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CASE STUDY

Marine pollution in small island ecosystems and the impact of domestic wastewater

I. Maliga[1,2], S. Purwono[3,*], R. Harini[4]

[1] *Department of Environmental Science, School of Postgraduate, Universitas Gadjah Mada, Yogyakarta, Indonesia*

[2] *STIKES Griya Husada Sumbawa, Sumbawa, Indonesia*

[3] *Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia*

[4] *Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia*

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ABSTRACT

BACKGROUND AND OBJECTIVES: Small islands with high population density are facing various environmental problems such as domestic wastewater pollution. Generally, in small islands lacking adequate wastewater management, pollution from domestic sources can severely affect the health of marine ecosystem. Therefore, this study was conducted on one of the most densely populated islands, namely Bungin Island, in Sumbawa Regency, West Nusa Tenggara Province, Indonesia. This study sought to analyze the state of surface seawater as influenced by the pollution stemming from domestic wastewater contamination.

METHODS: Water samples were collected from April to August 2024 during rainy and dry seasons. Three locations along marine area were tested ex-situ using six parameters for seawater, including physical, chemical, and microbiological. The assessment of marine water quality status was conducted through the application of the pollution index formula, which facilitated calculation and analysis. Alongside the analysis of surface seawater samples, this study incorporated domestic wastewater samples, employing seven parameters to evaluate and predict the pollution load affecting the aquatic ecosystem.

FINDINGS: The results showed that, in general, indications of light pollution were found at three test points in seawater of Bungin Island. Major pollution was influenced by the contribution of domestic activities. The key parameters identified during the dry season were the levels of dissolved oxygen and the values of total suspended solids. Meanwhile, the critical parameters in rainy season were salinity and orthophosphate values. Testing of domestic wastewater indicated that several quality indicators, such as chemical oxygen demand, total suspended solids, oil and grease, and total coliform, were below the acceptable quality thresholds. Consequently, this may lead to an escalation in the daily pollution load as time progresses. This pollution load was certainly a problem for marine ecosystem on Bungin Island.

CONCLUSION: The increase in population over time on densely populated islands will cause problems in the future related to domestic wastewater problems that threaten marine ecosystem. To prevent the escalation of environmental problems in the future, it is imperative to undertake appropriate mitigation strategies. This study provides a real picture concerning the threat of environmental damage that threatens one of the most densely populated islands in the world. Additionally, the results present further information that is beneficial for the worldwide sustainability of aquatic ecosystems.

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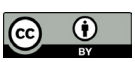



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*Corresponding Author:
Email: *spurwono@ugm.ac.id*
Phone: +62 816-4895-017
ORCID: 0000-0002-2355-6146

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INTRODUCTION

The rise in population is directly proportional to the increasing need for clean water (Gbandi, 2022). The demand for clean water in everyday life and business activities results in an escalation of domestic wastewater production (Silva, 2023). Direct entry of domestic wastewater into water bodies without proper handling causes problems with the carrying capacity of surface water (Kesari et al., 2021). Moreover, domestic wastewater interferes with the stability of aquatic ecosystems, which subsequently influences the biodiversity found within these ecosystems and the surrounding landscapes (Rimi and Dalhat, 2022). Globally, more than 80 percent (%) of domestic wastewater is discharged into water bodies without adequate treatment. Untreated domestic wastewater poses a threat to various ecosystems including several key ecosystems that occur on land, water, and coasts comprising coral reefs and other aquatic biota (Wear et al., 2021). This is the cause of several airborne and wastewater-related diseases (Agarwal et al., 2022). As time progresses, the critical importance of managing domestic wastewater is becoming more pronounced, particularly in light of the worldwide challenges associated with clean water shortage (Onu et al., 2023). The percentage of domestic wastewater, specifically greywater, accounts for 50-80% of the total domestic wastewater (Van de Walle et al., 2023). Greywater is composed of many pollutants, both organic and inorganic (Mahmoudi et al., 2021). Wastewater produced in domestic kitchens is largely characterized by the presence of carbon and a significant number of coliform bacteria contaminants. Meanwhile, bathroom sources predominantly contain many suspended solids, mineral salts, nutrients, organics, and pathogens (Koul et al., 2022). This is because domestic wastewater comes from the use of soap, detergent, shampoo, and urine (Jaax et al., 2024). Consequently, the nature of pollutants present in domestic greywater is highly complex and frequently encompasses new pollutants (Gholami et al., 2023). As depicted in Fig. 1, the degradation of both domestic and marine water bodies constitutes a major environmental challenge, primarily resulting from human actions, especially in areas characterized by high population concentrations (Adyasari et al., 2021). Domestic wastewater, which includes sewage, greywater, and runoff from households, contains various harmful substances such as organic matter, oils, grease, detergents, and pathogens. When wastewater that has not been properly treated or managed is discharged into nearby rivers, streams, or coastal environments, it contaminates the water system with pollutants, leading to a marked deterioration in water quality.

