Nutrient distribution, aquatic bacteria, and geospatial aspects of Pekalongan Port waters

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Abstract. Pekalongan National Fishery Port (PPN), the largest port on the northern coast of Java, supports extensive fish auction activities and other operations around the port area, potentially contributing to marine pollution. However, this coastal marine environment is influenced by natural processes, such as sedimentation, freshwater flows, mangroves, and conservation efforts. This study aims to observe the abundance of macronutrients, specifically phosphorus and nitrate, along with bacterial distributions across geospatial locations to assess the sustainability of the surrounding marine biota. Laboratory results show that phosphate levels in May were lower than in August and December, nitrate levels peaked in December, and bacterial abundance was highest in December. Geospatial analysis reveals that current movement affects the accumulation of organic materials along the coast, with seasonal changes and rainfall impacting the aquatic conditions substantially.
Key Words: nitrate, phosphorus, sedimentation, total bacterial plate count.

Introduction. Pekalongan, located on the north coast of Java, Indonesia, comprises coastal areas, river estuaries, and outlets that are categorized as coastal waters (Adinugorho et al 2018; Maslukah et al 2019). The area includes both dry and submerged lands influenced by marine characteristics like tides, sea breezes, and ecosystems (Ridlo & Yuliani 2018). Toward the sea, Pekalongan waters are influenced by natural processes from land, including sedimentation and freshwater inflows, as well as human activities such as aquaculture, port operations, and pollution from urban and industrial sources (Muharuddin 2019). The coastal region can be categorized by two boundary types: parallel to the coastline (longshore) and perpendicular to it (Mishbach et al 2021). Coastal estuary conditions in Pekalongan are impacted by interactions between land and ocean water masses, exhibiting physical properties such as tides, coastal currents, winds, and coastal geomorphology, as well as chemical properties such as salinity, pH, phosphate, and nitrate levels (Isnaini & Aryawati 2023).

Pelabuhan Perikanan Nusantara (PPN) of Pekalongan is a Class B national port in Indonesia, situated along the Banger River, featuring intensive activities like docking, fish processing, vessel repairs, and operational activities. Additionally, macro- and micro-waste from nearby settlements and rural areas flows into the Banger River. Assessing the health of these waters is crucial, as the estuarine ecosystem plays a role in chemical cycling and acts as a sustainable nutrient transfer agent, with nutrients being one of the water quality determinants (Meliala et al 2019). Notably, the abundance of macronutrients like phosphorus (P) and nitrogen (N) is essential, as they impact the growth of phytoplankton, algae, and aquatic plants (Ridwan et al 2018), can help determine the sustainability of marine biota (Widiardja et al 2021), and can help assess current and pollutant dispersion in coastal waters (Raharjo et al 2016).

Nitrate is formed through nitrification, a process in the nitrogen cycle that converts ammonia to nitrite and then nitrate under aerobic conditions (Agustiyani et al 2017). Nitrogen and phosphorus play significant roles in phytoplankton growth (Rahmah et al 2022). Their molecules contribute to chemo-autotrophic and photo-autotrophic processes during photosynthesis (Gurning et al 2020), generating oxygen and carbohydrates (Kamariah et al 2023) and forming various organic compounds such as fats, proteins, carbohydrates, and nucleic acids that constitute cellular structures in living organisms (Firdaus & Wijayanti 2019).

This research aims to examine phosphate, nitrate, and bacterial levels in the Pekalongan port waters, from the harbor area to offshore, under the influence of seasonal currents from the rainy to the dry season.

Material and Method. The quantitative research method was used in this study, emphasizing numerical data analysis to validate theories or hypotheses (Waruwu 2023). This scientific method adheres to empirical, objective, measurable, rational, and systematic principles (Agustianti et al 2022). Sampling was conducted *in situ* at 12 stations during both low and high tide in May, August and December 2024 in the waters of Pekalongan.

