LIMNOTEK Perairan Darat Tropis di Indonesia
transforming into ***Journal Limnology and Water Resources***
p-ISSN: 0854-8390 e-ISSN: 2549-8029
https://ejournal.brin.go.id/limnotek

Comparative Water Quality Assessment of Cascade Urban Lakes: Dori, Walini, and Dora in Bogor Regency, Indonesia

Aldiano Rahmadya[1,*], Ahmad Yusuf Afandi[1], Denalis Rohaningsih[1,2], Relita Novianti[1], Dewi Verawati[1], Aan Dianto[1,3]

[1] Research Center for Limnology and Water Resources-National Research and Innovation Agency (BRIN), KST Soekarno, Jl. Raya Bogor – Jakarta km. 46, Cibinong, Bogor 16911, Indonesia
[2] Department of Earth and Environmental Sciences, The University of Manchester, United Kingdom
[3] Graduate School of Natural Science and Technology, Shimane University, Japan

*Corresponding author's e-mail: aldi004@brin.go.id

Received: 16 July 2024; Accepted: 18 November 2024; Published: 20 December 2024

Abstract: Urban lakes are critical in flood mitigation, providing fresh water, and offering green spaces in urban environments. However, many urban lakes face increasing ecological pressures from various human activities. This study assesses the water quality and morphometric conditions of three urban lakes—Dori, Walini, and Dora in the Cibinong Botanical Garden Complex in Bogor Regency, located in a high-rise residential area. The study aims to evaluate the current water quality, identify contributing factors to water quality degradation, and compare conditions across the three lakes. Data was collected between January and April 2023, utilizing a Geographic Information System (GIS) for morphometric analysis and water quality measurements. Water quality was assessed in accordance with the standards set by Government Regulation No. 22 of 2021. Results indicate that Lake Dori, Walini, and Dora have surface areas of 3,406.96 m², 7,668.37 m², and 13,599 m², respectively. Based on water quality classifications, both Lake Walini and Lake Dori meet Class III standards (suitable for water use), while Lake Dora, though also in Class III, exhibits milder pollution indicators. These findings provide important insights for managing urban lakes and can guide future environmental policies.

Keywords: urban lakes, water quality, water status, environmental management, Indonesia

DOI: https://doi.org/10.55981/limnotek.2024.5611

1. Introduction

Urban lakes are unique ecosystems, natural or artificial water resources surrounded by urbanized or anthropogenically influenced areas. These lakes typically enhance comfort and beauty, fulfilling functions such as flood mitigation and fresh water supply (Ribbe *et al.*, 2023). Urban lakes and ponds are commonly found in parks or surrounded by green belts and vegetation, making them "green spaces" and "blue spaces" that provide essential facilities for urban residents (White *et al.,* 2010; Mishra *et al.,* 2020; Mitroi *et al.*, 2022). However, these lakes frequently experience environmental pressures from urbanization, leading to issues such as (1) poor inflowing water quality, (2) significant water level variations, (3) continuous stratification, (4) prolonged rainwater residence time, and (5) high organic carbon content (Walker and Lucke, 2018). As a result, urban lakes, often shallow and hyper-eutrophic, experience rapid degradation, with water quality challenges linked to urban activities (Birch and McCaskie, 1999).

In densely populated areas, such as Indonesia, urban lakes face significant ecological challenges. Increased population and urban development create greater demand for land and water resources, often without the infrastructure or policies to manage pollutants effectively. Consequently, urban lakes have become pollution hotspots (Wagner and Erickson, 2017; Jadeja *et al.,* 2022). Population and economic growth lead to increased development, increasing demand for residential, business, and industrial land, increasing wastewater, and adding ecological pressure on urban lakes (Vasistha and Ganguly, 2020).

In Indonesia, many urban lakes have undergone degradation, including sedimentation, shoreline change, and severe pollution. For instance, Lake Gintung has become heavily polluted according to the Indonesian government's water quality standards, making it unsuitable for consumption, fisheries, recreation, or irrigation (Maresi *et al.,* 2020). The Jakarta metropolitan area, known as Jabodetabek (Jakarta, Bogor, Depok, Tangerang, and Bekasi), is home to numerous urban lakes, many of which have been adversely affected by reduced water volumes, shrinking shorelines, and pollution. Bogor, a highland region within Jabodetabek, has also seen its urban lakes come under pressure from rapid population growth and increasing housing demand. A study by Henny and Meutia (2014) found that approximately 5% of Jakarta's urban lakes have shrunk by more than 50%, while 10-30% have experienced a reduction in area by less than 50%.

In Bogor, several urban lakes, including Lakes Dori, Walini, and Dora, form a cascading system within the densely populated Cibinong Botanical Garden Complex at the Cibinong Science Center – Botanical Garden (CSC-BG) operated by BRIN in Bogor Regency. These artificial lakes, with an average depth of approximately 1 meter for visitor safety, serve as tourist attractions and are fed by 23 spring sources (BRIN, 2024). These lakes are situated in high-rise residential areas, typically surrounded by tall buildings such as office complexes (Henny and Meutia, 2014). This area has a low risk of shoreline change, moderate sedimentation, and low to moderate algal bloom and pollution levels.

A previous study on Lake Dora in 2018 showed total nitrogen (TN) values of 0.556 mg/L and total phosphorous (TP) of 0.038 mg/L (Sulastri *et al.,* 2020), still below Class III of Indonesia's Government water quality standards. However, with accelerating urban development, there is a risk that environmental conditions around the lakes could further impact water quality.

This study aims to evaluate the current water quality of Lakes Dori, Walini, and Dora, identify parameters driving any observed degradation, and compare these across the three lakes. Findings from this research will contribute insights to inform management strategies for these essential urban ecosystems. Furthermore, the study also intends to provide a foundation for ongoing monitoring, pollution source identification, and sustainable lake management, benefiting government agencies, researchers, and the public in efforts to preserve and protect urban lakes.

2. Materials and Methods

2.1 Data Collection and Analysis

This study was conducted at Lakes Dori, Walini, and Dora from January to April 2023. These lakes form an inlet and outlet cascade system, with Lake Dora as the upstream lake and Dori as the downstream lake, while Walini is in between (Figure 1). Water sample collection and quality measurements were performed at the water surface twice weekly between 09:00 and 11:00.

