Assessment of limnological and alternative fisheries management of four oxbows upstream of Citarum River, West Java, Indonesia

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Abstract. An oxbow is a semi-enclosed body of water that forms in waterways or abandoned rivers as a result of alterations in the flow of the river. Oxbows are commonly distinguished by their extended periods of water retention, the capacity for significant nutrient preservation, and the prevalence of internal mechanisms. The heightened nutritional load might originate from both internal and external sources. The Citarum River contains numerous oxbows that require further investigation. The objective of this study was to assess the limnological state of the oxbows located upstream of the Citarum River, in order to provide a foundation for effective management strategies. The study was carried out at four oxbow lakes. The findings indicated that the upstream Citarum oxbows' water quality can be classified as 2 and 3 for Dara Ulin, Bojongsoang, and Cieunteung. These classifications deem the water suitable for recreational activities, aquaculture, animal husbandry, and crop irrigation. The Cikukang oxbow has a class 4 rating, indicating a significantly low oxygen concentration of less than 1 mg L^{-1}. Out of the four oxbows, none of them satisfied the class 1 standards for potable water. Dara Ulin, Cieunteung, and Cikukang experience elevated levels of phosphorus pollution, with concentrations above 1 mg L^{-1}. Every oxbow exhibits elevated levels of chlorophyll-*a*, indicating the presence of eutrophication. The eutrophication level in four oxbows located upstream of the Citarum River is high, indicating a high level of nutrients. According to the Comprehensive Pollution Index (CPI), these oxbows are considered polluted. One approach to developing fisheries is to replenish the population of native fish species, either as reserves or to stock fish that are preferred by the local community. The fish that are stocked are planktivorous, meaning they consume plankton as their natural food.
Key Words: water quality, eutrophic, stocking.

Introduction. An oxbow is a semi-enclosed water body in waterways, or abandoned rivers as a result of alterations in river flow (Hasan et al 2001; Halim et al 2018), and local people call it a horseshoe lake. Oxbow formations occur when a winding floodplain river becomes separated and isolated from the main river (Cullum et al 2006; Kusa et al 2014) either through natural processes or human intervention to straighten the river's bends (Juliandar & Rohmad 2019). The unsteadiness of river channels leads to the formation of oxbow lakes that extend along both sides of the current path of the river, taking the shape of elongated, curved pools of water (Koc et al 2009). Oxbows are typically characterized by extended periods of water retention, the capacity for significant nutrient retention, and the prevalence of internal processes (such as the breakdown of natural organic matter, particularly the absorption of nutrients by autotrophs, which support heterotrophs, facilitate trophic transfer, promote sedimentation, decomposition, and mineralization, and cause sediment resuspension). The increased nutrient load can originate from both internal sources, such as the discharge of nutrients from sediment, and external sources, such as the inflow from rivers and upland areas (Szabó et al 2013). In some developing countries, it is used for industrial water sources, in Kenya, for agricultural irrigation around the oxbow, and in Bangladesh for small-scale fish farming. Generally, they are used for agricultural, horticultural, and flood control activities and can be used as temporary storage during the flood season to reduce water overload (Kusa et al 2014).

The Citarum River holds the title of being the longest river in West Java, Indonesia. The river, spanning a distance of 297 km, begins from Situ Cisanti in the Gunung Wayang Valley situated south of Bandung City. The water moves in the direction of Muara Gembong, which is situated in Bekasi Regency on the northern side of Java Island. The Citarum River serves as a vital water source for the nearby cities, facilitating activities such as agricultural irrigation, fishing in the reservoir cascade of the Citarum River, and supplying water for drinking, industry, and hydroelectric generating plants. The introduction of pollution into the Citarum River, such as the discharge of wastewater, harms the quality of the river water Prahoro et al (2015) stated that in 2015, the waters in the oxbows of the upper Citarum River were severely polluted. As part of the efforts to restore the Citarum River, one of the objectives is to reactivate the oxbows and enlarge the river boundaries (Manalu 2019). No research has been undertaken by the relevant agencies on the water quality in the upstream Citarum River. This is evidenced by the lack of available water quality data in the region. This study was conducted by the Citarum Harum Programme, as specified in the Presidential Regulation of the Republic of Indonesia Number 15 of 2018. The objective of the program is to enhance the habitat and ecosystem of the Citarum watershed.

Oxbows can be utilized for fisheries purposes, including the establishment of cages (Chowdhury & Yakupitiyage 2000), as reserves for nursery grounds that produce seeds naturally, and for engaging in catch fisheries activities. Oxbows are very important in maintaining the biodiversity of river fish (Penczak et al 2004). Stocking can be employed to facilitate the establishment of fisheries in the Citarum River oxbows. Restocking native species to establish a reserve can also enhance water production and improve the well-being of nearby communities. Fish restocking is implemented to enhance fish replenishment due to the inherent limitations of natural fish rejuvenation (Kartamihardja 2019). The objective of this study was to assess the limnological status of oxbows located upstream of the Citarum River, in order to provide a foundation for their effective management.