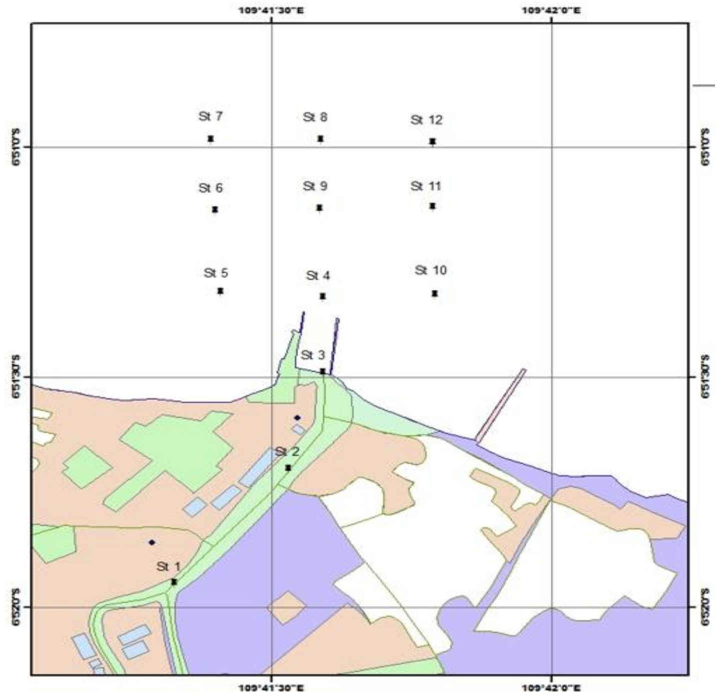

Figure 1. Water research location, Pekalongan.

To represent the study area comprehensively, data were collected in both dry and rainy seasons during May, August, and December 2024 to analyze currents at designated stations. Primary parameters included bacterial abundance (total plate count), nitrate, and phosphate concentrations, with supplementary variables. Samples were then transported to the Environmental Laboratory, Pekalongan Regency, for analysis.

Phosphate and nitrate levels were measured by water samples collected with a 1 L Nansen bottle at approximately 1 m depth during the transition from low to high tide across the 12 stations. Samples were stored in polyethylene bottles within a cooler box for further analysis.

Nitrate levels were quantified using a UV-Visible spectrophotometer with cadmium reduction, with measurements ranging from 0.01 to 1 mg nitrate at a wavelength of 543 nm. Two sample treatments were conducted: one through a reduction column test and one without. Nitrate concentration was calculated by subtracting nitrite levels without reduction from those with reduction:

Nitrate concentration = A-B

Where: A - nitrite concentration through reduction column; B - nitrite concentration without reduction column.

Phosphate levels were determined using a spectrophotometer at 885 nm, with a concentration range of 0.01–1 mg L^{-1}. A standard solution was prepared to determine the actual phosphate concentration using the formula (Phansi et al 2022):

$$X = A \times 10^{-6} \left(\frac{mols\ PO_4^{3-}}{L}\right) \times \left(\frac{95\ \times\ PO_4^{3-}}{1\ mol}\right) \times \left(\frac{10^6}{1\ g}\right)$$

Where: X - final phosphate concentration; A - phosphate concentration from spectrophotometer absorbance.

For bacterial analysis, water samples were collected using a 1 L Nansen bottles from each sampling station at a depth of approximately 1 m and preserved in cool glass bottles for laboratory analysis. Bacterial concentration was determined using a Petri dish, measuring colony-forming units (CFUs) with a range of 25–250 colonies. The formula used to calculate total bacterial colony count is as follows (Nurilmala et al 2019):

$$\mathrm{N} = \frac{\sum C}{\{(1xn1) + |(0.1xn2)\}x\ (d)}$$

Where: N - total colony count in colonies per mL or g; Σc - total colonies in all measured plates; N1 - number of plates at first dilution counted; N2 - number of plates at second dilution counted; d - first counted dilution.

