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Evaluation of the Biophysical and Chemical Conditions of the Aquatic Environment During the Rainy Season to Mitigate the Ecological Disaster of Ciguatera Fish Poisoning (CFP) and Harmful Algal Bloom (HABs) in the Gili Matra Marine Tourism Park-Lombok

Evaluasi Kondisi Biofisikakimia Lingkungan Perairan Pada Musim Hujan Untuk Mitigasi Bencana Ekologi *Ciguatera Fish Poisoning* (CFP) dan Marak Alga Berbahaya (MAB) di Taman Wisata Perairan Gili Matra-Lombok

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ABSTRAK

Ciguatera Fish Poisoning (CFP) dan fenomena Marak Alga Berbahaya (MAB) yang disebabkan oleh dinoflagellata bentik beracun merupakan salah satu bencana ekologi atau lingkungan yang dapat mengancam kesehatan manusia di kawasan pesisir Indonesia, seperti di kawasan Taman Wisata Perairan (TWP) Gili Matra yang terdiri dari 3 pulau yaitu Gili Meno, Air, dan Trawangan. TWP Gili Matra merupakan pusat wisata bahari dan kawasan konservasi laut di kawasan Nusa Tenggara Barat yang diketahui mengalami tekanan akibat aktivitas manusia dari kegiatan pariwisata dan perikanan yang berdampak negatif kepada ekosistem pesisir, terutama terumbu karang. Kondisi tersebut dapat meningkatkan kelimpahan komunitas dinoflagellata bentik beracun yang berpotensi menyebabkan terjadinya CFP dan MAB di TWP Gili Matra. Untuk itu diperlukan upaya mitigasinya agar risiko bencana ekologi CFP dan MAB dikemudian hari yang selain dapat menyebabkan terjadinya kerusakan ekosistem perairan TWP Gili Matra, tetapi juga kerugian ekonomi yang cukup besar, tidak terjadi. Menurut perhitungan ekonomi para ahli, nilai ekonomi kegiatan pariwisata di TWP Gili Matra, mencapai 26,86 triliun rupiah per tahun. Salah satu upaya mitigasi bencana ekologi CFP dan MAB adalah dengan mengetahui kondisi lingkungan perairan di TWP Gili Matra pada musim hujan. Berdasarkan hasil survei diketahui kondisi biofisikakimia lingkungan perairan pada musim hujan bulan Desember 2022 dan Maret 2024 dalam keadaan yang sangat baik dengan tingkat eutrofikasi sebagai indikator kualitas lingkungan perairan pada tingkat ultraoligotrofik dengan nilai skor TSI (Trophic State Index) 12,9-19,4 (<30) yang mengindikasikan bahwa kesuburan perairan sangat rendah, air jernih, konsentrasi oksigen terlarut tinggi sepanjang tahun dan mencapai zona hipolimnion.

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ABSTRACT

Ciguatera Fish Poisoning (CFP) and the phenomenon of Harmful Algal Bloom (HABs) caused by toxic benthic dinoflagellates are one of the ecological or environmental disasters that can threaten human health in coastal areas of Indonesia, such as in the Gili Matra Aquatic Tourism Park (ATP) area which consists of three islands, namely Gili Meno, Air, and Trawangan. ATP Gili Matra is a center for marine tourism and conservation areas

Keywords:
Biophysical chemical
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ATP Gili Matra
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in the West Nusa Tenggara region which is known to be under pressure due to human activities from tourism and fisheries activities that have a negative impact on coastal ecosystems, especially coral reefs. This condition can increase the abundance of toxic benthic dinoflagellate communities that have the potential to cause CFP and HABs in ATP Gili Matra. For this reason, mitigation efforts are needed so the risk of CFP and HABs ecological disasters in the future which can not only cause damage to the ATP Gili Matra aquatic ecosystem, but also significant economic losses, does not occur. According to economic calculations by experts, the economic value of tourism activities in ATP Gili Matra reaches IDR 26.86 trillion per year. One of the efforts to mitigate the ecological disaster of CFP and HABs is to understand the condition of the aquatic environment in ATP Gili Matra during the rainy season. Based on the survey results, it is known that the biophysical and chemical conditions of the aquatic environment during the rainy season in December 2022 and March 2024 are in very good condition with the level of eutrophication as an indicator of the quality of the aquatic environment at the ultraoligotrophic level with a TSI (Trophic State Index) score of 12.9-19.4 (<30) which indicates that water fertility is very low, the water is clear, the concentration of dissolved oxygen is high throughout the year and reaches the hypolimnion zone.

1. INTRODUCTION

1.1 Background

Harmful Algal Blooms (HABs) including in Plagues of the Seas that threats coastal ecosystem (Duarte et al., 2014). This phenomenon leads to oxygen depletion, mass fish deaths, and human poisoning (Hallegraeff, 2010). Poisoning occurs due to the consumption of marine biota that accumulates toxins (phytotoxin) of phytoplankton during blooming. One of the most fatal is Ciguatera Fish Poisoning (CFP), caused by the consumption of reef fish containing ciguatoxin (CTX) from benthic dinoflagellates such as Gambierdiscus toxicus (de Sylva, 1994; Lehane & Lewis, 2000; Randall, 1958). Other species such as Ostreopsis ovata and Prorocentrum lima also play a role in CFP (Burkholder, 1998; Lehane & Lewis, 2000).