Material and Method

Description of the study sites. The study was carried out in the upstream oxbows of the Citarum River, located before the Saguling reservoir. The sampling was performed in four out of ten oxbows. The study was carried out throughout the months of September and October 2020. The Citarum River originates in the Bandung Regency, located in the West Java Province of Indonesia.

Sampling site. The water sample was collected from four oxbows located upstream of the Citarum River, specifically Dara Ulin, Bojongsoang, Cieunteung, and Cikukang oxbows (Figure 1, Table 1).

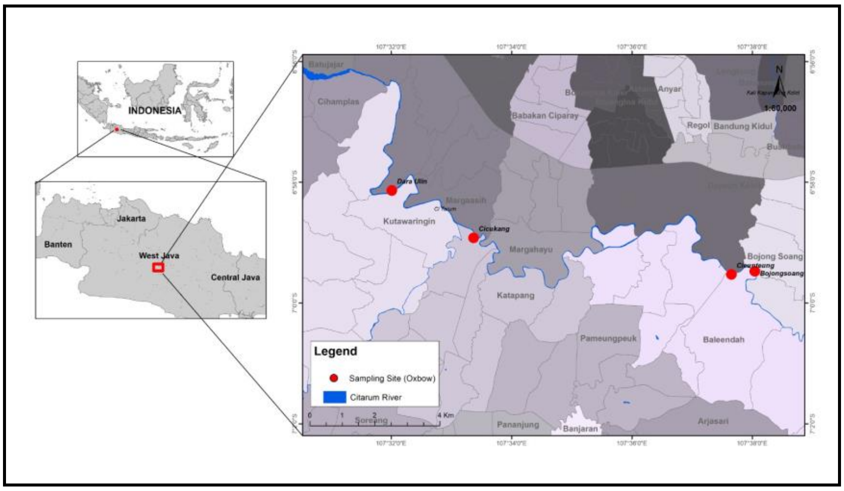

Figure 1. Research location: oxbows upstream of the Citarum River.

Table 1
Sampling stations among the oxbows upstream of the Citarum River

Oxbows	*Geographical position*		*Area (ha)*	*Location description*
	Latitude	*Longitude*		
Cieunteung	-6.99210°	107.62753°	4.2	- The site is situated in a densely populated urban residential zone - minimal fishing activity - ever stocking of fish
Bojosoang	-6.99122°	107.63400°	2.5	- The site is situated in a densely populated urban residential zone - minimal agricultural activity - recreational site
Cikukang	-6.98176°	107.55806°	1.27	- The site is situated in a densely populated urban residential zone - The majority of the riparian region - The watercolor is a deep shade of green
Dara Ulin	-6.96889°	107,53350°	9.40	- The site is situated in a densely populated urban residential zone - minimal fishing activity - recreational site

Sampling method. The observed water quality indicators included water temperature, total dissolved solute (TDS), total suspended solids (TSS), turbidity, pH, DO (Dissolved oxygen), free CO_2, alkalinity, total phosphorus (total P), nitrate ($N\text{-}NO_3$), nitrite ($N\text{-}NO_2$), total organic matter and chlorophyll-a (Table 2). The water temperature, TDS, pH, turbidity, and dissolved oxygen (DO) parameters were measured in real-time using the Horiba 10 U water quality checker. The alkalinity and CO_2 were measured using in-situ titrimetry. Water samples were collected using a one-liter sample bottle to measure the levels of TSS, nitrite, nitrate, total P, and total organic matter These samples were then analysed in the laboratory. The water sample for chlorophyll-a analysis was collected using a 250 mL sample bottle and preserved with 1 mL of $MgCO_3$. The analysis was conducted in the Water Chemistry laboratory of the Research Institute for Fish Resources Enhancement, following the standard method outlined in the American Public Health Association (APHA 2005).

Table 2
The analysis methods and instruments for measuring the observed parameters

No	*Parameters*	*Units*	*Methods/instrument*
1	Temperature	°C	Water quality checker/ Horiba 10 u
2	pH	unit	Water quality checker / Horiba 10 U
3	TDS	mg L^{-1}	Water quality checker / Horiba 10 U
4	TSS	mg L^{-1}	Gravimetric, Laboratory
5	DO	mg L^{-1}	Water Quality Checker/ Horiba 10 U
6	CO_2	mg L^{-1}	Titrimetric, insitu
7	Nitrite	mg L^{-1}	SNI.06-6989-72-2009 / Spectrophotometry
8	Nitrate	mg L^{-1}	Brucinesulphate / Spectrophotometry
9	Total P	mg L^{-1}	Ascorbate Acid / Spectrophotometry
10	Chlorophyll-a	mg m^{-3}	Trichromatic
11	Total organic matter	mg L^{-1}	Titrimetry, laboratory
12	Turbidity	NTU	Water quality checker / Horiba 10 U
13	Alkalinity	mg L^{-1} $CaCO_3$	Titrimetry in situ

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Analysis. The data were analysed using descriptive methods, following the guidelines outlined in the Republic of Indonesia Presidential Regulation No. 22 of 2021, which pertains to the implementation of environmental protection and management (Table 3). The Comprehensive Pollution Index (CPI) is a water quality metric that integrates multiple criteria to assess pollution levels. If there is an increase in the CPI, it is more probable that there would be negative consequences on the aquatic environment. The formulation CPI was as stated by Saha et al (2022).

$$CPI = \frac{1}{n}\sum_{i=0}^{n} M_i / S_i$$

Where:
CPI - comprehensive pollution index;
n - the total of parameters were observed;
Mi - the observed parameter's value;
Si - standard of water quality.

