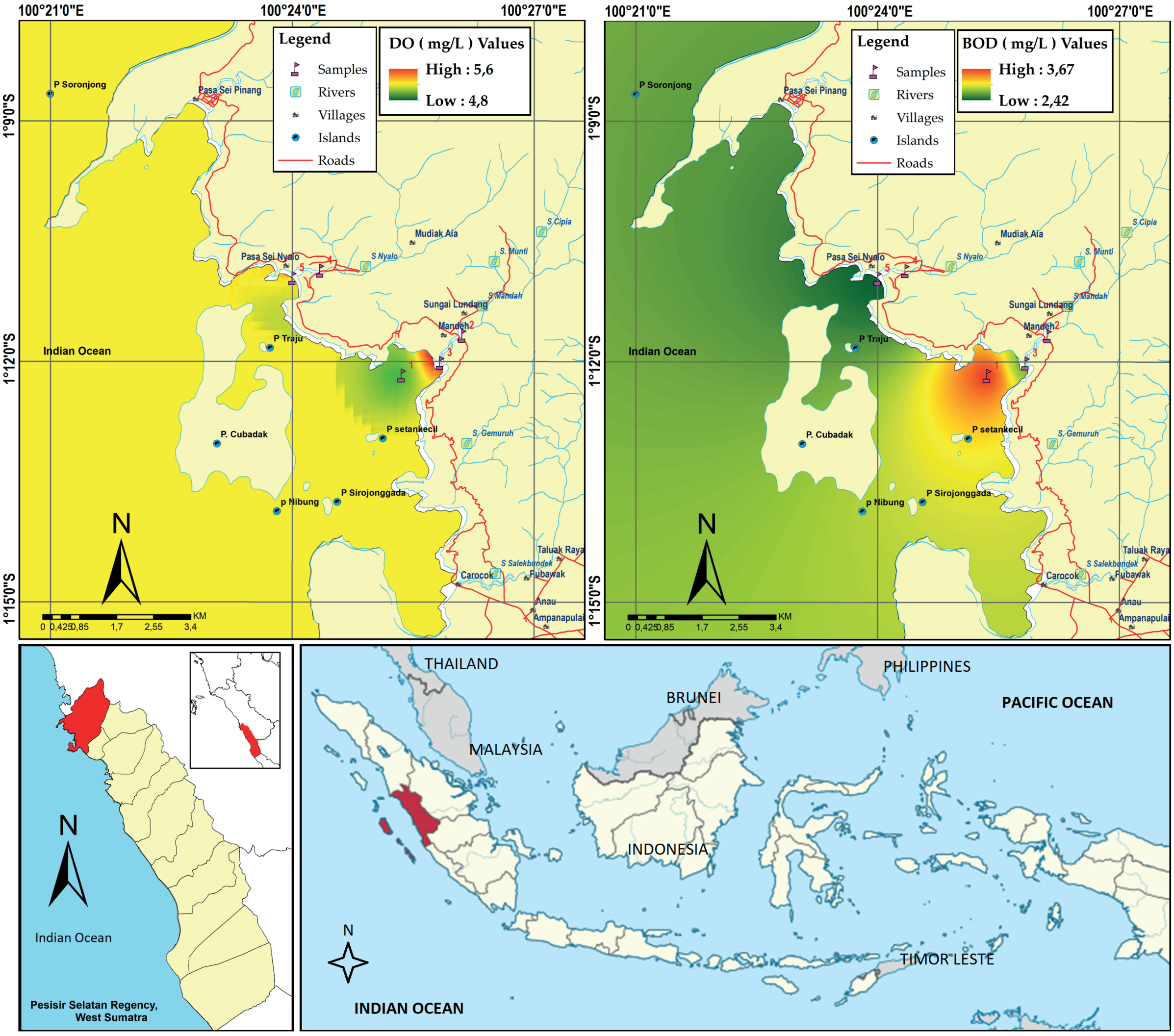

Fig. 3. Map of IDW interpolation for chemical parameters of seawater quality:1) DO; 2) BOD_5; 3) salinity; 4) NO_3-N; 5) NH_3-N; 6) PO_4-P; and 7) H_2S of seawater in region of Mandeh Bay waters