CFP is seafood poisoning (Friedman et al., 2017) which is prevalent in tropical regions such as the Caribbean, French Polynesia, and Australia (Hallegraeff, 2010). Cases have increased significantly in the last 40 years, for example >24,000 cases in French Polynesia (1960-1984) (Hallegraeff, 2010). Other tropical island countries report thousands of cases per year (1998-2008) (Soliño & Costa, 2020). In the subtropical regions (Australia, Japan, Europe), CFP is a new threat due to a combination of coral reef damage, increased macroalgae, ocean warming, and ocean acidification that has led to a shift in the distribution of benthic dinoflagellates to the subtropics (Hallegraeff, 2010).

In Indonesian waters, benthic dinoflagellates species potentially cause CFP, such as G. toxicus, Amphidinium sp., O. ovata, Ostreopsis siamensis, P. lima, P. concavum, and P. rhathymum, have been reported in studies in various waters in Indonesia, such as in the waters of Kepulauan Seribu (Widiarti et al., 2008; Widiarti & Pudjiarto, 2015). Moreover, the presence and high density of numerous benthic dinoflagellates genera, namely, Ostreopsis, Gambierdiscusand Prorocentrum, have also been reported in Bali (Kuta, Sanur, dan Nusa Dua) (Skinner et al., 2011), Padang beach (Thamrin, 2020), and Weh Island and north site of Aceh (Rubiah Island) (Widiarti et al, 2016). Although there have been no reports of CFP cases in Indonesia so far, which threaten to coastal ecosystems especially coral reefs, due to the pressure of various human activities on the coast can increase the risk of the occurrence of Benthic dinoflagellate HABs and trigger the emergence of CFP cases in Indonesia.

Gili Matra Marine Tourism Park (TWP), officially designated as the Aquatic Tourism Park of Gili Meno, Gili Air, and Gili Trawangan—and also known as TWP Gili Indah—is located off the coast of Lombok in West Nusa Tenggara, Indonesia. Administratively, it falls within Gili Indah Village in the Menang District of North Lombok Regency. The park is bordered by the Java Sea to the north and west, the Lombok Strait to the south, and Tanjung Sire to the east, spanning coordinates 8°20′–8°23′ S and 116°00′–116°08′ E. Encompassing an area of approximately 2,954 hectares, Gili Matra includes three islands—Gili Air (±175 ha), Gili Meno (±150 ha), and Gili Trawangan (±340 ha)—surrounded by rich marine waters. Originally designated as a protected area in 1993, its status shifted to a water tourism park in March 2009, and was later formalized as a Marine Tourism Park under the Decree of The Minister of Maritime Affairs and Fisheries of The Republic of Indonesia Number KEP.67/MEN/2009 (Balai Kawasan Konservasi Perairan Nasional Kupang, 2021). Ecologically, the park supports diverse coastal habitats, including mangrove forests—centered on Gili Meno and dominated by Bruguiera species—and widespread seagrass beds comprising eight species. To maintain ecological integrity and support sustainable resource use, Gili Matra TWP is managed through a zonation system, consisting of core, utilization, port, rehabilitation, and protection zones, along with two fisheries zones: traditional and modern sustainable fisheries (Balai Kawasan Konservasi Perairan Nasional Kupang, 2018).

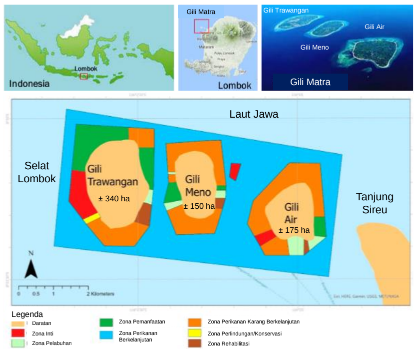

Figure 1. Map of Gili Matra Aquatic Tourism Park, Lombok, West Nusa Tenggara (Map modified from Ministry of Maritime Affairs and Fisheries, 2014)

To anticipate CFP and HABs risks as well as ecosystem damage in the Gili Matra TWP which has an economic value of marine tourism reaching IDR 26.86 trillion/year (BKKPN, 2019), an ecological disaster mitigation strategy is needed. Analysis of aquatic biophysical-chemical conditions (using 2022 and 2024 data) is important for the development of mitigation models. High tourist visits increase pressure on coastal ecosystems, especially coral reefs, through coral reef trampling activities, waste disposal, and overfishing (Kurniawan et al., 2023). Coral reef damage triggers the growth of macroalgae that become toxic benthic dinoflagellates substrates (de Sylva, 1994), potentially increasing the population of dinoflagellates that cause CFP. This can threaten the sustainability of marine tourism as the main source of income for the people and local government of Lombok.

1.2 Research Objectives

This study aims to evaluate the biophysical-chemical conditions of the Gili Matra TWP aquatic environment based on rainfall data in 2022 and 2024 for the development of CFP disaster mitigation models and the phenomenon of HABs in the framework of mitigation for CFP and HABs ecological disaster risk reduction.