CPI categorizes water quality by range: <0.20: clean; 0.21–0.40: sub-clean; 0.41–1.00: slightly polluted; 1.01– 2.00: moderately polluted, and >2.01: severely polluted.

Table 3

Lake water quality standards and its kind

No	*Parameters*	*unit*	*Class 1*	*Class 2*	*Class 3*	*Class 4*
1	TDS	mg L^{-1}	1,000	1,000	1,000	1,000
2	TSS	mg L^{-1}	25	50	100	400
3	pH	mg L^{-1}	6-9	6-9	6-9	6-9
4	DO	mg L^{-1}	6	4	3	1
5	Total P	mg L^{-1}	0.01	0.03	0.1	-
6	Chlorophyll-a	mg m^{-3}	10	50	100	200
	Allocation		Drinking water and other necessary needs	Recreational activities Aquaculture practices Animal husbandry practices Crop irrigation practices and other necessary needs	Aquaculture practices Animal husbandry practices Crop irrigation practices and other necessary needs	Crop irrigation practices and other necessary needs

Eutrophication is the enrichment of nutrients, especially phosphate and nitrogen, and excessive growth of phytoplankton and aquatic plants, resulting from decreased water quality in lakes, reservoirs, and other aquatic ecosystems (Liu et al 2012; Kaff 2012). The determination of eutrophication level was based on total phosphorus and chlorophyll-a (Table 4).

The estimated quantity of fish seeds for stocking, depending on primary production, is determined using the Welcomme & Bartley (1998) equation, as outlined below.

$$S = (qp/\widehat{w})\exp\left(-Z(t_c - t_o)\right)$$

Where:
S - stoking level (number of individuals);
q - potential fish yield (kg ha^{-1} $year^{-1}$);

p - proportion of catches of fish species stocked (%);
$\hat{w}$ - average weight of fish caught (kg individual^{-1});
Z - total mortality (year^{-1});
t_c - age at the time of caught (year);
t_o - age at the time of stocking (year).

The calculation of fish potential yield, which is used to determine stocking, is based on the equations developed by Almazan & Boyd (1978).

$$Y = -14.3+24.4x-0.15x^2$$

Where:
Y - potential fish yield (kg ha^{-1} year^{-1});
X - chlorophyll-a (mg m^{-3}).

Table 4
Criteria of eutrophication-based chlorophyll-a and total phosphorus (Jones & Lee 1982)

Criteria of eutrophication	*Chlorophyll-a (μg L^{-1})*	*Total P (μg L^{-1})*
Oligotrophic	< 2	< 7.9
Oligo-mesotrophic	2.1-2.9	8-11
Mesotrophic	3.0-6.9	12-27
Meso-eutrophic	7.0-9.9	28-39
Eutrophic	≥ 10	≥ 40

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Results. Based on search results from Google Maps and consultations with relevant agencies, it was found that there were ten oxbows located in the upstream section of the Citarum River, four of which being Dara Ulin, Bojongsoang, Cienteung, and Cikukang. Based on data from West Java Province, the Citarum region had 33 mm and 182 mm of rainfall in September and October 2020, respectively. During these months, there were a total of 5 and 16 days with rainfall. According to this information, September signifies the commencement of the period with abundant rainfall (transition period), while October signifies the conclusion of the period with little or no rainfall (early period). The results of water quality observations are presented in Table 5.

Table 5
Water quality of four oxbows at upstream Citarum River

Parameters/ Oxbows	*Dara Ulin*		*Bojongsoang*		*Cieunteung*		*Cikukang*	
	September	*October*	*September*	*October*	*September*	*October*	*September*	*October*
Temperature (℃)	27.86	25.7	29.29	26.1	29.66	26.8	29.11	25.8
TDS (mg L^{-1})	203	227.5	337	241.15	300	370.6	-	539.5
TSS (mg L^{-1})	60.83	52.67	27.5	12.33	59.95	25.33	140.48	35.19
Turbidity (NTU)	116	42.70	74	16.3	173	76.2	154	34
pH	7.36	6.51	9.43	8	10.55	8.52	10.26	7.37
Alkalinity (mg L^{-1} $CaCO_3$)	51.28	51.28	205.13	82.05	179.49	164.1	189.74	225.63
CO_2 (mg L^{-1})	3.3	1.072	0	0.858	0	0	7.33	5.360
DO (mg L^{-1})	3.54	4.43	4.65	6.61	7.24	9.55	0.40	0.44
Nitrate (mg L^{-1})	0.147	0.951	0.390	0.793	0.077	0.959	0.110	0.317
Nitrite (mg L^{-1})	0.025	0.080	0.349	0.235	0.007	0.597	0.026	0.059
Total P (mg L^{-1})	2.887	0.182	0.806	0.283	1.445	0.795	0.604	2.170
Total organic matter (mg L^{-1})	10.74	14.42	17.69	17.49	37.13	28.23	146.94	104.81
Chlorophyll-a (mg m^{-3})	11.15	21.80	517.15	29.47	327.90	31.78	527.21	18.13

