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Relationships of dissolved inorganic phosphate with chlorophyll-a and total suspended solids off the Bodri River, Indonesia

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ABSTRACT

The Bodri River is one of the main rivers in Kendal regency, central of Java. This river flows through three regencies, namely Temanggung, Semarang, and Kendal, with anthropogenic conditions such as agricultural areas, settlements, and fish ponds. Human activities have caused high concentrations of suspended solids (TSS) to enter the Bodri River estuary, carrying nutrients such as phosphate. This study aims to investigate the relationship between dissolved inorganic phosphate (DIP or phosphate) with chlorophyll-a (Chl-a) and TSS at the Bodri River. Water quality parameters, including turbidity, temperature, dissolved oxygen (DO), and salinity, were measured in the field. Meanwhile, Chl-a, phosphate, and TSS analyses in the laboratory. Based on Pearson correlation analysis, phosphate showed a strong positive correlation with chl-a ($p=0.000$; $r=0.959$) and TSS ($p=0.000$; $r=0.872$). The high correlation between phosphate and Chl-a is related to the role of phosphate as a nutrient that influences the growth of green phytoplankton (Chl-a), while phytoplankton itself is also a component of TSS. This study shows that phosphate nutrients play an important role in aquatic fertility, and when their concentrations are too high, they can cause eutrophication and increased TSS, which may negatively impact DO levels. Therefore, the presence of phosphate in water bodies requires continuous monitoring.

Keywords: phosphate, chlorophyll-a, total suspended solids, Bodri River.

INTRODUCTION

Phosphate nutrients play a critical role in aquatic ecosystems as they are a key nutrient for the growth of phytoplankton (Juntarasakul et al., 2024). Phytoplankton utilize phosphorus in the form of dissolved inorganic phosphate (DIP) for various biological processes, including the synthesis of chlorophyll-a (Chl-a), which is essential for photosynthesis. Therefore, Chl-a could be used as a quantitative proxy for phytoplankton biomass (Roeslaer et al., 2017; Robles-Tamayo et al., 2022; Shi and Wang, 2022). Moreover, the relationship between phosphate availability and Chl-a production is evident in coastal waters. For example, an investigation into different regions of the north coastal of Java demonstrated that areas with higher phosphorus input tended to have increased microalgal development, as suggested by higher chlorophyll-a biomass (Maslukah et al., 2023). This indicates that a sufficient supply of phosphate ions can potentially enhance chlorophyll-a production in phytoplankton populations.

However, when present in excess, phosphate can lead to eutrophication, characterized by accelerated plant growth and oxygen depletion in water bodies, which can have detrimental effects on aquatic life and water quality (Nadagouda et al., 2024). Phytoplankton play a critical role as components of total suspended solids (TSS) in aquatic systems, influencing both water quality and ecological dynamics. TSS includes organic and inorganic particles suspended in water, and phytoplankton contribute significantly to the organic component of TSS in low-turbidity estuarine environments (Kasim, 2012; Bibi et al., 2020). Elevated TSS levels can limit the light available to phytoplankton, potentially reducing their photosynthetic efficiency and, consequently, their growth and biomass production (Fanela et al., 2019). For example, in Lake Uiam, high concentrations of TSS during the summer correspond with increased turbidity and changes in phytoplankton community structure, indicating a seasonal impact on phytoplankton growth (Im et al., 2023). Moreover, TSS can interact with other environmental factors, such as nutrient availability. For instance, high TSS often accompany high levels of organic matter and nutrients like phosphate, which can boost certain phytoplankton taxa while inhibiting others, as observed in diverse aquatic environments (Im et al., 2023). This dynamic relationship underscores the complexity of the impact of TSS on phytoplankton, especially in estuaries, which may also occur in the Bodri estuary.