Approximately 36% of the global population lacks access to improved sanitation services, while nearly 1 billion people are deprived of clean drinking



Fig. 1: The contamination of domestic and marine waterways (Adyasari *et al*., 2021)

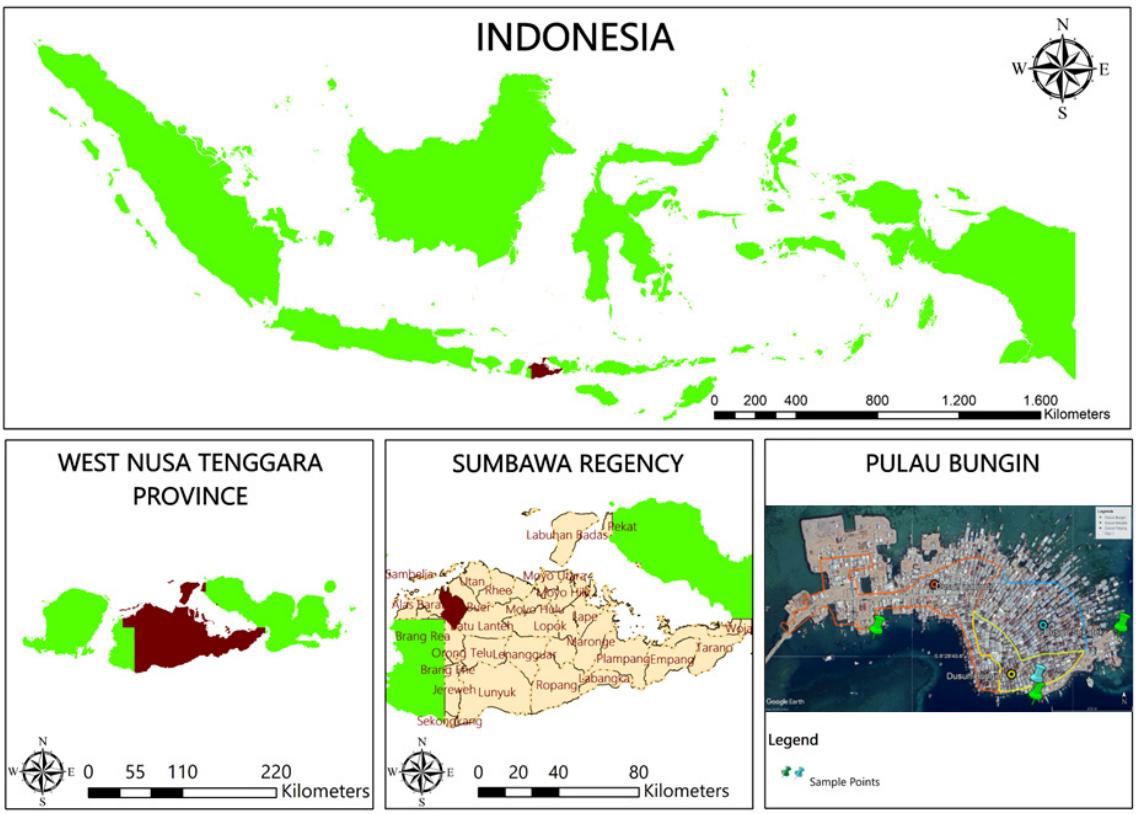


Fig. 2: Geographical location of the study location along with the sampling points in Bungin Island, Indonesia

water for daily needs (Simha et al., 2018). Estimates from World Health Organization (WHO) as well as the Collaborating Council on Water Supply and Sanitation indicate that only <18% of the population of coastal areas and small islands have access to domestic wastewater management services in developing countries (Wu et al., 2011). Small islands are at particularly high risk of domestic wastewater-related contamination (Akpinar-Elci and Sealy, 2014). Characterized by an area of under 2,000 square kilometers (km^2), small islands possess unique attributes that pertain to disaster management, resource distribution, and the interplay of social and physical dynamics (Forde et al., 2024). These islands are essential for preserving biodiversity and act as a fundamental basis for the equilibrium and sustainability of both coastal and marine ecosystems (Madramootoo and Virgil, 2024). Bungin Island is one of small islands in Sumbawa Regency that showed in Fig. 2 with a very high population density. It is mostly inhabited by Bajo Tribe, a community that lives in sea and coastal areas. Initially, this area was only 2 hectares (ha), but it was expanded through a reclamation system to 8.5 ha with a population of 3,400 people in 2023. The topography of Bungin Island is flat. The island is expanding through reclamation using dead coral. Despite its advantages, the reclamation process faces obstacles, notably in terms of costs and the procurement of dead coral. Consequently, the population density in this locality has escalated to 40,000 people/km2 thereby establishing Bungin Island as one of the most densely populated islands in the world. Bungin Island consists of dead coral and soil, with the characteristics of the land composition impeding the filtration process of domestic wastewater. Therefore, this could affect the extent of environmental pollution in the area surrounding the island. Basic sanitation conditions have not been implemented properly on Bungin Island. Environmental issues on Bungin Island are so intricate

that they can serve as a representative problem for other small islands facing similar challenges. Bungin Island exemplifies a typical coastal area lacking in domestic wastewater management, which poses significant risks to its environmental consequences. The problems of clean water, sanitation problems, and domestic wastewater management are still some of the main issues (Finnerty et al., 2023). This may lead to significant challenges for both the community and the surrounding environment. Coastal water pollution can disrupt marine ecosystems (Landrigan et al., 2020), affect seawater quality (Alorda-Kleinglass et al., 2024), and ultimately impact biodiversity (Pfenning-Butterworth *et al*., 2024). It also has negative impacts on fishing activities (Bergland et al., 2019), tourism (Garcés-Ordóñez et al., 2020), and the livelihoods of local communities (Beaumont et al., 2019). Moreover, the improper disposal of household wastewater may facilitate the transmission of diseases via the contamination of both water and food (Obaideen et al., 2022). Environmental pollution and other impacts are projected to become important problems in the future considering the increasingly complex conditions. Therefore, this study aimed to evaluate seawater quality and its impact on aquatic ecosystem. Samples were collected along the surface seawater of Bungin Island, Sumbawa Regency, in 2024.

