JPII 12 (4) (2023) 611-624

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

PHYSICO-CHEMICAL AND BIOLOGICAL WATER QUALITY OF TUNTANG ESTUARY, DEMAK, CENTRAL JAVA, AS A BASE FOR SUSTAINABLE RIVER MANAGEMENT

Y. Danurrachman*[1,2], M. Maryono[1,3], F. Muhamad[1,4], T. R. Soeprobowati[1,2,4], P. van der Maas[5]

[1]Master Program of Environmental Science, School of Postgraduate Studies, Diponegoro University, Indonesia
[2]Cluster for Paleolimnology (CPalim), School of Postgraduate Studies, Diponegoro University, Indonesia
[3]Department of Urban Planning, Diponegoro University, Indonesia
[4]Department of Biology, Faculty of Science and Mathematics, Diponegoro University, Indonesia
[5]Van Hall Larenstein University of Applied Sciences, Netherlands

DOI: 10.15294/jpii.v12i4.48413

Accepted: November 11th, 2023. Approved: December 29th, 2023. Published: December 31st 2023

ABSTRACT

The estuary, downstream of the river, accumulates pollutants from upstream and marine. Tuntang is one of the major rivers in Central Java, 139 km length from Rawapening Lake, and ends in the Java Sea. Mangroves are the dominant riparian vegetation in the downstream and estuary of the Tuntang River. This research analyzes the water quality and pollution index (PI) of Tuntang Estuary, Demak. Water samples were collected from four sites in February (wet season) and September 2022 (dry season) and were analyzed for temperature, TDS, pH, BOD, COD, DO, nitrate, nitrite, ammonia, TN, TP, Cd, Cu, Pb, Cr, fecal coliform, and total coliform. The water quality parameters of Tuntang Estuary in the dry season exceeded the threshold for Class I-III, such as TDS in T1 ((2530 mgL^{-1}), BOD (4.06-5.12 mgL^{-1}), COD (28.32-102 mgL^{-1}), DO for Class I and II (3.93-4.28 mgL^{-1}), Pb at T1 and T3 in the wet season, and T1 in the dry season, and Cr for Class I, II, and III (>. 0.05 mgL^{-1}), Pb (T1), and Cr for Class I, II, and III (>. 0.05 mgL^{-1}). In contrast, in the wet season, BOD (4.37-7.15 mgL^{-1}), Pb (T1 and T3), fecal coli, and coliform exceeded the threshold. The TN (0.83-2.48 mgL^{-1}) and TP in the wet season (0.45-0.53 mgL^{-1} at T1 and T1) indicated that Tuntang Estuary was in the eutrophic condition. Based on the PI method, the water quality of Tuntang Estuary is good to slightly polluted for Class I, II, and III. The sustainable river management that is appropriate to be developed for the Tuntang River is conserving the mangrove ecosystem in the Tuntang Estuary.

Keywords: physical-chemical biological parameter; pollution index; Tuntang Estuary, water quality

INTRODUCTION

Rivers are natural resources that play an important role in providing the availability of water on the land, as indicated in the Sustainable Development Goals (SDGs) number 15, and in maintaining clean water and sanitation (SDGs number 6). However, surface water quality is a sensitive and crucial issue in many nations, and it continues to be a big concern globally, driven by both natural and anthropogenic processes (Sener et al., 2017; Zhou et al., 2022). Water pollution can be caused by industrial, agricultural, geological, and residential activities (Helard et al., 2021).

Essential information on water quality that is influenced by precipitation, evaporation, and the quantity of natural material carried by river water bodies can be found in the physicochemical

***Correspondence Address**
E-mail: yogiswara.dr@gmail.com

characteristics of the rivers (Qu et al., 2018). River downstream to the estuary accumulates material from the upstream and catchment area around the downstream (Xu et al., 2021). The relationship between the upstream and downstream rivers is very complex between natural and anthropogenic activities (Baubekova et al., 2023).

Due to the influence of chemical elements like salinity, dissolved oxygen, pH, and nutrient content, as well as physical factors like temperature, turbidity, light, and current arising from the confluence of freshwater rivers with the ocean, the estuary is vulnerable (Liu et al., 2021). Both ecological and economic functions in the estuary are vital to the community (Booi et al., 2022). Numerous migratory birds use the estuary as a habitat (Canhan et al., 2021). Large volumes of sewage and industrial effluents have been dumped into it, as shown in the Estuary of Oued Souss, Morocco (Bergayou et al., 2019). A modification of the cross-sectional profile may result in an estuary that is dominated by ebbs instead of floods (Liang et al., 2019). In addition, hydrodynamic factors such as wind, tides, freshwater input, morphology, and geometry may influence water quality (Zarzuelo et al., 2023). An increase in population and industrialization in urban areas have impacted land-use change and water pollution (Tanaka et al., 2021), specifically in South East Asian, such as Malaysia (Zaki et al., 2021) and Vietnam (Pham et al., 2021), and India (Singh et al., 2021), Japan (Chao et al., 2020), China (Cai et al., 2021), and Australia (Birch et al., 2015). Those mangrove functions and problems occurred in Tuntang, as reported by Irsadi et al. (2019, 2020). The mangrove ecosystem is healthy growth in Tuntang Estuary that might contributed to the water quality stated. Therefore, monitoring water quality is a suitable approach to test it.

River management relies heavily on water quality monitoring (Susanti et al., 2020). To properly interpret the results of the water quality monitoring procedure, it is necessary to identify the sampling locations and analyze the water's features (Alilou et al., 2019). According to Komala et al. (2023) and Musliu et al. (2018), the physicochemical parameters are crucial for preserving the restoration system and controlling the water quality. The most commonly utilized water quality parameters are the physicochemical and biological factors (Soeprobowati et al., 2021).

Tuntang is one of the major rivers in Central Java; the upstream area is in Semarang Regency, the middle area is in Salatiga and Grobogan Regency, and the downstream region is in Demak Regency, which empties into the Java Sea. The channel of the Tuntang River is narrowing, and silting reduces the cross-sectional capacity of the river, which, in turn, drains flood discharge (Hadiwijaya et al., 2022).

The main problems of the Tuntang River are water quantity and water quality. Flooding in the Tuntang River occurs due to the postal floods flowing upstream (Rawapening Lake) or seawater inundation. These conditions influence the water quality in Tuntang Estuary. The downstream of Tuntang River Demak has been used for agriculture, forestry, fish ponds, fisheries, and household waste. The river flow in the mouth of Tuntang River inhibits the current speed of the southwestward longshore so that the rate of the longshore wind on the western side of the river mouth is weaker than on the eastern side. Therefore, the longshore wind in the Tuntang Estuary affects the coastal morphology (Wirasatriya et al., 2017). This current research differs from previous research focusing on the eutrophication in Rawapepning Lake, whose lot is to the Tuntang River (Soeprobowati et al., 2012; Piranti et al., 2018), or spatial distribution of Pb, Cd, and coliform in Demak (Tjahyono & Suwarno, 2018). The water quality status of the upstream Tuntang River has been studied (Saputro & Siwiendrayanti, 2023). Diatoms have been used to reconstruct flood records in the lower Tuntang River (Al Falah et al., 2023a) and to determine water quality in the Tuntang Estuary (Al Falah et al., 2023b). Therefore, this research focuses on the Tuntang River estuary spacious-temporally. Downstream river accumulates the upstream activities and processes (Xu et al., 2021).

