Hypothetical effects assessment of tourism on coastal water quality in the Marine Tourism Park of the Gili Matra Islands, Indonesia

Fery Kurniawan1,2 · Luky Adrianto1,2 · Dietriech Geoffrey Bengen3 · Lilik Budi Prasetyo4

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Abstract
Tourism is one of the most important issues facing marine protected areas (MPAs) and small islands worldwide. Tourism development is considered a contribution to pollution levels in the environment. This paper aims to evaluate the hypothetical effects of tourism development on water quality spatially and temporally using the coastal water quality index (CWQI) and Geographic Information System (GIS) in search of improved management for marine conservation areas. This study showed significant tourism influences on the CWQI in the Marine Tourism Park of the Gili Matra Islands, Lombok, Indonesia. Water quality variability indicates a significant spatiotemporal difference ($p < 0.05$) in the two tourism seasons. During the peak season of tourism, the CWQI decreased to poor conditions, i.e., ranging from 9.95 to 21.49 for marine biota and from 7.98 to 30.42 for marine tourism activities in 2013, and ranging from 39.52 to 44.42 for marine biota and from 44.13 to 47.28 for marine tourism activities, which were below the standard for both marine biota and marine tourism activities. On the contrary, it showed a better level (from poor to moderate) during the low season of tourism (ranging from 41.92 to 61.84 for marine biota and from 48.06 to 65.27 for marine tourism activities in 2014), providing a more acceptable condition for both aspects. The study proved that massive tourism development in the MPA and small islands could reduce water quality and increase vulnerability. Accordingly, integrated tourism management and the environment, waters, and land will be needed to develop sustainable tourism. The CWQI and GIS were applicable to assess water quality, both spatially and temporally, and become a quick reference in monitoring and initial evaluation of impact management.

Keywords Coastal water quality index · Gili Matra Islands · Marine Tourism Park · Marine protected area · Small islands · Tourism development

Fery Kurniawan
ferykurniawan@apps.ipb.ac.id
Extended author information available on the last page of the article
1 Introduction

The establishment of marine protected areas (MPAs) is important as a policy instrument for both promoting the sustainable use of marine resources, the conservation of marine species and ecosystem, and mitigating human impacts (Al-Abdulrazzak & Trombulak, 2012; Roberts et al., 2018; Zupan et al., 2018), both managed by the government, customary and local communities, or the private sector (Estradivari et al., 2022). MPAs aimed to preserve and improve the productivity of the fishery sector, thus providing prosperity for local communities inhabiting the areas (Ban & Frid, 2018; Bucaram et al., 2018). Currently, tourism development is also growing in the MPA and small islands. Tourism demand in the protected area and small islands are experiencing growth due to their natural beauty (Queiroz et al., 2014). Tourism has become an important economic development for many Small Island Developing States (SIDS) and one of the fastest developing sectors in the world (Salpin et al., 2016; UNWTO, 2014) and was able to change the traditional fisheries community to transition into tourism (Chen & Chang, 2017). In Indonesia, the use of MPAs and small islands as a marine tourism destinations, as reported in Nusa Lembongan Islands, Bali and Gili Matra Islands, Lombok, could be a promising way in order to enhance the beneficial value of MPAs and community welfare (Bottema & Bush, 2012; Hampton & Jeyacheya, 2014; Yulianto et al., 2007).

However, tourism growth has led to direct and indirect impacts on the coastal ecology and environment (Gladstone et al., 2013; Williamson et al., 2017; Zupan et al., 2018), thus affecting the benefits of ecosystem services (De Valck & Rolfe, 2018). Tourism, including the existing activities and intensive development, remarkably gives a negative contribution to environmental pollution (Le Grand et al., 2017; Liberatore et al., 2015; Moschino et al., 2017; Suciu et al., 2017), including marine debris (Wilson & Verlis, 2017; Hayati et al., 2015) and microbial bacteria (Torres-Bejarano et al., 2016). Also, tourism development leads to a rapid change in the landscape due to the increasing human population as a consequence of the growing number of visitors and urbanization (Bottema & Bush, 2012; D’Angelo & Wiedenmann, 2013; Hampton & Jeyacheya, 2014; Kurniawan et al., 2016a, 2016b; Ngah et al., 2012); consequently, the landscape of the island becomes more exposed and later contributes to the decline in seawater quality. The contribution of seawater quality degradation was caused by terrestrial runoff of waste materials from household and tourism industries on the land or as land-based nutrient enrichment and pollution (Edinger et al., 2000; Lapointe et al., 2004; Le Grand et al., 2017). Fabricius (2005) and Beher et al. (2016) stated that the runoff from the mainland is one of the most significant threats to the marine and coastal environments. Even some claim that it was the major source of water pollution in one particular case (D’Angelo & Wiedenmann, 2013; Jha et al., 2014; Sahu et al., 2013). The increasing human population is responsible for a significant increase in water-polluting nutrients, contributing to escalating pressure of human stressors, adversely affecting some existing aquatic ecosystems (such as coral reefs and seagrass) through the direct and indirect mechanisms. In a long time, these conditions with low flushing could also promote eutrophication (Kelly et al., 2021; Kermagoret et al., 2019; Vigouroux et al., 2021; Zhang et al., 2020), the decline in the quality of coastal ecosystems and the environment (D’Angelo & Wiedenmann, 2013; Devlin et al., 2015; Jiang et al., 2013; Kermagoret et al., 2019; Redding et al., 2013; Zhu et al., 2021), and reduce the value of the water utilization, including for water-based tourism activities such as swimming, snorkeling, diving, surfing and canoeing (WHO, 2003; Pharino, 2007; Ngah et al., 2012; Cheung...
et al., 2015). Moreover, poor water quality also induces deleterious effects on human health due to bacterial infection (Cheung et al., 2015; Thoe et al., 2012).