MATERIALS AND METHODS

Bungin Island is characterized by a community entity of fishermen who depend on marine and fisheries resources including coral reefs. Based on the location, the Island is right at the coordinates of 08º28'39" south latitude and 116º59'42" east longitude showed in Fig. 2. Bungin Island's rainfall distribution is comprehensively aligned with the monsoonal pattern, revealing that the NTB region undergoes a significant peak in rainfall during the rainy season, alongside a notable peak in the dry season over the course of the year. The difference between the rainy and dry seasons in areas with monsoonal rain patterns is generally obvious.

Water sampling

Samples were collected using one domestic wastewater sampling point originating from the Public Bathing, Washing, and Toilet (MCK) point usually accessed by residents for bathing, washing, and washing dishes. Subsequently, sampling of surface seawater was conducted at three sites that are representative of the study focus. Sampling points (Fig. 2) were determined purposively by considering the density of the community houses, the existence of a pier as one of the locations accessed by the community to load and unload fish caught by fishermen, and new locations reclaimed to become residential areas. The selection of these three sampling sites was determined by the identification of the highest levels of domestic activities following the delineation of the respective. These three sampling points indicate the division of the administrative territory on Bungin Island into three separate areas. The sampling was taken in dry and rainy seasons. The findings are considerably influenced by seasonal fluctuations, which encompass aspects such as pollution levels, salinity, dissolved oxygen, and nutrient loads. By taking samples during both wet and dry seasons, the study offers a more precise and thorough evaluation of the environmental issues on Bungin Island. This assures that all proposed solutions will successfully respond to the different pollution patterns that occur throughout the year.

Test parameters and quality standards

The sampling results at each point were tested at the Environmental Laboratory Center, Environment and Forestry Service, West Nusa Tenggara (NTB) Province, Indonesia. In compliance with the Regulation of the Ministry of Environment and Forestry Number 68 of 2016, domestic wastewater samples were evaluated for essential parameters. The analysis focused on total suspended solids (TSS), biological oxygen demand (BOD5), chemical oxygen demand (COD), ammonia, oil and grease, and total coliform (MLHK, 2016). For surface seawater, testing was carried out on parameters referring to Government Regulation (PP) Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, specifically in Appendix VIII related to seawater quality standards for marine biota (PP, 2021). Some of the parameters tested were pH, salinity, temperature as degree Celsius (°C), dissolved oxygen (DO), TSS, and orthophosphate (PO4 – P). The evaluation was performed twice, specifically in May during the rainy season and in August during the dry season. Table 1 shows the location of the sampling points and the reasons

Table 1: Coordinates of domestic wastewater and surface seawater sampling locations

Location name	Latitude	Longitudinal	Reason for taking points
Public toilet sampling point	-8.478684°	116.995565°	Domestic activities of the community who do not have private toilets, in addition to relying directly on the sea, there are still some who use public toilets.
Seawater point 1	-8.47737°	116.992027°	Representing one of the points where the density of the community houses that do not have private toilets is high in Tanjung Hamlet.
Seawater point 2	-8.478086°	116.996774°	Representing one of the points where the density of the community houses that do not have private toilets is high in Sekatek Hamlet.
Seawater point 3	-8.478817°	116.995601°	Representing one of the dock points for loading and unloading fish caught by fishermen on Bungin Island.

Table 2: Standard quality parameters for surface seawater and domestic wastewater samples

Standard quality parameters for surface seawater samples				
No.	Parameter	Standard quality	Unit	Point
1	Temperature	Natural	℃	Public toilet sampling points
2	TSS	20	Milligram per liter (mg/L)	
3	Salinity	33 - 34	%	
4	pH	7 – 8,5		
5	Orthophosphate	0.015	mg/L	
6	DO	>5	mg/L	
Sample quality standard parameters for domestic wastewater				
1	pH	6-9	-	Seawater points 1, 2, and 3
2	BOD	30	mg/L	
3	COD	100	mg/L	
4	TSS	30	mg/L	
5	Oil and grease	5	mg/L	
6	Ammonia	10	mg/L	
7	Total coliform	3000	Total/100 mL	

for selecting th locations as sampling points. These parameters were identified due to their significance in the evaluation of domestic wastewater and marine ecosystems. They possess the potential to create substantial environmental effects and are vital indicators of pollution. They cover a wide range of physical, chemical, and microbiological factors that directly affect the health of marine life and water quality. By choosing these parameters, the study addresses the most critical aspects of domestic wastewater pollution and its impact on aquatic environments. Table 2 outlines the testing parameters along with the corresponding quality standards for each parameter and their respective designation.