Table 5. Seawater quality standards for marine biota

Parameters	Unit	Quality standards
Phenol Compound	mg/L	0,002
PAH	mg/L	0,003
PCB	mg/L (ppm)	0,01
Surfactant (detergent)/MBAS	mg/L	1
Oil and fat	mg/L	1
Pesticide	mg/L (ppm)	0,01

Results of Pollutant Parameters of Seawater Quality

Some of the water pollutants that are often used as indicators of seawater quality are phenol compounds, PAH, PCB, surfactants (detergents), oils and fats, and pesticides. For the threshold value, the Minister of Environment'sDecreehas determined the quality standard value. More details can be seen in Table 5 below.

Phenol compounds, also known as carbolic acid or benzenol, are aromatic hydrocarbon compounds that are acidic and toxic. This compound is widely used in industry, both as a base material and as a material needed in the production process (Stich 1991). An example of the use of phenol is in the pharmaceutical industry, such as for antiseptics, aspirin drugs, and so on. The remaining compounds from industrial products can be transported into the water. These compounds are easily soluble in water, which can reduce seawater quality. The compound hasnegativeeffects on health issuessuch as lung, kidney, liver function, and cancer-causing substances.

The range of phenolic compounds at the sampling location was from the smallest to 0.0035 mg/L at location 1; 0.0151 mg/L at location; 0.0153 mg/L at location 2; and 0.0239 at location 3 using laboratory analysis with the Agilent 7890B GC System: Gas Chromatography. Compared to the quality standard value, the highest content of phenolic compounds at location 1 already exceeded the threshold value of 0.002 mg/L. Other water pollutants are known as PAH and PCB. PAHs are a large group of compounds that have many aromatic rings in their structure. Examples of PAH compounds include naphthalene, fluorene, pyrene, and others. These compounds are toxic, carcinogenic, or cancer-causing. Sources of PAH compound pollution are usually from industry, motor vehicles, or oil spills from transport ships and oil refineries. In the observation locations, no PCB compounds were identified, while the PAH was measured to be very low with a range of 0.0007 mg/L at location 2 and 0.00111 mg/L at location 3 using laboratory analysis with the Agilent 7890B GC System with 5977B MSD: GC-MS System. Even at location 1 (shipwreck), PAH was not identified. This value is very low when compared to the Minister of Environment's Decree'squality standard value of 0.003 mg/L.

Surfactants are chemical compounds that are widely used in detergents or other cleaning agents. The composition of surfactants can reach 15-40% of the total material used. Besides being able to damage the skin, this compound also has a carcinogenic effect. In waters, high concentrations of detergents can cause eutrophication. The amount of surfactant (detergent) in the observation sites was 0.2 mg/L at sites 1, 2, and 3. This was found using the Agilent 1260 Infinity II LC: Liquid Chromatography in a laboratory. The detergent concentration was much higher than the quality standard value. This suggeststhat there is pollution in the estuary that comes from the mainland. Meanwhile, the oil and fat content in the observation locations is 0.305 mg/L, respectively, at location 1; 0.823 mg/L at location 2; and 0.959 mg/L at location 3,according tolaboratory analysis with the Agilent 7890B GC System: Gas Chromatography. At location 3,the concentration was almost the same as the quality standard value. Using laboratory analysis with the Agilent 7890B GC System and the 5977B MSD: GC-MS System, the pesticide content was 0.025 mg/L in location 2, respectively; and 0.03 mg/L at location 3 using laboratory analysis. Apart from site1, all locations had higher pesticide content than the quality standard.