Tourism and the environment have interrelated relationships as a coupled social-ecological system (SES) and need appropriate sustainable development strategies (Kurniawan et al., 2019; Tang, 2015). Sustainable MPA management is observable from its quality indicators of both biotic and abiotic, environmental, threats, connectivity and management effectiveness (Al-Abdulrazzak & Trombulak, 2012; De Valck & Rolfe, 2018; Roberts et al., 2018). It is carried out to evaluate MPA in Indonesia, as presented in the Technical Guidelines for Evaluating the Management Effectiveness of Aquatic, Coasts and Small Islands Conservation Areas (E-KKP3K) in Indonesia (KEP.44/KP3K/2012). However, management effectiveness assessment focuses mostly on regulation, social and biophysical (species and ecosystem) aspects, regardless of water quality as a fundamental environmental aspect of habitat. In other words, there is still a gap in evaluating the region’s status for the sustainability of MPA and small islands. In fact, the natural quality is largely determined by the environmental condition, especially for MPA that is developed for tourism (Al-Abdulrazzak & Trombulak, 2012; De Valck & Rolfe, 2018; Tang, 2015).

This paper aims to evaluate the hypothetical effects of tourism development on water quality in search of improved management for marine conservation areas. In addition, this study assesses the water quality in the Marine Tourism Park (MTP) of the Gili Matra Islands spatially and temporally using the coastal water quality index (CWQI) and Geographic Information System (GIS).

2 Methodology

2.1 Study area

Gili Matra Islands consist of three small islands, namely Gili Trawangan, Gili Meno and Gili Ayer. MTP of Gili Matra Islands constitutes the National Marine Conservation Area (KKPN) established on February 16th, 1993, with a total area of 2954 ha (Fig. 1). These areas protect the important coastal habitat (coral reefs, seagrass, and mangrove) under the Minister of Marine Affairs and Fisheries (KKP), Republic of Indonesia. However, the management of the MTP only covers the water area of 2273.56 ha with the zoning system (Fig. 1), meaning that it does not cover the land area. Such sectoral and disintegration management can be a significant problem that needs to be solved.

Land use/land cover (LULC) in Gili Matra Islands was classified into shoal beach, sand beach, salty lake, mangrove area, mixed forest, plantation, bare areas, non-built-up areas, settlements area and tourism accommodation (Fig. 1). The LULC has changed significantly from 2010 to 2014 to tourism accommodation and settlement area, i.e., approximately 27.43% or 61.76 ha, and the biggest change was in the category of tourism accommodation (18.18% or 46.41 ha) (see Kurniawan et al., 2016a), as a result of the population explosion and development of tourism industry.

In the last few years, visitors significantly raised with an average increase of 19.08% from 2011 to 2014 (Dinas Pariwisata Lombok Utara/Department of Tourism of North Lombok, 2015). The favorite tourism activities included scuba diving, snorkeling, sunbathing, canoeing, sports fishing, and surfing (Dodds et al., 2010; Yulianto et al., 2007). Based on the monthly trend data, the highest tourist visit occurs in August (as the peak season of tourism), reaching 61,430 tourists in 2014 in one month, while the low
season occurs between February and April (Fig. 2) (primary data obtained from the Dinas Pariwisata Lombok Utara/Department of Tourism of North Lombok, 2015). The escalating number of visitors led to increasing environmental pressure, considering that the population of the Gili Matra Islands was already quite dense, reaching 4231 inhabitants in 2016. The largest population (2066 inhabitants) is located on Gili Trawangan Island, followed by Gili Ayer Island and Gili Meno Island, respectively, 1485 and 680 inhabitants (the primary data of Desa Gili Indah/Gili Indah Village, 2016). In that sense, the total population of local people and visitors at peak season could reach 65,661 inhabitants, resulting in serious pressure on the waters.

2.2 Data

The seawater quality data were collected from 12 sampling points in March 2014 and 6 sampling points in August 2013 and 2015. The sample was measured and collected from the water surface during the day, between around 8.00 a.m. and 3.00 p.m., with consideration, representing (1) the existence of the protected coastal ecosystems in the areas, namely the coral reefs and seagrass ecosystems, (2) the land use/cover, (3) the geography of the island, (4) the zoning system and (5) the tourism spots. The parameters of water quality were evaluated using in situ and ex situ methods. The in situ experiments included the determination of pH (using pH meter), dissolved oxygen—DO (using DO meter) and salinity (using refractometer) that were measured onboard. Meanwhile, ex situ tests for the determination of biochemical oxygen demand (BOD), orthophosphate, ammonia, nitrate, nitrite, total suspended solids (TSS) and turbidity were carried out in
the laboratory with the collection and preservation of samples using the standard protocol of American Public Health Association—APHA (Table 1) (APHA, 2012). Totally, 126 samples were analyzed for multiple parameters, i.e., 24 samples in 2013, 72 samples in 2014 and 30 samples in 2015. Samples were stored in plastic sample bottles with sample sizes according to the requirements of each parameter, i.e., 1000 mL for BOD and TSS, respectively, 100 mL for orthophosphate, nitrate, nitrite and turbidity, respectively, and 500 mL for ammonia. Samples were preserved in cold conditions (≤ 6 °C), and H2SO4 was added for ammonia, nitrate and nitrite.