Calculation of pollution index value

By employing the pollution index method, it is possible to determine the extent of surface seawater pollution on Bungin Island through the analysis of previously gathered parameter values. This method has been regulated according to the Decree of the Minister of Environment Number 15 of 2003, using Eq. 1 (MNLH, 2003):

$$Pij = \sqrt{\left(\frac{\left(\frac{C_i}{Lij}\right)_M^2 + \left(\frac{C_i}{Lij}\right)_R^2}{2}\right)} \quad (1)$$

Where;
Pij = Pollution index
Ci = Water quality parameter concentration
Lij = Water quality parameter concentration standard
M = Maximum
R = Average

There are specifics in DO parameters because the regulations state that the standard quality value is the minimum limit, using Eq. 2 (MNLH, 2003):

$$\frac{Ci}{Lij} new = \frac{Cim - Ciresults}{Cim - Lij} \quad (2)$$

Where, Cim is the maximum value of the parameter/ saturation.

When the new Ci/Lij value is > 1, then it should be continued, using Eq. 3 (MNLH, 2003):

$$\frac{Ci}{Lij} new = 1 + 5\log\frac{C}{L} Measurement \quad (3)$$

For temperature and PH which have a range, using Eq. 4 (MNLH, 2003):

For Ci < Li the average quality standard

$$\frac{Ci}{Lij} = \frac{Ci - Liaverage}{Li\min - Liaverage} \quad (4)$$

For Ci > Li the average quality standard, the Eq. 5 (MNLH, 2003) must be applied.

$$\frac{Ci}{Lij} = \frac{Ci - Liaverage}{Li\max - Liaverage} \quad (5)$$

Pollution index values are categorized into four according to Table 3.

Calculation of pollution load from domestic wastewater

Referring to the Minister of Environment Regulation Number 5 of 2014, the calculation of domestic wastewater pollution load, using Eq. 6 (MNLHK, 2014):

$$W = Q \times c \times f \quad (6)$$

Where;
W = Waste load carried by water bodies (Kg/Day)
Q = Wastewater discharge (m^3/day)
C = Concentration (mg/L)
F = Conversion factor $\frac{1kg}{1.000.000mg} \times \frac{1000l}{1m^3} = 0,001$

RESULTS AND DISCUSSION

Seawater quality

Table 4 shows the results of surface seawater measurements during the study process carried out in two seasons, namely rainy and dry on Bungin Island. The analysis revealed that in the rainy season, the parameters failing to meet quality standards included salinity across all sites and orthophosphate levels specifically at points 2 and 3. The standard salinity value of surface seawater is 33-34%, but the results show a very low value in the range of 8-9%. In this study, the reduced salinity values during the rainy season could be a result of freshwater influx from rainfall, which effectively dilutes the salt content in the surface water and consequently lowers salinity (Thomas et al., 2022). This seasonal pattern is common in coastal and estuarine environments,

Table 3: Seawater quality categories

PI value	Seawater quality status
PI ≤ 1	Meets quality standards
1 PI ≤ 5	Lightly polluted
5 < PI ≤ 10	Moderately polluted
PI > 10	Heavily polluted

Table 4: Results of seawater quality measurements based on parameters at 3 sampling point locations

No.	Parameter	Unit	Rainy Season			Dry Season			Standart deviation (SD)
			Point AL 1	Point AL 2	Point AL 3	Point AL 1	Point AL 2	Point AL 3	
1	pH	-	8.09	7.82	8.08	7.57	7.52	7.51	0.25
2	Salinity	%	2.94	3.09	3.04	30.7	30.8	30.2	13.77
3	Temperature	℃	31.6	31.7	32.1	30	31.7	29.6	0.95
4	DO	mg/L	5.32	5.59	5.88	4.59	5.59	5.05	0.42
5	TSS	mg/L	10.5	12	11	19	28	22	6.49
6	PO4 – P	mg/L	0.015	0.017	0.027	0.011	0.006	<0.003	0.007

specifically during periods of high rainfall when freshwater input exceeds the evaporation rate, causing a significant decrease in salinity (Akter et al., 2019). The presence of domestic greywater wastewater in surface seawater also plays a role in lowering the salinity levels. (Jarin et al., 2023; Zhao et al., 2020). Orthophosphate values that exceeded the quality standards were found at points 2 and 3. According to several studies, high concentrations of orthophosphate in marine waters are often caused by domestic waste, agriculture, and industrial activities that are not managed properly (Alamgir et al., 2023; Liu et al., 2021). Inefficient domestic wastewater treatment systems are a significant source of orthophosphate pollution, specifically in densely populated areas (Carrillo et al., 2020). According to several studies, high concentrations of orthophosphate in marine waters are often caused by domestic waste, agriculture, and industrial activities that are not managed properly Orthophosphate levels due to anthropogenic behavior cause orthophosphate levels that exceed quality standards potentially at risk of eutrophication.

