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Assessment of Water Pollution Levels in Lake Batur, Indonesia and their Effect on Water Weed Presence

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Lake Batur in Bangli Regency, Bali Province is a priority area for ecological quality restoration in Indonesia due to its vulnerability to environmental changes caused by diverse and intensive utilization. Agricultural activities, fisheries, and tourism affect the lake's water quality, leading to the uncontrolled growth of water weeds such as water hyacinth (*Pontederia crassipes*). To determine the relationship between water quality, community activities, and water weed presence, water samples were collected from 9 locations consisting of residential, tourist, aquaculture, and agricultural areas. In situ analysis was then conducted to measure turbidity, pH, temperature, dissolved oxygen (DO), total dissolved solids (TDS), total nitrogen, total phosphate, and ammonia levels. Results showed that pH, temperature, DO, total nitrogen, and ammonia levels remain within Indonesia's Grade I water quality standards, which means that water from the lake is still suitable for drinking and domestic use. However, TDS levels ranged from 712 to 1,950 mg/L in the first sampling and 1,340 to 1,950 mg/L in the second sampling. Additionally, total phosphate levels reached 0.37 mg/L, exceeding Grade IV water quality standards, indicating that the water is only suitable for crop irrigation and similar uses. Although Lake Batur's water quality index was recorded at 63.64 (moderate quality), it remains highly polluted by household waste, pesticides, chemical fertilizers from conventional agriculture, and waste products from fisheries and livestock farming. Since high phosphate levels trigger the growth and spread of water weeds such as water hyacinth, it is crucial to implement measures and policies to reduce pollution in the areas surrounding Lake Batur, which will help prevent disruptions to the lake's aquatic ecosystem.

Keywords: *Pontederia crassipes*, water hyacinth, water pollution, water quality index, water weeds

Introduction

The decline in water quality across various parts of the world is an issue that the United Nations' Sustainable Development Goals (SDGs) aim to address (Soeprobowati et al. 2017; Prasetyo et al. 2021b). This has also prompted the central government of Indonesia to establish a National Medium-Term Development Plan (Rencana Pembangunan Jangka Menengah Nasional [RPJMN]) oriented toward the restoration and conservation of water resources and their ecosystems. One such area is Lake Batur (Republic of Indonesia 2021b), which is administratively located in Kintamani District, Bangli Regency, Bali Province. The lake is surrounded by several villages, namely: Trunyan, Abang Songan, Abang Batu Wall, Buahan, Kedisan, South Batur, Central Batur, North Batur, Songan A, Songan B, Belandingan, Pinggan, and Sukawana (Sukmawantara et al. 2021). Lake Batur has an area of 16.05 km², an average depth of 50.8 m, and can hold 815.38 million m^3 of water (Agustina and Aprinica 2022). The water that floods Lake Batur comes from rainwater and seepage from surrounding mountains, with a water catchment area of around 105.35 km² (Kartini 2016; Pradnyawathi and Kartini 2019).

Lake Batur has a coastline of 21.4 km, which is surrounded by land with diverse topography. The land surrounding Lake Batur includes undulating lowlands to mountains (Mount

Batur, which is 1,717 m above sea level), while the north, east, and south are surrounded by steep hills and mountains (Mount Abang, which is 2,172 m above sea level). Lake Batur is an active caldera lake formed by a past eruption of Mount Batur. It is situated within a closed river basin, serving as a water catchment area for surrounding water sources (Agustina and Aprinica 2022). Lake Batur is located in the eastern part of the river basin and, morphologically, resembles a crescent moon. This causes the water in the lake to continue to increase, and during the rainy season, the lake area expands since there is no outlet to release the water. This then increases the amount of material that settles at the bottom of the waters carried by water seepage from land, thereby triggering shallowing (Soeprobowati et al. 2012; Prasetyo et al. 2022).