The upper section of the Bodri River is part of Temanggung regency and Semarang regency, while the downstream section is part of Kendal regency. According to Atmodjo's research (2010), the flow rate of the Bodri River during the study ranged from 9.17 to 54.48 m^3/s, the suspended material flow rate ranged from 0.03 to 0.21 g/L, and the sediment flow rate ranged from 0.26 to 0.42 kg/s. The flow of fresh water from upstream rivers carries organic and inorganic material originating from domestic and agricultural waste, both organic and inorganic which influence turbidity. The estuary area has a lower level of turbidity than the open sea (Sudar et al., 2024). This turbidity level is closely related to the presence of total suspended solids carried by the river to the estuary and other processes in the estuary, such as photosynthesis. TSS inputs from natural and human activities contain chemical elements such as phosphorus (P) nutrients, which then affect water fertility, as determined by Chl-a concentration (Maslukah et al., 2019). In a study conducted by Indrayanti et al. (2022) at the Kendal River estuary in Indonesia, it was found that there is a positive correlation between Chl-a and phosphate ($r = 0.880$). A positive correlation was also found between Chl-a and TSS, with a correlation value of 0.683. This indicates that the distribution of Chl-a at the Kendal regency estuary is significantly influenced by high nutrient inputs from activities on the land near the estuary. Another study (at the Bodri estuary, Kendal regency) found a positive correlation between TSS and Chl-a ($r = 0.927$) (Amna et al., 2022). However, that previous study did not examine the role of nutrients (phosphate) in relation to Chl-a and its connection to TSS. Therefore, further research is needed with a more comprehensive and complete set of components, specifically the concentration of Chl-a and its relationship with phosphate and suspended solid material. The results of this research will provide information on the extent of the role of phosphate in the growth of phytoplankton with green pigments (Chl-a) and its influence on TSS. This can assist in mitigation efforts, particularly in determining the triggering factors of eutrophication in estuarine and coastal waters.

MATERIALS AND METHODS

Study area

The determination of sampling stations was carried out using purposive sampling, a sampling technique that involves specific considerations in determining samples for specific purposes (Memon et al., 2021). These considerations include the physiography of the study site, which represents the overall condition of a water body. There were 14 stations used as research locations, four stations representing areas near the estuary (1, 7, 13, 14), three transition areas (8, 10, 2), and seven areas representing open sea waters (3, 4, 5, 6, 9, 11, 12). A more detailed map of the research location can be seen in the following Figure 1.

Sampling methode

Water sampling was carried out on the water surface using a bucket, then placed in 500 ml and 1000 ml sample bottles. Before use, the sample bottles were first cleaned using distilled water to prevent contamination from substances in the bottle, and after which the bottles were labeled per station. The bottles containing seawater samples are then stored in a cool box with ice to prevent changes in phosphate and chlorophyll