Due to the urban development of Tuntang downstream and estuary, this research aims to determine the water quality status based on the physicochemical and biological parameters and combine it with the pollution index (PI) of Tuntang Estuary, Demak. The pollution upstream of the Tuntang River may be accumulated in the estuary. This research also verifies that an established mangrove ecosystem in the Tuntang estuary may filter and purify water. The PI method helps provide information about water quality in a single index value as a pollution indicator against the standard (Syeed et al., 2023).

METHODS

The 139-kilometer-long Tuntang River drains into Rawapening Lake. The watershed of the Tuntang River spans a total of 1038.90 km2. This fieldwork was carried out at the Tuntang Estuary Demak in Central Java in the wet season of February 2022 and the dry season of September 2022. Purposive random sampling was used to identify four research locations with varying features that reflect activities occurring downstream of the Tuntang River (Figure 1).

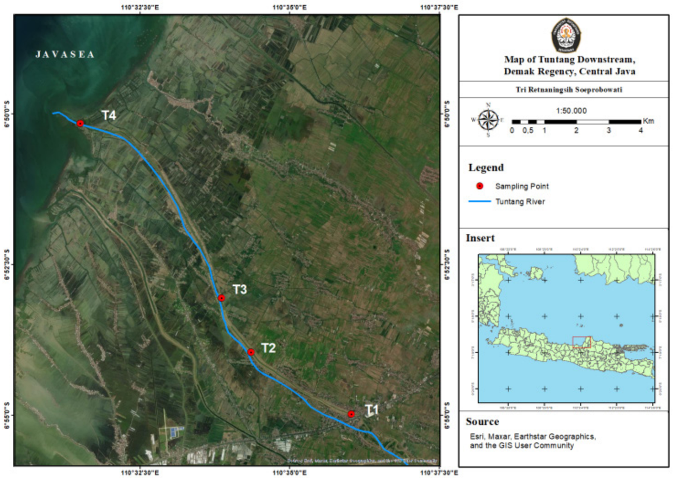

Figure 1. Four Research Sites Downstream of Tuntang River, Demak Regency, Central Java

Site 1 (T1) is near the highway to Demak, Site 2 (T2) is next to the embankment for housing, Site 3 (T3) is an inlet from an agricultural area, and Site 4 (T4) is a mangrove ecosystem in the estuary (Figure 2).

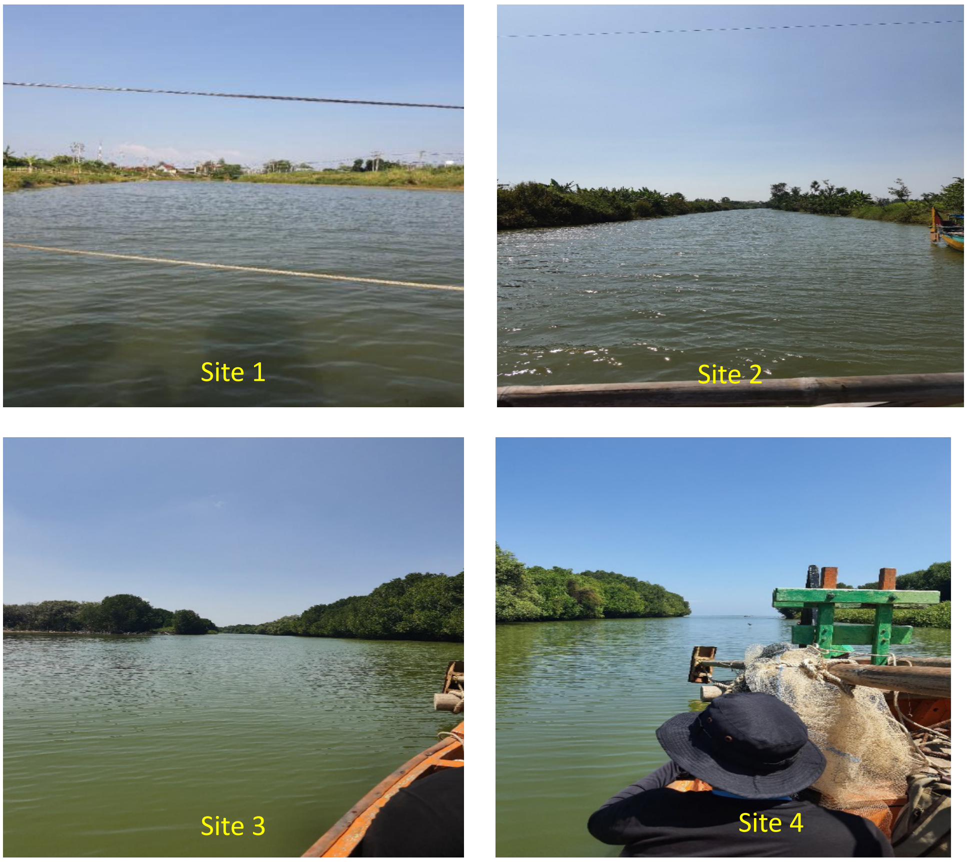

Figure 2. The Condition of Site 1-4 Downstream of Tuntang River, Demak Regency, Central Java. T1 is near the main road to Demak, T2 is next to the embankment for housing, T3 is inlet from an agricultural area, and T4 is a mangrove ecosystem in the estuary (September 2022)

In-situ measurement of water quality using water checker Horiba U50 for temperature, pH, total dissolved solids (TDS), and dissolved oxygen (DO) was measured using a DO meter (Table 1). Each research location collects water samples following the Indonesian National Standard (SNI 6989.57, 2008) for surface water sampling. Using a van Dorn water tester, the water samples were taken from the surface (20 cm), filled with one-liter clean plastic bottles, labeled, and placed inside a refrigerator. The Environmental Laboratory of Diponegoro University received these samples. Table 1 lists a few of the examined parameters.

Table 1. Methods for Determining Water Quality

Parameter	unit	Method
Temperature	°C	water checker Horiba U 50
pH	-	water checker Horiba U 50
TDS	mg L^{-1}	water checker Horiba U 50
DO	mg L^{-1}	DO meter
COD	mg L^{-1}	SNI 6989.2: 2009
BOD	mg L^{-1}	SNI 6989.72: 2009
Nitrate	mg L^{-1}	APHA 4500.NO3 B: 2017
Nitrite	mg L^{-1}	APHA 4500.NO2 B: 2018
Ammonia	mg L^{-1}	SNI 06 6989.30 : 2005
TN	mg L^{-1}	APHA 4500.NO2 B : 2018 wet destruction – indofenol
Tota phosphate	mg L^{-1}	APHA 4500. P-D: 2017
Pb	mg L^{-1}	SNI 6989.08: 2009
Cr	mg L^{-1}	SNI 6989.17: 2010
Cd	mg L^{-1}	SNI 6989.16: 2011
Cu	mg L^{-1}	SNI 6989.06: 2012
fecal coli	MPN/100mL	3M Petrifilm
total coliform	MPN/100mL	4M Petrifilm

Water samples collected from the fieldwork were then analyzed for chemical oxygen demand (COD), biological oxygen demand (BOD), nitrate, nitrite, ammonia, total nitrogen, total phosphate (as P), lead (Pb), Chromium (Cr), Cadmium (Cd), Cooper (Ci), fecal coli, and total coliform following the methods provided in Table 1.