The Lake Batur area continues to experience growth marked by increasing physical and non-physical development, which can have several positive and negative impacts on the environment, economy, and local communities (Nada et al. 2018; Kawer et al. 2019). Such a high and diverse level of utilization makes an aquatic ecosystem highly vulnerable to various environmental changes. Agricultural, aquaculture, residential, religious, tourist, and office activities that take place in both the water catchment areas and the water bodies decrease environmental quality through sedimentation, pollution from organic and inorganic materials, lower water quality, and eutrophication (Putri et al. 2023). Eutrophication, a condition where water becomes polluted due to the excessive entry of nutrients (especially nitrogen and phosphorus), triggers primary productivity and causes the uncontrolled dominance of aquatic plants (Grasset et al. 2016; Haseena et al. 2017; Sutadian 2017; Chander et al. 2018; Sudarmadji and Pudjiastuti 2018). As such, the presence of water hyacinth (*Pontederia crassipes*) covering the water surface in various areas of Lake Batur indicates that the condition of the lake's waters has experienced an increase in nutrients, especially nitrogen and phosphorus, due to human activities (Goshu and Aynalem 2017). This research aimed to determine the relationship between community activities and the water quality conditions of Lake Batur based on physicochemical parameters and the diversity of aquatic plants in the water body. The results of this study are expected to highlight the need for sustainable management to protect the lake's ecosystem.

Materials and Methods

Study area

Lake Batur is geographically located to the north of 8º11′18.9″S, the south of 8º17′33.1″S, the west of 115º19′16.7″E, and the east of 115º25′49.46″E (Suryati and Samuel 2018). For this study, the lake area was divided into 9 sites: Site 1 (Songan A Village, a densely populated residential area); Site 2 (Songan A Pier, a rice field and tourism area); Site 3 (Abangsongan Village, a fisheries' cultivation area); Site 4 (Buahan Village, a densely populated area with community activities and tourism); Site 5 (Songan B Village, a plantation and agricultural area); Site 6 (middle of the lake between Songan A Village and Songan B Village); Site 7 (middle of the lake between Trunyan Village and Central Batur Village); Site 8 (middle of the lake between Abangsongan Village and Central Batur Village); and Site 9 (middle of the lake between Abang Batu Wall Village and Kedisan Village) (Fig. 1).

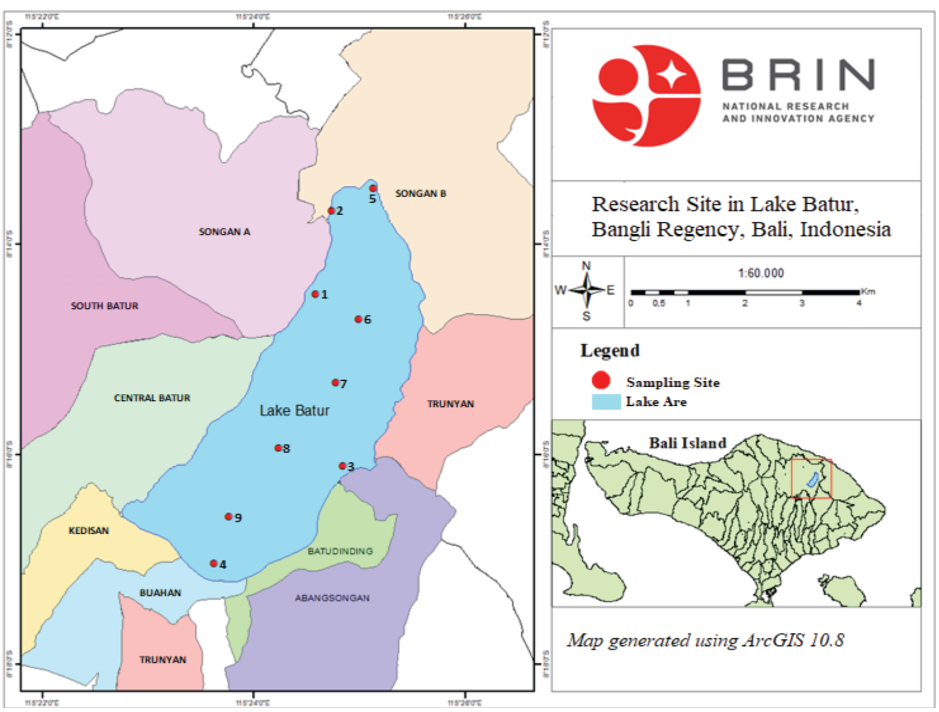

Fig. 1 **Map of the study sites in Lake Batur, Bali Province, Indonesia**

Sample Collection

The study was conducted from March to August 2023. In situ water quality measurements were performed using purposive random sampling, a technique determined based on specific considerations. The measured physicochemical parameters included turbidity, pH, temperature, DO, and total dissolved solids (TDS), assessed in situ using the HORIBA U-50 multi-parameter water quality checker (HORIBA Advanced Techno Co., Ltd., Japan). Each measurement was repeated 3 times at the same location and validated using GPS. Water quality measurements were conducted at depths of 0, 5, and 10 m across all study sites to obtain data from different vertical water layers. Water samples for total nitrogen (TN), total phosphate (TP), and ammonia analysis were collected using a Van Dorn style acrylic water sampler (Wildco, United States) with 3 replicates per site. Each 250 mL sample was stored in polyethylene bottles, labeled with a sampling code, and kept in a cold box for analysis at the Environmental Engineering Laboratory of Diponegoro University, Semarang, Indonesia.