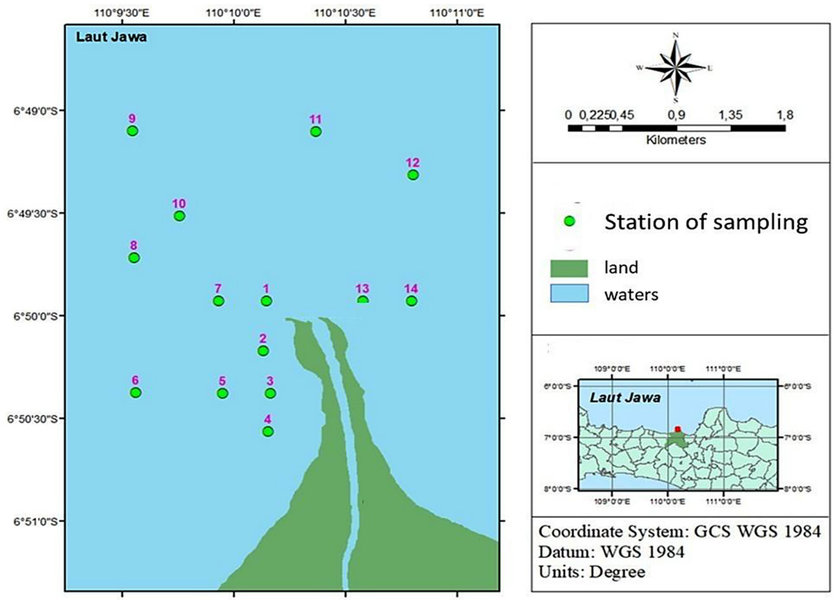

Figure 1. Area study

concentrations. Sampling is conducted from 09:00 to 12:30 WIB concurrently with measurements of water environmental parameters. The environmental parameters measured include salinity (‰), dissolved oxygen (DO) (mg/L), temperature (°C), transparency (cm), current direction (°), and current speed (m/s).

Chlorophyll-a analysis

Chlorophyll-a concentration measurements were performed using the method described by Parsons et al. (1984) (spectrophotometric method). A 1L (1000 ml) water sample was added with 6 drops of $MgCO_3$, mixed, and then filtered using 0.45 µm cellulose filter paper with the aid of a vacuum pump. The suspension retained on the cellulose filter paper was placed in a test tube for extraction with 10 ml of 90% acetone. Next, the sample was incubated in a refrigerator for 16 hours and centrifuged at a speed of 3000 rpm for 20 minutes to separate the cellulose paper or other materials that had not completely dissolved and settled. In the next step, the sample's absorbance is measured using a UV-VIS spectrophotometer at wavelengths of 664, 647, and 630 nm, and the chlorophyll-a concentration is calculated using Equation (1) and (2):

$$Ca = (11.85 \cdot E664) - (1.54 \cdot E647) - (0.008 \cdot E630) \quad (1)$$

$$Chl\text{-}a = (C \cdot v)/(V \cdot l),\ \mu g/L \quad (2)$$

where: Ca – the absorbance value substituted with C in the Equation (2), E664, E647, E630 – wavelength values for chlorophyll-a analysis; v – the volume of acetone (ml); V – the volume of water sample (L), l – the diameter of the cuvette (cm).

Phosphate analysis

Phosphate measurements were performed using spectrophotometry based on the molybdenum blue method with reagents including ammonium molybdate, sulfuric acid, ascorbic acid, and potassium antymonil tartrate. Absorbance values are read using a UV-Vis spectrophotometer at a wavelength of 885 nm (Parsons et al., 1984).

TSS analysis

TSS concentration analysis was measured using the gravimetric method following Wirasatriya et al. (2023). One liter of water was filtered using Whatman filter paper (GF/F) with the aid of a vacuum pump. The retained suspended solids were dried in an oven for 1 hour at 105 °C and weighed. The TSS value was calculated using the following equation 3:

$$TSS = (a–b)/c \quad (3)$$

where: TSS – total suspended solid (mg/L), a – weight of filter paper + TSS, b – weight of filter paper, c – volume of water sample (liter).

Statistical analysis of the relationship between DIP with Chl-a and TSS

To determine the correlation between Chl-a and phosphate (DIP) as well as Chl-a and TSS, the Pearson correlation approach was used with the help of IBM SPSS Statistics 26 software. Pearson correlation, also known as correlation product moment, is a statistical technique that is often used to find relationships between variables for numerical data (Holmes and Rinaman, 2014).

RESULTS AND DISCUSSION

Chlorophyll-a concentrations in the Bodri River estuary, varied from 5 to 6.8 µg/L (Figure 2). This variation was influenced by several factors, such as water light conditions and nutrient concentrations resulting from human activities (Samdin et al., 2024). The lowest chlorophyll-a concentration value in the water, 5 µg/L, was found at stations 9 and 11, which are areas far from the river mouth (Figure 2). Meanwhile, the highest concentration was found at station 13, an area near the river mouth with a concentration of 6.8 µg/L (Figure 2). Overall, the average chlorophyll-a concentration in Bodri waters is 6.1 µg/L (Table 1). Stations with concentrations above the average were found at station 13 (6.8 µg/L), station 14 (6.78 µg/L), station 1 (6.74 µg/L), station 2 (6.68 µg/L), Station 7 (6.65 µg/L), Station 3 (6.64 µg/L), Station 4 (6.55 µg/L), and Station 5 (6.3 µg/L) (Figure 2).