The BOD was measured after 5 days of incubation at 20 °C in a BOD incubator by Winkler’s titration method. Orthophosphate was measured by adding 10 mL vanadate-molybdate reagent to 35 mL of sample; spectrophotometric was used for measuring absorbance with a wavelength of 400 to 490 nm. Ammonia was measured using the titrimetric method by adding 10 mL indicating boric acid solution to the sample and distillate with standard 0.02 N H2SO4 titrant until the indicator turned a pale lavender. Calculate volume after titrated—before titrated. Nitrate was measured by adding 1 mL 1 M HCL to a 50-mL clear sample and read absorbance using spectrophotometric with a wavelength of 220 nm to obtain value absorbance NO3−-N and a wavelength of 275 nm to determine any interference due to dissolved organic matter. After that, calculate the formula value absorbance reduced by the intercept of the regression line shared slope of the regression line. Nitrite was measured using the colorimetric method by adding 2 mL color reagent to the sample mix and waiting between 10 min and 2 h. After that, measure absorbance at 543 nm with spectrophotometric. TSS was measured by filtering the sample and removing water using a vacuum after the dried residue, weight filter before and after used and calculate in final formula weight reduced weight before and multiplied 1000 then
| Parameters               | Peak season (2013)\(^a\) | Low season (2014) | Peak season (2015)\(^b\) | \(p\) value |
|--------------------------|----------------------------|-------------------|--------------------------|-------------|
|                          | Min | Max | Mean ± SD | Min | Max | Mean ± SD | Min | Max | Mean ± SD |             |
| pH                       | –   | –   | –         | 8.40 | 9.50 | 9.29 ± 0.33 | 7.70 | 8.50 | 8.15 ± 0.29 | 2.1E−06     |
| Salinity (‰)             | –   | –   | –         | 31.00 | 32.00 | 31.58 ± 0.51 | 27.00 | 33.00 | 31.00 ± 2.45 | 0.43        |
| DO (mg/L)                | –   | –   | –         | 4.80 | 7.10 | 5.86 ± 0.91  | 8.29 | 8.40 | 8.34 ± 0.05  | 6.3E−06     |
| BOD\(_3\) (mg/L)        | 0.75 | 6.26 | 3.21 ± 1.96 | 0.90 | 1.50 | 1.24 ± 0.20  | 1.00 | 1.20 | 1.13 ± 0.08  | 1.1E−03     |
| Orthophosphate (µg/L)    | 9.00 | 71.00 | 41.17 ± 25.97 | UDL | 5.00 | 3.25 ± 1.06  | 3.00 | 5.00 | 3.67 ± 0.82  | 1.4E−05     |
| Ammonia (µg/L)           | 60.00 | 149.00 | 98.83 ± 31.34 | 170.00 | 507.00 | 250.75 ± 97.21 | 30.00 | 157.00 | 70.17 ± 47.73 | 1.0E−04     |
| Nitrate (µg/L)           | 106.00 | 308.00 | 171.00 ± 79.35 | 3.00 | 38.00 | 14.92 ± 10.88 | 16.00 | 128.00 | 60.50 ± 43.95 | 3.6E−06     |
| Nitrite (µg/L)           | –   | –   | –         | –   | –   | –          | 9.00 | 17.00 | 12.83 ± 2.86  | –           |
| TSS (mg/L)               | –   | –   | –         | UDL | 20.00 | 10.17 ± 3.30 | –   | –   | –          | –           |
| Turbidity (NTU)          | –   | –   | –         | 0.32 | 1.49 | 0.65 ± 0.33  | –   | –   | –          | –           |

Italics columns are the average value of water quality that exceeds the quality standard
UDL: under the detection limit
Significant \(p\) values are in bold \((p < 0.05)\)
Source: \(^a\)KKP (2013)
\(^b\)KKP (2015) except for nitrate concentration
shared by sample volume (mL). The turbidity was measured when air bubbles disappeared with an ultrasonic bath or applied vacuum degassing after that, using a nephelometer to read stray light.

The results were also designed to observe CWQI during the peak season (in August) and low season (in March) of tourism. Current data are obtained from the Ocean Surface Current Analysis Real-time (OSCAR) at the study site during the sampling time of water quality was analyzed to emphasize the results of the spatial distribution analysis of CWQI.

### 2.3 Statistical analysis

Statistical analyses were conducted using PASW Statistics 18 (Predictive Analytics Soft Ware). The parameters of water quality were evaluated using descriptive statistics. The differences in conditions during peak and low seasons of tourism were compared using one-way ANOVA (analysis of variance) at p < 0.05, except for nitrite, TSS and turbidity because there was no repetition of sampling in different years.