Following Appendix VI of Government Regulation Number 22 of 2021 about the implementation of environmental protection and management for the rivers, the results of the physical and chemical parameter values of the obtained water were compared with the water quality standards for Class I, Class II, Class III, and Class IV for each parameter. Class I water is meant for drinking, raw water sources, and other uses that need the same water quality as the use; Class II water is meant for infrastructure and facilities related to water recreation, freshwater fish farming, animal husbandry, crop irrigation, and other uses that need the same water quality as the use stated; Class III water is designed for freshwater fish farming, animal husbandry, and other uses that require the same water quality as the use; and Class IV water is meant for irrigating crops and/or other uses that require the same water quality as the use (Table 2).

Table 2. River Water Quality Standards for Four Classes Used (Government Regulation Number 22 of 2021)

Parameter	Unit	Class			
		I	II	III	IV
Temperature	°C	Dev 3	Dev 3	Dev 3	Dev 5
TDS	mg L^{-1}	1000	1000	1000	2000
pH	mg L^{-1}	6-9	6-9	6-9	6-9
BOD	mg L^{-1}	2	3	6	12

COD	mg L^{-1}	10	25	40	80
DO	mg L^{-1}	6	4	3	1
Nitrate	mg L^{-1}	10	10	20	20
Nitrite	mg L^{-1}	0.06	0.06	0.06	-
Ammonia	mg L^{-1}	0.1	0.2	0.5	-
TN	mg L^{-1}	15	15	25	-
TP	mg L^{-1}	0.2	0,2	1	-
Cd	mg L^{-1}	0,01	0,01	0,01	0,01
Cu	mg L^{-1}	0,02	0,02	0,02	0,02
Pb	mg L^{-1}	0,03	0,03	0,03	0,5
Cr-IV	mg L^{-1}	0,05	0,05	0,05	1
Fecal coliform	MPN/ 100 ml	100	1000	2000	2000
Total coliform	MPN/ 100 ml	1.000	5.000	10.000	10.000

Determining the water quality state of the Tuntang River employed the Pollution Index (PI) approach, which corresponds to the Decree of the Indonesian Minister of Environment Number. 115/2003 about Guidelines for Determining Water Quality state. Water quality status was performed based on the recent data from this research (data on February 2022 and September 2022) combined with previous data from 2021 collected from Hera (2021), data from 2020 was collected from Suwarno et al. (2020), data from 2019 was collected from BPS (2022), the data from 2017 was collected from Tjahyono and Suwarno (2018). The Pollution Index (PI) value was determined with the formula (the Decree of the Indonesian Minister of Environment Number 115/2003 about Guidelines for Determining Water Quality Status) below:

$$PIj = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)^2 M + \left(\frac{Ci}{Lij}\right)^2 R}{2}}$$

Where:
PI_j: Pollution Index for designation (j)
C_i: Concentration of water quality parameters (i)
L_{ij}: Concentration of water quality parameters stated in the quality standard for water use (j)
(C_i/L_{ij})M: maximum value C_i/L_{ij}
(C_i/L_{ij})R: average value $C_{i/}L_{ij}$

The determination of water -quality status is based on the criteria in Table 3.

Table 3. Water Quality Status Classification based on Pollution Index **(**Minister Environment of Indonesian Decree Number 115/2003)

Score	**Criteria of Water Quality**
$0.0 \leq PIj \leq 1.0$	Good water quality
$1.0 \leq PIj \leq 5.0$	Lightly polluted
$5.0 \leq PIj \leq 10$	Polluted
PPIj > 10	Extremely polluted

RESULTS AND DISCUSSION

The water temperature of the Tuntang Estuary in the wet and dry seasons did not significantly differ, ranging from 28.5°C to 29.5°C in February 2022 and 31.05-31.47°C in September 2022 (Figure 3). The higher water temperature in September 2022 is due to hot weather and high sun radiation. The Tuntang Estuary's average water temperature still passes the criteria for water quality standards based on Government Regulation Number 22 of 2021 for classes I, II, III, and IV, with a 3°C divergence from the natural conditions of the surrounding environment. Seasons influence the temperature of water bodies, as do river size, flow, water speed, river forms, bed dimensions, and human activity near the river (Bonacci et al., 2021). Water chemical processes in the river increase as the temperature rises; hence, temperature affects the rate of photosynthesis, metabolism, and pollutant interaction (Marlina & Melyta, 2019).

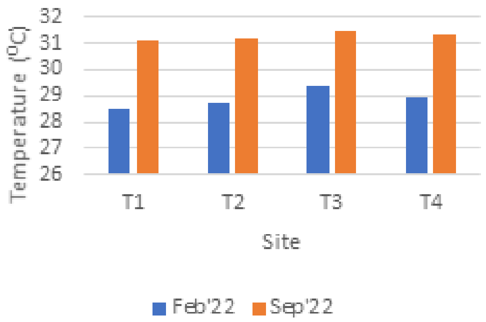

Figure 3. The Water Temperature of Tuntang Estuary, Demak Regency, Central Java

In February 2022 (wet season), the dissolved oxygen (DO) in research sites was above 7 mg L^{-1}, below the threshold water quality for the river for all classes (Government Regulation No 22 the Year 2021), but in September 2022 (dry season) above the threshold for Class I (sources for drinking water) and Class II (recreation infrastructure/facilities) (Figure 4). The water temperature influences the DO concentration, an increased temperature, decreased oxygen content, and the wind. The greater the wind speed, the higher the DO concentration (Marlina & Melyta, 2019). DO has been used to indicate water health (Hammond, 2009).

The concentration of BOD (Biological Oxygen Demand) in the wet season at all sites is more significant than in the dry season, exceeding the threshold for Class I and Class II water quality criteria. The BOD ranged from 4.37 to 7.15 mg L^{-1} in February 2022 and 4.06 to 5.12 mg L^{-1} in September 2022. T1 has the lowest concentration, while T4 has the highest concentration (Figure 5). T2 and T4 in February 2022 exceeded the water criteria for Class III, which is a maximum of 6 mg L^{-1}.

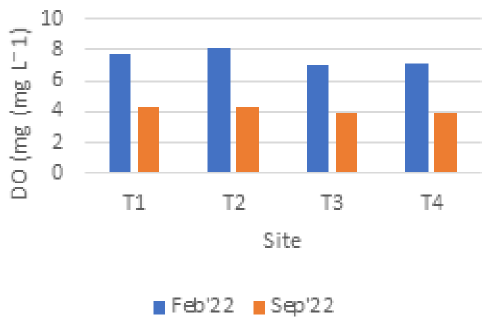

Figure 4. The Dissolved Oxygen (DO) of Tuntang Estuary, Demak Regency, Central Java

According to Government Regulation Number 22 of 2021, the BOD value of the Tuntang Estuary is higher than the permitted limits of 2, 3, and 6 mg/L for Class I, II, and III, which represent the quality requirements. However, it still falls below the 12 mg L-1 Class IV water quality threshold. Demak water below the Tuntang River is inappropriate for use as drinking water, recreational purposes, or aquaculture; nevertheless, agricultural uses are still permitted. According to Anniy et al. (2017), BOD measurements show contamination by organic matter, which is typically from industrial, agricultural, and natural sources. As a result, BOD increases the river downstream and correlates it with temperature.