Water quality level. Based on CPI with standard class 3 of Republic of Indonesia Presidential Regulation No. 22 of 2021 presented in Table 6.

Table 6

Water quality based on CPI value

Oxbows/Month	*September*		*October*	
	CPI	*Status*	*CPI*	*Status*
Dara Ulin	3.92	Polluted	0.64	Slightly polluted
Bojongsoang	2.59	Polluted	1.07	Moderate polluted
Cieunteung	2.52	Polluted	2.50	Polluted
Cikukang	2.13	Polluted	3.13	Polluted

Eutrophication level. The result of the level of eutrophication based on total phosphorus and chlorophyll-*a* is presented in Table 7. The oxbows located in the upstream section of the Citarum River have reached eutrophic levels due to the process of eutrophication.

Table 7

Eutrophication level based on total phosphorus and chlorophyll-a

Oxbows	*Based on total phosphorus*		*Based on chlorophyll-a*	
	September	*October*	*September*	*October*
Dara Ulin	Eutrophic	Eutrophic	Eutrophic	Eutrophic
Bojongsoang	Eutrophic	Eutrophic	Eutrophic	Eutrophic
Cieunteung	Eutrophic	Eutrophic	Eutrophic	Eutrophic
Cikukang	Eutrophic	Eutrophic	Eutrophic	Eutrophic

Estimation for stocking. Based on the estimated fish potential yield, the number of fish that can be stocked in the oxbow is presented in Table 8. The maximum number of seeds was stocked in Bojongsoang oxbow, 1256 ind year^{-1}, while the minimum was stocked at Dara Ulin oxbow, 692 ind year^{-1}.

Table 8

Number of seeds for stoking at upstream Citarum oxbow

Oxbows	*Number of seeds (individual year^{-1})*	*Fish potential yield (kg ha^{-1} year^{-1})*
Dara Ulin	692	692.4
Bojongsoang	1,256	654.6
Cieunteung	976	523.6
Cikukang	1,084	564.5

Discussion

Temperature. The temperature of water is crucial for the survival of aquatic organisms and is affected by factors such as air temperature, humidity, wind, and sunlight. The temperature has an impact on phytoplankton and zooplankton, which in turn impacts fish productivity (Kiran 2010), the growth of aquatic organisms, food intake, reproduction, and other biological activities of aquatic organisms (Halim et al 2018). The ideal temperature range for water is 20-30^{o}C, although tropical fish thrive at temperatures between 25-32^{o}C (Boyd 1990; Maresi et al 2016). Temperature is a determining factor in the growth of bacteria that break down organic matter and nutritional compounds. Specifically, these bacteria thrive at a temperature of 28^{o}C (Irianto & Triweko 2019). The temperature distribution in the waterways is affected by various elements, such as the intensity of sunshine, season, and meteorological conditions (Meliala et al 2019). The metabolic rate of aquatic organisms is directly correlated with the water temperature. There is a positive correlation between water temperature and metabolic rate. In other words, when the water temperature increases, the metabolic rate also increases (Halim et al 2018). In September, the temperature in the upstream Citarum River oxbow varies between 27.86-29.66°C whereas in October it ranges from 25.7-26.8°C (Table 5). The temperature in the upstream Citarum River oxbow is suitable to the survival and growth of plankton and fish species. The temperature during the rainy season in Pergau Reservoir, Malaysia, was lower compared to the transition season (Ismail et al 2023). Perhaps the amount of sunshine that reached the Earth's surface in September was greater than in October due to a decrease in the number of rainy days.

Total Suspended Solids (TSS). In September, the TSS value in the upstream Citarum oxbow varied between 27.5-140.48 mg L^{-1} while in October it ranged from 12.33 to 52.67 mg L^{-1} (Table 5). The highest occurs at the Cikukang oxbow in September, while the minimum water level is observed at the Bojongsoang oxbow in October. The high Total Suspended Solids (TSS) in the oxbow is believed to be caused by the large volume of water flowing into the oxbow, which carries sediment from the river and runoff in its vicinity. TSS refers to inorganic substances that consist of salts and a smaller amount of organic matter found in water. These particles have the ability to raise turbidity, increase nutrient load, and impede the penetration of light at the surface, which can have an impact on the overall well-being of aquatic organisms. The primary contributors of TSS in water bodies include (i) industrial and domestic waste, (ii) urban runoff, (iii) agricultural runoff, (iv) decaying plant matter, (v) resuspension, and (vii) phytoplankton. TSS can lead to increased water turbidity, which in turn hampers the rate at which phytoplankton carry out photosynthesis. This leads to a decline in the overall productivity of the water and ultimately disrupts the food chain within the aquatic ecosystem. Excessive amounts of suspended particles in water can have a negative impact on the organisms living in it. This is because these solids impede the entry of light into the water, which hinders the ability of phytoplankton and other aquatic plants to carry out photosynthesis (Irianto & Triweko 2019). TSS exhibits a high correlation with watercolor or chromaticity, which shows an upward trend with turbidity (Wagh et al 2021).