### 2.4 Coastal water quality index

The index rating of water quality aims to provide a single value to the water quality based on several parameters used (Abbasi & Abbasi, 2012; Poonam et al., 2013; Tyagi et al., 2013); thus, the status of water quality can be determined. Shyue et al. (1996), Gupta et al. (2003), Muthulakshmi et al. (2013), Al-Mutairi et al. (2014) and Jha et al. (2015) concluded that CWQI was an effective tool able to determining the status of coastal water

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1 http://www.oscar.noaa.gov/.
quality and understandable for managers and communities. In this study, CWQI was established using the following four steps (Fig. 3):

1. Parameter selection

The selection of water quality parameters considers water’s chemical and physical properties relating to the quality of coastal ecosystems, tourism activities and marine biota. Those parameters are highly meaningful and widely used in assessing seawater quality. The selection of parameters considers the purpose of the study and utilization of waters, i.e., tourism activities and marine biota. Several key parameters can affect the above conditions, including pH, salinity, DO, BOD$_5$, orthophosphate, ammonia, nitrate, nitrite, TSS and turbidity (see Shyue et al., 1996; Gupta et al., 2003; KEP.51/MENLH/2004; Orpin et al., 2004; Fabricius, 2005; Laapo et al., 2009; Reopanichkul et al., 2009; Schiff et al., 2011; Abbasi & Abbasi, 2012; Baohong et al., 2013; Muthulakshmi et al., 2013; Jha et al., 2015). Thus, these parameters were selected and considered to represent water quality in the MTP of Gili Matra Island. In addition, these parameters are also widely used in seawater quality analysis. However, data availability was also a major consideration in this study, especially for data in older years.

2. Developing subindex

This step aims to transform the water quality parameters into an index scale considering the standard for marine biota (especially coral reefs and seagrass) and the marine tourism activities based on the KEP.51/MENLH/2004, ASEAN Marine Water Quality Criteria, and condition of waters in the study area (Table 2). Subindex was made from the nonlinear explicit function, by making the estimation the curve based on the rating function values of 100 (“perfect” or $I=1$), 90 (“good” or $I=0.9$), 50 (“moderate” or $I=0.5$), 10 (“poor” or $I=0.1$) and 1 (“intolerable” or $I=0.01$). The rating values refer to Gupta et al. (2003) and Muthulakshmi et al. (2013). Then, generate mathematical equations from the graphic of the sensitivity function on each parameter (“Appendix”).

3. Assignment of weights

The weighting for each parameter was made based on the value of interest and sensitivity using the weighted arithmetic. Based on the study of Gupta et al. (2003), Muthulakshmi et al. (2013), Tyagi et al. (2013), Jha et al. (2015), and Sowjanya et al. (2015), the weighting is more capable of generating a description of the water condition, both in quality and spatial distribution. Assigning unit weights to each parameter was based on the following equation (Jha et al., 2015):

$$W_i = \frac{k}{SV_i} \tag{1}$$

where $W_i =$ unit weight of the $i$th parameter, $SV_i =$ recommended a standard value of the $i$th parameter and $k =$ constant of proportionality calculated by the following equation:

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2 http://asean.org.
### Table 2: Quality standards, standard values, normalized values and weight of unit index for coastal water quality parameters

| Parameters               | Quality standards | Changes allowed | Best standard values (SVi)<sup>b</sup> | Reference | Normalized best standard values (Vi) for CWQI parameters in 2013 | Weight of unit index (Wi) for CWQI parameters in 2014 | Weight of unit index (Wi) for CWQI parameters in 2015 |
|--------------------------|-------------------|-----------------|----------------------------------------|-----------|---------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
|                          | Marine biota      |                 | Marine tourism activities              |           | Marine biota                                                  | Marine tourism activities                        | Marine biota                                      | Marine tourism activities                        |
| pH                       | 7–8.5             | <0.2            | 7.75                                   | 1         | 0.13                                                          | –                                                 | 0.0265669                                         | 0.0227579                                         | 0.0282558                                         | 0.0239860                                         |
| Salinity (‰)             | 33–34             | <5%             | 33.5                                   | 1         | 0.03                                                          | –                                                 | 0.0061461                                         | 0.0052649                                         | 0.0065368                                         | 0.0055490                                         |
| DO (mg/L)                | >5                |                 | 5                                      | 1         | 0.20                                                          | –                                                 | 0.0411787                                         | 0.0352747                                         | 0.0437964                                         | 0.0371783                                         |
| BOD<sub>5</sub> (mg/L)   | <20               |                 | 1.25                                   | 1         | 0.80                                                          | 0.2042516                                         | 0.3410202                                         | 0.1647148                                         | 0.2844735                                         | 0.1751857                                         | 0.2998248                                         |
| Orthophosphate (µg/L)    | <15               |                 | 0.94                                   | 1         | 1.07                                                          | 0.2723536                                         | 0.2255431                                         | 0.2196343                                         | 0.1881443                                         | 0.2335965                                         | 0.1982973                                         |
| Ammonia (µg/L)           | <300              | <300            | 18.75                                 | 1         | 0.05                                                          | 0.0127657                                         | 0.0105716                                         | 0.0102947                                         | 0.0088187                                         | 0.0109491                                         | 0.0092946                                         |
| Nitrate (µg/L)           | <8                |                 | 0.5                                    | 1         | 2.00                                                          | 0.5106290                                         | 0.4228651                                         | 0.4117869                                         | 0.3527471                                         | 0.4379642                                         | 0.3717827                                         |
| Nitrite (µg/L)           | <55               |                 | 3.44                                   | 2         | 0.29                                                          | 0.02929                                           | –                                                 | –                                                 | –                                                 | –                                                 | 0.0637155                                         | 0.0540873                                         |
| TSS (mg/L)               | <20<sup>a</sup>   | <20             | 8.61                                   | 1, 2      | 0.12                                                          | 0.0239133                                         | 0.0204847                                         | –                                                 | –                                                 | –                                                 | –                                                 |
| Turbidity (NTU)          | <5                | <5              | 2.15                                   | 1         | 0.47                                                          | –                                                 | 0.0957644                                         | 0.0820342                                         | –                                                 | –                                                 | –                                                 |

1: Kepmen LH No. 51/2004 (KEP.51/MENLH/2004); 2: AMWQC (http://asean.org/)