2. METHODS

The method used in this study is a quantitative descriptive method. Primary data on aquatic biophysics was obtained through direct surveys in the field. Secondary data related to the environmental conditions of the waters of the Gili Matra Aquatic Tourism Park were collected from various related agencies such as the Kupang National Marine Conservation Area (BKKPN) and the Meteorology and Geophysics Agency (BMKG) and other related agencies.

2.1 Data Collection

Biophysical and chemical data on the waters of the Gili Matra Aquatic Tourism Park (TWP) during the rainy season were collected in December 2022 and March 2024. Water sampling was taken from nine stations in the Core Zone, Utilization Zone, and Sustainable Coral Fisheries Zone (Figure 2).

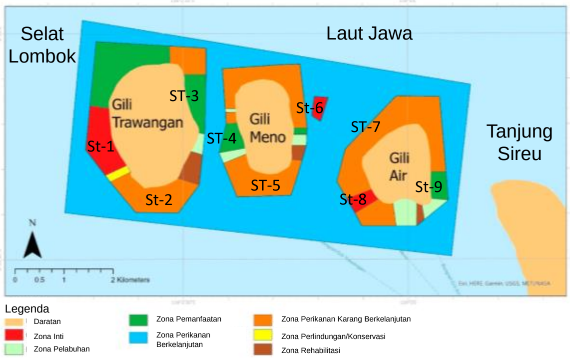

Figure 2. Aquatic biophysics sampling station in Gili Matra TWP
(Map modified from Ministry of Maritime Affairs and Fisheries, 2014).

2.2 Aquatic Biophysical Data

Water quality parameters (temperature, salinity, DO, pH, turbidity, TDS) were measured in situ at nine stations using the WQC Horiba U-5000. Clarity was assessed via Secchi disc depth. TSS was calculated by weighing 0.45 µm Whatman filter paper before and after filtration (SNI 06-6989.3-2004), and chlorophyll-a concentrations were analyzed fluorometrically.

2.3 Aquatic Chemistry Data

Sea surface water samples were taken using Van Dorn water sampling equipment at nine stations to measure the chemical parameters of phosphate (PO4), nitrite (NO2), nitrate (NO3), and ammonia (NH4). Seawater samples were screened using Whatman filter paper with a diameter of 47 mm and a pore size of 0.45 µm to measure phosphate (PO4), nitrite (NO2), nitrate (NO3), and ammonia (NH4) using a Hach DR 900 spectrophotometer.

2.4 Data Analysis

2.4.1 Analysis of Biophysical Data of the Aquatic Environment

Biophysical and chemical data of the aquatic environment were analyzed descriptively quantitatively to determine the changes based on the difference in sampling time in the rainy season. To determine the dominant chemical parameter factors for chlorophyll-a, N/P ratio analysis was used. To determine the eutrophication status of the waters, multiparameter analysis was used based on the parameters of total phosphate, chlorophyll-a, and brightness based on the analysis of TSI data (Trophic State Index) (Carlson,1997).

2.4.2 TSI Data Analysis

TSI data *analysis* was used to determine the status of eutrophication of waters in the Gili Matra TWP using the method of calculating the average TSI according to Carlson (1997) as follows:

$$\text{TSI (SD)} = 60 - 14.41 \ln \text{(SD)}$$

$$\text{TSI (CHL)} = 30.6 + 9.81 \ln \text{(CHL)}$$

$$\text{TSI (TP)} = 4.15 + 14.42 \ln \text{(TP)}$$

$$\text{TSI average} = \frac{\text{TSI (SD)} + \text{TSI (CHL)} + \text{TSI (TP)}}{3}$$

Description:

SD = Secchi disk (m), CHL = chlorophyll-a (µg/l), TP = Total phosphate (µg/l)

3. RESULTS AND DISCUSSION

3.1 Biophysical Conditions of Waters

The biophysical conditions of the aquatic environment (temperature, turbidity, brightness, TDS, TSS, and chlorophyll-a) of the Gili Matra TWP in the rainy season of 2022 and 2024 are seen in Tables 1 and 2, respectively.

Table 1. Biophysical conditions of the aquatic environment of Gili Matra TWP Rainy Season (December 2022)

Num.	Parameters	Unit	Station									Average
			1	2	3	4	5	6	7	8	9	
			Physics									
1	Temperature	°C	29.9	29.9	29.8	29.8	29.8	29.4	30.4	30.5	30.3	30.0
2	Turbidity	NTU	0	0	0	0	0	0	0	0	0	0
3	Brightness	%	100	100	100	100	100	100	100	100	100	100
4	TDS	ppm	28.0	28.1	28.0	28.0	27.5	27.6	27.9	28.0	27.9	27.9
5	TSS	mg/l	14.2	15.8	16.8	16.6	15.8	16.0	14.8	16.6	14.8	15.7

							Biology					
1	Chlorophyll-a	μg/l	0.48	0.64	0.82	0.86	0.70	1.21	0.54	0.35	0.64	0.69