Based on Figure 2, stations with concentrations exceeding the average are located near the river mouth and the mainland, which are influenced by aquaculture activities. The high chlorophyll-a concentrations are related to high nutrient levels, particularly phosphate, whose concentrations are shown in Table 2. The highest phosphate concentration is found at Station 13, at 0.928 µM (Figure 3), which is also characterized by high Chl-a levels of 6.8 µg/L (Figure 2). The lowest phosphate concentrations were observed at stations 9, 11, and 12, all with a phosphate concentration of 0.0386 µM (Figure 3) and chlorophyll levels of 5 µg/L (Figure 2).

The high concentration of phosphate ions in areas near estuaries is due to the fact that estuaries are influenced by river water inflows that carry various types of waste, both industrial and domestic, which are sources of nutrients, including phosphate, whose primary source is terrestrial (the result of rock weathering carried by water flow). These phosphates are later absorbed by phytoplankton and act as a growth and energy factor for phytoplankton (Mishbach et al., 2021). Phosphate ions are one of the important factors influencing the growth and presence of phytoplankton. In addition to being influenced by phosphate nutrients, the presence of TSS affects Chl-a concentrations in water bodies. The research findings of Indrayanti et al. (2022) indicate that the presence of TSS in water can have a positive correlation with Chl-a if the TSS in the water is dominated by phytoplankton, and conversely, it will have a negative

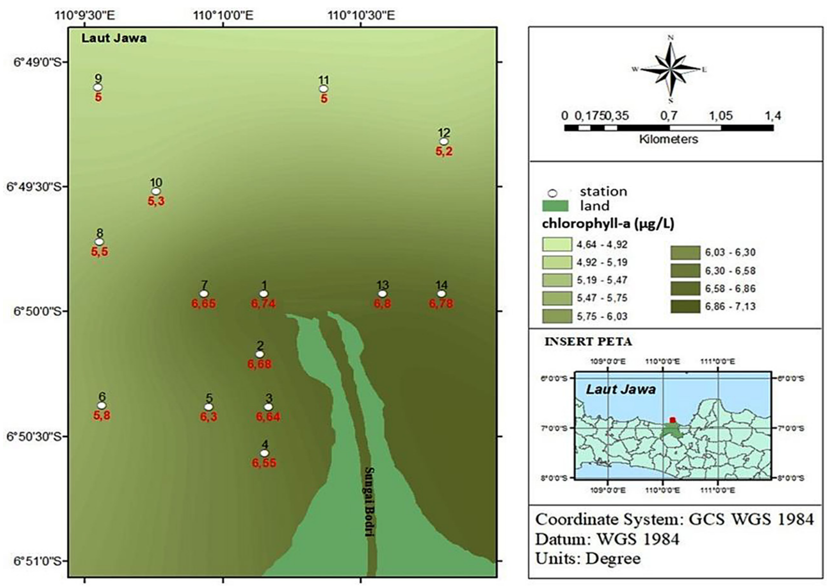

Figure 2. The distribution pattern of chlorophyll-a concentration

Table 1. The concentration of chlorophyll-a (Chl-a), phosphate, and TSS at the Bodri River estuary

Stations	Longitude (^{0}E)	Latitude (^{0}S)	Chl-a (µg/L)	DIP (µM)	TSS (mg/L)
1	110.16913	-6.8321	6.74	0.807	70.8
2	110.1689	-6.83617	6.68	0.798	65.5
3	110.1694	-6.8397	6.64	0.757	63.8
4	110.1692	-6.8428	6.55	0.695	60.4
5	110.1658	-6.8397	6.30	0.734	63.2
6	110.1593	-6.8396	5.80	0.446	58.6
7	110.1655	-6.8321	6.65	0.787	68.2
8	110.1592	-6.8286	5.50	0.556	62.4
9	110.1591	-6.8183	5.00	0.386	50.0
10	110.1626	-6.8253	5.30	0.45	59.5
11	110.1728	-6.8184	5.00	0.386	52.8
12	110.18	-6.8219	5.20	0.386	52.8
13	110.1763	-6.8321	6.80	0.928	75.2
14	110.1799	-6.8321	6.78	0.88	67.7
Average			6.07	0.643	62.2