Identification of water pollution sources in Lake Batur was conducted by observing pollutant-producing activities in the villages surrounding the lake. Aquatic weed species were also identified through field observations and referenced against the Practical Plant Identification Training Guide (Senterre 2016).

Data analysis

Data obtained consisted of water physicochemical data; data on the identified sources of water pollution; and data on aquatic weeds in the lake. The lake's water quality was analyzed in a comparative, descriptive manner, referring to Government Regulation No. 22 of 2021 on Environmental Protection, Organisation and Management concerning lake water quality standards (Republic of Indonesia 2021a) (Table 1).

Water quality was also analyzed based on the National Sanitation Foundation Water Quality Index (NSFWQI) (Oram 2010).

$$WQI = \sum Wi\ x\ Qi$$

Qi: Quality rating; Wi: Weighting factor

The Qi value of each parameter was obtained from the histogram by Oram (2010), while Wi is a weighting value determined by the NSFWQI. Interpretations of water quality levels were as follows (Noori et al. 2019): very good (90 to 100), good (70 to 90), moderate (50 to 70), poor (51 to 70), poor (31 to 50), and very poor (0 to 30).

Table 1 Lake water quality standards as per Government Regulation No. 22 of 2021 on Environmental Protection, Organisation and Management (Republic of Indonesia 2021a)

Parameters	Unit	Lake water quality standard			
		Grade I	Grade II	Grade III	Grade IV
Dissolved oxygen (DO)	mg/L	6	4	3	1
pH		6 – 9	6 – 9	6 – 9	6 – 9
Temperature	°C	DEV 3*	DEV 3*	DEV 3*	DEV 5*
Total dissolved solids (TDS)	mg/L	1,000	1,000	1,000	1,000
Total nitrogen	mg/L	0.65	0.75	1.9	-
Total phospate	mg/L	0.01	0.03	0.1	-
Ammonia	mg/L	0.10	0.20	0.5	-

*Notes: Interpretation of DEV in temperature: DEV 3 means the water temperature may change by up to ± 3 °C from its natural temperature; DEV 5 means the water temperature may change by up to ± 5 °C from its natural temperature. In Indonesia's water quality standards, the allowable deviation depends on the water classification, for example: Grades I, II, and III generally allow a maximum temperature deviation of 3 °C (DEV 3). Grade IV may permit a greater deviation, such as 5 °C (DEV 5).

Results and Discussion

Water quality of Lake Batur

Important physicochemical parameters of lake water include temperature, pH, salinity, DO, redox potential, TDS, total suspended solids (TSS), nutrients, and heavy metal contaminants (Gupta and Yadav 2020). Lake water conditions depend on the geological structure of the earth and anthropogenic activities in the lake area, which damage the potential for water use (Pesce and Wunderlin 2000; Goher et al. 2014). Lake water quality assessment can show water conditions related to its intended function (Vasistha and Ganguly 2020). For example, the quality of water used as raw material for drinking water will differ from the quality of water used for agricultural irrigation, recreation, or aquaculture.

The complexity and uncontrolled activities in the Lake Batur ecosystem affect the processing speed and productivity of these waters (See et al. 2021). Water quality will determine the standard of viability and life of aquatic biota, food availability, fertility levels, and water productivity capabilities. Following its function and role, water quality, as demonstrated through the assessment of each variable, will have limits on suitability and indicators of water fertility for water productivity, especially for fish farming activities (Gutiérrez et al. 2020).

Results showed that among the 7 physicochemical parameters measured, DO, pH, temperature, total nitrogen, and ammonia levels still met Grade I water quality standards (Fig. 2). Water classified under this standard could be used as standard drinking water or for other purposes with the same requirements.