Table 2. Biophysical conditions of the aquatic environment of Gili Matra TWP Rainy Season (March 2024)

Num.	**Parameters**	**Unit**	**Station**									**Average**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
							Physics					
1	Temperature	°C	30.2	30.3	30.5	30.4	30.4	30.5	30.5	30.4	30.3	30.4
2	Turbidity	NTU	0	0	0	0	0	0	0	0	0	0
3	Brightness	%	100	100	100	100	100	100	100	100	100	100
4	TDS	ppm	28.4	28.3	28.2	28.3	28.4	28.3	28.4	28.3	28.1	28.3
5	TSS	mg/l	0.199	0.213	0.212	0.198	0.199	0.196	0.213	0.221	0.198	0.210
							Biology					
1	Chlorophyll-a	μg/l	8.31	3.26	9.20	7.42	0.30	9.50	7.12	8.31	7.42	6.76

3.2 Water Temperature

Water temperature plays a fundamental role in sustaining aquatic life, influencing everything from species distribution to metabolic processes. It is considered one of the most accessible environmental parameters to measure and analyze (Hamuna et al., 2018). The temperature of water bodies affects the vitality and growth of aquatic organisms, with variations shaped by factors such as seasonal shifts, geographical latitude, diurnal cycles, atmospheric circulation, cloud cover, current dynamics, and water depth (Nontji, 2005). As a regulating force in aquatic ecosystems, temperature alters microbial activity, notably accelerating the decomposition of organic matter as it rises (Effendi, 2003). Additionally, elevated temperatures can trigger stratification—layering within the water column—that hinders vertical mixing. Without adequate circulation, the lower layers risk becoming oxygen-deprived and turning anaerobic. These temperature-induced changes in water structure can significantly influence the physical, chemical, and biological processes governing ecosystem health (Kusumaningtyas et al., 2014).Based on sea surface temperature data in the waters of the Gili Matra TWP in the rainy season of December 2022, it is known that the water temperature ranges from 29.8-30.5ºC with an average 30.0ºC (Table 1), slightly lower than the 2024 rainy season which ranges between 30.2-30.5ºC with an average 30.4 ºC (Table 2). Surface water temperature is influenced by meteorological conditions, including air temperature, where the air temperature in the rainy season in December 2022 is slightly lower than the air temperature in the rainy season in March 2024 as seen in Figure 3 (Weatherspark, 2022 dan 2024). The air temperature has affected the condition of the waters of the Gili Matra TWP. The increase in air temperature in the rainy season in March 2024 has raised the temperature from the average 30.0ºC to 30.4ºC. This is supported by the results of the research Syaifullah (2015) about the Sea Surface Temperature of Indonesian Waters and Its Relationship to Global Warming

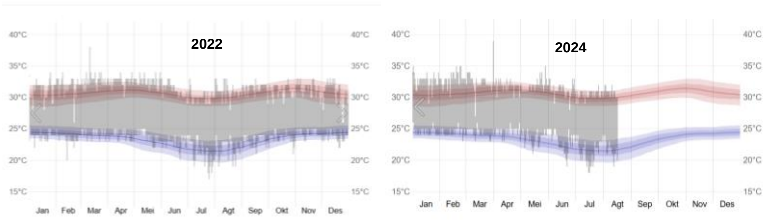

Figure 3. Air temperature around the waters of Gili Matra TWP, Lombok in 2022 and 2024 (Weatherspark, 2022 and 2024)

3.3 Turbidity, Brightness, TDS, TSS, and Chlorophyll-a

The results of turbidity and water brightness in the Gili Matra TWP show the same in the rainy season in December 2022 and March 2024, where the turbidity value is 0 NTU for all observation stations and the brightness is 100%. This means that the condition of the waters in the Gili Matra TWP during the rainy season in December 2022 and March 2024 is in a clear state. However, the values of TDS and TSS and chlorophyll-a are not zero. TDS in the rainy season in December 2022 ranged from 27.5-28.1 ppm with an average of 27.9 ppm, 0.4 ppm lower than the rainy season in March 2024 which ranged from 28.1-28.4 ppm with an average of 28.3 ppm. TSS in the rainy season in December 2022 ranged from 14.2-16.8 mg/l with an average of 15.7 mg/l, 15.5 mg/l higher than the rainy season in March 2024 which ranged from 0.196-0.221 mg/l with an average of 0.210 mg/l. Chlorophyll-a in the rainy season in December 2022 ranged from 0.35-1.21 μg/l with an average of 0.69 μg/l, 6.07 μg/l lower than the rainy season in March 2024 which ranged from 0.30-9.50 μg/l with an average of 6.76 μg/l.

Meanwhile, TDS, TSS, and chlorophyll-a have also changed. TDS has increased by 0.4 ppm from an average of 27.9 ppm in the rainy season in December 2022 to 28.3 ppm in the rainy season in March 2024. Likewise, chlorophyll-a increased by 6.07 μg/l, from an average of 0.69 μg/l in the rainy season in December 2022 to 6.76 μg/l in the rainy season in March 2024. On the other hand, TSS has decreased by 15.5 mg/l, from an average of 15.7 mg/l in the rainy season in December 2022 to 0.210 mg/l in the rainy season in March

2024. This is supported by the results from Ariebowo et al., (2020) about the analysis of the total suspended solids content based on the characteristics of rain in the Ciliwung River watershed, Octavianna (2023) about analysis of the relationship between rainfall intensity on chlorophyll-a parameters and sea surface temperature (SPL) in the Northern Waters of Java in 2007-2021, and Yulanda et al. (2023) about the relationship between temperature, salinity, pH, and TDS in the Brang Biji River of Sumbawa.