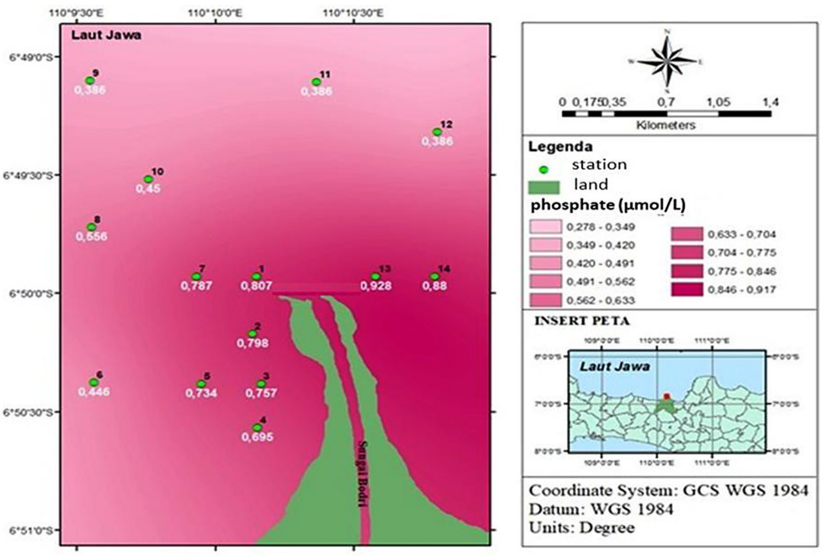

Figure 3. The distribution pattern of phosphate concentration

correlation if the TSS in the water is dominated by inorganic material (inorganic sediment). The study results show an average TSS value of 62.2 mg/L at the Bodri River estuary (Table 1). High TSS concentrations (above average) were found at station 13 (75.2 mg/L), station 1 (70.8 mg/L), station 7 (68.2 mg/L), station 14 (67.7 mg/L), station 2 (65.5 mg/L), station 3 (63.8 mg/L), station 5 (63.2 mg/L), and station 8 (62.4 mg/L) (Figure 4).

Based on Figure 4, stations with high TSS concentrations show the same pattern as Chl-a. This is related to the fact that TSS components can consist of both biotic and abiotic components, which in this study are dominated by organic material (in the form of phytoplankton). The highest TSS and Chl-a concentrations in this study were found at Station 13 (75.2 mg/L for TSS and 6.8 µg/L for Chl-a), as shown in Figure 4 and Figure 2. Meanwhile, the lowest TSS was found at station 9 (50 mg/L) and Chl-a (5 µg/L). The high TSS values in the estuary area are due to the estuary being a convergence point for river flows carrying various particles in the water column, both biotic and abiotic components (Wulandari et al., 2022). The results of the correlation analysis (Table 2) show a significant correlation between TSS