The measurement results during dry season showed that DO and TSS parameters exceeded the quality standards. Salinity levels around Bungin Island experience an increase during the dry season, contrasting with the rainy season. This phenomenon is largely due to high evaporation rates, lower rainfall, and limited water circulation. Local factors such as wastewater discharge also contribute to the rise in salinity. These combined factors have significant implications for the island's marine ecosystem (Akter et al., 2019). The high TSS value at the third sampling point is attributed to household waste activities and also to domestic activities from the fish auction dock on Bungin Island, which contributes to the high TSS concentration at the sampling point. Several factors likely contributed to the elevated levels of DO and TSS observed during the dry season. First, TSS levels concentrations often elevate because of diminished water volumes, which subsequently lowers the dilution of suspended particles in water (Nauman et al., 2019). Second, human activities such as domestic wastewater runoff can intensify sediment loading into water system during dry season (Adjovu et al., 2023). High TSS can have an impact on DO levels, because suspended solids block light penetration, reduce photosynthesis in aquatic plants, and oxygen production. In addition, the decomposition of organic matter in TSS depletes oxygen, which further reduces DO levels (Sepúlveda-Mardones et al., 2019). An overabundance of total suspended solids (TSS) can deposit on coral reefs, suffocating them and impairing their growth, reproductive capabilities, and critical metabolic activities. This sedimentation can also reduce the survival rate of young corals by blocking settlement sites and restricting recruitment, thus affecting reef resilience (Landrigan et al., 2020).

These dynamics underline the interrelationship between TSS and DO, specifically in ecosystems that are under pressure from human and environmental factors.

Marine pollution index

The test results of various seawater parameters on Bungin Island allow for the detection of pollution index values. The calculation results show pollution index values at each point. The calculation of the pollution index for Bungin Island, classified as light pollution, is illustrated in Table 5. The highest pollution index value is shown at Point 3, which is close to the pier. Pollution value is at 2.41. while at other points, namely at Points 1 and 2, it is 1.33 and 1.45 respectively. The light pollution index shows that there is already potential for pollution to occur.

Table 5: Results of pollution index calculation at sampling points in rainy season

Rainy season			Point 1			
No.	Parameter	Unit	CiJ	LiJ	Ci/Lij	Ci/Lij new
1	pH	-	8.09	7.75	1.04	1.09
2	Salinity	%	2.94	33.00	0.09	
3	Temperature	℃	31.60	29.00	1.09	1.19
4	DO	mg/L	5.32	6.00	0.89	
5	TSS	mg/L	10.50	20.00	0.53	
6	PO4 – P	mg/L	0.02	0.02	1.00	
Ci/Lij Maximum						1.19
Ci/Lij Average						0.80
Pollution index (Pij)						1.33
Category						Light pollution
Rainy season			Point 2			
No.	Parameter		CiJ	LiJ	Ci/Lij	Ci/Lij new
1	pH		7.82	7.75	1.01	1.02
2	Salinity		3.09	33.00	0.09	
3	Temperature		31.70	29.00	1.09	1.19
4	DO		5.59	6.00	0.93	
5	TSS		12.00	20.00	0.60	
6	PO4 – P		0.02	0.02	1.13	1.27
Ci/Lij maximum						1.27
Ci/Lij average						0.85
Pij						1.45
Category						Light pollution
Rainy season			Point 3			
No	Parameter		CiJ	LiJ	Ci/Lij	Ci/Lij new
1	pH		8.08	7.75	1.04	1.09
2	Salinity		3.04	33.00	0.09	
3	Temperature		32.10	29.00	1.11	1.22
4	DO		5.88	6.00	0.98	
5	TSS		11.00	20.00	0.55	
6	PO4 – P		0.03	0.02	1.80	2.28
Ci/Lij maximum						2.28
Ci/Lij average						1.03
Pij						2.41
Category						Light pollution

Based on the laboratory analysis results, domestic wastewater produced by human activities is a key factor in environmental pollution. Human wastewater that pollutes seawater is a source of environmental pollution that can result in health hazards, thereby heightening the incidence of diseases spread through water and food across the globe (Farkas et al., 2024).

Seasonal conditions are also a determining factor of pollution conditions. One example involves multiple nutrients, including phosphorus, which are found

in higher concentrations during the rainy season.. A previous study by Sebastiá et al., (2013) showed that total phosphorus correlated with rainfall, suggesting higher seasonal variations during wet periods, and significantly higher in coastal waters. The presence of pollution on small islands poses a serious threat to aquatic ecosystems, especially resulting in the degradation of coral reef habitats (Martyr-Koller et al., 2021). Table 6 shows pollution index calculation results on Bungin Island at the three seawater sampling points in the light pollution category. The critical parameters found were TSS values at sampling points 2 and 3. High population density and a variety of domestic activities, such as fishing boat docks and public toilet facilities, contribute to the significant pollution index observed in these locations.