The water quality parameters measured in this study include temperature, pH, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), nitrate (NO_3^-), ammonia (NH_3), and phosphate (PO_4^+). The first five parameters were measured on-site using a water quality checker (HORIBA U-52). The device was immersed in the water surface to obtain real-time readings of these physical and chemical properties. Additionally, 1L surface water samples were collected monthly at each sampling point using a water dipper to analyze NO_3^-, NH_3, and PO_4^+.

All water samples were stored in a chiller for preservation and analyzed within two days of collection. Samples were filtered using 0.45 µm filter paper to remove organic matter before nutrient analysis. Nutrient concentrations were determined using a Hach DR 3900 Spectrophotometer with specific reagents for each parameter. NO_3^- was measured via the cadmium reduction method (method 8192, detection limit: 0.01–0.05 mg/L), NH_3 with the salicylate method (method 8155, detection limit: 0.01–0.05 mg/L), and PO_4^+ with the ascorbic acid method (method 8048, detection limit: 0.02–2.50 mg/L).

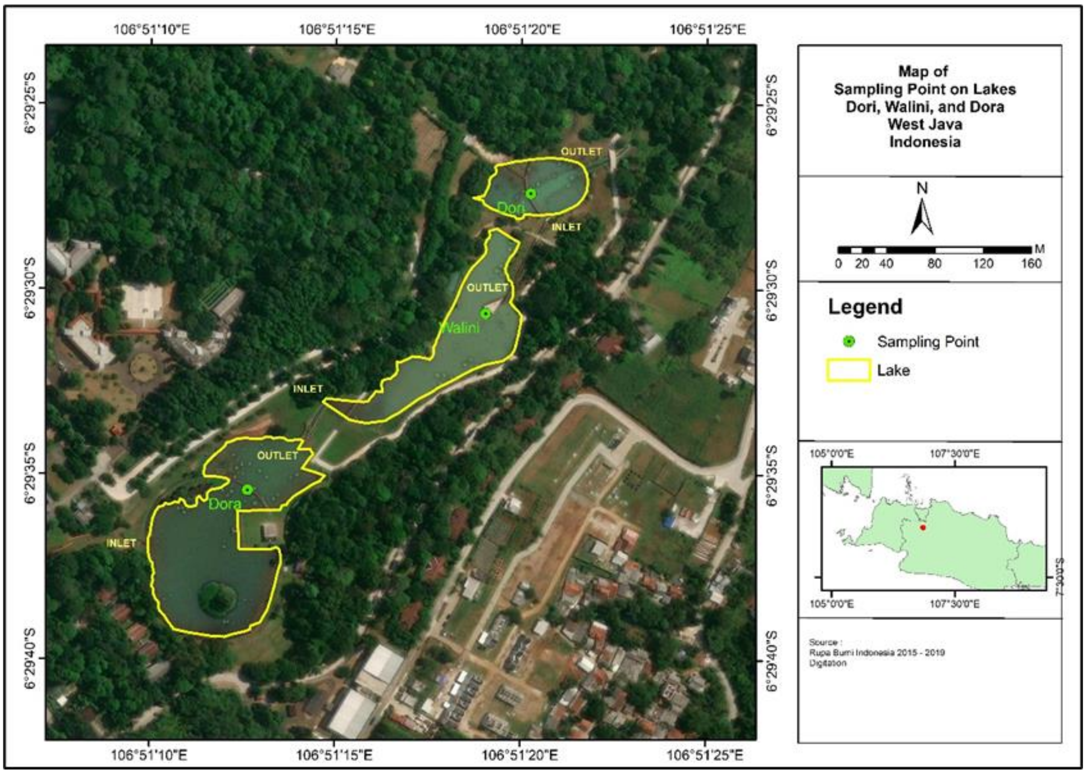

Figure 1. Sampling location of Lake Dori, Lake Walini, and Lake Dora.

2.2 Data analysis

The morphometric conditions of the lake surface were analyzed using free and open-source QGIS 3.22 software. Surface parameters to be analyzed include maximum length, effective maximum length, maximum width, average width, effective maximum width, surface area, shoreline perimeter length, and shoreline development index (Wetzel 2001) based on the extracted Google Maps in 2023 (Figure 1). The morphometric surface analysis method involves digitization on-screen using base maps available in QGIS.

A variance analysis (ANOVA) was conducted to determine whether there were any significant differences among the three lakes based on the measured parameters. A similarity index was also applied to assess how alike or different the lakes are. This index helps quantify the similarity or dissimilarity between entities, in this case, based on water quality data. The similarity results are visualized in a dendrogram. Hierarchical cluster analysis (HCA), ANOVA, and the Tukey HSD test were performed using Python.

The STORET Index calculation in this study includes several key physical and chemical parameters: pH, DO, turbidity, TDS, NO_3^-, NH_3, and PO_4^+. The collected data were evaluated by comparing each measured parameter to the corresponding standard outlined in Government Regulation No. 22 of 2021 on Implementation of Environmental Protection and Management. This assessment categorizes water quality status based on its suitability for different usage classes. This study performed STORET calculations for water quality classes I, II, and III, providing a detailed view of the lakes' compliance with regulatory standards.

3. Result and Discussion

3.1. Physical Condition

The quantification of the morphometric study revealed distinct surface morphological characteristics between the lakes. During the study, these three lakes were overgrown with aquatic plants. Lotus species covered the entire surface of Lake Dora, Lake Walini had aquatic plants in the water column, while aquatic plants covered the surface of Lake Dori but not as many as Lake Dora (Figure 2).

The quantification of the morphometric study revealed distinct surface morphological characteristics between the lakes. The result of the quantification of morphometric analysis is shown in Figure 3 and Table 1. These lakes have areas of 3,406.96 m² (Lake Dori), 7,668.37 m² (Lake Walini), and 13,599 m² (Lake Dora), Lake Dora was the largest from the other.

When analyzed using the Shoreline Development Index, all three lakes have a value greater than 1, indicating irregular lake shape. A value closer to or equal to 1 would suggest a more regular, circular lake morphology. A higher Shoreline Development Index value reflects greater human influence on the lake's shoreline, which can negatively impact the lake ecosystem and the sustainability of the surrounding natural environment (Wetzel, 2001).

Figure 2. The surface of Lake Dora (A), Lake Walini (B), and Lake Dori (C).

Table 1. Morphometric of Lakes Dori, Walini, and Dora.