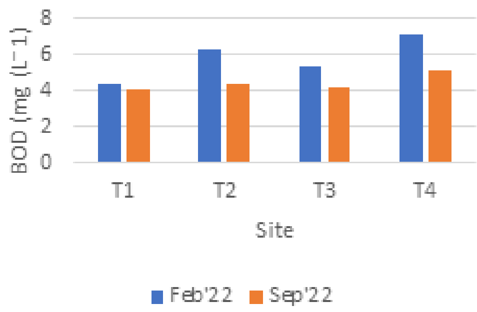

Figure 5. The BOD of Tuntang Estuary, Demak Regency, Central Java

The high concentration of COD (Chemical Oxygen Demand) relates to the increase in BOD. According to Government Regulation Number 22 of 2021, the COD during the wet season has surpassed the limits of Class I, II, III, and IV river water quality standards. Figure 6 shows that the Tuntang Estuary's COD concentration exceeds 10 mg L-1, making it unsuitable for use as a source of drinking water (25 mg L-1), recreational activities (25 mg L-1), aquaculture (40 mg L-1), and agriculture (80 mg L-1). The high COD concentration is associated with organic compounds that are difficult for these waters to break down, maybe from residential, agricultural, and aquaculture activities (Rahutami et al., 2022). The majority of garbage is produced by households and industries (Wang et al., 2020). Additionally, the oxidation of inorganic substances like nitrites and ammonia can raise the COD value (Tabla-Hernandez et al., 2022). The COD and BOD levels in these waters increase with decreasing oxygen content. However, COD cannot accurately reflect the wastewater degree because its concentration relates to the oxidant's types, the catalyst, and the reaction solution acidity (Patel & Jariwala, 2023).

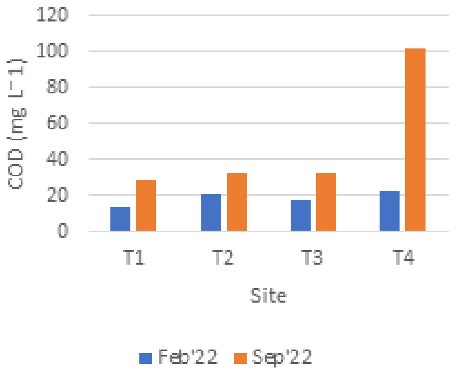

Figure 6. The COD of Tuntang Estuary, Demak Regency, Central Java

In both the wet and dry seasons, the Tuntang River's TDS (Total Dissolved Solids**)** fluctuated from 190 to 515 mg L-1. For both the wet and dry seasons, T4 has the highest concentration and is more turbid than other locations (Figure 7). There are two ways in which temperature can impact turbidity. One is how temperature affects the photoelectric elements in the turbidity sensor, such as the electrical components that emit and receive light (Hidayati et al., 2018). The other is how temperature affects how small particles move and are distributed in water (Rakotondrabe et al., 2018).

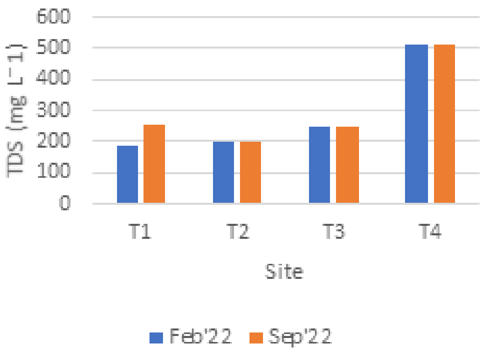

Figure 7. The TDS of Tuntang Estuary, Demak Regency, Central Java

Tuntang Estuary has a pH range of 6.03 to 6.6 (Figure 8). This pH value, which should be between 6 and 9, is still within the range of water quality criteria for Classes I, II, III, and IV (Government Regulation Number 22/2021). Since hydrogen ions are acidic, the pH of water indicates the existence of hydrogen ions in the solution. All four research sites had generally caustic water pH levels (Figure 5b). This pH is related to the limestone present in the riverbed and could also be related to runoff from agriculture. The distribution of seasons and day-night cycles might impact the acidity of water by affecting the temperature of the water (Romanescu et al., 2016).

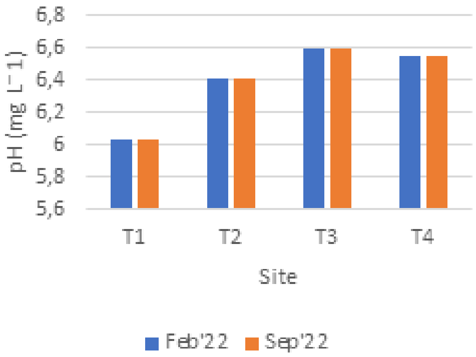

Figure 8. The pH of Tuntang Estuary, Demak Regency, Central Java

The nitrite, ammonia, and total nitrogen (TN) concentrations are still within the Class I, II, III, and IV water quality standards (Government Regulation Number 22 of 2021, concerning the implementation of environmental protection and management). Although they are greater in the wet season than in the dry (Figure 9), the nitrate (NO3-N) concentrations at Tuntang Estuary remain below the Government Regulation Number 22 of 2021 threshold for Class I, II, III, and IV. T2 has the highest nitrate concentration.

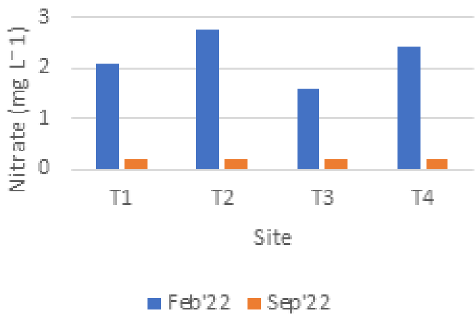

Figure 9. The Nitrate of Tuntang Estuary, Demak Regency, Central Java

The nitrite (NO_2-N) concentration is 0.01 mgL^{-1} in the wet season and 0.02 mgL^{-1} in the dry season (Figure 10). The use of manure and inorganic fertilizer in agriculture is related to the nitrate concentration (Wang et al., 2019). Neural tube abnormalities, thyroid disorders, colorectal cancer, and methemoglobinemia are all brought on by drinking water containing excessive nitrate levels (Ewaid & Abed, 2017; Ward et al., 2018).

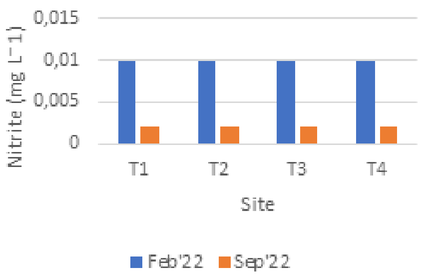

Figure 10. The Nitrite of Tuntang Estuary, Demak Regency, Central Java

The nitrite concentration must be below 1 mgL-1 for conventional drinking water treatment. The amounts of nitrite in natural waterways are inadequate. The unstable oxygen content and the ammonia-to-nitrate transition phase are the causes of the low nitrite concentration. If the water's pH is low, nitrite toxicity rises (Shishaye, 2017). The organic materials in the sediment break down to produce ammonia, which oxidizes to produce nitrate (Patty, 2014) (Figure 11).

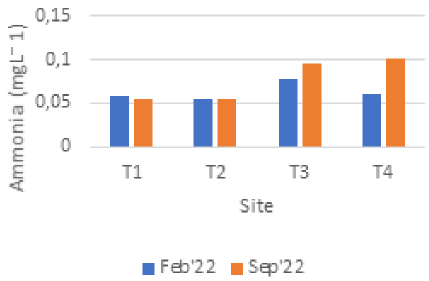

Figure 11. The Ammonia of Tuntang Estuary, Demak Regency, Central Java

Tuntang Estuary in Demak flows through ammonia-rich residential, agricultural, and industrial sectors. Elevated ammonia levels lower the oxygen content, which affects aquatic biota's metabolic and physiological functions (Zhang et al., 2017). Based on the TN concentration, Tuntang Estuary is eutrophic, as TN concentrations are above 0.75 mgL^{-1} (MoE, 2009) (see Figure 12).