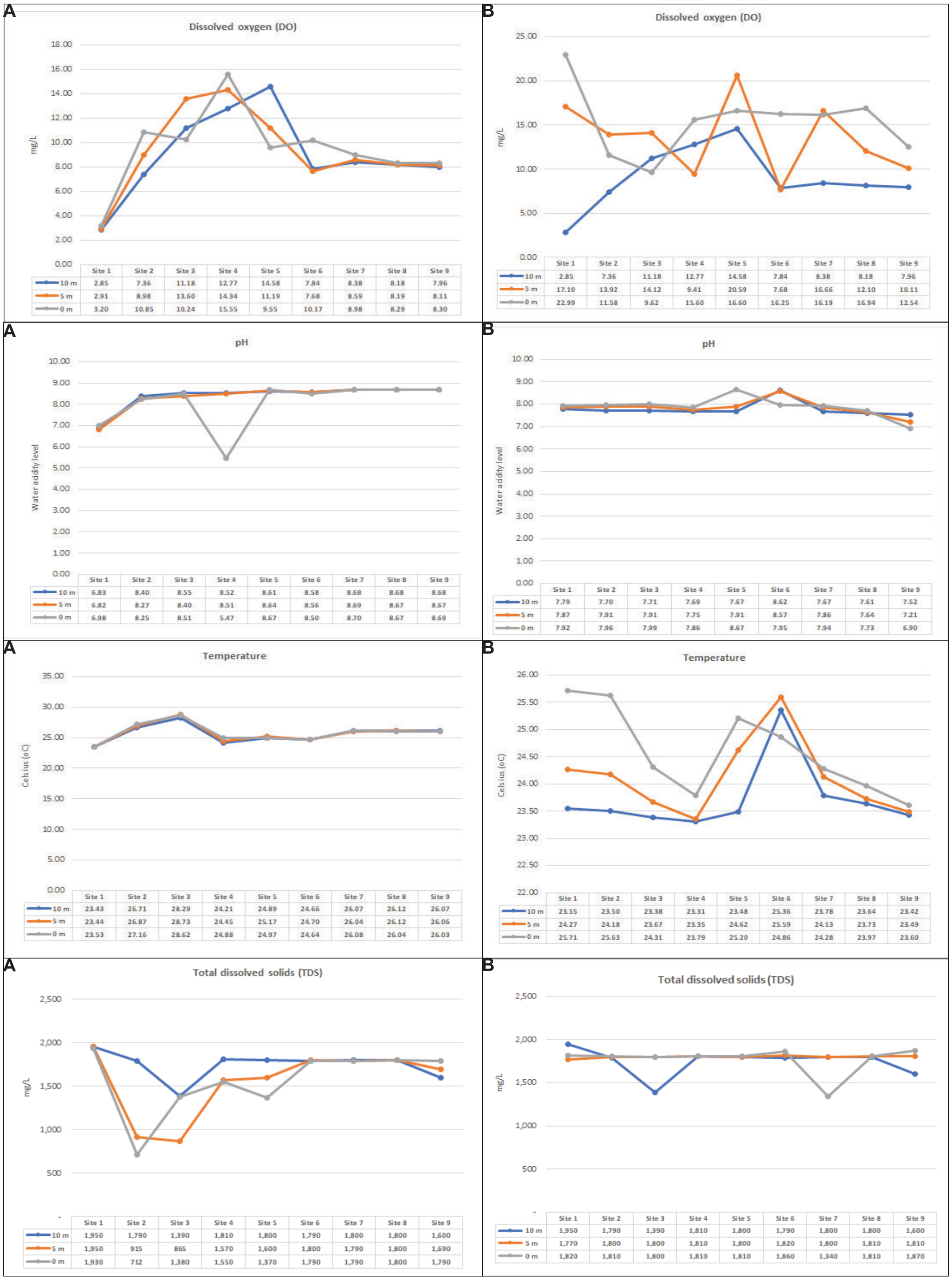

Fig. 2 Physicochemical analysis of dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS), total nitrogen, total phosphate, and ammonia in Lake Batur based on differences in depth and measurement time (A: Sampling I, 2023 Mar 15; B: Sampling II, 2023 Aug 22)

cont...Fig. 2 Physicochemical analysis of dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS), total nitrogen, total phosphate, and ammonia in Lake Batur based on differences in depth and measurement time (A: Sampling I, 2023 Mar 15; B: Sampling II, 2023 Aug 22)

Dissolved oxygen (DO) levels of water samples taken from Site 2, Site 3, Site 4, Site 5, Site 6, and Site 7 from depths of 0, 5, and 10 m all met Grade I quality standards. Generally, DO levels in these sites ranged from 7.36 to 15.55 mg/L in the first sampling and 7.36 to 22.99 mg/L in the second sampling. On the other hand, water samples from Site I met Grade III water quality standards, with values ranging from 2.85 to 3.20 mg/L in the first sampling and from 2.85 to 22.99 mg/L in the second sampling at all 3 depths.