No.	Parameter	Lake Dori	Lake Walini	Lake Dora
1	Maximum Length (m)	97.78	178.33	176.16
2	Effective Maximum Length (m)	94.78	178.33	176.16
3	Maximum Width (m)	46.24	61.36	111.70
4	Average Width (m)	35.94	43.00	77.20
5	Effective Maximum Width (m)	46.24	61.36	111.70
6	Surface Area (m^2)	3405.96	7668.37	13599.75
7	Shoreline Perimeter Length (m)	242.62	545.26	664.66
8	Shoreline Development Index	2.35	3.51	3.22

3.2. Physicochemical characteristics

The average temperature of the three lakes during the observation was 28°C (Table 2). The surface temperatures of the three lakes range from 26-32°C. Lake Dori ranges from 26-29°C, with the maximum temperature in April at 29.79°C and the minimum in June at 24.85°C. On the other hand, Lake Walini has a temperature range of 27 to 30°C, with the lowest temperature recorded in February at 27.2°C and the highest in April at 30.45°C. Meanwhile, Lake Dora has a temperature range of 27 to 29°C, with the lowest temperature in February and the highest in January at 29.94°C (Figure 4A).

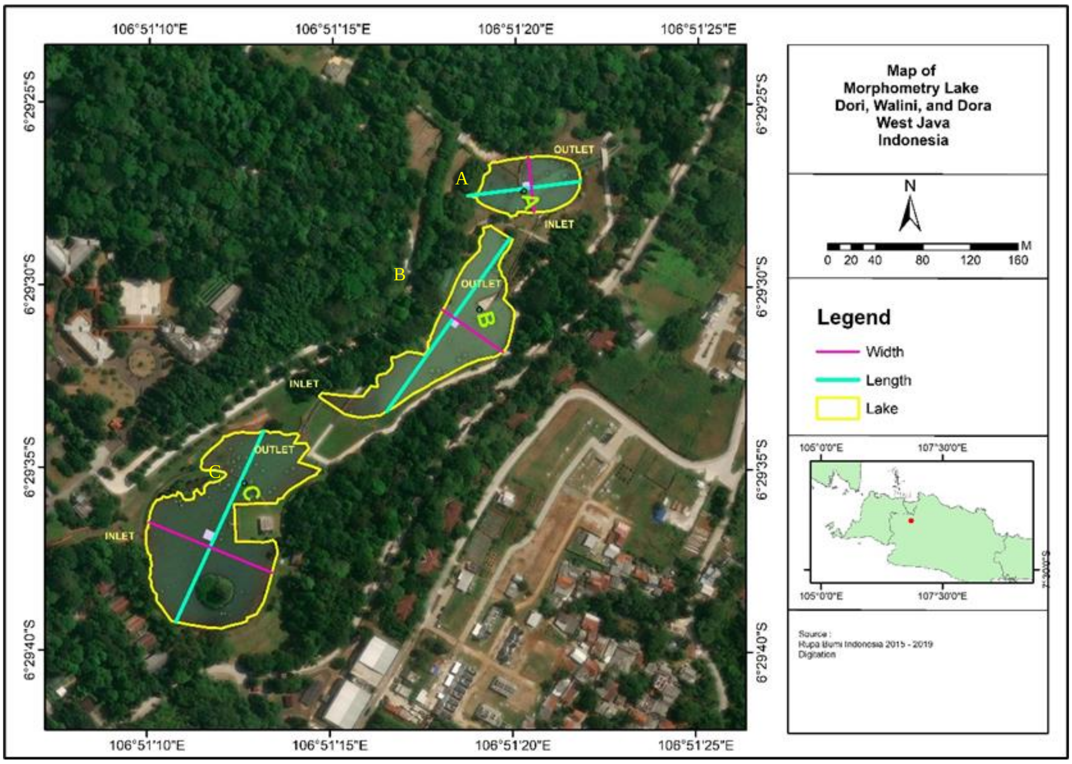

Figure 3. Morphometric of Lake Dori (A), Walini (B), and Dora (C).

Table 2. Average Water quality from Lake Dora, Lake Walini, and Lake Dori.

No.	Parameters	Dori	Walini	Dora
1	Temperature(°C)	28.38	28.93	28.78
2	pH	7.37	7.06	6.39
3	DO	6.29	6.00	4.79
4	Turbidity	89.27	110.36	45.70
5	TDS	0.04	0.04	0.045
6	NH_3	0.34	0.30	0.30
7	NO_3^-	0.15	0.06	0.06
8	PO_4^+	0.07	0.04	0.04

Temperature stratification can occur in lakes deeper than 20 meters in the water column, whereas in shallow lakes, the water column temperatures tend to undergo continuous mixing (Brönmark and Hansson, 2017). When observing the water temperatures of the three lakes, they appear to exhibit a similar pattern or trend. Although the graph (Figure 4A) shows differences in temperatures among the three lakes, the average temperature from the data is 28°C, ranging from 27-30°C. This range represents typical lake water temperatures in tropical regions (Fakhrudin *et al*., 2019; Jasalesmana *et al.,* 2019). The temperature dropped from January to mid-February because it was the rainy season. Fluctuations in temperature can be caused by factors such as sunlight intensity, wind strength and speed, air temperature, and rainfall (Magee and Wu, 2017; Jasalesmana *et al.,* 2019). In addition, from January to April 2023, it was the rainy season, and the light intensity was low because clouds covered the sun.

Photosynthesis of phytoplankton and submerged aquatic plants at Lake Dora was hampered by dense floating plants, which increased CO_2 production from its respiration process. Hence, the DO concentration decreases and simultaneously lowers the pH value. The pH value in water can fluctuate due to various factors, including the DO content. Oxygen can increase water pH by reducing its acidity. This occurs because oxygen reacts with compounds like carbon dioxide to form less acidic substances. pH changes are influenced by photosynthesis and respiration activities within the ecosystem in waters. Photosynthesis consumes carbon dioxide, which autotrophic organisms convert into sugars, reducing carbon dioxide levels and increasing water pH.

Conversely, ecosystem respiration increases carbon dioxide levels, decreasing water pH (Haghi *et al*., 2017). Comparing the pH and DO graphs (Figure 4B – 4C), pH generally decreases from January to April, corresponding inversely with the DO graph, which also shows a decrease. pH fluctuations are also influenced by water hardness, organic matter content, and oxygen levels. In this study, the observed pH values remain within the normal range, although Lake Dori shows relatively high values. DO levels also affect nutrient content; under toxic conditions, nutrients like nitrogen, sulfur, and carbon compounds exist in oxidized forms, such as nitrate, sulphate, and carbonate. These various forms of nutrients are relatively non-toxic under moderate conditions but still favor the growth of phytoplankton so the impact of phytoplankton accumulation (algae blooming) can cause water quality degradation (Li *et al*., 2020).