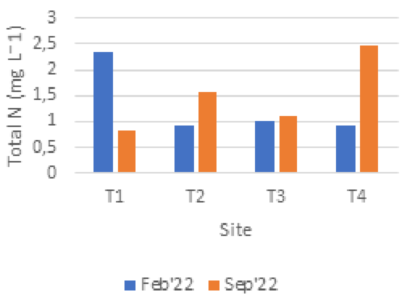

Figure 12. The Total Nitrogen of Tuntang Estuary, Demak Regency, Central Java

The phosphate concentration of Tuntang Estuary at all sites (Figure 13) is below the threshold for Class I (0.2), II (0.2), III (0.1), and IV (-) water quality standards (Government Regulation Number 22 of 2021, concerning the implementation of environmental protection and management). However, the TP concentration of Tuntang Estuary, particularly T1 and T2 in the wet season, is in the eutrophic condition; the concentrations are above 0.75 mg L^{-1} (MoE, 2009). The residual fertilizer in the environment increases the concentration of phosphates in rivers. A high phosphate concentration induces uncontrolled phytoplankton and aquatic plant growth (Tandjung et al., 2019). This is indicated by the color of the river water, which is green (Figure 2). High organic content increases water productivity and reduces dissolved oxygen (Bosman et al., 2021).

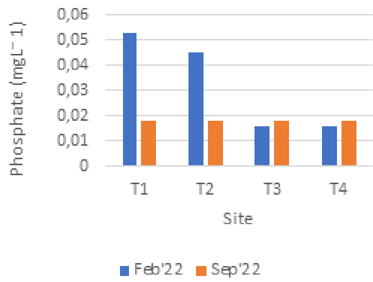

Figure 13. The Phosphate of Tuntang Estuary, Demak Regency, Central Java

The heavy metals analyzed in this research are lead (Pb), chromium (Cr), cadmium (Cd), and copper (Cu). The concentration of Cd and Cu are below 0.01 mg L^{-1}, whereas the concentrations of Pb at T1-T3 in the wet season and T1 in the dry season are above the water quality threshold for Class I, II, and III (0.03 mg L^{-1}, Figure 14).

Lead (Pb) pollution is reported in the Tuntang estuary by Tjahyono and Suwarno (2018). Lead is mostly utilized in the battery and cable manufacturing sector. Nonetheless, Pb is frequently included in engine fuel as an additive to raise the octane number (Tjahyono & Suwarno, 2018).

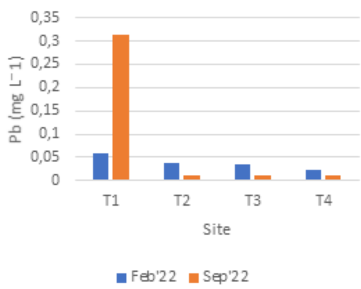

Figure 14. The Heavy Metal Pb in Tuntang Estuary, Demak Regency, Central Java

The concentration of Cr in February and September 2022 exceeded the water quality standard of 0.05 mg L^{-1} (Figure 15) for Class I, II, and III. Heavy metals are a group of pollutants that influence the ecosystem's health. Pb enters the food chain and is exposed to humans, which may induce the risk of various neurological diseases (Demaku & Bajraktari, 2019).

Naturally, heavy metals occur from geological processes and biological cycles. Heavy metal concentration varies greatly depending on the extent of exposure to the mineral (Rakotondrabe et al., 2018). However, heavy metals may originate from human activities (Seo et al., 2019).

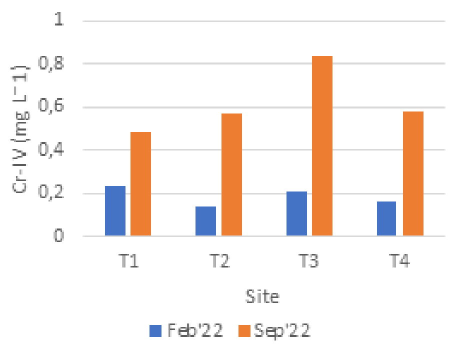

Figure 15. The Heavy Metal Cr in Tuntang Estuary, Demak Regency, Central Java

The concentration of fecal coli exceeded the criteria for Class I (source of drinking water), Class II (tourism), Class III (fisheries), and Class IV (agriculture), which is 100, 1000, 2000, and 2000 MPN/100 mL, respectively (Figure 16).

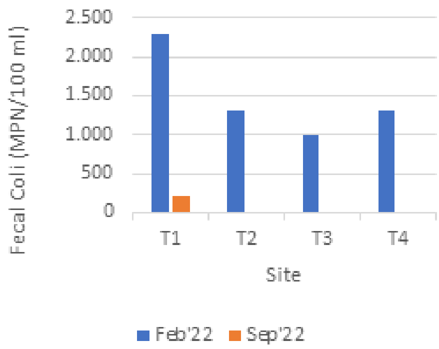

Figure 16. The Fecal coli in Tuntang Estuary, Demak Regency, Central Java

The concentration of total coliform is above the threshold water quality standards for Class I and II, which are 1000 and 5000 MPN/100 mL (Figure 17) (Government Regulation Number 22 of 2021, concerning the implementation of environmental protection and management). This indicates the contamination of bacteria or other pathogenic organisms from non-point sources from human and animal waste from domestic sewage. Based on the research in the Nakdong River in South Korea, total coliform is mainly affected by organic matter, and fecal coliform is primarily influenced by phosphate phosphorus and suspended solids. Rainfall is the most influential factor affecting both coliforms (Seo & Kim, 2019).

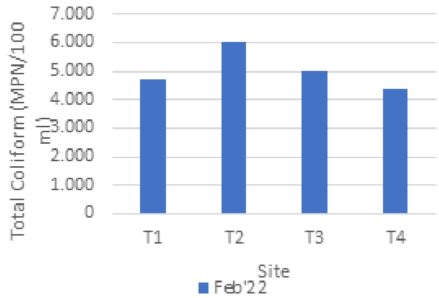

Figure 17. Total coliform in Tuntang Estuary, Demak Regency, Central Java

Based on the pollution index (PI), the water quality of Tuntang River in 2022 met the quality standard for slightly polluted (Table 2). This result is similar to research conducted by Tjahyono and Suwarno (2018), Suwarno et al. (2020), Hera (2021), and BPS (2022) that the Tuntang River is lightly polluted. The PI has a different concept from the STORET.

Table 2. Pollution index of Tuntang Estuary, Demak Regency

Year	Site	Water quality standard				Status of water quality
		I	II	III	IV	
2022	T1	3.52	3.55	3.54	0.46	good - slightly polluted
	T2	3.7	1.68	0.73	0.72	good - slightly polluted
	T3	2.20	1.47	0.75	0.72	good - slightly polluted
	T4	3.68	2.17	1.42	0.72	good - slightly polluted

PI is typically employed to quantify the amount of pollution to make the pollution levels in the drainage water system easier to grasp (Ruspita & Atika, 2022). PI is more representative to be implemented in Indonesia and has been used to determine water quality for Lampung Bay (Barokah et al., 2017), Warna and Pengilon Lakes, Central Java (Soeprobowati et al., 2021), and Kokok Putih River East Lombok Timur Fakhurrozi et al., 2022).

Because it synthesizes data from multiple factors into a single value, the PI aids in the status of water quality monitoring (Poonam et al., 2013). Regular monitoring is required to offer a more thorough water quality assessment for ecosystem health, and it should come after this initial fast assessment of water quality.