The light pollution value, although not yet a high risk to ecosystem, when not handled, pollution can increase and lead to worse conditions. This will influence the surrounding environment, given that the location's economic viability is significantly tied to its tourism potential, which supports the local community. Although seawater quality on Bungin Island is still in the light pollution category, mitigation efforts should be carried out immediately to increase the environmental risks. This corresponds with findings from studies performed in locations with comparable features, such as Gili Matra Island. The findings

Table 6: Results of pollution index calculation at sampling points in dry season

Dry season				Point 1	
No	Parameter	Cij	LiJ	Cij/Lij	Cij/Lij new
1	pH	7.57	7.75	0.98	
2	Salinity	30.70	33.00	0.93	
3	Temperature	30.00	29.00	1.03	1.07
4	DO	4.59	6.00	0.77	
5	TSS	19.00	20.00	0.95	
6	PO4 – P	0.01	0.02	0.73	
Ci/Lij maximum					1.07
Ci/Lij average					0.90
Pij					1.24
Category					Light pollution
Dry season				Point 2	
No	Parameter	Cij	LiJ	Cij/Lij	Cij/Lij new
1	pH – seawater	7.52	7.75	0.97	
2	Salinity – seawater	30.80	33.00	0.93	
3	Temperature	31.70	29.00	1.09	1.19
4	DO	5.59	6.00	0.93	
5	TSS of seawater	28.00	20.00	1.40	1.73
6	PO4 – P of seawater	0.01	0.02	0.40	
Ci/Lij maximum					1.73
Ci/Lij average					1.03
Pij					1.85
Category					Light pollution
Dry season				Point 3	
No	Parameter	Cij	LiJ	Cij/Lij	Cij/Lij new
1	pH	7.51	7.75	0.97	
2	Salinity	30.20	33.00	0.92	
3	Temperature	29.60	29.00	1.02	1.04
4	DO	5.05	6.00	0.84	
5	TSS	22.00	20.00	1.10	1.21
6	PO4 – P	0.00	0.02	0.13	
Ci/Lij maximum					1.21
Ci/Lij average					0.85
Pij					1.35
Category					Light pollution

Table 7: Laboratory analysis results of domestic greywater wastewater samples from the community on Bungin Island

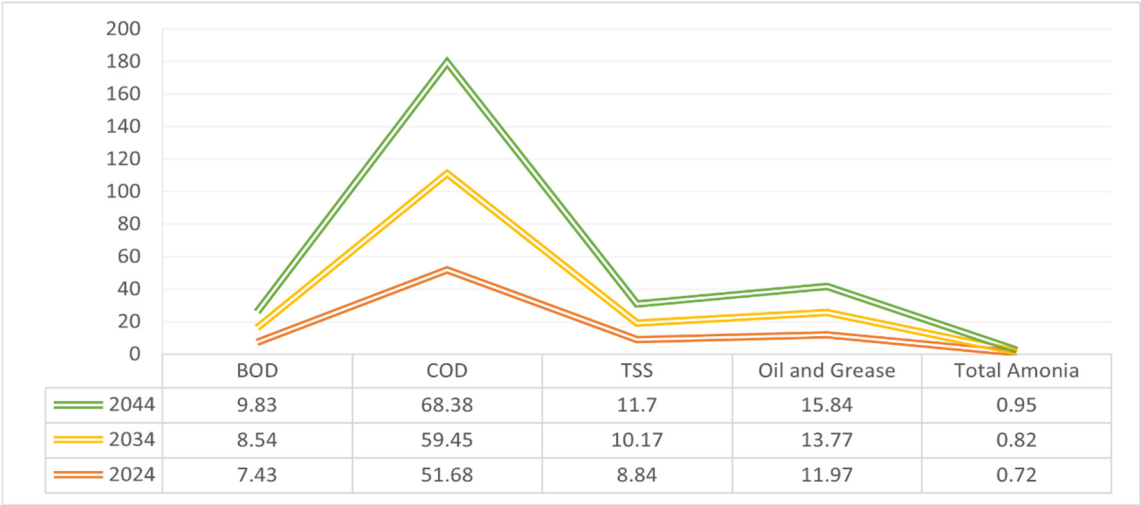
No.	Parameter	Unit	Result	EQS
1	pH	-	7.78	6 – 9
2	BOD	mg/L	27.31	30
3	COD	mg/L	190	100
4	Ammonia	mg/L	2.63	10
5	TSS	mg/L	32.5	30
6	Oil and Grease	mg/L	44	10
7	Total coliform	MPN/100 mL	160.000	3.000

indicate that high density of domestic activities can pose a threat to small islands, potentially leading to decreased water quality and increased vulnerability (Kurniawan et al., 2023). The significant human activities and increasing global marine pollution have been a major concern worldwide for the past few decades. This issue has reached a critical point that demands prompt intervention. The surge in marine pollution is disrupting the steady advancement and health of marine ecosystems. It is important to identify and regulate the quantity, composition, and transportation of pollutants in marine regions, as well as their impact on marine ecosystems. It is imperative to implement key strategies to stabilize marine ecosystems, such as boosting species variety and biodiversity, to strengthen their capacity to endure external pressures (Zhou et al., 2022). Light pollution has enduring ecological consequences for marine life, potentially resulting in substantial shifts in population dynamics, community structures, and the overall vitality of ecosystems. Light pollution resulting from domestic wastewater can have serious long-term impacts on marine ecosystems, including a decline in water quality (Glaser et al, 2019), eutrophication (Bergland *et al*., 2019), disruption of food webs (Farkas *et al*., 2024), changes in biodiversity (Pfenning-Butterworth *et al*., 2024), and economic consequences (Beaumont *et al*., 2019). To protect these ecosystems and sustain the health of marine environments, it is vital to engage in effective mitigation practices and manage waste appropriately. Utilizing real-time water quality sensors, remote sensing, community-based monitoring, biomonitoring, and integrated coastal programs can effectively track long-term pollution trends (Jerves-Cobo et al., 2020). By combining these technologies with routine evaluations, a detailed insight can be obtained into the effects of domestic wastewater and various pollutants on marine ecosystems, particularly those in the vicinity of Bungin Island.