The measurement results of DO values in the three lakes show a 2-9 mg/L range. The lowest DO level was recorded in Lake Dori, at 3.74 mg/L in April, while the highest was in January at 9.33 mg/L. Conversely, Lake Walini recorded its lowest DO level in May at 3.64 mg/L and its highest in February at 7.44 mg/L. On the other hand, Lake Dora had its lowest DO level in April at 2.01 mg/L and its highest in February at 7.02 mg/L (Figure 4C).

Various factors, such as temperature, influence the oxygen content in water; as water temperature rises, it facilitates the release of oxygen from water (Wetzel, 2001). The chart (Figure 4A) shows that the temperature decreases from January to April. Lakes deeper than 50 m experience stratification, resulting in oxygen-deprived or anoxic layers (Subehi *et al*., 2021). In contrast, urban lakes or ponds with depths less than 10 m allow light to reach the bottom, and mixing processes occur from the surface to the bottom, preventing the formation of anoxic layers in urban lakes. However, DO levels in surface water are influenced by other factors such as wind speed, air temperature, and rainfall (Magee and Wu, 2017; Jasalesmana *et al.,* 2019). The decrease in DO concentration since February is related to the rainy season and the decrease in light intensity, which leads to a decrease in photosynthesis and, therefore, a decrease in oxygen levels in the water. Lake Dora has a lower DO concentration than the other because aquatic plants have covered the surface water of Lake Dora, this plant can reduce the light intensity to penetrate the water column and reduce the photosynthesis, which means only respiration happens.

Additionally, according to Henny (2009), sulfide can significantly impact dissolved oxygen levels in the water. Sulfide can potentially deplete the toxic layer at the lake surface and may eliminate it entirely if the DO concentration in that layer cannot counteract the sulfide levels. This situation threatens aquatic organisms due to inadequate respiration oxygen and sulfide toxicity to biota (Putri *et al.,* 2024).

The result of the turbidity measurement shows that Lake Walini has the highest turbidity value than the other. This is because the water from Lake Dora (upstream) always flows to Lake Walini (middle stream), and carries the material from Lake Dora to Lake Walini. On the other hand, water from Lake Walini to Lake Dori (downstream) had water gates to separate them, and the water did not always flow to Lake Dori. This gives Lake Walini the highest turbidity value.

Generally, turbidity values in the three lakes range from 20.5 to 149.5 NTU. In Lake Dori, turbidity ranges from 57.5 to 116.45 NTU, with the lowest observed in January and the highest in April. Conversely, Lake Walini shows the lowest turbidity of 72.9 NTU in January and the highest of 149.5 NTU in March. Lake Dora has the lowest and highest turbidity values in April, at 20.3 and 82.8 NTU, respectively (Figure 4D).

Turbidity values significantly impact aquatic biota, as research shows that high turbidity can affect shrimp survival by disrupting respiration (Suhendar, 2020). Turbidity exceeding 50 NTU is considered high, and levels above 25 NTU can disturb aquatic organisms (Cech, 2005). Turbidity in lake ecosystems results from suspended particles such as sediments and phytoplankton, which reduce water clarity and light penetration (Çako *et al.,* 2013).

Elevated turbidity levels can have diverse ecological impacts, affecting visibility, foraging behavior, and prey detection in visual-hunting predators like fish (Lunt and Smee, 2020). Furthermore, turbidity can alter benthic macroinvertebrate communities, with different species thriving in pristine, semi-transparent, and turbid lakes, underscoring its influence on biodiversity and community composition (Sosa-Aranda and Zambrano, 2020).

The observations show that the three lakes' TDS values fluctuate monthly. Generally, TDS values tend to increase in March and experience significant decreases in May. The highest TDS values in Lakes Dori, Walini, and Dora occurred in January, at 0.048 g/L, 0.047 g/L, and 0.049 g/L, respectively, while the lowest values in May were 0.039 g/L, 0.044 g/L, and 0.038 g/L (Figure 4E).

Variations in TDS levels in natural water bodies typically arise from industrial discharge and changes in water balance, such as reduced inflow, increased water consumption, or heightened precipitation (Weber-Scannell Duffy, 2007). In this study, human activities and surrounding vegetation cover dominantly influence the cascade lake.

3.3. Nutrient Characteristics

Laboratory testing of water quality in the three lakes indicates NH_3 concentrations ranging from 0.25 to 0.30 mg/L in January. Lake Dori peaks in NH_3 levels in February at 0.47 mg/L, followed by stabilization from March to April. Lake Walini shows steady from January to February, then rises to its highest in March. Meanwhile, Lake Dora's NH_3 values increase until March before dropping to 0.16 mg/L in April (Figure 5A). Compared to Lake Gintung, one of the urban lakes near Jakarta (Maresi *et al.,* 2020), the NH_3 value in Lakes Dora, Walini, and Dori is relatively low.

NH_3 is a nitrogen compound that occurs naturally and dissolves in water, as the NH_4^+, with its form affected by pH and temperature. Under low pH conditions, NH_4^+ converts to ammonia, which is toxic to aquatic life, particularly fish (Edwards *et al*., 2024). Urban lakes, including Lake Dori, often exhibit higher NH_3 ranges due to anthropogenic factors like vehicle emissions, industrial activities, and runoff (Edwards *et al*., 2024).

NO_3^- is another essential water quality parameter, as excessive concentrations can disrupt aquatic ecosystems (Arnanda, 2023). Observations of NO_3^- levels in Lakes Dora, Walini, and Dori reveal a similar fluctuation pattern across all three lakes, with concentrations increasing from January to February and then decreasing through April. Lake Dori NO_3^- levels increased significantly from 0.14 mg/L in January to 0.34 mg/L in February. The availability of inorganic nutrients (NH_3, NO_2^-, and NO_3^-) in these lakes supports aquatic life, with nutrients typically declining during the rainy season.