DISCUSSIONS

According tothe description above, seawater quality lower in estuary locations than in locations further away from estuary areas. The value of the content of several pollutants shows that the estuary location is lightly polluted. This indicates the input of water pollutants from the mainland through river water to the sea. The measurements and analysis of hydrological conditions reveal that the average temperature, average salinity, DO, PO_4-P, NO_3-N, pH, and brightness at the observation locations remain relatively suitable for various purposes,adhering to the criteria outlined in Government Regulation No. 22/2021. In general, the seawater quality conditions (brightness, pH, and temperature) at the wreck site of the observation locations do not indicate extreme natural conditions that could lead to rapid weathering or chemical destruction of the sinking site. Until now, Indonesia has not developed a zoning system that can be used as a guideline to clarify the potential land use of an area or area for the development of historical heritage sites (e.g., shipwrecks) for the development of marine tourism.

Shipwrecks, like the renowned Liberty Wreck in Tulamben, Bali, are captivating sites for diving enthusiasts, serving as prime attractions for diving tourism. These submerged relics typically serve as focal points for marine biodiversity, fostering vibrant and distinct ecosystems akin to artificial reefs. According to Paxton et al. (2023), shipwrecks contribute significantly to the proliferation of marine life, offering habitat complexity that supports a diverse range of species. This ecological role enhances the attractiveness of shipwrecks for divers and researchers alike, as these sites not only provide thrilling underwater experiences but also offer unique opportunities for studying marine ecosystems in artificially created environments. Moreover, shipwrecks are increasingly recognized for their cultural and historical value, serving as underwater time capsules that preserve artifacts and structures from past eras. Tzanakis (2024) highlights that these sunken vessels have the potential to evolve into underwater museums, offering recreational excursions while simultaneously serving as educational platforms. This dual role is crucial in promoting the conservation of underwater cultural heritage, as noted by Brooks et al. (2023), who argue that the integration of cultural heritage preservation with tourism can lead to sustainable management practices that benefit both the environment and local communities.

In addition to their ecological and cultural significance, shipwrecks also contribute to the economic development of coastal regions. The tourism revenue generated by diving activities around shipwrecks can provide substantial financial support for local economies. As Islami (2024) discusses, the economic impact of shipwreck tourism extends beyond direct income, as it also fosters the development of related industries, such as hospitality, guiding services, and marine conservation initiatives. Furthermore, the potential of shipwrecks as training venues for aspiring divers cannot be understated. Shipwrecks offer unique challenges and learning opportunities that are essential for developing advanced diving skills. According to Ababneh (2024), training in shipwreck environments enhances divers' proficiency in navigation, buoyancy control, and underwater problem-solving, making these sites invaluable for both recreational and professional diver training programs. Overall, shipwrecks are multifaceted assets that contribute to marine biodiversity, cultural heritage preservation, economic growth, and diver education. The integration of these aspects into a cohesive management strategy, as suggested by Barianaki et al. (2024), can ensure that shipwrecks continue to provide ecological, cultural, and economic benefits while promoting sustainable tourism practices.

CONCLUSIONS

Conclusions from research results regarding seawater quality in diving tourism areas include physical, chemical, and water pollutants, namely: 1) the pH ranged from 7.12 to 7.61, with lower values near estuaries due to higher freshwater input. Despite fluctuations, the pH remains within the natural range for marine waters in Indonesia; 2) temperature ranged from 29.1 to 30.3°C, falling within the acceptable range for marine biota and tourism activities according to environmental standards; 3) turbidity ranged from 4.2 to 6.5 ntu, with values below the quality standard for marine tourism. However, increased turbidity near estuaries poses challenges to marine life due to sedimentation; 4) DO ranged from 4.6 to 5.6 mg/L, indicating adequate oxygen levels to support marine life and tourism activities. The locations fall within the lightly polluted category based on DO criteria; 5) BOD ranged from 2.42 and 3.67 mg/L, indicating relatively low levels and falling within acceptable limits for marine biota and tourism; 6) Salinity ranged from 32.2 to 33.3‰, with variations influenced by freshwater input but remaining suitable for marine life; 7) NO_3-N ranged from 1.15 to 1.3 mg/L, while NH^3-N ranged from 0.05 to 0.12 mg/L, both within acceptable ranges for marine biota; 8) PO_4-P ranged from 0.13 to 0.35 mg/L, indicating potential water pollutants from industrial or agricultural runoff and warranting monitoring to prevent eutrophication; 9) H_2S ranged from 0.005 to 0.09 mg/L, with higher concentrations near estuaries, indicating anaerobic bacterial activity but remaining within acceptable limits; 10) various water pollutants such as phenol compounds, PAH, PCB, surfactants, oils and fats, and pesticides were identified, with some locations exceeding quality standard values, particularly near estuaries. Overall, while the seawater quality parameters generally meet regulatory standards for marine biota and tourism, there are localized water contamination concerns, especially near estuaries. Continued monitoring and management efforts are essential to maintain and improve seawater quality, particularly in sensitive marine ecosystems like diving tourism areas. Additionally, the research highlights the potential of shipwrecks as diving tourism attractions and emphasizes the need for appropriate management and preservation of such sites for recreational and educational purposes. Sedimentation is, in general, the most important natural phenomenon to be studied in more detail in the future around the Mandeh Bay waters.