The pollution levels in Tuntang Estuary are influenced by garbage from industry, households, and agriculture. The mangrove ecosystem is seriously threatened by heavy metals, which are mostly found in industrial wastewater (Sun et al., 2022). Mangrove ecosystems have a high tolerance for heavy metals and serve as binding agents, pollution traps, and biofilters (Lufthansa et al., 2021). The downstream rivers can be improved by establishing forest cover to control erosion and sedimentation in the stream, arranging land use in the catchment area, and controlling pollution. T3 and T4 of this research (Figure 2c-d) mangrove ecosystems are well developed and may contribute to the natural water quality management. This result supports the hypothesis that mangrove ecosystems support water quality improvement.

Naturally, rivers can recover from the pollutants, called self-purification, a biological, chemical, and physical process that simultaneously works in the river (Sileshi et al., 2020). The purification process is related to the DO, the sources, and the use of oxygen in the river. Therefore, DO is the main parameter in water quality (Nugraha et al., 2020). The self-purification has been studied in the Bhavani River, India (Karthiga et al., 2017), wetland (Sileshi et al., 2020), Lituania (Šaulys et al., 2020), and Nigeria (Ogbuagu & Obele, 2021). In Indonesia, self-purification has also been studied in Banjarmasin (Zubaidah et al., 2019) and the Jajar River (Nugraha et al., 2020). The fluctuating water quality in Tuntang Estuary may be affected by many factors that work simultaneously, probably also self-purification. Further research about self-purification will improve the understanding of the river's mechanism.

CONCLUSION

In the Tuntang Estuary, a number of metrics have surpassed the river's water quality standard threshold, mostly for Class I (drinking water source), Class II (tourist), and Class III (aquaculture). These parameters include DO, BOD, COD, Pb, Cd, coliform, and total coliform. The water quality of the Tuntang Estuary is either good or slightly polluted, according to the pollution index. The Tuntang Estuary's eutrophic state is greatly impacted by anthropogenic activities (T1 and T2, Figure 13). Eutrophic conditions are indicated by the total phosphate content. The research is new in that it goes against the conventional method of measuring water quality, which involves comparing the standard value and the measured value of water parameter analysis using a water quality index such as PI. Management of nutrients, such as pound treatment before entering the river, could be developed to overcome the eutrophication problem in tropical rivers.

ACKNOWLEDGMENTS

This research was supported by Research for International Publication (RPI) from Diponegoro University with contract number 569-58/UN7.D2/PP/IV/2023. Thanks to Mirza Hanif Al Falah and Aulia Rahim for their help during fieldwork. World Class University Program supports part of this research through a staff exchange Program.

REFERENCES

Al Falah, M. H., Soeprobowati, T. R., Hadiyanto, H., Rahim, A., Noor, B. H., & Permatasari, N. (2023a). Diatom Stratigraphy as a Flood Record in the Lower Tuntang River, Demak, Central Java. Evergreen *10*(1), 272-282.

Al Falah, M. H., Soeprobowari, T. R, & Hadiyanto H. (2023). Epipelic diatom assemblages to determine water quality in the Tuntang River downstream, Demak, Central Java. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1137, No. 1, p. 012003). IOP Publishing.

Alilou, H., Nia, A. M., Saravi, M.M., Salajegheh, A., Han, D., & Enayat, B.B. (2019). A novel approach for selecting sampling points locations to river water quality monitoring in data-scarce regions. *Journal of Hydrology, 573*, 109-122.

Anny, F., Kabir, M., & Bodrud-Doza, M. (2017). Assessment of surface water pollution in urban and industrial areas of Savar Upazila, Bangladesh. *Pollution*, *3*(2), 243-259.

APHA 4500. P-D. (2017). Standard Methods for the. Examination of Water and Wastewater for phosphate ion.

APHA 4500.NO_3 B. (2017). Ultraviolet (UV) technique (Method *B*) that measures the absorbance of NO_3 at 220 nm

APHA 4500.NO_2 B .(2018). The colorimetric method is suitable for determining concentrations of 5 to 1000 ug NO_2

APHA 4500-NO2-B. (2018). Wet destruction for total nitrogen analysis

Baubekova, A., Akbari, M., Etemadi, H., Ashraf, F., Hekmatzadeh, A., & Haghighi, A.T. (2023). Causes & effects of upstream-downstream flow regime alteration over Catchment-Estuary-Coastal systems. *Science of The Total Environment, 85*8(3), 160045.

Barokah, G. R., Ariyani, F., & Siregar, T.H. (2017). Comparison of STORET and pollution index method to assess the environmental pollution status: a case study from Lampung Bay, Indonesia. *Squalen Bulletin of Marine and Fisheries Post Harvest and Biotechnology, 12*(2), 67-74.

Bergayou, H., Annajar, E. M, Lefrere, L., Moukrim, A., & Gillet P. (2019). Recovery of an Estuarine Ecosystem after the Stopping of Wastewater Discharge: Intertidal Macrobenthic Community Characterization in the Estuary of Oued Souss (Southwestern Morocco). J*ournal of Ecological Engineering*, *20*(11),133-145.

Birch, G. F., Lean, J., & Gunns, T. (2015). Historic change in catchment land use and metal loading to Sydney estuary, Australia (1788–2010). *Environmental Monitoring Assessment*, 187, 594.

Booi, S., Mishi, S., & Andersen, O. (2022). Ecosystem Services: A Systematic Review of Provisioning and Cultural Ecosystem Services in Estuaries. *Sustainability, 14*, 7252.

Bonacci, O., Ðurin, B., Bonacci, T. R., & Bonacci, D. (2022). The Influence of Reservoirs on Water Temperature in the Downstream Part of an Open Watercourse: A Case Study at Botovo Station on the Drava River. *Water, 14*, 3534.

Bosman, O., Soesilo, T. E. B., & Rahardjo, S. (2021). Pollution index and economic value of vannamei shrimp (*Litopenaeus vannamei*) farming in Indonesia. *Indonesian Aquaculture Journal, 16*(1), 51-60.

BPS. (2022). Kualitas air di Kabupaten Semarang. https://semarangkab.bps.go.id/indicator/152/664/1/kualitas-air-di-kabupaten-semarang.html. Access 23 December 2022

Cai, Z., Li, W., & Cao, S. (2021). Driving factors for coordinating urbanization with conservation of the ecological environment in China. *Ambio*, *50*, 1269–1280.

Canhan, R., Flemming, S. A., Hop, D. D., Drever, M. (2021). Sandpipers go with the flow: Correlations between estuarine conditions and shorebird abundance at an important stopover on the Pacific Flyway. *Ecology and Evolution, 11*, 6, 2828-2841.

Chao, Z., Wang, L., Che, M., & Hou S. (2020). Effects of different urbanization levels on land surface temperature change: taking Tokyo and Shanghai for example. *Remote Sensing*, *12*, 12.

Demaku, S., & N. Bajraktari. (2019). Physicochemical analysis of the water wells in the area of Kosovo energetic corporation (Obilio, Kosovo). J*ournal of Ecological Engineering*, *20*(7), 155-160.

Ewaid, S. H., & Abed, S. A. (2017). Water quality index for Al-Gharraf river, southern Iraq. *Egyptian Journal of Aquatic Research*, 43, 117-122.

Fakhrurrozi, F., Soeprobowati T. R., & Jumari J. (2022). The water quality index and phytoplankton communities of Kokoh Putih River, Sembalun, East Lombok, Indonesia. *AACL Bioflux, 15*(4), 2025-2040.