Total Dissolved Solids (TDS). The TDS refers to the combined concentration of all inorganic and organic substances that are dissolved in a liquid. In September, the TDS value in the upstream Citarum oxbow varied between 203 to 337 mg L^{-1} whereas in October it ranged from 227.5-539.6 mg L^{-1} (Table 5). These values remain within the water quality criterion for class 3, as defined by Presidential Regulation No. 22 of 2021. The relatively low TDS value is believed to be due to the lower presence of inorganic ions in the water (Isbeanny et al 2020). The TDS value exhibits a direct relationship with the electric conductivity (EC) value and is impacted by natural processes such as weathering and dissolution of rock and soil, as well as human activities including runoff and the discharge of residential and industrial waste (domestic and industrial waste) (Ismail et al 2023; Effendi 2003). Generally, TDS in the Citarum oxbow was greater during the rainy season in October compared to the transition season in September, similar to what occurred in the Pergau reservoir, Malaysia (Ismail et al 2023).

Turbidity. Turbidity is caused by the presence of suspended particles such as clay, silt, dissolved organic matter, bacteria, plankton, and other organisms. Turbidity hinders the entry of sunlight into the water, which in turn hampers photosynthesis in the lower layers. This leads to a drop in water productivity (Halim et al 2018; Irianto & Triweko 2019; Mandal et al 2018). Prolonged exposure to turbidity levels of 25 NTU might induce stress in certain freshwater fish species, impacting fish communities (Ismail et al 2023). Elevated turbidity can lead to the stratification of temperature and dissolved oxygen in the oxbow (Halim et al 2018; Irianto & Triweko 2019; Ismail et al 2023). According to the observation data, the turbidity levels in September varied between 74 and 173 NTU, which was higher compared to October, where the range was between 16.3 and 76.2 NTU (Table 5). The findings are consistent with those seen at Pergau Reservoir, indicating that turbidity levels are lower during the rainy season compared to the dry season (Ismail et al 2023). High turbidity is primarily caused by suspended inorganic particles, particularly silt. High turbidity levels are indicative of low water quality. The turbidity level in the four oxbows exhibited cloudy–muddy waters in September and cloudy waters in October. Turbidity is directly correlated with the Total Suspended Solids (TSS) value. When the TSS value is high, it results in high turbidity as well.

pH. The pH is a measure of the acidity or alkalinity level. The pH has a crucial role in the metabolism and physiological processes of organisms (Halim et al 2018). Enhancing water quality in water treatment procedures is crucial (Irianto & Triweko 2019). According to the Health Ministry Regulation of Indonesian Republic Number 907/Menkes/SK/VII/2002, the acceptable pH range for drinking water is 6.5-8.5. The pH value falls within the acceptable range of 6-9, as stipulated by Presidential Regulation No. 22 of 2021. In September, the pH in the upstream Citarum oxbows varies between 7.36 to 10.55, while in October it ranges from 6.5 to 8.52 (Table 5). In general, the pH value was higher in September compared to October. The pH levels in Cieunteung and Cikukang oxbows during September exceeded the water quality requirement. A pH level exceeding 9 poses a significant risk as it can lead to a rapid escalation in the toxicity of ammonia (Halim et al 2018). The pH decreases with an increase in temperature, which can harm aquatic biota because it impacts the rate of biological processes (Vasistha & Ganguli 2020). In the transition season, the pH level is elevated due to the demand for hydrogen molecules in the process of photosynthesis. As a result, the concentration of hydrogen ions drops, leading to an increase in pH (Ismail et al 2023).

Alkalinity. Alkalinity is a quantitative assessment of water's ability to resist changes in pH. The buffering capacity plays a crucial role in preserving the quality of water parameters. The primary origins of natural alkalinity are rocks that contain chemicals such as carbonate, bicarbonate, and hydroxide (Kiran 2010; Halim et al 2018). Alkalinity refers to the ability of water to counteract acidity, which is also known as acid neutralizing capacity (ANC) or the number of anions in water that can neutralize hydrogen cations. Alkalinity can be described as the ability of water to resist changes in pH by acting as a buffer. The water's alkalinity is a direct reflection of the carbonate concentration found in the nearby rock, soil, and bottom silt. The primary source of total alkalinity in water is often carbonate and bicarbonate ions. According to Harlina (2021), alkalinity levels below 10 ppm are classified as extremely low (indicating high acidity), levels between 10-50 ppm are classified as low, levels between 50-200 ppm are classified as medium, and levels above 200 ppm CaCO3 are classified as high (indicating very alkaline conditions). Alkalinity in September and October ranged from 51.28–205.13 mg L^{-1} $CaCO_3$ and 82.01-225.68 mg L^{-1} $CaCO_3$, respectively.