REFERENCES

Ababneh, A. (2024). Review Future Technologies in Underwater Cultural Heritage. Journal of the General Union of Arab Archaeologists, 9(2), 1-19. https://doi.org/10.21608/JGUAA2.2024.251548.1157

Adams K M. (2018). Tourism, economy, and society. Routledge Handbook of Contemporary Indonesia.

Ajwang V. (2024). Impact of Pollution on Coral Health in Coastal Reef Ecosystems. American Journal of Natural Sciences, 5(1), 33-43. https://doi.org/10.47672/ajns.2043

Alhadi Z. (2018). Community-based tourism development viewed from economic, social culture and environment aspects in Mandeh's integrated marine tourism area. MATEC Web of Conferences. 229, 01006. https://doi.org/10.1051/matecconf/201822901006

Ali I., and Sulistiyono S.T. (2020). A Reflection of "Indonesian Maritime Fulcrum" Initiative: Maritime History and Geopolitical Changes. Journal of Maritime Studies and National Integration, 4(1), 12-23. https://doi.org/10.14710/jmsni.v4i1.8081

Bastami K.D., Manbohi A., Mehdinia A., Hamzehpour A., Haghparast S., and Taheri M. (2024). Distribution of hydrogen sulfide, nitrogen, and phosphorus species in inshore and offshore sediments of the south Caspian Sea. Marine Pollution Bulletin, 202, 116330. https://doi.org/10.1016/j.marpolbul.2024.116330

Barianaki E., Kyvelou S.S., and Ierapetritis D.G. (2024). How to Incorporate Cultural Values and Heritage in Maritime Spatial Planning: A Systematic Review. Heritage, 7(1), 380-411. https://doi.org/10.3390/heritage7010019

Beaty F., Gehman A.L.M., Brownlee G., and Harley C.D. (2023). Not just range limits: Warming rate and thermal sensitivity shape climate change vulnerability in a species range center. Ecology, 104(12), e4183. https://doi.org/10.1002/ecy.4183

Brown A.R., Webber J., Zonneveld S., Carless D., Jackson B., Artioli Y., and Tyler C.R. (2020). Stakeholder perspectives on the importance of water quality and other constraints for sustainable mariculture. Environmental Science & Policy, 114, 506-518. https://doi.org/10.1016/j.envsci.2020.09.018

Brooks, C., Waterton, E., Saul, H., and Renzaho, A. (2023). Exploring the relationships between heritage tourism, sustainable community development and host communities' health and wellbeing: A systematic review. PloS one, 18(3), e0282319. https://doi.org/10.1371/journal.pone.0282319

Butler B.A. and Ford R.G. (2018). Evaluating relationships between total dissolved solids (TDS) and total suspended solids (TSS) in a mining-influenced watershed. Mine water and the environment, 37(1), 18-30. https://doi.org/10.1007/s10230-017-0484-y

Candra O., Putra A., Priyambodo D.G., Revina R., and Elfizon (2024). Variability between wind and sea waves based on environmentally friendly as renewable energy in Pariaman City. Journal of Sustainability Science and Management, 19(10), in press.