Nitrogen assimilation naturally occurs in waters as the water ecosystem utilizes it to grow. For instance, nitrogen plays a role in bacteria, such as cyanobacteria growth as their medium. Excessive amounts of ammonia, nitrate, and nitrite in water can trigger them to thrive. Continued nitrate levels increase in Lakes Dora, Walini, and Dori could lead to algal blooms, particularly cyanobacteria or blue-green algae (Luthfiani *et al*., 2021). Algal blooms can disrupt aquatic ecosystems by depleting oxygen, producing neurotoxins, and harming fish gills (Sosa-Aranda and Zambrano, 2020).

Based on Figure 5, PO_4^+ values in Lake Dori remained stable from January to March and decreased from March to April. At the beginning of the observation period, the PO_4^+ value in Lake Walini was 0.05 mg/L, decreasing to 0.03 mg/L in February. Similarly, Lake Dora also experienced the same PO_4^+ values from February to April (Figure 5C).

Lake Dori has higher nitrate and PO4 levels because it is downstream, so nutrients flow and accumulate. In January and February, the nitrate and PO4 levels increased due to the rainy season, so a lot of water flowed into Lake Dori and the sluice gates from Lake Walini were opened, causing an increased water flow into Lake Dori, which gradually decreased after February.

The fluctuation in PO_4^+ content in each lake is influenced by the quality of incoming water and the specific conditions of each lake, such as location, land use, biogeochemistry condition, water inlet source quality, and so on. The decrease observed in Lake Walini and Lake Dora could be due to PO_4^+ being absorbed by phytoplankton (Boyd and Musig, 1981) or aquatic plants. Additionally, PO_4^+ in water can easily bind with particulates and precipitate into lake sediments (Wang *et al.,* 2022).

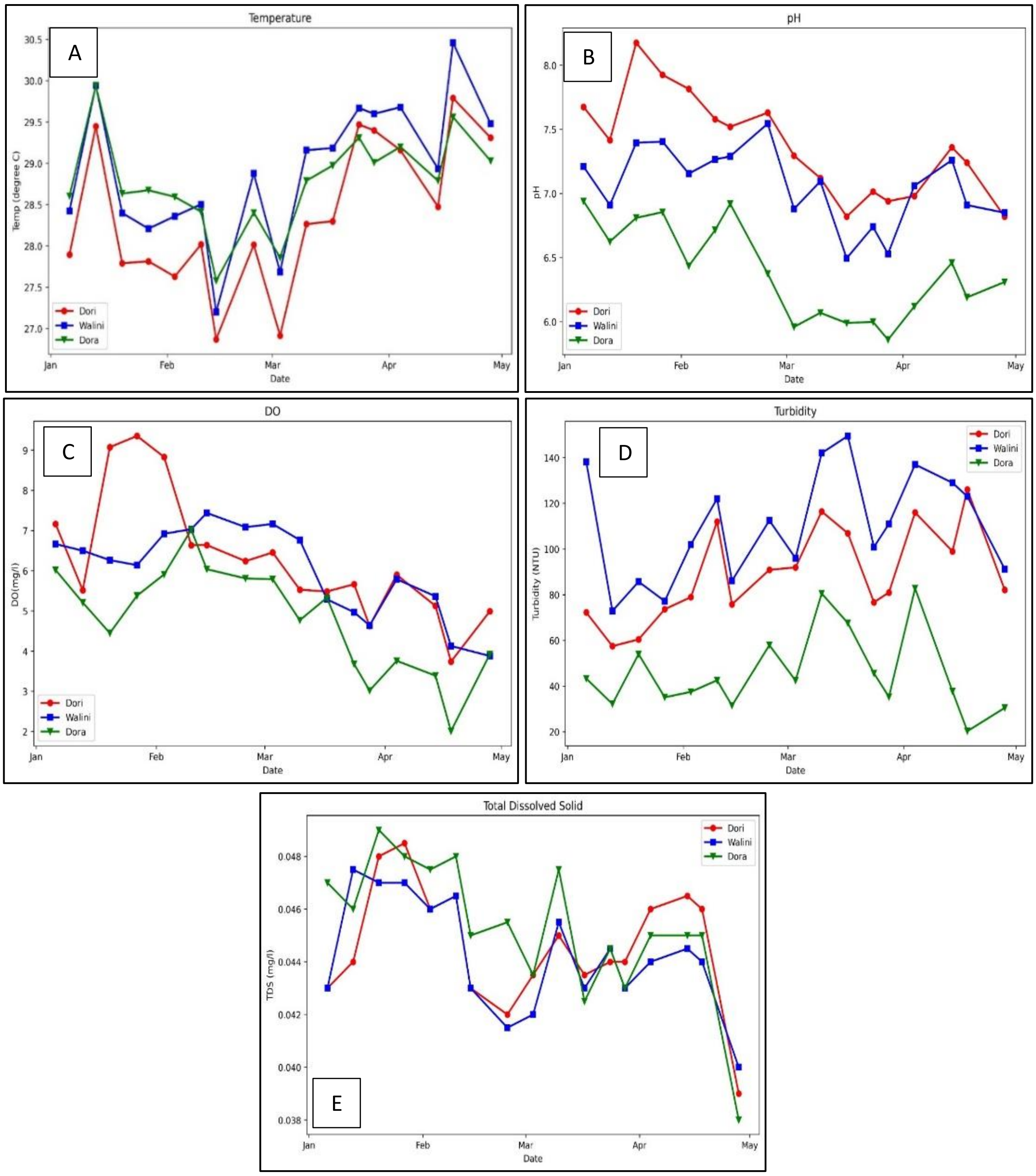

Figure 4. Graphic Water quality of Lakes Dora, Walini, and Dori. (A) Temperature; (B) pH; (C) Dissolved Oxygen; (D) Turbidity; (E) Total Dissolved Solid.