Supporting wind and tide data for May, August, and December were obtained from Climate Data Store (CDS) and the Geospatial Information Agency (BIG). Tidal data were processed using the admiralty method to establish values for low water level (LWL), mean sea level (MSL), and high water level (HWL). After obtaining the numerical modeling, the RMSE (Root Mead Square Error) value was calculated to determine the correlation coefficient value (Chaidir & Tuharea 2022).

Results. Laboratory results from samples collected at the 12 stations across varying climatic and tidal conditions based on RMSE analysis showed significant differences in approaching zero (0) in nitrate, phosphate, and bacterial levels (total plate count) (Table 1; Figures 2-4). Lab tests align with geospatial analysis, considering hydro-oceanographic environmental conditions. Phosphate concentrations during the rainy season (May) were lower than during transition months (August and December), though levels at stations 1–4 exceeded the quality standard each month, influenced by local wastewater inflows. The water quality standard for phosphate in port waters is 0.2 mg L^{-1} (Hendrayana et al 2022).

Nitrate levels remained below quality standards at all stations, consistent with the standard for Pekalongan waters. Nitrate and phosphorus levels increased during the dry season due to elevated temperatures and simultaneous regeneration and metabolic activity (Fadilah & Pratiwi 2019). The nitrate standard for port waters is 0.06 mg L^{-1}. (Hendrayana et al 2022).

The impact of temperature on bacterial growth exists, as observed in the bacterial count results, where August and December with transitional climates show higher levels than the rainy season (May). However, nutrient levels also increase along with bacterial growth (Roosheroe et al 2018; Ariadi & Mujtahidah 2022). From the 12 stations, relatively high levels were observed at stations 1 to 4, However, some stations did not detect bacteria, likely due to strong currents moving from the sea to the shore. The standard for port water quality in terms of bacterial variables should not exceed 5x10x5 MFU (Lestari et al 2022). The laboratory test results align with applicable testing standards, suitability, and systematic methods.

Table 1

Test results on phosphate and nitrate variables in high tide and low tide waters

Station	*Phosphate*						*Nitrate*						*Bacteria (Total plate number)*					
	May		*August*		*December*		*May*		*August*		*December*		*May*		*August*		*December*	
	High	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*
1	0.3	0.3	0.3	1.52	0.19	0.12	0.3	0.2	0.3	0.5	1.8	0.1	$1x10^3$	$2.5x10^3$	$3.2x10^4$	$4.9x10^4$	$4.1x10^3$	$3.9x10^3$
2	0.2	0.4	0.4	1.86	0.42	0.16	0.3	0.2	0.2	0.6	0.5	0.2	$2.8x10^2$	$1.6x10^3$	$2.3x10^4$	$5.2x10^3$	$2.8x10^3$	$5.6x10^3$
3	0.1	0.09	0.09	0.49	0.18	0.12	0.4	0.2	0.1	0.4	0.8	1.1	$4x10^2$	$4x10^2$	$4.7x10^3$	$4.6x10^3$	$6.1x10^2$	$2.6x10^3$
4	0.033	0.02	0.02	0.18	0.20	0.13	0.3	0.2	0.1	0.9	1.3	3.8	$1.7x10^2$	20.5x10	$7x10^0$	$3.1x10^1$	$3.8x10^2$	$2.0x10^3$
5	0.008	0.009	0.009	0.53	0.16	0.05	0.5	0.2	0.1	1.8	2	2.4	$1x10^2$	42x10	$5x10^0$	$6.8x10^1$	$9.1x10^2$	$5.8x10^1$
6	0.033	0.006	0.006	0.23	0.13	0.01	1.8	0.4	0.1	0.5	2.2	2.7	$1x10^2$	$3.6x10^2$	$6x10^0$	$1x10^0$	$4.4x10^2$	$0.9x10^1$
7	0.033	0.006	0.006	0.23	0.12	0.03	0.7	0.1	0.1	1	0.8	1.3	$1.7x10^2$	8x10	$5x10^0$	$3x10^2$	$2.7x10^2$	$4.7x10^1$
8	0.033	0.005	0.005	0.23	0.12	0.04	0.9	0.1	0.3	0.5	1.7	0.7	$1x10^2$	43.6x10	$1x10^0$	$1x10^0$	$4.2x10^1$	$0.4x10^1$
9	0.004	0.002	0.002	0.25	0.09	0.04	0.7	0.1	0.2	1	2	1.1	33.6x10	33.6x10	$1x10^0$	$1x10^0$	$5.1x10^1$	$2.2x10^1$
10	0.064	0.01	0.01	0.38	0.10	0.10	0.9	0.1	0.4	0.5	1.5	1	63.5x10	$2x10^2$	$3x10^0$	$8.3x10^1$	$2.3x10^2$	$1.3x10^1$
11	0.03	0.005	0.005	0.19	0.09	0.02	1	0.1	0.2	0.6	0.3	1.6	71.6x10	10.5x10	$1x10^0$	$2x10^0$	$9.8x10^1$	$6x10^1$
12	0.002	0.033	0.033	0.24	0.12	0.02	1.1	0.1	0.4	1.2	1.3	1.8	10x10	$1.1x10^2$	$1x10^0$	$3x10^0$	$2.7x10^2$	$0.8x10^1$