The TSS between zones in the rainy season in December 2022 and the rainy season in March 2024 showed uniformity with little difference in concentration between zones. The average TSS in the Utilization Zone in 2022 is slightly higher than the Core Zone and Sustainable Coral Fisheries Zone and vice versa in 2024 (Figure 4). An interesting finding from the biophysical conditions of the waters in the Gili Matra TWP is the increase in the average chlorophyll-a content in the rainy season in March 2024 by 6.07 μg/l compared to the rainy season in December 2022, along with the decrease in the average TSS by 15.5 mg/l, from an average of 15.7 mg/l in the rainy season in December 2022 to 0.210 mg/l in the rainy season in March 2024. The increase in chlorophyll-a content in the Core Zone, Utilization Zone and Sustainable Coral Fisheries Zone is seen in Figure 6. Based on the data as seen in Figures 4 and 5 on the distribution of TSS and chlorophyll-a in the Core Zone, Utilization Zone, and Sustainable Coral Fisheries Zone, it is known that if the TSS concentration is high, then chlorophyll-a becomes low and vice versa. This means that TSS is suspected to have affected the presence of chlorophyll-a in waters. TSS can block the photosynthesis process through lighting. The higher the TSS in the waters, the more the lighting will be reduced, and the development process of phytoplankton will be reduced (Zainuri et al., 2023).

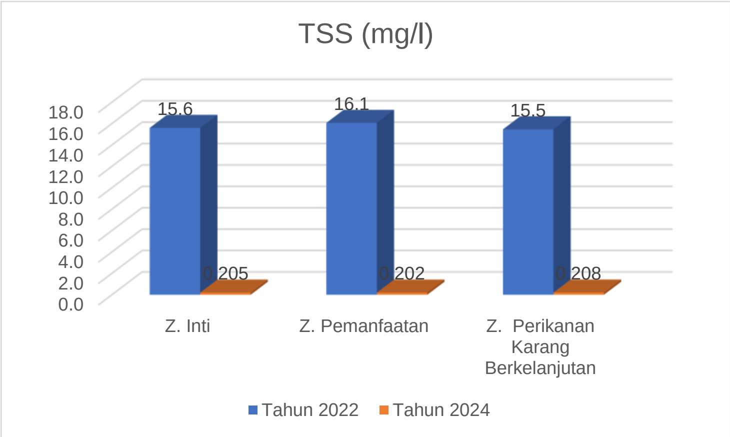

Figure 4. The average TSS of the rainy season in December 2022 and March 2024 in the Core Zone, Utilization Zone, and Sustainable Coral Fisheries Zone in the Gili Matra TWP (Gili Meno, Water and Trawangan)

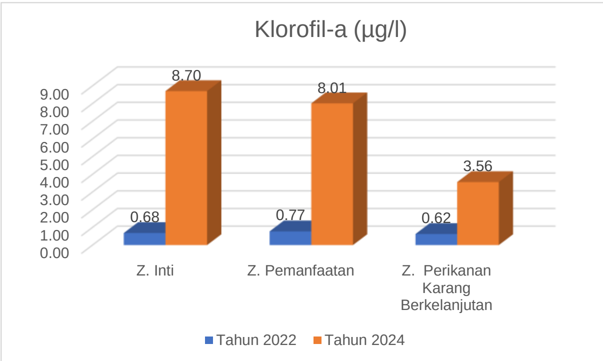

Figure 5. Chlorophyll-a average rainy season in December 2022 and March 2024 in the Core Zone, Utilization Zone and Sustainable Coral Fisheries Zone in the Gili Matra TWP (Gili Meno, Air and Trawangan)

3.4 Aquatic Chemical Conditions

The chemical conditions of the Gili Matra TWP aquatic environment analyzed consisted of parameters of salinity, DO, pH, phosphate, nitrate, nitrite, and ammonia during the rainy season in December 2022 and March 2024, seen in Tables 3 and 4.