Dissolved oxygen. Dissolved oxygen (DO) is a measure of the level of oxygen present in water, which serves as an indicator of its quality. The oxygen can be introduced through air diffusion, currents or water flow, photosynthetic activity, and turbulence. DO is crucial for fish productivity. DO is crucial for respiration, as it acts as the limiting factor for the majority of aquatic species. The DO concentration is a critical measure for assessing the quality of habitat and the overall health of aquatic ecosystems (Franklin 2014). DO in the upstream Citarum oxbow varies from 0.4-7.24 mg L^{-1} in September and 0.44-9.55 mg L^{-1} in October, as shown in Table 5. According to Ismail et al (2023), the solubility of oxygen is reduced as the water temperature increases. The research findings at the Sinau oxbow in Kapuas Hulu indicate a high level of oxygen, specifically ranging from 6.20–7.80 mg L^{-1} (Junardi et al 2019).

According to the Republic of Indonesia Presidential Regulation No. 22 of 2021, the dissolved oxygen (DO) content in Cikukang oxbow is below the water quality requirement and is very low, measuring less than 1 mg L^{-1}. This condition is referred to as an anoxic state and is indicated by the presence of dark green watercolor, as shown in Table 4. Cikukang has elevated TDS, resulting in elevated Biochemical Oxygen Demand (BOD) levels and reduced oxygen levels (Ismail et al 2023). The low DO is believed to be a result of pollution, specifically observed in various oxbows in Malaysia (Jawan & Sumin 2012). The DO is crucial in the oxidation and reduction of both organic and inorganic substances. It also governs the biological activity performed by aerobic or anaerobic organisms. Under aerobic conditions, the process of reducing chemical compounds into simpler forms of nutrients and gases is facilitated by the production of oxygen. Conversely, under aerobic conditions, oxygen will undergo oxidation of both organic and inorganic substances, resulting in the production of nutrients that can ultimately enhance water fertility. Water quality improves when the DO content increases (Elvince & Kembarawati 2021). The solubility of oxygen in water is influenced by variations in temperature and altitude. According to Junardi et al (2019), there is a negative correlation between the altitude and the solubility of oxygen.

Carbon dioxide (CO_2). The presence of carbon dioxide in water is mostly attributed to air diffusion, precipitation, breakdown of organic matter, and respiration of aquatic organisms. Elevated levels of CO_2 can have detrimental effects on aquatic organisms and can also cause corrosion (Irianto & Triweko 2019). The presence of an excessive amount of CO_2 in the water will impact the respiration process and impede the binding of oxygen, whereas the absence of CO_2 will impair the process of photosynthesis (Idrus 2018). In September, the concentration of CO_2 in the upstream Citarum oxbows ranged from 0-3.3 mg L^{-1}, while in October it ranged from 0-5.36 mg L^{-1} (Table 5), and the highest level was recorded in the Dara Ulin oxbow in September. The maximum allowable concentration of free CO_2 should not surpass 20 mg L^{-1} (Svobodova et al 1993). The rise in CO_2 levels is directly linked to the escalation of pollution (Halim et al 2018). One effective method to mitigate CO_2 is through the implementation of an aeration system for water treatment.

Nitrogen. Nitrogen is crucial for water, however, excessive amounts can lead to water issues. An overabundance of nitrogen can overstimulate the growth of algae and aquatic plants, leading to excessive blooming. Nitrate and nitrite are nitrogen compounds that serve as indicators of water fertility and health. Nitrogen-nitrite concentration in the upstream Citarum oxbows varied between 0.007–0.349 mg L^{-1} in September and between 0.059-0.597 mg L^{-1} in October, as shown in Table 5. The presence of elevated nitrite levels in the oxbows is believed to be a result of organic pollution, perhaps stemming from the proximity of densely populated residential areas. Nitrites are considered poisonous to a variety of fish and prawns when their concentration reaches 2 mg L^{-1} or more, as stated by Halim et al (2018).

In September, the nitrate contents varied between 0.077-0.390 mg L^{-1}, while in October they ranged from 0.317-0.951 mg L^{-1} (Table 5). Typically, nitrate levels are lower in September (a transitional time) compared to October, which is consistent with the observations in the Potorono reservoir (Lutfiana 2022), According to the Food and Drug Administration (FDA) and Environmental Protection Agency (EPA), the highest allowable levels for nitrite and nitrate concentrations are 1 and 10 mg L^{-1} respectively. Nitrite is highly hazardous to vertebrates, including fish. One of its main effects is the conversion of hemoglobin into brown-colored methemoglobin, which loses its ability to carry oxygen (Eddy & Williams 1987). Nitrate is a significant parameter due to its association with the "blue baby" syndrome and the creation of cancer-causing chemicals (Cullum et al 2010).