Government Regulation Number 22 of 2021 concerning the implementation of environmental protection and management.

Hadiwijaya, W., Soeharno, A. W. H., Nuhraha, E. O., & Isdiyana. (2022). Study on Morphological Change due to Flood in the Tuntang River. *The fourth International Conference on Sustainable Infrastructure and Build Environment: Sustainable Infrastructure and Built Environment - Challenges on Sustainable and Resilient Infrastructure and Built Environment ITB, Bandung, Indonesia*.

Hammond, D. G. (2009). Evaluating Dissolved Oxygen Regimes Along a Gradient of Human Disturbance for Lotic Systems in West-Central Florida, Theses and Dissertations, University of South Florida, Florida. *USF Tampa Graduate Theses and Dissertations.*

Helard, D., Indah S., & Wilandari M. (2021). Spatial variation of electrical conductivity, total suspended solids, and total dissolved solids in the Batang Arau River, West Sumatra, Indonesia. *IOP Conference Series: Materials Science and Engineering, 1041*, 012027.

Hera S. A. (2021). *Simulasi tata guna lahan terhadap kualitas air sungai dengan metode indeks pencemaran (Studi Kasus: Sungai Tuntang, Jawa Tengah).* PhD thesis. Diponegoro University, Semarang.

Hidayati, N., Soeprobowati, T. R., Helmi, M. (2018). The evaluation of water hyacinth (*Eichhornia crassipes*) control program in Rawapening Lake, Central Java, Indonesia. *IOP Conf. Series: Earth and Environmental Science, 142*, 012-016.

Irsadi, A., Anggoro, S., & Soeprobowati, T. R. (2020). Mangrove Conservation and Its Implication on Community Life of Bedono Village, Demak, Central Java. *AIP Conference Proceedings,* 2231 040041.

Irsadi, A., Anggoro, S., Soeprobowati, T. R., Helmi, M., & Khair, A. S. E. (2019). Shoreline and Mangrove Analysis along Semarang-Demak, Indonesia for Sustainable Environmental Management. *Jurnal Pendidikan IPA Indonesia*, *8*(1), 1–11.

Karthiga, D. M., Mano, B. E., Geethamani, R., & Abinaya, S. (2017). Self-purification capacity of Bhavani River, India. *Research Journal of Engineering Science 6*, 3, 1–9.

Komala, P. S., Soeprobowati, T. R., Takarina, N. D., Subehi, L., Wojewódka-Przybył, M., Primasari, B., Edwin, T., Ridwan, R., Rahmadiningsih, E. & Mardatillah, R. (2023). Spatio-temporal Changes of Water Quality Based on Water Quality Index Method in Tropical Lake of Indonesia. *Water, Air, and Soil Pollution, 234,* 594.

Liang H., Kuang, C., Gu, J., Ma, Y., Chen, K., & Liu X. (2019). Tidal Asymmetry Changes in a Shallow Mud Estuary by a Restoration Project. *Journal of Ocean University of China, 18*, 339–348.

Liu, D., Liu, H., Yu, K., Lu, Q., Guan, H., & Wu. (2021). Freshwater releases into estuarine wetlands change the determinants of benthic invertebrate metacommunity structure. *Frontier Ecology and Evolution, 9*(2021), 600.

Lufthansa, U. M., Titah, H. S., Pratikno, H. (2021). The Ability of Mangrove Plant on Lead Phytoremediation at Wonorejo Estuary, Surabaya, Indonesia. *Journal of Ecological Engineering, 22*(6), 253-268.

Marlina, N., & Melyta, D. (2019). Analysis Effect of Cloud Cover, Wind Speed, and Water Temperature to BOD and DO Concentration Using QUAL2Kw Model (Case Study in Winongo River, Yogyakarta). MATEC Web of Conferences 280.

Minister Environment of Indonesian Decree No. 115/2003 regarding the guideline for water quality status.

MoE (Indonesian Ministry of Environment). (2009). In MEF (Ministry of Environment and Forestry). The grand design of Indonesian lakes conservation and rehabilitation. *Ministry of Environment and Forestry, 94*, 2016.

Musliu, M. A., Bilalli, B., Durmishi, M., Ismaili, H., & Ibrahimi. (2018). Water quality assessment of the Morava e Binces River based on the physicochemical parameters and water quality index. *Journal of Ecological Engineering, 19*(6), 104-112.

Nugraha, W. D., Sarminingsih, A., & Alfisya, B. (2020). The Study of Self Purification Capacity Based on Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO) Parameters. *IOP Conference Series: Earth and Environmental Science, 448*, 012105.

Ogbuagu, F. U.,& Obele, C. N. (2021). Determination of self-purification process in three selected streams in Anambra state. *International Journal Applied Science Research, 1*, 1-12.

Patel, H. B., & Jariwala, N. D. (2023). Analysis of Pollutant Load Carrying Capacity of the River Tapi Using QUAL2Kw for Surat City. *Journal of Environmental Protection, 14*, 96-107.

Patty, S. I. (2014). Characteristics of phosphate, nitrate and dissolved oxygen in Gangga and Siladen Island Waters, North Sulawesi. *Jurnal Ilmiah PLatax 2*(2),74-84.

Pham, V. M., Van Nghiem, S., Van Pham, C., Luu, M. P .T., & Bui, Q. T. (2021). Urbanization impact on landscape patterns in cultural heritage preservation sites: a case study of the complex of Huế Monuments. V*ietnam Landscape Ecology, 36*, 1235–1260.

Piranti, A. S. Rahayu, D. R. U. S., Waluyo, G. (2018). Nutrient Limiting Factor for Enabling Algae Growth of Rawapening Lake, Indonesia. B*iosaintifi*ka *10*(1), 101-108.

Poonam, T., Tanushree, B., & Sukalyan, C. (2013). Water quality indices- important tools for water quality assessment: A review. *International Journal of Advances in Chemistry*, 1, 1.

Qu, L., Huang, H., Xia, F., Liu, Y., Dahlgren, R. A., Zhang, M., & Mei, K. (2018). Risk analysis of heavy metal concentration in surface waters across the rural-urban interface of the Wen-Rui Tang River, China. *Environmental Pollution, 237*, 639-649.

Rahutami, S., Said, M., Ibrahim, E., & Herpandi, H. (2022). Actual Status Assessment and Prediction of the Musi River Water Quality, Palembang, South Sumatra, Indonesia. *Journal of Ecological Engineering*, *23*(10), 68-79.

Rakotondrabe, F., Ngoupayou, J. M. N., Mfonka, Z., Rasolomanana, E. H., Abolo, A. J. N., & Ako, A. A. (2018). Water quality assessment in the Betare-Oya gold mining area (East-Cameroon): multivariate statistical analysis approach. *Science of The Total Environment*, *610*(611), 831-844.

Romanescu, G., Miftode, D., Pintilie, A. M., Constantin, C. C., & Sandu, I. (2016). Water quality analysis in mountain freshwater: Poaiana Uzului reservoir in the eastern Carpathians. *Revista de Chimie (Bucharest), 67*(11), 2318-2326.

Ruspita, R., & Aulia A. (2022). Analysis of Water Quality and Pollution Index at Karangantu Fishing Port Area, Banten. *Jurnal Akademika Kimia*, *11*(2), 96-104.

Saputro, A., & Siwiendrayanti A. (2023). Analysis of Water Quality Status in Tuntang River, Semarang Regency in 2022. *Jurnal Presipitasi, 20*(1), 186-195.