Christensen J.P. (2023). The roles of carbonate, borate, and bicarbonate ions in affecting zooplankton hatching success under ocean acidification. Marine Chemistry, 256, 104269. https://doi.org/10.1016/j.marchem.2023.104269

Dasgupta M., and Yildiz Y. (2016). Assessment of biochemical oxygen demand as indicator of organic load in wastewaters of Morris County, New Jersey, USA. Journal of Environmental & Analytical Toxicology, 6(3), 378. https://doi.org/10.4172/2161-0525.1000378

Davis J.C. (1975). Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. Journal of the Fisheries Board of Canada, 32(12), 2295-2332. https://doi.org/10.1139/f75-268

Devlin M., and Brodie J. (2023). Nutrients and eutrophication. In Marine Pollution: Monitoring, Management, and Mitigation. Springer Nature Switzerland. 75-100.

Dewata I., Hamdi, Putra, A., Hasmira M.H., Driptufany D.M., Fajrin., Yulius, H., Hidayat, M., Yusran, R., and Arman, A. (2024). Water quality of Batang Merao watershed and implementation of Landsat 8 OLI/TIRS for the transparency of Lake Kerinci waters. Journal of Sustainability Science and Management, 19(4), 110-121. http://doi.org/10.46754/jssm.2024.04.009

Dewata I., and Putra A. (2021). Kriging-GIS model for the spatial distribution of seawater heavy metals. Periodicals of Engineering and Natural Sciences (PEN), 9(2), 629-637. http://dx.doi.org/10.21533/pen.v9i2.1851

Dhanaraj, C. J. (2024). Harmful Effects of Water Pollution. Handbook of Water Pollution, Wiley, 123-148. https://doi.org/10.1002/9781119904991.ch5

Duan C., Yang M., Wang Q., Xue J., Yuan L., and Wu H. (2023). Impacts of salinity stress caused by ballast water discharge on freshwater ecosystems. Regional Studies in Marine Science, 65, 103079. https://doi.org/10.1016/j.rsma.2023.103079

El Silisna B., and Susanti R. (2020). Sport Tourism Event of Tour De Singkarak to Support Destination Management in West Sumatera, Indonesia. Journal of Tourism, 7(1), 55-72. https://doi.org/10.24922/eot.v7i1.58742

Figueroa S.M., and Son M. (2024). Transverse variability of residual currents, sediment fluxes, and bed level changes in estuaries with an estuarine dam: Role of estuarine type, dam location, and discharge interval. Continental Shelf Research, 274, 105196. https://doi.org/10.1016/j.csr.2023.105196

Hall N., Testa J., Li M., and Paerl H. (2023). Assessing drivers of estuarine pH: A comparative analysis of the continental USA's two largest estuaries. Limnology and Oceanography, 68(10), 2227-2244. https://doi.org/10.1002/lno.12345

Hamal R., Jaya A.A., Ratnasari R., and Walinono A.R. (2024). The Influence Of Source, Seed Weight And Scattering Distance On The Growth Of Seaweed (Kappaphycus Alvarezii) In Mandale Waters Pangkep District, South Sulawesi. International Journal of Economics, Business and Innovation Research, 3(01), 211-224. https://doi.org/10.70799/ijebir.v3i01.570

Hammer K., Schneider B., Kuliński K., and Schulz-Bull D.E. (2014). Precision and accuracy of spectrophotometric pH measurements at environmental conditions in the Baltic Sea. Estuarine, Coastal and Shelf Science, 146, 24-32. https://doi.org/10.1016/j.ecss.2014.05.003

Hao Y., Shen J., Zhang Y., Xie P., and Liu Y. (2023). Assessing the pollution level of a subtropical lake by using a novel hydrogen sulfide fluorescence technology. Environmental Research, 229, 115916. https://doi.org/10.1016/j.envres.2023.115916