Total phosphorus (Total P). Phosphorus is an essential plant nutrient for plants and primarily regulates the growth of aquatic plants (such as algae and macrophytes) in freshwater environments. The phosphorus concentrations in the Upstream Citarum River oxbows varied between 0.604-2.887 mg L^{-1} in September and between 0.182-2.170 mg L^{-1} in October (Table 5). The highest concentration was found in the Dara Ulin oxbow, followed by the Cikukang oxbow. According to the Republic of Indonesia Presidential Regulation No. 22 of 2021, all four oxbows have been classified as having water quality of class 4, with a concentration of more than 0.1 mg L^{-1}. According to Halim et al (2018), concentrations of total P exceeding 0.03 mg L^{-1} can lead to the occurrence of algal blooms in oxbows and reservoirs. The elevated phosphorus levels in the majority of the Citarum oxbows are believed to be a result of their proximity to densely populated residential areas, leading to contamination from domestic waste. Phosphorus is found in natural bodies of water in the form of inorganic orthophosphates ($PO4^{3-}$), polyphosphates, and biologically bound phosphorus. Orthophosphate and polyphosphate forms typically originate from sources such as fertilizers, detergents, chemicals, and trash. Organic phosphate is derived from the breakdown of plants and animals, as well as from livestock waste and chemicals for agriculture (Babošová et al 2021). The phosphorus concentration in water is affected by the water's morphology, which includes factors such as area, depth, and flushing rate (Dillon & Rigler 1974). Phosphorus transfer from the sediment to the water column only happens when there is a lack of oxygen, and it is limited to a depth of less than 20 cm below the water's surface (Søndergaard et al 2003). Phosphorus concentrations in water below 0.025 mg L^{-1} indicate unpolluted waters, whereas concentrations above 0.5 mg L^{-1} are a result of human activity. Phosphorus levels exceeding 0.1 mg L^{-1} lead to fast growth of algae and aquatic plants. Elevated levels of phosphorus are indicative of pollution that leads to eutrophication (Babošová et al 2021).

Total organic matter. Organic debris undergoes decomposition, resulting in the production of vital components for phytoplankton and aquatic plants, including nitrogen, phosphorous, potassium, calcium, and various other elements. The breakdown of organic matter is influenced by the presence of oxygen, the chemical makeup of the organic matter, and the decomposition rate of organic matter (Dauve et al 2001). Oxbow lakes serve a collect biogenic components and organic chemicals carried by water. Organic substances are separated from the water cycle in ecosystems and permanently deposited in the sediment at the bottom (Koc et al 2009). The four oxbows of the upstream Citarum River are situated in a residential neighborhood. As a result, the river is highly susceptible to the effects of domestic waste, which is evident from the significant presence of organic materials. Total organic matter concentrations varied between 10.74-146.94 mg L^{-1} in September and between 14.42-104.81 mg L^{-1} in October (Table 5). The highest value was seen at the Cikukang oxbow, indicating the presence of organic pollution. This is further evidenced by low levels of dissolved oxygen, high concentrations of total phosphorus, chlorophyll *a*, and the presence of dark green water

Chlorophyll-a. Chlorophyll-*a* is used to measure the quantity of suspended algae and the level of eutrophication in bodies of water. Elevated water temperatures and extended periods of daylight facilitate the proliferation of algae. The content of chlorophyll-a can be used to assess the level of eutrophication (Ismail et al 2023). The amount of planktonic (suspended) algae in a lake is estimated using chlorophyll-*a* concentration (Chowdhury et al 2016). The chlorophyll-*a* can be utilized as an indicator to assess water productivity (Astuti et al 2022; Zhang et al 2017). In September, the chlorophyll-a concentration varies between 11.5-527.21 mg m^{-3} and in October it ranges from 18.13-31.78 mg m^{-3} (Table 5). Higher chlorophyll-a levels determined high turbidity and a deep green color at the Cikukang oxbow. The elevated levels of chlorophyll-*a* suggest that the water has undergone eutrophication. The concentration of chlorophyll-a in the upstream Citarum river oxbow was high.

Based on the Republic of Indonesia Presidential Regulation No. 22 of 2021, the water quality classification in the four upstream Citarum River oxbows ranges from class 2 to 4 class. Dara Ulin, Bojongsoang, and Cieunteung oxbow are enrolled in class 2 during the month of October and class 3 during the month of September. The three oxbows can serve as venues for recreational activities, fishing, animal husbandry, and crop irrigation. However, the Cikukang oxbow is now classified as a class 4 water body, indicating the need for water quality enhancement to make it suitable for diverse applications. Out of the four oxbows, none of them satisfied the requirements for being classified as class 1 drinking water. Based on the standard, which uses the CPI, with a class 3 the four oxbows in the upstream of Citarum River are polluted.