<sup>a</sup>Specifically for coral and seagrass

<sup>b</sup>Best standard values are good category value of quality standards (on the quality position of “good” = 0.9), except to the parameters that have interval value, as pH and salinity, so the quality standard used mean value, or perfect value category (perfect = 1). k value in 2013 is 0.255097413 for the marine biota category and 0.21128363 for the marine tourism activities category, in 2014 is 0.205752239 for the marine biota category and 0.176269921 for the marine tourism activities category, and in 2015 is 0.218822397 for the marine biota category and 0.185776252 for the marine tourism activities category.
where \( k = \frac{1}{\sum_{i=1}^{n} V_i} \) (Eq. 2).

where \( l = \) normalization value and \( V_i = \) normalized permissible limit of the \( i \)th parameter (Eq. 3).

\[ V_i = \frac{1}{SV_i} \] (3)

4. Aggregation of subindex

This step aims to obtain the CWQI value based on the total value of all subindexes (the additive aggregation) determined using Eq. 4. Then, the CWQI value was ranked according to index criteria (Table 3).

\[ CWQI = \sum_{i=1}^{n} W_i \times q_i \] (4)

where \( n = \) the number of parameters and \( q_i = \) the quality rating of the \( i \)th parameter in the 0–100 range.

### 2.5 Mapping

The mapping was conducted to understand the spatial distribution of water quality conditions, seasonal data and spatiotemporal variations using ArcGIS 10.2.2. The GIS-based mapping was set according to time series; thus, updated data can be performed periodically to describe the existing changes and observe the actual condition and the potential impact distribution (Jha et al., 2014; Jha et al., 2015). GIS is a suitable tool to analyze the combination of space issues between user groups, stakeholders and decision-makers (Gimpel et al., 2015).

There were four main steps in GIS analysis (Fig. 3). The first step was building a spatial database. The spatial data was built based on the recorded coordinates when measuring and sampling water quality in the field. Data were entered in tabulation and entered as a spatial attribute database. Also, the data were converted into the formats required in the spatial analysis, such as coordinate system (WGS_1984_UTM_Zone_50S), units and data formats. The second step was to generate a thematic map of the distribution of water quality per parameter. The distribution map was created by interpolating data points from...
each selected parameter using Inverse Distance Weighted (IDW) with an output raster cell size of 1 m. IDW could produce data distribution gradually with the single variable (univariable) deterministically. In addition, IDW provides a quick data interpolation from a sparse data distribution on a regular grid or irregularly spaced samples (Jha et al., 2014; Li & Heap, 2014; Jha et al., 2015). The third step was overlaying analysis using a raster calculator in spatial analysis (Map Algebra). In this stage, all data were calculated based on the mathematic function and the weight of each parameter used to integrate the parameters into a single map. The fourth step was to create a reclassified CWQI map based on the CWQI category (Table 3).

3 Results

3.1 A single value of water quality

The descriptive statistics and distribution of the water quality parameters during the two tourism seasons are presented in Table 1 and Figs. 4, 5 and 6. The results demonstrated that tourism seasons showed a significant difference ($p < 0.05$) on all parameters except for salinity ($p = 0.43$). We also found that the average value of pH in 2014, salinity in 2014 and 2015, orthophosphate in 2013 and nitrate in 2013, 2014 and 2015 exceeded the standard of marine water quality. Nevertheless, the interval of change of pH and salinity values among

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3 http://www.esri.com/
seasons was still at a permissible level. In peak seasons, the level of orthophosphate and nitrate in most studied areas of MTP was much greater than the standard (Table 1, Figs. 4 and 5).

On the contrary, in the low season, the orthophosphate level was within the recommended level (3.25 ± 1.06 µg/L). In contrast, the nitrate level was slightly greater than the recommended level (Table 1) on partly the waters of Gili Ayer Island (Fig. 6). Blue Carbon Consortium reported a similar observation during the peak tourism season in 2016. High nitrate levels ranged from 89 to 120 µg/L in Gili Matra Region and 114 µg/L in

Fig. 5 Spatial distribution of water quality parameter values in surface water in the peak season of tourism in 2015
Fig. 6  Spatial distribution of water quality parameter values in surface water in the low season of tourism in 2014
Senggigi Beach as mainland of Gili Matra Island (BCC, 2017). Nevertheless, the recorded concentration of orthophosphate and nitrate was low compared to the study conducted at several tourism beaches in Bali, as reported by Sundra (2011). The study reported that orthophosphate levels ranged from 52 to 350 µg/L, while nitrate levels ranged from 294 to 407.5 µg/L.

3.2 Coastal water quality index

Based on the CWQI analysis, the results suggested that marine water quality ranged from 9.95 to 21.49 for marine biota and ranged from 7.98 to 30.42 for marine tourism activities indicating a poor level in 2013 (Table 4 and Fig. 7). Similar status was again observed in 2015 that seawater quality was at a poor level for both marine biota (39.52 to 44.42) and marine tourism activities (44.13 to 47.28), as presented in Table 4 and Fig. 7. However, the CWQI score in 2014 shows dissimilar results. In the low season of tourism, the water quality in the MTP of Gili Matra Islands was in the range of poor to moderate for both marine biota (41.92 to 61.84) and marine tourism activities (48.06 to 65.27) (Table 5 and Fig. 7). Such results indicate a problematic condition since the number of visitors in the low season will continue to increase (Fig. 2). The CWQI value in the low tourism season may serve as the threshold of visitor number meaningful for the existing management. A similar condition was reported by Laapo et al. (2009), finding that the index of water pollution in the Togean Islands increased during peak seasons.