Hemraj D.A., Falkenberg L.J., Cheung K., Man L., Carini A., and Russell B.D. (2023). Acidification and hypoxia drive physiological trade-offs in oysters and partial loss of nutrient cycling capacity in oyster holobiont. Frontiers in Ecology and Evolution, 11, 1083315. https://doi.org/10.3389/fevo.2023.1083315

Hermon D., Gusman M., Putra A., and Dewata I. (2022). Value estimating of the sedimentation rate at the shipwreck sites (MV Boelongan Nederland) the Mandeh Bay Region-Pesisir Selatan Regency. IOP Conference Series: Earth and Environmental Science, 967(1), 012007. https://doi.org/10.1088/1755-1315/967/1/012007

Isdianto A., and Luthfi, O.M. (2020). The Relation of Water Chemical Quality to Coral Reef Ecocsystems in Damas. Journal of Environmental Engineering and Sustainable Technology, 7(2), 26-34. http://dx.doi.org/10.21776/ub.jeest.2020.007.02.3

Islam M.S. (2024). Blue Economy, Complex Challenges: the Future of Marine Tourism in Bangladesh. Safran Kültür Ve Turizm Araştırmaları Dergisi, 7(1), 42-68. https://dergipark.org.tr/tr/pub/saktad/issue/84368/1443733

Jiang L., Lu X., Wang G., Peng M., Wei A., Zhao Y., and Soetaert K. (2023). Unraveling seasonal and interannual nutrient variability shows exceptionally high human impact in eutrophic coastal waters. Limnology and Oceanography, 68(5), 1161-1171. https://doi.org/10.1002/lno.12294

Jin X.L., Jing M., Chen X., Zhuang Z.X., Wang X.R., and Lee F.S. (2010). A study on the relationship between BOD and COD in a coastal seawater environment with a rapid BOD measurement system. Water science and technology, 61(6), 1499-1503. https://doi.org/10.2166/wst.2009.810

Junaidi M., Azhar F., Diniarti N., and Lumbessy S.Y. (2019). Estimation of organic waste and waters carrying capacity for lobster cage culture development in North Lombok District, West Nusa Tenggara Province. Aquaculture, Aquarium, Conservation & Legislation, 12(6), 2359-2370.

Kuroda T., Takai R., Kobayashi Y., Tanaka Y., and Hara S. (2008). Corrosion rate of shipwreck structural steels under the sea. OCEANS 2008-MTS/IEEE Kobe Techno- Ocean, 1-6. http://dx.doi.org/10.1109/OCEANSKOBE.2008.4531052

Kamp A., Høgslund S., Risgaard-Petersen N., and Stief P. (2015). Nitrate storage and dissimilatory nitrate reduction by eukaryotic microbes. Frontiers in microbiology, 6, 1492. https://doi.org/10.3389/fmicb.2015.01492

Kennedy M.D. (2013). Introducing geographic information systems with ARCGIS: a workbook approach to learning GIS. John Wiley &Sons.

Kenney M.A., Sutton-Grier A.E., Smith R.F. and Gresens S.E. (2009). Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy. Terrestrial Arthropod Reviews, 2(2), 99. https://doi.org/10.1163/187498209X12525675906077

Lee Y.W., Oh Y.H., Lee S.H., Kim D., and Joung D. (2023). Assessment of water quality in a coastal region of sea dike construction in Korea and the impact of low dissolved oxygen concentrations on pH changes. Journal of Marine Science and Engineering, 11(6), 1247. https://doi.org/10.3390/jmse11061247

Lee C., Wang S.B., and Kuo C.L. (1978). Benthic Macroinvertebrate and Fish as Biological Indicators of Water Quality, With Reference of Community Diversity Index. Bangkok. International Conference on Water Pollution Control in Development Countries. Bangkok. Thailand.