Water eutrophication has emerged as a significant global issue. Eutrophication is defined as the occurrence of elevated levels of nitrogen (N), phosphorus (P), and other inorganic nutrients in enclosed and slow-moving bodies of water, such as lakes, reservoirs, rivers, and freshwater wetlands. This leads to the proliferation of abundant phytoplankton. This leads to a drop in dissolved oxygen (DO), an increase in chlorophyll-*a* (Chl-a) concentration, and a decline in water quality (Zhang et al 2017; Hasan et al 2000). The assessment results, as shown in Table 4, indicate that all oxbows in the upstream Citarum River have experienced eutrophication and are currently at eutrophic levels, as indicated in Table 7. The Jatiluhur Reservoir has undergone eutrophication, reaching the eutrophic-hypertrophic stage. The Jatiluhur Reservoir serves as a storage facility for the Citarum River Cascade (Astuti et al 2022). Intervention is necessary to mitigate and regulate the extent of eutrophication.

Alternative fisheries management. To maximize the utilization of oxbows for both conservation purposes and productivity, stocking can be implemented. Restocking the Citarum River with native fish can be achieved by utilizing it as a reserve. The upstream Citarum River is home to a total of 17 indigenous fish species. Some economically significant fish species include the three spot gourami (*Trichopodus trichopterus* Pallas, 1770), Asian redtail catfish (*Hemibagrus nemurus* Valenciennes, 1840), bonylip barb (*Osteochillus hasselti* Valenciennes, 1840), semah mahseer (*Tor douronensis* Valenciennes, 1840), lalawak (*Puntius bramoides* Valenciennes, 1840), silver barb (*Barbonymus gonionotus* Bleeker, 1849), jambal (*Pangasius djambal* Bleeker, 1846) and Hampala barb (*Hampala macrolepidota* Kuhl & Van Hasselt, 1823) (Kartamihardja 2019). The Bojongsoang oxbow stocks the maximum quantity of seeds due to their elevated chlorophyll-a content. Chlorophyll-a is a measure of phytoplankton abundance, which serves as the primary food source for fish.

In addition to replenishing the population of indigenous fish, stocking can also be implemented to enhance fish productivity in the oxbow. A method to enhance fish output by engaging local people can be implemented through a CBF system, specifically, culture-based fisheries (CBF), which involves the regular stocking of fish seeds to augment fish harvest (Lorenzen 1995). The fish that are supplied should be species that are capable of efficiently utilizing the available feed resources and have low trophic levels. Fish that can consume phytoplankton, zooplankton, and detritus are more desirable than fish that are carnivorous or predatory (Cowx 1994). The economically significant indigenous fish species in the upper reaches of the Citarum River, which mostly consume plankton, include the three spot gourami (Muliah et al 2020), bonylip barb (Iskandar et al 2020), semah mahseer (Firman et al 2020), and silver barb (Muliah et al 2020). The stocking of introduced fish can be tailored to the tastes of the local community. Aquaculture-based fisheries (CBF) in Bangladesh utilize oxbows for fishing activities. This approach involves three primary actions: stocking seeds, harvesting, and frequent removal of water hyacinth (Hasan et al 2001; Boyd 1990). Management of fisheries oxbow lakes can be defined as the management of stock, the management of species, the management of fishing efforts, and the provision of organizational or infrastructure support. CBF procedures in oxbows rely solely on stocking and do not involve any energy input or feeding. Therefore, the productivity of the natural environment plays a crucial role in fish production (Hasan et al 2000). The CBF model allows for fisheries activities in oxbows by utilizing natural food sources such as plankton, without the need for additional commercial feed. This is determined based on water quality conditions and eutrophication levels. The abundance of plankton is indicated by the elevated chlorophyll concentration. When fish are harvested during CBF activities, they can be utilized for fishing tourism. Bojongsoang oxbow is an ideal spot for fishing due to its convenient accessibility and pristine nature (Firmansyah et al 2019).

Conclusions. Water quality of Dara Ulin, Bojongsoang, and Cieunteung oxbows is in 2nd class in October and 3rd class in September. Cikukang exhibits oxygen values below 1 mg L^{-1} indicating anoxic conditions. It also has elevated levels of total phosphorus, resulting in a dark green watercolor. Out of the four investigated oxbows, none fulfilled the requirements for class 1 drinking water. The locations with the highest levels of phosphorus contamination were Dara Ulin, followed by Cikukang and Cieunteung oxbows, with concentrations exceeding 1 mg L^{-1}. High levels of chlorophyll-a in all oxbows are indicative of eutrophication. The four oxbows located upstream of the Citarum River are at an eutrophic level. According to the CPI, these oxbows are considered to be polluted. The oxbows located upstream of the Citarum River can serve for fisheries activities, specifically as a reserve for indigenous fish species and fish production. Population growth can be achieved through the replenishment of indigenous fish or the introduction of non-native fish. The stocked fish predominantly consist of planktivorous species, which allows them to use the abundant plankton resources in their natural diet. The quantity of fish introduced into Dara Ulin, Bojongsoang, Cieunteung, and Cikukang are 692, 1256, 976, and 1.084 individuals every year, respectively.

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