Šaulys, V., Survilė, O., & Stankevičienė, R. (2020). An Assessment of Self-Purification in Streams. *Water*, *12*(1), 87.

Sener, S., Sener, E., & Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in aksu river (SW-Turkey). *Science of the Total Environment, 584,* 585, 131-144.

Seo, M., Lee, H., & Kim, Y. (2019). Relationship between Coliform Bacteria and Water Quality Factors at Weir Stations in the Nakdong River, South Korea. *Water*, *11*, 6, 1171.

Shishaye, H. A. (2017). Water quality analysis evaluation using graphical methods: a case of Lake Beseka, Ethiopia. *Ethiopian Journal of Environmental Studies & Management, 10*, 8, 1054-1070.

Sileshi, A., Awoke, A., Beyene, A., Stiers, I., & Triest, L. (2020). Water Purifying Capacity of Natural Riverine Wetlands in Relation to Their Ecological Quality. *Frontiers in Environmental Science*, 8.

Singh, P., Sabnani, C., & Kapse, V. (2021). Urbanization and urban fire dynamics using GIS and remote sensing: a case study in the city of Nagpur. *India Arab Journal of Geoscience*, 14, 2172.

SNI 06 6989.30. (2005). Method for ammonia analysis using Spectrophotometry

SNI 6989.06 (2012). Method for Cooper (Cu) analysis Atomic Absorption Spectrophotometry. Indonesian National Standard.

SNI 6989.08. (2009). Method for lead (Pb) analysis Atomic Absorption Spectrophotometry. Indonesian National Standard.

SNI 6989.16. (2011). Method for cadmium (Cd) analysis Atomic Absorption Spectrophotometry. Indonesian National Standard.

SNI 6989.17. (2010). Method for chromium (Cr) analysis Atomic Absorption Spectrophotometry. Indonesian National Standard.

SNI 6989.2. (2009). Chemical Oxygen Demand Analysis with Spectrophotometry. Indonesian National Standard.

SNI 6989.57. (2008). Method for surface water sample collection. Indonesian National Standard.

SNI 6989.72. (2009) Method for Biochemical Oxygen Demand Analysis. Indonesian National Standard.

Soeprobowati, T. R., Addadiyah, N. L., Hariyati, R., & Jumari, J. 2021. Physico-chemical and biological water quality of Warna and Pengilon Lakes, Dieng, Central Java. *Journal of Water and Land Management, 51*, 38-49.

Soeprobowati, T. R., Hadisusanto, S., Gell, P. & Zawadski, A. (2012). The Diatom Stratigraphy of Rawapening Lake, Implying Eutrophication History. *American Journal of Environmental Sciences, 8,* 3, 334-344.

Sun, X., Kong, T., Li, F., Häggblom, M. M., & Kolton, M. (2022). Desulfurivibrio spp. Mediate sulfur-oxidation coupled to Sb(V) reduction, a novel biogeochemical process. *ISME. J., 16*, 6, 1547–1556.

Susanti, R., Widiyastuti, K., Yuniastuti, A., & Fibriana, F. (2020). Feed and water management may influence the heavy metal contamination in domestic ducks from Central Java, Indonesia. *Water, Air, & Soil Pollution*, *231*, 1-11.

Suwarno, D., Hermawan, H., Mulyanto, Y., Widianto, D., Hartanto, D., Setiyadi, B., & Setijowarno, D. (2020). Kajian Kualitas Air Sungai Tuntang. Monograph, Technical Report. Unika Semarang.

Syeed, M. M. M., Hossain, M. S., Karim, M. R., Uddin, M. F., Hasan, M., & Khan, R. H. (2023). Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review. *Environmental and Sustainability Indicators, 18*, 100247.

Tabla-Hernandez, J., Dellepere, A. V., & Mangas-Ramirez, E. (2022). Predictive modelling to determine oxygen and ozone doses applicable to *in situ* remediation of polluted water bodies. *Environmental Research Letters*, *17*,1, 014038.

Tanaka, Y., Minggat, E., & Roseli, W. (2021). The impact of tropical land-use change on downstream riverine and estuarine water properties and biogeochemical cycles: A review. *Ecological Processes, 10*, 1, 1-21.

Tanjung, R. H. R., Hamuna, B., & Alianto. (2019). Assessment of water quality and pollution index in coastal waters of Mimika, Indonesia. J*ournal of Ecological Engineering, 20*, 2, 87-94.

Tjahjono, A., & Suwarno, D. (2018). The Spatial Distribution of Heavy Metal Lead and Cadmium Pollution and Coliform Abundance of Waters and Surface Sediment in Demak. *Journal of Ecological Engineering, 19*, 4, 43-54.

United Nations. (2016) The sustainable development goals report 2012. United Nations New York, 56.

Wang, H., Feng, C., & Deng, Y. (2020). Effect of potassium on nitrate removal from groundwater in agricultural waste-based heterotrophic denitrification system. *Science of the Total Environment*, 703.

Wang, J. Z., Fu, H., Qiao, F. & Liu. (2019). Assessment of eutrophication and water quality in the estuarine area of Lake Wuli, lake Taihu, China. *Science of the Total Environment*, *650*, 1392-1402.

Ward, M. H., Jones, R. R., Brender, J. D., De Kok, T. M., Weyer, P. J., Nolan, B. T., Villanueva, C. M., & Van Breda, S. G. (2018). Drinking Water Nitrate and Human Health: An Updated Review. *International Journal of Environmental Research and Public Health, 15*, 7, 1557.

Wirasatriya, A., Rochaddi, B., Faizah, A.N., Zaenuri, M., Muslim, Setiyono, H., Hariadi, &Marwoto, J. (2017). Study of longshore current in the mouth of Tuntang River in Morodemak village, Demak Regency, Indonesia and its possible effect on forming the coastal morphology. *International Journal of Civil Engineering and Technology (IJCIET), 8*, 11, 1–9.

Xu, F., Jia, Y., Niu, C., Sobkowiak, L. & Zhao, L. (2021). Evaluating spatial differences in the contributions of climate variability and human activity to runoff change in the Haihe River basin. *Hydrology Science Journal, 66*, 14, 2060-2073,

Zaki, M. R. M., Ying, P. X., Zainuddin, A. H., Razak, M. R., & Aris, A.Z. (2021). Occurrence, abundance, and distribution of microplastics pollution: an evidence in surface tropical water of

Klang River estuary, Malaysia. E*nvironmental Geochemical Health, 43*, 3733–3748

Zarzuelo, C., Valle-Levinson, A., López-Ruiz, A., Díez-Minguito, M., & Ortega-Sánchez M. (2023). Bridge-piling modifications on the momentum balance in an estuary: The role of tides, winds, and seasonality. O*cean Engineering, 271*, 113746.

Zhang, X., Wu, Y., Liu, X., Reis, S., Jin, J. (2017). Ammonia emissions may be substantially underestimated in China. *Environmental Science & Technology, 251*, 21, 12089-12096.

Zhou, L., Appiah, R., Boadi, E. B., Ayamba, E. C., Larnyo, E., & Antwi, H. A. (2022). The Impact of Human Activities on River Pollution and Health-Related Quality of Life: Evidence from Ghana. *Sustainability, 14*, 13120.

Zubaidah, T., Karnaningroem, N., & Slamet A. (2019). The Self-Purification Ability in The Rivers of Banjarmasin, Indonesia. *Journal of Ecological Engineering, 20*(2), 177-182.