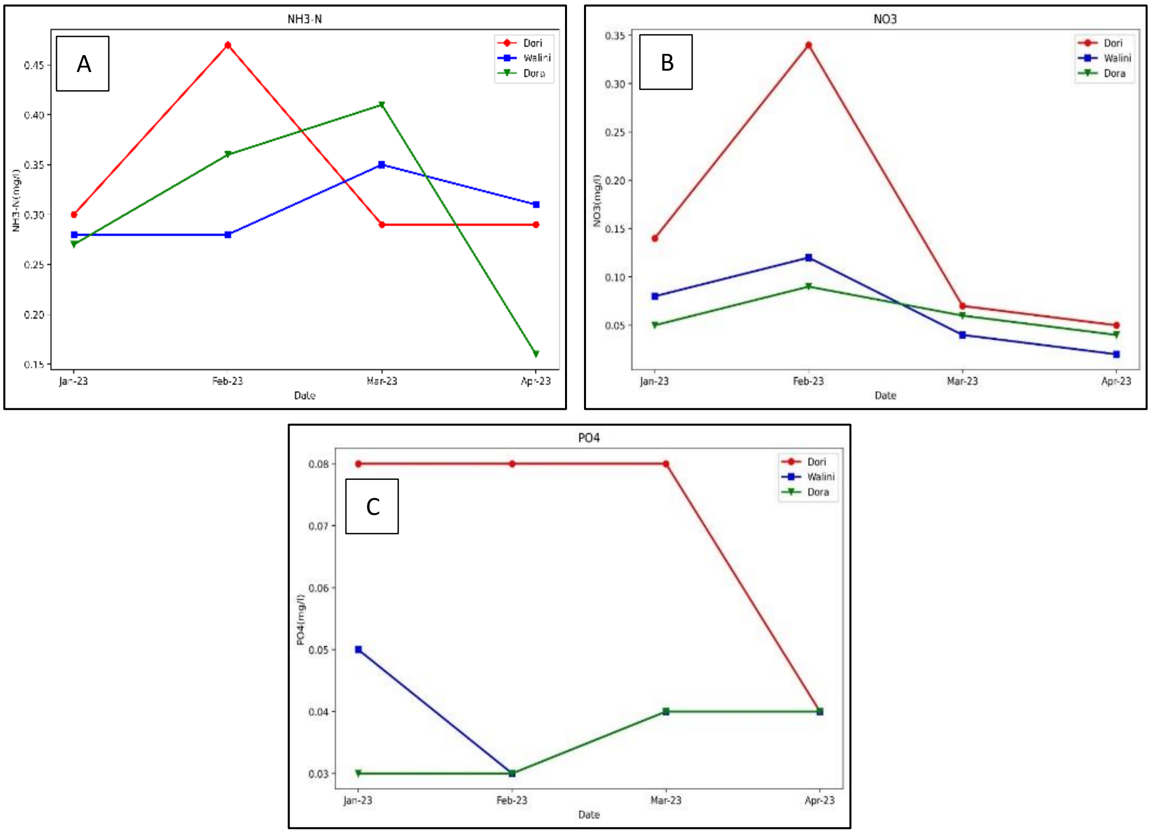

Figure 5. Graphic Nutrient of Lakes Dora, Walini, and Dori (A) NH_3; (B) NO_3^-; (C) PO_4^+.

3.4. A distinct characteristic between lakes

The similarity index analysis and dendrogram results indicate that the water quality at the Lakes Dori and Walini sites is more closely aligned, while Lake Dora shows more distinct characteristics (Figure 6). This distinction is illustrated by the shorter Euclidean distance between Lakes Dori and Walini, approximately 4, signifying a relatively high level of similarity. In contrast, Lake Dora connects to the Lake Dori-Walini group at a greater Euclidean distance of about 12, highlighting Lake Dora's substantial difference from the other two lakes.

ANOVA analysis results indicate no significant differences among the lakes for most measured parameters, except for the dissolved oxygen and turbidity parameters, which had a p-value below 0.05 (Table 3). This indicates that DO and turbidity levels varied significantly across the lakes.

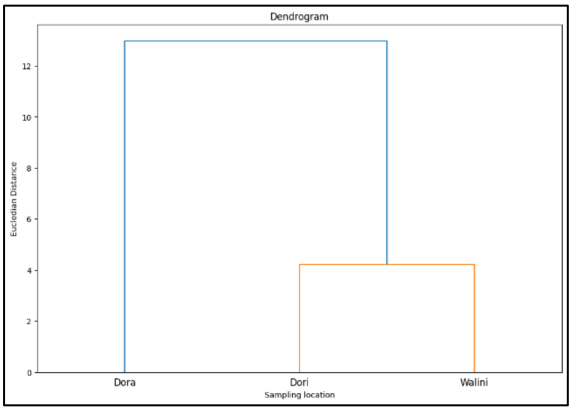

Figure 6. The similarity index from Lakes Dora, Walini, and Dori.

3.5. Lake Management Strategies Based on The Water Quality Status

Although the three lakes' physical and chemical water quality remains within the acceptable range of water quality standards, an analysis of lake management strategies based on the water quality status is essential. This analysis will help determine appropriate uses for these lakes in alignment with water class classifications established by regulations. Water quality status and class classifications guide pollution control or management strategies in aquatic environments (Ratnaningsih *et al.,* 2018). In urban lakes, class classification specifies the type of water use that is suitable for each lake's water quality.

Determining water pollution status and class classification follows Government Regulation No. 22 of 2021 on Implementation of Environmental Protection and Management, while the water quality status of the three lakes is evaluated using the STORET method (Canter, 1977), as it enables analysis of multiple water quality parameters. Additionally, measurements were conducted temporally at specific locations over a defined period, allowing water quality status to be assessed for each water class as specified in the regulations. The STORET calculations result for each water class in each lake are presented in Table 4.

Table 3. The result of the ANOVA analysis for the three urban lakes.

Parameter	Temperature	pH	DO	Turbidity	TDS	NH_3	NO_3^-	PO_4^+
p-Value	0.1222	5.5644	0.0040	1.60E-12	0.4289	0.8339	0.3678	0.0978
Significancy (Yes/No)	no	no	yes	yes	no	no	no	no

Determining water pollution status and class classification follows Government Regulation No. 22 of 2021 on Implementation of Environmental Protection and Management, while the water quality status of the three lakes is evaluated using the STORET method (Canter, 1977), as it enables analysis of multiple water quality parameters. Additionally, measurements were conducted temporally at specific locations over a defined period, allowing water quality status to be assessed for each water class as specified in the regulations. The STORET calculations result for each water class in each lake are presented in Table 4.

Table 4. Water Quality Status as per Water Classification of Lakes Dori, Walini, and Dora.

Lake Name	Water Quality Status		
	Class I	**Class II**	**Class III**
Dora	C	C	B
Walini	C	C	A
Dori	C	B	A

A: Meet quality standard
B: Slightly polluted
C: Moderately polluted

Table 4. shows none of the three lakes meet Class I or Class II water standards, as their water quality status falls within Class C or B, indicating moderate to slightly polluted. The source of contamination may originate from NH3 nutrients with relatively high concentrations, which is evident from the presence of aquatic plants on the lake surface.