Low DO levels at Site 1 may be explained by its proximity to a floating restaurant and an area where rotting horticultural crop residues are piled up and consequently pollute the water. When water seeps through the soil, it carries large amounts of dissolved substances from agricultural production residues in the soil and enters water bodies, thereby making the water less suitable for drinking and, in some cases, unpalatable (Bhateria and Jain 2016). Dissolved oxygen levels are also lowered by increasing temperature, which also affects the photosynthesis rate of aquatic plants, the metabolic rate of aquatic organisms, and organism sensitivity to toxic waste, parasites, and disease (Spellman 2013). This supports the DO levels obtained from Lake Batur, which were generally high since the measurements were carried out relatively early in the morning (08:00 to 10:00 West Indonesia Time) with a water temperature of 23.31 to 28.73 ºC. Across all sites, the water temperature was constant both at the first and second sampling and at all depths.

For the first and second sampling, pH levels generally ranged between 6.0 and 8.0. These values met Grade I quality standards, which means that the water in the lake could be used for various activities, including agriculture and fisheries.

These also comply with the criteria set by the United States Environmental Protection Agency (US EPA), which states that the pH for a freshwater environment should ideally be 6.5 to 9.0 (US EPA 2024). Most freshwater biota thrive at an optimal pH of 6.5 to 8.0, while marine waters are closer to 8.2 (Bhateria and Jain 2016; Prasetyo et al. 2024; Tirtadanu et al. 2024). While there is no one definitive pH range that universally ensures the survival of all freshwater biota, there is a gradual decrease in acceptability as the pH value deviates from the normal range (Rahim and Soeprobowati 2019; Mushtaq et al. 2020).

A pH below 7.0, which tends to be acidic, can affect the toxicity value of chemical compounds. Water becomes dangerously toxic when the pH is low and under anaerobic conditions. Oxygen concentration at the bottom of the water also influences pH levels (Zeng et al. 2023). The low oxygen levels at the bottom of Lake Batur, particularly at Site 1 (2.85 to 3.20 mg/L) in the first sampling, may slow down the decomposition process of organic matter (Liu et al. 2022), thereby triggering the acidity of the water with a low pH value (6.83; acidic). This results in the formation of toxic compounds which are dangerous for aquatic life (Tolkkinen et al. 2014; Zeng et al. 2023). Likewise, when oxygen levels increase, sulfur will oxidize to ions such as sulfate, which causes a decrease in the formation of hydrogen sulfide. The acidity level of a body of water greatly determines changes in sulfur content; for example, an increase in water acidity triggers a decrease in hydrogen sulfide levels. Waters with high (alkaline) pH levels of > 10 increase levels of toxic non-ionized ammonia (Ip et al. 2001; US EPA 2024). Sulfate pollution may also have a detrimental impact on freshwater biota — both plants and animals, including fish, invertebrates, and amphibians — and have negative effects on human health (Zak et al. 2021).

Total phosphate values from all 9 sites exceeded Grade III water quality standards; hence, water from these sites could only be used for freshwater aquaculture, animal husbandry, and gardening. Total nitrogen values for Site 2 (3,195 mg/L) and Site 3 (1,203 mg/L) also met Grade III water quality standards.

Moreover, in all 9 sites, TDS values exceeded Grade IV water quality standards, which means that water from these sites could only be used for crop irrigation and other similar purposes. These values ranged from 712 to 1,950 mg/L in the first sampling and 1,340 to 1,950 mg/L in the second sampling. Concentrations of TDS in natural freshwater usually vary between 20 to 1,000 mg/L. The solids mainly consist of bicarbonate (and carbonate at pH levels above 8.3) and chloride, depending on the solubility of minerals in various geological regions. High mineralization in lakes is usually influenced by rainfall factors and soil conditions that are very leached or underdeveloped. The activities around Lake Batur, such as those from agricultural and plantation areas, are one of the causes of erosion. Aside from this, the fluctuating trend of increasing lake water levels has resulted in agricultural land being eroded into the lake body (Putri et al. 2023), resulting in high TDS values as observed from the water samples from the lake. Total dissolved solids are also an indicator of the concentration of inorganic and organic salts such as chloride, magnesium, calcium, sodium, and nitrate, among others (Boyd 2015). The presence of residues can affect the taste of water, and dissolved residue concentrations of more than 1,200 ppm cause poor water taste (Fish et al. 2020). High TDS values can also indicate domestic waste contamination and rapid plankton growth (Amorim and Moura 2021).