Domestic wastewater quality measurement

Domestic greywater wastewater is one of the problems that causes pollution problems in surface seawater on Bungin Island. The issue stems from the community's ongoing challenges in properly handling domestic wastewater. The results of laboratory tests and the environmental quality standart (EQS) on domestic greywater wastewater samples in public toilet facilities are shown in Table 7.

Findings from the analysis demonstrated that several parameters exceeded the quality benchmarks, particularly COD, TSS, oil and grease, as well as total coliform. These conditions, when allowed to be discharged directly into the environment will have a significant impact on the aquatic ecosystem. COD measures the amount of oxygen needed to oxidize organic and inorganic matter in water. Elevated COD levels reflect a substantial amount of pollutants that are capable of oxidation. This phenomenon diminishes the DO concentration in water, which can induce stress or fatalities among aquatic species and play a role in the emergence of dead zones in aquatic ecosystems (Jerves-Cobo et al., 2020). TSS is suspended particle in water, which can be organic or inorganic. This particle blocks sunlight and affects water clarity. High TSS can cover aquatic habitats, inhibit photosynthesis, disrupt ecosystems, and clog fish gills, ultimately reducing biodiversity in waters (Dwumfour-Asare et al., 2020). Total coliform denotes a group of bacteria that serves as a key indicator of water quality, particularly in relation to contamination from fecal material or other potential pathogens (Dwumfour-Asare et al., 2017). High total coliform indicates potential contamination by disease-causing organisms, which poses a risk to human health and aquatic life resulting in waterborne diseases.



	BOD	COD	TSS	Oil and Grease	Total Amonia
2044	9.83	68.38	11.7	15.84	0.95
2034	8.54	59.45	10.17	13.77	0.82
2024	7.43	51.68	8.84	11.97	0.72

Fig. 3: Projection of daily pollution load in kg on Bungin Island

Projection of domestic wastewater pollution load

Calculation of domestic wastewater pollution load is carried out using Eq. 6. The calculation for the next 20 years using the exponential method in the process of population growth of an average of 1.4% per year is described in the projection of pollution load as shown in Fig. 3.

The upward trend observed in all parameters typically signifies a decline in water quality as time progresses. Increased concentrations of BOD, COD, TSS, oil and grease, along with ammonia, may result from a greater influx of pollutants originating from domestic wastewater sources (Zeb et al., 2024). The sensitive parameter in this part is COD and TSS. Increased levels of these parameters can cause stress on aquatic ecosystems. Higher concentrations of BOD and COD limit the oxygen accessible to aquatic species, while elevated TSS, oil, grease, and ammonia levels can damage aquatic ecosystems, decrease water clarity, and compromise biodiversity. The implications of rising BOD, COD, TSS, and other pollution indicators extend beyond localized environmental degradation. These parameters have broader ecological, economic, and social impacts that threaten biodiversity, livelihoods, tourism, and public health (Lukman et al., 2022). Therefore, to secure the long-term sustainability of small islands like Bungin Island, it is vital to address these concerns through better wastewater management, increased community education, and the adoption of sustainable tourism practices. The pollution load on each parameter is one of the challenges in the future because the increasing pollution load for the next 20 years will continue to occur if without good mitigation efforts, this will have a significant impact on damage to marine ecosystems. This is a global picture that is also experienced by small islands in the world with high population density but minimal efforts to mitigate domestic wastewater management. this is also experienced by Migingo Island in South Africa (Glaser et al, 2019). Both small islands share comparable traits and encounter identical threats associated with the environmental carrying capacity required to support human existence. To advance the domestic wastewater management system on Bungin Island, it is essential to implement future mitigation strategies. One example is to establish a centralized and community-based wastewater treatment system. This can serve as an initial step to encourage the community to engage in domestic wastewater management. In areas with limited space, such as Bungin Island, technology options such as integrated household constructed wetlands (IHCWS) or Membranes Bioreactor (MBR) can be considered (Wu et al., 2011). In addition to implementing technology-based systems, it is crucial to enforce rules and policies comprehensively in order to establish a sustainable management strategy. To successfully

mitigate pollution, it's crucial to take a multi-faceted approach that involves both local governments and communities. By offering vital infrastructure, enacting regulations, and providing funding, governments can be instrumental in environmental initiatives. At the same time, communities can support these efforts by raising awareness, implementing sustainable practices, and actively engaging in both environmental restoration and advocacy for relevant policies. Collaborative efforts will not only enhance water quality, but also protect local ecosystems and economic resources such as tourism and fisheries for future generations.