Lemy D.M., Teguh F., and Pramezwary A. (2019). Tourism development in Indonesia. Delivering Tourism Intelligence. 11, 91-108. https://doi.org/10.1108/S2042-144320190000011009

Luo H.W., Lin M., Bai X.X., Xu B., Li M., Ding J.J., Hong W.J., and Guo L.H. (2023). Water quality criteria derivation and tiered ecological risk evaluation of antifouling biocides in marine environments. Marine Pollution Bulletin, 187, 114500. https://doi.org/10.1016/j.marpolbul.2022.114500

MacIntosh A., Dafforn K., Penrose B., Chariton A., and Cresswell T. (2023). Assessing the ecological impacts of NORM-contaminated scale on marine infauna using sediment microcosms. Chemosphere, 340, 139939. https://doi.org/10.1016/j.chemosphere.2023.139939

McGeady R., Runya R.M., Dooley J.S., Howe J.A., Fox C.J., Wheeler A.J., Summer G., Callaway A., Beck S., Brown L.S., Dolly G., and McGonigle C. (2023). A review of new and existing non-extractive techniques for monitoring marine protected areas. Frontiers in Marine Science, 10, 1126301. https://doi.org/10.3389/fmars.2023.1126301

Millero F.J. (2013). Chemical Oceanography (4thed.). CRC Press. https://doi.org/10.1201/b14753

Mills K., John E.H., Muir D.D., Santodomingo, N., Johnson K.G., Hussein M.A.S., and Sosdian S. (2023). Growth responses of mixotrophic giant clams on nearshore turbid coral reefs. Coral Reefs, 42(2), 593-608. https://doi.org/10.1007/s00338-022-02259-9

Meera S.P., Bhattacharyya M., and Kumar A. (2023). Dynamics of mangrove functional traits under osmotic and oxidative stresses. Plant Growth Regulation, 101(2), 285-306. https://doi.org/10.1007/s10725-022-00817-3

Nabhan F., Bangkara B.A., Sugiarti S., Tuhuteru L., and Siagawati M. (2023). Identification of HR management best practices in marketing tourism production and services: scientific proof of progress in tourism destinations in several provinces in Indonesia. Enrichment: Journal of Management, 13(1), 313-322. https://doi.org/10.35335/enrichment.v13i1.1211

Paśmionka I.B., Bulski K., and Boligłowa E. (2021). The Participation of Microbiota in the Transformation of Nitrogen Compounds in the Soil—A Review. Agronomy, 11(5), 977. https://doi.org/10.3390/agronomy11050977

Paxton A.B., McGonigle C., Damour M., Holly G., Caporaso A., Campbell P.B., Meyer-Kaiser K.S., Hamdan L.J., Mires C.H., and Taylor J.C. (2023). Shipwreck ecology: Understanding the function and processes from microbes to megafauna. Bioscience, 74(1), 12–24. https://doi.org/10.1093/biosci/biad084

Prarikeslan W., Syah N., Barlian E., Suasti Y., and Putra A. (2020). A potential locations of marine tourism in Pasumpahan island, Padang city-Indonesia. International Journal of GEOMATE Journal, 19(72), 123-130. https://doi.org/10.21660/2020.72.ICGeo5

Putra A., Triyatno., Darwis R., Dewata I., Tanto T.A., Mustapha M.A., Razi P., and Zainul R. (2023). Suitability of Mangrove Ecosystems as a Protected Zone Based on Land-Use Changes. Physical Oceanography, 30(5), 866-881.

Putra A., Dewata I., Hermon D., Barlian E., Umar G., Widodo T., and Damanhuri H. (2023). Activity Recommendations Based on an Environmental Approach in Zoning of Marine Protected Areas (MAPS) Pariaman City-Indonesia. EnvironmentAsia, 16(3), 57-67. http://dx.doi.org/10.14456/ea.2023.35

Rahman M.H., Pandit D., Begum, N., Sikder M.N.A., Preety Z.N., and Roy T.K. (2023). Fluctuations of physicochemical parameters in the waters of the Chattogram Coastal Area, Bangladesh. Marine Science and Technology Bulletin, 12(4), 530-539. https://doi.org/10.33714/marstecbull.1246432