The average total phosphate concentration of Lake Batur water was 0.05 to 0.25 mg/L in the first sampling and 0.00 to 0.37 mg/L in the second sampling, indicating decreased water quality from pollution due to various activities in the lake's surrounding areas (Bai et al. 2021). In aquatic ecosystems, phosphorus plays an important role in transmitting energy during organism growth processes (Wetzel 2001). The pollution occurring in Lake Batur is confirmed by the results of the NSFWQI calculations, which serve as an assessment indicator (Table 2).

Table 2 Water quality analysis of Lake Batur based on the National Sanitation Foundation Water Quality Index (NSFWQI)

Parameters	Mean measurement results	Weight	Quality index	Wi × Qi
Dissolved oxygen (DO) (mg/L)	10.94	45.00	0.23	10.20
pH	8.05	85.00	0.16	13.60
Nitrate (mg/L)	0.32	88.00	0.13	11.73
Phosphate (mg/L)	0.56	57.00	0.13	7.60
Temperature changes (°C)	2.00	81.00	0.13	10.80
Turbidity (Nephelometric Turbidity Units [NTU])	11.41	71.00	0.11	7.57
Total dissolved solids (TDS) (mg/L)	1,697.00	20.00	0.11	2.13
NSWQI				63.64

Based on the results of this study, the WQI of water from Lake Batur was calculated at 63.64, which is categorized as moderate water quality. According to the Canadian Council of Ministers of the Environment (CCME), water with an index of 50 to 70 is classified as "fair" or "moderate", meaning that for certain uses, the water may not always meet quality standards without additional treatment (CCME 2001). In addition, research by Tyagi et al. (2013) confirmed that the water quality index in the moderate category indicates ecological pressure that can reduce the sustainability of aquatic ecosystems. The high TDS (1,697.00 mg/L) and total phosphate (0.56 mg/L) levels further confirm the decline in Lake Batur's water quality due to pollution from various anthropogenic activities, including domestic waste, agriculture, floating net cage fisheries, and the growing tourism industry around the lake (Agustina and Aprinica 2022; Purnomo et al. 2024).

Sources of Pollution in Lake Batur

Sources of pollution entering Lake Batur's water body can be classified into 2 groups of waste sources: waste originating from activities outside the lake (external) and waste originating from within the lake itself (internal) (Table 3).

Table 3 Two major sources of pollution identified in Lake Batur

External pollution sources	Internal pollution sources
• Waste from residential (domestic activities • Waste from tourism activities • Waste from agricultural activities • Waste from livestock activities	• Waste from the decomposing activities of dead lake organisms • Waste from aquaculture activities

Household waste containing detergent as a source of phosphate contributes to the high concentration of total phosphate (TP) in all sampling sites. Another cause is the entry of agricultural waste into the water body, especially fertilizers containing phosphate (Astuti et al. 2023) and residues from fish feed (Prasetyo et al. 2021b). This information is supported by the results of the conducted observations of the lake's surrounding areas, which include residential areas covering 6,648 ha (7.06%), trade and service areas covering 7,223 ha (7.67%), agricultural and plantation areas covering 70,950 ha (75.36%), and areas for other uses covering 9,329 ha (9.91%).

Horticultural land on the shores of Lake Batur is distributed across Kedisan Village, Buahan Village, Suter Village, Abang Batu Wall Village, Trunyan Village, Songan B Village, and Central Batur Village. Most cultivated plants around the lake are crops such as onions, chili peppers, eggplants, tomatoes, cabbages, chayotes, and various flowers. Efforts to obtain high agricultural production involve intensive fertilization (Handayani et al. 2011; Prasetyo et al. 2021a), with farmers applying fertilizers once a month. The types of fertilizer typically used include NPK, urea, and cow dung, with a dosage of 50 kg per month; hence, 150 kg of fertilizer is applied in a single harvest cycle. The effects of such practices are reflected in the high ammonia levels (0.88 mg/L) at Site 2, which are determined by the content of organic materials. With higher organic material content, the oxygen needed to break down organic material increases, thus also increasing the amount of ammonia produced in the process (Zuberer and Zibilske 2021; Prasetyo et al. 2022).