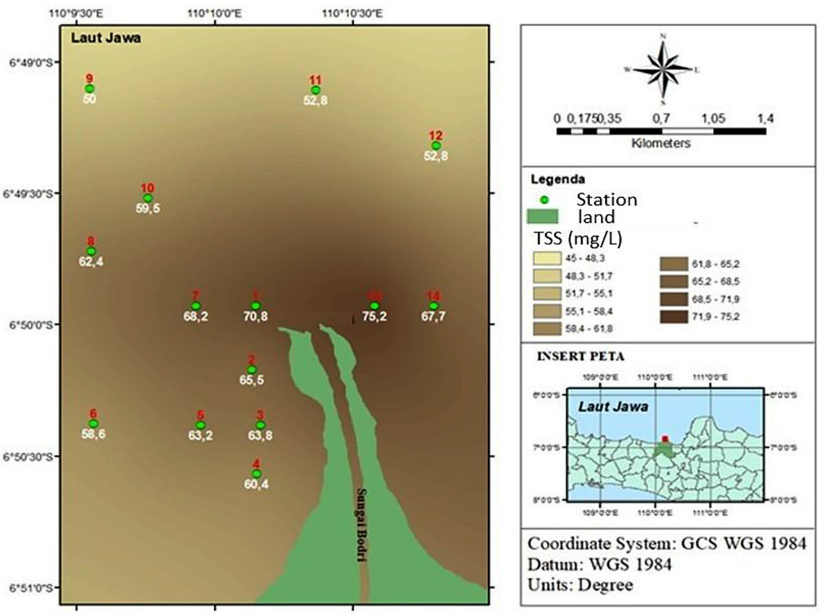

Figure 4. Distribution pattern map of TSS

Table 2. Pearson correlation between Chl-a with phosphate, TSS, and the other environmental parameters

Correlations		Chl-a	Phosphat	TSS	Dissolved oxygen	Transparancy	Temperature	Salinity
Chl-a	Pearson Correlation	1	.959**	.872**	-0.468	-0.668	-0.063	-0.481
	Sig. (2-tailed)		0.000	0.000	0.091	0.091	0.830	0.082
N		14	14	14	14	14	14	14

Note: ** Correlation is significant at the 0.01 level (2-tailed).

and Chl-a. Research by Muslim and Jones (2003) at the Great Barrier Reef in Australia also shows the same pattern, where Chl-a and TSS have a significant positive correlation ($r=0.49$; $P<0.001$).

In addition to phosphate and TSS, the presence and distribution of Chl-a in column waters are also influenced by other water quality parameters and hydro-oceanographic conditions. There are several environmental parameters that are related to Chl-a, including temperature, salinity, light intensity, and dissolved oxygen (DO) (Table 2). Other water quality parameters with low and negative correlations with Chl-a at the study site include temperature ($r = -0.063$) (Table 2), with a temperature range of 30–31.5°C. A negative but fairly strong correlation was found between Chl-a and DO ($r = -0.468$) and salinity ($r = -0.481$) (Table 2). Meanwhile, a very strong and negative correlation was found between Chl-a and water clarity ($r = -0.668$) (Table 2). This indicates that phytoplankton growth (which primarily uses Chl-a as its photosynthetic pigment) requires clear water in a water body. High turbidity conditions disrupt the photosynthesis process.

Based on Table 2, the relationship between Chl-a concentration and phosphate shows a significant positive correlation ($P=0.000$; $r=0.959$). This pattern is similar to that shown in the study by Ridho et al. (2020) in the coastal waters of Sungsang, South Sumatra, where the correlation between Chl-a and phosphate can be explained by 90.99% ($r=0.9$). Phosphate plays a significant role in influencing Chl-a concentration. In aquatic environments, phosphate ions are a nutrient critically needed by phytoplankton.

CONCLUSIONS

This study investigated the relationship between phosphate ions, chlorophyl-a, and total suspended solids at the mouth of the Bodri River, Kendal regency, Indonesia. The concentration of phosphate varied spatially, with the highest levels found near the river mouth and areas affected by aquaculture activities. The Chl-a concentrations followed a similar pattern to TSS, with the highest values observed at stations near the river mouth. TSS concentrations were also highest in the estuary area due to the convergence of river flows carrying various particles. Pearson correlation analysis showed a strong positive correlation between phosphate and Chl-a (r=0.959) and between phosphate and TSS (r=0.872). These findings highlight the important role of phosphat in influencing phytoplankton growth and water fertility at the Bodri River estuary. This study emphasizes the need for continuous monitoring of phosphate concentration to mitigate potential negative impacts such as eutrophication and increased TSS, which can negatively affect light intensity and dissolved oxygen levels in the water.

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