Ridwan N.N.H. (2015). Maritime Archaeology in Indonesia: resources, threats, and current integrated research. Journal of Indo-Pacific Archaeology, 36, 16-24. https://doi.org/10.7152/jipa.v36i0.14911

Ridwan N.N.H. (2019). Vulnerability of shipwreck sites in Indonesian waters. Current Science, 117(10), 1623-1628. https://www.jstor.org/stable/27138522

Röthig T., Trevathan-Tackett S.M., Voolstra C.R., Ross C., Chaffron S., Durack P.J., Warmuth L.M., and Sweet M. (2023). Human-induced salinity changes impact marine organisms and ecosystems. Global Change Biology, 29(17), 4731-4749. https://doi.org/10.1111/gcb.16845

Sánchez Ó.J., Ospina D.A., and Montoya S. (2017). Compost supplementation with nutrients and microorganisms in composting process. Waste Management, 69, 136-153. https://doi.org/10.1016/j.wasman.2017.08.012

Safitri M. (2021). Indonesia's Marine and Fishery Genetic Resource Conservation by Means of Intellectual Property. International Conference on Sustainable Development Goals (ISCIS). 1(1), 89-98.

Sarma, D., and Kumar, D. (2024). Eutrophication in freshwater and its microbial implications. In Chapter books of Handbook of Aquatic Microbiology, 194, Routledge.

Septiariva I.,. and Suryawan I.W.K. (2021). Development of water quality index (WQI) and hydrogen sulfide (H2S) for assessment around suwung landfill, Bali Island. Journal of Sustainability Science and Management, 16(4), 137-148. http://doi.org/10.46754/jssm.2021.06.0012

Stanford R.J., Wiryawan B., Bengen D.G., Febriamansyah R., and Haluan J. (2012). Identification Of Poor Fishing-Dependent Communities In Mainland West Sumatra. Buletin PSP, 20(1), 15-34.

Stich H.F. (1991). The beneficial and hazardous effects of simple phenolic compounds. Mutation Research/Genetic Toxicology, 259(3-4), 307-324. https://doi.org/10.1016/0165-1218(91)90125-6

Tortell P.D. (2005). Dissolved gas measurements in oceanic waters made by membrane inlet mass spectrometry. Limnology and Oceanography: Methods, 3(1), 24-37. https://doi.org/10.4319/lom.2005.3.24

Triyatno., Bert I., Idris., Hermon D., and Putra A. (2020). Hazards and morphometry to predict the population loss due of landslide disasters in Koto XI Tarusan-Pesisir Selatan. International Journal of GEOMATE, 19(76), 98-103. https://doi.org/10.21660/2020.76.ICGeo12

Tzanakis M. (2024). Underwater Phantasmagoria: The Touristization of Scuba Diving. In Scuba Diving Practices in Greece: A Historical Ethnography of Technology, Self, Body, and Nature, 139-176. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-48839-9_6

Villatoro M.M., Amos C.L., Umgiesser G., Ferrarin C., Zaggia L., Thompson C.E., and Are D. (2010). Sand transport measurements in Chioggia inlet, Venice lagoon: Theory versus observations. Continental Shelf Research, 30(8), 1000-1018. https://doi.org/10.1016/j.csr.2009.06.008

Weis, J.S. (2024). Marine Pollution: What Everyone Needs to Know®. Oxford University Press. https://doi.org/10.1093/oso/9780197556372.001.0001

Yi Y., Zhao F., Hou C., Zhang C., and Tang C. (2024). Mechanism and threshold of environmental stressors on seagrass in high-turbidity estuary: Case of Zostera japonica in Yellow River Estuary, China. Frontiers in Marine Science, 11, 1432106. https://doi.org/10.3389/fmars.2024.1432106

Yu H., Fang G., Rose K.A., Lin J., Feng J., Wang H., Cao Q., Tang Y., and Zhang, T. (2023). Effects of habitat usage on hypoxia avoidance behavior and exposure in reef-dependent marine coastal species. Frontiers in Marine Science, 10, 1109523. https://doi.org/10.3389/fmars.2023.1109523