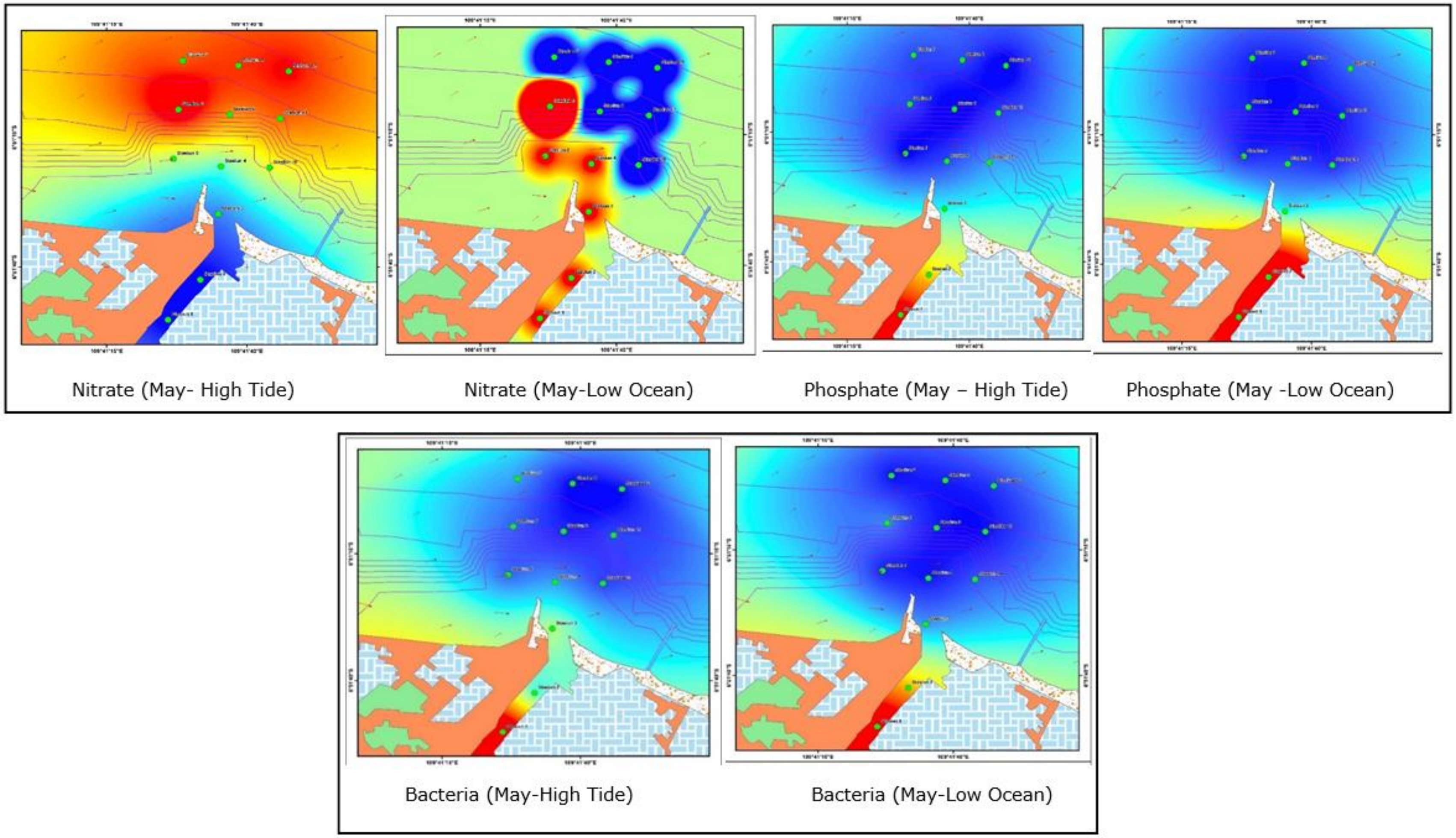

Figure 2. Geospatial interpolation distribution based on nitrate, phosphate and bacteria variables in May 2024.