Presence of water weeds

Community activities around Lake Batur have a significant impact on the presence of aquatic weeds, especially in terms of increasing their growth and spread (Table 4). One of the main contributing factors is anthropogenic activities such as fish farming with floating net cages, domestic waste disposal, and agricultural practices that use fertilizers and pesticides. Waste from these activities can increase the nutrient load in water, especially nitrogen and phosphorus (Prasetyo et al. 2021c; Purnomo et al. 2024).

Phosphorus (P) in its dissolved form is a limiting factor for the growth of aquatic plants and algae. Excessive P supply in water can cause explosive growth of aquatic plants such as water hyacinth and algae, which can endanger the stability of the ecosystem (Schindler et al. 2016). Phosphorus in water exists in both particulate and dissolved forms, with its chemical composition determining its bioavailability (Lin et al. 2012). Dissolved P can be further classified into inorganic P and organic P. The main component of dissolved organic P in water is in the form of orthophosphate (ortho-P), which is the most available for biological uptake (Bai et al. 2017). However, when the level of ortho-P is not sufficient for primary needs (i.e., during the process of algae growth in eutrophic lakes), the organic P can be converted into bioavailable P through different mechanisms (Gao et al. 2020). There were 8 types of aquatic plants observed in Lake Batur: parrot feather (*Myriophyllum brasiliensis*); waterthyme (*Hydrilla verticillata*); Nile cabbage or *kapu-kapu* (*Pistia stratiotes*); tiny duckweed or *toke-toke* (*Lemna perpusilla*); mosquitofern (*Azolla pinnata*); water spinach (*Ipomoea aquatica*); common stonewort (*Chara vulgaris*); and water hyacinth (*Pontederia crassipes*). The water hyacinth is an invasive species that spreads very quickly and can cause disruptions in Lake Batur's ecosystem (Pradnyawathi and Kartini 2019).

Water hyacinth was found to be abundant in several areas of Lake Batur, particularly along the shoreline in Site 1 (Songan A Village), Site 2 (Songan A Village Pier), Site 3 (Abangsongan Village), and Site 4 (Buahan Village). Large amounts of water hyacinth can cause closure of the lake's surface and blockage of water channels, resulting in flooding (Kriticos and Brunel 2016; Izzati et al. 2022; Prasetyo et al. 2022). They also reduce the amount of light entering the water, causing a decrease in the level of oxygen solubility and a consequent reduction in species diversity (Yan and Guo 2017; Dersseh et al. 2019). Water hyacinth also becomes a habitat for the development of vector insects and increases the rate of evapotranspiration, which has an impact on the health of communities around the lake (Kamau et al. 2015; Goshu and Aynalem 2017; Gupta and Yadav 2020). Moreover, dead water hyacinth plants sink to the bottom of the water, accelerating the shallowing process (Tobias et al. 2019).

Prayuda et al. (2017) reported that water hyacinth planted in different study areas in Lake Batur experienced a biomass increase from 1 to 4,382 kg (338.2%) in Songan, to 1,742 kg (74.6%) in Batur, to 1,925 kg (92.5%) in Buahan, and to 1,583 kg (158.3%) in Trunyan after 42 d. In this study, there is variability in the biomass increase of water hyacinth; The fastest biomass increase was observed in Site 1 (Songan A Village), an area with