Besides temperature conditions, DO levels also influence nutrient concentrations in water bodies (Arnando *et al.,* 2023). For instance, higher temperatures increase nitrate and phosphate levels due to enhanced water evaporation, impacting nutrient concentrations in the water. Additionally, low oxygen levels in water affect nitrate content, as inadequate oxygen disrupts or diminishes nitrification processes in aquatic environments.

In contrast to Lake Walini and Lake Dori, which contain several submerged aquatic plant species, Lake Dora is densely populated with emergent plants that majority extend above the water surface. While emergent plants help reduce excess nutrients in the water, the morphology and other factors, such as weather, dissolved oxygen levels, and biological activities within the water influence nutrient dynamics (Kreuzwieser and Gessler, 2010; Trombetta *et al.,* 2019). Due to differences in plant density and nutrient level, Lake Walini and Lake Dori meet Class III standards, which are classified as Class A (meeting water quality standards). These lakes are suitable for uses such as freshwater fish farming, livestock farming, and irrigation in compliance with Government Regulation No. 22 of 2021 on Implementation of Environmental Protection and Management. However, Lake Dora, classified as Class B (slightly polluted) under Class III criteria, is not recommended for maintaining aquatic organisms but may be used for other purposes, such as gardens or farmland.

4. Conclusion

This study found that the downstream lakes have a better water quality index than the upstream lakes, with Lake Dora acting as a buffer for further downstream lakes. Therefore, improving water quality for recreational purposes may best focus on Lake Dora. Further research is needed to assess the conditions of the surrounding watershed areas and their impact on fluctuating water quality in these lakes. This research is essential for enhancing our understanding of water quality dynamics and for developing more effective management strategies to preserve urban lake ecosystems.

Data availability statement

We state that the source of all required data has been written in the manuscript

Conflict of interest

All authors have declared that there is no conflict of interest in the writing and submission of the manuscript.

Contributor Statement

AR, AYA, DR, and **RN** are the main contributors for the work. They were developed the concept for the study, as well as conducted field investigation, formal analysis, and writing the manuscript. **AD** and **DV** as the co-authors contributed on formal analysis. While **AD** give substantial analysis for data interpretation, **DV** contributed on graphical data preparation and its analysis, and editing. All authors and co-authors declare that they reviewed and consented to the final version of the manuscript.

Acknowledgment

We convey our gratitude to the distinguished reviewer (s) and the editor (s) for their significant support during the publication process.

References

Arnanda R. 2023. Analisis Kadar Nitrat dalam Air Sungai dengan Menggunakan Spektrofotometer UV-Visible. *Jurnal Kolaboratif Sains* 6(3):181–184. DOI:10.56338/jks.v6i3.3357.

Arnando DA, Irawan A , Sari LI. 2023. Karakteristik Distribusi Zat Hara Nitrat Dan Fosfat Pada Air Dan Sedimen Di Estuaria Tanjung Limau Kota Bontang Kalimantan Timur. *Tropical Aquatic Sciences* 1(2): 46–53. DOI: 10.30872/tas.v1i2.639.

Birch S, McCaskie J. 1999. Shallow urban lakes: A challenge for lake management. *Hydrobiologia* 395–396. DOI: 10.1007/978-94-017-3282-6_31.

Boyd CE, Musig Y. 1981. Orthophosphate uptake by phytoplankton and sediment. *Aquaculture* 22(C):165–173. DOI: 10.1016/0044-8486(81)90142-3.

National Research and Innovation Agency (BRIN). 2024. Kebun Raya Cibinong BRIN: Platform riset dan konservasi tumbuhan berkonsep ekoregion. BRIN Press Release. Accessed 10 July 2024, https://www.brin.go.id/press-release/98236/kebun-raya-cibinong-brin-platform-riset-dan-konsevasi-tumbuhan-berkonsep-ekoregion

Brönmark C, Hansson LA. 2017. The biology of lakes and ponds. *The Biology of Lakes and Ponds*:1–338. DOI: 10.1093/oso/9780198713593.001.0001.

Çako V, Baci S, Shena M. 2013. Water Turbidity as One of the Trophic State Indices in Butrinti Lake. *Journal of Water Resource and Protection* 05(12):1144–1148. DOI: 10.4236/jwarp.2013.512120.

Canter LW. 1977. *Water Quality Criteria for the use of STORET in Assessing Water Quality in Streams and Rivers.* U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati Ohio.

Cech TV. 2005. *Principles of Water Resources History, Development, Management, and Policy*. Second Edition. Wiley. USA. ISBN: 978-1-118-79029-8

Edwards TM, Puglis HJ, Kent DB, Duran JL, Bradshaw LM, Farag AM. 2024. Ammonia and aquatic ecosystems – A review of global sources, biogeochemical cycling, and effects on fish. *Science of the Total Environment* 907:197911. DOI: 10.1016/j.scitotenv.2023.167911.

Fakhrudin M, Subehi L, Jasalesmana T, Dianto A. 2019. Dissolved oxygen and temperature stratification analysis for early warning system development in preventing mass mortality of fish in Lake Maninjau, West Sumatera-Indonesia. *IOP Conference Series: Earth and Environmental Science* 380(1). DOI: 10.1088/1755-1315/380/1/012002.

Haghi RK, Chapoy A, Peirera LMC, Yang J, Tohidi B. 2017. pH of CO2 Saturated Water and CO2 Saturated Brines: Experimental Measurements and Modelling. *International Journal of Greenhouse Gas Control* 66 (October): 190–203. DOI:10.1016/j.ijggc.2017.10.001.

Henny C. 2009. Dynamics of Biogeochemistry of Sulfur in Lake Maninjau. *Limnotek*, XVI(2):74–87.

Henny C, Meutia AA. 2014. Urban Lakes in Megacity Jakarta: Risk and Management Plan for Future Sustainability. *Procedia Environmental Sciences* 20: 737–46. DOI: 10.1016/j.proenv.2014.03.088.

Jadeja NB, Barneji T, Kapley A, Kumar R. 2022. Water pollution in India – Current scenario. *Water Security* 16. December 2020: p. 100119. doi: 10.1016/j.wasec.2022.100119.