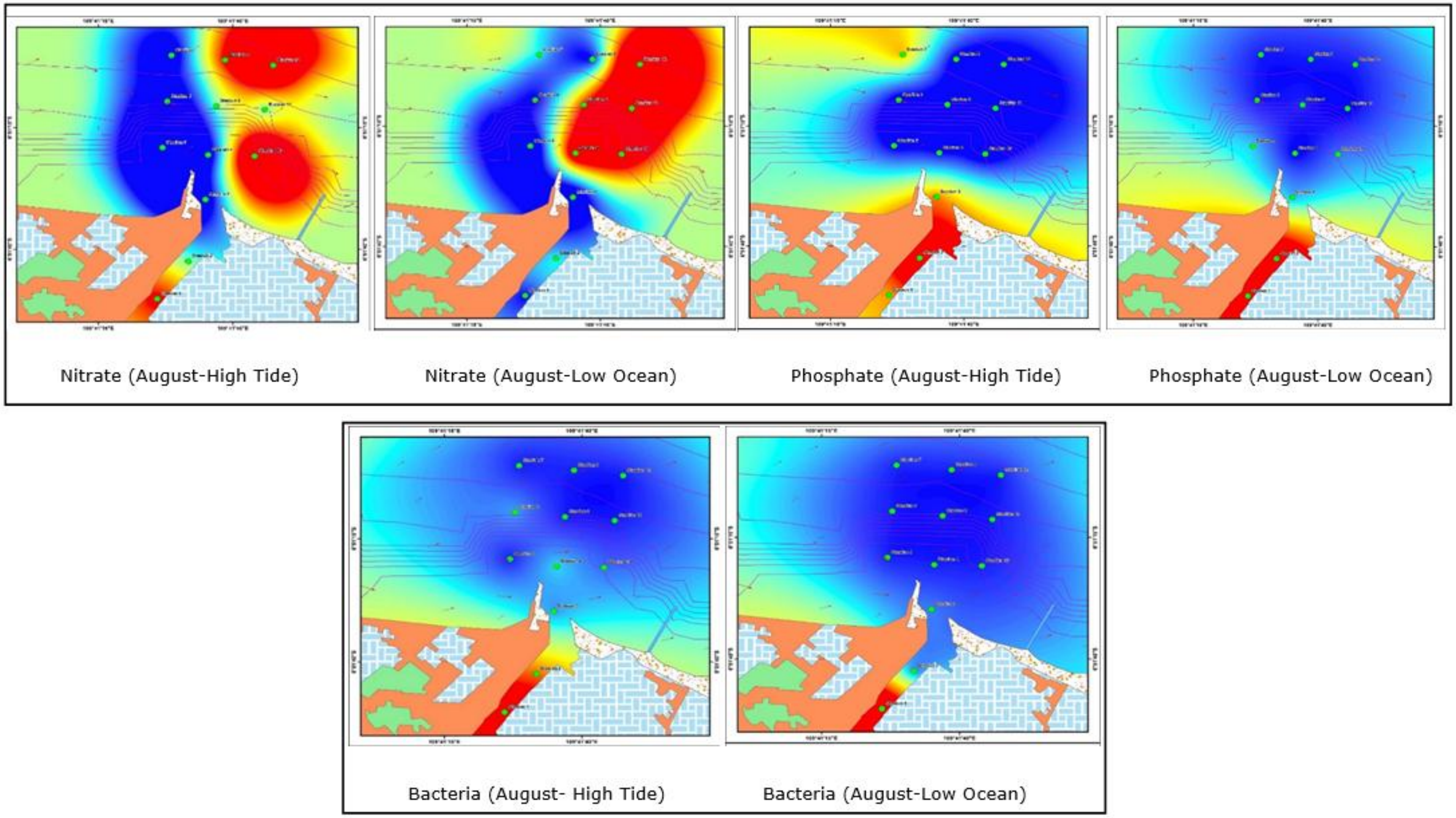

Figure 3. Geospatial interpolation distribution based on nitrate, phosphate and bacteria variables in August 2024.