Table 3. Chemical conditions of the water environment of the Gili Matra TWP Rainy Season (December 2022)

Num.	Parameters	Unit	Station									Average
			1	2	3	4	5	6	7	8	9	
1	Salinity	ppt	29.8	29.9	29.8	29.8	29.2	29.3	29.7	29.7	29.6	29.6
2	DO	mg/l	4.7	5.0	4.3	4.5	4.6	4.4	4.5	5.1	4.5	4.6
3	pH	mg/l	8.3	8.4	8.6	8.5	8.5	8.4	8.4	8.4	8.4	8.4
4	Phosphate	mg/l	0.08	0.09	0.02	0.06	0.04	0.08	0.02	0.06	0.04	0.08
5	Nitrite	mg/l	0.007	0.002	0.003	0.006	0.004	0.002	0.004	0.003	0.004	0.004
6	Nitrate	mg/l	2.7	4.5	2.7	2.7	3.8	3.3	3.3	3.6	3.7	2.7
7	Ammonia	mg/l	0.009	0.009	0.009	0.01	0.009	0.009	0.01	0.009	0.009	0.009
8	N/P Ratio		34.0	50.1	135.6	45.3	95.3	41.4	165.7	60.2	92.8	80.0

Table 4, Chemical conditions of the Gili Matra TWP waters during the rainy season (March 2024)

Num.	Parameters	Unit	Station									Average
			1	2	3	4	5	6	7	8	9	
1	Salinity	ppt	30.2	30.1	29.9	30.1	30.2	30.2	30.2	30.1	29.9	30.1
2	DO	mg/l	7.1	6.1	6.3	5.9	6.4	7.0	5.9	6.9	10.6	6.9
3	pH	mg/l	5.3	5.4	5.4	6.9	6.9	5.8	7.4	6.6	6.9	6.3
4	Phosphate	mg/l	0.14	0.25	0.10	0.06	0.29	0.04	0.03	0.09	0.17	0.14
5	Nitrite	mg/l	0.009	0.002	0.007	0.003	0.004	0.001	0.001	0.003	0.006	0.009
6	Nitrate	mg/l	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.02
7	Ammonia	mg/l	0.070	0.210	0.110	0.180	0.240	0.100	0.180	0.200	0.170	0.070
8	N/P Ratio		0.7	0.9	1.3	3.2	0.9	2.8	6.4	2.4	1.1	2.2

3.5 Salinity, DO and, pH of Waters

Salinity represents the total concentration of dissolved salts in seawater and serves as a key parameter influencing aquatic life. It directly affects the osmotic pressure within the water column—where an increase in salinity corresponds to higher osmotic pressure, shaping the physiological responses of marine organisms (Gufran & Baso, 2007 in Widiadmoko, 2013). Natural variations in salinity often arise due to differences in evaporation rates and precipitation levels, both of which are influenced by climatic and geographic conditions. Understanding these fluctuations is essential for assessing habitat stability and managing ecological resilience in marine environments. Based on the chemical data of the aquatic environment in Table 3 and Table 4, it is known that sea surface salinity in the Gili Matra TWP in the rainy season in December 2022 ranges from 29.2-29.8 ppt with an average of 29.6 ppt (Table 3). Meanwhile, salinity in the rainy season in March 2024 ranges from 29.9-30.2 ppt with an average of 30.1 ppt (Table 4). The salinity of sea waters is influenced by meteorological conditions, including rainfall, which in the rainy season in December 2022 is likely to be higher than the rainy season in March 2024 as seen in Figure 6 (Weatherspark, 2022 and 2024; Suhanda and Putra, 2021, about the influence of seasons on the distribution of temperature, salinity, and density in the Halmahera Sea).

DO in the rainy season in December 2022 ranged from 4.3-5.1 mg/l with an average of 4.6 mg/l. Meanwhile, in the rainy season in March 2024, DO ranges from 5.9-10.6 mg/l with an average of 6.9 mg/l, 2.40 mg/l higher than the rainy season in December 2024. The high levels of DO in the rainy season in March 2024 seem to be influenced by the high rate of photosynthesis processes in the waters as indicated by the high levels of chlorophyll-a in the rainy season in March 2024. The abundance of phytoplankton represented by chlorophyll-a is one of the factors that affect the high DO in addition to the diffusion of free air from the atmosphere and the movement of surface water (Tahir, 2016; Susanti et al. 2018).

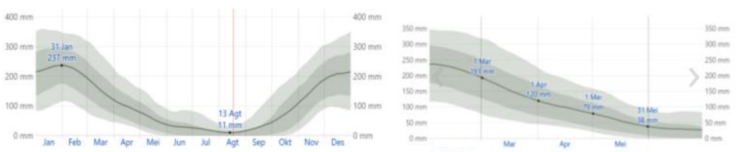

Figure 6. Rainfall around the waters of Gili Matra TWP, Lombok in 2022 and 2024 (Weatherspark, 2022 and 2024)

The pH in the rainy season in December 2022 ranges from 8.3-8.6 with an average of 8.3 higher than the rainy season in March 2024 which ranges from 5.3-7.4 with an average of 6.3. There are several factors that affect the pH concentration in water, namely fertility, biological processes (Patty et al., 2015), and temperature (Westlab, 2016; Fisher, 2020; Savitri, 2023). The survey results show that there has been an increase in the average water temperature from 30.0°C in the rainy season in December 2022 to 30.4°C, which is accompanied by a decrease in pH from 8.3 to 5.3.

3.6 Phosphate, Nitrate, Nitrite, Ammonia, and N/P Ratio

Phosphate (PO4-P) is one of the essential elements in the ocean for protein metabolism and formation. Thomas (1955) in Kadim et al. (2017), Phosphorus is a very important limiting factor in productive and non-productive waters, phosphorus plays an important role in determining the number of phytoplankton. Phosphate (PO4) in the waters of Gili Matra TWP in the rainy season in December 2022 ranged from 0.02-0.09 mg/l with an average of 0.08 mg/l, increasing in the rainy season in March 2024 to an average of 0.14 mg/l with a range of 0.03-0.29 mg/l.