Table 4 Community activities and water weed presence per study site

Site	Village/Area	Description	Community activities	Weeds (including area coverage)
1	Songan A	Residential, densely populated	Household waste production and tourism activities	*Pontederia crassipes* and *Hydrilla verticillata* were found in abundance, especially in shallow areas. *Pistia stratiotes*, *Lemna perpusilla*, and *Azolla pinnata* were also found in small amounts.
2	Songan A Pier	Rice field, tourism site	Pesticide application, household waste production, and tourism activities	*Pontederia crassipes* and *Ipomoea aquatica* were found on the edge of the pier near the rice field area.
3	Abangsongan	Residential, fisheries with floating cages	Household waste production, fish feeding	*Pontederia crassipes* and *Hydrilla verticillata* were found in abundance, especially in shallow lakeside areas. *Pistia stratiotes*, *Lemna perpusilla*, and *Azolla pinnata* were also found in small amounts.
4	Buahan	Densely populated area and center of tourism activities	Household waste production and tourism activities	*Pontederia crassipes* and *Hydrilla verticillata* were found in abundance, especially in shallow lakeside areas. *Pistia stratiotes*, *Lemna perpusilla*, and *Azolla pinnata* were also found in small amounts.
5	Songan B	Residential, plantation and agricultural areas	Production of household waste, pesticide application, and waste from livestock activities	*Pontederia crassipes* was found scattered in small numbers. *Hydrilla verticillata* and *Ipomoea aquatica* were also found, especially in shallow lake areas.
6	Middle of the lake between Songan A Village and Songan B Village	The central area of the lake is free from human activity (only fishing activities and transporting tourist passengers by boat)	Only fishing activities and passenger transportation (tourists) by boat	*Hydrilla verticillata*, *Myriophyllum brasiliense*, and *Chara vulgaris* were found in small and uneven amounts.
7	Middle of the lake between Trunyan Village and Central Batur Village	The central area of the lake is free from human activity (only fishing activities and transporting tourist passengers by boat)	Only fishing activities and passenger transportation (tourists) by boat	*Hydrilla verticillata*, *Myriophyllum brasiliense*, and *Chara vulgaris* were found in small and uneven amounts.
8	Middle of the lake between Abangsongan Village and Central Batur Village	The central area of the lake is free from human activity (only fishing activities and transporting tourist passengers by boat)	Only fishing activities and passenger transportation (tourists) by boat	*Hydrilla verticillata*, *Myriophyllum brasiliense*, and *Chara vulgaris* were found in small and uneven amounts.
9	Middle of the lake between Abang Batu Wall Village and Kedisan Village	The central area of the lake is free from human activity (only fishing activities and transporting tourist passengers by boat)	Only fishing activities and passenger transportation (tourists) by boat	*Hydrilla verticillata*, *Myriophyllum brasiliense*, and *Chara vulgaris* were found in small and uneven amounts.

numerous floating net cages. The leftover food and waste from fish cultivated in these floating net cages increased the water's phosphate content to 0.56 mg/L. Large amounts of P waste also cause eutrophication, which triggers the explosive growth of algae and water hyacinth, consequently disrupting aquatic ecosystems (Alvarez-Vázquez et al. 2014; Dauda et al. 2019). This result is similar to the observations of Junaidi et al. (2022) who found that the source of organic waste from floating net cage fish cultivation is leftover artificial feed, which causes water fertility after sedimentation. The pile of feed residue is poisonous and can kill the fish in the net cages if upwelling occurs (Rahim and Soeprobowati 2019; Dhiman et al. 2024).

In Site 1, eutrophication is triggered by agricultural activities on the lake border since agricultural waste increases water hyacinth biomass. Site 4, however, is a residential area that mainly produces domestic waste from toiletries, laundry, and defecation. Community consumption activities in the area also produce waste such as spice wrappers, used cooking oil, and food waste.

Water hyacinth at Site 7 (Trunyan Village), which is a plantation and agricultural area, increased by 158.3% from the initial weight, reaching a wet weight of 2,583 kg. This area produces residual waste from fertilizer applications and other agricultural activities. Nande et al. (2023) also stated that agricultural waste in the form of pesticides entering the water, air, and soil can trigger eutrophication and cause pollution.

Based on lake ecosystem management guidelines and the lake/reservoir water pollution load capacity approach outlined in the Minister of the Environment Regulation Number 28 of 2009 (Ministry of Environment 2009), floating net cage fish cultivation should not be allowed in Lake Batur since it is a closed-basin body of water without any outlet. This causes all fish food residues and other waste to accumulate at the bottom of the lake (Pradnyawathi and Kartini 2019). Therefore, efforts need to be made to restore Lake Batur's environmental quality, as its degradation reduces its ecological, social, economic, and cultural functions. Existing policies must be strictly enforced to significantly lessen the number of fl oating net cages in the lake. Conventional agricultural activities using excessive chemical fertilizers must be reduced, and switching to organic farming practices may also be recommended. Moreover, relevant government agencies should formulate and implement a zoning plan for Lake Batur, which will establish border arrangements and guidelines for fisheries, t ourism, and other activities allowed in the area.

Conclusion

Lake Batur's water quality index was recorded at 63.64, indicating moderate water quality. However, the lake remains polluted by household waste, pesticides, and chemical fertilizers from conventional agriculture practices, and waste from fisheries and livestock farming. The high phosphate levels which exceed Grade IV water quality standards trigger the growth and rapid spread of water hyacinth, disrupting the lake's aquatic ecosystem. To restore Lake Batur's environmental quality and prevent further degradation, immediate action is needed to reduce pollution sources and implement sustainable management strategies.

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