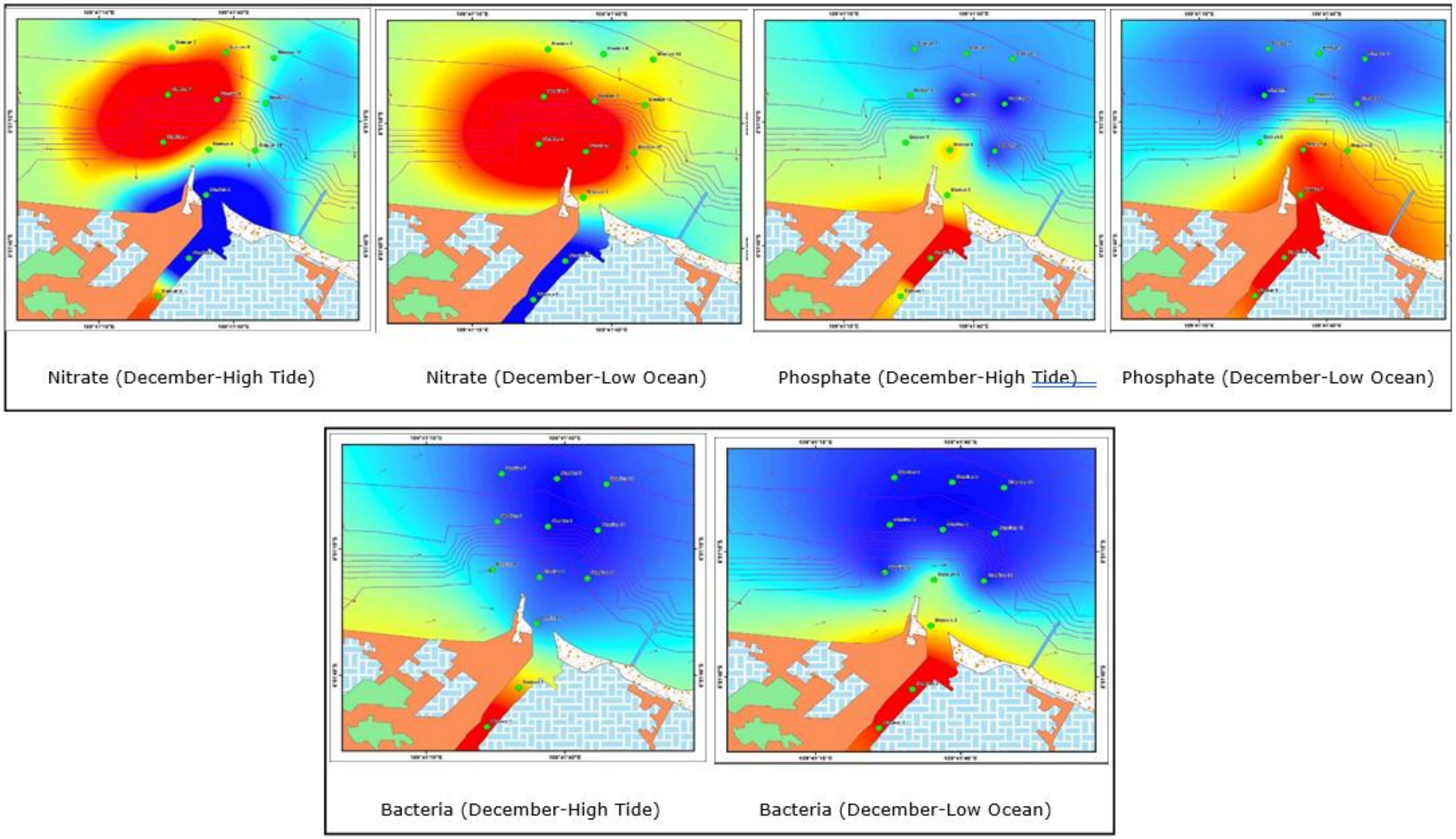

Figure 4. Geospatial interpolation distribution based on nitrate, phosphate and bacteria variables in December 2024.

Discussion

Geospatial interpolation distribution. In May, the geospatial interpolation distribution for phosphate levels reveals tidal influence. During high tide, the movement from land to sea is considerable, driven by tidal flows. When tidal flow is low, phosphate levels spread more uniformly, yet stations 1 through 4 show elevated phosphate values, attributed to the higher phosphate levels that coincide with consistent bacterial movements. Elevated bacterial values at these stations are due to the intense activity at the port, leading to increased bacterial concentrations in the waters.

In August, nitrate distribution patterns showed high land-to-sea currents during low tide, while both nitrate and phosphate variables showed slower movement, with peak concentrations in the port area due to port activities. Bacterial movement, in contrast, is more pronounced in open waters and slower in port areas.

December's nitrate distribution shows strong currents during low tide in offshore areas, with a tendency for currents to flow toward land. Phosphate movement is slower in both directions, and distinct contours appear between sea and port waters. Bacterial movement remains consistent, though distribution values are significantly higher within the port area.

Nitrate and phosphate compounds serve as indicators of water fertility, with their concentrations affected by irrigation quality and waste disposal. Domestic and industrial waste discharge impacts nitrate and phosphate levels, while bacteria play a crucial role in aquatic ecosystems by decomposing organic matter. This mineralization process produces essential nutrients, a key source