The result indicates that anthropogenic factors are the main contributors to pollution sources. The low value of CWQI is commonly found in the settlement area, tourism accommodation area, port and the mainland (Lombok Island). Wastewater resulting from agricultural runoff (coconut plantation) and domestic and tourism activities elevates the pollution due to improper management of water and solid waste. In addition, rivers and runoff of the mainland (land-based pollution) were also regarded as the source of pollution. Naturally, coastal water quality should be in good condition in the dry season (coinciding with the peak season in Gili Matra). However, in this study, we found a converse the fact that the CWQI value was in poor condition during the dry season, while the value showed a better condition (moderate level) during the rainy season (coinciding with the low season in Gili Matra).

3.3 Spatial distribution of CWQI

The distribution of water quality was spatially associated with the geographic location of the islands and surface current condition (Figs. 7 and 8). The results showed that the CWQI value for the water area on the west side of Gili Trawangan, facing Lombok Strait, was better than other water areas, including the east side of Gili Trawangan, around Gili Meno and Gili Ayer (Fig. 7). As depicted in Fig. 8, this condition is highly confirmed by current conditions. In August 2013, the current direction led to the south at speeds ranging from 0.1 to 0.3 m/s, resulting in poor CWQI values concentrated around the southern region, similarly in August 2015 and March 2014, where the direction of the current led to the southeast at speeds ranging from 0.2 to 0.3 m/s and 0.1–0.2 m/s, respectively, resulting in poor CWQI values concentrated in the southeast region. These findings suggested that
| Parameters | Beneficial uses | Sampling stations in 2013 |  | Sampling stations in 2015 |  |
|------------|----------------|---------------------------|---|---------------------------|---|
|            |                | 1 2 3 4 5 6               | 1 2 3 4 5 6 |                           |   |
| pH         | a              | – – – – – –               | 2.46 | 2.63 | 2.69 | 2.67 | 2.53 | 2.72 |
|            | b              | – – – – – –               | 2.09 | 2.23 | 2.29 | 2.26 | 2.15 | 2.31 |
| Salinity   | a              | – – – – – –               | 0.56 | 0.56 | 0.53 | 0.45 | 0.53 | 0.56 |
|            | b              | – – – – – –               | 0.48 | 0.48 | 0.45 | 0.38 | 0.45 | 0.48 |
| DO         | a              | – – – – – –               | 6.64 | 6.56 | 6.60 | 6.57 | 6.64 | 6.57 |
|            | b              | – – – – – –               | 5.64 | 5.57 | 5.60 | 5.57 | 5.63 | 5.57 |
| BOD₅       | a              | 15.94 11.90 18.89 9.91    | 15.37 | 15.37 | 15.55 | 15.37 | 15.74 | 15.55 |
|            | b              | 20.57 11.46 28.88 7.95    | 22.85 | 22.85 | 23.40 | 22.85 | 23.95 | 23.40 |
| Orthophosphate | a | 1.8647 9.5932 1.8647 0.0393 0.0068 0.0137 | 14.44 | 14.44 | 12.38 | 14.44 | 10.62 | 12.38 |
|            | b              | 1.5445 7.9456 1.5445 0.0325 0.0056 0.0113 | 12.26 | 12.26 | 10.51 | 12.26 | 9.01  | 10.51 |
| Ammonia    | a              | 0.00024 3.69E−08 1.97E−06 1.28E−05 0.00123 1.82E−05 | 0.81  | 0.63  | 0.93  | 0.65  | 0.35  | 0.93  |
|            | b              | 0.00020 3.06E−08 1.63E−06 1.06E−05 1.02E−03 1.51E−05 | 0.60  | 0.46  | 0.73  | 0.48  | 0.28  | 0.73  |
| Nitrate    | a              | 7.75E−10 0.00021 3.67E−05 1.15E−14 0.00021 9.39E−08 | 2.36E−15 0.00036 0.000117 4.77E−12 0.00027 0.40886 |
|            | b              | 6.42E−10 0.00018 3.04E−05 9.57E−15 0.00018 7.78E−08 | 2.00E−15 0.00031 0.000100 4.05E−12 0.00023 0.34712 |
| Nitrite    | a              | – – – – – –               | 3.86  | 4.03  | 3.40  | 3.70  | 3.12  | 4.39  |
|            | b              | – – – – – –               | 3.28  | 3.42  | 2.89  | 3.14  | 2.65  | 3.73  |
| CWQI       | a              | 17.81 21.49 20.75 9.95 15.18 15.05 | 44.16 | 44.22 | 42.09 | 43.84 | 39.52 | 43.51 |
|            | b              | 22.11 19.40 30.42 7.98 18.65 18.31 | 47.21 | 47.28 | 45.86 | 46.95 | 44.13 | 47.07 |

*Marine biota

*Marine tourism activities
the water area facing the open sea was in better condition, as indicated by the high CWQI value.