CONCLUSION

In conclusion, the quality of surface seawater on Bungin Island, a densely populated island, was measured at three sampling points using six main physical, chemical, and microbiological parameters, namely pH, temperature, TSS, Salinity, DO, and orthophosphate. The process of measuring the quality of surface seawater was carried out during two seasons, namely rainy and dry. Results from the analysis indicated the presence of light pollution, with the most significant pollution recorded at Point 3 during the rainy season. The primary parameters of interest in this research included salinity and orthophosphate during the rainy season, while DO and TS) were emphasized in the dry season. The findings emphasize the importance of monitoring water quality throughout the year to account for seasonal changes. Different parameters become critical at various times, so understanding these dynamics is vital for assessing marine ecosystem health and implementing effective pollution management strategies. The observed variations in pollution levels and critical parameters highlight the need for targeted interventions to the specific environmental conditions of each season. An extended examination of domestic greywater wastewater samples was carried out at public toilet locations, given that a significant number of people depend on these facilities for their personal hygiene needs. The sampling results were analyzed using seven parameters including pH, BOD_5, COD, TSS, Ammonia, oil and grease, as well as total coliform. The results showed that the critical parameters that exceeded the quality standards were COD, TSS, oil and grease, as well as total coliform. The detection of these parameters above the established quality standards is alarming, indicating that the wastewater treatment may be insufficient or improperly managed. Their combined impact on the marine environment includes reduced water quality, the potential for eutrophication, and harm to marine biodiversity. If left unaddressed, this pollution could cause long-term damage to the ecosystem, endangering both the environment and the livelihoods of people who depend on these waters for fishing and other activities. This indicates a slight degree of pollution, aligning with the domestic wastewater sampling results that point to household activities as the principal contributors to the pollution. Pollution load analysis calculations show that over time, up to 20 years into the future, there will be problems with pollution loads from domestic activities on Bungin Island. This will have an impact on the aquatic ecosystem and the health of the surrounding community. Therefore, to tackle the challenge of domestic greywater quality that influences marine ecosystems, early mitigation measures must be undertaken. Furthermore, it is important to explore the effects of mildly contaminated seawater on marine organisms and public health.

AUTHOR CONTRIBUTIONS

I. Maliga conducted the literature review, designed the study, performed data collection, data analysis and interpretation, and prepared the article. S. Purwono performed the literature review for biological and chemical parameters and analyzed and interpreted the data, especially on the water test results. R. Harini conducted the literature review for site selection for the study, sampling, and data collection and analyzed and interpreted the data, especially those related to location and mapping.

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CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent,

misconduct, data fabrication and falsification, double publication and submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
°C	Degree Celsius
BOD_5	Five-day biological oxygen demand
BPPT	Center for Higher Education Funding
C	Concentration (mg/L)
C i	Water quality parameter concentration
Ci/Lij Max	The maximum value of the pollution index of all parameters
Ci/Lij	Pollution index of each parameter
Cij/Lij new	Pollution index of each new parameter (if the value of the previously calculated pollution index is higher than 1)
COD	Chemical oxygen demand
DO	Dissolved oxygen
EQS	Environmental Quality Standard
et al.,	et alia (others)
eq	Equation
F	Conversion factor

$$\frac{1\ \text{kg}}{1.000.000\ \text{mg}} \times \frac{1000\ \text{l}}{1\ \text{m}^3} = 0,001$$

Fig.	Figure
Ha	Hectarare
Km²	Square kilometers
Lij	Water quality parameter concentration standard
LPDP	Indonesia Endowment Funds for Education
M	Maximum
MCK	Bathing, Washing, and Toilet
mg/L	Miligram per liter
MLHK	Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia (Minister of Environment and Forestry of the Republic of Indonesia)
MNLH	Menteri Negara Lingkungan Hidup (Secretary of State for Environment of the Republic of Indonesia)
NTB	West Nusa Tenggara Province
PI	Pollution index
PO4-P	orthophosphate
PP	Peraturan Pemerintah (Government regulation)
Q	Wastewater discharge (m^3/day)
R	Average
SD	Standart deviation
TSS	Total solid suspended
W	Waste load carried by water bodies (kg/Day)
WHO	World Health Organization

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AUTHOR (S) BIOSKETCHES

Maliga, I., Ph.D. Candidate, [1]Department of Environmental Science, School of Postgraduate, Universitas Gadjah Mada, Yogyakarta, Indonesia. [2]STIKES Griya Husada Sumbawa, Sumbawa, Indonesia.
- Email: *igamaliga1990@mail.ugm.ac.id*
- ORCID: 0000-0002-1071-2402
- Web of Science ResearcherID: NA
- Scopus Author ID: 58029226800
- Homepage: http://www.pasca.ugm.ac.id/v3.0/id/programs.sub-40

Purwono, S., Ph.D., Professor, Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.
- Email: *spurwono@ugm.ac.id*
- ORCID: 0000-0002-3061-9758
- Web of Science ResearcherID: NA
- Scopus Author ID: 6506448140
- Homepage: https://chemeng.ugm.ac.id/profil-suryo-purwono/

Harini, R., Ph.D. Associate Profesor, Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia.
- Email: *rikaharini@ugm.ac.id*
- ORCID: 0000-0002-2801-5111
- Web of Science ResearcherID: NA
- Scopus Author ID: 57195483722
- Homepage: https://acadstaff.ugm.ac.id/Rika1973

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