Nitrate (NO3-N) is the main form of nitrogen in natural waters. Nitrate (NO3-N) in the rainy season in December 2022 ranged from 2.7-4.5 mg/l with an average of 3.3 mg/l higher compared to the rainy season in March 2024 which ranged from 0.01-0.03 mg/l with an average of 0.01 mg/l without change. Nitrite (NO2) in the rainy season in December 2022 ranges from 0.002-0.007 mg/l with an average of 0.004 mg/l and in the rainy season in March 2024 it ranges from 0.001-0.009 mg/l with an average of 0.004 mg/l with an average of 0.004 mg/l.

Ammonia is a chemical compound that has an important role in various areas of human life. Ammonia can also cause environmental damage if disposed of carelessly. The ammonia levels in seawater vary widely and can change rapidly. Ammonia can be toxic to biota if its levels exceed the maximum threshold. Ammonia (NH3) in the rainy season in December 2022 ranges from 0.002-0.007 mg/l with an average of 0.004 mg/l and in the rainy season in March 2024 it ranges from 0.009-0.010 mg/l with an average of 0.009 mg/l with an average of 0.009 mg/l.

Redfield Ratio (N/P) is widely used as a biochemical composition in marine ecosystem analysis (Taguchi,2016). The ratio of Redfield inorganic nitrogen to phosphorus in deep ocean waters is approximately 16:1. The N/P Ratio of Gili Matra TWP in the rainy season in December 2022 ranges from 34.0-165.7 with an average of 80.0 mg/l much higher compared to the rainy season in March 2024 ranging from 0.7-6.4 with an average of 2.2. This means that in the rainy season in December 2022, phosphate is a limiting factor in aquatic fertility because the N/P Ratio is greater than 16. Meanwhile, in the rainy season in March 2024, nitrogen is a limiting factor in the rush of waters because the N/P Ratio is less than 16.

3.7 Eutrophication and Tropic Status Index

Eutrophication is defined as the enrichment of water with nutrients in the form of inorganic matter needed by plants and resulting in an increase in the primary productivity of the water (Effendi, 2003). Eutrophication is one of the main factors causing the deterioration of the aquatic environment. If there are nutrients needed for phytoplankton growth, there will be a population explosion. The explosion of phytoplankton is one of the factors that cause eutrophication due to the addition of organic matter in the waters (Jenie dan Rahayu, 1993)

Trophic status is an indicator of the fertility level of a body of water that can be measured from nutrients and brightness levels and other biological activities that occur in a body of water (Zulfia dan Aisyah, 2013). Trophic status is defined as the total weight of living organic matter (biomass) in a body of water at a given location and time (Noviasari, 2018). An overview of the trophic status of a body of water can be obtained, one of which is by calculating the total concentration of phosphorus (an important substance for algae growth), chlorophyll-a concentration (an overview of the number of algae presences in waters) and the level of water brightness. Another method to classify fertility levels is to calculate nitrate and phosphate content as well as plankton abundance (Zulfia dan Aisyah, 2013).

The TSI is the basis for determining trophic status (aquatic fertility) using algae biomass, and its value ranges from 0-100 (Carlson, 1977). The TSI is a simple index because it requires little data and is generally easy to understand. Algae biomass estimation was also carried out by measuring three parameters, namely chlorophyll-a, Secchi depth, and total phosphate. The doubling of algae biomass is indicated by the reduction of the Secchi depth value, the total phosphate will also affect the Secchi depth value. An increase in total phosphate will affect the growth of algae biomass. The estimation of algae biomass can be seen from the content of chlorophyll-a (Carlson, 1997). The trophic status categories based on Carlson's trophic status index can be seen in Table 5 (Utomo et al., 2011). Sulastri et al., (2010), selected phosphorus parameters to classify the ecological status of the lake and reported that phosphorus had a positive response and correlation to chlorophyll-a, total nitrogen, total suspended solid and had a negative relationship with the depth of the Secchi disc as well as a positive relationship with biological changes such as phytoplankton, zooplankton and fish.

Table 5. Trophic status score based on the Carlson Tropic Status Index

Score	Trophic Status	Description
<30	Ultraoligotrophic	Very low fertility, clear water, the high dissolved oxygen concentration and it reaches the hypolimnion zone.
>30-40	Oligotrophic	Low water fertility, clear water is possible with periodic anoxic restriction in the hypolimnetic zone.
>40-50	Mesotrophic	Moderate water fertility, moderate water brightness, increased changes in anoxic properties in the hypolimnetic zone, support water sports activities aesthetically
>50-60	Mild Eutrophic	High water fertility and decreased water brightness, hypomnetic zones are anoxic, there are problems with aquatic plants, only fish are able to live in warm water, support water sports activities but need to be handled.
>60-70	Moderate Eutrophic	High water fertility, blue-green algae domination, clumps occur, aquatic plant problems are extensive.
>70-80	Severe Eutrophic	High water fertility, blooming algae/aquatic plants forming layers such as hypereutrophic conditions.
>80	Hypereutrophic	The fertility of the waters is very high, there are algae clumps, there are often fish deaths, aquatic plants are slightly dominated by algae.