4 Discussion

The poor water condition negatively impacts the existing ecosystem, particularly for coral reefs and tourism activities. Kurniawan et al. (2016b) reported that coral reefs were reduced (from 25.13 to 16.50%) from 2000 to 2013 and affected the area’s vulnerability. The declining quality of water can reduce the tourism suitability, the environmental carrying capacity and the assimilation capacity of the waters environment of the Gili Matra Islands. Based on the value of water quality parameters, nitrate constitutes the main parameter and indicates a bad condition. From 2013 to 2015, it is also an excessive level over the standard of marine water quality. The nitrate concentration presenting high dissolved nitrogen in
Table 5  CWQI values of the MTP of the Gili Matra Islands in the low season of tourism in 2014

| Parameters         | Beneficial uses | Sampling stations |
|--------------------|-----------------|-------------------|
|                    |                 | 1  2  3  4  5  6  | 7  8  9  10 11 12 |
| pH                 | a               | 1.78  2.38  1.78  | 1.24  1.39  1.24  | 1.24  1.24  1.24  | 1.24  1.24  1.24 |
|                    | b               | 1.52  2.04  1.52  | 1.07  1.19  1.07  | 1.07  1.07  1.07  | 1.07  1.07  1.07 |
| Salinity           | a               | 0.51  0.52  0.51  | 0.52  0.51  0.52  | 0.52  0.52  0.52  | 0.52  0.52  0.52 |
|                    | b               | 0.44  0.45  0.44  | 0.44  0.44  0.44  | 0.44  0.45  0.45  | 0.45  0.45  0.45 |
| DO                 | a               | 4.12  4.12  4.12  | 3.72  4.12  3.80  | 3.85  3.95  3.85  | 3.85  4.12  3.87 |
|                    | b               | 3.53  3.53  3.53  | 3.19  3.53  3.25  | 3.25  3.13  3.13  | 3.53  3.32  3.32 |
| BOD₅               | a               | 14.97 14.80 14.28 | 14.12 14.12 13.95 | 14.45 14.45 14.28 | 14.45 13.95 14.80 |
|                    | b               | 25.86 25.55 24.67 | 24.39 24.39 24.10 | 24.96 24.67 24.96 | 24.96 24.10 25.55 |
| Orthophosphate     | a               | 11.64 15.83 15.84 | 11.64 13.58 9.98  | 11.64 15.83 11.64 | 15.83 13.58 11.63 |
|                    | b               | 9.97 13.56 11.63  | 9.97 11.63 8.55  | 9.97 13.56 9.97  | 13.56 11.63 9.97 |
| Ammonia            | a               | 0.15 0.23 0.25   | 0.28 0.17 0.06    | 0.02 0.29 0.19    | 0.20 0.14 0.12 |
|                    | b               | 0.13 0.20 0.21   | 0.22 0.15 0.05    | 0.25 0.16 0.17    | 0.18 0.12 0.08 |
| Nitrate            | a               | 9.6219 2.2264 0.5152 | 1.2398 9.6219 17.2792 | 0.0115 0.5152 0.0115 | 0.0006 1.2398 3.9983 |
|                    | b               | 8.2432 1.9074 0.4414 | 1.0621 8.2432 14.8032 | 0.0098 0.4414 0.0098 | 0.0005 1.0621 3.4253 |
| TSS                | a               | 1.81 2.05 1.59   | 1.59 2.32 1.81    | 2.32 2.32 2.05    | 2.05 0.24 1.81 |
|                    | b               | 1.55 1.76 1.37   | 1.37 1.98 1.55    | 1.99 1.98 1.76    | 1.76 0.20 1.55 |
| Turbidity          | a               | 9.41 9.53 9.48   | 9.57 9.54 9.57    | 9.57 9.51 9.44    | 8.73 9.26 9.26 |
|                    | b               | 8.06 8.16 8.20   | 8.12 8.20 8.20    | 8.20 8.14 8.09    | 8.09 7.48 7.93 |
| CWQI               | a               | 54.01 51.68 48.45 | 45.06 53.04 61.84 | 41.92 44.22 47.96 | 43.19 46.08 49.21 |
|                    | b               | 59.30 57.15 52.01 | 51.19 57.73 65.27 | 48.06 50.46 53.53 | 49.59 51.62 55.04 |

*a*Marine biota  
*b*Marine tourism activities
water can lead to lower quality of the coral reefs. In the long term, this condition promotes several disadvantageous conditions such as elevated coral mortality, decreased coral health and reproduction, reduced rate of classification, increased growth of algae as competitors for coral reefs and declined fish availability (Chazottes et al., 2002; D’Angelo & Wiedenmann, 2013; Fabricius, 2005; Koop et al., 2001; Marubini & Atkinson, 1999; Ngah et al., 2012; Redding et al., 2013; Reopanichkul et al., 2009). Moreover, it can also increase the vulnerability of the seagrass ecosystem because it affects the growth, the number of leaves, the distribution, the decrease in the ability of the new generation and the blooming/explosion of epiphyte on the seagrass (Jiang et al., 2013; Kahn & Durako, 2006; Lapointe et al., 2004). The elevated nitrate concentration was not recommended for tourists directly contacting the water (KEP.51/MENLH/2004).

In terms of sustainable tourism management, the increasing risk of visitor’s safety was associated with the decreasing natural condition, ultimately affecting the number of visitors. Additionally, the damaged coastal ecosystem is considered a failure to manage conservation areas.

Therefore, the seawater quality should also indicate an area’s status, besides social and ecosystem indicators. Generally, the water quality is considered a complement to ecosystem monitoring and is not comprehensively analyzed. Water quality should be

Fig. 8 Speed and direction of ocean surface current in Gili Matra Region during the sampling time of water quality
periodically monitored to understand the environmental system and changes over time through the detection of trends; thus, guidelines for management and regulation can be made by the actual condition and the utilization of existing resources, enabling to achieve the main purpose of the management (NAS, 2002; Karydis & Kitsiou, 2013; Jha et al., 2014; Mishra et al., 2015). The monitoring program should reduce the uncertainty of environmental impacts and implementation of planning and decision-making. The manager must compose specific monitoring purposes by making the target, establishing the criteria and standards, and understanding the existing criteria and standards; designing sampling; choosing the main variables; understanding the ecological characteristics of the water quality; the management and the data storage; the data analysis; choosing the integrated approach; evaluating the policies and criteria, including the cost-effectiveness, the adjustment to the existing dynamics and the distribution of impacts and fairness (NAS, 2002; Karydis & Kitsiou, 2013; Schernewski et al., 2015).