of nourishment for many organisms. Therefore, the relationship between bacteria and marine ecosystems - particularly in nutrient provision - serves as a useful indicator of water fertility (Nursubekhi et al 2018; Ariadi et al 2021). Bacterial activity is inseparable from nutrient levels, as bacteria are primary agents of decomposition in marine environments (Sa'diyah 2023).

Understanding the role of decomposer bacteria provides valuable insights into their functions and benefits, contributing with critical information for managing wastewater containing dissolved organic matter, nitrates, and phosphates (Mufaidah et al 2016; Ramadhan & Yusanti 2020). Globally, 60% of areas with elevated nitrate levels in water are impacted by human waste (Maslukah et al 2019). Dissolved forms of phosphorus are essential in aquatic areas, although in nature, dissolved phosphorus is less prevalent than particulate forms (Raharjo et al 2016; Lestari et al 2021).

Conclusions. The shifting currents between May, August, and December are shaped by port and open-sea tidal dynamics, leading to nutrient and bacterial accumulation in port waters, which contribute to sediment buildup and siltation in navigational channels. Observations indicate that organic phosphate concentrations are lower in the rainy season (May) compared to transitional months (August and December). However, concentrations at stations 1 to 4 consistently exceed quality standards each month. Nitrate levels remain within quality standards at each collection station, though tidal conditions contribute to elevated total bacterial counts, especially at stations 1 to 4, where port activities and residential wastewater flow into the Banger River.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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