Source: Utomo et al., (2011)

Based on the results of the analysis of the TSI as seen in Table 6, it is known that the water conditions in the Gili Matra TWP during the rainy season in December 2022 and March 2024, respectively have ultraoligotrophic status. The TSI score in the rainy season in December 2022 ranged from 15.3-17.5 (<30) with the TSI score for the Core Zone of 17.5, the Utilization Zone of 15.3, and the Sustainable Coral Fisheries Zone of 15.6. Such water conditions include the category of waters with very low fertility, clear water with high dissolved oxygen concentrations throughout the year and reaching the hypolimnion zone. Likewise, in the rainy season in March 2024, the trophic status of the Gili Matra TWP is included in the ultraoligotrophic category with a TSI score ranging from 12.9-19.4 (<30). The TSI score of the Core Zone is 12.9, the Utilization Zone and the Sustainable Coral Fisheries Zone are 14.2 and 19.4, respectively. The position of the Gili Matra TWP which is open water and is located in the Lombok Strait which is an Indonesian Through Flow (ITF) with strong currents coming from both the Pacific Ocean and the Indian Ocean (Gordon et al., 2010). Waters like this have excellent water circulation, so the process of rinsing or cleaning pollutants can run well.

Table 6. Gili Matra TWP Waters trophic status score based on Carlson's Tropical Status Index

Location	Score	Trophic Status	Description
Rainy season December 2022			
Core Zone	17.5	ultraoligotrophic	Very low fertility, clear water, the dissolved oxygen concentration is high and reaches the *hypolimnion* zone.
Utilization Zone	15.3		
Sustainable Coral Fisheries Zone	15.6		
Rainy season March 2024			
Core Zone	12.9	ultraoligotrophic	Very low fertility, clear water, high dissolved oxygen concentration and it reaches *the hypolimnion zone*.
Utilization Zone	14.2		
Sustainable Coral Fisheries Zone	19.4		

3.8 Ecological Disaster Mitigation CFP and HABs

CFP and the phenomenon of HABs caused by toxic benthic dinoflagellates are one of the ecological or environmental disasters that can threaten human health in coastal areas of Indonesia, such as in the Gili Matra Marine Tourism Park (TWP) area which consists of 3 islands, namely Gili Meno, Air, and Trawangan. Stressed water conditions due to human activities can increase the abundance of toxic benthic dinoflagellates which have the potential to cause CFP and HABs in the Gili Matra TWP. For this reason, mitigation efforts are needed so that the risk of CFP and HABs ecological disasters in the future, which in addition to causing damage to the aquatic ecosystem of the Gili Matra TWP, but also considerable economic losses, does not occur. According to economic calculations by experts, the economic value of tourism activities in the Gili Matra TWP reaches IDR 26.86 trillion per year. One of the efforts to mitigate CFP and HABs ecological disasters is to know the condition of the aquatic environment in the Gili Matra TWP.

Ecological disasters such as CFP and the phenomenon of HABs are not yet known, even though globally the CFP and HABS disasters have threatened various countries such as Indonesia which has many tourist destinations based on the natural beauty of the sea (snorkeling) and diving on coral reefs and the beauty of the beaches of small islands such as in the Gili Matra TWP. To maintain the sustainability of the Gili Matra TWP tourist destination, monitoring the status of the waters in the Gili Matra TWP is needed to prevent CFP and HABs disasters. Based on the results of monitoring the biophysical conditions of the waters and the level of aquatic fertility (eutrophication) in the Core Zone, Utilization Zone, and Sustainable Coral Fisheries Zone, it is known that the aquatic environmental conditions are very good with the level of aquatic fertility (eutrophic) ultraoligotrophic or the very low aquatic fertility level both in the rainy season of December 2022 and March 2024 with TSI score 12.9-19.4 (<30), brightness level 100%, phosphate (PO_4) levels averaged 0.08 mg/l and 0.14 mg/l, and chlorophyll-a averaged 0.69 μg/l and 6.76 μg/l.

4. CONCLUSION

The biophysical-chemical conditions of the Gili Matra TWP aquatic environment based on the results of the evaluation in the rainy season in December 2022 and March 2024 are in very good condition with a TSI score of 12.9-19.4 (<30), brightness level of 100%, phosphate level (PO_4) of 0.08 mg/l and 0.14 mg/l, and chlorophyll-a of 0.69 μg/l and 6.76 μg/l. This condition describes the waters in a state of very low fertility, clear water, high dissolved oxygen concentrations throughout the year and reaching the hypolimnion zone. The ecological disasters of CFP and HABs which can cause damage to the aquatic ecosystem and considerable economic losses in the Gili Matra TWP which has a value of 26.86 trillion rupiah per year, will not occur if disaster mitigation is pursued from an early stage by routinely monitoring the biophysical-chemical conditions of the aquatic environment and conducting disaster risk assessments in the Gili Matra TWP.

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