Tourism and environment management must be integrated into a sustainable development strategy (Cheung et al., 2015; Tang, 2015). Land and sea management system should be evaluated and adjusted based on purpose, utilization and activity permitted in the conservation rules and the ecotourism concepts by the carrying capacity owned, including social-ecological carrying capacity (Adrianto et al., 2021) and the existing zoning system. An improved management approach is strongly needed to protect the ecosystem and supply goods and services. The threats and vulnerability factors could be reduced by controlling activity and development areas as a source of pollutants close to the important ecosystem as well as reducing the level of runoff from the land (NAS, 2002; Orpin et al., 2004; Beher et al., 2016), especially through changing the island landscape nearby the beach (Kurniawan et al., 2016a, 2016b). Structuring landscape and layout of hard infrastructure development are undoubtedly required because this may also increase conflict (Sassi et al., 2006). Large-scale tourism industries have to prepare a Waste Water Treatment Plant (WWTP), whereas communal WWTP can be constructed for the small-scale tourism industry and householders. Finally, collaboration and a participatory process are needed to develop a long-term perspective of tourism development in MPA, both local community and entrepreneurs (Richins, 2008; Sardianou et al., 2015; Sdrali et al., 2014).

5 Conclusions

Hypothetically, tourism development has influenced spatiotemporal variations in CWQI value in the MTP of the Gili Matra Islands. The CWQI value is worse during the peak season of tourism than during the low season. Generally, a large number of tourists every month and year and the development of tourism support facilities affect poor water quality, especially for orthophosphate and nitrate parameters. In the long term, the excess level of these two parameters could affect marine biota and marine tourism activities. This condition will make the management of marine conservation areas challenging and possible failure; furthermore, the management of land and waters is separate, even though the land area is the center of tourism development and activities.
According to the case studies, the CWQI built in combination with GIS was applicable to assess water quality for tourism and marine biota, both spatially and temporally. Both can make it easier for managers to communicate and visualize the status and condition of the waters to managers and all stakeholders so that sustainable management can be achieved. Also, this CWQI was powerfully used to compare water quality in a composite manner with several different parameters. Moreover, Indonesia still does not have a standard seawater quality index, so the CWQI will be useful. Correspondingly, CWQI can be compared and seen in trends and patterns of change. In addition, CWQI can quickly see the effects of activities in the water area. This gain can be used by area managers in monitoring and making initial evaluations and mitigating impacts that will arise. Therefore, seawater quality should be included as an indicator in assessing and evaluating conservation area management. The seawater quality should be periodically observed and analyzed during peak and low seasons of tourism because CWQI can indicate the current tourism levels and warnings of impacts. The area management system must integrate water and land aspects based on the existing carrying capacity.

This study included limited data in the distribution of data and the number of water quality samples. Furthermore, water quality data have not been measured based on trends for each tourism season and year; the spatial distribution used is a linear assumption in the interpolation model used and lacks serial data or monitoring. In addition, this study still focuses on physicochemical parameters; there are no microbiological parameters. WHO (2003) and Cheung et al. (2015) reported that contaminated waters and coasts were exposed to pathogenic microorganisms and could promote harmful effects on tourist’s health, particularly on the skin. These limitations should be considered in future studies, especially in the use of CWQI. In addition, the correlation analysis of the source of effects on water quality also needs to be assessed, especially from the aspect of land use as a source of land pollution hypothetically.

Furthermore, this study was conducted before the Covid-19 pandemic exploded. Due to the pandemic, tourism has collapsed, and there are no tourist visits at the MTP of the Gili Matra Islands. So, the results from this study can be used to compare current or further water quality conditions. In addition, the study results can be the basis for reorganizing tourism management in the MTP of the Gili Matra Islands so that it does not affect the decline in CWQI and does not exceed the existing carrying capacity in the future.

Appendix

See Fig. 9.
Fig. 9 Function of the sensitivity curve for each parameter of CWQI
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Authors and Affiliations

Fery Kurniawan\textsuperscript{1,2} · Luky Adrianto\textsuperscript{1,2} · Dietriech Geoffrey Bengen\textsuperscript{3} · Lilik Budi Prasetyo\textsuperscript{4}

\textsuperscript{1} Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Kampus IPB Dramaga, Jl Raya Dramaga, Bogor, West Java 16680, Indonesia

\textsuperscript{2} Center for Coastal and Marine Resources Studies, IPB University (Bogor Agricultural University), Kampus IPB Baranangsiang, Jl. Raya Pajajaran No. 1, Bogor, West Java 16127, Indonesia

\textsuperscript{3} Department of Marine Sciences and Technology, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Kampus IPB Dramaga, Jl Raya Dramaga, Bogor, West Java 16680, Indonesia

\textsuperscript{4} Department of Forest Resources Conservation and Ecotourism, Faculty of Forestry, IPB University (Bogor Agricultural University), Kampus IPB Dramaga, Jl Raya Dramaga, Bogor, West Java 16680, Indonesia