Jasalesmana T, Zulti F, Triwisesa E, Santoso AB, Fakhrudin M. 2019. Pengaruh Wind Stress terhadap Stratifikasi Suhu Harian Kolom Air Danau Maninjau. *LIMNOTEK Perairan Darat Tropis di Indonesia* 26(1):55–64.

Kreuzwieser J, Gessler A. 2010. Global climate change and tree nutrition: Influence of water availability. *Tree Physiology* 30(9):1221–1234. DOI: 10.1093/treephys/tpq055.

Li Y, Nwankwegu AS, Huang Y, Norgbey, Paerl EHW, Acharya K. 2020. Evaluating the Phytoplankton, Nitrate, and Ammonium Interactions during Summer Bloom in Tributary of a Subtropical Reservoir. *Journal of Environmental Management* 271: 110971. DOI:10.1016/j.jenvman.2020.110971.

Lunt J, Smee DL. 2020. Turbidity alters estuarine biodiversity and species composition. *ICES Journal of Marine Science* 77(1):379–387. doi: 10.1093/icesjms/fsz214.

Luthfiani F, Sunardi S, Kasmara H. 2021. The Dynamic of Blue-Green Algae (Cyanobacteria) in Eutrophic Tropical Waters, The Cirata Reservoir. *Indonesian Journal of Limnology* 1(1):1–6. doi: 10.51264/inajl.v1i1.4.

Magee MR, Wu CH. 2017. Response of water temperatures and stratification to changing climate in three lakes with different morphometry. *Hydrology and Earth System Sciences* 21(12): 6253–6274. DOI: 10.5194/hess-21-6253-2017.

Maresi SRP, Soesilo TEB, Meutia AA. 2020. Water Quality Status of an Urban Lake in the Dry Season from 2017 to 2020 (Situ Gintung, Banten Province, Indonesia). *E3S Web of Conferences* 211: 1–10. DOI:10.1051/e3sconf/202021103008.

Mishra HS, Bel S, Vassiljev P, Kuhlmann F, Niin G, Grellier J. 2020. The development of a tool for assessing the environmental qualities of urban blue spaces. *Urban Forestry and Urban Greening*. 49:126575. DOI: 10.1016/j.ufug.2019.126575.

Mitroi V, Maleval V, Deroubaix JF, Leite BV, Humbert JF. 2022. What urban lakes and ponds quality is about? Conciliating water quality and ecological indicators with users perceptions and expectations about urban lakes and ponds quality in urban areas. *Journal of Environmental Policy and Planning* 24(6): 701–718. DOI: 10.1080/1523908X.2022.2037413.

Putri MR, Jasalesmana T, Abdurrachman M, Henny C, Nomosatryo, Albani AS. 2024. The Impact of Weather Condition Changes on Vertical Distribution of Sulfides in Lake Maninjau Based on Observation Data. *LIMNOTEK Perairan Darat Tropis di Indonesia* 1(2): 1–11. DOI: 10.55981/limnotek.2024.2203.

Ratnaningsih D, Lestari RP, Nazir E, Fauzi R. 2018. Pengembangan Indeks Kualitas Air Sebagai Alternatif Penilaian Kualitas Air Sungai the Development of Water Quality Index As an Alternative Assessment of River Water Quality. *Ecolab* 12(1):53–61. DOI:10.20886/jklh.2018.12.2.53-61.

Ribbe L, Dekker G, Thapak G. 2023. Urban wetlands and water bodies. Managing Urban Rivers: from Planning to Practice. DOI: 10.1016/B978-0-323-85703-1.000079.

Sosa-Aranda I, Zambrano L. 2020. Relationship between turbidity and the benthic community in the preserved Montebello Lakes in Chiapas, Mexico. *Marine and Freshwater Research* 71(7) : 824–831. doi: 10.1071/MF19090.

Subehi L, Ridwansyah I, Fukushima T. 2021. Dissolved Oxygen Profiles and Its Problems at Lake Maninjau, West Sumatra – Indonesia. *Indonesian Journal of Limnology*, 1(1):7–11.

DOI: 10.51264/inajl.v1i1.3.

Suhendar DT, Suhendar IS, Zaidy AB. 2020. Hubungan Kekeruhan terhadap Materi Partikulat Tersuspensi (Mpt) dan Kekeruhan terhadap Klorofil dalam tambak udang. *Journal of Fisheries and Marine Research* 4(3). DOI: 10.21776/ub.jfmr.2020.004.03.3

Sulastri, Akhdiana I, Khaerunissa N. 2020. Phytoplankton and Water Quality of Three Small Lakes in Cibinong, West Java, Indonesia. *IOP Conference Series: Earth and Environmental Science* 477(1). DOI: 10.1088/1755-1315/477/1/012016.

Trombetta T. Vidussi F, Mas S, Parin D, Simier M, Mostajir B. 2019. Water temperature drives phytoplankton blooms in coastal waters. *PLoS ONE* 14(4):1–28. DOI: 10.1371/journal.pone.0214933.

Vasistha P, Ganguly R. 2020. Water quality assessment of natural lakes and its importance: An overview. *Materials Today: Proceedings* Elsevier: 544–552. DOI: 10.1016/j.matpr.2020.02.092.

Wagner T, Erickson L. E. 2017. Sustainable Management of Eutrophic Lakes and Reservoirs. *Journal of Environmental Protection* 08(04): 436–463. DOI: 10.4236/jep.2017.84032.

Walker C, Lucke T. 2018. Urban Lakes as a WSUD System. *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions*. Elsevier Inc. DOI: 10.1016/B978-0-12-812843-5.00013-7.

Wang Z, Guo Q, Tian L. 2022. Tracing phosphorus cycle in global watershed using phosphate oxygen isotopes. *Science of the Total Environment* 829:154611. DOI: 10.1016/j.scitotenv.2022.154611.

Weber-Scannell PK., Duffy L. K. 2007. Effects of total dissolved solids on aquatic organisms: A review of literature and recommendation for salmonid species. *American Journal of Environmental Sciences* 3(1): 1–6. DOI: 10.3844/ajessp.2007.1.6.

Wetzel, R. G. 2001. *Limnology: Lake and River Ecosystem. Low Temperature Physics. Third Edit. New York: Academic Press*. DOI: 10.1063/1.3224729.

White M, Smith A, Humphryes K, Pahl S, Snelling D, Depledge M. 2010. Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology* 30 (4): 482–493. DOI: 10.1016/j.jenvp.2010.04.004.